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Precambrian Basement of the Western Canada Sedimentary Basin in Northern Alberta

Alberta Energy and Utilities Board
Alberta Geological Survey

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Acknowledgments

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Abstract

The crystalline basement of northern Alberta is part of western Laurentia and is mostly covered by Phanerozoic strata of the Western Canada Sedimentary Basin (WCSB). The Early Proterozoic Athabasca Group covers a limited portion of the basement south of Lake Athabasca; north of Lake Athabasca, the crystalline basement is exposed in the northeastern corner of the province. Existing geological information on the sub-WCSB crystalline basement of northern Alberta has been variously assembled to support several, partly conflicting, Proterozoic terrane-accretion models. These tectonic models and the currently available geological and geophysical information are briefly reviewed herein.

Basement subdivisions of northern Alberta that have been inferred from potential field data, particularly aeromagnetic data, include, from east to west, the Taltson, Buffalo Head, Chinchaga, Ksituan and Nova domains. The Great Slave Lake Shear Zone and the Snowbird Tectonic Zone roughly bound these domains to the northwest and southwest, respectively. The aeromagnetic domains are routinely interpreted as basement terranes and Early Proterozoic subduction-related magmatic arcs, although the petrological, geochemical and geochronological constraints are rather loose.

The Bouguer gravity anomaly, long-wavelength gravity data and deep seismic data do not contribute substantially to the accreted-terrane model for northern Alberta. Except for the Great Slave Lake Shear Zone, geophysical and geological data obtained from drillcore cannot be corroborated to convincingly support cryptic sutures between the distinct terranes that have been previously postulated in northern Alberta. The Early Proterozoic terrane-accretion model for the northern Alberta basement requires further investigation and testing.

Phanerozoic reactivation of the sub-WCSB basement, documented in the Peace River Arch area and along the Great Slave Lake Shear Zone, may also characterize other shear zones that extend beneath the Phanerozoic cover. Basement reactivation is of critical importance for understanding the role of basement structure in controlling sedimentation and diagenetic patterns in the WCSB basin, as well as in the development of hydrocarbon traps and reservoirs, and of pathways for mineralizing fluids in the Phanerozoic stratigraphy.

1 Introduction

This report is a first stage in the effort by the Alberta Geological Survey (AGS) to compile, update and integrate all existing information on the Alberta basement into a comprehensive database. The database will be delivered to the public in a digital format that can be queried using an ArcView® interface. The database will include existing petrological, geochemical and geochronological data collected from disparate published and unpublished sources. In addition, a large set of petrographic and geochemical data on Precambrian basement core samples, accumulated over the last several decades at the University of Alberta, is being compiled and updated in cooperation with R.A. Burwash at the University of Alberta in Edmonton.

The complex lithotectonic assemblages that form the western margin of the exposed Canadian Shield extend westward beneath the Western Canada Sedimentary Basin (WCSB) and can be recognized farther west in the metamorphic core complexes and tectonic slices of the Cordillera, which indicates a greater areal extent prior to Mesozoic and Cenozoic tectonism. The tectonic history of the exposed Canadian Shield adjacent to the edge of the Phanerozoic strata provides a context for the interpretation and inferred continuation of Shield elements into the Alberta subsurface. An appreciation of the tectonic fabric and evolution of the Shield and its continuation beneath the WCSB is relevant to the development of the Phanerozoic sedimentary sequence, more specifically the degree to which basement structures may have controlled anomalous sedimentation, diagenetic and structural patterns in the WCSB.

The study of core from deeply buried rocks, and maps from aeromagnetic, gravity, electrical conductivity and seismic surveys, have been used to define supposedly distinct entities and their boundaries beneath the WCSB in northern Alberta (e.g., Hoffman, 1988; Ross et al., 1994).

A brief summary of the current tectonic models for the western Canadian Shield, including northern Alberta, is presented in chapter 3, 'Tectonic Setting'. A brief overview of inferred structures from potential field data within the basement of the WCSB in northern Alberta is included in chapter 4, 'Geophysical Data'(*after* Ross, 1990; Ross et al., 1989, 1991, 1994; Ross and Stephenson, 1989). For detailed discussions of inferred structures and domain boundaries from seismic refraction-reflection studies and electromagnetic-magnetotelluric studies, see the summary papers by Ross and Stephenson (1989), Sweeney et al. (1991) and Jones and Craven (1990). An inventory of existing petrological, geochemical and geochronological results from basement core studies in northern Alberta is presented in chapter 5, 'Drillcore Data', which is taken from Ross et al. (1989), Thériault and Ross (1991), Villeneuve et al. (1993) and Burwash et al. (1994, 2000).

2 Previous Work

The Leduc oil discovery of 1947 led to intensive hydrocarbon exploration in the WCSB. Since then, about 4000 wells have penetrated the entire WCSB stratigraphy and intersected the underlying Precambrian basement. However, only about 10% of these wells have been cored (Burwash et al., 1994). Petrography, whole-rock geochemistry and isotopic age determinations have been carried out on many of these cores. A major constraint on work with the cores is the uneven distribution of sample localities. The Precambrian basement is poorly known beneath deeper and several shallower parts of the basin. Less than ten wells penetrate the Alberta basement below the –3000 m structural contour and only two below the -3500 m contour. The uneven distribution of basement core means that the basement of the WCSB foredeep and a large area north of Birch Mountains are virtually unknown, with the basement south of latitude 55°N being sparsely cored. At the end of 2000, a database search indicated that, out of a total of 58 405 wells drilled north of the latitude 55°N, 568 intersected the basement, whereas only 44 out of a total of 226 702 wells drilled south of this latitude intersected the basement. In northern Alberta, a high proportion of data was obtained from wells in the area of the Peace River Arch (as discussed in Section 5).

Information on Precambrian core samples from the WCSB was first published by Burwash (1957) and integrated into the 'Basement Map of North America' (Flawn, 1967). In following years, detailed petrography and whole-rock geochemistry on core samples helped define the 'Athabasca mobile zone', a belt of dynamic metamorphism and potassium metasomatism that extends across northern Alberta (Burwash and Krupička, 1969, 1970; Burwash and Culbert, 1976).

Point-specific geological information extracted from core was gradually complemented by geophysical data, which permitted indirect identification of discrete metamorphic-structural domains of the crust and to a lesser extent of the upper mantle. The uppermost 15 km of the upper crust are well depicted by potential field data (aeromagnetic and gravity anomaly maps), enabling researchers to trace into the subsurface the variations in crustal structure that are apparent in the exposed Shield. A study of the buried Shield beneath the Athabasca Group in northeastern Alberta extended geological interpretation of airborne geophysics to the easternmost part of the sub-WCSB (Wilson, 1986). Based on the published geological and geophysical maps, the subsurface Precambrian of the WCSB was divided into five major structural units by Burwash et al. (1994, 2000). Smaller basement domains were subsequently defined, based on the magnetic signatures of the basement in Alberta, together with U-Pb zircon geochronology on zircons separated from cuttings from Alberta wells (e.g., Ross et al., 1989; Ross, 1990).

The 'long-wavelength' structure of the crust and mantle (filtered subsets of potential field data), and deep seismic refraction and reflection studies, have led to interpretation of the possible causative mechanisms associated with basin formation and subsidence patterns (Stephenson et al., 1989; Ross and Eaton, 1999). The ten-year (1991–2001) LITHOPROBE program examined the deep crustal structure of Alberta and provided new constraints on the role of basement structure in the evolution of the WCSB.

Radioactive heat generation in the basement rocks was studied and represented on maps at the scale of Alberta or the entire WCSB by Burwash and Burwash (1989) and Bachu and Burwash (1994).

3 Tectonic Setting

3.1 Regional Tectonic Setting

Continental-scale synthesis of field relations, U-Pb geochronology and airborne geophysical data in the late 1980s resulted in a coherent tectonic framework for the Precambrian evolution of Laurentia and the Canadian Shield, which included the sub-WCSB basement (Hoffman, 1987, 1988, 1989). This work recognizes the importance of accretionary and collisional processes, operative during the interval 2.0 to 1.8 Ga, in the assembly of the Canadian Shield. Inferred distinct domains include deformed and metamorphosed passive-margin and foreland-basin sedimentary sequences, accreted terranes of island-arc affinity and continental-margin magmatic arcs of calc-alkaline affinity. The latter elements provide distinct aeromagnetic signatures that allow each of these orogens to be traced beneath the Phanerozoic sedimentary cover. Early Proterozoic orogenic belts in western Canada (Figure 1) include the Wopmay Orogen (1.97–1.84 Ga), Taltson–Thelon Orogen (2.0–1.9 Ga) and Trans-Hudson Orogen (1.88–1.79 Ga).

The following Proterozoic plate tectonics scenario is extracted from Hoffman's (1988) chapter 'Collisions in the North'. The Slave Province is a Late Archean (2.7–2.5 Ga) granite-greenstone terrane that served as a foreland for the Thelon Orogen (2.02–1.91 Ga) to the east and the Wopmay Orogen (1.95–1.84 Ga) to the west. The Thelon Orogen resulted from a dextral-oblique collision between the Slave and Rae provinces, followed by indentation of the Rae hinterland by the Slave foreland (Gibb, 1978; Hoffman, 1987). Indentation was accommodated by dextral-oblique crustal shortening across the Queen Maud Uplift, a reactivated Archean granulite-grade domain in the hinterland, and by 600 to 700 km of dextral slip on the Great Slave Lake Shear Zone, which is an intracontinental transform structure exposed as a zone of continuous mylonite 25 km wide (Hanmer, 1988; Hoffman, 1987). Crustal wedges were extruded

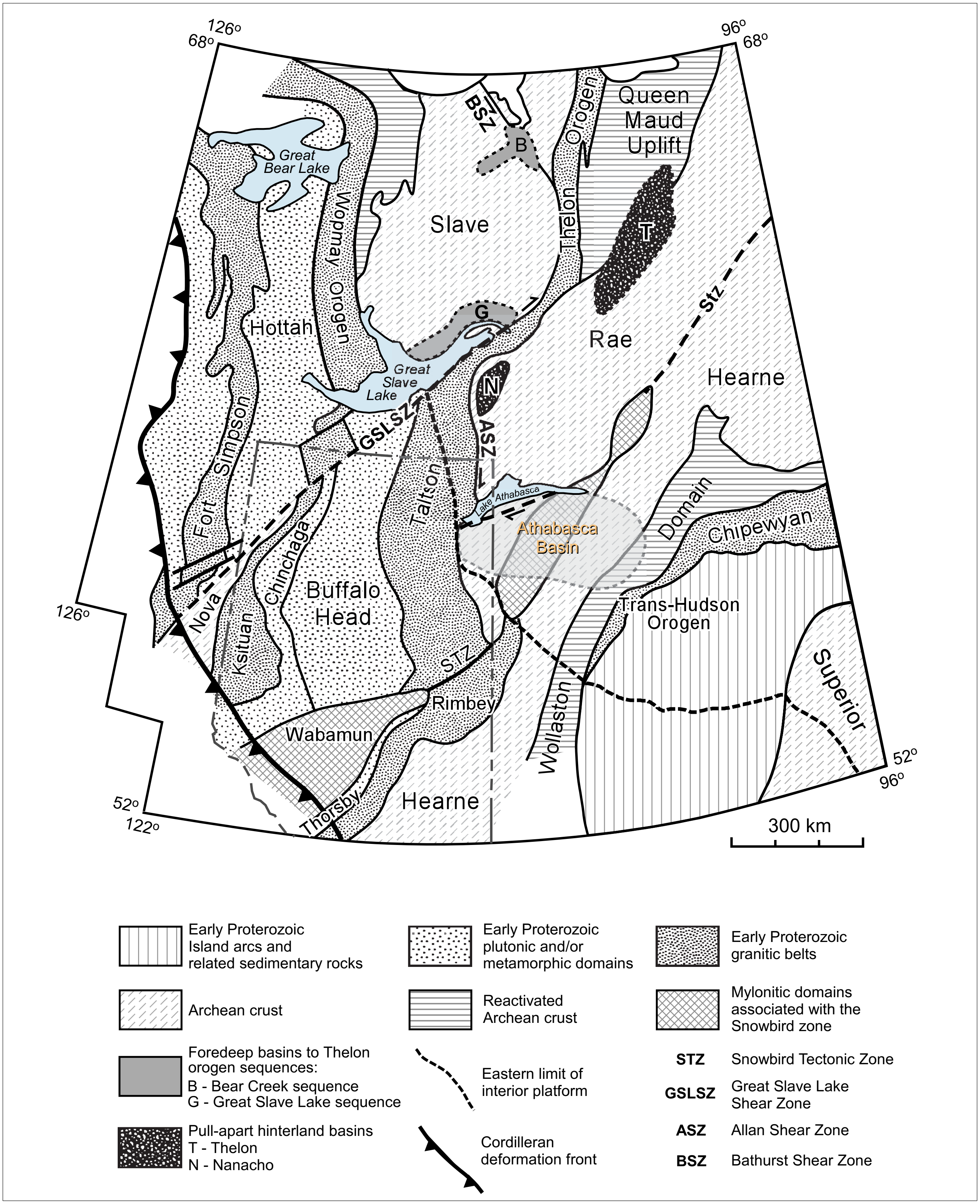


Figure 1. Generalized map of exposed and subsurface crustal domains of the western Canadian Shield (compiled from Hoffman, 1988, Ross et al., 1991).

