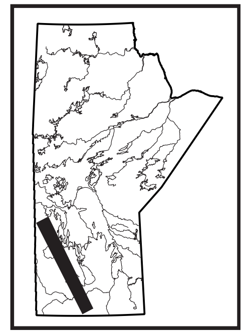
GS-16 Late Cretaceous (Santonian–Campanian) marine microfossils of the Manitoba escarpment, southwestern Manitoba

by R. Muehlbauer[1], D.C. Kelly[1], J.D. Bamburak and M.P.B. Nicolas



Muehlbauer, R., Kelly, D.C., Bamburak, J.D. and Nicolas, M.P.B. 2014: Late Cretaceous (Santonian–Campanian) marine microfossils of the Manitoba escarpment, southwestern Manitoba; *in* Report of Activities 2014, Manitoba Mineral Resources, Manitoba Geological Survey, p. 181–186.

Summary

Late Cretaceous strata exposed along the Manitoba escarpment contain diverse assemblages of marine microfossils (foraminifera and radiolaria), which provide an opportunity to relate local and regional spatiotemporal variations in biofacies to past changes in ocean-climate conditions driven by sea-level fluctuations within the Cretaceous Western Interior Seaway (WIS) of North America (McNeil and Caldwell, 1981; McNeil, 1984; Caldwell et al., 1993; Schröder-Adams et al., 2001). The response of planktonic foraminifera to environmental change across the Santonian–Campanian boundary (ca. 83.5 Ma) is of particular interest to this ongoing study. Bulk-sediment samples were collected at roughly 1 m intervals from the Boyne Member of the Carlile Formation up through the overlying Gammon Ferruginous, Pembina, Millwood and Odanah members of the Pierre Shale. The stratigraphic succession contains numerous bentonite beds including a set of tightly bundled and widely correlative ash beds referred to as the 'Ardmore' bentonite succession. These ash beds are within early Campanian strata and are ascribed to the Pembina Member of the Pierre Shale (Hatcher and Bamburak, 2010). It is hoped that use of this marker horizon will help improve biostratigraphic correlation within the region, and will also assist in determining if comparable changes in microfossil assemblages occur at other geographically distant localities where the 'Ardmore' bentonite beds are preserved. Cursory examination of the study samples reveals occurrence of peak abundances of planktonic foraminifera within the Boyne Member during the Niobrara transgression, followed by peak radiolaria abundances in the Millwood Member during what was likely the ensuing Claggett transgression. This striking change in microfossil assemblages is attributed to the southerly advance of Arctic boreal waters as global climate cooled during the early Campanian. This work is part of a broader study into the Late Cretaceous (Cenomanian–early Campanian) microfossils of the WIS of North America.

Introduction

The early part of the Late Cretaceous (Cenomanian–Santonian stages, ca. 100–83.5 Ma) is typified by a prolonged 'greenhouse' state in global climate and elevated levels of oceanic crust production that included the emplacement of massive oceanic plateaus (Larson, 1991; Friedrich et al., 2012). The rapid rates of seafloor spreading, fuelled by this 'superplume' magmatism, led to a major reorganization in the tectonic configuration of the ocean basins and a long-term highstand in global eustasy that, in turn, led to the formation of vast epicontinental seaways (Berggren and Hollister, 1974; Miller et al., 2005). One such feature is the Western Interior Seaway (WIS) of North America that, at times during the Late Cretaceous, extended from the Tethyan realm in the Gulf of Mexico to boreal regions in the Arctic Ocean (Kauffman, 1984). In extreme cases, these tectonically forced changes to paleogeography, in conjunction with marine productivity, conspired to foster widespread dysoxic to anoxic conditions within the world's ocean basins. These 'oceanic anoxic events' are manifested in the Late Cretaceous stratigraphy as organic-rich beds of black shale and prominent fluctuations in marine carbon-isotope records (Schlanger and Jenkyns, 1976; Arthur et al., 1988; Jarvis et al., 2006). This protracted period of tectonic upheaval and episodic black shale deposition gradually waned across the Santonian–Campanian boundary (ca. 83.5 Ma) as global climate steadily cooled (Jones and Jenkyns, 2001; Friedrich et al., 2012). The environmental change wrought by this fundamental shift in Earth-system processes fostered a major turnover in the taxonomic composition of marine plankton, most notably the planktonic foraminifera (Wonders, 1980; Silva and Sliter, 1999). However, efforts to study the planktonic foraminiferal response to this 'Santonian turnover' event have been hampered by the presence of an extensive unconformity truncating many deep-sea sedimentary records straddling the Santonian–Campanian boundary (Ando et al., 2013). By contrast, Late Cretaceous strata exposed along the Manitoba escarpment preserve rich and diverse microfossil assemblages, which include planktonic foraminifera (McNeil and Caldwell, 1981); hence, this stratigraphic record affords the opportunity to document the response of marine plankton within the WIS of North America.

