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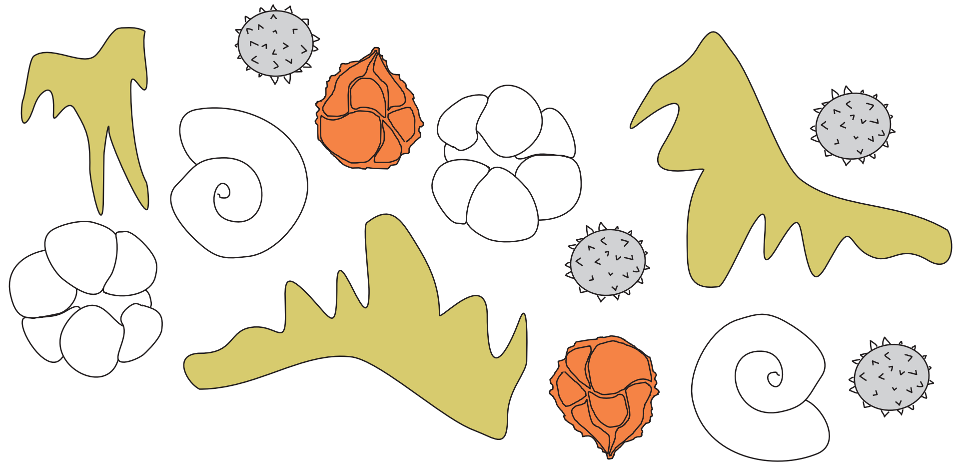
Williston Basin Project (Targeted Geoscience Initiative II): Results of the biostratigraphic sampling program, southwestern Manitoba (NTS 62F, 62G4, 62K3)



By
M.P.B. Nicolas

Manitoba

Geoscientific Paper GP2008-1

Williston Basin Project (Targeted Geoscience Initiative II): Results of the biostratigraphic sampling program, southwestern Manitoba (NTS 62F, 62G4, 62K3)

by M.P.B. Nicolas

Winnipeg, 2008

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Abstract

In the early stages of stratigraphic correlations for the Targeted Geoscience Initiative II Williston Basin Project, issues of timing and proper stratigraphic correlation were identified between southwestern Manitoba and eastern Saskatchewan. A biostratigraphic sampling program was undertaken to help resolve these problems. This report discusses the results for the Manitoba samples.

In Manitoba, the biostratigraphic program was focused on Mississippian- and Cretaceous-age rocks. A suite of 37 Mississippian samples was submitted for conodont analysis, from the following units: Daly Member, Cruickshank Crinoidal facies, Basal Limestone facies and Routledge Shale facies of the Lodgepole Formation; and Upper Member of the Bakken Formation. All Mississippian samples indicated deep-water deposition, and the conodont colour alteration index (CAI) for all the Mississippian samples had a value of 1, indicating that the rocks are thermally immature (McCracken, 2005). The age ranges were typical for these units in this part of the basin, ranging from Lower Tournaisian *sulcata* Zone to Upper Tournaisian *typicus* Zone, with the exception of a couple of samples from the Cruickshank Crinoidal mounds that have a lower age range of Upper Femennian *styriaca* Zone.

A suite of 20 samples from various Cretaceous intervals was analyzed for micropaleontology, particularly foraminifera, palynology and dinocysts. The Mesozoic intervals sampled include the Swan River Formation; Skull Creek Member of the Ashville Formation; and Morden Member of the Carlile Formation. The age of the Swan River Formation was determined as Aptian to Middle Albian; that of the Ashville Formation, Skull Creek Member and Pense 'P4' equivalent as Late Albian *Haplophragmoides gigas* Zone to *Miliammina manitobensis* Zone; and that of the Carlile Formation, Morden Member as Early Turonian *Hedbergella loetterlei* Zone to Late Turonian *Pseudoclavulina* sp. – *Trochmammina* sp. Zone.

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Introduction

The objective of the Targeted Geoscience Initiative II (TGI II) Williston Basin Project (Figure 1) was to produce a geological model of Phanerozoic rocks over eastern Saskatchewan and southwestern Manitoba, in order to enhance understanding of the hydrocarbon and mineral potential, through subsurface geological, geophysical and hydrogeological mapping. During the course of picking and correlating the subsurface stratigraphy between the two jurisdictions, issues of timing and proper stratigraphic correlation were recognized. A biostratigraphic sampling program was undertaken to help resolve these problems.

The biostratigraphic program was focused on Mississippian- and Cretaceous-age rocks in southwestern Manitoba (Figure 2). The Mississippian section was sampled for conodont analysis, which is useful in determining age, water depth, depositional environment and, to a certain extent, thermal maturity of the sediment. There has not been much work published on the conodonts of the Mississippian, especially in eastern Saskatchewan and southwestern Manitoba.

The Cretaceous section was sampled for foraminifera (forams), palynology (pollen) and dinoflagellate (dinocyst) analysis, which helps to provide some biostratigraphic control with respect to age and depositional environment. McNeil and Caldwell (1981) did a thorough analysis of the foram faunal assemblages of the Manitoba Escarpment, which provides a good reference base for the TGI samples.

The Paleontology Lab at the Geological Survey of Canada

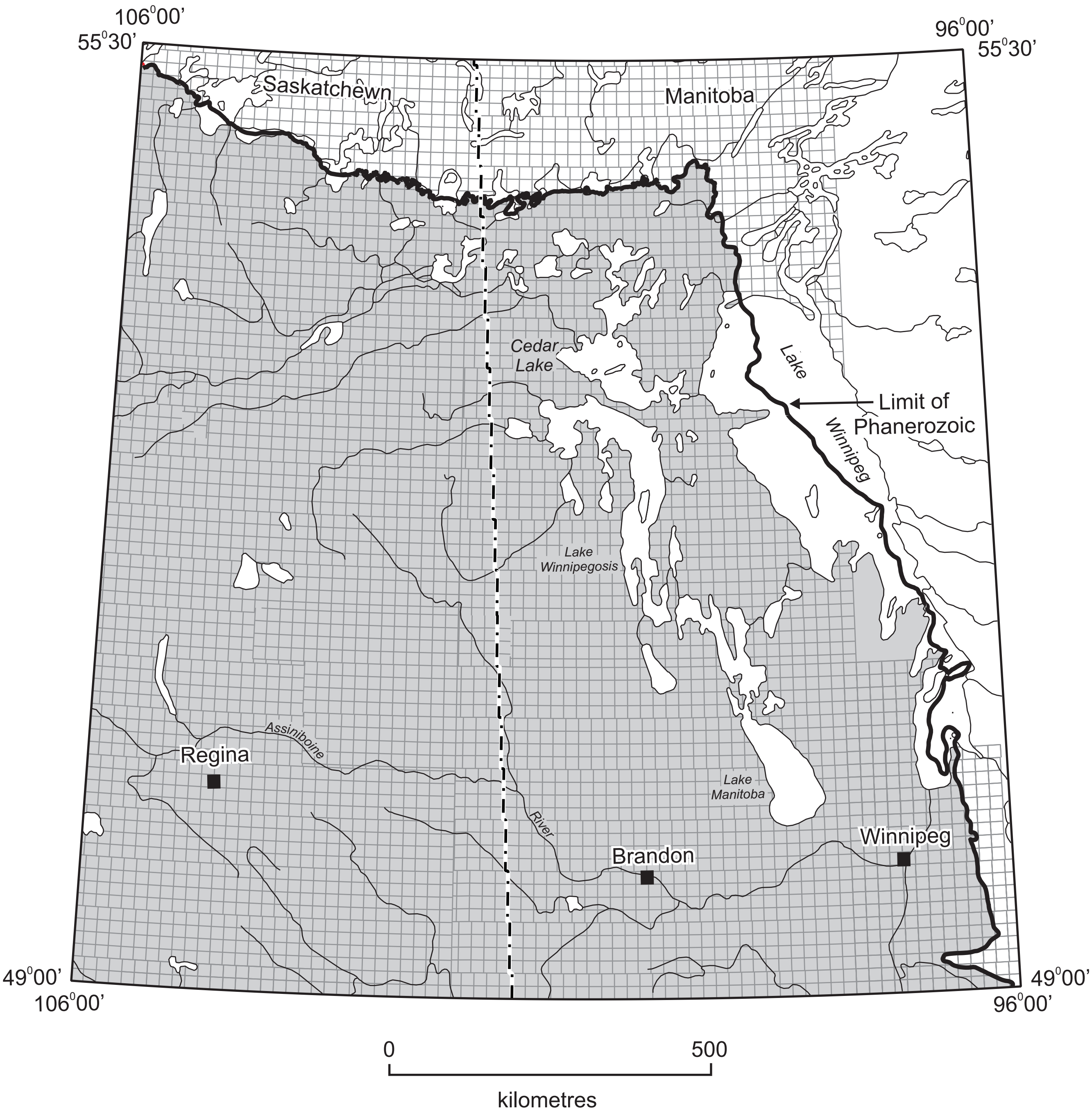

Figure 1: *Targeted Geoscience Initiative II Williston Basin Project area (in grey).*