laterally from the indentation zone: the one bounded by the Great Slave Lake Shear Zone (GSLSZ) and Allan Shear Zone (ASZ) escaped southwestward, while another bounded by the Bathurst Shear Zone (BSZ) escaped north-northwestward. The deformed alluvial-lacustrine Nonacho Basin, although not precisely bracketed in terms of age, is probably related to sinistral wrench faulting associated with tectonic escape from the indentation zone (Aspler and Donaldson, 1985).

A cryptic suture zone (Gibb and Thomas, 1976), transposed by dextral slip and east-dipping dip-slip shear zones (Thompson et al., 1985; Henderson et al., 1987), is inferred between Archean rocks of the Slave Province and the Thelon magmatic zone to the east, which is characterized by 2.02 to 1.91 Ga granitic to dioritic plutons (van Breemen et al., 1987a, b; Bostock et al., 1987). The Taltson–Thelon Orogen comprises magnetite-series and subordinate ilmenite-series plutons, and is expressed as a distinctive belt of magnetic anomalies, more than 80 km wide, that can be traced for 2550 km from central Alberta to Prince of Wales Island in the central Arctic archipelago (Figure 1). Exposed for 1000 km, the Taltson–Thelon magmatic zone is interpreted as a composite, precollisional magmatic arc and postcollisional anatectic batholith.

Foreland thrust-fold belts and autochthonous foreland basins, which are related to the Thelon Orogen, are preserved in two structural depressions:

- In the northeastern Slave Province, the foredeep was initiated by drowning of the Kimerot platform, followed by deposition of a flysch-molasse wedge that thins from 5.5 km in the east to 1.5 km over a syndepositional flexural arch in the foreland. The Kimerot Platform sequence consists of the Goulburn Supergroup, which comprises a basal, eastward-thickening wedge (0–500 m) of shallow-shelf quartzite and carbonate and is overlain by the Bear Creek foredeep sequence (Grotzinger and McCormick, 1987).

- On the southeastern margin of the Slave Province, a complex basin contains three Early Proterozoic sequences. The oldest sequence is the Wilson Island Group, a rift-like succession at least 8 km thick. The Wilson Island Group is unconformably overlain by volcanic and clastic sedimentary rocks of the 3 to 7 km thick Great Slave Supergroup. The Great Slave Supergroup is divided into the lower Sosan Group, with source area to the northeast, and the upper stratigraphic unit, with source area to the southwest. The Wilson Island and Sosan groups are involved in northwest-verging thrust nappes, with the younger Sosan Group in a structurally lower position.

The GSLSZ is coeval with the Wilson Island Group (1.9 Ga), but was periodically tectonically active until at least the Paleozoic. Finally, the Great Slave Supergroup is unconformably overlain by the Et-Then Group, which may be correlative in age with the Nonacho Group, formed in a pull-apart basin southeast of the GSLSZ (Figure 1).

3.2 Terrane Accretion Model for the Northern Alberta Basement

The major Early Proterozoic Taltson and Wopmay collisional orogens, featuring continental-scale magmatic arcs, can be traced into the subsurface of northern Alberta by discrete gravity and magnetic signatures. In Hoffman's (1988) original model, the basement of northern Alberta was mainly assigned to the Taltson Orogen. Subsequently, a series of smaller scale crustal fragments and magmatic arcs were postulated for the aeromagnetic domains with distinct fabrics and isotope signatures, in the unexposed basement of northern Alberta, between a narrower Taltson Orogen to the east and the Wopmay Orogen to the west (e.g., Ross et al., 1991; Thériault and Ross, 1991). A review of the aeromagnetic domains in northern Alberta, and of the drillcore data that support their interpretation as distinct basement terranes, is included in the next two chapters.

The tectonic history of the basement domains involves the assembly of Archean crustal nuclei to form the composite Buffalo Head–Chinchaga Terrane sometime between 2.32 and 1.99 Ga (Figures 2 and 3). This was followed by plate subduction to the east and west of the Buffalo Head–Chinchaga Terrane that generated the Taltson and Ksituan magmatic arcs between 1.99 and 1.90 Ga. In this interpretation, the Taltson Orogen forms the weld between Proterozoic crustal slivers that have been accreted to the Archean Rae Province (Ross et al., 1991), in the same way that the Wopmay Orogen welded Proterozoic crust (1.97 Ga) of the Hottah Terrane to the Archean Slave Province (Hoffman, 1988).

In contrast to the above tectonic model that involves a mosaic of continental fragments, Burwash et al. (1994, 2000) have argued for a more uniform sub-WCSB basement in northern Alberta (Figure 4). The portion of basement bounded by the Taltson and Ksituan magmatic arcs to the east and west, and by the GSLSZ and Snowbird Tectonic Zone to the north and south, respectively, would define the Athabasca Polymetamorphic Terrane (APT). The APT would represent the southwestward extension of the pre-Taltson basement, exposed in the Shield in northeastern Alberta and adjacent northwestern Saskatchewan and Northwest Territories, with similar tectonic and metamorphic history (Burwash et al., 1994). To the south, the APT is truncated by a cryptic suture zone now represented by the steeply northwest-dipping Warburg Fault, with the Central Alberta intrusions (CAI; Figure 4) in its thickened hanging wall interpreted as a magmatic arc younger than the Taltson or Ksituan (Burwash et al., 2000).

4 Basement Subdivisions in Northern Alberta Inferred from Potential Field Data

Potential-field data from the Western Canada Sedimentary Basin were used to further interpret the structure of the crust that underlies the basin. Calibration of airborne-geophysics anomaly patterns with analogues exposed in the Shield, where field relationships and kinematics are known, allows the mosaic of sub-WCSB basement domains to be placed in a dynamic, tectonic framework of terrane accretion and amalgamation (e.g., Ross et al., 1991; Ross, 1992). The current tectonic assemblage map for the Canadian Shield is a generalized illustration of exposed and covered basement domains derived primarily from the airborne magnetic and gravity potential-field data (Figure 1). It should be emphasized that the domains beneath the Phanerozoic cover of the WCSB are, if anything, even more “generalized and interpretive in nature” (Ross et al., 1994). Nevertheless, several of the major structural discontinuities that formed during collisional assembly of the Shield can be traced clearly into the subsurface.

4.1 Aeromagnetic Anomalies

4.1.1 Background

Aeromagnetic data over the exposed Canadian Shield were acquired by the Geological Survey of Canada through contract surveys flown at an average terrain clearance of about 305 m and a line spacing of 800 m (Ross et al., 1994). Data in the Interior Plains were acquired largely through donations from petroleum companies of surveys that, for the most part, were flown between 1956 and 1966; details of the line spacing, line elevation and survey company are commonly unknown. The data were digitized from donated maps rather than from survey analog tape records. The GSC regional aeromagnetic anomaly map that includes northern Alberta was produced from data interpolated onto a 2 km grid with an artificial illumination source from the southeast to emphasize the predominant northerly- and northeasterly-trending structure of the region (Ross et al., 1994).

Examination of aeromagnetic anomalies in the Canadian Shield suggests that, to a first-order approximation, lithology controls the aeromagnetic signal, with uncertain contributions from remanent magnetization and dipole effects. The aeromagnetic expression of known lithotectonic domains in the Canadian Shield provides a means of calibrating the interpretation and subdivision of subsurface aeromagnetic anomalies inferred to be caused by basement sources (e.g., Garland and Burwash, 1959;