[1] Department of Geoscience, University of Wisconsin, 1215 W Dayton St., Madison, Wisconsin 53706 U.S.

Geographic setting and stratigraphic framework

The Late Cretaceous sedimentary succession of Manitoba is exposed along a gentle escarpment trending northwest and extending into Saskatchewan and North Dakota. Santonian–Campanian sedimentary rocks are well exposed in the Pembina Hills region of the Manitoba escarpment (Figure GS-16-1). At that location, both the chalky and calcareous shale units of the Boyne Member of the Carlile Formation are exposed. These units contain an abundance of planktonic and benthic foraminifera. A relatively thin deposit of oxidized shale representing the Gammon Ferruginous Member of the Pierre Shale unconformably rests atop the Boyne Member. This shale was likely deposited after the Niobrara transgression as planktonic foraminifera are extremely rare throughout this interval. Overlying the Gammon Ferruginous is another unconformity followed by deposits of the Pembina Member black shale and the 'Ardmore' bentonite succession. This proves to be a very important marker surface as it is correlative for ~1000 km across the WIS (Bertog et al., 2007) and the bentonite beds have yielded a radioisotope age of ~80 Ma (Obradovich, 1993; Hicks et al., 1999; Bamburak et al., 2013), placing it firmly within the early Campanian. Microfossil assemblages within shale of the Pembina Member are very depauperate. Conformably deposited above the Pembina Member are the Millwood and Odanah members of the Pierre Shale, both of which are much more siliceous than the underlying shale units.

Future work will be done on samples from various known localities (McNeil and Caldwell, 1981; McNeil, 1987; Bamburak and Christopher, 2004; Bamburak and Nicolas, 2010) of the Cenomanian–Turonian record of the Manitoba escarpment, particularly the Keld and Assiniboine members of the Favel Formation, which were deposited during the Greenhorn transgression. These members are expected to contain an abundance of foraminifera, as evidenced from previous work and their close affinity to the Boyne Member units. Sediment samples were collected through the Favel Formation in August of 2014 from the Porcupine Hills and Duck and Riding mountain areas along the Manitoba escarpment.

Materials and methods

A total of 72 bulk-sediment samples were collected at roughly1 m intervals through the Carlile and Pierre Shale formations. An aliquot of 4–6 g from each sample was weighed and processed for microfossils. Each aliquot of sediment was disaggregated using a warm, pH-buffered solution consisting of hydrogen peroxide, sodium hexametaphosphate and distilled water. Disaggregated sediment samples were then rinsed with tap water over a 63 µm sieve and placed in an oven at ~30˚C to dry. After drying,