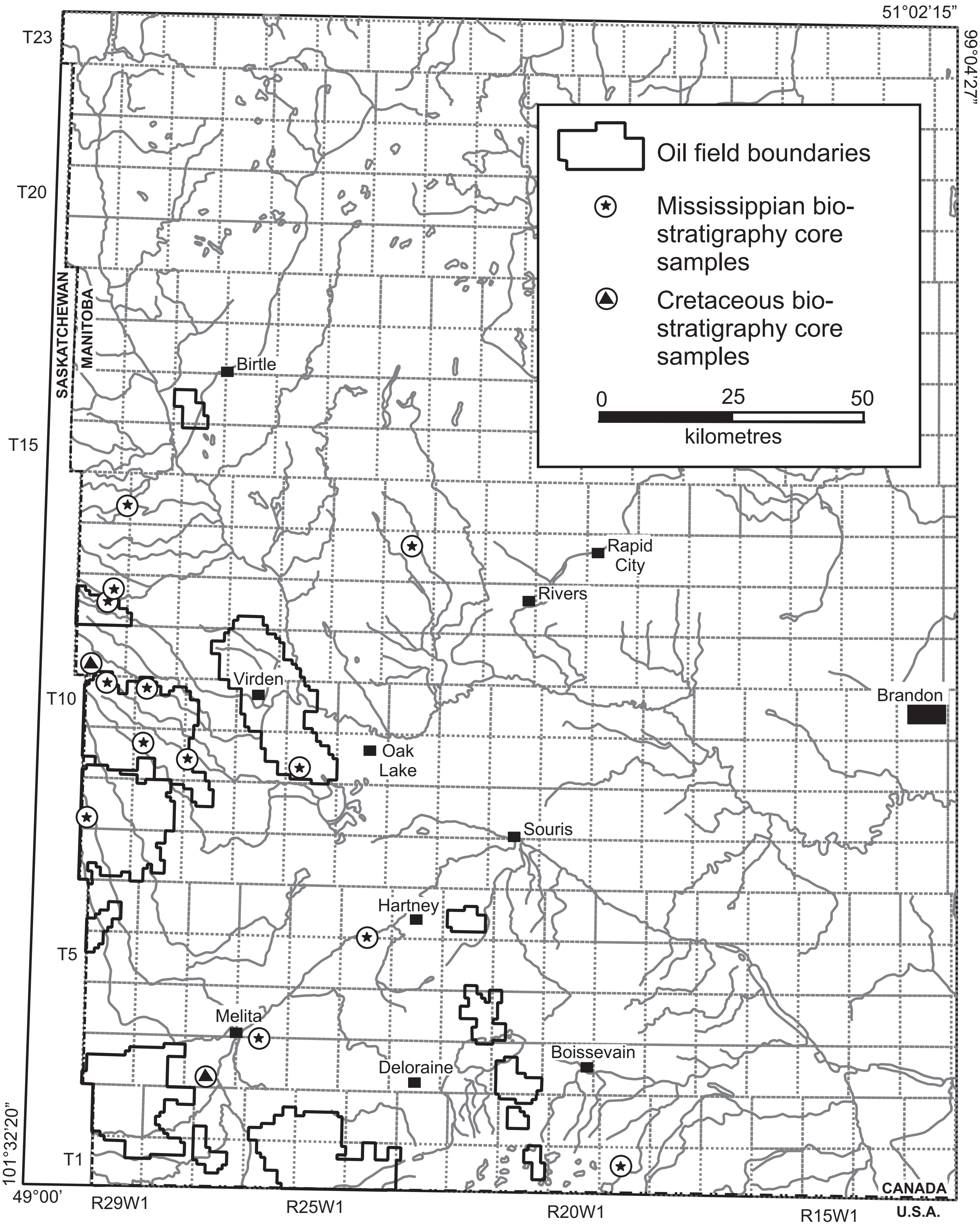

Figure 2: *Locations of Manitoba wells sampled for biostratigraphic analysis, Targeted Geoscience Initiative II Williston Basin Project.*

(GSC) in Calgary analyzed all samples. A.D. McCracken was responsible for the conodont work, D.H. McNeil was responsible for the foram analysis, J.M. White was responsible for the palynology analysis, and D.J. McIntyre from Manuka Palynologic Consulting, on contract to the GSC, and was responsible for the dinocyst analysis.

Geological setting

Southwestern Manitoba represents the eastern extent of the Western Canada Sedimentary Basin (WCSB), which includes the Williston Basin and Elk Point Basin sub-basins. These sedimentary basins have rocks ranging in age from Cambrian to Cretaceous. Continental tectonic forces affected basinal changes throughout the Phanerozoic, with a major angular unconformity separating the Paleozoic and Mesozoic strata. The Paleozoic unconformity represents the largest time lapse in the history of the Phanerozoic, and is mostly due to tectonic uplift (McCabe, 1959). A progressive erosional truncation of the Paleozoic formations, from youngest in the west to oldest in the east, towards the basin margin, reflects the dynamic tectonic forces that affected the Williston Basin during this time. The Devonian–Mississippian boundary represents a change in basin dynamics that was accompanied by sea-level changes characterized by the deep- to shallow-water carbonate sequences of the Mississippian.

The Mesozoic formations form part of the eastern erosional edge of the WCSB and follow an age pattern similar to that of the Paleozoic, from youngest in the west to oldest in the east, overstepping and unconformably overlying the Paleozoic sequence. The Mesozoic formations in Manitoba were deposited within the east-median hinge and eastern platform zones of a major epicontinental sea (Bamburak and Christopher, 2004) and are characterized by sandstone and shale sequences.

Stratigraphy

The biostratigraphic program was focused on Mississippian- and Cretaceous-age rocks in southwestern Manitoba. The Mississippian units sampled include the Daly Member, Cruickshank Crinoidal facies, Basal Limestone facies and Routledge Shale facies of the Lodgepole Formation; and the Upper Member of the Bakken Formation. The Mesozoic intervals sampled include the Swan River Formation; the Skull Creek Member of the Ashville Formation; and the Morden Member of the Carlile Formation.

The Ashville Formation consists of four members: Skull Creek, Newcastle, Westgate and Belle Fourche. The Skull Creek, Newcastle and Westgate members, referred to in Manitoba as the Lower Ashville Member, constitute the section from the base of the Fish Scale Zone to the top of the Swan River Formation, or Jurassic or Paleozoic rocks, depending on the location. The Lower Ashville sits conformably on the Swan River, but disconformably on Jurassic and Paleozoic rocks when the Swan River is absent due to erosion or nondeposition. The Skull Creek Member consists predominantly of dark grey shale with occasional sandy lenses and siltstone beds (McNeil and Caldwell, 1981). The lower part of the Skull Creek, as historically defined in Manitoba, includes the transgressive glauconitic marine shale of the Pense Formation 'P4' unit; it is this relationship that is investigated in this report. This member correlates with the Joli Fou Formation in Saskatchewan.

The Swan River Formation in Manitoba consists of fine-grained silica sandstone and sand, with silt and light to dark grey clay and shale. This unit lies unconformably on the erosional surface of Jurassic and Paleozoic rocks, and is conformably overlain by the shale of the Ashville Formation.

The Lodgepole Formation consists of a shelf-to-slope sequence of argillaceous, oolitic, crinoidal and cherty limestone. This formation lies conformably on the Bakken Formation and conformably underlies the Mission Canyon Formation, or the Lower (Red Beds) Member of the Jurassic Amaranth Formation when beyond the Mission Canyon subcrop edge.

The Bakken Formation consists of the two black shales of the Upper and Lower members, separated by the siltstone and sandstone of the Middle Member. The Lower Member is only preserved locally in sinkholes caused by salt-collapse structures resulting from dissolution of the Prairie Evaporite. The Middle Member sits disconformably on the Three Forks Formation when the Lower Member is absent. The Bakken is conformably overlain by the Mississippian Lodgepole Formation. The subcrop trend of this formation is covered by Mesozoic rocks.

More detail on the stratigraphic relationships of these units can be found in Nicolas (work in progress, 2008) for the Mesozoic stratigraphy, and Nicolas and Barchyn (2008) for the Paleozoic stratigraphy.

Mississippian conodont analysis

A suite of 37 Mississippian-age samples was submitted for conodont analysis. The Mississippian samples analyzed were from the Daly Member, Cruickshank Crinoidal facies, Basal Limestone facies and Routledge Shale facies of the Lodgepole Formation; and the Upper Member of the Bakken Formation. The conodont fossil assemblages present in the samples give approximate temporal ranges and relative relationships for the various units, as discussed below. Detailed taxonomic results and interpretation are presented in McCracken (2005); a summary of those findings is provided in Appendix 1.

Lodgepole Formation: Cruickshank Crinoidal facies and Daly Member

Uncertainties in the temporal relationships of various Mississippian horizons were encountered during the formation-top picking and verification stage of this project, particularly within the facies of the Lodgepole Formation and the Upper Member of the Bakken Formation. Of particular interest was the Waulsortian-type mound in the Cruickshank Crinoidal facies of the Lodgepole Formation in the Kirkella Field (Twp. 12, Rge. 29, W 1st Mer.). The productive mound in 11-15-12-29W1 had been cored, as had an offset well that exhibited normal Lodgepole stratigraphy at 4-26-12-29W1. Biostratigraphic methods were applied to these two wells to verify the temporal relationships between the mound and off-mound units. The theory was that, if mound formation occurred in deep water at the toe of the shelf slope, the mound should predate the juxtaposed normal Lodgepole basin-fill strata above the Cruikshank Shale marker by a significant amount of time.

Conodont results indicate that the off-mound facies in the

Daly Member in 4-26-12-29W1 (Appendix 1, Table 4) are of Middle to Upper Tournaisian age, straddling the Lower *crenulata* Zone and the *typicus* Zone, and the mound facies of the Daly Member in 11-15-12-29W1 (Appendix 1, Table 5) indicates a wider age range of Late Femennian to Upper Tournaisian, straddling the *styriaca* Zone and the *anchoralis-latus* Zone (Figure 3). The mound in the Cruickshank Crinoidal facies in 11-15-12-29W1 has an earliest confirmed age of Lower Tournaisian *praesulcata* Zone, and an oldest age of Upper Tournaisian *typicus* Zone. While there were no conodont taxa indicating that the age of this mound is definitively older than the surrounding off-mound facies, its age range is larger than those found in all other off-mound samples. The on-mound Daly Member sample also has a wide age range, suggesting that perhaps this sample is actually part of the Cruickshank Crinoidal facies mound, and not the Daly Member as originally thought.

These results were inconclusive with respect to the theory that mound formation predated the juxtaposed normal Lodgepole basin-infill, but do not rule out the possibility that the end of mound growth and the deposition of the overlying Daly Member may coincide with normal Daly Member deposition. Although the biostratigraphic resolution over this time interval in these sedimentary rocks is not precise enough to say for certain that the mound predates the normal Lodgepole basin-infill, especially by a significant amount of time, the possibility of this being the case should not be discounted. This new information would be useful in reconstructing the Lodgepole stratigraphic package and assessing trapping potential of anomalous depositional features, such as the mounds.

Lodgepole Formation: Basal Limestone and Routledge Shale facies

Conodont samples were analyzed from the Basal Limestone and Routledge Shale facies of the Lodgepole Formation. The age for the Routledge Shale facies is middle Lower to late Middle Tournaisian, the oldest age represented by the *sulcata* Zone and the youngest by the Upper *crenulata-isotacha* Zone (Figure 3). The Basal Limestone facies is middle to late Middle Tournaisian; this narrow age band is represented by the Lower *crenulata* Zone and the Upper *crenulata-isotacha* Zone (Figure 3). The ages reported for the lower Lodgepole units appear to be normal for this part of the basin (Higgins et al., 1991).

Bakken Formation: Upper Member

Conodont analysis of the Upper Member of the Bakken Formation was also conducted, and indicates an earliest age of Lower Tournaisian *sulcata* Zone to a youngest age of Middle Tournaisian *sandbergi* Zone (Figure 3). These ages agree with the temporal relationships adopted for the Bakken Formation in this and other parts of the basin (Higgins et al., 1991).