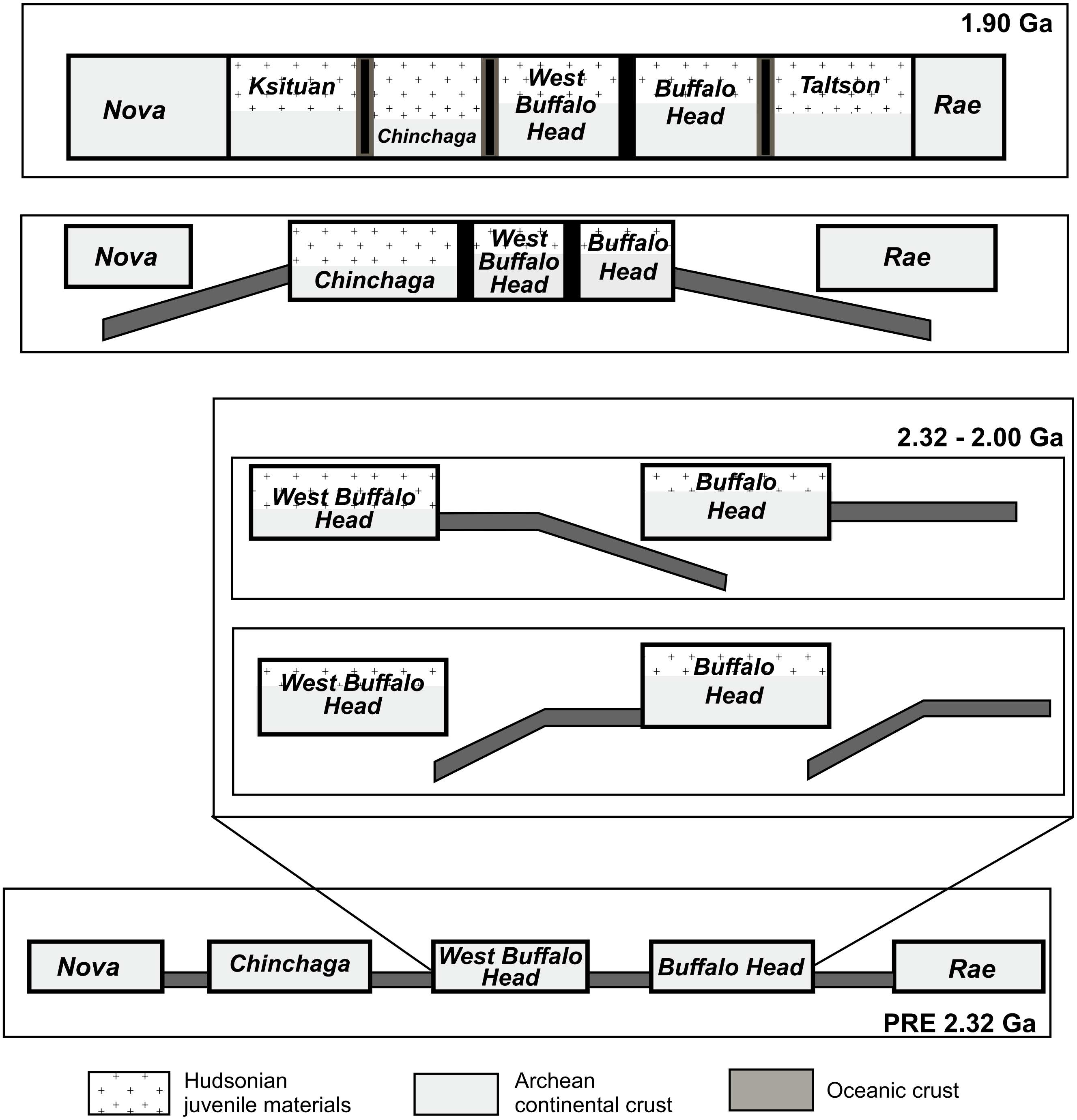
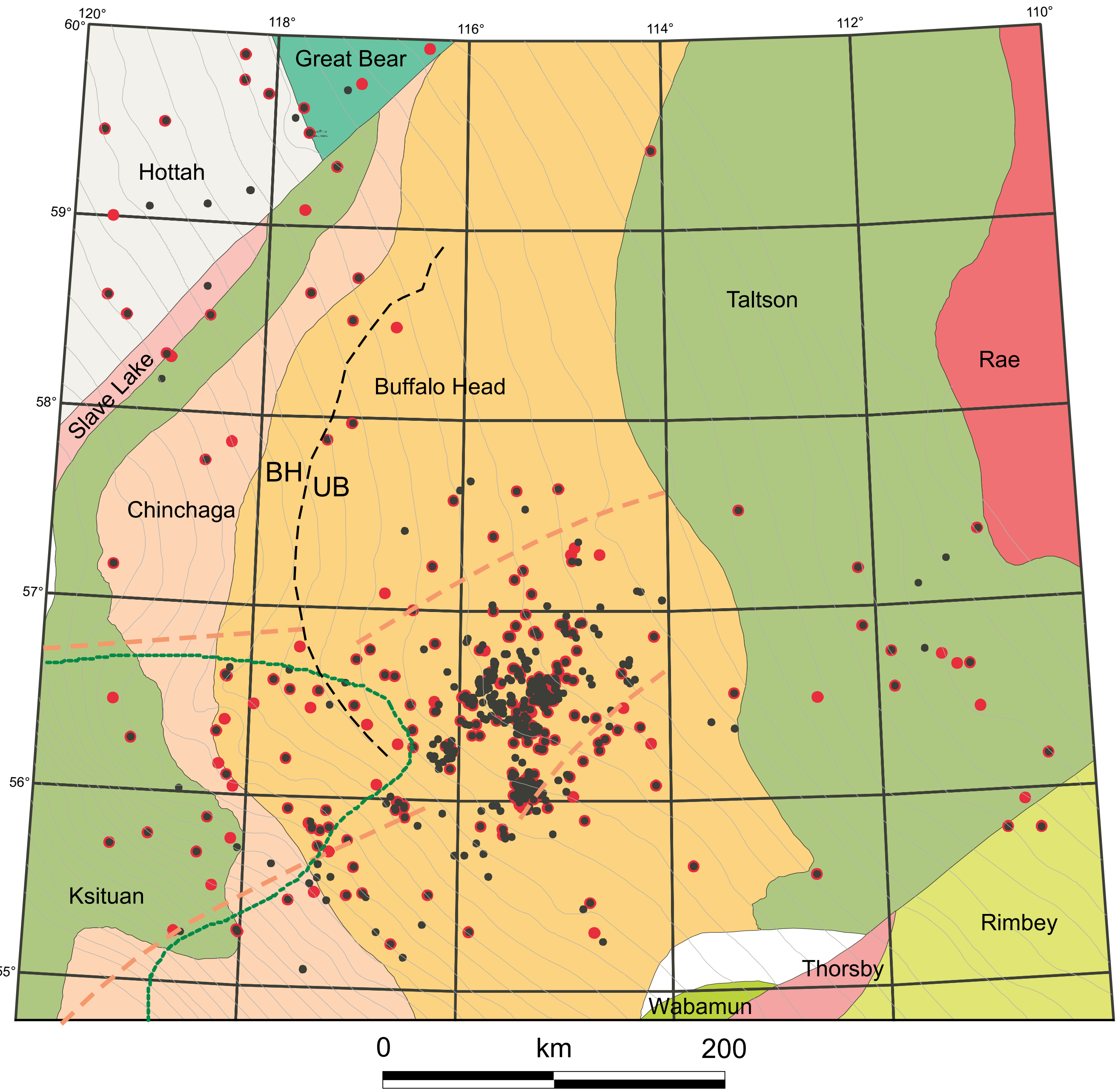


Figure 2. Plate tectonic scenario for the postulated Hudsonian assembly of the northern Alberta basement (compiled from Ross, 1990; Theriault and Ross, 1991).



- Wells with basement core north of latitude 55°N extracted in December 2000 from the database provided by the International Datashear Corporation (IDC)
- Basement intersecting well north of latitude 55°N that has a sample in custody of the University of Alberta
- Basement structural contours
- Outline of the Peace River Arch (from O'Connell, 1994)
- Elk Point Group zero edge (from Meijer Drees, 1994)
- Taltson — Basement terrane (from Ross et al., 1994); BH and UB refer to the "Buffalo Head High" and "Utikuma Belt" of aeromagnetic anomalies, respectively (Ross, 1990)

Figure 3. Location of core samples from the basement of the Western Canada Sedimentary Basin in northern Alberta. Small differences between the sample location (red dots) and the well location (black dots) may be due to the fact that a sampled well may have been originally identified by the collar location while the EUB policy is to record in the database the bottom-hole location. Samples that do not correspond to a well in the database may be from a well that has no, or incomplete picks in the database, and consequently could not yet be identified and retrieved from the database.

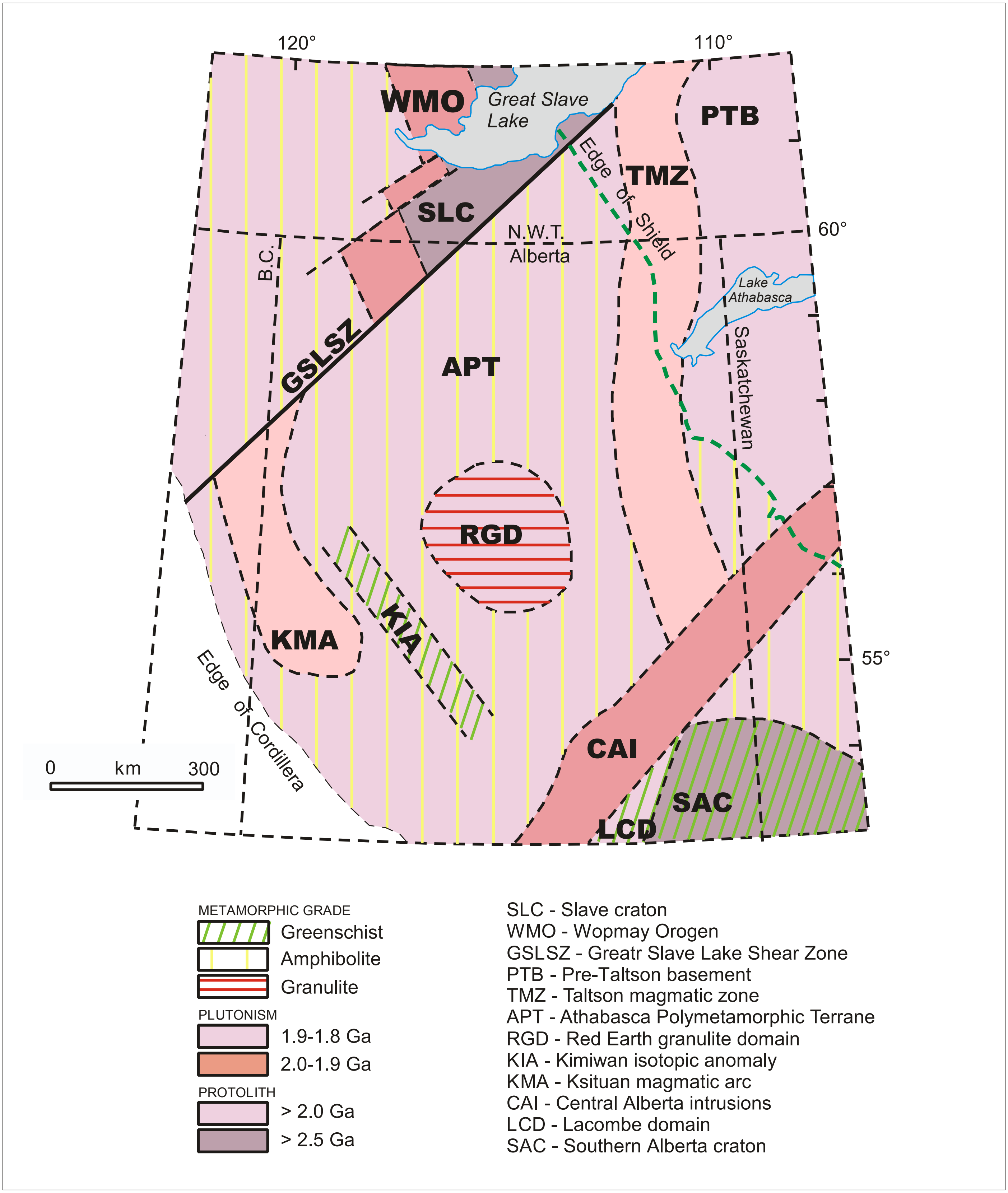


Figure 4. Tectonic map of the Precambrian basement of northern Alberta after Burwash et al., (2000).

Coles et al., 1976; Hoffman, 1988; Ross et al., 1991). Although this approach is simplistic, it is justified in northern Alberta because many structures and domains can be traced from outcrop into the subsurface. Major aeromagnetic highs in the subsurface are interpreted more confidently as magmatic belts when they appear to be the extension of exposed magmatic rocks (e.g., Taltson domain) and more tentatively where there is no outcrop control (e.g., Rimbey, Buffalo Head and Ksituan domains).

The overlying Phanerozoic sedimentary rocks of the WCSB have a damping effect that reflects the attenuation of high-frequency aeromagnetic components because of increased depth to the source. Nevertheless, the similarity of aeromagnetic wave number distribution over the exposed Shield and the Phanerozoic sedimentary section allowed removal of near-surface high-frequency components and interpretation of the aeromagnetic anomalies as being sourced largely in basement rather than within the sedimentary cover (Teskey et al., 1989). The smooth, curvilinear form of sediment isopachs in the WCSB, if not an artifact introduced by the isopach-generation process as suggested by Burwash et al. (1994), may be additional evidence that variable depth to basement has negligible effect on aeromagnetic signal variation (Cordell and Grauch, 1985). Similarly, hydrocarbon-related magnetization, produced during the transformation of hematite to magnetite and/or pyrrhotite during fluid migration, is below the detection limit of the GSC regional-scale aeromagnetic data (Ross et al., 1994).

