The 2020 Canada datapack for TimeScale Creator: a new tool for Mesozoic–Cenozoic stratigraphy of the Canadian North

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Bringué, M., Fensome, R.A., Poulton, T.P., Galloway, J.M., Bujak, J.P., Golding, M.L., Orchard, M.J., and Williams, G.L., 2022. The 2020 Canada datapack for TimeScale Creator: a new tool for Mesozoic–Cenozoic stratigraphy of the Canadian North; in *Sedimentary basins of northern Canada: contributions to a 1000 Ma geological journey and insight on resource potential, (ed.) D. Lavoie and K. Dewing; Geological Survey of Canada, Bulletin 609, p. 237–286. https://doi.org/10.4095/326099*

Abstract: The Geo-mapping for Energy and Minerals (GEM) program (2010–2020) provided a unique opportunity to advance the current level of understanding of the geological history of the Canadian North. In this contribution, based on the Trans-GEM Event Stratigraphy activity, a compilation of Mesozoic–Cenozoic stratigraphic data from across the GEM program regions and beyond is presented, with a focus on biostratigraphic events, using TimeScale Creator®, a JAVA package that facilitates the compilation and comparison of large amounts of stratigraphic data while keeping track of changing absolute ages. The '2020 Canada datapack', which incorporates some information re-evaluated and refined from an earlier datapack, includes schemes using dinoflagellate cysts, spores and pollen, foraminifers and conodonts, and a new synthesis of Canadian Arctic Jurassic ammonite and *Buchia* bivalve biostratigraphy. This datapack will continue to be augmented after completion of the GEM program and will become a major tool in supporting an understanding of Canada's sedimentary basins, their resource potential and management.

Résumé : Le programme Géocartographie de l'énergie et des minéraux (GEM), qui s'est déroulé de 2010 à 2020, a offert une occasion unique d'améliorer notre compréhension de l'histoire géologique du Nord canadien. Dans cette contribution, fondée sur l'activité de stratigraphie événementielle trans-GEM, nous présentons une compilation des données stratigraphiques se rapportant aux successions du Mésozoïque-Cénozoïque dans les régions du programme GEM, et au-delà de celles-ci, en nous concentrant sur les événements biostratigraphiques à l'aide de TimeScale Creator®, un progiciel Java facilitant la compilation et la comparaison de grandes quantités de données stratigraphiques, tout en tenant compte des changements des âges absolus. Le dossier de données Canada 2020, qui intègre des renseignements réévalués et améliorés provenant d'un dossier de données antérieur, comprend des schémas fondés sur les kystes de dinoflagellés, les spores et le pollen, les foraminifères et les conodontes, ainsi qu'une nouvelle synthèse des données biostratigraphiques sur les ammonites et le bivalve *Buchia* de l'Arctique canadien remontant au Jurassique. Nous prévoyons que le dossier de données continuera de croître une fois le programme GEM terminé, et deviendra un outil majeur pour la compréhension des bassins sédimentaires du Canada, de leurs ressources potentielles et de la gestion de celles-ci.

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INTRODUCTION

Overview

The Mesozoic–Cenozoic history of what is today Canada involved the development of major sedimentary basins, including the basins of offshore eastern Canada, developed on the passive margins of the North Atlantic Ocean and Labrador Sea; the Western Interior Basin, a foreland basin inboard of the evolving Cordilleran Orogen; and the Sverdrup Basin, a successor basin superimposed on previously deformed lower Paleozoic rocks, which now underlies much of the Canadian Arctic Islands. A detailed understanding of the rock units, their correlation, and the resources they potentially contain presents an ongoing challenge, particularly in remote areas of the vast Canadian North.

Advancing geoscience for sustainable economic development in the Canadian North has been the primary objective of the Geo-mapping for Energy and Minerals (GEM) program since the inception of its first phase in 2010. The present contribution involves the use of a new tool that will facilitate the study of Canadian sedimentary basins by providing up-to-date stratigraphic data across the GEM regions of interest (Fig. 1), much of which were generated under GEM-funded research activities. Most of this stratigraphic data can be compiled and consequently visualized using the free JAVA package, TimeScale Creator® (TSC; *see* 'TimeScale Creator' section).

Context

Strictly, stratigraphy is the study of rock layers (strata), primarily sedimentary and layered volcanic rocks. In the broader sense, it encompasses the history of the Earth as reflected in the rock record. Historically, stratigraphy has been divided into two related subdisciplines, lithostratigraphy and biostratigraphy. Lithostratigraphy is the study of the rocks themselves, particularly their succession and relationships to other strata. Lithostratigraphy can provide an initial sense of relative ages within a local area or region. As the concept of geological, or 'deep', time developed, it became clear that other methods were needed to extend and consolidate the understanding of how sedimentary rocks interrelate in space and time on local to global scales. The first major step was the inception of biostratigraphy — the use of fossils to determine relative ages of the rocks containing them — by W. Smith (Winchester, 2001) and others in the early to mid-nineteenth century. Biostratigraphy is based primarily on the succession of species through time due to evolution, and it continues to make a fundamental contribution to determining the ages of Phanerozoic sedimentary rocks. Biostratigraphic information can be presented directly as events (such as the originations and extinctions of particular species) or indirectly as packages known as biozones (or just zones), in which several events or assemblages of fossils are used for definition. It was the combination of lithostratigraphic and biostratigraphic studies in the nineteenth century that led to the formulation of the geological time scale of erathems, systems, and stages that is largely still in use today for the Phanerozoic. The early time scale was a relative one and involved only an extremely limited sense of absolute time, with age estimations varying wildly (Gorst, 2001).

A major innovation during the early twentieth century was the development of radiometric dating (Lewis, 2000). The ability to date selected rocks based on ratios of some elements and isotopes provided the ability to calibrate in absolute ages the relative geological time scale developed through litho- and biostratigraphic means. Radiometric dating can be used primarily with igneous rocks, but the dating, for example, of volcanic ash and lavas within sedimentary sequences, and the application of crosscutting relationships between igneous rocks and strata, provide critical insights. Lithostratigraphy, biostratigraphy, and radiometric dating together provide the fundamental basis for the discipline of stratigraphy today but continue to be augmented by an array of new methodologies such as magnetostratigraphy (correlation using changes in magnetic polarity recorded in rocks), sequence stratigraphy, and chemostratigraphy. The array of new methodologies developed in the past few decades was reviewed in Gradstein et al. (2005, 2012). Application of these techniques leads to refinement and minor recalibration of the geological time scale on an ongoing basis. To provide stability to the definitions of chronostratigraphic units, specific sections and points are being designated in the rock record to mark global chronostratigraphic units or (usually) boundaries, the updated status of which can be found at http://www.stratigraphy.org/gssp/ (International Commission on Stratigraphy, 2019a).

In parallel with modern stratigraphic developments, the closely related but separate concepts of chronostratigraphy and geochronology have arisen. Chronostratigraphy relates to physical rock units in time, whereas geochronology deals with the parallel intervals of time. Erathem, system, series, and stage are chronostratigraphic terms, the equivalent geochronologic terms being era, period, epoch, and age as defined in the International Commission on Stratigraphy stratigraphic guide (International Commission on Stratigraphy, 2019b). An example of the use of this terminology would be as follows: 'hadrosaurs are common in rocks of the Cretaceous System; they lived during the Cretaceous Period.' The terms 'lower' and 'upper' are chonostratigraphic terms, with 'early' and 'late' as geochronologic equivalents; the term 'middle' is generally used in both contexts, in contrast with the use of the term 'mid' by some earlier authors (e.g. Harland et al., 1990) as a geochronologic term.

It is beyond the scope of the present work to provide a history of the geological time scale. Early developments were summarized by Berry (1968) and Harland et al. (1982). The development of the first volume of *A Geologic Time Scale* in Harland et al. (1982) was a significant milestone, followed by *A Geologic Time Scale 1989* (Harland et al., 1990). In

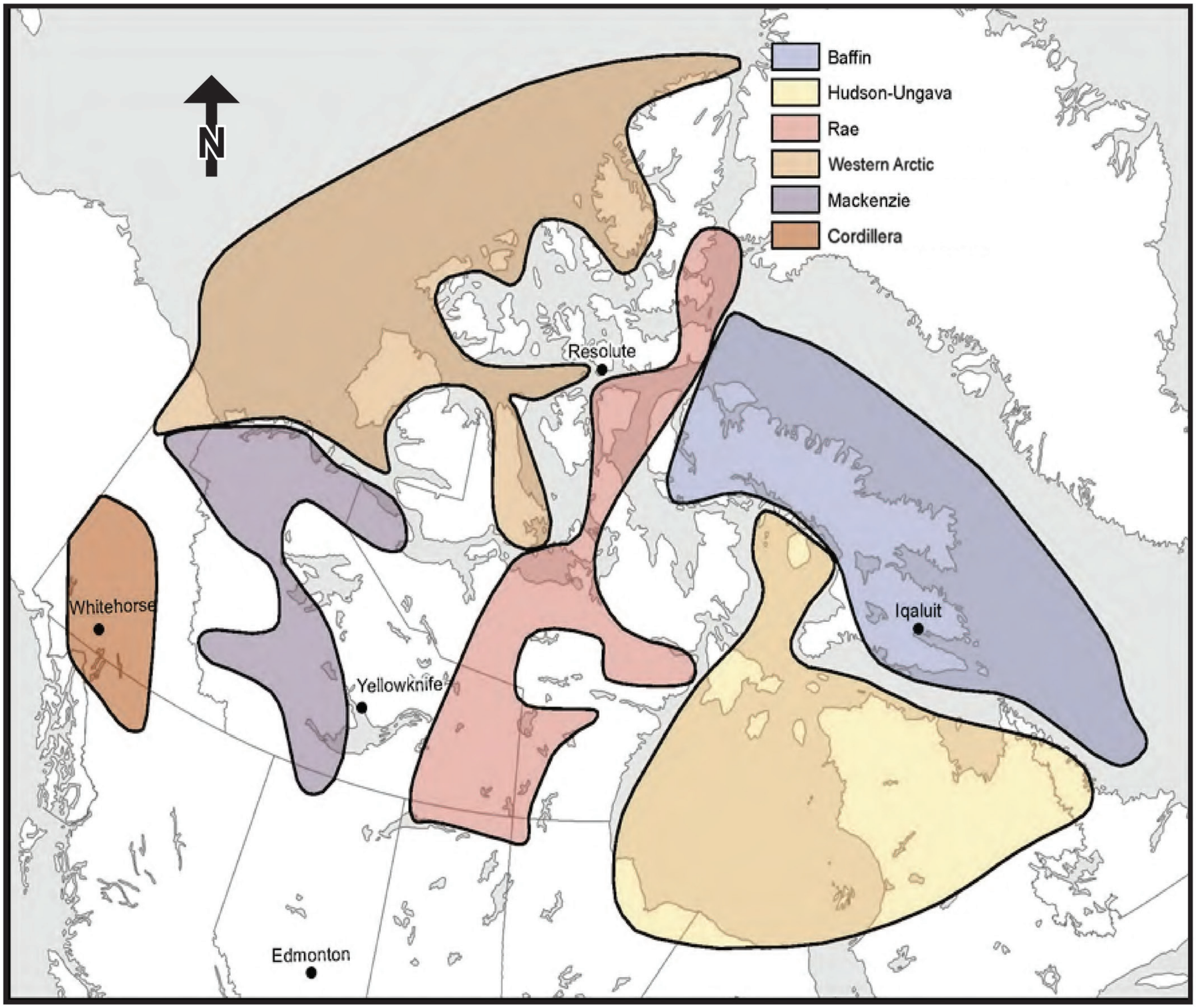


Figure 1. Geo-mapping for Energy and Minerals (GEM) program primary regions of interest, covering most of Canada's North (*modified from* Natural Resources Canada, 2018).

recent decades, international chronostratigraphic standards have been governed by the International Commission on Stratigraphy (ICS; International Commission on Stratigraphy, 2019c), which produces regular updates to the *International Chronostratigraphic Chart* (ICC; Cohen et al., 2013). The ICS governs the names and definitions of chronostratigraphic units, as reflected in the ICC. The ICC also cites absolute ages for unit boundaries, but these are not formally 'governed' in any sense by the ICS, and indeed are subject to ongoing revision. A series of highly influential publications, succeeding the Harland et al. publications and based on the ICC, but not formally associated with it, began with the substantive *A Geologic Time Scale 2004* (Gradstein et al., 2005). This was superseded by a two-volume set entitled *A Geologic Time Scale 2012* (Gradstein et al., 2012). A shorter summary update, *A Concise Geologic Time Scale — 2016*, was subsequently published by Ogg et al. (2016). The most recent version is *The Geologic Time Scale 2020* (Gradstein et al., 2020), which is used herein. For the purposes of this paper, versions of *A Geologic Time Scale* will be referred to as 'GTS', with the appropriate year appended (e.g. GTS 2004 refers to *A Geologic Time Scale 2004* by Gradstein et al., 2005). It is this series of publications that led to the development of TimeScale Creator (*see* 'TimeScale Creator' section). Absolute-age calibrations in the GTS publications (and hence in TimeScale Creator) may vary slightly from those in the ICC.

Trans-GEM Event Stratigraphy activity

Biostratigraphic data have contributed considerably to the present understanding of the geological history of Canada's North (e.g. Dixon, 1999; Harrison et al., 1999a; Nøhr-Hansen et al., 2016; Evenchick et al., 2019; Galloway et al., 2019). Such data can be presented as part of a biozonation scheme, or as a series of events such as first occurrences and last occurrences. Although each approach has its benefits and drawbacks, a combination of both approaches has been used to present data herein. Several types of biozones are defined in the literature (e.g. range, interval, assemblage, and abundance; Fig. 2; North American Commission on Stratigraphic Nomenclature, 2005) and the types of zones chosen for a particular study are determined by several factors, including the type of fossil recovered; the number of specimens recovered; the spatial and temporal ranges of the species in question; personal and traditional preferences; and the state of knowledge at the time of study. The use of biostratigraphic events is becoming more prevalent in some micropaleontological subdisciplines, and first and

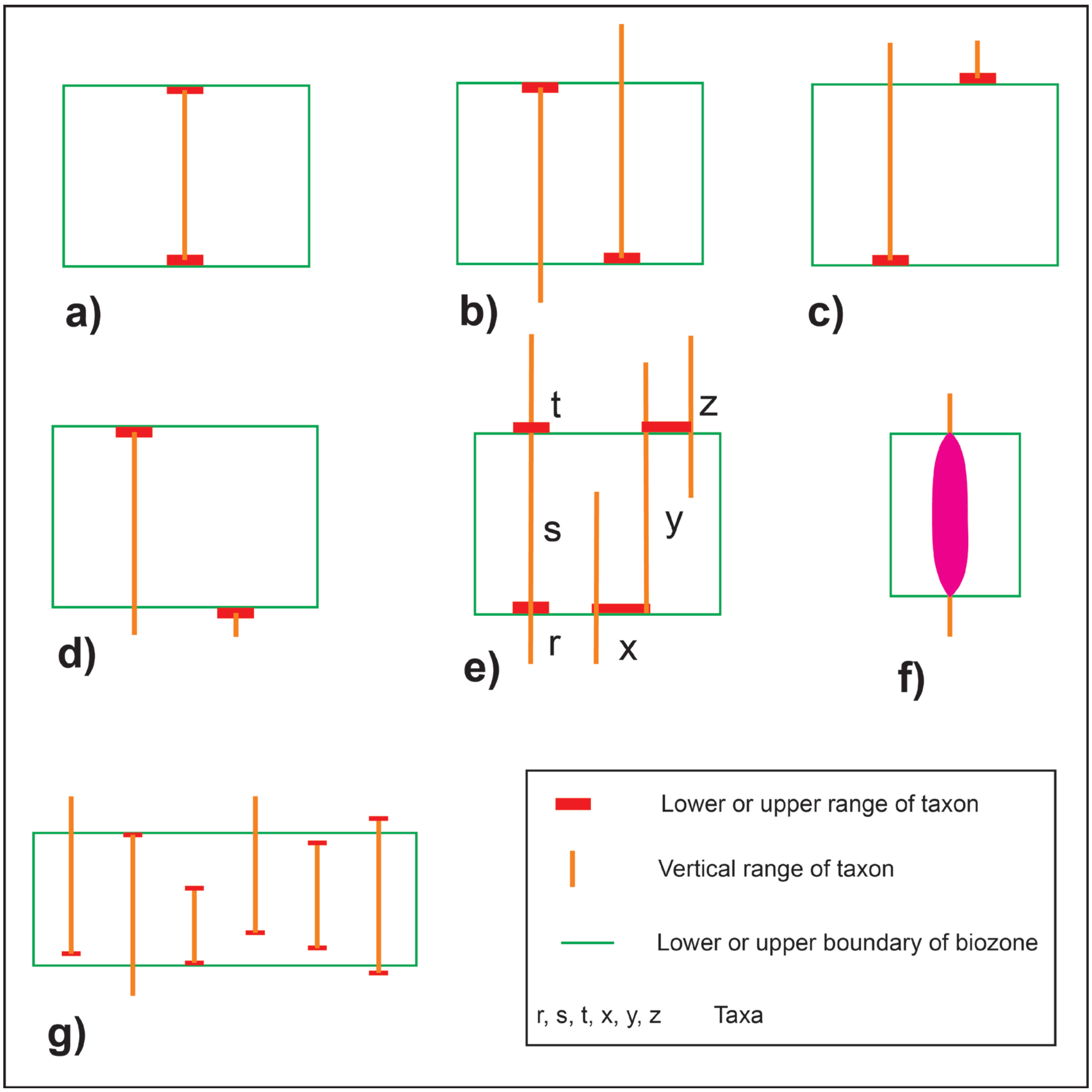


Figure 2. Principal types of (bio)zones used in biostratigraphy: **a)** taxon-range biozone, based on the range of a taxon; **b)** concurrent-range biozone, based on range of co-occurrence of two taxa; **c–d)** interval biozone, based on an interval between the lowest (c) and highest (d) occurrences of taxa; **e)** lineage biozone, based on successive stages within an evolutionary lineage; **f)** abundance biozone, based on an interval when a specific taxon is particularly common; **g)** assemblage biozone, based on overlapping ranges of multiple taxa. *Adapted from* North American Commission on Stratigraphic Nomenclature (2005).

last occurrences of fossil taxa have been successfully used to correlate between regions (e.g. Fensome et al., 2008; Galloway et al., 2013; Nøhr-Hansen et al., 2016).