Samples taken in the Three Forks Formation were found to be barren of conodonts.

Thermal maturity

The thermal maturity of all Mississippian samples, as indicated by the conodont colour alteration index (CAI), is low (CAI value of 1), indicating that the rocks are thermally immature. Such immaturity indicates that the rocks were never exposed to sources of sufficient heat, from burial, heat conduction or other mechanisms, for them to reach the oil-generation and -expulsion window. This immaturity is further supported by the Rock-Eval®–TOC results, discussed in Nicolas and Barchyn (2008), which show that both the Bakken and the Routledge units have T_{max} values indicating the rocks are thermally immature and were never heated enough to become local source rocks, despite their high TOC values.

Depositional environment

The conodont taxa indicate that all Mississippian samples are characteristic of deep-water deposition (McCracken, 2005). This is in agreement with the findings of McCabe (1959) and Klassen (1996) that the Lodgepole Formation in Manitoba displays a slope-to-shelf transition. Of interest is the deep-water deposition findings for the Upper Member of the Bakken Formation. McCabe (1959) suggested that the Upper and Lower members of the Bakken Formation were deposited in either deep-water marine conditions or terrestrial swamp conditions, favouring the latter. These new conodont results indicate that the Upper Member was, in fact, deposited in deep-water conditions. The Lower Member was not analyzed as part of this biostratigraphy program, but the author recommends that conodont analysis be done on the Lower Member.

Cretaceous microfossil analysis

A suite of 20 samples from various Cretaceous intervals was analyzed for micropaleontology, in particular foraminifera, palynology and dinocysts. The intervals sampled include the Swan River Formation; Skull Creek Member of the Ashville Formation; and Morden Member of the Carlile Formation. Detailed taxonomic results and interpretation are in White (2005) and McNeil (2007), and a summary of those findings is provided in Appendices 2, 3 and 4.

Swan River Formation and Ashville Formation: Skull Creek Member

The purpose of the samples from the Swan River Formation and the Skull Creek Member of the Ashville Formation was to help identify the transition zone between these intervals, referred to in Saskatchewan as the Pense Formation P4 unit. In Manitoba, the upper Swan River consists dominantly of marine glauconitic sandstone and shale that mark the initial transgressive phase of the Greenhorn marine cycle of sedimentation (McNeil and Caldwell, 1981), whereas the Skull Creek consists of transgressive marine shale. In Saskatchewan, the P4 unit is stratigraphically located just above the sandstone and shale of the lower Pense and Cantuar formations and marking the top of the Mannville Group, and represents the initial transgression of the sea as it flooded the terrestrial sequences. During the early mapping stages of this project, inclusion of the P4 unit in Manitoba into the Mannville Group versus the Ashville Formation was a stratigraphic correlation issue, particularly because this top is a significant stratigraphic marker. Paleontological analysis was therefore used in an attempt to resolve this problem.

The foram results provided enough resolution over the sampling interval for the author to question the presence of

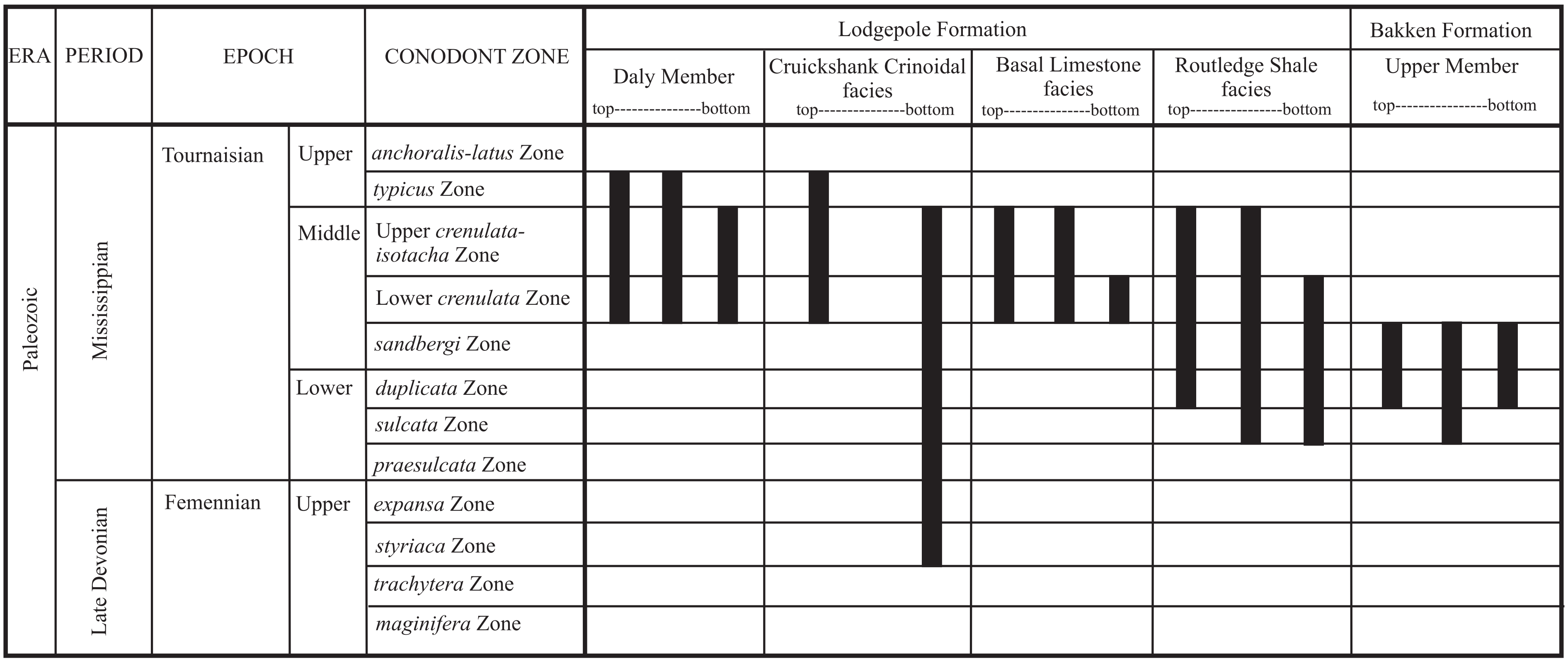

Figure 3: *Average temporal ranges and biostratigraphic summary of the Mississippian conodont samples ("top---bottom" indicates relative stratigraphic position of the sample within the unit).*

the Pense P4 unit in many parts of Manitoba, and whether the samples labelled as P4 during sampling may actually be lower Skull Creek. The palynology and dinocyst results were inconclusive on this issue (White, 2005; McNeil, 2007).

The micropaleontology confirmed that these units have ages typical of what has been assumed for these units (Caldwell et al., 1993). The Middle Albian age determined for the Swan River samples is in accordance with those of the eastern part of the basin (McNeil, 1984). The Skull Creek samples had an age of Late Albian *Haplophragmoides gigas* Zone, where *H. gigas* is a characteristic foram of the Skull Creek Member (Figure 4). The forams in the Pense P4 samples were all found to be characteristic of the lower Skull Creek and of the Late Albian *H. gigas* Zone (Figure 4). The upper Swan River to Skull Creek interval represents the secondary Skull Creek cyclothem (McNeil and Caldwell, 1981; McNeil, 1984) within the Greenhorn cyclothem (Kauffman, 1967, 1969; McNeil and Caldwell, 1981; McNeil, 1984), an interval with tight biostratigraphic resolution.

Carlile Formation: Morden Member

The purpose of the micropaleontology analysis on the Morden Member of the Carlile Formation was to verify its age and depositional environment. These samples were identified as Turonian by palynology and dinocysts (White, 2007), which is in agreement with the dates for the unit in other parts of the basin (McNeil, 1984). The Carlile samples were barren of foram microfossils.

Depositional environment

The faunal assemblage found in the Swan River Formation and lower Skull Creek Member of the Carlile Formation are indicative of marine waters of lower than normal salinity, whereas samples from the upper Skull Creek Member are indicative of low-salinity, shallow, modern marine waters, as indicated in McNeil (1984, 2007). The boundary between the lower and upper Skull Creek is marked by a peak in the transgression of the sea, with the upper Skull Creek representing the beginning of a regressive phase (McNeil, 1984). This change in sea level can be seen in the samples from this study by the disappearance of *Ammobaculites petilus* and *Ammomarginulina asperata* and the appearance of *Miliammina* (McNeil, 1984, 2007).

The depositional environment of the Morden Member of the Carlile Formation cannot be determined due to the absence of foram microfossils in the samples.

Conclusions

Conodont analysis on Mississippian samples from the Bakken Formation and various members and facies of the Lodgepole Formation yielded ages that are normal for these units in the eastern part of the basin. All of the Mississippian samples indicate deep-water deposition. The ages for the Upper Member of the Bakken Formation range from late Lower to early Middle Tournaisian. The age for the Routledge Shale facies of the Lodgepole Formation is middle Lower to late Middle Tournaisian; that of the Basal Limestone facies is middle to late Middle Tournaisian; that of the Cruickshank Crinoidal facies is late Upper Famennian to late Middle Tournaisian for mound facies and middle Middle to early Upper Tournaisian for off-mound facies; and that of the Daly Member is middle Middle to early Upper Tournaisian. Generally these ages follow as expected from oldest to youngest with their respective member/facies in stratigraphic order. The Cruickshank Crinoidal mound facies is the only one with an age that is potentially older than the surrounding Lodgepole infill, but the results are inconclusive. Further work is need to properly evaluate the temporal relationship of these facies, but the results of this study suggest that growth of the mound may have started early and it was then buried by normal Lodgepole deposition. This new information would be useful in reconstructing the Lodgepole stratigraphic package and assessing the trapping potential of anomalous depositional features, such as the mounds.

The conodont colour alteration index (CAI) indicates that the Mississippian samples are immature, having never undergone an intense heating, by burial, thermal conduction or other mechanisms, that would make these organic-rich rocks capable of oil generation and expulsion in this part of the basin. Of particular importance to this is the Bakken and Routledge units, both of which have high to very high TOC results but whose T_{max} results indicate that the rocks are thermally immature and were never heated enough to become local source rocks (Nicolas and Barchyn, 2008).