The Proterozoic, dominantly calc-alkaline, magnetite-rich magmatic welds between formerly separate crustal fragments correspond to remarkable, high-amplitude, curvilinear, positive aeromagnetic anomalies (Hoffman, 1988). Consequently, major aeromagnetic highs in the subsurface of Alberta are interpreted as magmatic belts. The likely cause of the negative aeromagnetic signal is the regional metamorphism that transformed iron oxides into iron silicates and/or caused oxidation of magnetite to hematite (Strangway, 1970; Robinson et al., 1985; Gastil et al., 1990). The transformation of strongly ferrimagnetic iron oxides into antiferrimagnetic iron silicates and/or hematite also occurs in shear zones as a consequence of hydration and metamorphism during deformation (Watanabe, 1966). Examples of this are seen in the Great Slave Lake Shear Zone and may account for the narrow aeromagnetic lows that contribute to the striated fabric typical of deformed magmatic rocks in the Taltson Belt. Shearing can reduce the magnetic susceptibility of mafic gneiss by several orders of magnitude (Watanabe, 1966), resulting in linear, negative aeromagnetic anomalies. The less deformed rocks, by contrast, become magnetic highs. Loss of magnetization during shearing is proposed as an interpretation of prominent curvilinear aeromagnetic lows, such as the Thorsby low, and for the finely striated magnetic fabric that occurs over the Lacombe domain in the subsurface of central Alberta (Burwash et al., 1994; Ross et al., 1994).

A caution with respect to the above ‘conclusions’ is that the geological interpretation of airborne geophysical data, although invaluable, is still empirical and thus not definitive. This interpretation should be viewed as preliminary, because physical parameters of similar intensity can characterize very different rocks. For example, remarkably high aeromagnetic anomalies that are routinely interpreted to reflect calc-alkaline plutonic rocks also correspond to high-grade metamorphic rocks in the Eyehill high of eastern Alberta. The interpretation of regionally extensive negative aeromagnetic anomalies can be equally ambiguous. For example, the Konth syenogranite of the Taltson Belt corresponds to a negative aeromagnetic anomaly due to its peraluminous character, with the main opaque mineral phase being ilmenite, which is antiferrimagnetic (Bostock, 1987). Finally, depending on the ratio of induced to remanent magnetism and on the Earth’s magnetic polarity at the time the rocks cooled below the Curie point, even magnetite-bearing rocks can produce a negative aeromagnetic signal.

4.1.2 Taltson Domain

In the subsurface immediately west of the Rae Province lies a 150 to 200 km wide, north-trending belt of strike-parallel, tightly corrugated, positive aeromagnetic anomalies that are contained within broader aeromagnetic lows (Thériault and Ross, 1991). This subsurface magnetic expression is the southern continuation of the extensively exposed Taltson magmatic zone (Figure 1). In the Fort McMurray area, old geophysical data were interpreted to document northerly-trending lineaments offset by later northeast-trending faults (Garland and Bower, 1959).

4.1.3 Buffalo Head Domain

West of the Taltson domain lies the Buffalo Head domain, defined as a 200 to 300 km wide, elongate region of internally complex, north-trending, convex-westward, moderately positive aeromagnetic anomalies containing aeromagnetically negative septa. To the west, the Buffalo Head domain is bounded by the Chinchaga low and, to the south, it is truncated against the Wabamun high across what is inferred to be a fault splay from the Snowbird Tectonic Zone (Figure 3). To the north, the Buffalo Head domain curves to the northeast and merges with the positive aeromagnetic anomalies within the Great Slave Lake Shear Zone. Internally, the Buffalo Head domain may be divisible into two, and possibly three, distinct subdomains based on aeromagnetic expression and geochronology (Figures 1 and 2). The westernmost subdomain (the 'Buffalo Head high') is characterized by high-relief, positive aeromagnetic anomalies with narrow negative septa and a strong north trend. In contrast, the eastern subdomain is characterized by subdued positive anomalies with a diminished linearity (the 'Utikuma Belt'). Finally, the southwestern portion of the Buffalo Head domain is a broad, low-relief, negative anomaly with little internal fabric.

4.1.4 Chinchaga Low

The Chinchaga low is a prominent, curvilinear, aeromagnetic low (Figures 1 and 3) that wraps around the west-facing outline of the Buffalo Head high and around the southern boundary of the Ksituan high. The western limit of the Chinchaga low, at about latitude 55°N, is currently unconstrained, whereas, to the north, the western boundary conforms to the Ksituan high. As the Chinchaga low curves to the northeast, it becomes attenuated and is truncated by the Great Slave Lake Shear Zone. To the south, the Chinchaga low is juxtaposed sharply with the aeromagnetically positive rocks of the Wabamun high across the westward continuation of a splay from the Snowbird Tectonic Zone.

4.1.5 Ksituan High

The Ksituan high is a prominent, north-trending aeromagnetic high that contrasts sharply with the negative magnetic signature of the Chinchaga low immediately east of it. The strong, positive aeromagnetic signature of the Ksituan high resembles aeromagnetic signatures of relatively undeformed magmatic arcs of the Canadian Shield. The northern segment of the Ksituan high is only 10 km wide, whereas it is up to 130 km wide in the south and terminates against the enveloping Chinchaga low along an irregular boundary. The boundary of aeromagnetic signatures between the Ksituan and Chinchaga domains is very sharp in the east, suggesting a structural contact; in the south, the same boundary is irregular, suggesting that it may be magmatic in nature. To the north, at about latitude 57°N, the Ksituan high narrows and bends to the northeast, before being truncated by the GSLSZ. To the west, the Ksituan domain includes a narrow aeromagnetic low (Kiskatinaw low) that trends northerly and marks the boundary with the Nova domain. Internally, the aeromagnetic fabric of the Ksituan high is characterized by moderately elongate, positive domains separated by narrow lows; this suggests that the basement rocks have undergone penetrative deformation.

4.1.6 Nova Domain

The Nova domain is a 10 km wide, northeast-trending, positive aeromagnetic signature with little internal fabric. This geophysical entity is bounded to the northwest by the subsurface extension of the Great Slave Lake Shear Zone and to the southeast by a narrow (1–3 km wide) aeromagnetic low interpreted as a fault juxtaposing the Nova and Ksituan domains.

4.1.7 Great Slave Lake Shear Zone

The basement in northwestern Alberta and northeastern British Columbia is transected by a pronounced, northeast-trending geophysical discontinuity. Where it is exposed south of Great Slave Lake, the anomaly corresponds to a 25 km wide corridor of five mylonitic belts (Hanmer, 1988), known as the Great Slave Lake Shear Zone (GSLSZ; Figure 1). The GSLSZ formed during the Hudsonian northeastward translation of the Slave Province relative to the Rae Province (Hoffman, 1987, 1988; Hanmer, 1988). The aeromagnetic expression of this corridor is one of striated positive and negative anomalies that mimic the strong deformation typical of the shear zone. In contrast, the subsurface extension of this shear zone to the southwest is recognized only by truncation of tectonic elements; there, its geophysical signature indicates a broad zone of ductile deformation or a largely brittle component of motion in this region (Ross et al., 1994). The subsurface extension of the Great Slave Lake Shear Zone was identified long ago and is commonly referred to as the Hay River Fault (Lavoie, 1958). Based on its aeromagnetic signature, the GSLSZ can be traced as far west as the eastern edge of the Cordillera (Ross et al., 1994; Geiger and Cook, 2001).

4.1.8 Other Aeromagnetic Domains in Northwestern Alberta

Two domains that occur immediately north of the GSLSZ are the Early Proterozoic Great Bear arc (1.885–1.840 Ga; Hoffman and Bowring, 1984) and the Hottah Terrane (1.95–1.91 Ga; Hildebrand et al., 1987), both of which can be traced into the subsurface from exposures in the Great Bear Lake region.

West of the Hottah Terrane is the Fort Simpson high, a north-trending, strong, positive aeromagnetic anomaly that has been interpreted as a magmatic belt based on the shape and magnitude of the aeromagnetic signal (Hoffman, 1987). The extension of the Fort Simpson high south of the Hay River Fault is uncertain, due largely to a lack of sufficiently detailed aeromagnetic data.

4.1.9 Snowbird Tectonic Zone

Across central Alberta, the Snowbird Tectonic Zone (STZ) is a composite belt of northeasterly-trending, curvilinear aeromagnetic and gravity anomalies that truncates the northerly-trending geophysical fabrics of northern Alberta. It can be traced from Hudson Bay, across the Shield and through Alberta as far west as the Foothills. Although dramatic in its potential-field expression and presence of mylonitic rocks, the timing, kinematics and tectonic significance of this structure are still uncertain.

4.2 Gravity-Anomaly Data

4.2.1 Bouguer Gravity Anomaly

The Bouguer gravity-anomaly map for the WCSB was constructed using data obtained from the National Geophysical Data Centre (Ross et al., 1994). The spacing of observations in the study area ranges from 6 to 13 km, with an average spacing of 8 km throughout much of the Prairie Provinces. Gravity data have had a terrain correction applied, with sea level used as a datum, and have been interpolated onto a 4 km grid, offering a reasonable compromise between detail permitted by the data and artifacts introduced by the interpolation procedure.

The Bouguer anomaly map is dominated by the contribution to background gravity of long-wavelength values associated with crustal thickening in the Cordilleran Orogen and the presence of high heat flow in the southern Omineca Belt of the Cordillera (Goodacre, 1972; Sweeney et al., 1991). Additional contributions may arise from variations in the thickness of continental crust and the thermal structure of the lithosphere (Stephenson et al., 1989; Ross and Stephenson, 1989; Pilkington, 1991; Pilkington et al., 2000), as well as a westward increase in sediment thickness.

The strong regional gradient caused by continental-scale effects (e.g., the Cordilleran Orogen) diminishes the visibility of fine detail in the gravity field related to upper crustal and shallow basement structure beneath the WCSB. There are only two features of regional extent readily obvious on the Bouguer gravity map of the WCSB: the Snowbird Tectonic Zone (STZ) in central Alberta and the Vulcan low in southern Alberta. The gravity break associated with the STZ was originally referred to as the Fond du Lac gravity low (Walcott, 1968) or the Kasba–Edmonton gravity low (Burwash and Culbert, 1976). The STZ and its inferred extension into Alberta form one of the most dramatic gradients on the entire map of the WCSB and continue to the frontal thrust of the Rocky Mountains. Its northern boundary represents one of the few places in Alberta where gravity and magnetic lineaments closely coincide. Seismic and gravity data suggest that this lineament is a northwest-dipping, high-angle thrust, called the Warburg Fault, that can be traced northeastward on the exposed Shield into the Virgin River Shear Zone (Burwash and Muehlenbachs, 1997). The Vulcan low in southern Alberta is also a gravity anomaly but is outside the area considered in the present review and is not discussed further.

A derivative version of the Bouguer field, the horizontal gravity-gradient map, removes the relatively long-wavelength contributions from Cordilleran sources and accentuates the gravity anomalies of the upper (approximately) 15 km of crust (Sharpton et al., 1987). Horizontal gravity gradients reflect the juxtaposition of crustal bodies of contrasting density and/or thickness. In several areas of the WCSB horizontal gravity-gradient map, there are short linear anomalies oriented at a high angle to the predominant aeromagnetic trend; these may depict intrasedimentary features or just be an artifact introduced by inadequate density of gravity stations (Ross et al., 1994). In northeastern Alberta, similar anomalies are present over the exposed Taltson Belt, suggesting that they may be a feature of the basement. Surprisingly, the GSLSZ, a major crustal break that separates rocks supposedly of dramatically different ages (Ross, 1990), is not associated with a gravity gradient. This may indicate that the rocks on either side of this discontinuity have similar density and thickness. Similarly surprising, the Peace River Arch (PRA), a major crustal perturbation, does not coincide with a particular pattern of gravity gradients. In the vicinity of the arch, the horizontal gravity-gradient map shows moderately steep gradients with a northerly trend, subparallel to the aeromagnetic fabric (Sharpton et al., 1987). There is therefore no pattern of gravity gradients that coincides with the trend of the PRA, which suggests that formation of the arch did little to modify upper crustal structure in the region.