Objectives

Developing an event scheme for the Mesozoic and Cenozoic across the Arctic was undertaken in 2017 under the auspices of the Trans-GEM Event Stratigraphy activity. With the availability of TimeScale Creator, the focus of the activity shifted somewhat to developing a new TSC datapack to incorporate stratigraphic (primarily biostratigraphic) data from the GEM regions; the new datapack will facilitate data visualization, comparison, and correlation within and between the GEM regions (Fig. 1).

The 2020 Canada datapack has been designed with the following objectives:

- to initiate the compilation of a comprehensive, up-to-date event-stratigraphy scheme for the Canadian Arctic (*see* Trans-GEM Event Stratigraphy activity section)
- to revise and update the Mesozoic–Cenozoic portion of an earlier, unchecked Canadian datapack (*see* 'Review and update of the 2010 Canada datapack' section), which includes both litho- and biostratigraphic data
- to provide data that are dynamically tied to standard chronostratigraphic schemes, such as ammonite zonations and international stages, and to organize the data in a format that supports future updates to the GTS and reference schemes
- to allow for the easy visualization and comparison of Canadian stratigraphic data (from GEM regions of interest and beyond) across geographical areas and fossil groups
- to make Canadian litho- and biostratigraphic data freely available to the public, in line with the Open Government Science Initiative — for example, Canada's digital charter (Innovation, Science and Economic Development Canada, 2019) and data strategy roadmap for the Federal Public Service (Privy Council Office, 2019).

Thus, the 2020 Canada datapack provides free, updated stratigraphic information that will remain current, in a format that fosters easy comparison of stratigraphic records across GEM regions of interest and different fossil groups.

TIMESCALE CREATOR

TimeScale Creator (TSC) is a JAVA package operated by the Geologic TimeScale Foundation (GTS Foundation) based at Purdue University in West Lafayette, Indiana. It was developed by some authors of the GTS volumes (J. Ogg, F. Gradstein, and G. Ogg) to record general stratigraphic data and keep track of ongoing changes to the geological time scale. The TSC website (Geologic TimeScale Foundation, 2019) describes TimeScale Creator as "a free JAVA package [that] enables you to explore and create charts of any portion of the geologic time scale from an extensive suite of global and regional events in Earth History." The data used to build it are founded on the GTS series of publications, but TSC is designed to contain limitless amounts of data that can be selectively downloaded, and users of the TSC Pro version can add their own data. The Geological Survey of Canada (GSC) subscribes to TSC Pro, but any user can access and visualize the data using the free version of TSC. The GTS Foundation provides regular updates that incorporate any refinements to the absolute-age calibrations of chronostratigraphic units, which are thus reflected in charts generated from TSC. These updates, together with the public availability of software and data, make TSC the ideal platform to store Canadian stratigraphic data.

Using TSC

The TSC website contains tutorials (Geologic TimeScale Foundation, 2019b) that help potential users operate the program, which can be run online on any browser that supports JAVA, or from a personal computer after downloading the most recent version from the download page. Upon launch, the program automatically loads a default datapack that contains the up-to-date chronostratigraphic scale (currently the GTS 2020), a full suite of 'master' reference schemes (e.g. the chronostratigraphic time scale, the geomagnetic polarity scheme) and several other types of data (e.g. paleogeographic maps, biozones, bioevents, transgressive–regressive cycles, stable isotopic curves). The user can generate customized charts by selecting the time interval of interest and selecting data — organized in successive columns — to be plotted. The vertical scale and column width can be expanded to better view densely populated intervals, and the order of data columns can be changed, allowing the user to place data sets of interest next to each other for direct comparison. The 'Global Priority Filtering' function allows users to generalize data to avoid overcrowding on charts, especially in data-dense areas; however, note that this function may result in inaccurate displays of information.

An important feature of TSC is a 'MouseOver' option that allows background information to be displayed in a 'popup' window. This applies only to the 'live' output in TSC, as such layers of information are lost upon exporting to PDF or printing. Information available in popups ranges from details on age calibration to comments from the source publication and may include hyperlinks to pictures and other web material.

Packages of information (datapacks; Geologic TimeScale Foundation, 2019c) can be downloaded from the TSC website. Most are publicly available, including the default TSC datapack, which acts as a backbone to the program. Onto this, users can add additional datapacks for personal use, or for public use via the GTS Foundation.

The 2010 Canada datapack

Among the datapacks available on the TSC website is the 'Arctic and Central Canada' datapack, hereafter referred to as the '2010 Canada datapack' (Geologic TimeScale Foundation, 2019c). Its content is described on the webpage as follows:

> Scales of the main Arctic-region zonations (35 columns). Lithostratigraphic columns (ca. 350 columns) recalibrated from Arctic and Canada volumes of the DNAG (1989) compilation, with all formations linked to the on-line lexicon of the Geological Survey of Canada. Arctic Island transect (6 segments) provided by Geol. Surv. Canada (2010), with formations linked to the lexicon.

This 2010 Canada datapack was compiled by the GTS Foundation under contract to the GSC in 2010 and, unlike the 2020 Canada datapack, is not restricted to the Mesozoic and Cenozoic. Although never proofed or checked due to the retirement of key personnel and changes in priorities, the compilation represented a far-sighted initiative by then Acting Director of GSC-Calgary, G.S. Nowlan. As indicated, the data were derived from some fundamental publications on Canadian geology and were focused on Arctic Canada and the Western Canada Sedimentary Basin (incorporating the Mesozoic–Paleogene Western Interior Basin).

Best practices adopted for the 2020 Canada datapack

The first step in developing the 2020 Canada datapack was to establish best practices for data entry, which is performed in Excel for TSC. There are three types of spreadsheets involved: 1) reference, or 'master' sheets (e.g. 'MasterChronostrat', 'MasterDino', 'MasterNanno', following the GTS 2020), provided by the GTS Foundation and mostly based on data in the GTS publications that contain reference schemes; 2) data-entry sheets, in which ages are dynamically tied to reference schemes and all relevant information is captured; and 3) output sheets, where the information is recalled from data-entry sheets and arranged in a format that TSC will read, from a tab-delimited .txt file. Because several individuals and spreadsheets have been involved with data entry, format consistency is paramount to ensure consistent data entry and seamless updates in the future.

The development of a datapack involves the compilation of workbooks, each containing master, data, and output spreadsheets, from which output files are later combined. Typically, each individual performing data entry works on their own workbook(s). While the number of workbooks and output spreadsheets that form a datapack does not impact the end product, experience has shown that fewer is better for a more efficient datapack compilation.

When formulas in Excel were being dynamically coded, care was taken to tie events or boundaries to the appropriate reference scheme. For instance, most Jurassic foraminifer- and dinoflagellate-zone boundaries (e.g. Davies, 1983) are tied to Subboreal (Hettangian through Callovian) and Boreal (Oxfordian–Tithonian) ammonite zones, whereas some Cenozoic foraminifer zones are tied to nannofossil zones, since they were compared with (and calibrated against) Greenland strata (Harrison et al., 1999b). This aspect is case-specific and depends on what the individual who generated the data relied on to assign ages. Biostratigraphic events in the Arctic often lack independent control, as the region is far removed from classic, well-dated sections and radiometric dates are sporadic; hence, the events tend to be assigned relative ages on the basis of several lines of evidence. As elsewhere, events may vary slightly in age between basins. Thus, in the absence of clear statements in the source publications, ages have been tied to chronostratigraphic (stage) boundaries. This standardization and optimization of data structure will not necessarily be noticeable on the charts, but will ensure that future updates to the GTS and changes to any reference schemes will seamlessly translate into meaningful and accurate shifts in the absolute ages assigned to events or boundaries displayed on the charts.

Finally, for event-data columns, species sharing the same first or last occurrences were grouped for optimal readability on the charts. Charts depicting ranges of individual taxa can also be developed using TSC, but data-entry protocols would be different from those used in the present project.

THE 2020 CANADA DATAPACK

The state-of-the-art 2020 Canada datapack incorporates new data, as well as some data brought forward from its 2010 predecessor. The current datapack focuses on Mesozoic–Cenozoic biostratigraphy and, where possible, event stratigraphy. It includes both revised and new stratigraphic data; many of the latest data sets were generated from GEM-funded research activities (e.g. Galloway et al., 2012, 2013, 2015, 2019; Pugh et al., 2014; Herrle et al., 2015; Hadlari et al., 2016; Evenchick et al., 2019). Another substantial source of data new to the 2020 version is sourced from the ongoing Circum-Arctic lower Paleozoic to Cenozoic palynological events (CAPE) project. The CAPE project was initiated by British palynologist J. Bujak and involves GSC co-editors and contributors (Bujak et al., 2021). This project is an international effort to compile a pan-Arctic event palynostratigraphy for the Devonian to Cenozoic interval, and some Mesozoic–Cenozoic parts of the Canadian data set for CAPE are included in the 2020 Canada datapack. A complete list of data included in the new datapack is presented in Appendix A.

Review and update of the 2010 Canada datapack

The 2010 Canada datapack included both lithostratigraphic and biostratigraphic data. The lithostratigraphic portion was based entirely on Decade of North American Geology charts (Trettin, 1991a, b, c; Stott, 1993a, b, c) and one GSC open file (Dewing and Embry, 2007) used to generate the 'Canadian Arctic Island transect suite'. Since these lithostratigraphic data still largely represent a current understanding, they have been directly incorporated into the 2020 Canada datapack, with only a few minor corrections. Of note is the omission, from the Canadian Arctic Island transect suite, of some formal members in the Early Triassic Bjorne Formation (Cape Butler, Pell Point, and Cape O'Brien members) and their shaly equivalents in the Blind Fiord Formation (Confederation Point, Smith Creek, and Svartfjeld members), as well as the Cape Lockwood, Hot Weather, and Slidre members in the Late Jurassic Awingak Formation. These members are only recognized in their type localities and are therefore of limited value to regional stratigraphy (K. Dewing, pers. comm., 2019).

In contrast to the lithostratigraphic content, some biostratigraphic data sets have undergone a more thorough revision since 2010. As the 2020 Canada datapack focuses on Mesozoic and Cenozoic strata, Paleozoic biostratigraphic data are not included (although they are still available as part of the 2010 datapack). Many columns from the 2010 datapack consisted of redundant information, often derived from figures in publications that incorporated reference schemes (e.g. Tethyan or Subboreal ammonite zones); these schemes are already in TSC as part of the default or other publicly available datapacks. Such duplication has been avoided in the new datapack, and 'cleaned-up' columns of regional data have been tied to standard, updated reference schemes provided by the GTS Foundation as 'master' sheets (e.g. MasterChronostrat, MasterNanno). As described above, care was taken to tie events or boundaries to the appropriate reference scheme, including stage boundaries where necessary.

Additional revisions include a mention in several column headers of the geographical location of the data rather than the author who compiled them. For instance, 'Ammonites (Harrison)' now reads 'Ammonites (Sverdrup Basin)'. References have also been updated to acknowledge, where possible, the individual(s) who generated the data, not just the authors of data compilations. Changes applied to each data column from the 2010 Canada datapack are summarized in Appendix B, which also specifies the reference schemes used to determine ages. Several zonation schemes are preserved as 'legacy' for their historical value, with boundaries now defined with reference to standard schemes (and hence updatable) but without reinterpretation. However, where available from range charts in the original publications, the events used to generate these zonation schemes have been plotted and are now available in the 2020 Canada datapack.

Given the importance of ammonite and *Buchia* (bivalve) horizons for biostratigraphy of the northern Canadian Jurassic and Cretaceous systems, special attention has been given to updating the Arctic Jurassic ammonite biohorizons from the Sverdrup Basin and the northern Yukon and adjacent northwesternmost Northwest Territories (incorporating the Richardson, Ogilvie, Barn, and British mountains; hereafter referred to as the northern Yukon region), the two areas for which data are available. A full description of updates is provided in the section entitled 'Jurassic ammonite and *Buchia* bivalve occurrences'.

New data from GEM regions of interest

The 2020 Canada datapack was designed as a tool to easily compare biostratigraphic data across all GEM regions. Although a few Canadian Arctic and Subarctic regions were already represented in the 2010 Canada datapack (e.g. Yukon, Beaufort–Mackenzie Basin, Sverdrup Basin), some GEM regions were missing, including large portions of the eastern Arctic, such as the Labrador–Baffin area. The 2020 Canada datapack now incorporates detailed biostratigraphic data (quality-checked by the present authors) from all GEM regions of interest (Appendix A), except the Rae region, which is devoid of Mesozoic and Cenozoic strata, and the Hudson Bay–Ungava region, where Mesozoic–Cenozoic biostratigraphic data remain scarce. An effort was made to include biostratigraphic schemes based on as many different fossil types as possible in each region, including ammonites, bivalves, foraminifers, conodonts, and dinoflagellate cysts, as well as pollen and spores. Any user who has loaded the 2020 Canada datapack in TSC can select the columns of interest and compare biostratigraphic events (for example based on dinoflagellate cysts) across different Arctic regions by ticking the desired data columns and arranging them in the order of their preference. For consistency and ease of comparison, dinoflagellate-cyst taxonomy has been updated to conform to Fensome et al. (2019) for the following sources: Brideaux and McIntyre (1975), Fisher and Riley (1980), McIntyre and Brideaux (1980), Davies (1983), Poulton et al. (1993a, b), McIntyre (1996a, b, c), and Harrison et al. (1999a, b).

Of particular importance to the stratigraphy of northern Canada are the new lithostratigraphic and palynostratigraphic data sets for the Labrador–Baffin Seaway (Fig. 3); these now fill a critical gap in the spatial and temporal coverage of Canadian strata in TSC. The data were acquired from a suite of offshore wells and combined with data from the West Greenland margin, leading to a new biostratigraphic framework for this broad and previously understudied region (Nøhr-Hansen et al., 2016). Another noteworthy addition to the 2020 Canada datapack involves a suite of benthic foraminifer biostratigraphic data sets (including both calcareous and agglutinated forms) from Upper Jurassic to Cenozoic strata of the Beaufort–Mackenzie Basin. The data were extracted from five charts from the *Geological Atlas of the Beaufort–Mackenzie Area* (Dixon, 1996; Fowler, 1996;

Figure 3. Labrador–Baffin Seaway lithostratigraphy and biostratigraphy (palynological events) produced in TimeScale Creator (Geologic TimeScale Foundation, 2019a): **a)** Cenozoic. *Adapted from* Dickie et al. (2011) and Nøhr-Hansen et al. (2016).

Standard chronostratigraphy: For boundary definitions, status, and nomenclature *see* International Stratigraphic Commission (2019a).

Labrador-Baffin Seaway lithostratigraphy: Lithostratigraphic columns from Nøhr-Hansen et al. (2016), using data from Dickie et al. (2011).

Labrador-Baffin Seaway palynoevents: Ranges/events from Nøhr-Hansen et al. (2016).

Figure 3. (cont.) b) Cretaceous. *Adapted from* Dickie et al. (2011) and Nøhr-Hansen et al. (2016).

Hedinger, 1996; McNeil 1996a, b, c), with updated taxonomy from McNeil (1997) and minor range modifications by D.H. McNeil (pers. comm., 2019). The modified data are now available as event schemes in the 2020 Canada datapack (e.g. Fig. 4). These foraminifer data sets provide important biostratigraphic control and are widely used in this economically important GEM region. A new lithostratigraphic chart of Cretaceous strata across the Sverdrup Basin, Banks Island, the Horton–Anderson plains, the Richardson Mountains, and the Snake, Peel, Arctic Red, and Hume rivers areas (Fig. 5) also provides a valuable reference for ongoing work in the Western Arctic and Mackenzie GEM regions, where recent studies have provided new insight on the detailed stratigraphic framework of the Canadian North, particularly in the Sverdrup Basin (e.g. Galloway et al., 2012, 2013, 2015; Pugh et al., 2014; Herrle et al., 2015; Hadlari et al., 2016).

Other new data

Several data sets deemed relevant to (bio)stratigraphic control of age-equivalent strata in the Canadian North are included in the 2020 Canada datapack, even though their geographical provenance is not directly or primarily located within GEM regions of interest. In particular, a data set of Late Cretaceous–Paleocene terrestrial palynomorphs across the Western Interior Basin, mostly reflecting data from localities from the southern parts of Alberta, Saskatchewan, Manitoba, and even northern Montana (Braman and Sweet, 2012), is included because it provides a reference framework for age-equivalent strata in northern Canada that were connected by the Western Interior Seaway at the time of deposition.

Similarly, a new compilation of Triassic conodont zones across Canada is provided (Fig. 6). The data column has been compiled using existing conodont zonation schemes from the Western Canada Sedimentary Basin in the Cordillera and from the Sverdrup Basin in the Arctic. The Triassic conodont record of the Cordillera is more complete than that of the Arctic and, therefore, it is not possible to recognize all the zones presented here in all the GEM regions of interest. The Triassic rock record of the western Cordillera is particularly fragmentary due to the wide paleogeographic distribution of its constituent terranes, and the conodonts from this region have not been included in the present datapack; additional columns for the terranes will be provided in the future. The conodont zones presented in the 2020 Canada datapack are a mixture of interval, acme, and assemblage zones, with different types of zones utilized depending on the diversity of the faunas and their geographic and temporal distribution across a particular time interval. The conodont zonation is tied to the ammonoid zonation for the Triassic of western and Arctic Canada, as compiled by Tozer (1994) and updated by Bucher (2002) and Ji and Bucher (2018). The Triassic conodont compilation is based primarily on the work of Orchard (1991, 2007, 2014, 2018), Orchard and Tozer (1997), Carter and Orchard (2007), Orchard and Zonneveld (2009), Golding et al. (2014), and Henderson et al. (2018) for the Western Canada Sedimentary Basin; and Henderson and Baud (1997), Nakrem et al. (2008), and Orchard (2008) for the Sverdrup Basin and correlative Boreal strata in Svalbard. The present compilation supersedes a previous conodont scheme available in TSC's default datapack that was based on Orchard and Tozer (1997) alone.