Micropaleontology was used to help determine the biostratigraphic relationships of the Swan River Formation; Pense Formation; Skull Creek Member of the Ashville Formation; and Morden Member of the Carlile Formation. Foraminiferal results suggest that the Pense P4 unit does not extend into all areas of Manitoba, while the palynology for this interval in inconclusive. The Swan River and Skull Creek were both found to be Middle to Late Albian in age. The Turonian age for the Morden sample was determined by palynology and dinocysts. All ages determined for the Mesozoic samples were in accordance with ages from previous work in the eastern part of the basin.

Acknowledgments

The author wishes to thank A.D. McCracken, D.H. McNeil and J.M. White from the Paleontology Lab at the Geological Survey of Canada (GSC) in Calgary, and D.J. McIntyre from Manuka Palynologic Consulting, for analyzing the samples. D.H. McNeil is acknowledged for time, patience and technical support in helping the author to better understand the results. D. Barchyn is acknowledged for his engaging thoughts and ideas on this topic, as well as for his time in reviewing this paper. Thanks also go to M. Yurkowski and J. Christopher of Saskatchewan Energy and Resources and K. Kreis for their guidance and suggestions, and to J. Bamburak for his technical review of this paper.

References

Bamburak, J.D. and Christopher, J.E. 2004: Mesozoic stratigraphy of the Manitoba Escarpment: WCSB/TGI II Field Trip Guidebook, Sept. 7–10, 2004; Manitoba Industry, Economic Development and Mines, unpublished report, 83 p.

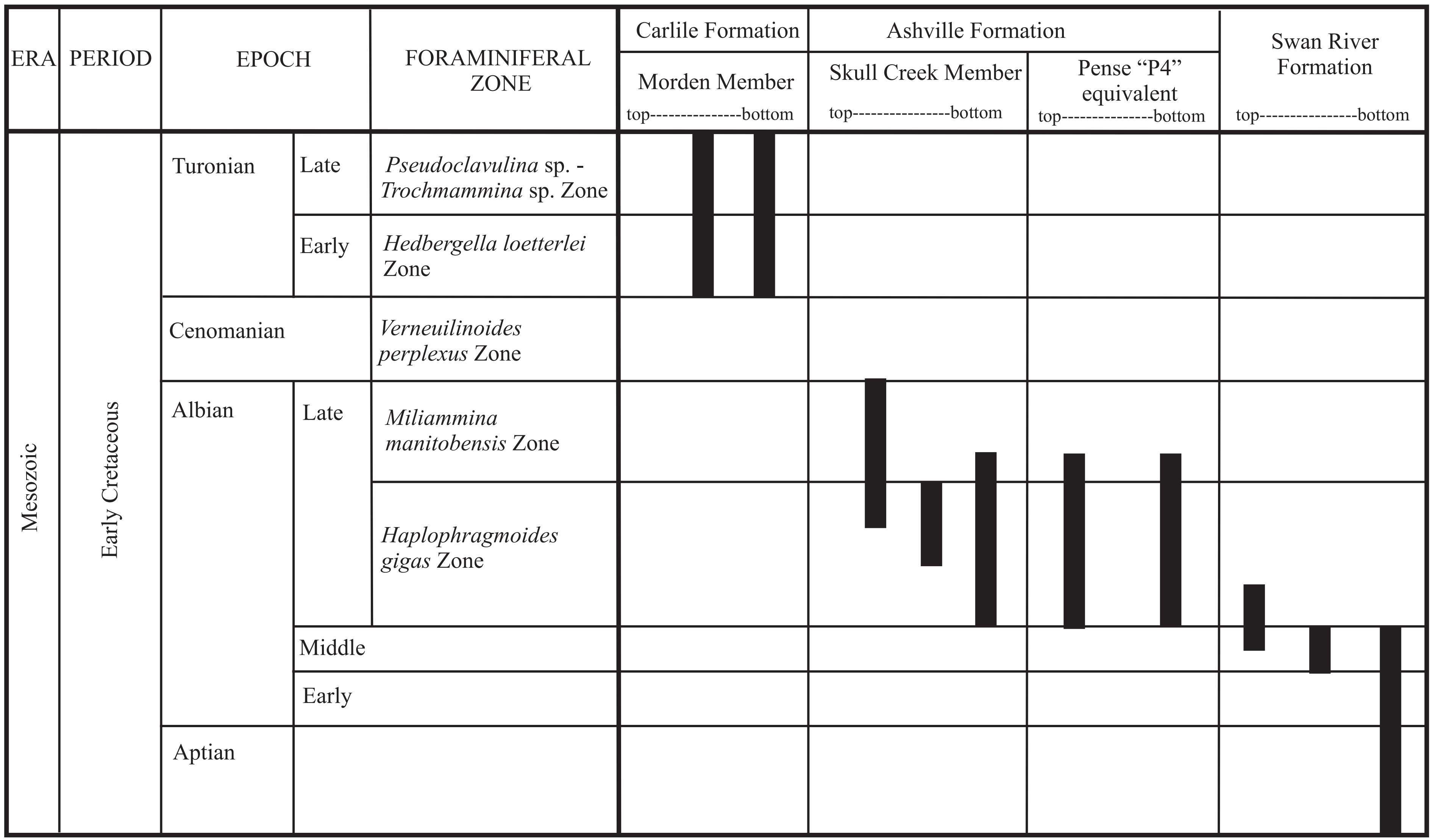

Figure 4: *Average temporal ranges and biostratigraphic summary of the Cretaceous micropaleontology samples (“top---bottom” indicates relative stratigraphic position of the sample within the unit).*

Caldwell, W.G.E., Diner, R., Eicher, D.L., Fowler, S.P., North, B.R., Stelck, C.R. and von Holdt, W.L. 1993: Foramaminiferal biostratigraphy of Cretaceous marine cyclothems; *in* Evolution of the Western Interior Basin, W.G.E. Caldwell and E.G. Kauffman (ed.), Geological Association of Canada, Special Paper 18, p. 495–575.

Higgins, A.C., Richards, B.C. and Henderson, C.M. 1991: Conodont biostratigraphy and paleoecology of the uppermost Devonian and Carboniferous of the Western Canada Sedimentary Basin; *in* Ordovician to Triassic Conodont Paleontology of the Canadian Cordillera, M.J. Orchard and A.D. McCracken (ed.), Geological Survey of Canada, Bulletin 417, p. 215–251.

Klassen, H.J. 1996: An overview of the regional geology and petroleum potential, Lodgepole Formation, southwestern Manitoba; Manitoba Energy and Mines, Petroleum Branch, Petroleum Open File POF15-96, 42 p.

Kauffman, E.G. 1967: Coloradoan macroinvertebrate assemblages, central Western Interior, United States; *in* Paleoenvironments of the Cretaceous Seaway in the Western Interior, Colorado School of Mines, Department of Publications, Golden, Colorado, p. 67–143.

Kauffman, E.G. 1969: Cretaceous marine cycles of the Western Interior; Mountain Geologist, v. 6, no. 4, p. 227–245.

McCabe, H.R. 1959. Mississippian stratigraphy of Manitoba; Manitoba Department of Mines and Natural Resources, Mines Branch, Publication 58-1, 99 p.

McCracken, A.H. 2005: Report on 37 Early Carboniferous conodont samples (Con. No. 1695) from the subsurface of Manitoba submitted by M. Nicolas (Manitoba Industry, Economic Development and Mines, Petroleum Branch) in 2004, NTS 62F07, 62F11, 62F14, 62G04, 62K03; Geological Survey of Canada–Calgary, Paleontological Report 05-ADM-2005, 25 p.

McNeil, D.H. 1984: The Eastern Facies of the Cretaceous System in the Canadian Western Interior; *in* The Mesozoic of Middle North America, D.F. Stott and D.J. Glass (ed.), Canadian Society of Petroleum Geologists, Memoir 9, p. 145–171.

McNeil, D.H. 2007: Micropaleontology report on 20 core samples from six exploration wells in southwestern Manitoba (NTS 62F, 62K); Geological Survey of Canada–Calgary, Paleontological Report 06-DHM-2007, 9 p.

McNeil, D.H. and Caldwell, W.G.E. 1981: Cretaceous rocks and their foraminifera in the Manitoba Escarpment; Geological Association of Canada, Special Paper 21, 439 p.

Nicolas, M.P.B, and Barchyn, D. 2008: Williston Basin Project (Targeted Geoscience Initiative II): Summary report on Paleozoic stratigraphy, mapping and hydrocarbon assessment, southwestern Manitoba; Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Geoscientific Paper GP2008-2, 21 p.

White, J.M. 2005: Palynological report on 20 samples of Cretaceous age, from the Skull Creek Member of the Ashville Formation, Swan River Formation and Morden Shale (NTS 062-F- 02, 03, 07, 11, 14; 062-K-02); Geological Survey of Canada–Calgary, Paleontological Report 01-JMW-2005, 20 p.

Appendix 1 — Summary of conodont analysis results

This is only a summary of the taxonomic findings. See McCracken (2005) for more detail on these results, relative abundances and counts, taxonomic references and biostratigraphic interpretations.

Table 1: Conodont results for the T.L. Cleary Turtle Mtn. Prov. 6-21-1-19-WPM well, 100/06-21-001-19W1/00, licence no. 1149.

GSC loc. no.	Sample no.	Formation	Sample TVD (m)	Conodonts species identified	CAI	Age
C-421708	Rout1-1-C	Lodgepole Formation, Routledge Shale facies	974.14	Indeterminate ramiform element	1? *	Indeterminate
C-421709	Rout1-3-C	Lodgepole Formation, Routledge Shale facies	975.49	*Bispathodus stabilis*	1	Late Devonian (Late Famennian) to Carbonifer-ous (Middle Tournaisian) - Upper *marginifera* Zone to *crenulata-isosticha* Zone
				Indeterminate ramiform elemen		
C-421710	Rout1-5-C	Lodgepole Formation, Routledge Shale facies	978.39	*Bispathodus aculeatus aculeatus*	1	Carboniferous (Early Tournaisian) - *sulcata* Zone into lowest part of *sandbergi-duplicata* Zone
				Bispathodus stabilis		
				Indeterminate P element		
				Indeterminate ramiform element		
				Polygnathus communis carina		
				Polygnathus communis communis		
				Polygnathus sp.		
				Pseudopolygnathus primus		
				Siphonodella sulcata		

* Most conodonts are slightly weathered with white surfaces.

Table 2: Conodont results for the Mag 7 Barons Melita 11-33-3-26-WPM well, 100/11-33-003-26W1/00, licence no. 4094.