The horizontal gravity-gradient method was successfully used to define basement fractures in central Alberta (Edwards et al., 1995). A similar study is currently being prepared by the Alberta Geological Survey for a major portion of northeastern Alberta.

4.2.2 Long-Wavelength Gravity Data

The long-wavelength components of the gravity-anomaly data depict properties of the crust and lithospheric mantle, such as variations in thickness, thermal structure and average density. However, recognition of specific causes for these properties is still somewhat ambiguous due to uncertainties in the depths of the sources of the anomalies and the age of the anomalies.

Sprenke and Kanasewich (1982) and Stephenson et al. (1989) computed isostatic residuals from the Bouguer gravity field for western Canada and then filtered these residuals to examine different wavelength components of the gravity field (i.e., at 400–700 km and 700–1200 km). One of the most prominent patterns on the 400 to 700 km wavelength image seems to be associated with the amplitude shift in gravity along the Kasba Lake–Edmonton–Thorsby gravity low, suggesting that this discontinuity extends through much of the crust. The 400 to 700 km and 700 to 1200 km long wavelength/band-pass–filtered maps of the contoured isostatic residuals for the WCSB show an overall crustal thinning that coincides with the PRA (Stephenson et al., 1989).

Integrated with deep seismic studies such as reflection (Kanasewich et al., 1969; Zelt and Ellis, 1989) and/or refraction investigations (*see* review in Ross and Stephenson, 1989), wavelength-filtered gravity data can provide insight into causative mechanisms of basin formation, given that their wavelengths approximate the wavelengths of the basin. For example, a regional seismic refraction program, which was carried out in 1985 in the Peace River Arch region, suggested that trends in crustal thickness, the character of the Mohorovičić discontinuity and seismic velocity in the uppermost mantle can be inherited from the assembly of Early Proterozoic tectonic domains (Ellis et al., 1986; Stephenson et al., 1989; Zelt and Ellis, 1989). Alternatively, the apparent relative crustal thickening along the Devonian axis of the PRA (an upwarp of the lower crust), inferred structural grain at the base of the crust along the axis of the PRA, and intracrustal reflectors that appear to dip gently away from the axis of the PRA are all interpreted as crustal anomalies related to formation of the PRA (Ross, 1990). The presence of intermediate-velocity lower crust was interpreted to have resulted from the injection of mafic magmas into the lower crust, perhaps during uplift of the arch (Stephenson et al., 1989). This was used as evidence for an active 'thermal-extensional' origin for the PRA, analogous to other regions affected by rift-related mafic magmatism.

5 Drillcore Data

5.1 Basement Topography and Geologically Inferred Structures

Configuration of the basement topography shows a pre-Paleozoic erosional surface dipping gently to the southwest into the foreland basin of the Cordilleran Orogen. Several irregularities of the unconformity at the base of the Phanerozoic cover interrupt the southwest regional dip of this surface (Figure 3). Prior to burial, differential erosion of Precambrian rock units probably would have imparted an etched grain to the sub-Paleozoic unconformity. Differences in basement elevation of up to 100 m between wells in adjacent townships exist, but a virtual absence of published seismic reflection data limits direct mapping of basement faults across the basin floor. As well, it must be realized that local basement topography is smoothed by computer contouring, so possible fault scarps are minimized or overlooked (Burwash et al., 1994). Therefore, the vast areas of poor or extremely sparse drillhole data coverage preclude identification of basement structures through direct geological means. Such interpretations require indirect and combined investigations (e.g., geophysical data and satellite imagery).

The Early Paleozoic Peace River Arch in northwestern Alberta is by far the most significant regional basement structure with a well-documented complex history of uplift and subsidence (e.g., Cant, 1988). Conjugate northeast- and northwest-trending faults control the basement topography and sedimentation patterns over the arch (Cant, 1988). Vertical movements totalling several hundred metres occurred along these faults in late Paleozoic time. The fundamental cause of the differential uplift of the Peace River Arch is a subject of ongoing discussion (*see* Pană, et al., 2001).

The western margin of the Shield adjacent to the WCSB is cut by a number of shear zones of regional extent. For example, the northeast-trending Hudsonian Great Slave Lake Shear Zone has been geologically mapped at the East Arm of Great Slave Lake as a major, dextral, transcurrent, ductile mylonite complex. The Phanerozoic reactivation of the Great Slave Lake Shear Zone as the 'McDonald' brittle fault zone is indicated in northwestern Alberta by the disturbance of Paleozoic and (?) Mesozoic strata and a distinct topographic expression. It has also been identified in the subsurface farther west in northeastern British Columbia, where it coincides with the Hay River Fault (Lavoie, 1958) or Hay River Fault Zone (Williams, 1990).

In northeastern Alberta, a series of northerly-trending sinistral shear zones of early Hudsonian age has been geologically mapped on the Alberta Shield as the Warren Shear Zone (Godfrey, 1986) or Leland Lakes Shear Zone (McDonough et al., 1995). To the south, however, they appear to bend southwesterly into the topographic depression between the Birch and Caribou mountains. Tight isoclinal folds in Devonian evaporite strata at Peace Point (W.N. Hamilton, pers. comm., 2001) and intensely jointed carbonate rocks at Vermilion Chutes along the Peace River line up along the southwesterly projections of these shear zone(s), which suggests Devonian–post-Devonian reactivation (Pană, 2002). The north-trending Allan Shear Zone has been subjected to recurrent movement after regional metamorphism (Burwash et al., 1994). The dextral Black Bay and Grease River shear zones, which have been geologically mapped in Saskatchewan, project under the WCSB in the northern Birch Mountains; these structures most likely overprinted the basement in northeastern Alberta.

5.2 Petrology

Basement core from all areas in northern Alberta includes primarily high-grade metamorphic and/or plutonic rocks of a deep crustal level. The most abundant rock types in the northern Alberta basement are: quartzofeldspathic gneiss (58%), granitoid (16%), granulite (10%), metasedimentary rocks (5%), mylonite (5%) and amphibolite (4%), with all other types constituting less than 2% (Burwash et al., 2000). In northern Alberta, between the Taltson and Ksituan magmatic arcs, the Athabasca Polymetamorphic Terrane, which includes the Peace River Arch, consists of more than 80% gneiss and granulite, whereas inferred supracrustal rocks form less than 5% (Burwash et al., 2000). Although the abundance of rock types varies spatially, defining boundaries between terranes on this basis is tenuous (Burwash et al., 1994).

The distinction between granite and gneiss in core samples, without supporting observations at the outcrop, becomes partly subjective (Burwash et al., 2000). The term 'granite' was used in a very broad sense to include rocks with hypidiomorphic granular texture that are weakly foliated or nonfoliated and range in composition from granite to quartz diorite, as defined by Streckeisen (1976). The main criterion adopted for naming drillcore samples currently in the collection of the University of Alberta is that strongly foliated rocks are metamorphic and nonfoliated or weakly foliated rocks are igneous. Most of the core samples are classified as gneiss, although the granite protolith can still be clearly recognized. The 'gneiss' records deformation of granitoid rocks under medium- to high-grade metamorphic conditions. The distinction between diorite and amphibolite, or between charnockite and granulite, is also partly subjective without outcrop data.

Textural-mineralogical relationships in many basement rocks from northern Alberta indicate multiple phases of deformation and recrystallization (Burwash and Krupička, 1969; Burwash, 1978). Pressure-temperature determinations based on results of electron-microprobe analyses are available for many of the rock units of the exposed Shield in northeastern Alberta. Very high temperatures are indicated in the Taltson magmatic zone (Chacko, 1997; Berman and Bostock, 1997). For the sub-WCSB basement, the spatial distribution of data points is too uneven to allow the construction of a metamorphic facies map. In the only area with a high concentration of basement core samples (map area NTS 84B, Peerless Lake), closely spaced wells penetrated almost exclusively granulite and orthogneiss (Burwash et al., 2000). Temperature estimates on orthogneiss from the subsurface of north-central Alberta are currently underway as part of a M.Sc. thesis at the University of Alberta, funded in part by the Alberta Geological Survey. The two-feldspar thermometer indicates peak temperatures of approximately 920°C, which is typical for high-grade metamorphism (Ranger, 2001). In the same area, apparently randomly distributed lower temperatures of approximately 780°C indicate partial re-equilibration of the granulitic paragenesis. Using the Fuhrman and Lindsley (1988) calibration model for a pressure of 7 kbar, temperatures have been calculated in an attempt to define isotherms of the Hudsonian metamorphism. The choice of 7 kbar was based on estimates of the pressure conditions during granulite-facies metamorphism in northeastern Alberta (e.g., Langenberg and Nielsen, 1982; Chacko, 1997). An elliptical area of granulite-facies metamorphism was defined around Red Earth Creek (labelled 'RGD' in Figure 4). However, the true extent of the granulite-facies rocks may be much wider, including most of the exposed and covered basement of northern Alberta with areas or lineaments of lower grade overprint. Sub-greenschist– to greenschist-facies mylonite has been intersected by drillholes in the GSLSZ, and in the Rimbey and Lacombe domains of the STZ. Along the southwestern margin of the Buffalo Head Terrane, Muehlenbachs et al. (1993) discovered the Kimiwan isotopic anomaly (KIA), a 50 by 250 km linear zone of retrogressed rocks with $\delta^{18}O$ values lowered to the range 1 to 5‰ (relative to Standard Mean Ocean Water). The KIA was interpreted as a zone of crustal extension formed in the late stages of the Hudsonian Orogeny (Burwash et al., 1993).

The relative scarcity of prograde greenschist-facies samples is believed to indicate that the supracrustal rock units have been largely eroded from the Alberta basement (Burwash et al., 2000).

5.3 Geochemistry

A limited set of chemical analyses from basement core was reported and interpreted by Burwash and Culbert (1976). Their study showed good correlation of variables considered in their 'R-mode' and 'canonical analysis', and the results were interpreted to document potassium metasomatism. The map generated for the canonical coefficients is a northeast-trending belt across northern Alberta. On both petrographic and geochemical grounds, an elongated domain that includes the Peace River Arch and its flanks was separated from adjacent terranes as the 'Athabasca mobile belt' (Burwash et al., 1994). Data used in this study, complemented by another set of data acquired by R.A. Burwash of the University of Alberta under contract with the Geological Survey of Canada, were kindly provided to the Alberta Geological Survey. Existing data from whole-rock analyses for major elements and selected trace elements, combined with petrographic data acquired over the last several decades by the University of Alberta, have been included in the Survey's preliminary database. In an attempt to supplement this data set, 21 samples from north-central Alberta have been re-analyzed for the complete suite of trace elements used in modern discriminatory plots for the tectonic setting of granitoid rocks. In addition, another series of approximately 40 geochemical analyses of basement core will be completed during fiscal 2002–2003.

5.4 Geochronology

5.4.1 Background

Potassium-argon (K-Ar), rubidium-strontium (Rb-Sr), argon-argon ($^{40}Ar/^{39}Ar$), and uranium-lead (U-Pb) geochronology on basement drill core and cuttings, as well as samarium-neodymium (Sm-Nd) isotope geochemistry, have been used as a 'ground truthing' method for the interpretations of basement subdivisions derived from potential-field data (Burwash, 1957; Burwash et al., 1962; Collerson et al., 1988; Ross et al., 1989, 1991; Thériault and Ross, 1991; Villeneuve et al., 1991, 1993; Burwash et al., 1994). Each method provides a valuable, but different, kind of information.

