

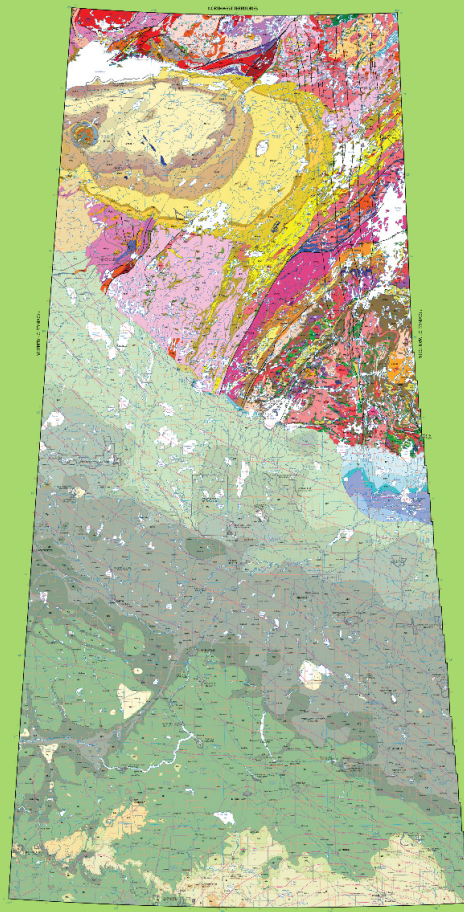
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Miscellaneous Report 2021-2

## **Notes to Accompany the New 2021 Edition of the 1:1 000 000- scale Geological Map of Saskatchewan**

Ralf Maxeiner, Ken Ashton, Sean Bosman,  
Colin Card, Dan Kohlruss, Arden Marsh,  
Ryan Morelli, and William Slimmon

Scientific Editors: Jason Berenyi, Ryan Morelli, and Melinda Yurkowski  
Production Editor: Jessica Leeper





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**Front cover:** An image of the new 2021 edition of the Geological Map of Saskatchewan

## Foreword

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*Due to the global COVID-19 pandemic, for the first time in the 72-year history of the Saskatchewan Geological Survey (SGS), there were no field mapping projects undertaken in northern Saskatchewan in 2020. This, together with availability of key non-field personnel, presented a unique opportunity for the SGS to 'dust-off' a number of unfinished legacy projects. Over the course of eight months, a team of geoscientists and GIS analysts across the SGS worked on updating an earlier draft of a new 1:1 million-scale Geological Map of Saskatchewan (1M map) to replace the 1999 version compiled by Bob Macdonald and Bill Slimmon. The new map was published in the spring of 2021. Publication of this report represents the culmination of that work.*

*This report describes the work done to compile the new edition of the 1M map. It highlights some changes to our understanding of the province's geology, which was based on work by the SGS and other organizations over the past 20 years. Publication of the map and this report marks an important milestone in the continuing efforts by the SGS to unravel the geological history of the province. As outlined in the report, the map will provide a solid foundation of understanding Saskatchewan's geology and thereby will help focus future resource development projects in the province. Also, it will be an invaluable source of information for educational organizations and to the general public for years to come.*

*Dr. Gary D. Delaney  
Chief Geologist  
Saskatchewan Geological Survey  
Resource Development  
Ministry of Energy and Resources*

*June 2021*



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## Abstract

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*The new edition of the 1:1 000 000-scale Geological Map of Saskatchewan replaces the existing 1999 version and can be found on the publications page of the Saskatchewan Geological Survey (SGS) website for download. This new edition of the map displays a comprehensive and updated synthesis of the geology of the province, on the basis of work undertaken by the SGS and other organizations over the past 20 years. The map provides industry clients with up-to-date geological context for resource evaluation in the province and is an invaluable source of information for educational organizations and to the general public.*

*Apart from the main geological bedrock map and its accompanying legend, the map also contains smaller inset maps showing the modified lithostructural domains of the Canadian Shield and the projected magnetic domains beneath the sedimentary rocks of the Athabasca Supergroup and Phanerozoic cover. The Precambrian geology was updated considerably compared to the predecessor map, particularly in the Rae Province north of Lake Athabasca, in the boundary zone between the southern and central Hearne provinces, and in the Reindeer Zone. Depiction of the Athabasca Supergroup underwent significant changes to both mapped contacts and stratigraphic nomenclature. Also, the map has seen numerous revisions relating to the distribution of Phanerozoic units, including delineation of Late Cretaceous formations across the entire province and changes affecting the footprint of the Colorado Group, particularly between Prince Albert and Lac La Ronge.*

*The inset maps also display the locations of astroblemes, a simplified fault network, and a number of important Phanerozoic features, such as the location of the dissolution edge of the Prairie Evaporite Formation, the Shaunavon shelf and the Swift Current platform. In addition to the bedrock geology, the main map displays the elevation contours (relative to mean sea level) of Precambrian basement beneath Phanerozoic strata. Furthermore, a more detailed and differentiated set of faults are displayed, distinguishing between multiply reactivated major shear zones, early thrust faults, late faults, and fault systems.*

**Keywords:** *Archean, Paleoproterozoic, Mesoproterozoic, Phanerozoic, Reindeer Zone, Trans-Hudson Orogen, Western Canada Sedimentary Basin, Athabasca Basin, Rae Province, Hearne Province, Sask craton, Saskatchewan, Geological Map*



# Notes to Accompany the New 2021 Edition of the 1:1 000 000-scale Geological Map of Saskatchewan

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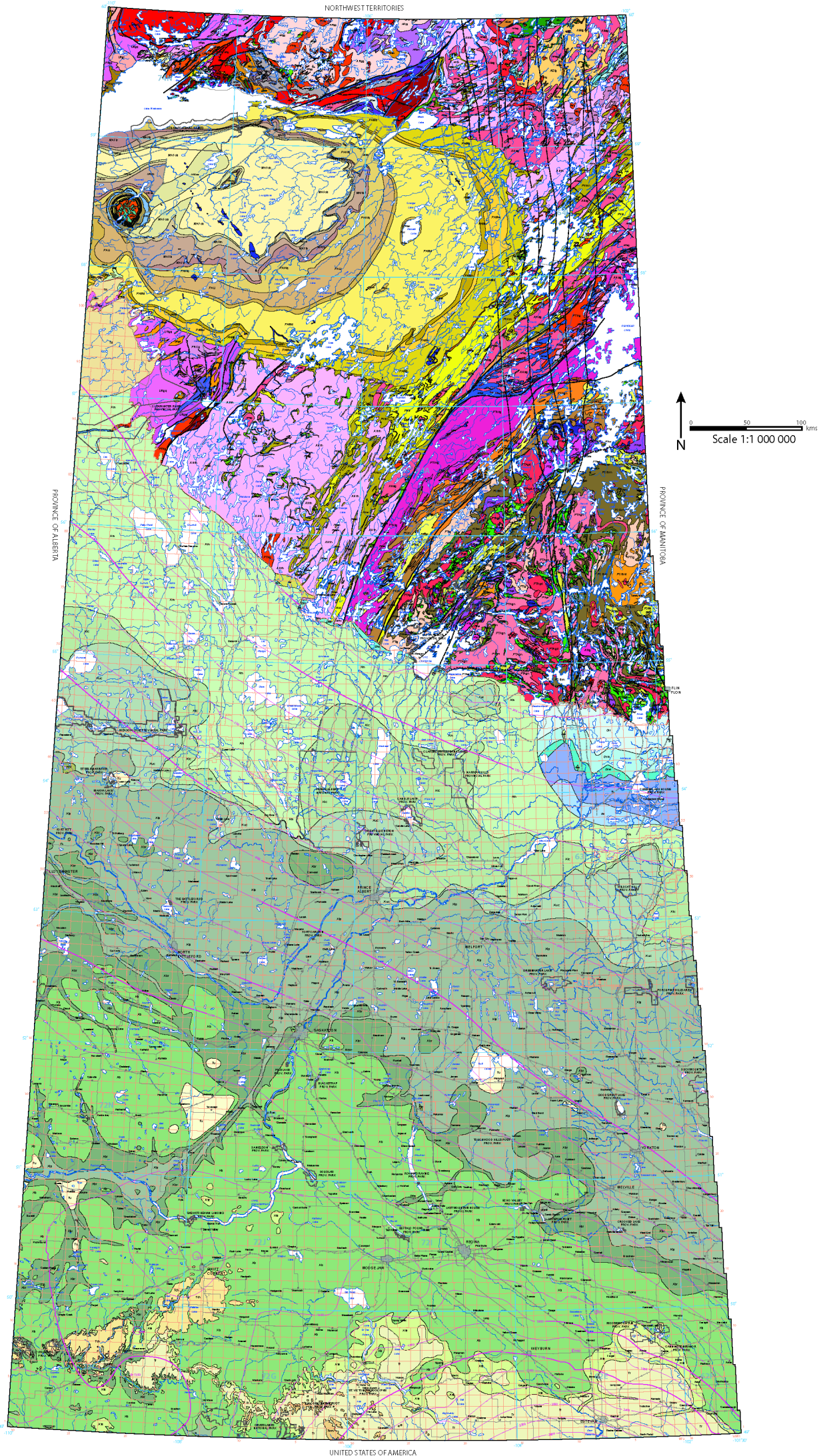
This paper is accompanied by the map separate entitled:

Maxeiner, R., Ashton, K.E., Bosman, S., Card, C., Kohlruss, D., Love, M., Love, T., Marsh, A., Morelli, R. and Slimmon, W.L. (2021): Geological Map of Saskatchewan; Saskatchewan Geological Survey, Saskatchewan Ministry of Energy and Resources, scale 1:1 000 000.

## Introduction

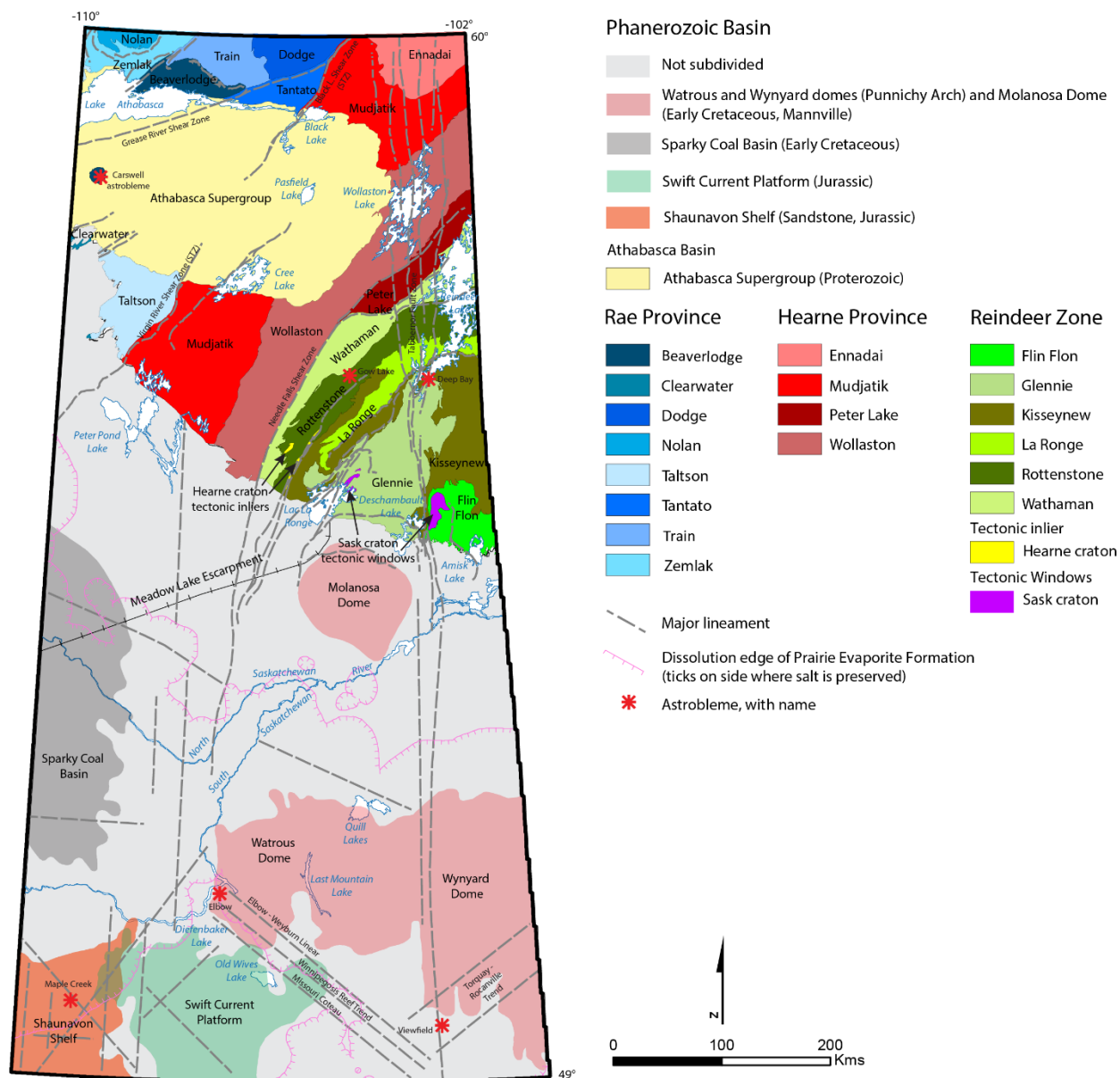
A new edition of the 1:1 000 000-scale geological map (1M map) of Saskatchewan (Figure 1) was recently released (Maxeiner *et al.*, 2021), replacing the 1999 version (Macdonald and Slimmon, 1999). This report is not a summary of the province's geology, which can be found elsewhere (SGS, 2003), rather it provides some explanatory notes regarding the map's creation and implemented changes.

One of the insets on the map (Figure 2) shows the main geological components of the province. In the northwestern Canadian Shield, the Rae and Hearne provinces are essentially Archean-cored cratonic blocks that are unconformably overlain by Paleo- to Mesoproterozoic rocks contained in the Athabasca Basin. The southeastern part of the Shield is dominated by Proterozoic rocks of the Reindeer Zone. The Phanerozoic rocks underlying the southern and western portion of the province were dominated by Cretaceous strata—although Cambrian to Devonian rocks occur in the Cumberland Lake, Lac La Ronge, and Clearwater River areas along the edge of the Canadian Shield. In the southwestern part of the province, outcrops of Cretaceous rocks are prominent in the Frenchman Valley and Grasslands National Park, as well as sporadically along many of the glacial melt water channels and lakeshores throughout southern Saskatchewan. Paleogene to Neogene strata are mainly along the southern border with the United States. Although they are not shown on the map, unconsolidated Quaternary sediments form a thin discontinuous veneer throughout much of the province (Simpson *et al.*, 1997), obscuring many of the rocks of the Shield and Phanerozoic Basin.



**Figure 1** – An image of the revised 2021 1M map of Saskatchewan but without the legend and other marginalia. The Township and Range designations were displayed for the Phanerozoic portions of the map, and the National Topographic System grid was displayed for the Precambrian Shield part of the map. See Figures 3, 4, and 5 for legends explaining abbreviations on the map.

## Lithostructural Domains of the Canadian Shield and Phanerozoic Structural Elements



**Figure 2** – An inset map to the new 1M map of Saskatchewan showing the lithostructural domains of the Canadian Shield and Phanerozoic structural elements. Abbreviation on map: STZ = Snowbird tectonic zone.