GSC loc. no.	Sample no.	Formation	Sample TVD (m)	Conodonts species identified	CAI	Age
C-421688	BL2-2-C	Lodgepole Formation, Basal Limestone facies	1050.58	Indeterminate fragment	1?	Indeterminate
C-421689	BL2-3-C	Lodgepole Formation, Basal Limestone facies	1054.05	*"Spathodnathodus" abnormis*	1	Carboniferous (Middle Tournaisian) - Lower *crenulata* Zone to Upper *crenulata-isosticha* Zone
				Bispathodus stabilis		
				Elictognathus laceratus		
				Indeterminate P element		
				Indeterminate ramiform element		
				Polygnathus communis communis		
				Polygnathus longiposticus		
				Siphonodella isosticha		
C-421690	BL2-5-C	Lodgepole Formation, Basal Limestone facies	1055.83	Indeterminate ramiform element	1	
				Polygnathus communis communis		
				Siphonodella isosticha		

Table 3: Conodont results for the Chevron Virden 11-8-6-25-WPM well, 100/11-08-006-25W1/00, licence no. 4011.

GSC loc. no.	Sample no.	Formation	Sample TVD (m)	Conodonts species identified	CAI	Age
C-421711	Rout2-2-C	Lodgepole Formation, Routledge Shale facies	721.42	Indeterminate ramiform element *Pseudopolygnathus primus* *Siphonodella cooperi*	1? *	Carboniferous (Early to Middle Tournaisian) - *sandbergi-duplicata* Zone to the Upper *crenulata-isosticha* Zone
C-421712	Rout2-4-C	Lodgepole Formation, Routledge Shale facies	722.4	Indeterminate ramiform element	1	Indeterminate

* Weathered conodonts with white surfaces.

Table 4: Conodont results for the Tundra Sinclair A3-7-8-29-WPM well, 102/03-07-008-29W1/00, licence no. 5144.

GSC loc. no.	Sample no.	Formation	Sample TVD (m)	Conodonts species identified	CAI	Age
C-421715	UB2-1-C	Bakken Formation, Upper Member	1010.61	*Bispathodus aculeatus aculeatus* *Bispathodus stabilis* *Elictognathus laceratus* Indeterminate P element Indeterminate ramiform element *Polygnathus communis communis* *Polygnathus inornatus* *Pseudopolygnathus fusiformis* *Pseudopolygnathus primus* *Siphonodella cooperi* *Siphonodella duplicata*	1	Carboniferous (Early to Middle Tournaisian) - *sandbergi-duplicata* Zone
C-421716	UB2-5-C	Bakken Formation, Upper Member	1012.32	*Bispathodus aculeatus aculeatus* *Bispathodus stabilis* Indeterminate P element Indeterminate ramiform element *Pseudopolygnathus fusiformis* *Pseudopolygnathus primus* *Siphonodella duplicata* *Siphonodella sulcata*	1	Carboniferous (Early Tournaisian) - *sulcata* Zone to lowest *sandbergi-duplicata* Zone
C-421717	MB1-8-C	Bakken Formation, Middle Member	1013.38	Indeterminate ramiform element	1?	Indeterminate
C-421718	TF1-10-C	Three Forks Formation	1013.71	Barren	1	Indeterminate
C-421719	TF1-12-C	Three Forks Formation	1014.3	Indeterminate ramiform element	1?	Indeterminate

Table 5: Conodont results for the Chevron Daly 1-30-9-28-WPM well, 100/01-30-009-28W1/00, licence no. 490.

GSC loc. no.	Sample no.	Formation	Sample TVD (m)	Conodonts species identified	CAI	Age
C-421685	BL1-1-C	Lodgepole Formation, Basal Limestone facies	848.84	Indeterminate ramiform element	1	Carboniferous (Early to Late Tournaisian) - Lower *crenulata* Zone to *typicus* Zone
				Polygnathus communis communis		
				Siphonodella isosticha		
C-421686	BL1-3-C	Lodgepole Formation, Basal Limestone facies	860.09	*Bispathodus stabilis*	1	Carboniferous (Early to Late Tournaisian) - Lower *crenulata* Zone to *typicus* Zone
				Indeterminate ramiform element		
				Polygnathus communis communis		
				Polygnathus longiposticus		
				Siphonodella isosticha		
C-421687	BL1-5-C	Lodgepole Formation, Basal Limestone facies	869.9	*"Spathodnathodus" abnormis*	1	Age range Carboniferous (Middle Tournaisian) - Lower crenulata Zone
				Bispathodus stabilis		
				Indeterminate P element		
				Polygnathus communis communis		
				Polygnathus longiposticus		
				Pseudopolygnathus triangulus triangulus		
				Siphonodella cooperi		
				Siphonodella crenulata		
				Siphonodella isosticha		

Table 6: Conodont results for the Tundra Daly Prov. COM 12-29-10-28-WPM, 100/12-29-010-28W1/00, licence no. 3869.

GSC loc. no.	Sample no.	Formation	Sample TVD (m)	Conodonts species identified	CAI	Age
C-421720	UB3-1-C	Bakken Formation, Upper Member	809.6	*Bispathodus aculeatus aculeatus*	1	Carboniferous (Early to Middle Tournaisian) - *sandbergi-duplicata* Zone to Upper *crenulata-isosticha* Zone
				Bispathodus stabilis		
				Indeterminate ramiform element		
				Polygnathus communis communis		
				Pseudopolygnathus fusiformis		
				Pseudopolygnathus primus		
				Siphonodella cooperi		
C-421721	UB3-6-C	Bakken Formation, Upper Member	811.15	*Bispathodus aculeatus aculeatus*	1 *	Carboniferous (Early to Middle Tournaisian) - *sandbergi-duplicata* Zone to Upper *crenulata-isosticha* Zone
				Bispathodus stabilis		
				Indeterminate ramiform element		
				Polygnathus communis communis		
				Polygnathus sp.		
				Pseudopolygnathus primus		

* Conodonts were eroded and weathered white.

Table 7: Conodont results for the Tundra Kola Unit No. 2 3-33-10-29-WPM well, 100/03-33-010-29W1/00, licence no. 4489.

GSC loc. no.	Sample no.	Formation	Sample TVD (m)	Conodonts species identified	CAI	Age
C-421713	UB1-1-C	Bakken Formation, Upper Member	853.5	*Bispathodus aculeatus aculeatus* *Bispathodus stabilis* Indeterminate ramiform element *Polygnathus communis communis* *Polygnathus sp.* *Pseudopolygnathus primus* *Siphonodella duplicata*	1	Carboniferous (Early to Middle Tournaisian) - *sandbergi-duplicata* Zone
C-421714	UB1-5-C	Bakken Formation, Upper Member	855.61	*Bispathodus aculeatus aculeatus* *Bispathodus stabili* *Elictognathus laceratus* *Polygnathus communis carina* *Polygnathus communis communis* *Pseudopolygnathus fusiformis* *Pseudopolygnathus primus* *Siphonodella cooperi*	1	Carboniferous (Early to Middle Tournaisian) - *sandbergi-duplicata* to the Upper *crenulata-isosticha* Zone

Table 8: Conodont results for the Chevron Kirkella DIR 11-15-12-29-WPM well, 100/11-15-012-29W1/00, licence no. 4840.

GSC loc. no.	Sample no.	Formation	Sample TVD (m)	Conodonts species identified	CAI	Age
C-421699	Ldp2-1-C	Lodgepole Formation, Daly Member	699.8	*"Spathodnathodus" abnormis* Indeterminate P element Indeterminate ramiform element *Polygnathus communis communis*	1	Late Devonian (Late Famennian) to Carboniferous (Late Tournaisian) - *styriaca* Zone to *anchoralis-latus* Zone
C-421700	Ldp2-3-C	Lodgepole Formation, Cruickshank Crinoidal facies	706.25	Indeterminate ramiform element *Siphonodella isosticha*	1	Carboniferous (Middle to Late Tournaisian) - Lower *crenulata* Zone to the *typicus* Zone
C-421701	Ldp2-5-C	Lodgepole Formation, Cruickshank Crinoidal facies	708.74	Indeterminate ramiform element *Siphonodella sp.*	1?	Carboniferous (Early to Late Tournaisian)
C-421702	Ldp2-6-C	Lodgepole Formation, Cruickshank Crinoidal facies	712.07	*Bispathodus stabili* Indeterminate ramiform element *Polygnathus communis communis* *Siphonodella isosticha*	1	Carboniferous (Middle to Late Tournaisian) - Lower *crenulata* Zone to the *typicus* Zone
C-421703	Ldp2-7-C	Lodgepole Formation, Cruickshank Crinoidal facies	717.7	*Bispathodus stabilis* Indeterminate ramiform element	1	Late Devonian (Late Famennian) to Carboniferous (Middle Tournaisian) - Upper *marginifera* Zone to the Upper *crenulata-isosticha* Zone
C-421704	Ldp2-8-C	Lodgepole Formation, Cruickshank Crinoidal facies	721.41	*"Spathodnathodus" abnormis* Indeterminate ramiform element *Siphonodella isosticha*	1	Carboniferous (Middle to Late Tournaisian) - Lower *crenulata* Zone to the *typicus* Zone
C-421705	Ldp2-9-C	Lodgepole Formation, Cruickshank Crinoidal facies	722.51	*Bispathodus stabilis* Indeterminate P element	1	Late Devonian (Late Famennian) to Carboniferous (Middle Tournaisian) - Upper *marginifera* Zone to the Upper *crenulata-isosticha* Zone
C-421706	Ldp2-10-C	Lodgepole Formation, Cruickshank Crinoidal facies	726.15	Indeterminate ramiform element *Polygnathus communis communis* *Siphonodella sp.*	1	Carboniferous (Early to Late Tournaisian) based on the occurrence of *Siphonodella* sp.
C-421707	Ldp2-11-C	Lodgepole Formation, Cruickshank Crinoidal facies	728	Indeterminate P element Indeterminate ramiform element *Polygnathus communis*	1	Late Devonian (Late Famennian) to Carboniferous (Late Tournaisian) - *styriaca* Zone to *anchoralis-latus* Zone

Table 9: Conodont results for the Husky Kirkella 4-26-12-29-WPM well, 100/04-26-012-29W1/00, licence no. 4907.