The existing K-Ar data for the Alberta crystalline basement consist largely of biotite and less commonly muscovite and hornblende analyses. Potassium-argon dates between 1.6 and 1.9 Ga were interpreted to record the Hudsonian regional metamorphic event, whereas three K-Ar dates on hornblende separates, ranging from 2.0 to 2.2 Ga, were interpreted to record Archean inheritance (Burwash et al., 1962, 1994). Potassium-argon ages reported by Burwash et al. (1962) have been recalculated for the decay constants of Steiger and Jager (1977); the recalculated ages range from 2090 ± 40 Ma to 1470 ± 40 Ma, with 1.7 to 1.8 Ga ages being the most frequent (Plint and Ross, 1993). The significance of K-Ar ages in polymetamorphic rocks is limited, as they are calculated using the entire amount of argon from the sample, irrespective of its lattice site. The northern Alberta samples have older Archean emplacement ages, so the K-Ar ages of 1.7 to 1.8 Ma indicate widespread uplift and cooling of granulite terranes following the Hudsonian event. However, their interpretation as being due to postmetamorphic cooling is conjectural.

The $^{40}Ar/^{39}Ar$ technique can discriminate between initial closing temperature and argon loss due to subsequent processes, making the dates much more significant geologically. The $^{40}Ar/^{39}Ar$ ages are calculated for different heating increments, a technique that allows separation of argon released from crystal rims and defects at initial low temperatures from argon released from the core of the crystals. Accurate cooling ages are obtained when several high-temperature steps produce the same amount of argon and implicitly the same ages, resulting in a flat line in the age versus ^{39}Ar diagram (plateau ages). Sometimes, the ages obtained for the low-temperature steps can be interpreted as the age of disturbance subsequent to crystal cooling. Plint and Ross (1993) reported the only three $^{40}Ar/^{39}Ar$ plateau ages from northern Alberta: 1) muscovite from a pegmatite in the Buffalo Head domain at latitude 58°N yielded 1882 ± 12 Ma; 2) muscovite from a low-grade mylonite on a quartzofeldspathic protolith in the Nova domain, adjacent to the GSLSZ, yielded a 1712 ± 11 Ma plateau age; and (3) hornblende from an amphibolite in the southern part of the Chinchaga domain yielded a 1934 ± 12 Ma plateau age. The biotite, muscovite and hornblende plateau ages with closing temperatures of approximately 300°C, 350 to 375°C and 500 to 550°C, respectively, represent the time of uplift of a medium- to high-grade crustal domain above these isotherms. The $^{40}Ar/^{39}Ar$ dates on hornblende and muscovite from the Buffalo Head and Chinchaga domains indicate slow uplift and cooling (1°C per million years) of the granulite facies basement of northern Alberta. The $^{40}Ar/^{39}Ar$ age from the low-grade mylonite with a paragenesis that constrains the temperature to less than 350°C may be the crystallization age of syntectonic muscovite and record late deformation under greenschist-facies conditions along the GSLSZ at ca. 1712 Ma.

The Rb-Sr system was also used to date the late deformation occurring during indentation of the Slave Province into the composite Churchill Province between 1840 and 1735 Ma (Henderson et al., 1990).

The time of the crustal extension in the KIA region was initially considered to be bracketed by Rb-Sr and K-Ar dates of 1780 and 1690 Ma (Chacko et al., 1995). Analysis for $^{40}Ar/^{39}Ar$ by laser incremental-heating mass spectrometry on unaltered hornblende from the east-central KIA yielded an age of 1933 ± 13 Ma, similar to U-Pb zircon ages from the nearby Ksituan magmatic arc and almost synchronous with the Taltson arc (Burwash et al., 2000). In contrast, hornblende from a hydrothermally altered amphibolite from the southwestern KIA (Virginia Hills) yielded an $^{40}Ar/^{39}Ar$ age of 1794 ± 12 Ma. The $^{40}Ar/^{39}Ar$ spectra indicate that both biotite and hornblende are overprinted, with biotite showing an argon-loss spectrum. It can thus be concluded that rocks cooled at ca. 1933 Ma were overprinted by a linear zone of crustal extension that permitted the deep circulation of meteoric fluids responsible for alteration and for ^{18}O depletion at ca. 1794 Ma.

Uranium-lead isotopic analysis provides a high-resolution age-dating method for small volumes of rock, such as oil-well drill cuttings. Uranium-lead dates on various uranium-bearing accessory minerals have different geological significances, depending on their paragenetic-textural relationships and the inferred PT path of the rock. Uranium-lead dates from northern Alberta basement exist for zircon, monazite and titanite, which have closure temperatures of greater than 800°C, 700°C and 600°C, respectively. Uranium-lead dates on zircon are inferred to be the times of crystallization of the zircon from magma, or the culmination of a metamorphic event. Uranium-lead dates on monazite and titanite, when concordant with those from zircon, are also interpreted as the times of crystallization from magma. Typically, however, the dates on monazite and titanite in medium- to high-grade metamorphic terranes are younger, recording the culmination of a postemplacement metamorphic event. Thus, a sound interpretation of the U-Pb ages is usually derived by integrating them with Sm-Nd model ages.

The Sm-Nd model ages, or the ‘crustal residence time’, are the inferred time of separation of sialic crustal material from the mantle. The depleted mantle model (Goldstein et al., 1984) is currently favoured over the chondritic model (DePaolo and Wasserburg, 1976). Assigning ‘age’ significance to Sm-Nd dates obtained from samples in northern Alberta, based on frequency histograms (Burwash et al., 1994), is unwarranted. When corroborated with U-Pb emplacement ages, the Sm-Nd model ages indicate that varying ratios of juvenile Proterozoic material have been added to the Archean crust during the development of Hudsonian magmatic arcs (Collerson et al., 1989; Thériault and Ross, 1991). The concept of crustal recycling by deformation and metasomatism, which was originally suggested by Burwash and Krupička (1969, 1970) on petrographic grounds for northern Alberta, is fully supported by the Sm-Nd data.

In summary, the integration of Sm-Nd model ages and U-Pb ages is the best approach for inferring the age of the protoliths within the distinct aeromagnetic domains that have been delineated in northern Alberta. This process leads to the identification of three distinct magmatic belts (Taltson, Ksituan, and Rimbey or Central Alberta), with emplacement ages of 1800 to 2000 Ma, in the subsurface of northern Alberta (Figures 2 and 3), as well as a composite reactivated Archean crustal fragment (Buffalo Head–Chinchaga). A review of the U-Pb and Sm-Nd dates for these domains and their interpretation follows.

5.4.2 Taltson Domain

In northeastern Alberta, the exposed Taltson magmatic zone (TMZ) is dated at 1990 to 1910 Ma (McDonough et al., 1995). To the north, the exposed TMZ comprises a 1986 Ma quartz diorite to granodiorite suite and 1955 to 1935 Ma peraluminous granitoid rocks (Bostock et al., 1987). To the south, U-Pb dating of zircon and monazite from drill cores of the unexposed segment of the Taltson zone yielded ages in the 1975 to 1937 Ma range. Two drillcore samples of syenogranite, two of monzogranite, and one of hornblende granite were analyzed for Sm-Nd isotope concentrations and ratios. Initial εNd values range from –3.7 to –9.7, in agreement with the range of values obtained for the exposed portion of the TMZ (Thériault and Bostock, 1989). Depleted mantle neodymium model ages (T_{DM}) vary from 2.57 to 2.68 Ga. The Nd isotopic signatures of the Taltson domain granitic rocks reflect recycling of material with a prolonged crustal history during the Early Proterozoic. As suggested by Thériault and Bostock (1989), the Taltson zone may be the result of continental-arc magmatism followed by continent-continent collision between the Rae Province and the Buffalo Head domain, implying pervasive melting of pre-existing crust. Such a tectonic setting is compatible with the postulated evolution of the 1.91 to 2.02 Ga Thelon Tectonic Zone (van Breemen et al., 1987a, b), the supposed northern continuation of the Taltson zone, which is believed to be a magmatic arc resulting from the eastward subduction of oceanic lithosphere beneath the Rae Province, followed by collision of the Slave Province into the Rae Province (Hoffman, 1988).

5.4.3 Buffalo Head Domain

Drillcore samples recovered from the Buffalo Head domain are mainly metaplutonic rocks ranging in composition from gabbro to leucogranite, with minor metavolcanic and high-grade gneissic rocks (Thériault and Ross, 1991; Burwash et al., 1994). Uranium-lead crystallization ages fall in the 2324 to 1993 Ma range, with four occurrences of plutonic rocks in the narrow range 1.999 to 1.993 Ga. Although the older ca. 2.3 Ga U-Pb ages are predominantly from the southwest sector of this basement domain, a correlation cannot be made between lithology, age and geographic location (Ross, 1990). Consequently, the originally inferred subdivisions of the broader Buffalo Head Terrane (‘Buffalo Head high’ and ‘Utikuma’ subdomains) have been abandoned (Ross et al., 1994).

A total of 12 samples (five of granitic gneiss, three of gabbro gneiss, two of biotite-hornblende granite, one of leucogranite and one of felsic metavolcanic rock) were analyzed for Sm-Nd isotopes. Initial εNd values scatter over the +0.2 to –6.3 range, whereas T_{DM} model ages vary from 2.83 to 2.51 Ga, with a preponderance of 2.8 to 2.7 Ga ages. Rock types and initial εNd values are not correlative (i.e., there is no apparent interrelation between rock type and $^{147}Sm/^{144}Nd$ values). The spectrum of initial εNd results observed may be interpreted as the result of evolution from discrete crustal sources of varying crustal residence ages. A more realistic interpretation, however, is to consider the scatter of initial values as a consequence of mixing various proportions of crust of evolved Nd isotopic composition with magmas of a more primitive signature. Mixing between mantle-derived and pre-existing crustal components has been well documented in Phanerozoic orogenic belts, and there is no evidence suggesting that similar processes were not operative in the Precambrian. On the basis of Nd isotopic evidence, Thériault (1994) suggested that the Buffalo Head Terrane may represent a slice rifted off the pre-Taltson basement. Isotopic compositions of granitic rocks from the TMZ indicate that both the early and late intrusions are of intracrustal origin, formed in a plate interior rather than a plate-margin setting (Chacko et al., 2000). If this is so, similar metamorphic histories for the pre-Taltson basement both east and west of the Taltson belt might be expected (Burwash et al., 2000).

5.4.4 Chinchaga Domain

Drilled basement in the Chinchaga low consists of metasedimentary and metaplutonic rocks and one occurrence of massive porphyritic granitic rock (Ross et al., 1994). Uranium-lead dates on gneiss range from 2.17 to 2.08 Ga, implying partial age equivalence with rocks of the Buffalo Head Terrane to the east. However, the 1.999 to 1.993 Ga plutonic rocks of the central and western Buffalo Head Terrane and the ca. 2.3 and 2.0 Ga ages are absent from the Chinchaga low. Uranium-lead crystallization ages and the strongly negative aeromagnetic signature of the Chinchaga domain were interpreted to indicate a potentially separate crustal entity from the Buffalo Head domain.

Three samples from the Chinchaga domain yielded initial εNd values of +0.6 (quartzofeldspathic gneiss), –0.4 (porphyritic granite) and –1.8 (monzonite gneiss), and crustal residence ages of 2.57, 2.46 and 2.68 Ga, respectively. The $^{147}Sm/^{144}Nd$ ratios fall in the 0.0943 to 0.1205 range, typical of light rare-earth element (LREE)–enriched crust. Despite the relatively small number of samples analyzed, the Nd-isotope signatures of the Chinchaga domain suggest a greater proportion of juvenile material in the petrogenesis of its rocks relative to the Taltson and Buffalo Head domains, thus further distinguishing the Chinchaga as a discrete entity (Figure 2).