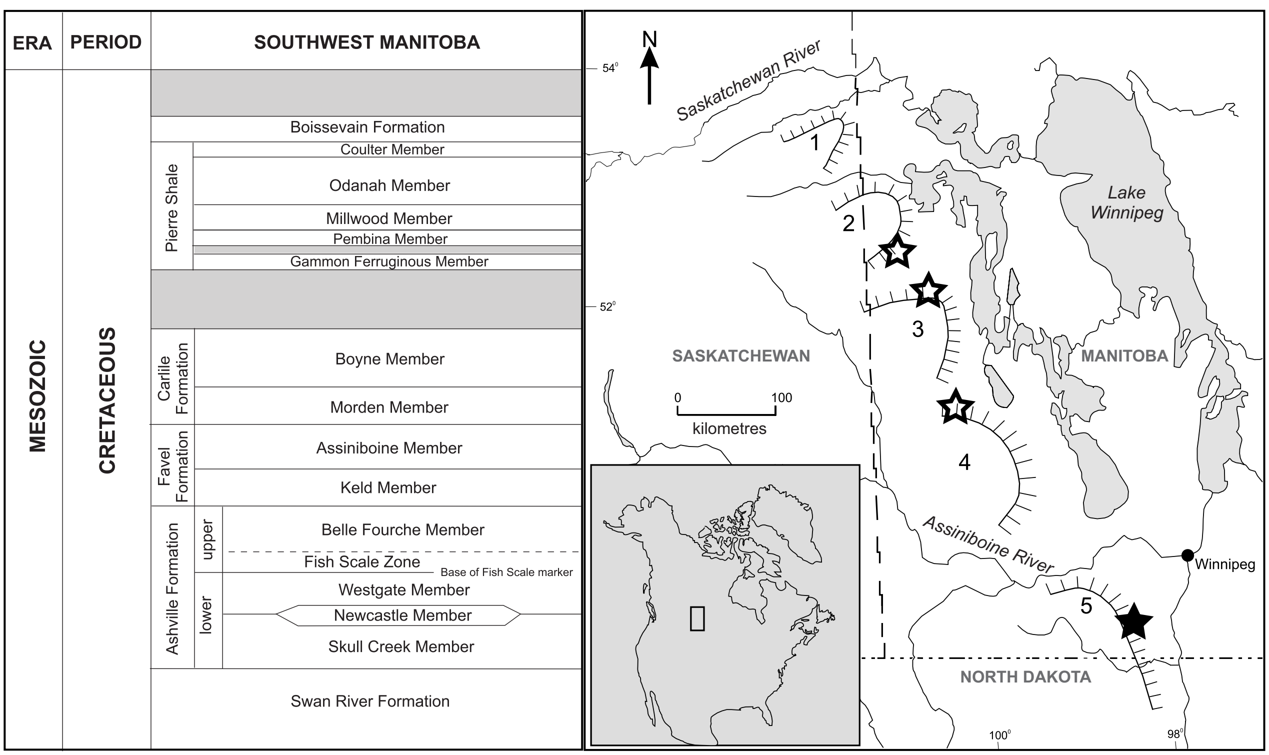


Figure GS-16-1: *Late Cretaceous stratigraphy (left) of the Manitoba escarpment (Nicolas and Bamburak, 2009) and localities visited on the escarpment (right). The solid black star represents the study area, from which data in this report was generated; unfilled stars represent areas where samples have been collected, but are still being processed: 1, Pasquia Hills; 2, Porcupine Hills; 3, Duck Mountain; 4, Riding Mountain; 5, Pembina Hills (modified after McNeil and Caldwell, 1981).*

each sample was passed through a 75 µm sieve and split a number of times to attain a manageable amount of microfossils for faunal counts. Representative specimens of key taxa were imaged using scanning electron microscopy and are shown in Figure GS-16-2.

Results

Examination of microfossil assemblages gleaned from Late Cretaceous strata of the Pembina Hills study area reveals important large-scale trends that track fluctuations in sea level. Within the Boyne Member of the Carlile Formation, an abundance of foraminifera occurs during the Niobrara transgression, whereas radiolaria are largely absent from this unit. In general, foraminifera are present, but relatively rare, within the lower calcareous shale unit of the Boyne Member. Foraminiferal abundances rapidly increase across the upper contact of the calcareous shale unit with peak abundances in both benthic