GSC loc. no.	Sample no.	Formation	Sample TVD (m)	Conodonts species identified	CAI	Age
C-421694	Ldp1-1-C	Lodgepole Formation, Daly Member	688.9	Indeterminate fragment *Siphonodella isosticha*	1	Carboniferous (Middle to Late Tournaisian) - Lower *crenulata* Zone to *typicus* Zone
C-421695	Ldp1-2-C	Lodgepole Formation, Daly Member	691.8	*Elictognathus laceratus* Indeterminate ramiform element *Polygnathus communis communis* *Siphonodella isosticha*	1	Carboniferous (Middle to Late Tournaisian) - Lower *crenulata* Zone to typicus Zone
C-421696	Ldp1-4-C	Lodgepole Formation, Daly Member	699.23	Indeterminate fragment	1?	Age indeterminate
C-421697	Ldp1-5-C	Lodgepole Formation, Daly Member	702.25	*Polygnathus communis communis*	1	Late Devonian (Late Famennian) to Carboniferous (Late Tournaisian) - *styriaca* Zone to the *anchoralis-latus* Zone
C-421698	Ldp1-6-C	Lodgepole Formation, Daly Member	706	*"Spathodnathodus" abnormis* *Bispathodus stabilis Indeterminate ramiform element* *Polygnathus communis carina* *Polygnathus communis communis* *Protognathus kockeli* *Siphonodella isosticha*	1	Carboniferous (Middle Tournaisian) - Lower *crenulata* Zone to Upper *crenulata-isosticha* Zone

Table 10: Conodont results for the CDCOG et al. Willen 3-13-14-29-WPM well, 100/03-13-014-29W1/00, licence no. 2557.

GSC loc. no.	Sample no.	Formation	Sample TVD (m)	Conodonts species identified	CAI	Age
C-421691	BL3-1-C	Lodgepole Formation, Basal Limestone facies	631.44	*"Spathodnathodus" abnormis* *Bispathodus stabilis* Indeterminate ramiform element *Polygnathus communis communis* *Polygnathus longiposticus* *Siphonodella isosticha*	1	Carboniferous (Middle Tournaisian) - Lower *crenulata* Zone to Upper *crenulata-isosticha* Zone
C-421692	BL3-2-C	Lodgepole Formation, Basal Limestone facies	636.34	*Bispathodus stabilis* *Elictognathus laceratus* Indeterminate ramiform element *Polygnathus communis communis* *Polygnathus longiposticus* *Siphonodella cooperi*	1	Carboniferous (Early to Middle Tournaisian) - *sandbergi-duplicata* Zone to Upper *crenulata-isosticha* Zone
C-421693	BL3-4-C	Lodgepole Formation, Basal Limestone facies	638.03	*Bispathodus stabilis* *Dinodus fragosus* *Elictognathus laceratus* Indeterminate ramiform element *Polygnathus communis communis* *Polygnathus inornatus* *Polygnathus longiposticus* *Pseudopolygnathus triangulus triangulus* *Siphonodella cooperi* *Siphonodella crenulata*	1	Carboniferous (Middle Tournaisian) - Lower *crenulata* Zone

Appendix 2 — Summary of formaniferal analysis results

This is only a summary of the taxonomic findings. See McNeil (2007) for more detail on these results, relative abundances and counts, taxonomic references and biostratigraphic interpretations.

Table 11: Foraminiferal results for the NCE PET Waskada Prov. WSW 11-29-1-25-WPM well, 100/11-29-001-25W1/00, licence no. 2543.

GSC loc. no.	Sample No.	Formation (stratigraphic position determined from analysis)	Sample TVD (m, approx.)	Foraminiferal species identified	Miscellaneous fragments	Residue	Age
C-442712	Mor-1-F	Carlile Formation, Morden Member (indeterminate)	472.4	Barren of microfossils	Inoceramus prisms, abundant Fish fragments, abundant	Small amount of medium light-grey shale, flat pellets of white clay abundant, glauconite common	Indeterminate
C-442713	Mor-5-F	Carlile Formation, Morden Member (indeterminate)	478.8	Barren of microfossils	Inoceramus prisms, abundant	Very light-grey clay and medium light-grey clay	Indeterminate

Table 12: Foraminiferal results for the Anglo Ex Skelton 14-4-3-27-WPM well, 100/14-04-003-27W1/00, licence no. 262.

GSC loc. no.	Sample no.	Formation (stratigraphic position determined from analysis)	Sample TVD (m, approx.)	Foraminiferal species identified	Miscellaneous fragments	Residue	Age
C-442700	K2SC-1-F	Ashville Formation, Skull Creek Member	594	*Saccammina* sp. (coarse grained)	Leiosphaeridia sp. (algal cyst, thin, medium size)	Trace of medium grey shale with small amount of very fine-grained sandstone, glauconite rare	Late Albian, mid *H. gigas* Zone
		(mid Skull Creek Member)		*Hippocrepina* sp.	fish fragments – rare		
				Lagenammina alexanderi			
				Reophax? sp. (large, flattened)			
				Haplophragmoides gigas			
				Haplophragmoides linki			
				Ammobaculites fragmentarius			
				Ammobaculites petilus			
				Ammobaculites tyrrelli			
				Ammomarginulina asperata			
				Ammobaculoides whitneyi			
				Pseudobolivina variana			
				Gaudryina canadensis			
C-442701	K2SC-2-F	Ashville Formation, Skull Creek Member	597	*Saccammina lathrami*		Very small residue, pyrite common, few grains of very fine	early Late Albian, lower *H. gigas* Zone
		(lower Skull Creek Member)		*Saccammina sp. (coarse grained)*		quartz	
				Hippocrepina sp.			
				Lagenammina alexanderi			
				Ammodiscus anthosatus			
				Haplophragmoides gigas			
				Haplophragmoides linki			
				Ammobaculites fragmentarius			
				Ammobaculites tyrrelli			
				Ammomarginulina asperata			
				Ammobaculoides whitneyi			
				Textularia sp.			
				Pseudobolivina variana			
				Gaudryina canadensis			

Table 12: Foraminiferal results for the Anglo Ex Skelton 14-4-3-27-WPM well, 100/14-04-003-27W1/00, licence no. 262. *(continued)*

GSC loc. no.	Sample no.	Formation (stratigraphic position determined from analysis)	Sample TVD (m, approx.)	Foraminiferal species identified	Miscellaneous fragments	Residue	Age
C-442702	K2SC-3-F	Ashville Formation, Skull Creek Member (basal Skull Creek Member)	601	*Saccammina lathrami* *Saccammina sp. (coarse grained* *Lagenammina alexanderi* *Ammodiscus anthosatus* *Haplophragmoides gigas* *Haplophragmoides linki* *Ammobaculites fragmentarius* *Ammobaculites petilus* *Ammobaculites tyrrelli* *Ammomarginulina asperata* *Ammobaculoides whitneyi* *Trochammina sp.* *Gaudryina canadensis*		Trace of medium dark grey shale, pyrite very abundant	early Late Albian, basal *H. gigas* Zone
C-442703	K2SR-4-F	Swan River Formation (Swan River Formation)	602	Barren of microfossils	Inoceramus prisms abundant	Poorly sorted, rounded, fine to coarse-grained quartz sand with some dark yellow-ish orange to white clay matrix	
C-442704	K2SR-5-F	Swan River Formation (Swan River Formation)	610	Barren of microfossils	Fish fragments rare	Rounded, fine to coarse-grained, quartz sand, some pyrite	Indeterminate, possible Middle Albian

Table 13: Foraminiferal results for the Chevron Hartney 16-33-5-24-WPM well, 100/16-33-005-24W1/00, licence no. 9.

GSC loc. no.	Sample no.	Formation (stratigraphic position determined from analysis)	Sample TVD (m, approx.)	Foraminiferal species identified	Miscellaneous fragments	Residue	Age
C-442694	K1SC-1-F	Ashville Formation, Skull Creek Member	477	*Bathysiphon brosgei*	fish fragments – rare	Small residue, rare quartz grains, yellow-brown to yellow-grey clay or silty particles	Late Albian, mid to upper *H. gigas* Zone
		(mid to upper Skull Creek Member)		*Hippocrepina? sp.*	inoceramid prisms – rare		
				Haplophragmoides gigas?			
				Haplophragmoides sp.			
				Ammomarginulina asperata?			
				Hedbergella sp.			
C-442695	K1SC-2-F	Ashville Formation, Skull Creek Member	478	*Haplophragmoides sp.*	fish fragments – rare	Small amount of light grey to dark yellowish orange silt or very fine-grained sandstone, trace of glauconite	early Late Albian, lower *H. gigas* Zone
		(lower Skull Creek Member)		*Ammobaculoides whitneyi*			
C-442696	K1P4-3-F	Ashville Formation, Skulll Creek Member, Pense "P4" Formation equivalent	480	*Bathysiphon brosge*	Lancettopsis sp. (algal cyst)	Glauconite very abundant, minor amount of quartz grains and pyrite, fine brownish crystals common (siderite?)	early Late Albian, lower *H. gigas* Zone
		(lower Skull Creek Member)		*Saccammina sp. (coarse grained)*	fish fragments - common		
				Lagenammina alexanderi			
				Ammodiscus anthosatus			
				Haplophragmoides gigas			
				Haplophragmoides link			
				Ammobaculites asperata			
				Ammobaculites fragmentarius			
				Ammobaculites tyrrelli			
				Textularia? sp.			
				Pseudobolivina variana			
				Trochammina sp.			
				Gaudryina canadensis			

Table 13: Foraminiferal results for the Chevron Hartney 16-33-5-24-WPM well, 100/16-33-005-24W1/00, licence no. 9. *(continued)*

GSC loc. no.	Sample no.	Formation (stratigraphic position determined from analysis)	Sample TVD (m, approx.)	Foraminiferal species identified	Miscellaneous fragments	Residue	Age
C-442697	K1P4-4-F	Ashville Formation, Skulll Creek Member, Pense "P4" Formation equivalent	453.5	*Haplophragmoides gigas*		Glauconite very abundant, trace of quartz	early Late Albian, lower *H. gigas* Zone
		(lower Skull Creek Member)		*Haplophragmoides linki*			
				Ammobaculites fragmentarius			
				Ammobaculites tyrrelli			
				Ammomarginulina asperata			
				Ammobaculoides whitneyi			
				Trochammina sp.			
				Gaudryina canadensis			
C-442698	K1SR-5-F	Swan River Formation	485	*Saccammina lathrami*		Fine-grained quartz sand with some medium-sized Grains, muscovite common, glauconite rare	early Late Albian, basal *H. gigas* Zone
		(basal Skull Creek Member)		*Saccammina sp. (coarse grained)*			
				Lagenammina alexanderi			
				Ammodiscus anthosatus			
				Reophax? sp. (large, flattened)			
				Haplophragmoides gigas			
				Haplophragmoides linki			
				Ammobaculites fragmentarius			
				Ammobaculites petilus			
				Ammomarginulina asperata			
				Ammobaculoides whitneyi			
				Trochammina sp.			
				Gaudryina canadensis			
C-442699	K1SR-6-F	Swan River Formation	490	Barren of microfossils		Medium grey clay with minor amount of fine sandstone and some medium-sized quartz grains	Indeterminate, possibly Middle Albian
		(Possibly Pense Formation or upper Swan River Formation)					

Table 14: Foraminiferal results for the Chevron Woodnorth Prov. 5-18-9-27-WPM, 100/05-18-009-27W1/00, licence no. 81.