Relative to the 1999 map, there was considerable change due to new mapping (e.g. surface, core, and geophysical well log investigations) by staff of the SGS. The Rae craton north of Lake Athabasca (Ashton *et al.*, 2017) and the northeastern-most corner of the province, in the Hearne craton (Harper and Slimmon, 2005), have both undergone considerable revisions. Also, the Reindeer Zone was substantially updated due to extensive 1:20 000-scale revisional bedrock mapping and subsequent compilations of this work (e.g. Corrigan, 2000; Maxeiner and Ashton, 2012; Delaney, 2016; MacLachlan, 2020). In the Athabasca Basin region, significant changes to mapped contacts and stratigraphic nomenclature resulted from large, basin-wide projects such as the Exploration and Technology Initiative (EXTECH) IV (Jefferson and Delaney, 2007) and the Athabasca Ore Systems Project (Bosman and Ramaekers, 2015). Geophysical advances and compilation of outcrop location information better represent exposures of Mesoproterozoic mafic intrusions crosscutting the Athabasca Supergroup. Lastly, the extents of the Phanerozoic formations were refined in many instances, and the elevation of Precambrian basement contours has changed considerably compared to the 1999 edition (Christopher, 2003; Marsh and Love, 2014).

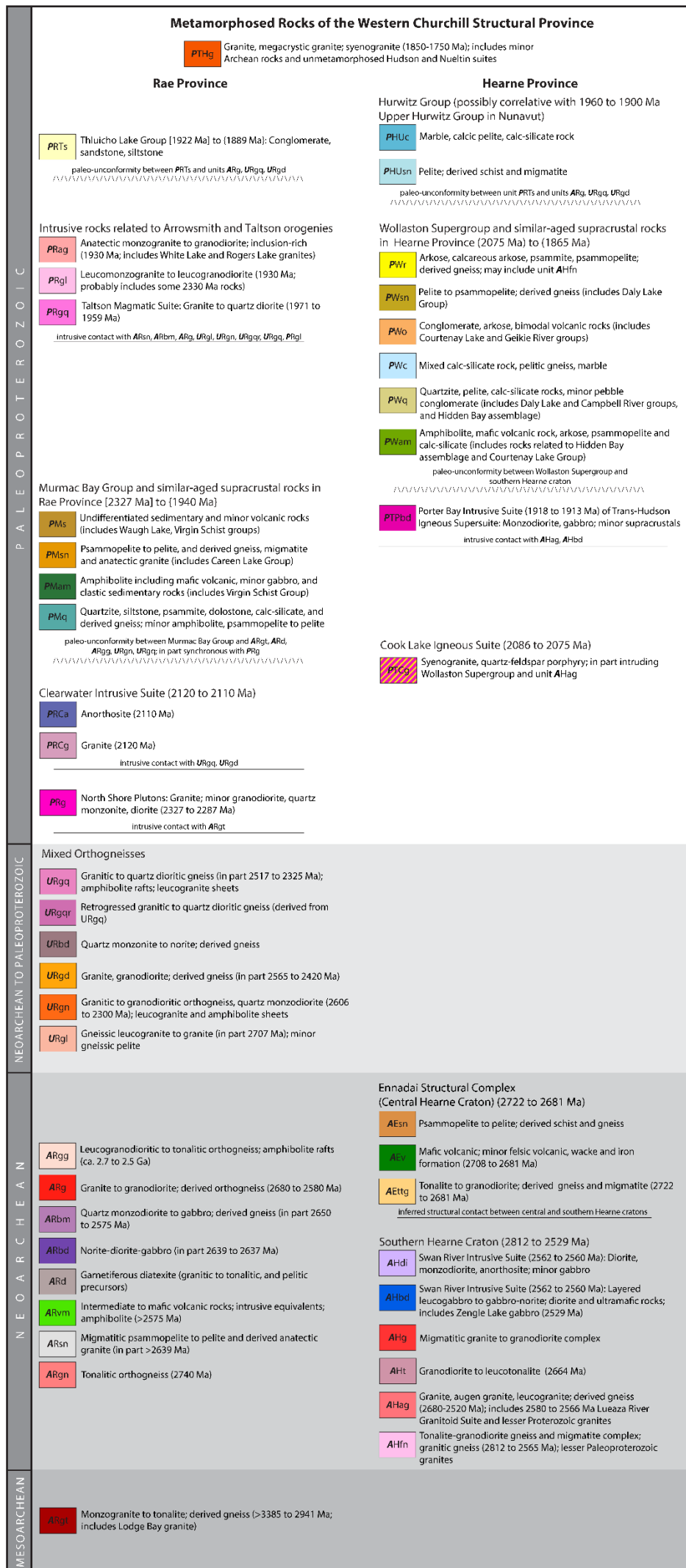
## Methods

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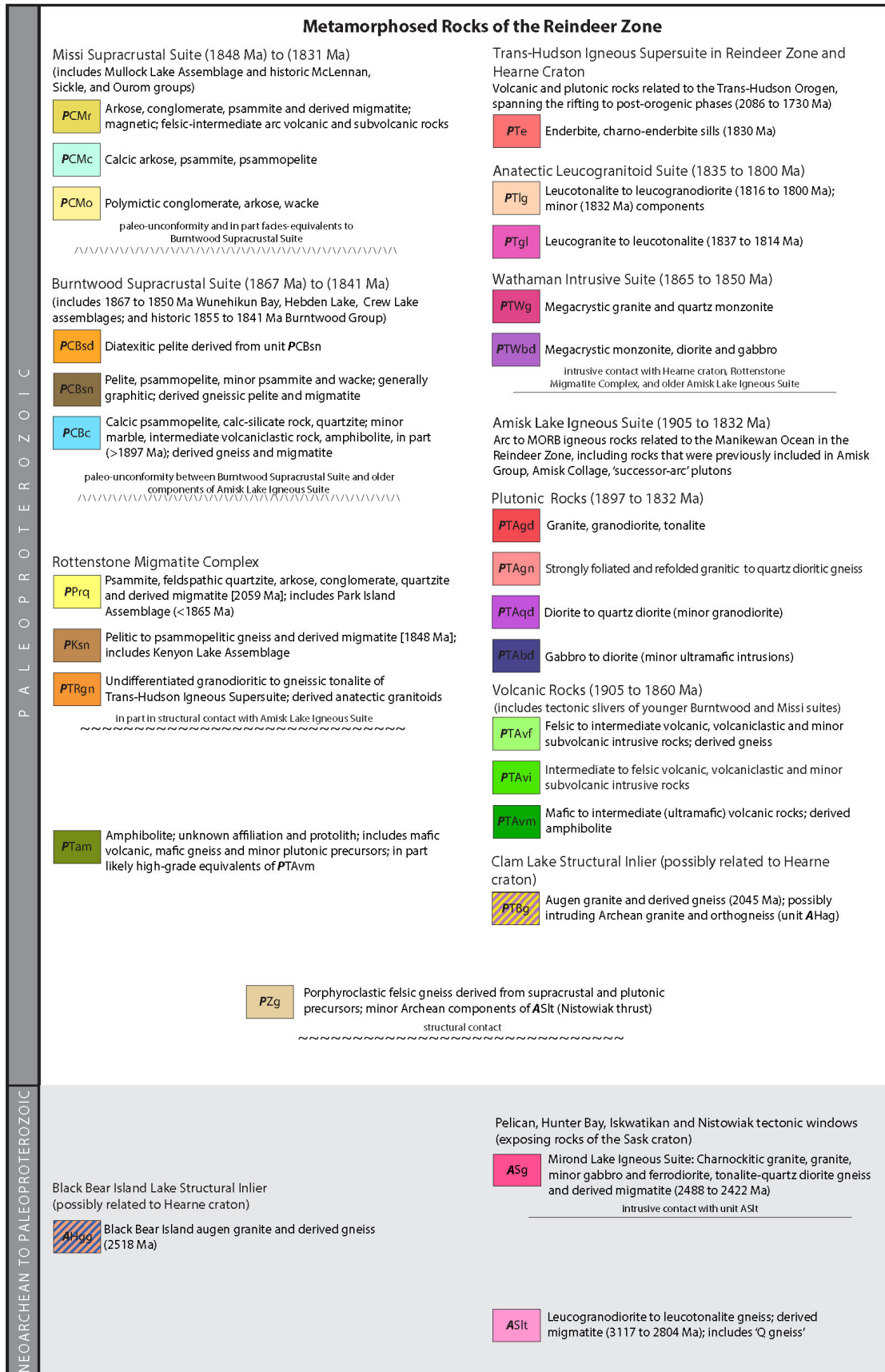
The northern portion of the 1M map, depicting the metamorphosed Precambrian rocks of the Canadian Shield (Figure 1), primarily comes from the provincial 1:250 000-scale bedrock compilation series of maps, some of which were recently updated (e.g. Ashton, 2009; Harper and Slimmon, 2005). Where more detailed mapping was completed but not incorporated into an updated 1:250 000-scale geological compilation, more detailed source mapping information was used, like the 1:20 000-scale Summary of Investigation maps and reports. Where available, compilations of 1:50 000- and 1:100 000-scales (e.g. Ashton and Card, 2005; Ashton and Hartlaub, 2008; Maxeiner and Ashton, 2012) were utilized to relocate or define boundaries of the 1M geological map units. For the Phanerozoic strata, the map's linework was generated using data derived from reports (Christopher, 2003) and regional mapping projects (Marsh and Love, 2014).