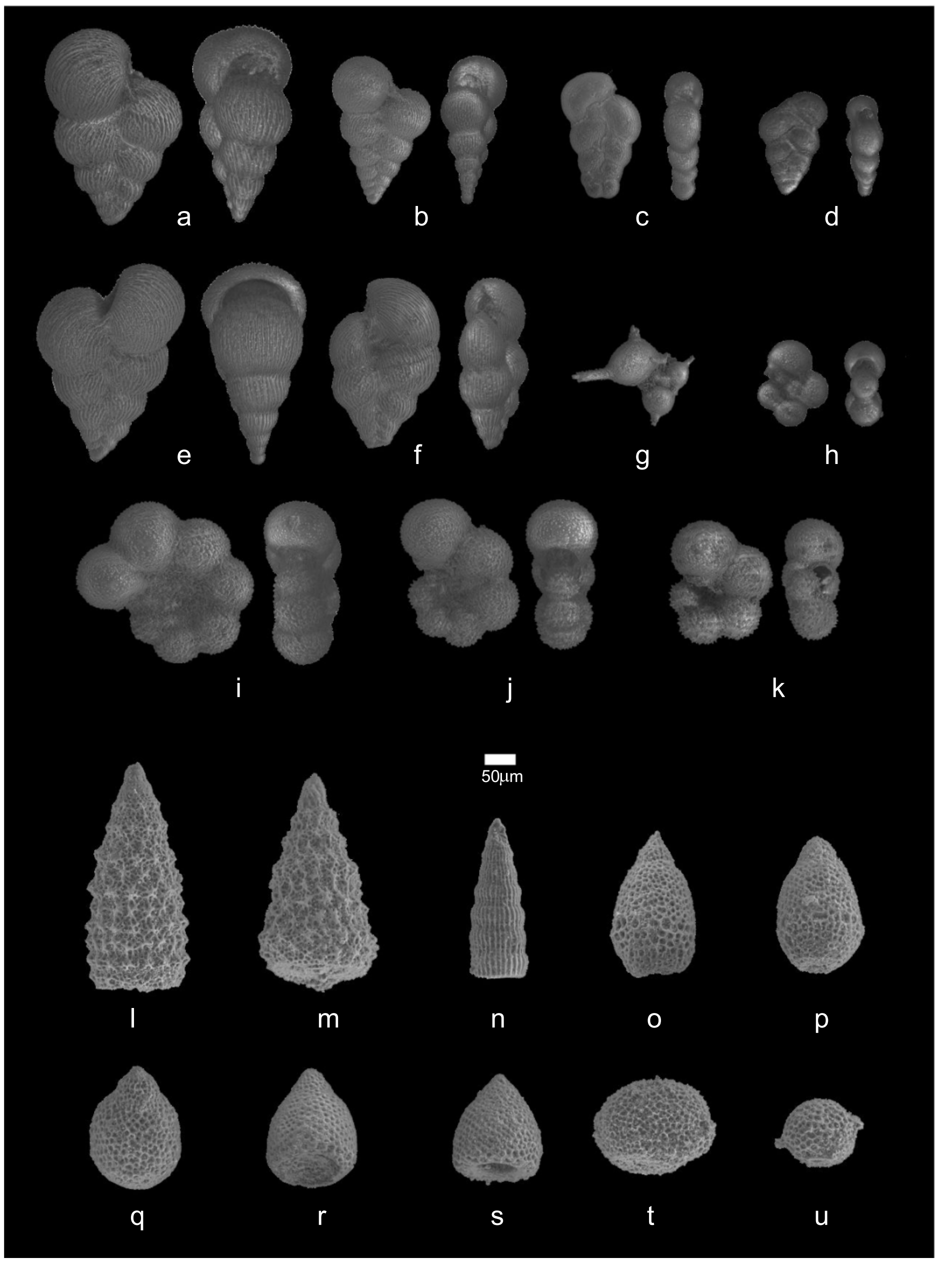


Figure GS-16-2: *Scanning electron microscope images of select taxa of planktonic foraminifera from the Boyne Member (a–k) and radiolaria from the Millwood Member (l–u):* ***a)*** Heterohelix striata; ***b)*** Heterohelix globulosa; ***c)*** Heterohelix planata; ***d)*** Laeviheterohelix pulchra; ***e)*** Pseudotextularia plummerae; ***f)*** Heterohelix sphenoides; ***g)*** Schackoina multispinata; ***h)*** Globigerinelloides volutus; ***i)*** Globigerinelloides prairiehillensis; ***j)*** Globigerinelloides multispinus; ***k)*** Hedbergella delrioensis; ***l)*** Lithostrobus *sp.?;* ***m)*** Lithostrobus *sp.?;* ***n)*** Dictyomitra multicostata; ***o)*** Stichocapsa Tyrelli?; ***p)*** Tricolocapsa salva?; ***q)*** Theocampe sphaerocephala?; ***r)*** Dictyocephalus macrostoma; ***s)*** Cyrtocalpis crassitestata?; ***t)*** Cenellipsis hexagonalis?; ***u)*** Caryosphaera equidistans?

foraminifera (~1800 tests per gram) and planktonic foraminifera (~11 000 tests per gram) being recorded within the overlying chalky unit of the Boyne Member (Figure GS-16-3).