Another important source of data included in the 2020 Canada datapack comes from the ongoing CAPE project, of which three of this paper's authors (J.P. Bujak, R.A. Fensome, and G.L. Williams) are co-editors, in collaboration with G. Mangerud of the University of Bergen in Norway. Most of the 'Bujak Arctic palynological data' (Fig. 7; Appendix A) were established from wells located offshore in the Canadian Arctic and Alaskan waters, and several data columns consist of compilations that extend beyond the boundaries of northern Canada. For instance, the column 'Bujak Arctic climatic events' captures widely recognized variations in the Earth's climate, at least for the Northern Hemisphere.

JURASSIC AMMONITE AND *BUCHIA* BIVALVE OCCURRENCES, SVERDRUP BASIN AND NORTHERN YUKON REGION

Ammonites have been a fundamental source of biostratigraphic control of Jurassic–Cretaceous strata in the Sverdrup Basin and the northern Yukon region, and in these regions of Canada faunas of the bivalve *Buchia* have also been of critical value in the Late Jurassic and earliest Cretaceous. An overview of this Canadian ammonite and *Buchia* data, much overdue, is provided in Appendix C; the update is incorporated into the 2020 Canada datapack.

Ammonite biohorizons and successions

The TSC summary chart of Arctic Canada's Jurassic ammonite biostratigraphy presented in Figure 8 and Appendix C contains updates and references to original paleontological sources and previous summary compilations for regional geology reports (Callomon, 1984; Poulton et al., 1993a, b; Poulton, 1994, 1997; Poulton *in* Harrison et al., 1999a, 2000). It provides current correlations within and beyond the Arctic basins and to zones in the international standard time scale, introducing revisions required by new information on the ages of Boreal Middle Jurassic faunas from recent studies in Eurasia, as discussed for each time interval in Appendix C. There has been little new collecting and no recent descriptive studies or revisions of the Arctic faunas within Canada, and no taxonomic revisions are introduced here. The areas represented in Figure 8 are the Sverdrup Basin and the Brooks–Mackenzie Basin (Balkwill et al., 1983) of the northern Yukon region. Some of the most significant ammonite taxa from the northern Yukon

Standard chronostratigraphy: For boundary definitions, status, and nomenclature *see* International Stratigraphic Commission (2019a).

Foraminifer zones: Revised by D.H. McNeil (pers. comm., 2019), using data from Fowler (1996). Hedinger (1996), and McNeil (1996a, b, c); updated taxonomy from McNeil (1997); Sr isotope data from McNeil and Miller (1990), and McNeil et al. (2001).

Cenozoic calcareous benthic foraminifers: Ranges/events from McNeil (1996c), with minor updates by D.H. McNeil (pers. comm., 2019); updated taxonomy from McNeil (1997); Sr isotope data from McNeil et al. (2001).

Cenozoic agglutinated benthic foraminifers: Ranges/events from McNeil (1996b), with minor updates by D.H. McNeil (pers. comm., 2019); updated taxonomy from McNeil (1997).

Figure 4. Beaufort-Mackenzie Basin foraminifer biostratigraphic data (zones and events) produced in TimeScale Creator (Geologic TimeScale Foundation, 2019a): **a)** Cenozoic. Adapted from Fowler (1996), Hedinger (1996), and McNeil (1996a, b, c), with taxonomy updated according to McNeil (1997) and revised by D.H. McNeil (pers. comm., 2019).

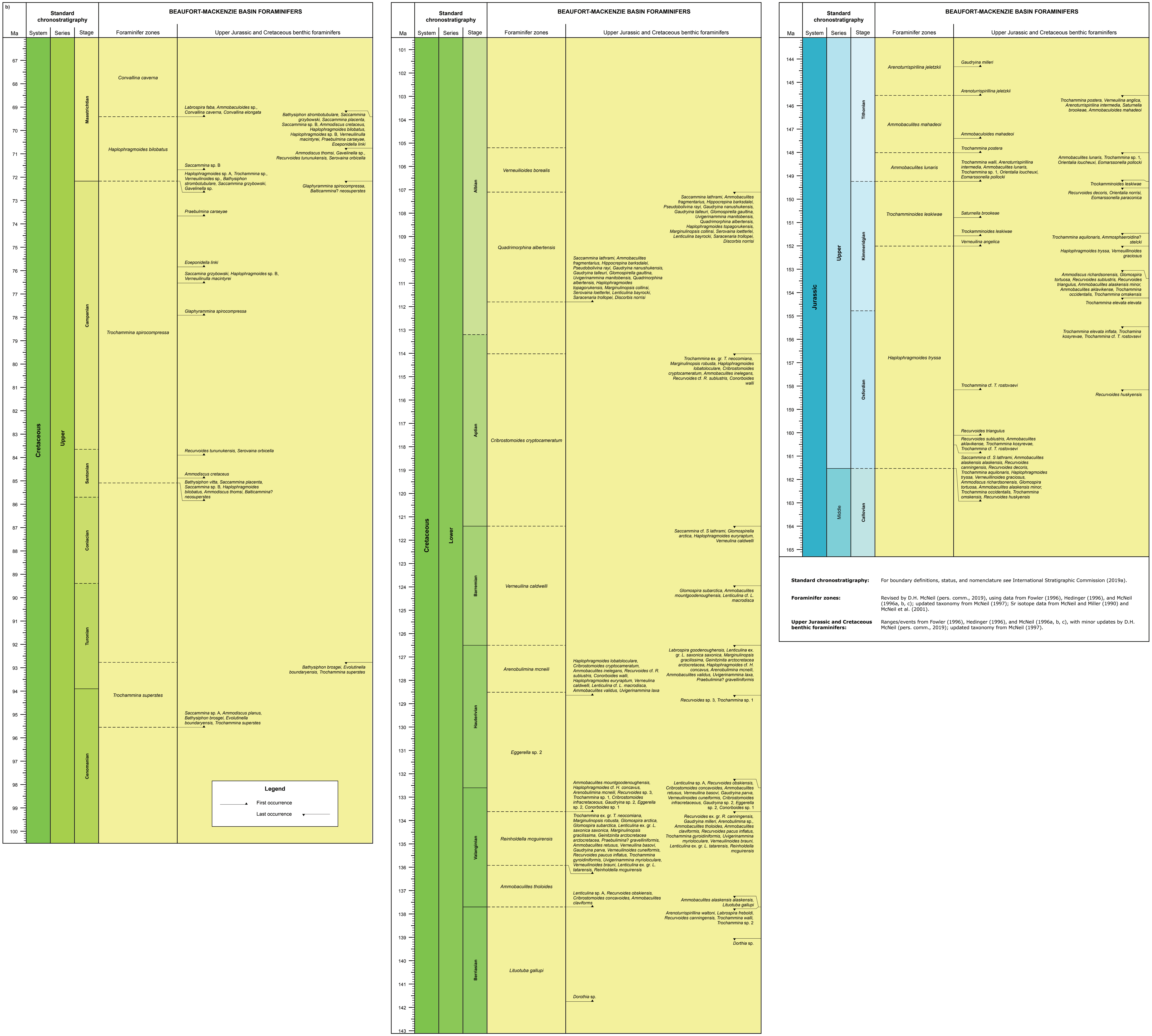


Figure 4. (cont.) Beaufort–Mackenzie Basin foraminifer biostratigraphic data (zones and events) produced in TimeScale Creator (Geologic TimeScale Foundation, 2019a): **b)** Callovian (Middle Jurassic) to Maastrichtian (Upper Cretaceous). *Adapted from* Fowler (1996), Hedinger (1996), and McNeil (1996a, b, c), with taxonomy updated according to McNeil (1997) and revised by D.H. McNeil (pers. comm., 2019).

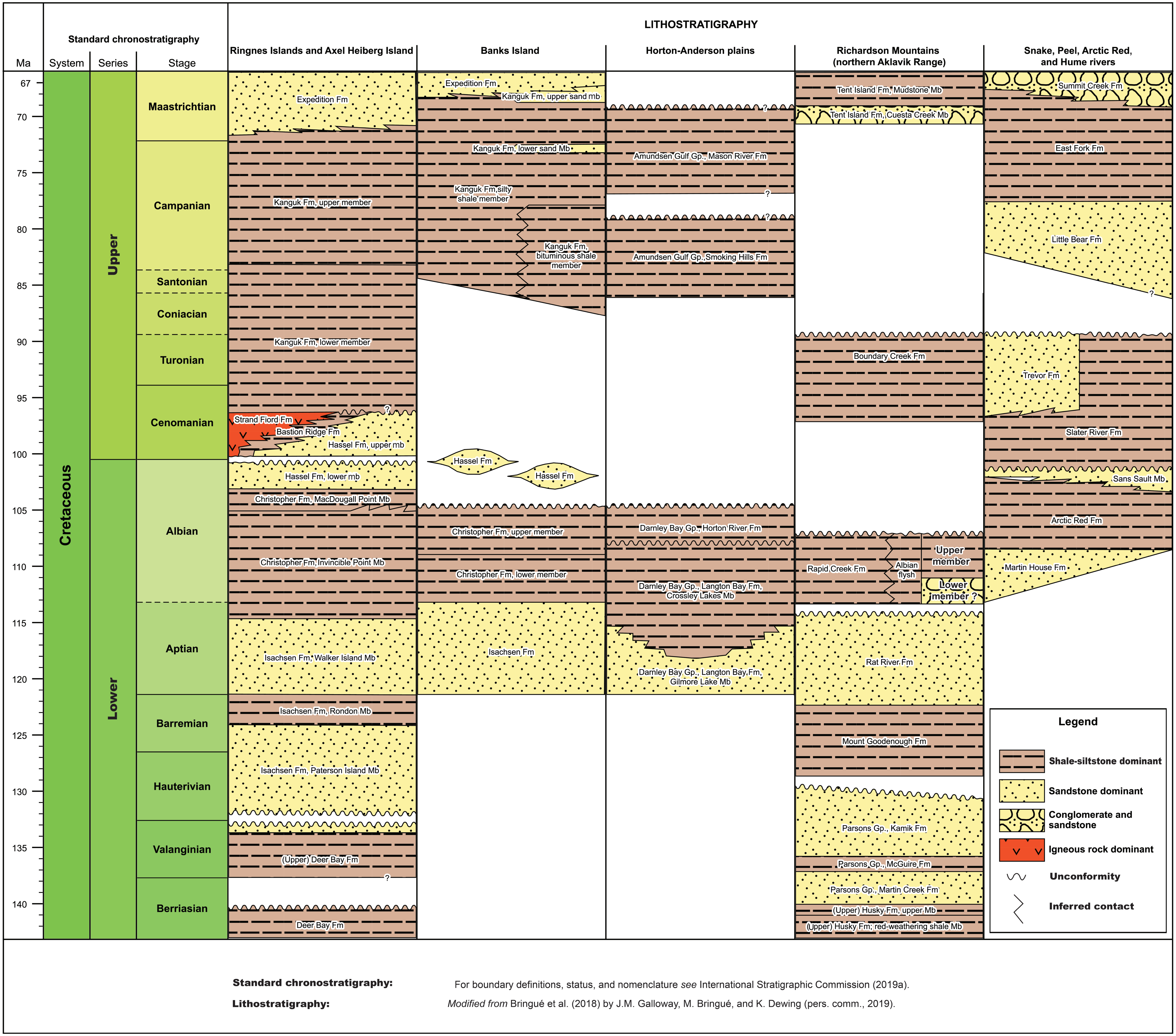
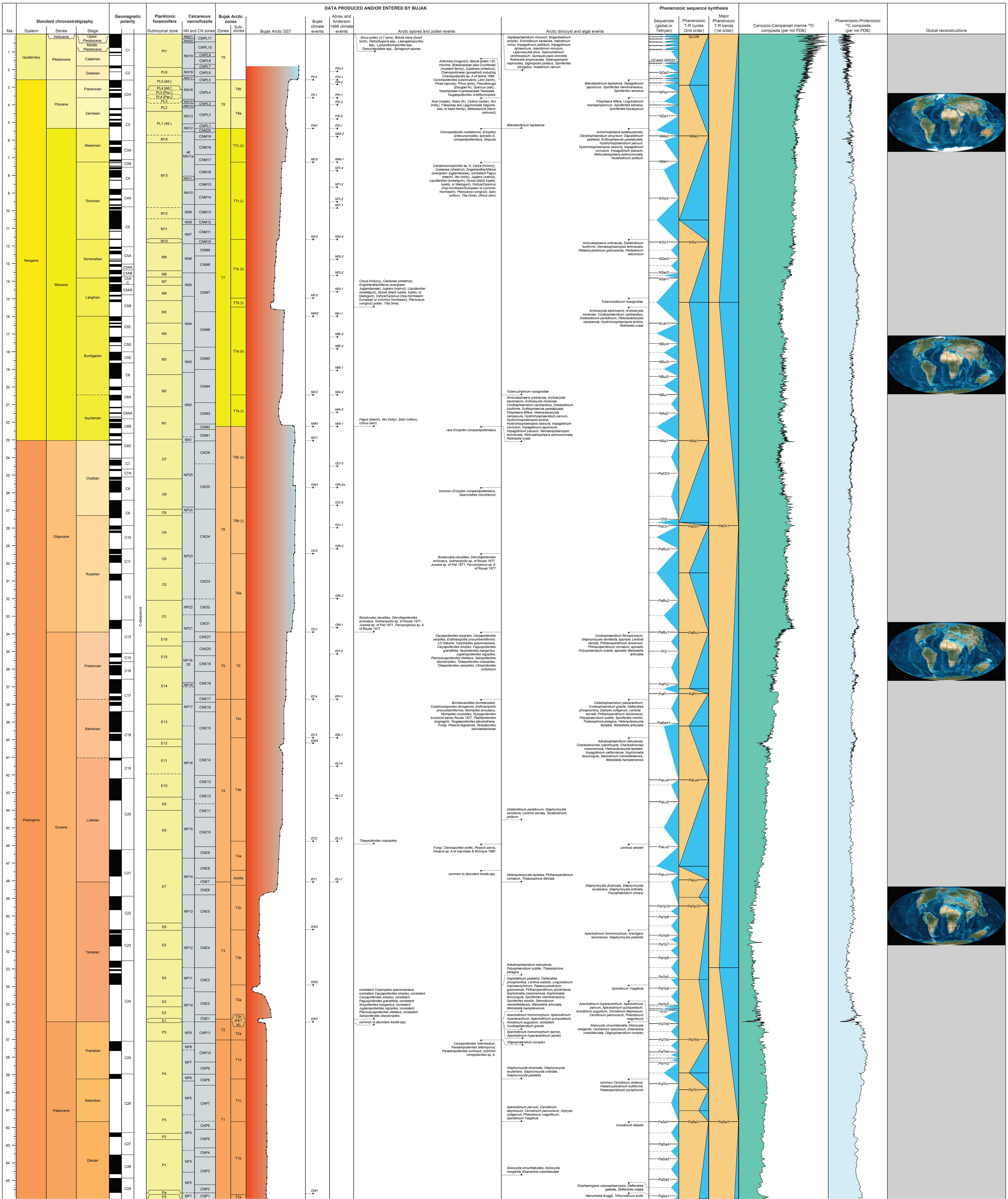


Figure 5. Cretaceous lithostratigraphic chart for the Sverdrup Basin and western Arctic (*modified from* Bringué et al., 2018) produced in TimeScale Creator (Geologic TimeScale Foundation, 2019a). Question mark (?) denotes uncertainty.

Figure 6. Triassic ammonoid and conodont zonation of western and northern Canada (Western Canada Sedimentary Basin (WCSB) and Sverdrup Basin) produced in TimeScale Creator (Geologic TimeScale Foundation, 2019a). Note that the vertical scale differs between left (Upper Triassic) and right columns (Lower and Middle Triassic). Sources appear at the base of the figure.



Standard chronostratigraphy: For boundary definitions, status, and nomenclature *see* International Stratigraphic Commission (2019a).

Geomagnetic polarity: As provided by the Geologic TimeScale Foundation; composites for Cenozoic-Late Jurassic C- and M-sequences from Ogg et al. (2016).

Planktonic foraminifers: As provided by the Geologic TimeScale Foundation, using data from Wade et al. (2011).

Calcareous nannofossils: As provided by the Geologic TimeScale Foundation, using data from Backman et al. (2012) and Agnini et al. (2014). Neogene: mainly Lourens et al. (2005). Paleogene: from various Ocean Drilling Program studies and Berggren et al. (1995a, b). Reviewed and enhanced by P. Brown (unpub. data, 2011).

Bujak Arctic zones and subzones: J. Bujak (unpub. data, 2020) from the Circum-Arctic lower Paleozoic to Cenozoic palynological event project.

Bujak Arctic climatic events: J. Bujak (unpub. data, 2020) from the Circum-Arctic lower Paleozoic to Cenozoic palynological event project.

Abreu and Anderson 1998 climate events: Abreu and Anderson (1998).

Bujak Arctic spores, pollen, and fungi events: J. Bujak (unpub. data, 2020) from the Circum-Arctic lower Paleozoic to Cenozoic palynological event project.

Bujak Arctic dinocyst and algal events: J. Bujak (unpub. data, 2020) from the Circum-Arctic lower Paleozoic to Cenozoic palynological event project.

Phanerozoic sequence synthesis: As provided by the Geologic TimeScale Foundation, using data from Hardenbol et al. (1998).

Cenozoic-Campanian marine ^{18}O composite: As provided by the Geologic TimeScale Foundation, *adapted from* Cramer et al. (2009); *see also* Saltzman and Thomas (2012).