GSC loc. no.	Sample no.	Formation (stratigraphic position determined from analysis)	Sample TVD (m, approx.)	Foraminiferal species identified	Miscellaneous fragments	Residue	Age
C-442708	K4SC-1-F	Ashville Formation, Skull Creek Member	477	*Saccammina lathrami*	fish fragments – rare	Small amount of medium light-grey shale	Late Albian, upper *H. gigas* zone
		(upper Skull Creek Member)		*Hippocrepina?* sp.			
				Lagenammina alexanderi			
				Miliammina manitobensis			
				Haplophragmoides gigas?			
				Pseudobolivina variana			
				Eggerella? sp.			
				Gaudryina canadensis?			
C-442709	K4SC-2-F	Ashville Formation, Skull Creek Member	479	*Haplophragmoides gigas?*		Small amount of medium light-grey shale	Late Albian, mid *H. gigas* Zone
		(mid Skull Creek Member)		*Haplophragmoides* sp.			
				Ammobaculoides whitneyi			
				Hedbergella sp.			

Table 15: Foraminiferal results for the Chevron Elkhorn 7-8-11-29-WPM well, 100/07-08-011-29W1/00, licence no. 134.

GSC loc. no.	Sample no.	Formation (stratigraphic position determined from analysis)	Sample TVD (m, approx.)	Foraminiferal species identified	Miscellaneous fragments	Residue	Age
C-442710	K5SC-1-F	Ashville Formation, Skull Creek Member (Skull Creek Member)	543.5	*Ammobaculites fragmentarius*	*Lancettopsis* sp. (algal cyst)	Traces of medium-grey shale, very fine-grained quartz and pyrite	Late Albian, *H. gigas* Zone
C-442711	K5SC-2-F	Ashville Formation, Skull Creek Member (lower Skull Creek Member)	544.5	*Saccammina* sp. (coarse grained) *Ammodiscus anthosatus* *Haplophragmoides gigas* *Ammobaculites fragmentarius* *Ammobaculites tyrrelli* *Gaudryina canadensis*		Glauconite very abundant, finely crystalline siderite? abundant, pyrite common, some fine to medium- sized quartz grains	Late Albian, lower *H. gigas* Zone

Table 16: Foraminiferal results for the Imperial Norman 4-27-13-23-WPM well, 100/04-27-013-23W1/00, licence no. 642.

GSC loc. no.	Sample no.	Formation (stratigraphic position determined from analysis)	Sample TVD (m, approx.)	Foraminiferal species identified	Miscellaneous fragments	Residue	Age
C-442705	K3P4-1-F	Ashville Formation, Skulll Creek Member, Pense “P4” Formation equivalent (lower Skull Creek Member)	401	*Haplophragmoides gigas* *Ammobaculites fragmentarius*		Very fine-grained quartz sandstone and medium light grey shale, glauconite rare	Late Albian, *H. gigas* Zone
C-442706	K3SR-2-F	Swan River Formation (Swan River Formation)	402		fish fragments – common	subrounded, fine to coarse-grained quartz sand, some white clay, pyrite, and trace of lignite; bi-pyramidal quartz crystals common	Indeterminate, possibly Middle Albian
C-442707	K3SR-3-F	Swan River Formation (Swan River Formation)	405	Barren of microfossils		Only a few very fine quartz grains present	Indeterminate

Appendix 3 — Summary of palynology analysis results

This is only a summary of the taxonomic findings. See White (2005) for more detail on these results, relative abundances and counts, taxonomic references and biostratigraphic interpretations.

Table 17: Palynology results for the NCE PET Waskada Prov. WSW 11-29-1-25-WPM well, 100/11-29-001-25W1/00, licence no. 2543.

GSC loc. no.	Sample no.	Formation	Sample TVD (m, approx.)	Acritarchs and dinoflagellates	Gymnosperm pollen and spores	Angiosperm pollen	Age
C-442712	Mor-1-P	Carlile Formation, Morden Member	472.4	*Chatangiella* sp. cf. *C. granulifera*	*Cicatricosisporites? australiensis*	*Ajatipollis* sp. cf. *A. tetraedralis*	Turonian
				Heterosphaeridium difficile		*Clavatipollenties minutus*	
				Paleoperidinoum cretaceum		*cf. Foveotetradites* sp. , a thin-walled, obligate, microreticulate tetrad, even luminae, colpi not visible	
				Odontochitina sp.		*Fraxinoipollenites venustus*	
				Surculospaeridium longifurcatum		*Liliacities* sp	
				unidentified hystricosphaerid dinoflagellate		*Psilatricolpites parvulus*	
						Retitrescolpites vermimurus	
						?*Retitricolpites* sp.	
						Reticulate, tricolpate	
C-442713	Mor-5-P	Carlile Formation, Morden Member	478.8	*Cribroperidinium* sp		*Ajatipollis* sp. cf. *A. tetraedralis*	Turonian
				unidentified hystricospaerid dinoflagellate		*Fraxinoipollenites venustus*	
						Retitricolpites sp	
						Retitricolpites vulgaris	
						Striatopollis paraneus	

Table 18: Palynology results for the Anglo Ex Skelton 14-4-3-27-WPM well, 100/14-04-003-27W1/00, licence no. 262.

GSC loc. no.	Sample no.	Formation	Sample TVD (m, approx.)	Acritarchs and dinoflagellates	Gymnosperm pollen and spores	Angiosperm pollen	Age
C-442700	K2SC-1-P	Ashville Formation, Skull Creek Member	594	*Pterodinium* sp.	*Cicatricosi-sporites hallei*	*Tricolpites* sp., micro-foveolate or eroded	Albian
				?Algal test, multiporate, not pollen	*Gleicheniidites* sp. cf. *G. circinidites*		
C-442701	K2SC-2-P	Ashville Formation, Skull Creek Member	597	*Canningia* sp.	*Alisporites* spp.	*Clavatipollenites minutus*	late Aptian or younger, probably of late Middle or Late Albian age
				Canningia turrita Brideaux	*Appendicis-porties jansonii*	*Fraxinoipollenites constrictus*	
				?*Criproperidinum* sp.	*Cicatricosi-sporites australiensis*	cf. *Foveotricolpites concinnus*	
				Hystrichodinium voightii	*Classopollis classoides*	cf. *Racemonocolpites exoticus*	
				Kiokansium unituberculatum	T-C-T	*Retimonocolpites textus*	
				Palaeoperidinium cretaceum	?spore	reticulate, tricolpate pollen	
				Spiniferites sp.			
				Tanyosphaeridium sp.			
				unidentified dinoflagellate			
C-442702	K2SC-3-P	Ashville Formation, Skull Creek Member	601	*Apteodinium granulatum*	*Alisporites* spp.	cf. *Foveotricolpites concinnus*	late Aptian or younger, probably of late Middle or Late Albian age
				?*Cribroperidinium* sp.	*Appendicis-porties jansonii*	?*Racemonocolpites* sp.	
				Cribroperidinium exilicristatum	*Appendicis-porties ?erdtmanii*	*Retitricolpites georgensis*	
				?*Pareodinia* sp.	*Classopollis classoides*		
				unidentified dinoflagellate	T-C-T		
C-442703	K2SR-4-P	Swan River Formation	602	*Fromea* ?n. sp.		*Retitricolpites* sp.	late Aptian or younger, probably of late Middle or Late Albian age
				Oligosphaeridium sp.			
				Palaeoperidinium cretaceum			
				Pterodinium sp.			
				unidentified dinoflagellates			
C-442704	K2SR-5-P	Swan River Formation	610	*Cribroperidinium* sp.	spore	*Racemonocolpites exoticus*	Albian
				Nyktericysta davisii		*Retitricolpites maximus*	
				Odontochitina sp.		*Retitricolpites vulgaris*	
				?*Pareodinia* sp.		*Striatopollis paraneus*	

Table 19: Palynology results for the Chevron Hartney 16-33-5-24-WPM well, 100/16-33-005-24W1/00, licence no. 9.

GSC loc. no.	Sample no.	Formation	Sample TVD (m, approx.)	Acritarchs and dinoflagellates	Gymnosperm pollen and spores	Angiosperm pollen	Age
C-442694	K1SC-1-P	Ashville Formation, Skull Creek Member	477	*Paleoperidinium* sp. cf. *pyrophorum*	*Appendicisporites jansonii*	*Phimopollenites pseudocheros*	Albian
				Paleoperidinium cretaceum	*Cicatricosisporites* sp. cf. *C. subrotundus*	?*Racemonocolpites* sp.	
				cingulate, apical archepyle	*Cicatricosisporites hallei*	*Retitricolpites* sp., microrugu-reticulate	
				peridinoid, drooping apex	*Classopollis classoides* (Pflug)		
				peridinoid dino with apical peripharagm	T-C-T		
					Trilobosporites apiverrucatus		
C-442695	K1SC-2-P	Ashville Formation, Skull Creek Member	478	*Apteodinium granulatum*	*Equisetosporites* sp.	?*Asteropollis* sp.	Albian
				Cribroperidinium sp.		*Clavatipollenties hughesii*	
				Paleoperidinium cretaceum		cf. *Phimopollenites pseudocheros*	
						Foveotricolpites sp.	
						cf. *Foveotricolporites callosus*	
						Tricolpites sp.	
C-442696	K1P4-3-P	Ashville Formation, Skulll Creek Member, Pense "P4" Formation equivalent	480	*Fromea* n. sp.?	*Appendicisporites jansonii*	*Artemisia/Ambrosia* pollen, modern contamination	Albian
				Cribroperidinium	*Cicatricosisporites hallei*	*Chenopodiineae*, modern contamination	
				?*Callaiosphaeridium* sp.	*Cicatricosisporites potomacensis*	?*Retimonocolpites* sp.	
				Florentinia sp.	*Classopollis classoides* (Pflug)	*Retitricolpites* sp.	
				Oligosphaeridium reniform	T-C-T	angiosperm, crushed, ?striate	
				Oligosphaeridium complex			
				Spiniferites sp.			
C-442697	K1P4-4-P	Ashville Formation, Skulll Creek Member, Pense "P4" Formation equivalent	453.5	*Palaeoperidinium cretaceum*		cf. *Liliacities* sp.	Albian
C-442698	K1SR-5-P	Swan River Formation	485	*Apteodinium granulatum*	*Alisporites* spp., common	cf. *Clavatipollentites hughesii*	late Middle Albian or younger
				Cribroperidinium edwardsii	*Classopollis classoides* (Pflug)	*Clavatipollenites minutus*	
				Cribroperidinium exilicristatum	*Pristinispollenites crassus*	angiosperm, microreticulate? apertures not observable	
				Odontochitina striatoperforata	T-C-T	*Fraxinoipollenites constrictus*	
				Tanyosphaeridium sp.	*Cicatricosisporites hallei*	*Retitricolpites georgensis*	
				?multiporate spherical object, does not look like an angiosperm		*Racemonocolpites exoticus*	
				unidentified striate dinoflagellate with precingular archeopyle		angiosperm? reticulate?	
C-442699	K1SR-6-P	Swan River Formation	490	*Gonyaulacysta* sp. cf. *G. cassidata*	*Aequitriradites verrucosus*		Aptian to Ceno-manian
					Alisporites spp		
				Freshwater algae and fungi:	*Cicatricosisporites australiensis*		
				Botryococcus sp.	*Cerebropollenites mesozoicus*		
				Chomotriletes minor	*Equisetosporites* sp.		
				Schizosporis reticulatus	*Pristinispollenites crassus*		
					T-C-T		
					Thick-walled, coarse verrucate, cingulate spore		