The overlying Gammon Ferruginous and Pembina members of the Pierre Shale contain very few microfossils. The lack of marine microfossils and the unconformable nature of these deposits suggest that both of these units were deposited during the regression that separated the Niobrara and Claggett transgressive cycles. Above the 'Ardmore' bentonite beds of the Pembina Member lies the Millwood Member. This siliceous shale contains a preponderance of radiolaria, with peak abundances of ~45 000 tests per gram (Figure GS-16-3). The superabundance of radiolaria, being exclusively marine zooplankton, indicates that deposition of the Millwood Member was associated with renewed sea-level rise during the Claggett transgression. In addition, the basal Millwood Member was found to contain a diverse fauna of calcareous benthic foraminifera. The occurrence of this benthic foraminiferal fauna is restricted to the lowermost part of the Millwood Member as the upper part of this stratigraphic unit is typified by very low abundances of foraminifera (Figure GS-16-3). The abundance of radiolaria tapers off and the quality of preservation steadily declines toward the top of the Millwood Member. The overlying Odanah Member is generally devoid of marine microfossils, but the high SiO_2 content of this siliceous shale and its indurated nature suggest that the scarcity of radiolaria may be due to poor preservation and diagenesis (Young and Moore, 1994).

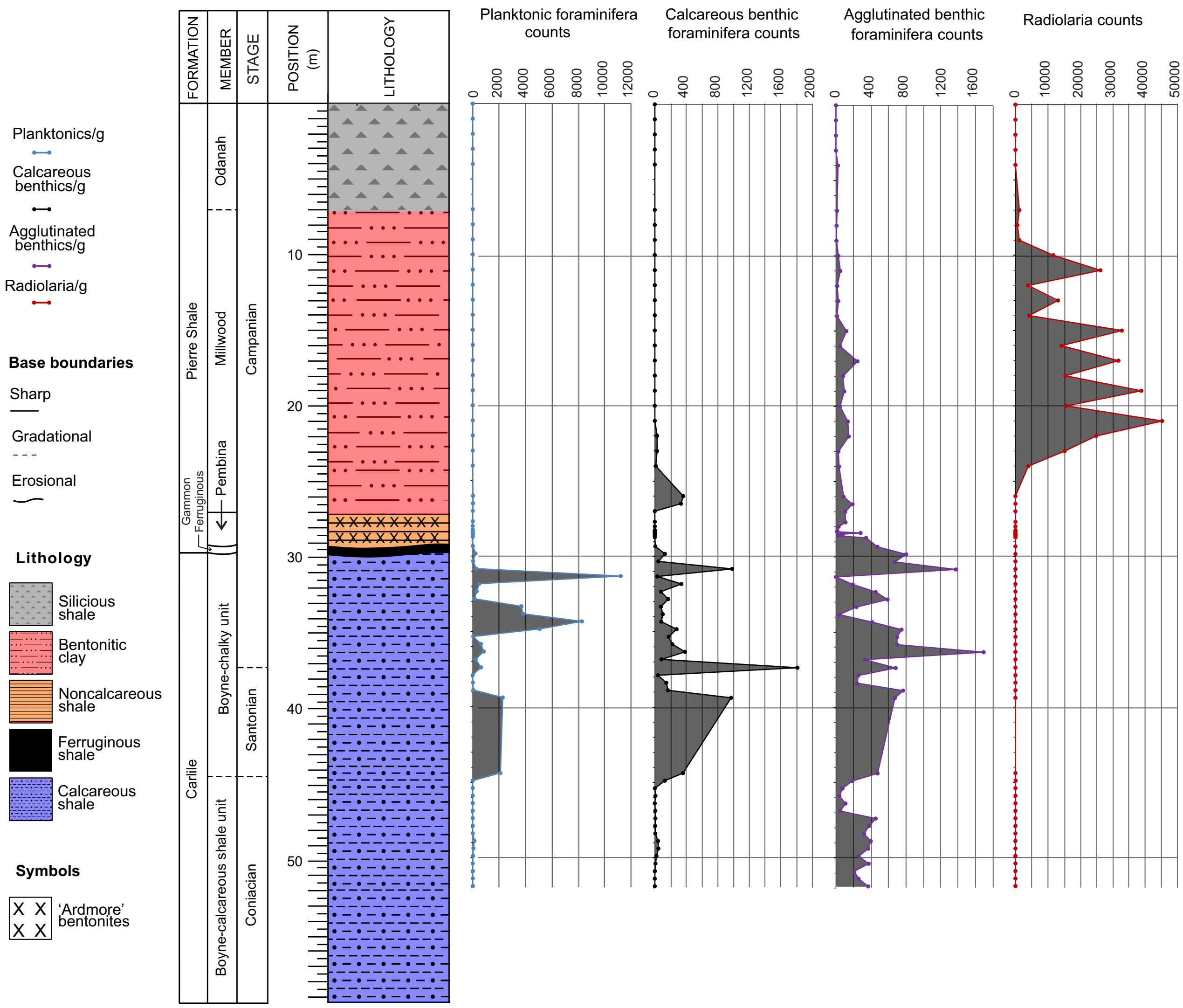


Figure GS-16-3: Microfossil counts of individual tests per gram of dry bulk sediment collected from the Pembina Hills study area. Counts have been generated at roughly 1 m resolution throughout the composite section for planktonic foraminifera, calcareous and agglutinated benthic foraminifera, and radiolaria. Note the change in horizontal scale from one microfossil group to the next.

Conclusions

Late Cretaceous strata exposed along the face of the Manitoba escarpment record a stratigraphic succession of changes among marine microfossil assemblages across the Santonian–Campanian boundary. Salient aspects of this faunal succession are: 1) peak foraminiferal abundances in the Boyne Member of the Carlile Formation, with the abundance of planktonic foraminifera peaking in the upper (chalky) unit; 2) a