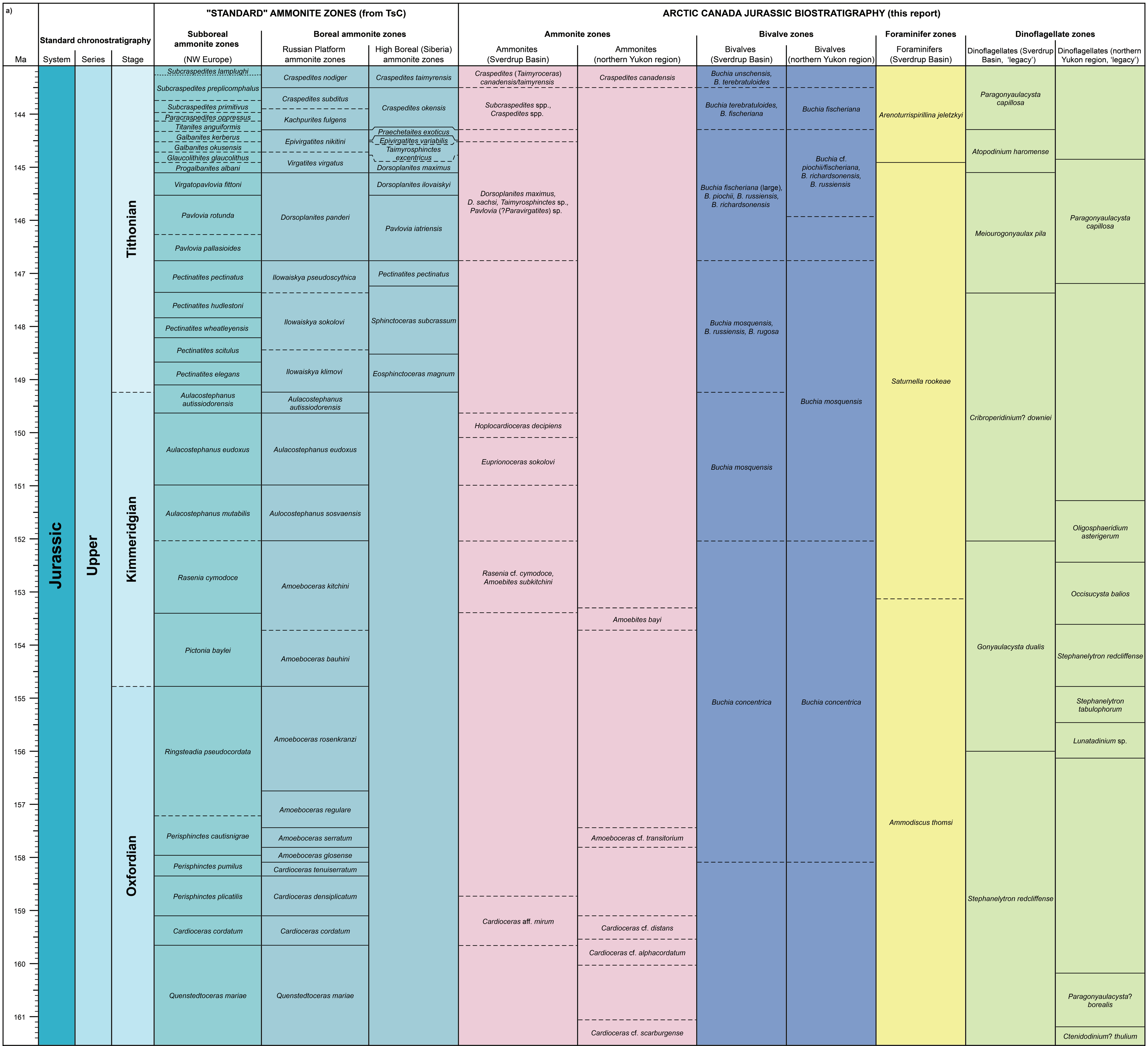
Phanerozoic-Proterozoic ^{13}C composite: As provided by the Geologic TimeScale Foundation, *adapted from* Cramer et al. (2009); *see also* Saltzman and Thomas (2012).

Global reconstructions: As provided by the Geologic TimeScale Foundation; globes from Blakey (2020) based on reconstructions from Scotese (2003).

Abbreviations

Atl.	Atlantic
CN	Coccolith zone - Neogene
CP	Coccolith zone - Paleogene
LO	Last occurrence
NN	Calcareous nannofossil zone - Neogene
NP	Calcareous nannofossil zone - Paleogene
Pac.	Pacific
PDB	Peedee Belemnite
SST	Sea-surface temperature
T-R	Transgressive-regressive

Figure 7. Summary chart of Cenozoic geological data showing several data columns produced and/or entered by J.P. Bujak (unpub. data, 2020), showing Arctic zones and subzones, Arctic sea-surface temperature (SST), climate events (*modified from* Abreu and Anderson, 1998), Arctic spores and pollen events, and Arctic dinocyst and algal events, and put into the context of different data types (including geomagnetic polarity, planktonic foraminifers sub-tropical zone, calcareous nannofossils NN and CN zones, Phanerozoic transgressive–regressive (T–R) sequence synthesis, and ^{18}O and ^{13}C composites) available in TimeScale Creator (Geologic TimeScale Foundation, 2019a).



Standard chronostratigraphy: For boundary definitions, status, and nomenclature *see* International Stratigraphic Commission (2019a).

Subboreal ammonite zones: As provided by the Geologic TimeScale Foundation. Upper Jurassic: R. Enay *in* Cariou and Hantzpergue (1997), with updates from M. Rogov (unpub. data, 2010, 2011).

High Boreal (Siberia) ammonite zones: As provided by the Geologic TimeScale Foundation, using data from Jenks et al. (2015), *modified from* Konstantinov and Klet (2009).

Ammonites (Sverdrup Basin): Poulton, this paper.

Ammonites (northern Yukon region): Poulton, this paper.

Bivalves (Sverdrup Basin): Poulton, this paper, using data from Harrison et al. (1993a).

Bivalves (northern Yukon region): Poulton, this paper, using data from Poulton (1993a).

Foraminifers (Sverdrup Basin): Harrison et al. (1999a), using data from Wall (1983).

Dinoflagellates (Sverdrup Basin, 'legacy'): E.H. Davies *in* Harrison et al. (1999a), using data from Davies (1983).

Dinoflagellates (northern Yukon region, 'legacy'): E.H. Davies *in* Poulton et al. (1993a).

Figure 8. Ammonite and *Buchia* horizons for the Sverdrup Basin and northern Yukon produced in TimeScale Creator (TSC; Geologic TimeScale Foundation, 2019a). Charts include 'standard' ammonite zones provided by the Geologic TimeScale Foundation for reference, as well as other biostratigraphic data (foraminifer zones and dinoflagellate 'legacy' zones): **a)** Upper Jurassic. 'Legacy' zones are zonation schemes preserved for their historical value.

Standard chronostratigraphy:	For boundary definitions, status, and nomenclature *see* International Stratigraphic Commission (2019a).
Subboreal ammonite zones:	As provided by the Geologic TimeScale Foundation. Middle Jurassic: C. Mangold *in* Cariou and Hantzpergue (1997), with updates from M. Rogov (unpub. data, 2010, 2011).
Ammonites (Sverdrup Basin):	Poulton, this paper.
Ammonites (northern Yukon region):	Poulton, this paper.
Foraminifers (Sverdrup Basin):	Harrison (1999a), using data from Wall (1983).
Dinoflagellates (Sverdrup Basin, 'legacy'):	E.H. Davies *in* Harrison et al. (1999a), using data from Davies (1983).
Dinoflagellates (northern Yukon region, 'legacy'):	E.H. Davies *in* Poulton et al. (1993a).

Figure 8. (cont.) Ammonite and *Buchia* horizons for the Sverdrup Basin and northern Yukon produced in TimeScale Creator (TSC; Geologic TimeScale Foundation, 2019a). Charts include 'standard' ammonite zones provided by the Geologic TimeScale Foundation for reference, as well as other biostratigraphic data (foraminifer zones and dinoflagellate 'legacy' zones): **b)** Middle Jurassic. 'Legacy' zones are zonation schemes preserved for their historical value.

Standard chronostratigraphy: For boundary definitions, status, and nomenclature *see* International Stratigraphic Commission (2019a).

Subboreal ammonite zones: As provided by the Geologic TimeScale Foundation. Lower Jurassic: J.-L. Dommergues *in* Cariou and Hantzpergue (1997), with updates from M. Rogov (unpub. data, 2010, 2011).

Ammonites (Sverdrup Basin): Poulton, this paper.

Ammonites (northern Yukon region): Poulton, this paper.

Foraminifers (Sverdrup Basin): Harrison et al. (1999a), using data from Wall (1983).

Dinoflagellates (Sverdrup Basin, 'legacy'): E.H. Davies *in* Harrison et al. (1999a), using data from Davies (1983).

Figure 8. (cont.) Ammonite and *Buchia* horizons for the Sverdrup Basin and northern Yukon produced in TimeScale Creator (TSC; Geologic TimeScale Foundation, 2019a). Charts include 'standard' ammonite zones provided by the Geologic TimeScale Foundation for reference, as well as other biostratigraphic data (foraminifer zones and dinoflagellate 'legacy' zones): **c)** Lower Jurassic. Sources appear at the base of the figure. 'Legacy' zones are zonation schemes preserved for their historical value.

region were illustrated as northeastern Pacific examples in a circum-Pacific compilation of faunas in Westermann (1993). The few Jurassic ammonite occurrences in west-central Yukon that, although north of the Arctic Circle, are in a thrust sheet of an imperfectly known and possibly more southerly pericratonic tectonic provenance (Frebold et al., 1967; Poulton and Tempelman-Kluit, 1982) are not discussed here. These, and other occurrences of Boreal faunas in the series of transported terranes farther south along the coast of British Columbia, have been included as 'Arctic' in some previous reports involving Arctic Canadian Jurassic fossils (e.g. Callomon, 1984; Rogov, 2019).

Ammonites are the primary tool for dating and correlating Jurassic strata globally (Callomon, 1995; Gradstein et al., 2012; Yacobucci, 2015) because of their morphological diversity, rapid evolution, common occurrence, and long history of study (recent reports summarizing evolutionary traits relevant to Canadian Arctic ammonites include Neige and Rouget, 2015; Schweigert, 2015). However, ammonites are sparse in Canadian Jurassic strata from the upper Oxfordian upward, and the bivalve *Buchia* has been important for providing Late Jurassic and Early Cretaceous age control in Arctic Canada. The usefulness of *Buchia* species derives from their wide distribution across the Boreal realm and south along the Pacific margin, as far as northern California (e.g. Jeletzky, 1984). Nearly all of the published ages based on micropaleontological and palynological analyses of Jurassic strata have been determined through extrapolation from ammonite or *Buchia* occurrences. Entirely independent dating of Arctic Canada micropaleontological or palynological assemblages through correlations with faunas elsewhere (e.g. European standard sections) is rare or rarely stated; and, in any case, those sections are also primarily dated by ammonites. Therefore, the revision of the ages of ammonite faunas will require updates to the ages of other stratigraphic elements (biozones, bioevents, lithostratigraphic units) tied to 'ammonite control'.

The first recording of Jurassic ammonites in Canada was by S. Haughton (1857) from material collected in 1853 during a Franklin search expedition; these were from Prince Patrick Island in Arctic Canada. Jurassic strata were not definitively recognized in the Arctic Islands again until the site was revisited by E.T. Tozer in 1954 (Poulton, 1994). The first reported Jurassic ammonites in the northern Yukon region were mistakenly identified as Cretaceous (Meek, 1859), as was the next discovery (Whiteaves *in* McConnell, 1891). These finds probably came from a well-exposed section at Salmon Cache Canyon along the Porcupine River, a locality studied by Poulton (1987). Primary original data sources and revisions for the biostratigraphically most useful ammonite faunas are identified in Appendix C; these include both detailed taxonomic treatments and the most significant identifications in faunal lists.

Many of the Jurassic ammonites available from the Canadian Arctic occur as single specimens or are associations in beds that are separated by long unexposed or poorly fossiliferous intervals or were collected without detailed stratigraphic context. Their ages have been interpreted by comparison with published ammonite sequences elsewhere. It is not reasonable to consider such occurrences as zones (implying ranges with recognizable tops and bottoms), and it is not feasible to develop an event scheme from them. For the most part, these occurrences represent fossiliferous 'biohorizons', for which the probable upper and lower age limits, as compared with the most appropriate Boreal or Subboreal chronozone scales, are indicated by dashed lines in Figure 8. Changes in successive ammonite occurrences reflect evolution/extinction events within a basin or the replacement over time of one major taxonomic group by another due to, for example, migration facilitated by new marine connections or other competitive factors.

Examples of evolutionary successions within Boreal lineages in particular Arctic basins are the richly fossiliferous Middle Jurassic successions of several zones along Porcupine River, northern Yukon (Poulton, 1987) and on western Axel Heiberg Island (Frebold, 1964b), where a single ammonite family (Cardioceratidae) predominates over an extended period. This group has been particularly well studied, and a series of subjectively recognized distinctive populations ('transients', corresponding to a modern biological-species population with intraspecific variability) has been established (Callomon, 1995; Callomon et al., 2015). Some of the morphologically distinct variants in each population have been named formally as varieties, subspecies, or species — the last in the sense of morphospecies or paleospecies (*see* Allmon, 2013, for a recent discussion of the species concept in paleontology and attempts to marry biological concepts with stratigraphic utility). Within a productive biohorizon, the variants may overlap morphologically, and each of these variants has its own, longer, stratigraphic range. The proportion of each variant also varies geographically, leading to the erection of regional zones in some areas, designated with the name of the dominant morphospecies. This is particularly the case during some intervals in the latest Jurassic of the Arctic, when relatively low sea levels caused isolation of individual basins with little faunal interchange between them.

An example of faunal replacement of one ammonite group by another involves the replacement of the late Sinemurian *Echioceras* by the late Pliensbachian *Amaltheus* (the early Pliensbachian is not definitively recognized in Arctic Canada); the two genera are not closely related, belonging in separate superfamilies. Such replacements commonly correspond to periods of marine transgression into small or shallow seas, which commonly left discontinuous stratigraphic records with hiatuses representing episodes of marine regression and regional extinction (e.g. Yacobucci, 2015).

The absolute age calibration depicted on the TSC Jurassic chart (e.g. Fig. 8) is not tightly controlled. No universally accepted, biostratigraphically constrained radiometric dates exist between the late Pliensbachian and the Albian (Gradstein et al., 2012; Pană et al., 2018). The numerical ages for most of the Jurassic and Lower Cretaceous interval boundaries have been interpolated between sparse, precisely dated horizons for the GTS 2020 numerical-age model, using a variety of techniques, as explained in Gradstein et al. (2012) and Ogg et al. (2016).

Buchia zonation

The Boreal bivalve *Buchia* is important for dating and correlation of the Late Jurassic and Early Cretaceous because of its abundance in the many areas where ammonites are rare or absent and because the steps in the sequence of morphotype associations have reasonably well-known age ranges over large areas (e.g. Jeletzky, 1966, 1984; Rogov and Zakharov, 2009). The *Buchia* zones illustrated for the Sverdrup Basin and the northern Yukon region are simplified from the detailed studies of Jeletzky (1966, 1984). Like some of the well-known ammonite groups, most *Buchia* zones comprise associations of several forms that have been formally named as species but perhaps represent variants in diverse populations of a single biospecies. The succession of generally distinctive polymorphic populations is recognizable when enough material is available for study, but the dominant morphology (often distinguished as a named species) varies somewhat from region to region. Individual morphospecies were more long-ranging. Whereas Jeletzky (e.g. Jeletzky, 1984, Fig. 9) conceived of several overlapping or concurrent range zones, they are illustrated in the datapack (*see* Fig. 8) and described (Appendix C) as successions of assemblages or 'zones' for which the name gives a sense of the dominant morphospecies. This approach facilitates plotting of the zones in TSC and enables comparison with the more finely subdivided Russian *Buchia* zonations (e.g. Rogov and Zakharov 2009; Zakharov, 2015). The charts provided by those authors and Jeletzky (1984) demonstrate the considerable degree of regional variation in predominant morphospecies across the Boreal realm and their geographically variable stratigraphic ranges. Rogov and Zakharov (2009) viewed the *Buchia* zones in Eurasia as a mix of zone types, some that begin with the first occurrence of the nominal species and others that are acme zones. Their boundaries are somewhat diffuse, partially subjective, and perhaps partly diachronous. Although the order of the *Buchia* zones is consistent across the Arctic, their age limits are imprecise given the paucity of ammonite control and the regional variation in the dominant *Buchia* morphospecies. One particularly distinctive and relatively short-lived early Berriasian species, *Buchia okensis*, has contributed particularly to Canadian historical discussions of the interregional correlation of the base of the Cretaceous (e.g. Jeletzky, 1984).

Jurassic faunal provincialism

Northern (Boreal) versus southern (Tethyan) latitudinal differentiation has affected marine organisms to varying degrees through time. It is particularly extreme during times when northern seas were separated from southern ones by landmasses or connected only by narrow or shallow epicontinental seaways. Such was the case during the Jurassic, before the supercontinent Pangea broke up sufficiently for the opening Atlantic Ocean to provide ready connection between the Arctic and Tethys oceans. These paleogeographic effects would have exacerbated the impact of reduced solar radiation in the north; northern seas and, particularly, small, isolated basins would have been colder, to some extent chemically distinct, and more influenced by local factors such as inflow of fresh water. However, the connections remained sufficient at most times, and the Arctic water mass was sufficiently large to maintain normal marine salinities and normal, albeit distinctive, marine faunas (Zakharov et al., 2012). The Jurassic faunas of Arctic Canada, Alaska, Siberia, and Svalbard are clearly Boreal, but the southern limits of Boreal faunas waxed and waned, sometimes extending into the North Atlantic and western Europe, down the Pacific coasts, and into the interiors of North America and Eurasia.

Boreal Jurassic marine faunas are generally less diverse than coeval southern faunas, and carbonate rocks and thick-shelled organisms are uncommon (Imlay, 1965; Smith and Tipper, 1986; Page, 2008). Some latitudinal differentiation can be seen in the Early Jurassic, but the isolation of sedimentary basins was especially strong in parts of the Middle and Late Jurassic when north–south connections were nonexistent or reduced to shallow epicontinental seaways in the North Atlantic, North Pacific, and eastern European regions. During extended periods of isolation, independent evolution within the northern basins resulted in lineages of Boreal ammonites that have little or nothing in common with southern faunas (e.g. the Cardioceratidae; Page, 2008; Zakharov et al., 2012; Callomon et al., 2015). The *Buchia* group of bivalves was another of the many marine faunal groups that also developed within the Arctic (Zakharov et al., 2012).