The revisions were carried out by SGS staff members (e.g. the co-authors of the map and this report) who conducted the work necessitating the changes and/or are the most familiar and knowledgeable about the rocks of a particular area. By geological zone, the areas of responsibility included: 1) the Rae Province north and south of the Athabasca Basin (K. Ashton and C. Card), 2) the Hearne Province northeast, south, and east of the Athabasca Basin (C. Card and R. Maxeiner), 3) the Reindeer Zone (R. Maxeiner, R. Morelli, and K. Ashton), 4) the Athabasca Supergroup (S. Bosman), and 5) the Phanerozoic strata (A. Marsh, D. Kohlruss, and S. Bosman).

Revision of the geological map necessitated revision of the accompanying geological legends (Figures 3, 4, and 5). Consequently, the revision facilitated an attempt to better adhere to the changing ideas surrounding lithostratigraphic and lithodemic nomenclature. Several references were quite useful in this regard, like the revised North American Stratigraphic Code (NACSN, 2005), a guide outlining the application of lithostratigraphic terminology in Precambrian terrains (Easton, 2009), a British Geological Survey document on the lithodemic classification of intrusive rocks (Gillespie *et al.*, 2008), and the Lexicon of Canadian Stratigraphy (Glass, 1997). Regarding the Precambrian lithodemic nomenclature, principles set forth by Easton (2009) and Gillespie *et al.* (2008) provided the basis for the nomenclature adopted in the naming of geological entities. In many cases, existing terminology was modified to fit the new guidelines, but some terms were so firmly entrenched in the geological literature that they were left unchanged. Several publications documenting the origin and/or use of historic geological terms were extremely useful in this revision of the nomenclature, including Lewry and Sibbald (1977), Macdonald and Broughton (1980), Macdonald (1987), and SGS (2003). Naming of the Precambrian geological rock units follows international standards set out by Streckeisen (1976) and others, as well as some internal guideline papers by Maxeiner *et al.* (1999) and Maxeiner *et al.* (2017).



**Figure 3** – A legend of metamorphosed Precambrian rocks of the western Churchill Structural Province as depicted on the 2021 1M map. Bracket conventions for age constraints on legends: (1920 Ma) - direct age of crystallization of igneous rocks or deposition of sedimentary rocks (e.g. Douglas Formation), and crystallization ages can bracket deposition of supracrustal rocks; [1920 Ma] - youngest detrital zircon, and implies the maximum depositional age for a sedimentary sequence; {1920 Ma} - minimum age based on other evidence (e.g. metamorphism).



**Figure 4** – A legend of metamorphosed Precambrian rocks of the Reindeer Zone as depicted on the 2021 1M map. Bracket conventions as defined in Figure 3.

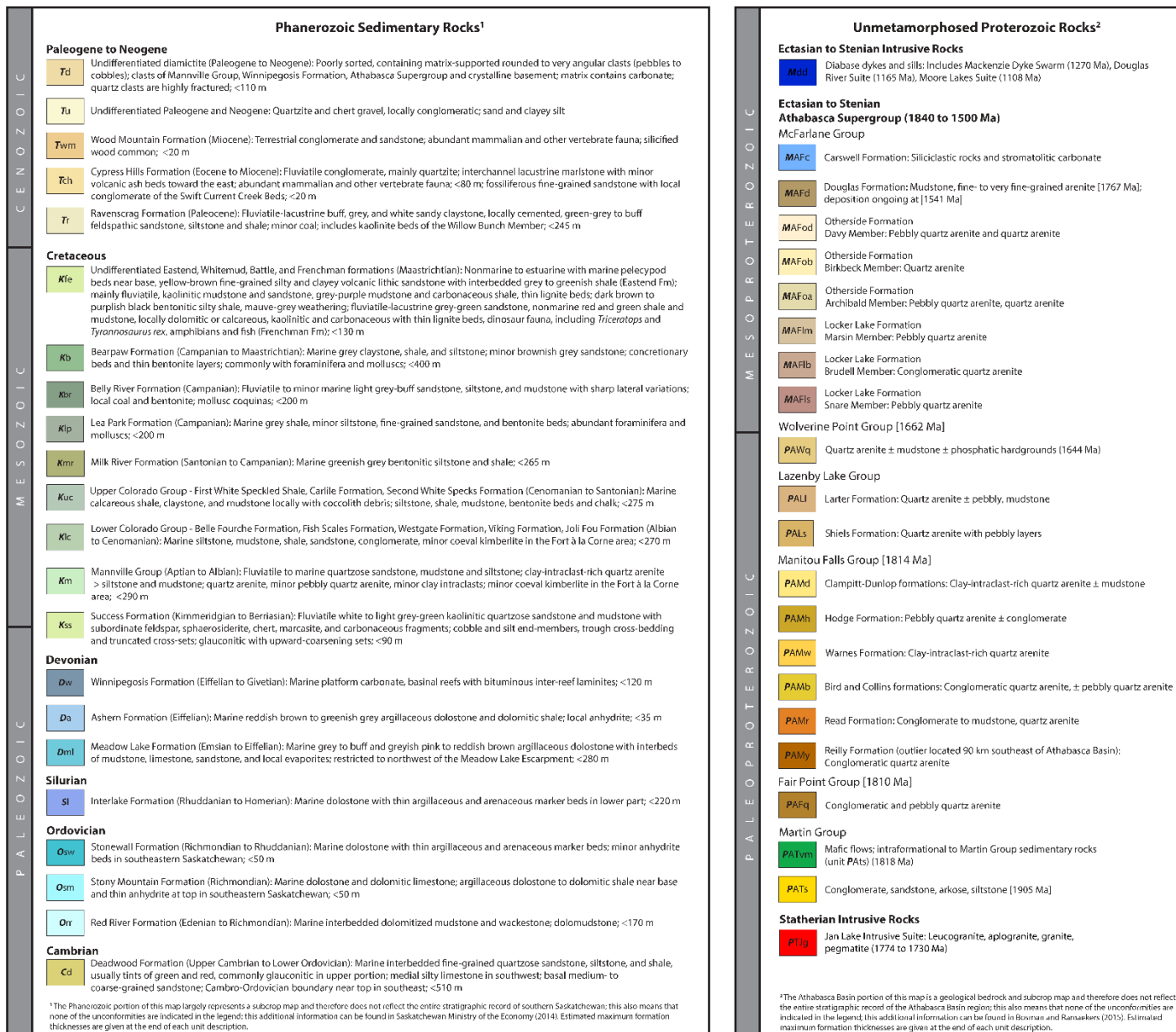


Figure 5 – A legend of Phanerozoic sedimentary rocks and unmetamorphosed Proterozoic rocks as depicted on the 2021 1M map. Bracket conventions as defined in Figure 3.