sharp decline in foraminiferal abundances within the Gammon Ferruginous and Pembina members of the Pierre Shale; 3) a transitory occurrence of a diverse benthic foraminiferal fauna within the basal Millwood Member of the Pierre Shale; 4) a dramatic increase in radiolarian abundances up through the Millwood Member; and 5) a conspicuous absence of marine microfossils within the overlying Odanah Member of the Pierre Shale.

Deposition of the Boyne Member of the Carlile Formation occurred during the sea-level highstand of the Niobrara transgression. The appreciable scarcity of marine microfossils within the Gammon Ferruginous and Pembina members of the Pierre Shale suggests that both of these units were deposited during a regressive phase that separated the Niobrara and Claggett transgressions. Renewed sea-level rise during the Claggett transgression is signalled by the appearance of a diverse benthic foraminiferal fauna within the lowermost Millwood Member, followed by a preponderance of radiolaria and the disappearance of foraminifera. The prominent increase in radiolaria within the Millwood Member likely reflects the southerly advance of boreal waters within the WIS as global climate cooled during the early Campanian (Pugh et al., 2014).

Economic considerations

Biostratigraphic correlation is important to the recovery of oil and gas resources. By updating the biostratigraphic zonation of the Boyne Member, as well as creating a foraminiferal abundance proxy, correlation throughout the region surrounding the Manitoba escarpment may be refined. In addition, the high abundance of radiolaria in the Millwood Member could serve as a broad and persistent taphonomic indicator, which may prove useful for onsite drilling operations throughout much of the Manitoba escarpment. Such a thick succession of radiolaria would most certainly be apparent in well cuttings, even at a sampling resolution as coarse as 10–15 m. Foraminiferal abundance may also serve as a proxy for microporosity within the Late Cretaceous shale units of the Manitoba escarpment. Peak microporosity in conjunction with peak total organic-carbon values (Nicolas and Bamburak 2009, 2011, 2012; Nicolas et al., 2010) may provide added constraints for recovering gas from shallow, unconventional shale deposits.