The term 'Boreal realm', or 'Boreal superrealm', encompasses several Arctic areas with differing regional ammonite zonations, reflecting some degree of separation from each other, and more broadly includes several 'Subboreal' areas, also with independent zonations (e.g. Page, 2008). It is not always clear in the literature what the terms 'Boreal' and 'Subboreal' refer to paleogeographically. Most usefully, Ogg et al. (2016, p. 170) and Wimbledon (2017) specified distinct Dorset, North Sea, Nordvik, and Russian Platform regional zonations using geographic names; but confusingly, Ogg et al. (2016, p. 175), following Cope (2008) and others, labelled the eastern English zonation as 'Boreal'. Shurygin et al. (2011) decried the common practice of mixing zones from different faunal realms into single regional hybrid zonations, particularly the insertion of Russian Platform zones into the high Arctic zonation. However, this practice allows for the presentation of a single scale for a region and, when well explained, highlights the intervals with confident north–south correlations based on mixed faunas in areas of occasional intermixing, perhaps due to higher relative sea levels (e.g. Yacobucci, 2015).

Globally distributed (pandemic or cosmopolitan) and East Pacific endemic higher rank taxa characterize Arctic Canadian Hettangian and Sinemurian (Early Jurassic) faunas, although with distinct Arctic representatives at the family and lower ranks (Page, 2008), whereas more distinctly northern (Boreal) higher rank taxa begin to appear in the Pliensbachian (e.g. Taylor et al., 1984; Page, 2008). Correlations between northern and southern faunal provinces are particularly problematic for extensive intervals from the late Bajocian through to the earliest Cretaceous; a single, globally applicable, chronostratigraphic zonal scheme does not exist for some of these intervals. The Boreal early Bajocian to early Callovian *Boreiocephalites–Amoeboceras* cardioceratid-ammonite succession of Arctic Canada has been commonly illustrated as a succession of 'floating boxes', not tightly connected to the Europe-based standard scales (Callomon, 1984). The Canadian ammonites are so similar to the rich faunas of East Greenland and elsewhere across the Arctic that correlations are confident at most levels (Callomon, 1959, 1984, 1993; Frebold, 1964b; Poulton, 1987; Callomon et al., 2015). However, regional differences in the predominant species in each succession inhibit precise correlation of some zones (Callomon, 1984). For some of the associations in the northern Yukon sequence, Poulton (1987) erected a regional zonation for northwestern Canada based on named morphospecies that do not exhibit obvious morphologic intergradation; this scheme was reproduced by Von Hillebrandt et al. (1993).

Recent studies in rare areas of north–south faunal mixing have resulted in new correlations between the Middle Jurassic Tethyan and Boreal ammonite faunas. The correlations in this report of Canadian Arctic late Bajocian to middle Bathonian ammonites are largely a result of the 2002 discovery of *Arcticoceras harlandi* in association with Tethyan *Oraniceras* just above *Parkinsonia* in the succession at Saratov on the Russian Platform (Mitta et al., 2014). The adjusted correlations of each succeeding fauna to international zones for this interval are similar to those now adopted by workers across Russia (Meledina, 2014; Mitta et al., 2014; Gulyaev, 2019) and East Greenland (Kelly et al., 2015). The age designations of these intervals in the Canadian Middle Jurassic Boreal ammonite succession in previous literature are obsolete.

In the 2020 Canada datapack, the Arctic Canada ammonite biohorizons for these intervals have been tied to the Subboreal scale of chronozones provided by TSC, which was based on the compilation for northwestern European basins by the Groupe Français d'Étude du Jurassique (Cariou and Hantzpergue, 1997), with minor updates. The latest Jurassic Arctic Canadian ammonite and *Buchia* occurrences have been tied to the northern Siberia ('high Boreal') zonation provided by TSC, which incorporates recent interpretations for the Jurassic–Cretaceous boundary interval from Nordvik (Schnabl et al., 2015). The standard columns offered in TSC illustrate the base of the Cretaceous within the Subboreal (northwestern European) *Subcraspedites preplicomphalus* Zone and within the high Boreal (northern Siberia) *Craspedites taimyrensis* Zone, in accordance with the current proposal for the base of the Cretaceous (Wimbledon, 2017, Fig. 1).

The proposal to define the base of the Cretaceous in the Tethyan realm, currently in development, uses the base of the widespread calpionellid *Calpionella alpina* Zone as a primary marker in a 'sandwich' with secondary markers, including nannofossil and calcareous dinoflagellate-cyst events, ammonites (*Delphinella*), and magnetic anomalies (Wimbledon, 2017). Magnetic reversal correlations, and perhaps belemnites (*Arctoteuthis tehamaensis*), recognized in northern Siberia may permit correlation of the base of the Cretaceous from the Boreal into the Tethyan realm (e.g. Dzyuba, 2010; Schnabl et al., 2015). Canadian Arctic successions, without known calpionellids and with generally low abundance and a low-diversity biota, continue to be correlated confidently only with northern Siberia, based on limited occurrences of ammonites and *Buchia*. Geochemical curves, such as ^{13}C anomalies, may play an increasingly important role in addressing this issue (Galloway et al., 2019).

SUMMARY AND CONCLUSIONS

The new TSC 2020 Canada datapack, which incorporates stratigraphic data from the GEM regions of interest, with a focus on biostratigraphic-event stratigraphy, is intended to facilitate data visualization, comparison, and correlation within and between the GEM regions. A major advantage of using TSC is that it is periodically revised with updated age calibrations of the geological time scale, which are automatically reflected in the absolute ages of events or zone boundaries.

The new datapack incorporates new data, as well as some data re-evaluated and integrated from its 2010 predecessor. The 2020 Canada datapack focuses on Mesozoic–Cenozoic litho- and biostratigraphy. It includes revised stratigraphic data as well as new inputs, many of which were generated from GEM-funded research activities. Given their importance in the stratigraphy of Jurassic and Cretaceous strata of northern Canada, a detailed update of the Jurassic ammonite and *Buchia* biostratigraphy for the Sverdrup Basin and northern Yukon region is provided. Also included in the datapack are new lithostratigraphic and palynostratigraphic data sets for the Labrador–Baffin Seaway, filling a critical gap in the spatial and temporal coverage of Canadian strata in TSC. Another noteworthy addition to the 2020 Canada datapack consists of a suite of benthic (calcareous and agglutinated) foraminifer biostratigraphic data sets from Upper Jurassic to Cenozoic strata of the Beaufort–Mackenzie Basin in the Northwest Territories. These data sets provide important biostratigraphic control in economically important GEM regions.

Several other data sets are also included due to their relevance to biostratigraphic control of age-equivalent strata in the Canadian North, even though their geographical provenance is not primarily located within GEM regions. In particular, Late Cretaceous–Paleocene terrestrial palynomorph events across the Western Interior Basin are included because they provide a reference framework for age-equivalent strata in the Canadian North that were connected by the Western Interior Seaway at the time. Likewise, a new compilation of Triassic conodont zones across Canada is included, providing a reference framework for biostratigraphic control of Triassic exposures across the country.

New, quality stratigraphic data will continue to be added to the datapack as they become available. Future iterations of the Canada datapack would ideally fill other critical gaps in underrepresented regions and time intervals across Canada, as well as include new types of data such as carbon-isotope curves and other chemostratigraphic data sets, which are currently contributing significantly to the understanding of Canadian geology. The 2020 Canada datapack will become a major tool in supporting an understanding of Canada's sedimentary basins, and their resource potential and management, in line with the larger vision of the GSC, as exemplified by the Canada-3D project (National Geological Surveys Committee, 2019). The use of TSC consolidates the current understanding of the fourth dimension of Canadian geology.

ACKNOWLEDGMENTS

The authors would like to thank Keith Dewing and Dave McNeil (GSC-Calgary) as well as Dennis Braman (formerly of the Royal Tyrrell Museum) for their clarifications on data included in the 2020 Canada datapack. Julia Davison and Krista Boyce (GSC-Calgary) are gratefully acknowledged for their help entering biostratigraphic and lithostratigraphic data, respectively. The authors also wish to thank the Geologic TimeScale Foundation, Purdue University, and in particular James Ogg and Gabi Ogg, for providing up-to-date chronological reference schemes and for their support building the datapack; they are especially grateful to James Ogg for his prioritization of help in updating the Canada 2020 datapack to GTS 2020. The authors are grateful to Martin Head (Brock University) for insightful discussion on current chronostratigraphic issues, as well as for insightful reviews by Nikole Bingham-Kozlowski (GSC-Atlantic) and Dave McNeil that improved the manuscript. They also thank Denis Lavoie (GSC-Québec) and Michel Plouffe (GSC-Ottawa) for their support and encouragement. Terry Poulton is particularly grateful to the late John Callomon (University College, London) for the many years of companionship and advice, and the sharing of his knowledge of ammonites. More recently, Mikhail Rogov (Geological Institute of the Russian Academy of Sciences) has generously assisted with the identification and dating of many Canadian specimens. In particular, he has allowed access to his recent Panboreal compilation of Kimmeridgian and Volgian ammonites (Rogov, 2019), in which he has reviewed several Canadian collections, together with photographs provided by Terry Poulton for that purpose. Bill Wimbledon (University of Bristol) has also provided invaluable comments regarding the latest Jurassic ammonite correlations and the current procedure for designating a base for the Cretaceous system.

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Appendix A

The following tables list all biostratigraphic (Table A1) and lithostratigraphic (Table A2) data included in the 2020 Canada datapack.

The data sets ‘Canadian Arctic Islands lithostratigraphy’, ‘Northern Canada lithostratigraphy’, and ‘Central Canada lithostratigraphy’ listed in Table A2 are based on regional charts from volumes of the Decade of North American Geology published by the Geological Survey of Canada (Trettin, 1991a, b, c; Stott, 1993a, b, c).

Table A1. List of biostratigraphic data included in the 2020 Canada datapack (*modified from* Geologic TimeScale Foundation, 2019c).

Data set		Source	Comments
Western/Arctic Canada Triassic Biostrat			
	WCSB/Sverdrup Basin ammonoid zones	Tozer, 1994; Bucher, 2002; Ji and Bucher, 2018; Golding and Orchard (this report)	Compiled by Golding and Orchard. Ages tied to 'master' reference schemes (subboreal ammonite zones, stages, and substages)
	WCSB/Sverdrup Basin conodont zones	Golding and Orchard (this report)	Compiled by Golding and Orchard. Most ages tied to 'master' reference schemes (subboreal ammonite zones, stages, and substages), and other ages tied to the "WCSB/Sverdrup Basin ammonoid zones"
Western/Arctic Canada Jurassic Biostrat			
Ammonite zones			
	Ammonites (Sverdrup Basin)	Poulton (this report)	Updated by Poulton. Ages now tied to 'master' reference schemes (subboreal [Hettangian–Callovian] and boreal [Oxfordian–Tithonian] ammonite zones)
	Ammonites (northern Yukon region)	Poulton (this report)	Updated by Poulton. Ages now tied to 'master' reference schemes (subboreal [Hettangian–Callovian] and boreal [Oxfordian–Tithonian] ammonite zones)
Bivalve zones			
	Bivalves (Sverdrup Basin)	Harrison et al., 1999a	Updated by Poulton. Ages now tied to 'master' reference schemes (boreal ammonite zones)
	Bivalves (northern Yukon region)	Poulton et al., 1993a	Updated by Poulton. Ages now tied to 'master' reference schemes (boreal ammonite zones)
Foraminifer zones			
	Foraminifers (Sverdrup Basin)	Harrison et al., 1999a	Ages now tied to 'master' reference schemes (subboreal [Hettangian–Callovian] and boreal [Oxfordian–Tithonian] ammonite zones)
Dinoflagellates			
	Dinoflagellate zones (Sverdrup Basin, legacy)	Harrison et al., 1999a	Kept for 'historical' value. Source data (Davies, 1983) now available as events. Ages now tied to 'master' reference schemes (subboreal [Hettangian–Callovian] and boreal [Oxfordian–Tithonian] ammonite zones)
	Dinoflagellate events (Sverdrup Basin)	Davies, 1983	Data (events) entered by Bujak. Ages tied to 'master' reference schemes (subboreal ammonite zones)
	Dinoflagellate zones (northern Yukon region, legacy)	Poulton et al., 1993a	Kept for 'historical' value. Ages now tied to 'master' reference schemes (stages). Taxonomy updated following Fensome et al. (2019)

Table A1. (cont.)

Data set		Source	Comments
Western Arctic Upper Jurassic–Cenozoic Biostrat			
Beaufort–Mackenzie Upper Jurassic–Cenozoic foraminifers			
	Upper Jurassic–Cenozoic foraminifer zones	Fowler, 1996; Hedinger, 1996; McNeil, 1996a, b, c, 1997; D.H. McNeil (pers. comm., 2019)	Revised by D.H. McNeil (pers. comm., 2019). Source data (Fowler, Hedinger, and McNeil *in* Dixon, 1996) now available as events. Ages now tied to 'master' reference schemes (stages)
	Cenozoic calcareous benthic foraminifers	McNeil, 1996c, 1997	Ages tied to 'master' reference schemes (series). Events capture overall FOs and LOs; users are referred to the original publications for variations in abundance
	Cenozoic agglutinated benthic foraminifers	McNeil, 1996b, 1997	Ages tied to 'master' reference schemes (series). Events capture overall FOs and LOs; users are referred to the original publications for variations in abundance
	Upper Jurassic and Cretaceous benthic foraminifers	Fowler, 1996; Hedinger, 1996; McNeil, 1996a, 1997	Ages tied to 'master' reference schemes (stages). Events capture overall FOs and LOs; users are referred to the original publications for variations in abundance
Beaufort–Mackenzie Cretaceous–Cenozoic dinoflagellates			
	Dinoflagellate zones (legacy)	Harrison et al., 1999b	Kept for 'historical' value. Source data (McIntyre *in* Dixon, 1996) now available as events. Ages now tied to 'master' reference schemes (stages). Taxonomy updated following Fensome et al. (2019)
	Dinoflagellate events	McIntyre, 1996a, b, c; Fensome et al., 2019	Ages tied to 'master' reference schemes (series/stage). Taxonomy updated following Fensome et al. (2019)
Western Arctic Cretaceous–Cenozoic palynology			
	N Richardson Mountains dinocyst events (Valanginian)	McIntyre and Brideaux, 1980	Data (events) entered by Bujak. Precise ages uncertain. Ages tied to 'master' reference schemes (stages)
	N Richardson Mountains spores events (Valanginian)	McIntyre and Brideaux, 1980	Data (events) entered by Bujak. Precise ages uncertain. Ages tied to 'master' reference schemes (stages)
	Horton River dinocyst and acritarch events (Aptian–Albian)	Brideaux and McIntyre, 1975	From exposures along the Horton River (Anderson Plains, N.W.T.). Langton Bay and Horton River formations. Ages tied to 'master' reference schemes (stages/substages)
	Horton River spores and pollen events (Aptian–Albian)	Brideaux and McIntyre, 1975	From exposures along the Horton River (Anderson Plains, N.W.T.). Langton Bay and Horton River formations. Ages tied to 'master' reference schemes (stages/substages)
	WIS pollen and spores (Upper Cretaceous–Paleocene)	Braman and Sweet, 2012	Ages tied to 'master' reference schemes (series/stages)

Table A1. (cont.)

Data set		Source	Comments
	Western/Arctic Canada pollen and spores zones (Upper Cretaceous–Cenozoic)	Harrison et al., 1999b	Ages now tied to 'master' reference schemes (stages)
Eastern Arctic Mesozoic–Cenozoic Biostrat			
	Jurassic–Cretaceous boundary dinocyst events	Fisher and Riley, 1980	Data (events) entered by Bujak. Events recorded over Arctic and Eastern Canada, Greenland, and NW Europe. Ages tied to 'master' reference schemes (stages/substages and subboreal ammonite zones)
	Labrador–Baffin Seaway palynoevents	Nøhr-Hansen et al., 2016	Ages tied to 'master' reference schemes (series/stages)
Offshore Arctic Mesozoic–Cenozoic palynology (Bujak data)			
	Bujak Arctic zones	Bujak (unpublished data)	Unpublished data by J.P. Bujak (JPB), established mostly from Arctic Canada and Alaska offshore well data. Details to be provided in CAPE (*see* text). Ages tied to 'master' reference schemes (series/stages)
	Bujak Arctic subzones	Bujak (unpublished data)	Unpublished data by JPB, established mostly from Arctic Canada and Alaska offshore well data. Details to be provided in CAPE (*see* text). Ages tied to 'master' reference schemes (series/stages)
	Bujak Arctic dinocyst and algal events	Bujak (unpublished data)	Unpublished data by JPB, established mostly from Arctic Canada and Alaska offshore well data. Details to be provided in CAPE (*see* text). Ages tied to 'master' reference schemes (series/stages). Taxonomy updated following Fensome et al. (2019)
	Bujak Arctic spores, pollen, and fungi events	Bujak (unpublished data)	Unpublished data by JPB, established mostly from Arctic Canada and Alaska offshore well data. Details to be provided in CAPE (*see* text). Ages tied to 1) Bujak Arctic (sub)zones, and 2) 'master' reference schemes (stages and subboreal ammonite zones)
Arctic Cenozoic climate (Bujak data)			
	Bujak Arctic climatic events	Bujak (unpublished data)	Unpublished data compiled and entered by JPB. Data represent global (Northern Hemisphere) events. Ages tied to 'master' reference schemes (series/stages)
	Abreu and Anderson (1998) climate events	Abreu and Anderson, 1998	Data (events) entered by JPB. Data represent global events. Ages absolute (i.e. not updated)
	Bujak Arctic SST	Bujak (unpublished data)	Unpublished data by JPB, established mostly from Arctic Canada and Alaska offshore well data. Details to be provided in CAPE (*see* text). Ages tied to 'master' reference schemes (stages)

CAPE = Circum-Arctic lower Paleozoic to Cenozoic palynological events project; FO = first occurrence; LO = last occurrence; SST = sea-surface temperature; WCSB = Western Canada Sedimentary Basin; WIS = Western Interior Seaway.