5.4.5 Ksituan Domain

The Ksituan high was interpreted to correspond to a magmatic arc (KMA) dominated by metaplutonic rocks of largely calc-alkaline composition (e.g., Thériault and Ross, 1991). The drillcore samples from this domain are predominantly hornblende-biotite granitic gneiss, consistent with the strong positive aeromagnetic signature. Uranium-lead crystallization ages on samples from the Ksituan domain are in the range 1986 to 1900 Ma. This range does not overlap with crystallization ages obtained from rocks of the Chinchaga low immediately to the east (Ross et al., 1991), but does overlap with cooling ages from titanite grains in this region (Villeneuve et al., 1993). This suggests a younger tectonomagmatic event that resulted in KMA granitoid emplacement and reactivation-metamorphism of the older basement to the east.

Two samples yielded very similar initial εNd values of –2.1 and –1.8, and indistinguishable T_{DM} ages of 2.63 and 2.62 Ga. Although this reflects the incorporation of Archean crust in the granitic rocks of the Ksituan domain, the participation of the Archean component in these rocks is not as pronounced as in the Buffalo Head and Taltson domains to the east.

5.4.6 Nova Domain

A mylonitic mafic gneiss from the Nova domain has yielded a U-Pb zircon age of 2808 Ma. On this basis, Ross et al., (1991) postulated that the Nova domain may be a dislocated remnant of the Slave Province, the dominant lithotectonic entity north of the GSLSZ, whose southwestern region contains 3.9 to 2.8 Ga gneissic rocks. The interpretation is tenuous because it implies that the Nova-Ksituan contact is a cryptic suture, with the Ksituan arc to the southeast of the Slave indenter being in an identical position with the Thelon arc. Such a correlation is, however, unacceptable in light of the obvious continuity of the Thelon into the Taltson magmatic zone. Archean crust has, however, been documented south of the GSLSZ (Henderson and Thériault, 1994) and may represent the westernmost extension of the Rae terrane.

5.4.7 Rimbey Domain

The Rimbey positive aeromagnetic anomaly, trending northeast across central Alberta, was interpreted as a discrete 1850 to 1780 Ma magmatic arc, also referred to as the Central Alberta intrusions (CAI; Burwash et al., 2000). The CAI granitic rocks were emplaced in the thickened crust south of the Warburg Fault and are younger than the Taltson or Ksituan (Figure 4).

In contrast to a tectonic model that postulates a mosaic of continental fragments (e.g., Ross et al., 1994), Burwash et al. (1994, 2000) have argued for a more uniform sub-WCSB basement in northern Alberta (Figure 4). Their Athabasca Polymetamorphic Terrane (APT) would represent the southwestward extension of the pre-Taltson basement exposed in the Shield in northeastern Alberta, with a similar tectonic and metamorphic history (Burwash et al., 1993). Uranium-lead zircon ages in the APT range from 2400 to 1900 Ma (Ross et al., 1991), whereas depleted mantle Nd model ages are all Archean (Villeneuve et al. 1993). Burwash et al. (2000) made the point that the APT represents Archean crustal material that was reworked during Early Proterozoic magmatic activity in the APT, coeval with that of the pre-Taltson basement. This view is supported by Bostock and van Breemen (1994), who concluded that "east of the Taltson magmatic zone, 2.44 to 2.27 Ga granites were emplaced into older, likely Archean crust" in the Fort Smith–Hill Island Lake area of the Northwest Territories. Similarly, in the Tazin Lake area of northwestern Saskatchewan, granitic rocks dated at 2.36 to 2.18 Ga intrude 2.6 Ga granitic gneiss (Van Schmus et al., 1986). The association of the northern Alberta basement with the Archean Rae is also supported by recent isotope data, which indicate that the Taltson magmatic belt formed in the distant hinterland of a convergent plate margin (Chacko et al., 2000).

6 Reactivation of the Sub-WCSB Basement

6.1 Background

Basement reactivation is of critical importance in understanding the role of basement structure in Alberta Basin evolution, particularly for controlling sedimentation and diagenetic patterns in the basin. In general, there is widespread acceptance of basement reactivation in the Alberta Basin as an explanation for anomalous linear sedimentation patterns inferred to have been controlled (or at least influenced) by basement structures. The following discussion provides the pros and cons for this supposition.

Faults known and inferred in the stratigraphic sequence are usually compared and matched with basement 'breaks' shown by the aeromagnetic field data, either as first vertical derivative or profile residual maps. Their 'commonality' (Leblanc and Morris, 1999) in some areas led to the supposition that basement control of Phanerozoic structures in the Alberta Basin is quite common, if not pervasive (e.g., Gay, 2001). In contrast, Ross and Eaton (1999) concluded that "direct basement control of the presence and orientation of faults in the sedimentary section seems unlikely," as the strength and thermal age of sub-WCSB lithospheric mantle was too great to allow pervasive basement reactivation.

Reactivation of the basement has often been invoked as a default mechanism to explain local coincidence of trends of isopachs, facies transitions, erosional levels on transgressive erosion surfaces, synsedimentary faults and modern production trends with basement structures (Gay, 2001 and references therein). Precambrian fault reactivation is viewed as the principal mechanism responsible for localizing particular facies or thickness changes, like the Devonian reefs (e.g., Greggs and Greggs, 1989), drainage patterns in the Devonian (e.g., Dec et al., 1996) or Cretaceous (e.g., Leckie et al., 1990), depositional patterns inferred from stratigraphic thickness changes (e.g., Hart and Plint, 1990), or facies changes (e.g., Dix, 1990). The linear distribution of some oil, gas and coal deposits in the Alberta Basin, in a regional and/or local sense, is believed to be caused by reactivation of high-angle basement faults (Lyatsky, 2000). It must be realized, however, that mapping of tectonic discontinuities in the sub-WCSB basement requires a combination of geological data, airborne geophysical data and seismic images of both the sedimentary section and the underlying basement.

The close correlations of the long axes of oil fields in the Alberta Basin with one of the main jointing directions observed in the bedrock (Babcock, 1976), and with airphoto-lineament directions (Misra, 1991), are considered additional evidence of basement control on the deformation pattern at small and larger scale, respectively (Gay, 2001). It must be emphasized that both lineament analysis on satellite imagery and well-isopach patterns are only means of inference/speculation on the existence of a basement fault. Basement faults are not 'mapped' from the surface or from the sedimentary section! In particular, the joints measured by Babcock (1976) and Pană (2002) are in Phanerozoic rocks and may or may not have an explicit connection with the Precambrian basement.

Integrating cross-sectional (seismic) and map (aeromagnetic) data acquired over regions of previously inferred basement reactivation (e.g., the southern PRA), Ross and Eaton (2001) suggested that "although evidence of basement reactivation is present locally in the Alberta Basin, its correlation with basement structural fabrics is not pervasive."

Nonetheless, new structures can and do form, they crosscut the near-basement reflection and their orientation is oblique to pre-existing structural fabrics. Whether basement faults are reactivated or are new depends on the rheology of the basement and on the orientation and rheology of pre-existing fault zones. The degree of reactivation is spatially variable and decays with distance from the Cordillera, suggesting lithosphere-scale thermomechanical control (Ross and Eaton, 2001). The role and extent of basement reactivation should be understood as the 'surficial' crustal expression of lithospheric thermal history and rheological properties, which ultimately is a reflection of plate-scale tectonic processes.

Ross and Eaton (2000) emphasized for the hydrocarbon explorationists in the Alberta Basin that "it is important to bear in mind that not all faults or shear zones are inherently zones of weakness." It is well established that deformation below the brittle-ductile transition in the crust (12–15 km depth) results in gneiss or ductile mylonite, which may become stronger than adjacent rocks (e.g., Sibson, 1977; White et al., 1980). Such processes are usually invoked to explain branching and lateral spreading of shear zones over several kilometres in width, as deformation partitioned into weaker rocks adjacent to strain-hardening regions of the shear zones (Hanmer, 1988). Ross and Eaton's (2001) point was indeed needed to balance the proliferation of the preconceived idea that basement structures throughout the basin are zones of weakness It is also important to note, however, that all major shear zones from the Shield that project under the northern WCSB are ductile shear zones with late greenschist and sub-greenschist grade overprint as a consequence of progressive exhumation during deformation. Major shear zones, such as the Great Slave Lake, Warren and Allen, include phyllosilicate minerals and crush domains that are not annealed, and have certainly evolved through strain softening and reaction weakening to become weaker than adjacent rocks and therefore a focus of deformation (White and Knipe, 1978; Wintsch et al., 1995). This leads to the development of a fault plane or fault zone that is collinear with the shear zone, but with substantially diminished rock strength, largely through the production of phyllosilicate zones (Hanmer, 1988). Such fault zones may indeed become zones of weakness that act to focus younger deformation.

The strike and dip of basement fractures relative to paleostress axes should be carefully considered before postulating structural reactivation. Also, it has been demonstrated that reactivation during extension is mechanically more likely than compressional reactivation of basement faults (Sibson, 1995).

6.2 Selected Examples of Basement Reactivation from Northern Alberta

6.2.1 Peace River Arch

The Peace River Arch (PRA) is a region of anomalous subsidence and uplift in the northern part of the Alberta Basin. It is an entirely subsurface structure, characterized by many sedimentological, structural and diagenetic aberrations (de Mille, 1958; Lavoie, 1958; Williams, 1958; Sikabonyi and Rogers, 1959; Stott, 1982; Cant, 1988).

The PRA is a northeast-trending, Late Proterozoic to Devonian basement structure developed nearly perpendicular to the northerly-trending, curvilinear basement terranes, as inferred from aeromagnetic-anomaly data and horizontal gravity-gradient maps. In addition, the length of the arch axis is greater than the width of any of the individual basement domains that it crosses, suggesting that the formation of the arch was not influenced or controlled by the Precambrian structure of the basement. There is no apparent potential-field signal associated with the PRA, which suggests that little modification of crustal properties occurred during its formation. This lack of a potential-field signal and magmatism led Ross (1990) to infer a passive flexural isostatic mechanism for PRA formation.

Seismic refraction studies demonstrate a slight thinning of the crust close to the axis of the arch (from approximately 44 to 38 km), with gently outward-dipping (away from the arch) lower crustal structure and the presence of lower crust of anomalous velocity beneath the arch. The presence of intermediate-velocity lower crust has been interpreted as reflecting the presence of mafic sills that may be the mark of a thermal driving force for the anomalous behaviour of the PRA and therefore a rift-like or thermal-extensional active mechanism of formation (Stephenson et al., 1989).

The crustal fabric that resulted from Early Proterozoic terrane collisions has been of local importance in controlling sedimentation and diagenetic processes in the sedimentary cover, but cannot account entirely for the anomalous crustal behaviour of the arch. The structural discontinuities that formed during Precambrian accretion were locally reactivated during the Phanerozoic (O'Connell, 1990). The most convincing example is the Carboniferous Dunvegan Fault, which coincides with a segment of the aeromagnetic ‘break’ between the Precambrian Ksituan and Chinchaga domains. The collapse of the basement arch and the development of the Carboniferous Peace River Embayment (PRE) were implicitly related to normal faults and graben structures (e.g., Cant, 1988). A number of basement faults documented in published geological reports over the last half century in the PRA region have vertical offsets of several hundred metres (Pană et al., 2001).