Table 20: Palynology results for the Chevron Woodnorth Prov. 5-18-9-27-WPM, 100/05-18-009-27W1/00, licence no. 81.

GSC loc. no.	Sample no.	Formation	Sample TVD (m, approx.)	Acritarchs and dinoflagellates	Gymnosperm pollen and spores	Angiosperm pollen	Age
C-442708	K4SC-1-P	Ashville Formation, Skull Creek Member	477	?Algal test, multiporate *Aptea polymorpha* *Pseudoceratium eisenackii* ?*Pterodinium* sp.		*Racemoncolpites exoticus* *Retitricolpites virgeus* *Tricolpites* sp.	late Middle or Late Albian
C-442709	K4SC-2-P	Ashville Formation, Skull Creek Member	479	?*Paleoperidinoum cretaceum* *Heterosphaeridium difficile* *Odontochitina* sp. apex *Pseudoceratium eisenackii* *Pseudoceratium expolitum*	*Equisetosporites* sp.	*Psilatricolpites parvulus* cf. *Racemonocolpites exoticus* Reticulate, ?tricolpate *Retitricolpites* sp. ?*Rousea* sp. Unknown palynomorph, *Azonia*-like shape and reticulum, one torn colpus	late Middle or Late Albian

Table 21: Palynology results for the Chevron Elkhorn 7-8-11-29-WPM well, 100/07-08-011-29W1/00, licence no. 134.

GSC loc. no.	Sample no.	Formation	Sample TVD (m, approx.)	Acritarchs and dinoflagellates	Gymnosperm pollen and spores	Angiosperm pollen	Age
C-442710	K5SC-1-P	Ashville Formation, Skull Creek Member	543.5	*Micrhystridium* cf. *M. stellatum* *Odontochitina striatoperforata* *Tanyosphaeridium* sp unidentified dinoflagellate	*Cicatricosisporites australiensis* *Cicatricosisporites* sp. cf. *Anemia exilioides*	*Clavatipollenties hughesii* *Foveotricolporites* sp. *Liliacidites* sp. *Penetetrapites* sp. *Retitricolpites* sp. *Retitrescolpites vermimurus* ?porate pollen, but not stained possible primitive *Azonia*	post- late Middle Albian
C-442711	K5SC-2-P	Ashville Formation, Skull Creek Member	544.5	*Deflandrea limpida* *Fromea fragilis* *Fromea* sp. *Luxadinium propatulum* *Microdinium* sp.· *Odontochitina striatoperforata* *Pseudoceratium eisenackii* *Tanyosphaeridium* sp.	?Megaspore fragment	*Arecipites* sp. *Ajatipollis* sp. cf. *A. tetraedralis* *Phimopollenites megistus* *Retitricolpites* sp. cf. *Retitricolpites vulgaris* *Triporopollenites* sp.	post- late Middle Albian

Table 22: Palynology results for the Imperial Norman 4-27-13-23-WPM well, 100/04-27-013-23W1/00 licence no. 642.

GSC loc. no.	Sample no.	Formation	Sample TVD (m, approx.)	Acritarchs and dinoflagellates	Gymnosperm pollen and spores	Angiosperm pollen	Age
C-442705	K3P4-1-P	Ashville Formation, Skulll Creek Member, Pense “P4” Formation equivalent	401	*?Paleoperidinoum cretaceum*	*Equisetosporites* sp.	*Fraxinoipollenites venustus*	late Middle to Late Albian
				Pseudoceratium eisenackii	*Pristinuspollenites* sp	*Retitricolpites* sp.	
				Kiokansium williamsii		*cf. Retitricolpites maximus*	
						cf. *Rousea* sp.	
C-442706	K3SR-2-P	Swan River Formation	402	*Cribroperidinium* sp		*Retitricolpites* sp. cf. *R. georgensis*	Middle Albian or younger
				Odontochitina striatoperforata		*Liliacidites* sp.	
				?Paleoperidinium pyrophorum			
				unidentified dinoflagellate, pointed apex and antapex, cingulate , papillate apical and antapical horns			
				?Spongodinium sp.			
C-442707	K3SR-3-P	Swan River Formation	405	Barren of microfossils.	Barren of microfossils	Barren of microfossils	Inderterminate

Appendix 4 — Summary of dinocyst analysis results

This is only a summary of the taxonomic findings. See Appendix 1 of White (2005) for more detail on these results, relative abundances and counts, taxonomic references and biostratigraphic interpretations.

Table 23: Dinocyst results for the NCE PET Waskada Prov. WSW 11-29-1-25-WPM well, 100/11-29-001-25W1/00, licence no. 2543.

GSC loc. no.	Sample no.	Formation	Sample TVD (m, approx.)	Dinocyst species identified	Age
C-442713	Mor-5-P	Carlile Formation, Morden Member	478.8	*Odontochitina operculata*	Turonian
				Endoscrinium campanula	
				Surculosphaeridium longifurcatum	
				Heterosphaeridium difficile	
				Florentinia cooksoniae	
				Caligodinium aceras	
				Eurydinium glomeratum	
				Chatangiella sp.?	

Table 24: Dinocyst results for the Anglo Ex Skelton 14-4-3-27-WPM well, 100/14-04-003-27W1/00, licence no. 262.

GSC loc. no.	Sample no.	Formation	Sample TVD (m, approx.)	Dinocyst species identified	Age
C-442700	K2SC-1-P	Ashville Formation, Skull Creek Member	594	*Odontochitina operculata*	Albian
				Oligosphaeridium complex	
				O. albertense	
				Palaeoperidinium cretaceum	
				Kiokansium unituberculatum	
				Pseudoceratium eisenackii	
				Fromea complicata	
				F. fragilis	
				Cribroperidinium exilicristatum	
				Hystrichodinium voightii	
				Apteodinium grande	
C-442704	K2SR-5-P	Swan River Formation	610	*Oligosphaeridium complex*	Albian
				Odontochitina operculata	
				Palaeoperidinium cretaceum	
				Oligosphaeridium albertense	
				O. totum	
				Kiokansium unituberculatum	
				K. williamsii	
				Fromea complicata	
				F. fragilis	
				Pseudoceratium eisenackii	
				Hystrichodinium voightii	
				Nyktericysta davisii	

Table 25: Dinocyst results for the Chevron Hartney 16-33-5-24-WPM well, 100/16-33-005-24W1/00, licence no. 9.

GSC loc. no.	Sample no.	Formation	Sample TVD (m, approx.)	Dinocyst species identified	Age
C-442694	K1SC-1-P	Ashville Formation, Skull Creek Member	477	*Cribroperidinium* species, including *C. edwardsii, C. exilicristatum, C. intricatum* *Odontochitina operculata* *Palaeoperidinium cretaceum* *Oligosphaeridium complex* *O. albertense* *O. totum* *Fromea complicata* *F. amphora* *Circulodinium distinctum* *C. brevispinosum* *Pseudoceratium eisenackii*	Albian
C-442695	K1SC-2-P	Ashville Formation, Skull Creek Member	478	*Palaeoperidinium cretaceum* *Oligosphaeridium albertense* *O. complex* *Fromea complicata* *F. fragilis* *Apteodinium granulatum* *Cribroperidinium edwardsii* *C. exilicristatum*	Albian
C-442697	K1P4-4-P	Ashville Formation, Skulll Creek Member, Pense "P4" Formation equivalent	453.5	*Odontochitina operculata* *Oligosphaeridium complex* *O. albertense* *Palaeoperidinium cretaceum* *Kiokansium unituberculatum* *Pseudoceratium eisenackii* *Fromea complicata* *F. fragilis* *Cribroperidinium exilicristatum* *Hystrichodinium voightii* *Apteodinium grande*	Albian

Table 26: Dinocyst results for the Chevron Woodnorth Prov. 5-18-9-27-WPM well, 100/05-18-009-27W1/00, licence no. 81.

GSC loc. no.	Sample no.	Formation	Sample TVD (m, approx.)	Dinocyst species identified	Age
C-442708	K4SC-1-P	Ashville Formation, Skull Creek Member	477	*Aptea polymorpha* *Palaeoperidinium cretaceum* *Apteodinium grande* *A. granulatum* *Hystrichodinium voightii* *Cribroperidinium edwardsii* *Fromea fragilis* *Oligosphaeridium totum* *Chichaouadinium vestitum* *Pseudoceratium eisenackii* *P. expolitum*	Late Albian or late Middle Albian

Table 27: Dinocyst results for the Imperial Norman 4-27-13-23-WPM well, 100/04-27-013-23W1/00, licence no. 642.

GSC loc. no.	Sample no.	Formation	Sample TVD (m, approx.)	Dinocyst species identified	Age
C-442706	K3SR-2-P	Swan River Formation	402	*Odontochitina operculata*	Albian
				Palaeoperidinium cretaceum	
				Oligosphaeridium albertense	
				O. totum	
				Fromea fragilis	
				Wuroia sp.	
				Kiokansium unituberculatum	
				Subtilisphaera pirnaensis	
				Stiphrosphaeridium anthophorum	