Some areas of the map include geological details that are not easily resolvable on 1M-scale printouts and would usually be reserved for 1:250 000-scale compilations (e.g. Rae Province north of Lake Athabasca, Carswell structure in the western Athabasca Basin, and Reindeer Zone northwest of Lac La Ronge). This level of detail was intentionally chosen because the map is available in digital forms as a scaleable PDF file and a layer on the Saskatchewan Mining and Petroleum GeoAtlas. Thus, such areas of detailed geology can be digitally enlarged for better resolution.

A number of concessions must be made when creating a map at the provincial scale—an obvious one being the level of detail that can be depicted. Therefore, it should be recognized that this map represents a generalization of the actual geological units. For example, units of mafic volcanic rocks in the Reindeer Zone commonly contain considerable elements of intermediate and felsic volcanic rocks, as well as minor interbedded sedimentary rocks, iron formation, and even thin sheets of plutonic rocks. Most geological units depicted on the map are similarly representative of a broader, compositional spectrum.

The 1999 1M-scale map included mine locations and listed the resource potential of individual Phanerozoic formations, like stating if they were oil- and gas-bearing or if they were mined for silica sand or aggregate. Since this information is available in the newly released 2021 Mineral Resource Map of Saskatchewan (SGS, 2021), it was not duplicated in the new version of the map, thereby streamlining the legend.

The base of the 1:1 000 000-scale topographic map uses CanVec (*i.e.* Canadian Vector) files, which are digital cartographic reference products generated by Natural Resources Canada. The map was projected in UTM NAD83 CSRS98 (*i.e.* Canadian Spatial Reference System, 1998)<sup>1</sup> in Extended Zone 13. The map was processed using ArcMap 10.x software.

Detailed references for this work were not provided, since the list would be too extensive and susceptible to accidental omissions. Interested readers can visit the publications part of the SGS website and search the maps and reports published for a given area between 1999 and 2020 (Government of Saskatchewan, Ministry of Energy and Resources, 2021). This list contains hundreds of publications, many of which were used to create this new map. Searches can also be done spatially through the GeoAtlas portal.

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<sup>1</sup> European Petroleum Survey Group (EPSG) code 2151

## Geological Bedrock Maps and Legends

The 1M map (Figure 1) represents the current state of knowledge and was based on the previous edition compiled by Macdonald and Slimmon (1999). It is a geological bedrock map; thus, the legends of the unmetamorphosed sedimentary basins do not reflect the entire stratigraphic record of Phanerozoic sedimentary rocks, which are in the SGS (2014) or the Athabasca Supergroup (Bosman and Ramaekers, 2015). Per the meaning of ‘bedrock’, only those units that outcrop or subcrop under Quaternary cover are on the map (Neuendorf *et al.*, 2005).

**Table 1 – Rock code suffixes used in the metamorphosed Precambrian rocks legend.**

Lithological Code	Rock Types
am	Amphibolite
an	Anorthosite
bd	Aabbro-diorite
bm	Monzodiorite-gabbro
bq	Diorite-tonalite
c	Calcic psammopelite, calc silicate, or marble
d	Diatexite
di	Diorite-quartz diorite
g	Granite
gd	Granite-granodiorite-tonalite
gg	Gneissic granitoid
gl	Leucogranite
gn	Felsic orthogneiss
gq	Granite to quartz diorite
lg	Leucogranodiorite
m	Monzodiorite
o	Conglomerate
pd	Diatexitic plutonic rocks
q	Quartzite
r	Psammite, quartzite, or arkose
s	Dupracrustal rock
sd	Diatexitic pelite
sn	Pelite
sp	Wacke, greywacke, or psammopelite
t	Tonalite
v	Volcanic rock
vf	Felsic volcanic rock
vi	Intermediate volcanic rock
vm	Mafic volcanic rock
Age Abbreviation	Age
A	Archean
C	Cambrian
D	Devonian
J	Jurassic
K	Cretaceous
M	Mesoproterozoic
O	Ordovician
P	Paleoproterozoic
S	Silurian
T	Paleogene and Neogene
U	Uncertain

Several grids are visible on the map. The Dominion Land Survey system is in light brown extending northwards to the edge of the Canadian Shield. Labels for townships are shown along the sides and ranges along the bottom of the map in five township/range increments.

Additionally, the National Topographic System (NTS) grid is shown for the entire province with NTS labels denoted on the map and lines of latitude and longitude labelled along the map margins.

The lithological codes (e.g. ***PTAbd***) use the following format: the first letter (capitalized, bold, and italicized) denotes the geological era or period, and the second and, sometimes, third letter(s) denote a major geological subdivision (e.g. ‘A’ = Athabasca Supergroup, ‘R’ = Rae craton, ‘T’ = Trans-Hudson Igneous Supersuite, ‘m’ = Mannville Group, *etc.*). For most crystalline Precambrian rocks, the last one to two lower case letter(s) denote rock type (e.g. ‘o’ = conglomeratic rocks, ‘sn’ = pelitic rocks, ‘vm’ = mafic volcanic rocks, *etc.*), but the last letters in the Athabasca Supergroup and Phanerozoic sedimentary rock codes indicate group, formation, member, or rock type (Table 1).

The map legends were organized by region and age. Two legend blocks (Figures 3 and 4) contain metamorphosed Precambrian rocks, one Phanerozoic sedimentary rocks, and one unmetamorphosed Proterozoic rocks (Figure 5).

The oldest rocks (unit ***ARgt***) in Saskatchewan are found in a legend block (Figure 3) dedicated to the rocks of the western Churchill Structural Province (Stockwell, 1961)—a term modified here from the definitions of Lewry *et al.* (1985), Hoffman (1988), and Hanmer (2004). Historically, all of the exposed Shield of Saskatchewan was referred to as the Churchill Structural Province (Stockwell, 1961)—a region characterized by K-Ar ages of ca. 1700 Ma. Aided by the emergence of more accurate age dating methods, Lewry *et al.* (1985) and Hoffman (1988) showed that the western part of the Churchill Structural Province included Archean basement and platformal cover rocks of the Rae and Hearne provinces reworked

during the Paleoproterozoic. Rocks of the predominantly juvenile Reindeer Zone of the Trans-Hudson Orogen were separated as a distinct lithostructural entity.

Use of the terms Rae and Hearne provinces follows the definitions by the SGS (2003), which explains that the term 'province' applies to a present-day geographic area that contains crystalline basement rocks with an Archean core, as well as metamorphosed platformal cover rocks, together recording a common history for a long period of geological time (SGS, 2003). On the other hand, cratons refer to old Archean continents that participated in geological processes in the past, such as orogenic events. The exception to this rule is the Sask craton, which is not part of a geological province but commonly described as part of the Reindeer Zone. This exception owes to entrenched usage of the terms Sask craton and Reindeer Zone in the geological literature.

Similarly, the use of the term lithostructural domain is in accordance with the definitions by the SGS (2003), which follow its original use by Lewry and Sibbald (1977). A lithostructural domain consists of two-dimensional, geographical entities distinguished by rocks with distinct lithological and/or structural characteristics and are designated by geologists (SGS, 2003). The domains shown in Figure 2 differ from terranes, cratons, volcanic arcs, or other such geological entities that were caught up in past geological events. For example, the Flin Flon Domain is made up of a collage of lithotectonic assemblages that formed over some 80 million years in a variety of different plate tectonic settings, including island arc, ocean floor, and intraoceanic sedimentary basins.

### Metamorphosed Precambrian Rocks

This section of the legend subdivides the rocks of the Shield largely based on lithology and age and groups them into a number of distinct geological building blocks. The left column of the western Churchill Structural Province legend block contains rocks of the Rae Province, whereas the right side lists those of the Hearne Province. The subdivisions of the Rae Province include Meso and Neoproterozoic rocks—a large group of mixed orthogneisses of largely unknown or poorly constrained Neoproterozoic to Paleoproterozoic ages—and Paleoproterozoic plutonic and supracrustal suites. The Archean rocks include granitoid suites of  $\geq 3.0$  Ga, 2.74 Ga, and 2.64 to 2.57 Ga age. However, the Paleoproterozoic group is in several distinct, subdivided entities: a unit (**URgq**) containing possible 2.5 to 2.3 Ga granitoids related to the Arrowsmith Orogen in the Taltson Domain, the 2.3 Ga North Shore Plutons representing post-collisional intrusions related to the Arrowsmith Orogen, the 2.1 Ga *Clearwater Intrusive Suite* (a newly defined entity comprising granitic and anorthositic units), the 2.3 to 1.9 Ga Murmac Bay Group including all contemporaneous supracrustal rocks in the Rae Province and the Virgin Schist Group, intrusive rocks related to the 1.97 to 1.93 Ga Taltson orogeny, and finally the 1.92 to 1.89 Ga Thluicho Lake Group.