Table A2. List of lithostratigraphic data included in the 2020 Canada datapack (*modified from* Geologic TimeScale Foundation, 2019c).

Data set	Data column	Source
New Canadian lithostratigraphic data (GEM-focused)		
Sverdrup Basin Mesozoic lithostratigraphy		
	Mesozoic stratigraphy of the Sverdrup Basin	Hadlari et al., 2016 (Fig. 2)
Cretaceous lithostratigraphy of Sverdrup Basin and western Arctic		
	Ringnes Islands and Axel Heiberg Island	Bringué et al., 2018 (Fig. 2.1)
	Banks Island	Bringué et al., 2018 (Fig. 2.1)
	Horton–Anderson plains	Bringué et al., 2018 (Fig. 2.1)
	Richardson Mountains (northern Aklavik Range)	Bringué et al., 2018 (Fig. 2.1)
	Snake, Peel, Arctic Red, and Hume rivers	Bringué et al., 2018 (Fig. 2.1)
Labrador–Baffin Seaway Cretaceous and Cenozoic lithostratigraphy		
	Labrador margin	Dickie et al., 2011; Nøhr-Hansen et al., 2016 (Fig. 3)
	SE Baffin Island	Nøhr-Hansen et al., 2016 (Fig. 3)
	Bylot Island	Nøhr-Hansen et al., 2016 (Fig. 3)
Canadian Arctic Islands transect suite		
Ellef Rignes Island strat		
	Ellef Rignes–Sutherland transect	Dewing and Embry, 2007
Sutherland O-23		
	Sutherland–Helena transect	Dewing and Embry, 2007
Helena Island		
	Helena–E Bathurst transect	Dewing and Embry, 2007
Bathurst Island strat		
	Cornwallis Island transect	Dewing and Embry, 2007
Between Cornwallis and Somerset islands		
	Somerset–Brodeur transect	Dewing and Embry, 2007
NW Baffin Island		
	North Baffin–Melville transect	Dewing and Embry, 2007
Canadian Arctic Islands lithostratigraphy		
Banks–Baffin islands (south Arctic transect)		
Banks–Victoria region		
	NW Banks Island	Trettin, 1991a
	Central Banks Island	Trettin, 1991a
	SE Banks Island	Trettin, 1991a

Table A2. (cont.)

Data set	Data column	Source
	Victoria and Stefansson islands	Trettin, 1991a
	Prince of Wales Island	Trettin, 1991a
Lancaster region (south)		
	W Somerset Island	Trettin, 1991a
	E Somerset Island	Trettin, 1991a
	N Baffin Island	Trettin, 1991a
Baffin region		
	Bylot Island	Trettin, 1991a
Foxe Plain		
	Foxe Basin	Trettin, 1991a
Devon–southern Ellesmere Island		
Lancaster region (Devon Island)		
	Devon Island	Trettin, 1991a
Southern Ellesmere Island		
	SW Ellesmere	Trettin, 1991a
	Fram Fiord	Trettin, 1991a
	W Makinson Inlet	Trettin, 1991a
	E Makinson Inlet	Trettin, 1991a
	Bache Peninsula	Trettin, 1991a
Melville–N Devon Island		
Sverdrup lowland (east)		
	Prince Patrick Island	Trettin, 1991a
	Eglinton Island	Trettin, 1991a
Parry upland		
	NW Melville Island	Trettin, 1991a
	Central Melville Island	Trettin, 1991a
	NE Melville Island	Trettin, 1991a
	Cameron Island	Trettin, 1991a
	W Bathurst Island	Trettin, 1991a
	Central Bathurst Island	Trettin, 1991a
	E Bathurst Island	Trettin, 1991a
	N Cornwallis Island	Trettin, 1991a
	S Cornwallis Island	Trettin, 1991a

Table A2. (cont.)

Data set	Data column	Source
	E Grinnel Peninsula	Trettin, 1991a
Mackenzie–Axel Heiberg		
Sverdrup lowland		
	Mackenzie, Brock, and Borden islands	Trettin, 1991a
	Lougheed Island	Trettin, 1991b
	King Christian and Ellef Ringnes islands	Trettin, 1991b
	Ellef Ringnes Island	Trettin, 1991b
	Amund Ringnes Island	Trettin, 1991b
	Cornwall Island	Trettin, 1991b
	Graham Island (Sverdrup lowland)	Trettin, 1991b
Axel Heiberg Island		
	S Axel Heiberg Island	Trettin, 1991b
	W-central Axel Heiberg Island	Trettin, 1991b
	NW Axel Heiberg Island	Trettin, 1991b
	E Axel Heiberg Island	Trettin, 1991b
	N Axel Heiberg Island	Trettin, 1991b
S Ellesmere–NE Ellesmere		
	Bjorne Peninsula and south	Trettin, 1991b
	Svendsen Peninsula (central Ellesmere Island)	Trettin, 1991b
	Raanes Peninsula	Trettin, 1991b
	Western Fosheim Peninsula (central Ellesmere Island)	Trettin, 1991b
	Eastern Fosheim Peninsula	Trettin, 1991b
	S of Caledonian Bay	Trettin, 1991b
	Caledonian Bay (central Ellesmere Island)	Trettin, 1991b
	Copes Bay to Carl Ritter Bay	Trettin, 1991b
	SW Judge Daly Promontory (central Ellesmere Island)	Trettin, 1991b
	SE of Ella Bay (central Ellesmere Island)	Trettin, 1991b
	Head of Ella Bay	Trettin, 1991b
	St. Patrick Bay (central Ellesmere Island)	Trettin, 1991b
N Ellesmere transect		
Central Ellesmere Island		
	Blue Mountains	Trettin, 1991b
	Western Svartfjeld Peninsula	Trettin, 1991b

Table A2. (cont.)

Data set	Data column	Source
	Van Hauen Pass (central Ellesmere Island)	Trettin, 1991b
	Head of Hare Fiord (central Ellesmere Island)	Trettin, 1991b
	Ooblooyah Bay (central Ellesmere Island)	Trettin, 1991b
	East of mouth of Tanquary Fiord (central Ellesmere Island)	Trettin, 1991b
Northern Ellesmere Island (central)		
	McKinley Bay (central Ellesmere Island)	Trettin, 1991c
	Head of Tanquary Fiord (central Ellesmere Island)	Trettin, 1991c
	Henrietta Nesmith Glacier (central Ellesmere Island)	Trettin, 1991c
	Lake Hazen (central Ellesmere Island)	Trettin, 1991c
Northernmost Ellesmere Island		
	Head of Emma Fiord	Trettin, 1991c
	Kleybolte Peninsula	Trettin, 1991c
	S of Phillips Inlet	Trettin, 1991c
	Head of Yelverton Inlet	Trettin, 1991c
	Wooton Peninsula to SE of Milne Inlet	Trettin, 1991c
	M’Clintock Glacier (northern Ellesmere Island)	Trettin, 1991c
	M’Clintock Inlet	Trettin, 1991c
	Head of M’Clintock Inlet	Trettin, 1991c
	Head of Disraeli Fiord (northern Ellesmere Island)	Trettin, 1991c
	E of Disraeli Fiord to Markham Fiord	Trettin, 1991c
	Cape Columbia to Cape Nares (northern Ellesmere Island)	Trettin, 1991c
	NW of Clements Markham River	Trettin, 1991c
	Crescent Glacier to Clements Markham Inlet (northern Ellesmere Island)	Trettin, 1991c
	Feilden Peninsula, Parry Peninsula, Parker River (northern Ellesmere Island)	Trettin, 1991c
	NW of Piper Pass (northern Ellesmere Island)	Trettin, 1991c
Northern Greenland		
Kane Basin–Independence Fiord region		
	Inglefield Land	Trettin, 1991c
	Washington Land	Trettin, 1991c
	Petermann Glacier	Trettin, 1991c
	Western North Greenland (south)	Trettin, 1991c
	Southern Peary Land–Independence Fiord	Trettin, 1991c

Table A2. (cont.)

Data set	Data column	Source
	Danmark Fiord	Trettin, 1991c
N Greenland region		
	Western North Greenland (north)	Trettin, 1991c
	Northern Peary Land	Trettin, 1991c
Northern Canada lithostratigraphy		
Canadian Arctic and Mackenzie area		
	Romanzoff uplift/Babbage depression (British–Barn mountains Old Crow Basin)	Stott, 1993a
	Yukon Coastal Plain/Rapid depression (Mackenzie Bay)	Stott, 1993a
	West Richardson Trough/White uplift (White Mountains)	Stott, 1993a
	East Richardson Trough/White uplift (northern Richardson Mtns.)	Stott, 1993a
	Mackenzie Delta	Stott, 1993a
	Campbell uplift (Inuvik)	Stott, 1993a
	Anderson Basin (Anderson Plain)	Stott, 1993a
	Brock Inlier (Melville Hills)	Stott, 1993a
	Coppermine homocline	Stott, 1993a
Northern Yukon and Mackenzie fold belt		
Northern Yukon fold complex		
	Kandik Basin (Kandik River)	Stott, 1993a
	Eagle fold belt (Eagle Plain)	Stott, 1993a
	Bonnet Plume Basin	Stott, 1993a
	Eastern Ogilvie Arch (eastern Wernecke Mountains)	Stott, 1993a
Yukon Mackenzie fold belt		
	Frontal Mackenzie Mountains (Snake River)	Stott, 1993a
	Mackenzie Arch (Arctic Red River)	Stott, 1993a
	Mackenzie synclinorium (Mountain River)	Stott, 1993a
	Northern Franklin Mountains (Norman Wells)	Stott, 1993a
	Keele Arch (Fort Norman)	Stott, 1993a
	Great Bear Basin (western Great Bear Lake)	Stott, 1993a
Central Yukon to Yellowknife		
	Misty Creek embayment (Twitya River)	Stott, 1993a
	Sekwi Mountain	Stott, 1993a
	East Glacier/Lake Nahanni	Stott, 1993a

Table A2. (cont.)

Data set	Data column	Source
	Frontal Mackenzie Mountains (Redstone River)	Stott, 1993a
	Franklin Mountains (Cap Mountain)	Stott, 1993a
	Bulmer Lake Arch (Bulmer Lake)	Stott, 1993a
	Great Bear Plain/Lac la Martre	Stott, 1993a
Southern Northwest Territories		
	Selwyn Basin (Flat River)	Stott, 1993a
	Southern Mackenzie fold belt (Kotaneelee and Liard ranges)	Stott, 1993a
	Tathlina Arch (Trout Lake)	Stott, 1993a
	Hay River platform (Hay River Pine Point)	Stott, 1993a
Central Canada lithostratigraphy		
Northern British Columbia–Alberta		
Northern BC Rocky Mountain fold belt		
	Gataga high (Gataga River)	Stott, 1993b
	Roosevelt graben (Mount Churchill)	Stott, 1993b
	MacDonald platform (Summit Lake)	Stott, 1993b
	Liard and Scatter rivers	Stott, 1993b
Northern BC Interior platform		
	Zama Lake	Stott, 1993b
Middle British Columbia–Alberta		
Middle BC Rocky Mountain fold belt		
	Western Rocky Mountains (Ware map area)	Stott, 1993b
	Eastern Rocky Mountains (Halfway map area)	Stott, 1993b
	Peace River Arch/embayment (Pine Pass)	Stott, 1993b
Middle BC Interior platform		
	Peace River plains (Fort St. John)	Stott, 1993b
	Hay River Basin (Fort McMurray)	Stott, 1993b
Middle Alberta–Saskatchewan		
	Front Range (Narraway River)	Stott, 1993b
	Swan Hills	Stott, 1993b
	Cold Lake	Stott, 1993b
	Cumberland House	Stott, 1993b

Table A2. (cont.)

Data set	Data column	Source
Lower mid Alberta–Saskatchewan		
Lower mid Alberta Rocky Mountain fold belt		
	Mount Robson syncline (Mount Robson)	Stott, 1993b
	Eastern Main ranges (Jasper)	Stott, 1993b
	Western Alberta ridge (Roche Miette)	Stott, 1993b
	Eastern Alberta foothills (Brûlé)	Stott, 1993b
Lower mid Alberta Interior platform		
	Edmonton	Stott, 1993b
	Lloydminster	Stott, 1993b
	Saskatoon	Stott, 1993b
	Lake Winnipegosis	Stott, 1993b
Southern Alberta–Saskatchewan		
Southern Alberta Rocky Mountain fold belt		
	Western Rocky Mountains (Stanford–Hughes ranges)	Stott, 1993b
	Main Ranges Basin (Kickinghorse River)	Stott, 1993b
	Main Ranges platform (Spray River/Connor Lake)	Stott, 1993b
	West Alberta Arch/Front Range (Exshaw)	Stott, 1993b
	Western Alberta foothills (Turner Valley)	Stott, 1993b
Southern Alberta Interior platform		
	Calgary/Drumheller	Stott, 1993b
	North Williston Basin (Moose Jaw/Regina)	Stott, 1993b
	Eastern platform (Lake Manitoba)	Stott, 1993b
Far southern Alberta–Manitoba		
Far southern Rocky Mountain fold belt		
	Fernie Basin (Elko/Fernie)	Stott, 1993c
	Front-Ranges Foothills (Waterton/Pincher Creek)	Stott, 1993c
Far southern Interior platform		
	Sweetgrass Arch (Cypress Hills)	Stott, 1993c
	West Williston Basin (Maple Creek/Swift Current)	Stott, 1993c
	Central Williston Basin (Big Muddy/Willow Bunch)	Stott, 1993c
	East Williston Basin (Brandon)	Stott, 1993c

Table A2. (cont.)

Data set	Data column	Source
Hudson platform		
	Bell Arch (Southampton, Coats, and Mansel islands)	Stott, 1993c
	Northern Hudson Bay	Stott, 1993c
	Central Hudson Bay	Stott, 1993c
	Northern Hudson Bay lowland	Stott, 1993c
	Central Hudson Bay lowland	Stott, 1993c
	North James Bay lowland	Stott, 1993c
	Central James Bay lowland	Stott, 1993c
	South James Bay lowland	Stott, 1993c
West St. Lawrence platform/lowlands		
	Michigan Basin (Windsor/Sarnia)	Stott, 1993c
	Allegheny Basin (western Lake Erie)	Stott, 1993c
	Michigan Basin (Manitoulin Island)	Stott, 1993c
	Algonquin Arch	Stott, 1993c
	Allegeheny Basin (Niagara Peninsula)	Stott, 1993c
Central St. Lawrence platform/lowlands and Laurentian highlands (and outliers within Superior and Grenville provinces)		
	Lake Timiskaming and Ottawa Valley outliers–Ottawa embayment	Stott, 1993c
	Pembroke–Arnprior outlier, Ottawa, and St. Lawrence River	Stott, 1993c
	Montréal	Stott, 1993c
	Saint-Hyacinthe	Stott, 1993c
	West Lac Saint-Jean, Chicoutimi outlier, Québec	Stott, 1993c
	Nicolet/Yamaska	Stott, 1993c
East St. Lawrence platform/lowlands		
	N Shore and Mingan Island/Anticosti Island	Stott, 1993c
	Gulf of St. Lawrence	Stott, 1993c
	Port au Port Peninsula	Stott, 1993c
	Southeast Labrador/Strait of Belle Isle	Stott, 1993c
	Canada Bay	Stott, 1993c

Appendix B

Table B1 provides a summary of changes applied to each ‘Arctic Canada Biostrat’ column of the 2010 Canada datapack, highlighting some of the quality control applied to data incorporated in the 2020 version of the Canada datapack (*modified from* Geologic TimeScale Foundation, 2019c).

Table B1. Summary of changes applied to each 'Arctic Canada Biostrat' column of the 2010 Canada datapack.

Data set (2010 Canada datapack)	New name	Source	Action(s)	Comment(s)
Arctic Canada Cenozoic Biostrat				
1) Cenozoic foram and nannofossil mixed zones				
Cenozoic scale	–	Harrison et al., 1999b	Deleted	Redundant/outdated reference scheme
2) Beaufort–Mackenzie Basin				
Foraminifers	Upper Jurassic–Cenozoic foraminifer zones	Harrison et al., 1999b	Renamed, expanded and revised, formulas updated	Revised by McNeil (pers. comm., 2019) and expanded to include Cretaceous and Upper Jurassic zones. Source data (McNeil *in* Dixon, 1996) now available as events. Ages now tied to 'master' reference schemes (stages)
Dinoflagellates	Dinoflagellate zones (legacy)	Harrison et al., 1999b	Renamed, formulas updated	Kept for 'historical' value. Source data (McIntyre *in* Dixon, 1996) now available as events. Ages now tied to 'master' reference schemes (stages). Taxonomy updated following Fensome et al. (2019)
3) Western/Arctic Canada				
Pollen, spores	Western/Arctic Canada pollen and spores zones (Upper Cretaceous–Cenozoic)	Harrison et al., 1999b	Formulas updated	Ages now tied to 'master' reference schemes (stages)
Arctic Canada Jurassic Biostrat	(Now "Western/Arctic Canada Jurassic Biostrat")			
1) Ammonite zones				
Jurassic subboreal/boreal ammonite zones	–	Harrison et al., 1999a	Deleted	Redundant/outdated reference scheme
Boreal zones	–	Harrison et al., 1999a	Deleted	Redundant/outdated reference scheme
Ammonites (Harrison)	Ammonites (Sverdrup Basin)	Harrison et al., 1999a	Updated, renamed, formulas updated	Ages now tied to 'master' reference schemes (subboreal [Hettangian–Callovian] and boreal [Oxfordian–Tithonian] ammonite zones)
Ammonites (Poulton)	Ammonites (northern Yukon region)	Poulton et al., 1993a	Updated, renamed, formulas updated	Ages now tied to 'master' reference schemes (subboreal [Hettangian–Callovian] and boreal [Oxfordian–Tithonian] ammonite zones)

Contents

Table B1. (cont.)