6.2.2 Great Slave Lake Shear Zone

Where exposed, the Great Slave Lake Shear Zone (GSLSZ) is “a corridor of five mylonite belts” derived in large part by deformation of the megacrystic Laloche Batholith (Hanmer, 1988). Progressively younger mylonite units represent both cooler temperatures and lower pressure, with the older units formed under granulite conditions and the youngest formed in greenschist-facies conditions. During syntectonic cooling, either isobaric or with accompanying uplift, the locus of high strain narrowed and jumped laterally, abandoning relatively older mylonite units. Thus, the sequence of narrowing mylonite belts represents a series of progressively shallower sections through the GSLSZ. Two identical greenschist-facies mylonite belts within the GSLSZ, the Laloche River and Hornby Channel ultramylonite units, consist of generally fissile rocks with chlorite, white mica, epidote and quartz. In places, 1.93 Ga granite veins cut the greenschist-facies ultramylonite belts. However, clear evidence of subsequent deformation leaves open the possibility that the GSLSZ remained a zone of crustal weakness. The granitoid veins themselves are locally foliated to protomylonitic, and the injection zone is cut by regionally concordant belts, narrower than 10 m, of chlorite-bearing mylonite zones. In addition, all mylonite types are cut by a

500 m wide zone of pervasive breccia, which in turn is cut by discrete, east-trending, vertical fault planes spaced at metre intervals.

All these tectonite zones are cut by subconcordant, vertical quartz veins (‘stockworks’) that are 25 m wide by up to 40 km long (Hanmer, 1988). Significantly, similar ‘stockworks’ within the Devonian carbonate rocks that cap the GSLSZ to the southwest are associated with the Pine Point Mississippi Valley–type (MVT) deposits (Sangster, 1995). Although no major fracture has been mapped in the Devonian sequence at Pine Point, small faults and cleavages are common (e.g., Campbell, 1967). Hydrothermal dolomitization and mineralization of the Devonian carbonate rocks are confined to two trends that coincide with scarps in the basement and line up with the GSLSZ mylonitic belts exposed on the Shield to the northeast. To the southwest, the Devonian section is disturbed by faults that coincide with or parallel the aeromagnetic trace of the GSLSZ. Devonian carbonate core from drillhole 16-34-118-21W5, located above the aeromagnetic trace of the GSLSZ, was briefly examined in the summer of 2001; at least 10 m of highly brecciated and mineralized dolomitic limestone of the Keg River Formation were intersected at a depth of approximately 1280 to 1290 m. There is a distinct possibility that the GSLSZ has accommodated stress buildups during the Mesozoic orogenies in the Cordillera.

6.2.3 Leland Lake and Warren Shear Zones

The Leland Lake and Warren shear zones, which are exposed in the Shield of northeastern Alberta, consist of high- to low-grade mylonite. Displacement along the high-grade mylonite units of the Leland Lake Shear Zone ceased before 1933 Ma (i.e., the age of the Slave granite dike that intruded and truncated the western part of the shear zone; cf. McDonough et al., 1995). The eastern margin of the shear zone is not sealed by intrusions and consists of a 50 to 500 m wide belt of lower amphibolite– to greenschist-grade mylonite derived from high-grade mylonite and Slave granite (McDonough et al., 1995). The age of the younger, low-grade mylonite has never been documented. The syntectonic mineral assemblage indicates that deformation took place under low- to very low-grade metamorphic conditions typical of shallow structural levels, which required exhumation from granulite metamorphic conditions. It is reasonable to assume that unroofing of at least 20 km of crust may have taken considerable time. Devonian facies and thickness changes (Pană et al., 2001) and local weak strain observed in outcrops at Peace Point and Vermilion Falls (Pană, 2002), along the southwesterly projection of these Precambrian shear zones, suggest Devonian and post-Devonian weak reactivation of the Leland Lake and/or Warren shear zones. Direct dating of the greenschist-facies mylonitic textures is critical in relating shear-zone reactivation to stratigraphic anomalies and observed strain in the cover sequences.

6.2.4 Allan Shear Zone

The Allan Shear Zone is a north-trending, mainly granulite-grade mylonite belt near the transition zone between the Taltson magmatic zone and Archean Rae Province rocks of northeastern Alberta. The deformed Wylie Lake intrusion (1963 Ma) and the undeformed Charles Lake granite (1932–1919 Ma) constrain the timing of high-grade deformation (McDonough et al., 1995). However, high-grade mylonite is largely overprinted by younger, predominantly sinistral deformation, and the Charles Lake granite is deformed into greenschist mylonite. A splay of the Allan Shear Zone, named the Bayonet Lake Shear Zone, consists largely of interlayered chlorite-biotite schist and quartzofeldspathic high-grade mylonite layers showing dextral S-C fabrics superposed on the older, coplanar, high-grade mylonite. Displacement on greenschist mylonite is demonstrated by the offset of pegmatite dikes that cut the high-grade mylonite. The $^{40}Ar/^{39}Ar$ data record slow regional isostatic uplift and cooling through hornblende, muscovite, biotite and K-feldspar closure temperatures (525–170°C) between ca. 1900 and 1700 Ma (Plint and McDonough, 1995). However, low-grade shear-zone activity may have continued and no direct isotope dates exist on the greenschist mylonite. The southernmost exposure of the Allan Shear Zone main branch bends southwestward under the Devonian carbonate successions of the WCSB, suggesting that it cuts obliquely through the Taltson magmatic zone in the approximate direction of the PRA–PRE. Along strike to the southwest, the Allan Shear Zone projects into the northern Birch Mountains, where a possible Jurassic south-facing scarp and several topographic lineaments point to Phanerozoic shear-zone reactivation (Pană et al., 2001).

6.2.5 Loon River Graben

Starting from the recognition of a set of lineaments trending north along the eastern slope of the Buffalo Head Hills toward the Loon River lowland, Eccles et al. (2002) have derived a structural emplacement model for kimberlites that includes Cretaceous reactivation of a major basement shear zone. In their view, the Loon River lowlands immediately east of the Buffalo Head Hills represent the topographic expression of a half graben developed above a north-trending, east-dipping, transcrustal normal detachment. A discussion of the evidence provided by Eccles et al. (2002) for their Loon River graben is beyond the scope of this review. However, a brief review of their arguments for postulating a major basement shear zone is included here. In support of their interpretation, Eccles et al. (2002) invoked previously inferred basement tectonic discontinuities in the region, including 1) a possible crustal discontinuity suggested by Ross (1990) between the 'Buffalo Head high' and the 'Utikuma Belt' subdomains of the Buffalo Head aeromagnetic domain; 2) a possible dextral shear zone offsetting the eastern part of the Devonian Peace River Arch (PRA) to the south, as suggested by Trotter (1989) and O'Connell (1990); and 3) normal faults affecting the basement–Granite Wash unconformity, identified by Angus et al. (1989).

The interpretation of a graben in the Loon River area, developed as the result of Cretaceous basement reactivation, is not precluded. However, both the original data and data selected by Eccles et al. (2002) from the geological literature should be viewed cautiously. In particular, none of the basement features mentioned above can be reliably related to the northerly-trending geomorphological feature interpreted as the western border fault of the Loon River graben. Original data on the three basement features invoked by Eccles et al. (2002) are at odds with their interpretation:

- Contrasting magnetic-field data noted between the 'Buffalo Head high' and the 'Utikuma Belt' subdomains do not correlate with variations in rock type or age (Ross, 1990). Consequently, the aeromagnetic subdomains cannot be assigned to different terranes and their boundaries are therefore likely lithological rather than tectonic. In fact, the interpretation of a possible tectonic character for the subdomains has been long abandoned, even by the original proponent (Ross et al., 1994). Secondly, even if it were tectonic, the contact originally suggested by Ross (1990) is, in fact, 50 to 100 km west of the Loon River lowlands.

- The original interpretation of a southwesterly convex trace of a dextral shear zone across the PRA was derived from ambiguous evidence: although arbitrarily traced, the PRA boundaries were used by the original authors (Trotter, 1989; O'Connell, 1990) as markers to support the offset along the postulated shear zone, whereas the Granite Wash isopachs used to define the PRA are not offset by this shear zone. Consequently, the original interpretation of a shear zone is highly speculative. It is unclear how this curvilinear, southwestward-convex shear zone, if present, relates kinematically to the straight, northerly-trending, normal fault that is supposed to mark the western boundary of the Loon River graben of Eccles et al. (2002). Finally, as with the Buffalo Head–Utikuma contact, the trace of this postulated shear zone is located tens of kilometres west of the Loon River lowlands.

- The spatial relationships of the horst and graben structures defined in subsurface by Angus et al. (1989) and the Loon River graben postulated by Eccles et al. (2002) are unclear. Firstly, the original cross-sections by Angus et al. (1989) encompass transects that are one order of magnitude smaller than the inferred graben. Secondly, two of the four cross-sections reproduced, with permission, by Eccles et al. (2002) in support of their interpretation, are parallel to their northerly-trending fault bordering the Loon River graben, and thus depict differently oriented horst and graben structures.

To conclude with respect to the structural setting of the Buffalo Head Hills and Loon River lowlands, existing subsurface data (e.g., Keith, 1990) indicate that a northwesterly-trending zone of enhanced Late Paleozoic subsidence does underlie the south-central Buffalo Head Hills and a northerly-trending zone of Devonian subsidence roughly underlies the Loon River lowlands (*see* compilation by Pană et al., 2001). However, the correlation between the possibly basement-controlled Paleozoic troughs, the subsequent depositional features and the straight, northerly-trending eastern slope of the Buffalo Head Hills remains, at best, speculative and needs to be further investigated.

7 Discussion and Conclusions

The crustal structure of the basement is key to understanding the sedimentary and diagenetic patterns in the WCSB. In the absence of the constraints imposed by outcrop map, the geological map of the sub-WCSB Precambrian basement must be based on all available geological and geophysical data. Petrological and geochronological information extracted from basement core, combined with potential-field data, seismic-reflection profiling and analogies with exposed and/or better studied regions of the Shield can all enhance the mapping of shallow basement in the subsurface of the WCSB.

Existing data suggest that most of the WCSB in northern Alberta is floored by granulite terranes with major batholitic complexes. It appears that sialic crust has been differentiated from the mantle during the Archean and reactivated by the Hudsonian tectonomagmatic events. Although not precluded, a Kenoran tectonomagmatic event (2800–2400 Ma), inferred by Burwash et al. (1994), remains to be unequivocally documented.

Archean inheritance in the basement of northern Alberta is suggested by Sm-Nd model ages greater than U-Pb emplacement ages. Early and Middle Archean rocks (greater than 2900 Ma) occur in the exposed parts of the Slave, Superior and Wyoming provinces. The Slave and Superior provinces extend beneath the Phanerozoic cover of the southern District of Mackenzie and southwestern Manitoba. The extension of the Wyoming craton into southern Alberta, as indicated by a U-Pb zircon age of 3278 +22/–21 Ma (Villeneuve et al., 1993), supports the assumption that Archean crustal fragments, reactivated and welded into Laurentia, extend beneath the WCSB. The Superior, Slave and Wyoming cratons and their extensions play a critical role in the basement of the WCSB (Burwash, 1994).

Two major Hudsonian magmatic belts can be traced from the exposed Shield beneath the WCSB in northern Alberta. To the west of the Slave Province, the Wopmay Orogen extends beneath the cover rocks of northern Alberta, west of the Archean core sample, and is truncated by the GSLSZ. To the east of the Slave Province, the Taltson–Thelon magmatic zone (Bostock et al., 1991) can be traced southward from the GSLSZ to the Snowbird Tectonic Zone (STZ). Across central Alberta, the STZ is accompanied by the Central Alberta igneous belt (Burwash et al., 2000).

Transcurrent movement along the major northeast-trending shear zones, including the GSLSZ and STZ, left a clear magnetic signature, especially where they offset magmatic arcs. Phanerozoic reactivation of some of these major and minor basement structures has played an important role in the stratigraphic record of the WCSB.

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