The Hearne Province side of the western Churchill Structural Province legend block differentiates between Neoproterozoic intrusive rocks of the southern Hearne craton and those of the largely coeval *Ennadai Structural Complex* of the central Hearne craton exposed along the border with the Northwest Territories. The Ennadai Structural Complex is a new term introduced here to distinguish the weakly metamorphosed, mostly juvenile, intrusive and supracrustal rocks of the Ennadai greenstone belt and their high-grade equivalents from the rest of the Hearne craton. Its extent is approximate and partly based on its relatively low gravity and magnetic response. The Paleoproterozoic components of the Hearne Province include two minor but important intrusive units: 1) the newly coined *Cook Lake Igneous Suite* represented by units of feldspar porphyry and foliated syenogranite located in the transition zone between the eastern Wollaston and western Peter Lake domains, respectively—which are thought to record a ca. 2.1 Ga rift event along the southern margin of the Hearne craton, and 2) continental arc rocks of the 1.91 Ga Porter Bay Intrusive Suite restricted in extent to the Peter Lake Domain.

Rocks of the 2.1 to 1.86 Ga Wollaston Supergroup and similar-aged supracrustal rocks were situated throughout the Wollaston and Mudjatik domains. The Campbell River (*i.e.* Peter Lake Domain) was included in this unit, and all of the rocks were subdivided based on rock composition rather than stratigraphic setting. Units of marble (**PHUc**) and pelite (**PHUsn**) exposed in the northeast corner of the province are ascribed to the ca. 1.9 Ga Upper Hurwitz Group.

The Reindeer Zone portion of the map (Figure 1 or 2) and legend (Figure 4) has undergone considerable change because of detailed remapping campaigns throughout the region and a reorganization of unit subdivisions. Neoproterozoic and earliest Paleoproterozoic rocks of the Sask craton were divided into two units and were exposed in

a number of tectonic windows in the Flin Flon and Glennie domains. A new area of Archean rocks was added in the southern Rottenstone Domain—an area where the Black Bear Island structural inlier contains a 2.52 Ga augen granite that is tentatively thought to originally be part of the Hearne craton. The remaining rocks of the Reindeer Zone are Paleoproterozoic in age and related to the 2.1 to 1.7 Ga Trans-Hudson Orogen. Following the guidance of Gillespie *et al.* (2008), the term *Trans-Hudson Igneous Supersuite* (THIS) was employed for all of the igneous rocks related to the orogen, spanning the rifting to post-orogenic phases. Distinct subdivisions of THIS include the 2.0 Ga Clam Lake augen granite (which may be equivalent to the Cook Lake Igneous Suite of the Hearne craton), the 1.91 to 1.83 Ga *Amisk Lake Igneous Suite* (which represents the volumetrically largest component of the Reindeer Zone), the 1.87 to 1.85 Ga Wathaman Intrusive Suite, and a number of syn- to post-orogenic granitoids suites. The Amisk Lake Igneous Suite includes plutonic and volcanic rocks that are directly related to the opening and closing of the Manikewan Ocean and includes rocks that were previously included in the historic 'Amisk Group' or 'Amisk collage' (Lucas *et al.*, 1996). The Suite also includes the arc plutonic rocks that succeeded the formation of the Flin Flon-Glennie Complex commonly referred to as 'successor arc plutons' (Syme *et al.*, 1998).

Metasedimentary rocks of the Reindeer Zone were subdivided into three distinct entities. The 1.87 to 1.84 Ga *Burntwood Supracrustal Suite* (Zwanzig, 1990) includes a variety of supracrustal assemblages and former groups such as the Crew Lake and Hebden Lake assemblages and the Burntwood Group, whereas the 1.85 to 1.83 Ga *Missi Supracrustal Suite* includes the historic McLennan, Sickle, Ourom, and Missi groups, as well as the Mullock Lake assemblage. The *Rottenstone Migmatite Complex* is dominated by highly metamorphosed pelitic (**PKsn**) and psammitic (**PPrq**) rocks that are isotopically more evolved (Maxeiner, 2020) than those of the Burntwood and Missi supracrustal suites. The Complex also includes undifferentiated intrusive rocks related to THIS.

## Unmetamorphosed Proterozoic Rocks

The section of the legend depicting the unmetamorphosed rocks (Figure 5) comprises units of the 1.84 to 1.5 Ga Athabasca Supergroup. It includes rocks of the Martin, Fair Point, Manitou Falls, Lazenby Lake, Wolverine Point, and McFarlane groups, and generally has subdivisions at the Formation level. Rocks of the 1.7 Ga *Jan Lake Intrusive Suite* (**PTJg**), located in the Reindeer Zone and a component of THIS, were not metamorphosed and were included in this legend block. Similarly, mafic intrusive rocks of the 1.27 Ga Mackenzie Dyke Swarm, 1.17 Ga Douglas River Suite, and 1.11 Ga Moore Lakes Suite collectively comprise the youngest unit in the 'Unmetamorphosed Proterozoic Rocks' legend box (Figure 5).

Since publication of the 1999 map, most of the previous unit names and map contacts changed due to the significant amount of work in the Athabasca Basin region. This change is the result of an improved understanding of the Athabasca Supergroup stratigraphy based on drillcore logging from industry drilling. For example, the William River and Points Lake subgroups are no longer used under the Athabasca Supergroup nomenclature; WPa, an informal member of Wolverine Point in Ramaekers (1990), is now part of the Lazenby Lake Group; and the Fair Point Group (historically the Fair Point Formation on the 1999 map by Macdonald and Slimmon, 1999) is no longer thought to be 'partly equivalent' to the Manitou Falls Group (historically the Manitou Falls Formation on the 1999 map by Macdonald and Slimmon, 1999).

Another significant change is the removal of the stratigraphic subdivision 'MFa', which was an informal member of the Manitou Falls Formation (Ramaekers, 1990). 'MFa' was originally mapped (in outcrop and sparsely available drillcore) along the southern margin of the Athabasca Basin (Ramaekers, 1990), straddling the Snowbird tectonic zone and west of the Mirror River, and a small area west of Cree Lake. The type-strata of MFa included interbedded pebbly conglomerate and well-sorted quartz arenite containing locally abundant clay intraclasts. It displayed convoluted bedding, had varied paleocurrent directions, and was up to 600 m thick. This lithological unit was different than the uranium exploration industry's MFa unit in the eastern Athabasca Basin around the McArthur River camp. In the east, MFa was mapped consistently as a basal conglomeratic quartz arenite, generally between 20 to 40 m thick with relatively uniform paleocurrents. During the EXTECH IV study, analysis of new drillcore in the south-central area of the Athabasca Basin helped clarify the stratigraphic relationships in the Virgin River area and correlation of this stratigraphy with the Manitou Falls Formation in the eastern part of the basin (Ramaekers *et al.*, 2007). Therefore, the

term became obsolete because the originally defined MFa by Ramaekers (1990) included more than one unit in the updated stratigraphic framework.

The Read Formation, applied to the lowermost lithostratigraphic unit of the Manitou Falls Group, is an interbedded conglomerate, quartz arenite and mudstone similar to the MFa variant described by industry. Based on ongoing research, however, the Read Formation was mapped across much of the Athabasca Basin region. On the 1999 map in the area northeast of Cree Lake, MFa is now part of the clay-intraclast-rich Warnes Formation of the Manitou Falls Group. The old MFa unit in the area straddling the Snowbird tectonic zone was subdivided into the Read Formation to the Clappitt-Dunlop formations of the Manitou Falls Group. The reader should refer to Ramaekers *et al.* (2007) and Bosman and Ramaekers (2015) for the historic progression of the stratigraphic nomenclature of the Athabasca Supergroup. Readers interested in a complete table of stratigraphic units for the Athabasca Supergroup should see Table 1 of Bosman and Ramaekers (2015).