Acknowledgments

The authors thank H. Muehlbauer, J. Harrison and B. Linzmeier for providing vigorous field assistance, as well as Shell Oil Company for their help in funding this research.

References

Ando, A., Woodard, S.C., Evans, H.F., Littler, K., Herrmann, S., Macleod, K.G., Kim, S., Khim, B.-K., Robinson, S. A. and Huber, B.T. 2013: An emerging palaeoceanographic “missing link”: multidisciplinary study of rarely recovered parts of deep-sea Santonian–Campanian transition from Shatsky Rise; Journal of the Geological Society, v. 170, p. 381–384.

Arthur, M. A., Dean, W.E. and Pratt, L.M. 1988: Geochemical and climatic effects of increased marine organic carbon burial at the Cenomanian/Turonian boundary; Nature, v. 335, p. 714–717.

Bamburak, D.J. and Christopher, J.E. 2004: Mesozoic stratigraphy of the Manitoba escarpment: WCSB/TGI II Field Trip Guide; Manitoba Geological Survey–Saskatchewan Geological Survey, 7–10 September 2004, 87 p.

Bamburak, J.D. and Nicolas, M.P.B. 2010: Upper Cretaceous stratigraphy of the Pembina Hills area: Manitoba Geological Survey Field Trip Guide; Manitoba Geological Survey, 18 May 2010, 55 p..

Bamburak, J.D., Nicolas, M.P.B. and Hatcher, J. 2013: Radiometric dating of Late Cretaceous bentonite beds in southwestern Manitoba; *in* Report of Activities 2013, Manitoba Mineral Resources, Manitoba Geological Survey, p. 129–136.

Berggren W.A. and Hollister C.D. 1974: Paleogeography, paleobiogeography and the history of circulation in the Atlantic Ocean *in* Studies in Paleo-Oceanography, W.W. Hay (ed.), Society of Economic Paleontologists and Mineralogists, Special Publication 20, p. 126–186.

Bertog, J., Huff, W. and Martin, J.E. 2007: Geochemical and mineralogical recognition of the bentonites in the lower Pierre Shale Group and their use in regional stratigraphic correlation; *in* The Geology and Palaeontology of the Late Cretaceous Marine Deposits of the Dakotas, J.E. Martin and D.C. Parris (ed.), Geological Society of America, Special Paper 427, p. 23–50, doi:10.1130/2007.2427(03).

Caldwell, W.G.E., Diner, R., Eicher, D.L., Fowler, S.P., North, B.R., Stelck, C.R. and von Holdt Wilhelm, L. 1993: Foraminiferal biostratigraphy of Cretaceous marine cyclothems; Geological Association of Canada, Special Paper 39, p. 477–520.

Friedrich, O., Norris, R.D. and Erbacher, J. 2012: Evolution of middle to Late Cretaceous oceans—A 55 my record of Earth’s temperature and carbon cycle; Geology, v. 40, p. 107–110.

Hatcher, J. and Bamburak, J.D. 2010: Stratigraphic correlation of multiple bentonite horizons from the Upper Cretaceous Pierre Shale (Pembina Member) of Manitoba (part of NTS 62G1, 2); *in* Report of Activities 2010, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 178–185.

Hicks, J.F., Obradovich, J.D. and Tauxe, L., 1999, Magnetostratigraphy, isotopic age calibration and intercontinental correlation of the Red Bird section of the Pierre Shale, Niobrara County, Wyoming, USA; Cretaceous Research, v. 20, p. 1–27.

Jarvis, I.A.N., Gale, A.S., Jenkyns, H.C. and Pearce, M. A. 2006: Secular variation in Late Cretaceous carbon isotopes: a new δ13C carbonate reference curve for the Cenomanian–Campanian (99.6–70.6 Ma); Geological Magazine, v. 143, p. 561–608.

Jones, C.E. and Jenkyns, H.C. 2001: Seawater strontium isotopes, oceanic anoxic events, and seafloor hydrothermal activity in the Jurassic and Cretaceous; American Journal of Science, v. 301, p. 112–149.