Data set (2010 Canada datapack)	New name	Source	Action(s)	Comment(s)
Yukon ammonites	–	Poulton, 1987	Deleted	Data now incoporated into new 'Ammonites (northern Yukon region)' column
2) Bivalve zones				
Bivalves (Harrison)	Bivalves (Sverdrup Basin)	Harrison et al., 1999a	Renamed, formulas updated	Ages now tied to 'master' reference schemes (boreal ammonite zones)
Bivalves (Poulton)	Bivalves (northern Yukon region)	Poulton et al., 1993a	Renamed, formulas updated	Ages now tied to 'master' reference schemes (boreal ammonite zones)
Wrangellia bivalves	–	Aberhan et al., 1998	Deleted	Fragmented information; not within GEM regions of interest
Stikinia bivalves	–	Aberhan et al., 1998	Deleted	Fragmented information; not within GEM regions of interest
Western Interior bivalves	–	Aberhan et al., 1998	Deleted	Fragmented information; not within GEM regions of interest
3) Foram zones				
Foraminifers (Harrison)	Foraminifers (Sverdrup Basin)	Harrison et al., 1999a	Renamed, formulas updated	Ages now tied to 'master' reference schemes (subboreal [Hettangian–Callovian] and boreal [Oxfordian–Tithonian] ammonite zones)
4) Dinoflagellate zones	(Now "Dinoflagellates")			
Dinoflagellates (Harrison)	Dinoflagellate zones (Sverdrup Basin, legacy)	Harrison et al., 1999a	Renamed, formulas updated	Kept for 'historical' value. Source data (Davies, 1983) now available as events. Ages now tied to 'master' reference schemes (subboreal [Hettangian–Callovian] and boreal [Oxfordian–Tithonian] ammonite zones)
Dinoflagellates (Poulton)	Dinoflagellate zones (northern Yukon region, legacy)	Poulton et al., 1993a	Renamed, formulas updated	Kept for 'historical' value. Ages now tied to 'master' reference schemes (stages). Taxonomy updated following Fensome et al. (2019)
Arctic Canada Devonian–Cambrian Biostrat				
Multiple	–	Multiple	Deleted	Pre-Mesozoic data, not included in 2020 Canada datapack

GEM = Geo-mapping for Energy and Minerals program.

Appendix C

This appendix provides updated identifications and age determinations, as well as references to both original paleontological sources and previous summary compilations, as documentation for the summary chart of Arctic Canada's Jurassic ammonite and *Buchia* biostratigraphy presented in Figure 8.

This is not a complete guide, as it does not include all instances in the literature where fossil determinations have been simply repeated without embellishment and unpublished sources have not been considered. Early discoveries of fossils without stratigraphic context, and commonly misidentified and misdated, are noted only where use of their name has implied significant potential for age determinations.

Ammonites: Early Jurassic

Early Hettangian. *Psiloceras* sp. and *Caloceras* cf. *johnstoni* (J. de C. Sowerby) were described and illustrated by Frebold and Poulton (1977), and *Psiloceras*(?) sp. was described and illustrated by Poulton (1991).

Latest Hettangian or earliest Sinemurian. *Badouxia*(?) and *Ectocentrites*(?) sp. were described and illustrated by Poulton (1991).

Early Sinemurian. Arietitid ammonites were described and illustrated as *Arietites sensu lato* (not re-studied since) from Melville and Mackenzie King–Borden islands and northern Richardson Mountains by Frebold (1960, 1964a); *Charmasseiceras* sp. and *Coroniceras* (*Primarietites*) sp. were illustrated from Borden Island by Frebold (1975). *Coroniceras*, *Arnioceras*(?), and *Charmasseiceras* were listed by Poulton (1994) and Poulton *in* Harrison et al. (1999a, 2000) but not yet illustrated, from the western Arctic Islands. *Coroniceras* (or *Arietites*?) and *Arnioceras* cf. *douvillei* (Bayle) were described and illustrated by Poulton (1991) from the northern Richardson Mountains.

Late Sinemurian. *Oxynoticeras oxynotum* (Quenstedt), *Oxynoticeras* sp., *Arctoasteroceras jeletzkyi* Frebold, and *Gleviceras*(?) sp. were described and illustrated from the northern Richardson Mountains by Frebold (1960, 1964a); *Arctoasteroceras jeletzkyi* was subsequently discussed and *Gleviceras plauchuti* Frebold illustrated from Prince Patrick Island (Frebold, 1975). *Aegasteroceras* (*Arctoasteroceras*) *jeletzkyi* Frebold, *Aegasteroceras* (*Arctoasteroceras*) sp., *Oxynoticeras oxynotum* (Quenstedt), *Oxynoticeras*(?) sp., *Gleviceras* sp., *Microderoceras*(?), and *Paltechioceras*(?) were described and illustrated, or listed, from the northern Richardson Mountains by Poulton (1991).

Echioceras sp., illustrated by Frebold (1960) from the northern Richardson Mountains, was designated *Echioceras aklavikense*, and also described from Melville Island with *Echioceras arcticum* Frebold (1975, both species); *Echioceras arcticum* and *Echioceras* cf. *arcticum* were identified from Borden Island and northern Yukon, respectively (Frebold, 1975); *Echioceras aklavikense* Frebold, *Echioceras*(?), including *Vermiceras*, which was identified earlier by Stelck (*in* Jeletzky, 1967), and *Arietites* by Frebold (1960; noted also by Poulton et al., 1982), *Paltechioceras* (*Orthechioceras*) cf. *radiatum* (Trueman and Williams), and *Paltechioceras*(?) sp. were described and illustrated, or listed, by Poulton (1991).

Late Pliensbachian. *Amaltheus stokesi* (J. Sowerby) and *Amaltheus* sp. were described and illustrated from Axel Heiberg and Prince Patrick islands by Frebold (1975). *Amaltheus* sp. was listed from the northern Richardson Mountains and northern Yukon by Frebold (1964a); *Amaltheus stokesi*, *A. bifurcus* Howarth, and *A. margaritatus* de Montfort(?) were illustrated or listed from that area by Poulton (1991). The precise age of *Pleuroceras*(?) described and illustrated by Poulton (1991) from a locality in the northern Yukon area that also produced *Amaltheus* from a nearby location is not clear, but perhaps the *Pleuroceras spinatum* Zone is also represented there.

Latest Pliensbachian or earliest Toarcian. Hall and Howarth (1983) assigned *Protogrammoceras paltum* (Buckman) from Axel Heiberg Island to the *Pleuroceras spinatum* Zone, but it has been stated in a recent review (Caruthers et al., 2018) to occur in both the late Pliensbachian and the early Toarcian in North America.

Early Toarcian. *Harpoceras* aff. *exaratum* (Young and Bird) and mainly finely ribbed *Dactylioceras* species such as *Dactylioceras* cf. *semicelatum* (Simpson) were illustrated or listed from northern Yukon (Frebold, 1964a, 1975; Frebold et al., 1967); *Hildaites* species were listed from the Arctic Islands (Frebold, 1964a, 1975); *Harpoceras* (or *Tiltoniceras*?) sp., *Dactylioceras*(?) sp., *Paltarpites*(?), *Grammoceras*(?), *Hildaites*(?), *Collina*(?) aff. *simplex* Fucini and *Ovaticeras* cf. *ovatum* (Young and Bird) were described and illustrated, or listed, from the northern Yukon–Richardson Mountains area by Poulton (1991).

Middle Toarcian. *Dactylioceras commune* (Simpson), *Pseudolioceras compactile* (Simpson), *Peronoceras spinatum* (Frebold), *Peronoceras polare* (Frebold), and *Peronoceras* aff. *desplacei* (d'Orbigny) and *Grammoceras*? were recognized first by Frebold (*in* Tozer, 1956), and described and illustrated from Cornwall, Prince Patrick, and Ellesmere islands by Frebold (1958, 1960, 1964a; the *Peronoceras* species were assigned originally to *Coeloceras*, then to *Catacoeloceras*). Unidentified harpoceratids from Prince Patrick and Borden islands, illustrated and compared with *Harpoceras exaratum* (Young and Bird) by Imlay (1955) and Frebold (1960), were associated with *Dactylioceras commune*; several forms of *Dactylioceras* from Prince Patrick Island were compared with various published species, and 'probable *Hildoceras*' was identified by Imlay (1955). Frebold (1975) described and illustrated *Pseudolioceras spitsbergense* and other components of the widespread *Peronoceras–Pseudolioceras* association from Prince Patrick Island, which he considered to be late Toarcian, but which are now considered to be middle Toarcian. *Dactylioceras commune*, a coeloceratid ammonite, *Pseudolioceras kedonense* Repin (?), and *Pseudolioceras lectum* (Simpson) and *Pseudolioceras* sp. were described and illustrated, or listed, by Poulton (1991) from northern Yukon. *Peronoceras* cf. *polare* (Frebold) identified by Frebold (1975; the record repeated by Poulton et al., 1982) from northern Yukon was not relocated in the original collection, which may be Middle Jurassic (Poulton, 1991). *Zugodactylites* cf. *braunianus* (d'Orbigny) indicating the *Zugodactylites braunianus* Subzone was illustrated from Ellef Ringnes Island by Frebold (1975).

Late Toarcian. The record of *Grammoceras* cf. *boreale* (Whiteaves) from northern Ellesmere Island (Frebold, *in* Nassichuk and Christie, 1969) has been corrected — it is absent there (Frebold, 1975). The identification and age of the specimens from Cameron Island illustrated as *Pleydellia*? sp. and as early Bajocian in age (now Aalenian) by Frebold (1960) have not been reconsidered, but *Pleydellia* is known elsewhere in the western Arctic Islands (Poulton, 1994, Table 1). A significant sequence of ammonites through the Toarcian–Aalenian boundary interval is present in collections listed by Poulton (1994) from the western Arctic Islands.

Ammonites: Middle Jurassic

It is important to note that the Aalenian stage, basal to the Middle Jurassic, was not differentiated in North American publications prior to about 1982, before which it constituted the early Bajocian, and it was subsequently introduced gradually by different authors. The middle Bajocian referred to prior to its adoption is now the early Bajocian. The Callovian stage, now the highest in the Middle Jurassic, was previously included in the Late Jurassic.

Early Aalenian. *Leioceras opalinum* (Reinecke) and *Pseudolioceras mclintocki* (Haughton) have been described and illustrated from Prince Patrick Island and are now known from many other Arctic localities as well (Frebold, 1958, 1960, 1961, 1964a, 1975). They were first identified as *Ludwigia* (*Lioceras*) *opalina* and *'Harpoceras' m'clintocki* or *Ludwigia m'clintocki*, respectively, and thought to be early Bajocian (Frebold *in* Tozer, 1956). *Leioceras* cf. *opalinum* (Reinecke), *Leioceras* sp.(?), *Pseudolioceras mclintocki* (Haughton), and *Pseudolioceras* spp. were described and illustrated from northern Yukon by Poulton (1991).

Late Aalenian. *Pseudolioceras mclintocki* (Haughton) occurs not only in the *Leioceras opalinum* Zone (Frebold, 1960), but also with *Erycitoides howelli* (White) (Poulton, 1991), through much or all of the Aalenian across Arctic Canada. *Erycitoides* cf. *howelli* was first identified, as *Erycites*, in northern Yukon (Frebold, 1960, 1961, 1964a; Frebold et al., 1967); *Erycitoides* is now known in Sverdrup Basin as far east as northern Ellesmere Island. *Erycitoides howelli*, *Erycitoides kialagvikense* (White), *Erycitoides spinatus* Westermann(?), *Erycitoides* sp., *Pseudolioceras mclintocki*, *Pseudolioceras* aff. *whiteavesi* (White), *Pseudolioceras* spp., and *Planammatoceras* spp. were described and illustrated by Poulton (1991) from the northern Yukon and northern Richardson Mountains. *Ludwigella*(?) from Prince Patrick Island, figured in Imlay (1955), was considered to be Toarcian *Pseudolioceras* by Poulton (1994).

Early Bajocian. *Arkelloceras* was first reported by Frebold (*in* Tozer, 1956) as a new but unnamed genus and species, and subsequently described and illustrated as three new species, widespread across the Canadian Arctic — *Arkelloceras mclearni*, *Arkelloceras tozeri*, and *Arkelloceras elegans* (species of Frebold, 1958, 1961, 1964b; Frebold et al., 1967; Poulton et al., 1982; Poulton, 1997). The early Bajocian (*Otoites sauzei* or perhaps earliest *Stephanoceras humphriesianum* Zone) age of *Arkelloceras*, suggested from small specimens in otherwise southerly faunas in western Alberta and southern Alaska (Westermann, 1964; Imlay, 1964), has been supported in eastern Siberia by Meledina (2014). *Abbasites*? and *Ludwigia* reported from northern Ellesmere Island (Frebold, *in* Nassichuk and Christie, 1969) have not been re-examined.

Boreiocephalites borealis (Spath) and *Boreiocephalites warreni* Frebold were described and illustrated, or listed, from the northern Richardson Mountains area (Frebold, 1961, 1964a). These species were assigned to *Cranocephalites*; *Boreiocephalites* Meledina is now widely used to accommodate the early species of the lineage (Howarth, 2017). Poulton et al. (1982) reported *Cranocephalites* cf. *indistinctus* Callomon from northern Yukon, and Callomon (1984) considered Frebold's figure of *Cranocephalites* (Freebold, 1958, Pl. 8) to represent the Greenland regional *Cranocephalites indistinctus* Zone on Prince Patrick Island.

Late Bajocian. *Cranocephalites vulgaris* Frebold was identified first as *Arctocephalites* (*Cranocephalites*) cf. *vulgaris* var. *robusta* in Tozer (1956) and described and illustrated, or listed, by Frebold (1958, 1961, 1964a) from Prince Patrick Island. Those illustrations and the presence of *Cranocephalites* cf. *pompeckji* (Madsen), *Cranocephalites* aff. *vulgaris*, and *Cranocephalites* aff. *maculatus* in northern Yukon (Poulton et al., 1982) were the basis for the recognition of the Greenland regional *Cranocephalites pompeckji* Zone by Callomon (1984). The apparent absence of *Cranocephalites* across the remainder of the Sverdrup Basin may indicate a regional hiatus below the McConnell Island shale sequence above the *Arkelloceras* beds.

Arctocephalites elegans Spath and other *Arctocephalites* species were described and illustrated by Frebold (1961, 1964a, b) from the richly fossiliferous successions on western Axel

Heiberg Island and from poorly localized specimens from northern Yukon. Additional ammonite collections by A.F. Embry and J.H. Wall were identified by Poulton, and the sequences were re-collected by Poulton in 1985. Specimens from a well-exposed sequence in northern Yukon were described by Poulton (1987), who named regional morphospecies representing the widespread Boreal *Arctocephalites arcticus* Zone, with its early and generally small *Arctocephalites* species. The lowest, regional *Arctocephalites spathi* Zone, contains morphospecies *Arctocephalites spathi* Poulton, *Arctocephalites ellipticus* Spath, and possibly *Arctocephalites* aff. *sphaericus* Spath (Poulton, 1987). Following joint collecting with Poulton at this locality, and based on illustrations in the literature and a preview of Poulton (1987), Callomon (1984) designated two subdivisions of the *Arctocephalites arcticus* Zone in Arctic Canada (Callomon, 1984, faunas C4 and C5), noting the similarities and differences of the variations in their populations with the East Greenland equivalents.

The succeeding regional *Arctocephalites porcupinensis* Zone in northern Yukon conforms with the local ranges of *Arctocephalites callomoni* Frebold and a variant of *Arctocephalites* aff. *nudus* Spath and is conspicuous by the abundance of *Arctocephalites porcupinensis* Poulton in its upper half. This interval, described by Poulton (1987), coincides with fauna C6 in Callomon (1984). The *Arctocephalites arcticus* (Whitfield) morphotype does not appear until high in this zone, so the lower, *Arctocephalites spathi* Zone may represent an interval not present in the *Arctocephalites arcticus* Zone elsewhere. *Cadoceras crassum* Madsen and *Cadoceras* cf. *freboldi* Spath, illustrated by Frebold (1961) from specimens found in talus below the well-exposed sequence of early Bathonian to early Callovian beds in northern Yukon, were considered to be particularly rotund *Arctocephalites*(?) species derived from the upper *Arctocephalites porcupinensis* to lower *Arctocephalites amundseni* regional zones (Poulton, 1987), likely globose morphotypes of the more common, possibly highly labile, associated *Arctocephalites* species. The age and affinities of *'Cadoceras crassum'* and *Cadoceras* aff. *barnstoni* identified by Frebold (*in* Jeletzky, 1972) from a stratigraphically uncontrolled locality elsewhere in northern Yukon are unknown (Poulton et al., 1982).

Early Bathonian. As well as containing the higher continuing morphospecies that first appear in the underlying beds such as *Arctocephalites arcticus* Spath, the *Arctocephalites amundseni* regional zone is indicated in northern Yukon (Poulton, 1987) by larger *Arctocephalites* species in its lower part — *Arctocephalites amundseni* Poulton [for *Cadoceras*(?)] aff. *pseudishmae* Spath (Frebold, 1961) — which indicate the widespread Boreal *Arctocephalites greenlandicus* Zone. *Arctocephalites frami* Poulton comprises the probably highest local fauna in these *Arctocephalites greenlandicus* Zone equivalents. Callomon (1984) indicated that the zone in East Greenland is similarly divisible, with three subzones recognized.

Middle Bathonian. *Arcticoceras ishmae* (Keyserling) from northern Yukon and Prince Patrick Island, some identified as *Arcticoceras kochi* Spath by Frebold (1961, 1964a), indicate the widespread Boreal *Arcticoceras ishmae* Zone. Those from northern Yukon were further described by Poulton (1987). *Arcticoceras harlandi* Rawson in northern Yukon indicates the lower Boreal *Arcticoceras harlandi* Subzone. This widely used terminology is retained in this paper, although the species has been considered a junior synonym of *Arcticoceras excentricum* Voronetz (e.g. Gulyaev, 2019). The highest subzone may be indicated by '*Arcticoceras* cf. *crassiplicatum*' reported by Callomon (1984), apparently a *nomen nudum* with no description having been published. Several taxa suggest connection with standard sequences in Europe — *Oxycerites birkelundi* Poulton, *Parareineckeia* sp., *Choffatia*(?) sp. (Poulton, 1987).