## Phanerozoic Sedimentary Rocks

Relative to the 1999 map legend, the Phanerozoic section of the legend (Figure 5) was simplified to show only the rock units represented on the map (*i.e.*, bedrock beneath Quaternary cover). Consequently, much of the Devonian to Jurassic parts of the stratigraphic section, present in the subsurface, are not represented on the map or in the legend. Readers interested in the complete stratigraphic section of Saskatchewan should refer to the province's "Stratigraphic Correlation Chart" (SGS, 2014).

The 1M map includes numerous revisions from the previous version relating to the distribution of Phanerozoic units. In particular, the Cretaceous Lea Park, Belly River and Bearpaw formations were delineated across the entire province, and the distribution of the Cretaceous Belly River Formation has changed considerably in the Prince Albert area and north of Regina. Similarly, the footprint of the Colorado Group (Klc and Kuc) has increased between Prince Albert and Montreal Lake. These changes result from datasets produced since the previous 1999 map (Christopher, 2003; Saskatchewan Industry and Resources *et al.*, 2004; Kreis *et al.*, 2004; Marsh and Heinemann, 2006; Whittaker, 2004; Heinemann and Marsh, 2009; Marsh and Love, 2014), primarily from extensive new oil and gas well data.

The Patterson Lake area, southwest of the Athabasca Basin, is another area on the map that underwent considerable change—with the recognition of a Cenozoic diamictite unit that contains clasts of the Mannville Group, Winnipegosis Formation, and Athabasca Supergroup—and formed after bitumen migration into the Mannville Group sandstones (Bosman *et al.*, 2017; 2018). Recent drilling in this region has provided abundant new core, which has led to an improved map. The previous map showed rocks of the Mannville and Meadow Lake formations and, although these are present as small outliers, they commonly are subjacent to this diamictite.

On the map, the depth to Precambrian basement (in metres relative to mean sea level) is a series of contour lines with 150 m spacing. The positions of these lines have undergone significant change since 1999, showing considerably more detail particularly in southeastern and southwestern Saskatchewan. A number of new basement domes were recognized in the Swift Current and Moose Mountain areas, whereas the deepest part of the Phanerozoic basin is located southwest of Estevan (Marsh and Love, 2014).

### Precambrian Lithostructural Domains and Phanerozoic Structural Elements

This component of the map (Figure 2) illustrates the lithostructural domain subdivisions in the Rae and Hearne provinces and Reindeer Zone comprising the exposed rocks of the Canadian Shield. It also shows depositional, erosional, and structural features relating to the Phanerozoic strata. Major, selected structural lineaments are depicted and named, as well as the location of confirmed astroblemes.

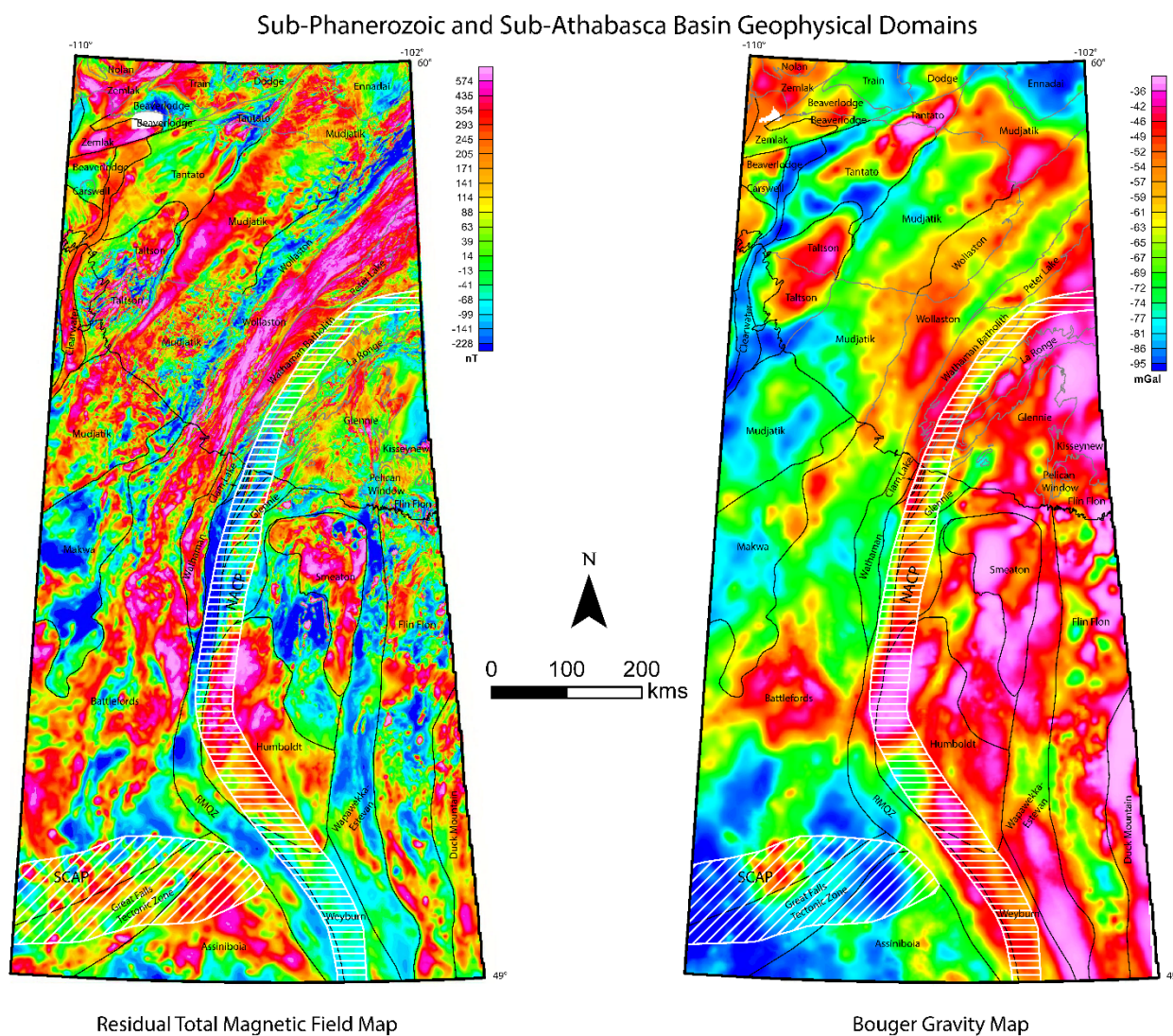
The Rae and Hearne provinces, comprising Archean basement rocks and overlying metamorphosed Paleoproterozoic cover sequences, are separate from each other by the enigmatic Snowbird tectonic zone (STZ). Each of the two provinces have their own distinct geological history, which includes the amalgamation of smaller cratonic blocks, until middle to late Paleoproterozoic time when they collided during the inferred Snowbird orogeny (Berman *et al.*, 2007). The Rae and Hearne cratons are flanked by the Paleoproterozoic Taltson Orogen to the west and Trans-Hudson Orogen to the east. The Sask craton is only exposed in small tectonic windows. Archean rocks dominate it, but it is also structurally overlain by Paleoproterozoic volcano-plutonic arc rocks and derived clastic sedimentary rocks of the Reindeer Zone. These Reindeer Zone rocks formed primarily in an oceanic environment as the Rae-Hearne, Sask, and Superior (exposed in central Canada) cratons converged prior to amalgamating during the Trans-Hudson orogeny.