Kauffman, E.G., 1984: Paleobiogeography and evolutionary response dynamic in the Cretaceous Western Interior Seaway of North America: Jurassic-Cretaceous biochronology and paleogeography of North America; Geological Association of Canada, Special Paper 27, p. 273–306.

Larson, R.L. 1991: Geological consequences of superplumes; Geology, v. 19, p. 963–966.

McNeil, D.H. 1984: The eastern facies of the Cretaceous System in the Canadian Western Interior; Canadian Society of Petroleum Geologists, Memoir 9, p. 145–171.

McNeil, D.H. 1987: Overview of Cretaceous stratigraphy in the Manitoba escarpment at Pembina and Riding Mountains, Manitoba; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Saskatoon, Saskatchewan, 25-27 May, 1987, Field Trip Guidebook 2, p. 1–14.

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.

Miller, K.G., Wright, J.D. and Browning, J.V. 2005: Visions of ice sheets in a greenhouse world; Marine Geology, v. 217, p. 215–231.

Nicolas, M.P.B. and Bamburak, J.D. 2009: Geochemistry and mineralogy of Cretaceous shale, Manitoba (parts of NTS 62C, F, G, H, J, K, N): preliminary results; *in* Report of Activities 2009, Manitoba Innovation, Energy, and Mines, Manitoba Geological Survey, p. 165–174.

Nicolas, M.P.B. and Bamburak, J.D. 2011: Geochemistry and mineralogy of Cretaceous shale, southwestern Manitoba (parts of NTS 62F, G, J, K, N, 63C): phase 2 results; *in* Report of Activities 2011, Manitoba Innovation, Energy, and Mines, Manitoba Geological Survey, p. 143–149.

Nicolas, M.P.B. and Bamburak, J.D. 2012: Update on the Shallow Unconventional Shale Gas Project, southwestern Manitoba (parts of NTS 62C, F, G, H, J, K, N, O, 63C); *in* Report of Activities 2012, Manitoba Innovation, Energy, and Mines, Manitoba Geological Survey, p. 134–140.

Nicolas, M.P.B., Edmonds, S.T., Chow, N. and Bamburak, J.D. 2010: Shallow unconventional Cretaceous shale gas in southwestern Manitoba: an update (parts of NTS 62C, F, G, H, J, K, N); *in* Report of Activities 2010, Manitoba Innovation, Energy, and Mines, Manitoba Geological Survey, p. 159–169.

Obradovich, J.D. 1993: A Cretaceous time scale; *in* Evolution of the Western Interior Basin, W.G.E. Caldwell and E.G. Kauffman (ed.), Geological Association of Canada, Special Paper 39, p. 379–396.

Pugh, A.T., Schröder-Adams, C.J., Carter, E.S., Herrle, J.O., Galloway, J., Haggart, J.W., Andrews, J.L. and Hatsukano, K. 2014: Cenomanian to Santonian radiolarian biostratigraphy, carbon isotope stratigraphy and paleoenvironments of the Sverdrup Basin, Ellef Ringnes Island, Nunavut, Canada; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 413, p. 101–122.

Schlanger, S.O. and Jenkyns, H.C. 1976: Cretaceous oceanic anoxic events: causes and consequences; Geologie en Mijnbouw, v. 55, p. 179–184.

Schröder-Adams, C.J., Cumbaa, S.L., Bloch, J., Leckie, D. A., Craig, J., Seif El-Dein, S. A., Simons, D.-J.H. and Kenig, F. 2001: Late Cretaceous (Cenomanian to Campanian) paleoenvironmental history of the Eastern Canadian margin of the Western Interior Seaway: bonebeds and anoxic events; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 170, p. 261–289.

Silva, I.P. and Sliter, W.V. 1999: Cretaceous paleoceanography: Evidence from planktonic foraminiferal evolution; Geological Society of America, Special Paper 332, p. 301–328.

Wonders, A.A.H. 1980: Middle and Late Cretaceous planktonic foraminifera of the western Mediterranean area; Utrecht Micropaleontological Bulletins, v. 24.

Young, H.R. and Moore, P.R. 1994: Composition and depositional environment of the siliceous Odanah Member (Campanian) of the Pierre Shale in Manitoba; Geological Society of America, Special Paper 287, p. 175–195.