Late Bathonian. *Cadoceras barnstoni* (Meek), originally thought to be Cretaceous (Meek, 1859) but recognized to be Jurassic by Frebold (1964b), is closely similar to associated *Cadoceras variabile* Spath in the northern Yukon, characterizing the Boreal *Cadoceras variabile* Zone of East Greenland (Callomon, 1984; Poulton, 1987). Other taxa from this horizon in northern Yukon that may aid extrabasinal correlation include *Paracadoceras* sp., *Kepplerites* spp. including *Kepplerites* aff. *rosenkrantzi* Spath, and possibly *Oecotraustes*(?) sp. (Poulton, 1987). *Iniskinites yukonensis* Frebold and other *Iniskinites* species (including *Loucheuxia bartletti* Poulton) appear to be endemic northern eurycephalitinids. *Cadoceras barnstoni* may indicate the presence of the regional Boreal *Cadoceras variabile* Zone on Ellef Ringnes Island (Frebold, 1964b; Frebold in Stott, 1968), but the varieties of *'Cadoceras barnstoni'* reported to be associated with *Cadoceras bodylevskyi* and *Cadoceras* cf. *falsum* on Axel Heiberg Island (Frebold, 1964b) are likely misidentified early Callovian species.

Cadoceras (*Paracadoceras*) sp., located stratigraphically above *Cadoceras barnstoni* in the Salmon Cache Canyon sequence (Poulton, 1987), was indicated previously to be earliest Callovian (Callomon, 1984, fauna C10), but reconsideration of the age of overlying *Cadoceras*, discussed below, suggests that this species may be latest Bathonian. Some of the early *Cadoceras* species are commonly although inconsistently attributed to *Paracadoceras* as a genus or subgenus of *Cadoceras* (e.g. Callomon, 1984; Mitta, 2016). Uncertainties regarding the stratigraphic level and faunal associations of its small, microconch(?) East Pacific type specimen (*Paracadoceras harveyi* Crickmay; *see* Howarth, 2017, p. 69) may render its widespread usage questionable, but its status is not reconsidered in this paper.

A number of *Cadoceras* species and varieties have been described from Arctic Canada (Frebold, 1961, 1964b; Poulton, 1987), mainly without stratigraphic context, but those in sequences at Salmon Cache Canyon in northern Yukon and in the '*Cadoceras* beds' of western Axel Heiberg Island provide a reliable sequence of two associations in each area. Some of the confusion regarding the stratigraphic positions of various Arctic Canada Callovian cadoceratids may be due to insufficiently appreciated variability within their populations and to overinterpretation of the biostratigraphic significance of individual morphotypes found without stratigraphic context.

Early Callovian. The early Callovian age for the lower *Cadoceras* bed with *Cadoceras bodylevskyi* (Frebold, 1964b) at Vantage Hill is supported most recently by the discovery of this species with other earliest Callovian ammonites in the successions of Germany and the Russian Platform (Mitta et al., 2015; Mitta, 2016). Frebold (*see* Freebold, 1964b, p. 24) had initially compared them with large *Cadoceras* in the *Kepplerites tychonis* Zone in East Greenland, thought by Callomon (1959) to be lower Callovian; and Callomon (Callomon 1984, faunas C11, 12) placed them high in the early Callovian based on close similarities with the ammonite succession in East Greenland (Callomon 1959, 1993) and northwestern Europe. In contrast, Kiselev and Rogov (2007) suggested a latest Bathonian age for the '*bodylevskyi* biohorizon' based on the stratigraphic position of two fragments they identified as *Cadoceras* cf. *bodylevskyi* occurring without associated age-diagnostic ammonites, in European Russia.

The ammonites from northern Yukon identified as C*adoceras bodylevskyi* and dated as earliest Callovian by Poulton (1987; *see also* Callomon, 1984; Von Hillebrandt et al., 1993) have been revised in recent European studies, first to *Paracadoceras poultoni* Gulyaev and earliest Callovian (Gulyaev, 2005), then to *Cadoceras* (*Paracadoceras*) *breve* Blake, of early, but not consistently earliest, Callovian age (Kiselev and Rogov, 2007). The name *Cadoceras bodylevskyi*?/*brevi* used in the northern Yukon column of TimeScale Creator acknowledges these discussions.

The higher *Cadoceras* beds with *Cadoceras septentrionale* Frebold on Axel Heiberg Island were thought by Frebold (1964a, b) to correlate with the international standard *Sigaloceras calloviense* Zone (late early Callovian at that time; now in the lower middle Callovian) in the Greenland zonation of Callomon (1959). Callomon (1984) subsequently thought it to lie immediately below the international standard *Proplanulites koenigi* Subzone and later 'somewhat arbitrarily' within it (Callomon, 1993). *Cadoceras septentrionale* has also been identified on Ellef Ringnes Island in association with *Kepplerites* sp. (Frebold *in* Stott, 1968), but both species are not yet described or illustrated. The collection studied by Frebold (1964b) included morphotypes that he identified as *Cadoceras septentrionale* var. *latidorsata*, indicating variability in the population, but confusing correlations with a locality in northern Yukon based on isolated collections that only include the non-typical morphotype, as discussed below.

Early and middle Callovian(?). Callomon (1984) considered the relative sequence of *Cadoceras septentrionale* and stratigraphically uncontrolled but distinctive *Cadoceras voronetsae* Frebold (perhaps including *Cadoceras arcticum* Frebold) to be conjectural, but in TimeScale Creator, the order he proposed has been used (Fig. 8). Callomon regarded specimens of *Cadoceras* cf. *arcticum* from the Babbage River area of northern Yukon and from northeastern Alaska (Callomon, 1984, fauna D4) to resemble late cadoceratids of the *Sigaloceras calloviense* Standard Zone. The possible late middle Callovian age of similarly poorly controlled *Stenocadoceras canadense* (Frebold, 1964a) follows the comment by Callomon (1984) on the evolutionary grade of its ventral ribbing and may be similarly speculative. Callomon illustrated it (Callomon, 1984, faunas C14, D5, and Fig. 4), without *Cadoceras* associates. However, its associate in the northern Richardson Mountains (Aklavik Range; Frebold, 1964a), *Cadoceras septentrionale* var. *latidorsata*, was reported to occur with *Cadoceras septentrionale sensu stricto* on Axel Heiberg Island (Frebold, 1964a).

Late Callovian. The record of late Callovian (*Peltoceras athleta* Standard Zone) *Longaeviceras* (Poulton, 1997, Table 10.1) is incorrect; no definitive late Callovian fossils have been reported in northern Yukon or adjacent Northwest Territories. However, *Longaeviceras* is well represented elsewhere across the Arctic, including northern Alaska (Callomon, 1984).

Ammonites: Late Jurassic to earliest Cretaceous

Some recent authors subdivide the Volgian Boreal stage into lower, middle (characterized by dorsoplanitid ammonites), and upper substages (e.g. Shurygin et al., 2011), whereas Jeletzky (1984) and Ogg et al. (2016, 'E' and 'Lt' on Fig. 12.4) use only lower and upper subdivisions. The comments below are limited to providing an interpretation of the intention of the original authors as required and in the context of the correlations between the Boreal, Subboreal, and Tethyan columns provided in TimeScale Creator. Whereas some authors have referred to middle (or middle-) Kimmeridgian, it is standard now to subdivide the Kimmeridgian stage into lower and upper.

Early Oxfordian. *Cardioceras* (*Scarburgiceras*) aff. *mirum* Arkell was identified by Frebold (1961, 1964a) from Axel Heiberg Island, noting that *Cardioceras* (*Scarburgiceras*) *mirum* itself occurs in the basal Oxfordian *Cardioceras* (*Scarburgiceras*) *praecordatum* Subzone of the *Quenstedtoceras mariae* Zone. Specifically, unidentified *Cardioceras*, indicating the lower or middle Oxfordian, also occurs in the western Arctic Islands (Tan and Hills, 1978; Poulton, 1994). *Cardioceras* appearances at several localities across the northern Yukon area, although poorly controlled biostratigraphically, suggest a sequence of several species similar to various European species of the early Oxfordian *Quenstedtoceras mariae* and *Cardioceras cordatum* zones. They include *Cardioceras* spp. aff. *Cardioceras* *cordatum* and *Cardioceras alphacordatum* illustrated by Frebold et al. (1967), and listed by Callomon (1984) and Poulton (1997).

Middle Oxfordian. Two specimens from the Babbage River area of northern Yukon, previously figured as early Oxfordian, were re-identified as *Cardioceras* (*Maltoniceras*) sp. of middle Oxfordian [upper *Cardioceras* (*Subvertebriceras*) *densiplicatum* Zone] age (Callomon, 1984).

Late Oxfordian to early Kimmeridgian. *Amoeboceras*, generally poorly preserved and usually not specifically identified, has been collected at various localities across the Canadian Arctic, commonly with the bivalve *Buchia concentrica* (Sowerby) (Frebold, 1961, 1964a; Fricker, 1963; Frebold et al., 1967). Callomon (Callomon, 1984, fauna C18) re-identified a specimen from northern Yukon, reported by Poulton (1978) as *Cardioceras*, as early late Oxfordian *Amoeboceras* (*Prionodoceras*) cf. or aff. *transitorium* Spath. Small fragments of *Amoeboceras* figured in Frebold et al. (1967, Pl. III) were suggested to be perhaps latest Oxfordian [*Amoeboceras* (*Prionodoceras*) *rozenkrantzi* Zone] by Callomon (1984) but were re-identified as *Amoeboceras bayi* (Birkelund and Callomon) and assigned to the *Amoeboceras bayi* Boreal Subzone of the early Kimmeridgian by Rogov (2019).

Early Kimmeridgian. Frebold (1961) noted the similarity of *Amoeboceras* sp. indet, which he illustrated from Mackenzie King Island, to early Kimmeridgian *Amoeboceras* (*Prionodoceras*) *ravni* Spath, and Rogov (2019) recognized *Amoebites* cf. *subkitchini* (Spath) among them. *Rasenia* aff. *orbignyi* (Tornquist), identified from Mackenzie King Island by H. Frebold (*in* Tan and Hills, 1978), was assigned to *Rasenia* cf. *cymodoce* (d'Orbigny) by Rogov (2019), who attributed both to the Boreal middle Kimmeridgian *Amoeboceras* (*Amoebites*) *kitchini* Zone.

Late Kimmeridgian. *Amoeboceras* spp. resembling subgenera *Amoebites* and *Hoplocardioceras* reported by Frebold (*in* Balkwill et al., 1977), were re-identified by M. Rogov from photographs supplied by Poulton as *Hoplocardioceras decipiens* (Spath) and *Euprionoceras sokolovi* (Bodylevsky), which indicate the Boreal *Aulacostephanus eudoxus* Zone.

Middle Tithonian/middle Volgian. Dorsoplanitid ammonites, variously reported as *Dorsoplanites*, *Taimyrosphinctes*, *Pavlovia*(?), *Pavlovia* (?*Paravirgatites*), or *Laugeites*?, come from several localities on Ellesmere and Axel Heiberg islands (Frebold, 1961; Jeletzky, 1966, 1984; Callomon, 1984; Schneider et al., 2018). *Dorsoplanites* ex gr. *panderi* Michalski and the associated ammonite *Pavlovia*? were figured from northern Ellesmere Island by Frebold (1961); the latter was re-interpreted as *Pavlovia* (?*Paravirgatites*) by Callomon (1984) and as *Taimyrosphinctes* by Rogov (2019). Rogov and Zakharov (2009) had compared some of the early reported species with Eurasian *Dorsoplanites gracilis* Spath and *Dorsoplanites flavus* Spath, as well as *Laugeites*. Schneider et al. (2018) reported the co-occurrence of *Dorsoplanites maximus* Spath and *Dorsoplanites sachsi* Michaelov confirming the presence of the Boreal *Dorsoplanites maximus* Zone on northern Ellesmere Island. Galloway et al. (2019) suggested that Jeletzky's report of specifically unidentified dorsoplanitids (Jeletzky, 1984), with large *Buchia fischeriana* (d'Orbigny), provides a middle Volgian age for a recently discovered Arctic regional ^{13}C negative excursion.

Late Volgian. *Craspedites* (*Subcraspedites*) cf. *sowerbyi* Spath and *Craspedites* (*Craspedites*) aff. *subditus* (Trautschold) were described and illustrated from Rollrock Lake, northern Ellesmere Island, by Jeletzky (1984). They were re-assigned by Rogov and Zakharov (2009) to *Subcraspedites sowerbyi* Spath and *Craspedites* cf. *thurrelli* Casey, respectively. A higher fauna in the same section with "*Craspedites* (*Subcraspedites*) n. sp. aff. *praeplicomphalus* Swinnerton and *Craspedites* (*Craspedites*) n. sp. aff. *subditus*", described and illustrated by Jeletzky (1984), was updated to *Subcraspedites* cf. *preplicomphalus* and *Craspedites* cf. *thurrelli* by Rogov (2019). These faunas were interpreted to correspond to the regional *Subcraspedites preplicomphalus* and *Craspedites okensis* zones of eastern England and Siberia, respectively (Jeletzky, 1984; Rogov, 2019).

Latest Volgian–early Berriasian (Cretaceous). *Craspedites* (*Taimyroceras*) *canadensis* Jeletzky (1966) from Slidre Fiord, northern Ellesmere Island, approximates the *Craspedites taimyrensis* Zone of northern Siberia and the *Craspedites nodiger* Zone of Europe (Jeletzky, 1984; Rogov and Zakharov, 2009; Rogov, 2019). The current proposal for the base of the Cretaceous places it within the *Craspedites taimyrensis* Zone (Wimbledon, 2017).

Early Cretaceous. Arctic Canada species variously reported in earlier literature as *Tollia* (*Subcraspedites*?) sp., *Praetollia antiqua* Jeletzky, *Praetollia fedorovi* (Klimova), *Pseudocraspedites anglicus* (Shulgina), and *Subcraspedites* aff. *suprasubditus* (Bogoslovsky) by Jeletzky (1973, 1984) as latest Tithonian are now considered to be Early Cretaceous *Borealites*, including *Borealites* (*Ronkinites*).

Buchia zones, Late Jurassic

***Buchia concentrica* Zone.** The stratigraphic range of the very distinctive and widespread bivalve *Buchia concentrica* (Sowerby) corresponds in general with that of the ammonite *Amoeboceras sensu lato* (i.e. late Oxfordian and early Kimmeridgian), although there are not enough sequential multitaxial faunas in Arctic Canada to constrain the ages further.

***Buchia mosquensis* Zone.** The range of *Buchia mosquensis* (Buch), encompassing approximately the late Kimmeridgian and early Tithonian, is poorly controlled by ammonites in Arctic Canada. Jeletzky (1980) summarized the occurrences of *Buchia mosquensis* in the northern Yukon and adjacent western Northwest Territories. The upper part in Sverdrup Basin (Jeletzky, 1984) contains *Buchia russiensis* (Pavlow) and other morphospecies, indicating its general correspondence with the *Buchia russiensis* Zone of Russia (e.g. Zakharov, 2015). Schneider et al. (2018) identified *Buchia rugosa* (Fischer) from northern Ellesmere Island, assigning it to the early Tithonian, and *Buchia rugosa* has been added to the early Volgian *Buchia* fauna in TSC on the basis of this Canadian occurrence. Zakharov (e.g. Rogov and Zakharov, 2009) had distinguished an early Volgian *Buchia rugosa* regional zone in northern Siberia, within the widespread and longer ranging *Buchia mosquensis* Zone. Regional variations would seem to contradict the usefulness of the more refined morphospecies zones within this interval over wide areas.

***Buchia fischeriana* Zone.** Jeletzky (1984) reported large *Buchia fischeriana* (d'Orbigny) *sensu lato* with dorsoplanitid ammonites in the lower part of the range zone of this bivalve in the Sverdrup Basin. The lower limit that is illustrated for this zone conforms with that of the associated dorsoplanitids; the upper limit permits continuity of the species into the next higher zone, which contains more typical small representatives of *Buchia fischeriana* (Jeletzky, 1984). In Sverdrup Basin, this interval also contains *Buchia piochii* (Gabb), *Buchia russiensis,* and rare *Buchia richardsonensis* Jeletzky (Jeletzky, 1984, Fig. 10). The zone's essentially middle Volgian distribution corresponds approximately with the former 'upper lower Volgian' (e.g. Jeletzky, 1966). Jeletzky (1966) suggested that beds with *Buchia richardsonensis* Jeletzky and *Buchia russiensis* (Pavlow) in the northern Richardson Mountains correspond with the lower *Kachpurites fulgens* Zone of the Russian Platform and that lower beds characterized by 'advanced' forms of *Buchia* aff. *fischeriana* with *Buchia piochii* var. *mniovnikensis* (Pavlow) correspond with the Russian Platform *Epivirgatites nikitini* and *Virgatites virgatus* zones. Later, in Jeletzky (1980), he is less specific, generalizing only intervals with *Buchia* cf. and aff. *Buchia piochii* and *Buchia fischeriana* below and with *Buchia fischeriana* above.

***Buchia terebratuloides–unschensis* zones.** *Buchia terebratuloides* (Lahusen) has a range zone extending from the base of the *Subcraspedites–Craspedites* beds to the top of the Berriasian *Praetollia* (i.e. *Borealites*) *fedorovi* Zone (Jeletzky, 1984), which Jeletzky (1966, 1984) considered to be latest Volgian or Tithonian. Small typical *Buchia fischeriana* occur in the lower part, with the *Subcraspedites–Craspedites* ammonite fauna at its only known locality on northern Ellesmere Island, and *Buchia unschensis* (Pavlow) occurs only in the upper upper Volgian, and with lesser geographic distribution than *Buchia terebratuloides* (Jeletzky, 1966, 1984). This upper interval corresponds to the Russian *Buchia unschensis* Zone (e.g. Rogov and Zakharov, 2009).