The configuration and boundaries of these lithostructural domains constituting the Rae and Hearne provinces and Reindeer Zone have changed a number of times since the release of the 1999 edition of the 1M map (Ashton, 1999; Card, 2012; Maxeiner, 2020), particularly in the southern Rae Province, the northern Hearne Province, and the Reindeer Zone (Figure 2). Readers interested in a more detailed overview of the provincial Precambrian geology at the lithostructural domain scale should refer to the “Geology, and Mineral and Petroleum Resources of Saskatchewan” (SGS, 2003) and to papers summarizing recent updates to the domain reclassification (*e.g.* Maxeiner, 2020; Ashton *et al.*, 2017; Card 2012).

In the waning stages and aftermath of the Trans-Hudson orogeny, unmetamorphosed, dominantly siliciclastic sedimentary rocks of the Athabasca Supergroup were deposited unconformably on rocks of the western Churchill Structural Province and were preserved in several stacked basins in the Athabasca Basin region. The major lineaments plotted on Figure 2 include a selection of multiply-reactivated shear zones, thrust faults, and subvertical brittle to semibrittle faults. Depicted on the main geological map are a larger number of and a more differentiated breakdown of faults and structural lineaments in the Canadian Shield (Figure 1). In the southern half of the province, the surface of the Precambrian basement beneath the Phanerozoic strata is irregular and contains numerous structural discontinuities that affected the overlying Phanerozoic cover rocks (Kent and Christopher, 1994; Christopher, 2003). Many of these irregularities in the Precambrian surface may simply result from differential paleoweathering, whereas others were produced by the reactivation of structures rooted in the Precambrian basement that affected the facies distribution of overlying strata through time. Features like the northwest-trending Elbow-Weyburn Trend, Winnipegosis Reef Trend, and Missouri Coteau broadly coincide with inferred tectonic boundaries in the basement (Figure 6). Some, like the Swift Current Platform, were outlined on isopach or structural trend maps, whereas others represent landforms preserved in the present-day topography (*e.g.* the Missouri Coteau).

Other depositional and erosional boundaries in the Phanerozoic strata are not as obviously linked to irregularities in the Precambrian surface or to the reactivation of Precambrian structural discontinuities. These boundaries more likely result from geological processes during Phanerozoic time. The Meadow Lake Escarpment marks the northern erosional edge of Ordovician-Silurian carbonates, north of where the Middle Devonian strata infill the erosional low above Cambrian sandstones (Haidl, 1989). Comprising the Watrous and Wynyard domes, the Punnichy Arch is a basement-controlled antiformal complex that extends along the northern solution edge of the Middle Devonian Prairie Evaporite salt beds and represents the northern rim of the Williston Basin. The Winnipegosis Reef Trend—marking the southwestern edge of the Prairie Evaporite—and the Elbow-Weyburn Linear—delineating the eastern margin of the Swift Current Platform—both parallel the surface expression of the Missouri Coteau. The Swift Current Platform, a dome-like feature reactivated through time, is a region of thinning Devonian strata and has undergone numerous

vertical fluctuations throughout the Phanerozoic, acting as a depositional basin during the Middle Jurassic time. The Shaunavon Shelf demarcates the western flank of the Swift Current Platform and terminates the Middle Jurassic Shaunavon Formation sandstone. The Molanosa Dome is another basement-controlled feature that remained tectonically active through much of the Phanerozoic—acting as a paleo-upland during deposition of Cretaceous strata. The Sparky coal basin represents an area where peat growth was equilibrated with sea-level rise for an extended period during the Early Cretaceous, which led to the development of broad depositional flats and the subsequent formation of paralic coal seams. The northeast-trending, basement-controlled Torquay-Rocanville Trend in southeast Saskatchewan coincides with down-warped stratigraphy and a series of salt sinks. It also parallels, and is possibly coincident with, the northern projection of the Weldon-Brockton-Froid-Fromberg fault zone from the United States portion of the Williston Basin (Christopher, 1961; Gerhard *et al.*, 1987).



**Figure 6** – Sub-Phanerozoic and Sub-Athabasca Basin geophysical domains (after Kreis *et al.*, 2004). Abbreviations on map: nT = nanotesla, mGal = milligals, SCAP = Swift Current Anorogenic Province (white diagonal hatch), NACP = North American Central Plains (white horizontal hatch), RMQZ = Reindeer magnetic quiet zone. (Base maps modified from Miles and Oneschuk, 2016, and Jobin *et al.*, 2017).

## Geophysical Maps

In addition to the “Precambrian Lithostructural Domain and Phanerozoic Structural Element” inset (Figure 2), the 1M map includes an inset map showing the domainal classification of the Shield extrapolated beneath the Athabasca Basin and Phanerozoic strata (Figure 6). This inset map represents a modified subdivision of the sub-Phanerozoic

Precambrian rocks based on the extrapolation of major tectonic features from the Shield on provincial total field aeromagnetic and Bouguer gravity maps and on seismic data (Kreis *et al.*, 2004). In this modified version, a number of the boundaries were slightly changed. Some previously nameless domains were provided names (e.g. Duck Mountain and Clam Lake), and geophysical domains were added beneath the Athabasca Basin where none were previously designated.

To summarize, some of the main features of this inset map are as follows: the Taltson, Zemplak, Beaverlodge, and Tantato domains of the Rae Province were extrapolated under the Athabasca Basin where some are truncated and/or offset by the northeast-trending Grease River Shear Zone. The Taltson Domain extrapolated northward under the Athabasca Basin and also extended under the Phanerozoic cover. The Clearwater Domain (exposed in the Clearwater River valley but best defined under the Phanerozoic cover) also extends northward under the Athabasca Basin. A boundary between the Taltson and Tantato domains was defined based on their distinct magnetic and gravity signatures.

In the Hearne Province, the Mudjatik Domain was extrapolated southwestward to the Alberta border, whereas the extrapolated Wollaston Domain was subdivided into the Makwa and Battlefords domains based on magnetic intensity. The Assiniboia Domain was identified as an entity distinct from the Battlefords Domain based on the disruption of magnetic signatures that may mark the Great Falls Tectonic Zone or a related tectonic front marking the boundary between the Hearne and Wyoming cratons. A number of ca. 1.76 Ga post-tectonic, anorogenic high-level granitic and extrusive rocks comprising the Swift Current Anorogenic Province (SCAP in Collerson *et al.*, 1989; white diagonal hatch) overlap the Great Falls Tectonic Zone and are likely responsible for the round to oval shaped areas of elevated magnetic signatures that disrupt the northwesterly-trending aeromagnetic pattern in this area. In the western Churchill Structural Province, rocks of the Ennadai and Clearwater domains, as well as the southwestern-most part of the province, are characterized by very low Bouguer gravity signatures.

The Diefenbaker Domain corresponds to the Reindeer magnetic quiet zone (RMQZ in Burwash *et al.*, 1993) and represents the southern extension of the Rottenstone Domain. It overlaps with the broadly correlative North American Central Plains conductivity anomaly (NACP in Reitzel *et al.*, 1970; white horizontal hatch) and occurs along the boundary between the Hearne and Sask cratons. Isotopically evolved granitic gneisses and a 2045 Ma granite, together making up the newly minted Clam Lake Domain (Maxeiner, 2020), likely represent an inlier of the Hearne craton in the Reindeer Zone. The Sask craton has been subdivided by magnetic characteristics into the Tobin, Smeaton, Humboldt, and Weyburn domains. Structurally overlying rocks of the Wapawekka-Estevan Domain flank the Sask craton and probably represent a tectonized boundary zone between the craton and juvenile rocks of the exposed Glennie and Flin Flon domains to the north and east, respectively. The Tabernor Fault Zone is thought to extend southward through the eastern component of the Wapawekka-Estevan Domain. The Flin Flon Domain was extrapolated southward to the American border and bounded to the east by the Duck Mountain Domain, which represents a transition zone between juvenile rocks of the Reindeer Zone and the predominantly Archean rocks of the Superior craton farther east. It may be correlative with the Churchill-Superior Boundary Zone in Manitoba (Weber, 1990). High Bouguer gravity signatures characterize the majority of the Reindeer Zone rocks.

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