Contents

Subsurface structures in southern Northwest Territories and northern Alberta: Implications for mineral and petroleum potential

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Morrow, D.W., MacLean, B.C., Miles, W.F., Tzeng, P., and Pană, D., 2006: Subsurface structures in southern Northwest Territories and northern Alberta: Implications for mineral and petroleum potential; *in* Potential for Carbonate-hosted Lead-zinc Mississippi Valley-type Mineralization in Northern Alberta and Southern Northwest Territories: Geoscience Contributions, Targeted Geoscience Initiative, (ed.) P.K. Hannigan; Geological Survey of Canada, Bulletin 591, p. 41–59.

Abstract: Subsurface mapping indicates that the region northwest of the Great Slave Shear Zone contains an array of previously identified northeast-trending faults and fault zones that cross abrupt inflections of contours on structure and isopach maps. The Tathlina Fault Zone, the Rabbit Lake Fault Zone, and the Cameron Hills Structure (formerly "Hay River Fault Zone") are all large, northeast-trending fault arrays that lie northwest of the shear zone. Southeast of the shear zone, contours on subsurface structure maps display fewer pronounced inflections, and inferred faults are fewer in number except in the Peace River Arch area. A new feature defined in this study, the Enterprise Structure, extends northeast near and subparallel to Hay River.

Aeromagnetic and seismic data demonstrate the presence of subvertical faults, and a large, well-defined magnetic "low" extends about 70 km northwest from the Great Slave Shear Zone at the west end of Buffalo Lake.

Résumé : La cartographie de la subsurface indique que la région située au nord-ouest de la zone de cisaillement du Grand lac des Esclaves renferme des zones de failles et des failles à orientation nord-est, reconnues préalablement, qui recoupent des inflexions abruptes des courbes sur les cartes des structures et les cartes des isopaques. La zone de failles de Tathlina, la zone de failles de Rabbit Lake et la structure de Cameron Hills (anciennement la « zone de failles de Hay River ») constituent toutes de vastes faisceaux de failles de direction nord-est qui se trouvent au nord-ouest de la zone de cisaillement. Au sud-est de la zone de cisaillement, les courbes de niveau des cartes des structures subsuperficielles présentent un nombre moins élevé d'inflexions prononcées et les failles présumées sont moins nombreuses, sauf dans la région de l'arche de Peace River. La structure Enterprise, une nouvelle entité définie lors de cette étude, s'étend vers le nord-est près de la rivière Hay et lui est presque parallèle.

Des données aéromagnétiques et sismiques révèlent la présence de failles subverticales, alors qu'un grand « creux » magnétique bien délimité s'étend vers le nord-ouest sur environ 70 km à partir de la zone de cisaillement du Grand lac des Esclaves à l'extrémité ouest du lac Buffalo.

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INTRODUCTION

Figure 1 outlines the area of investigation in this report. This area, bounded by latitudes 56°30' and 62°00' north and by longitudes 110°00' and 120°00' west, coincides with the subject area of a Targeted Geoscience Initiative project (TGI project number 232-110-010009) that began in the spring of 2001. This project is jointly operated and funded by the Geological Survey of Canada, the Alberta Geological Survey and the Government of the Northwest Territories, and is motivated by the need to understand the regional potential for lead-zinc mineralization in Alberta and in the Northwest Territories. Exploration for oil and gas provides additional motivation for this study, particularly for carbonate-hosted reservoirs that are similar to the dolomitized host rock of "Mississippi Valley Type" lead-zinc deposits.

One world-class lead-zinc deposit occurs within the study area. The Pine Point Mine, located along the south shore of Great Slave Lake (Fig. 1), has produced 70.8 million tons of 3.3% lead and 7.0% zinc during a production history extending from 1964 until 1988 (Rhodes et al., 1984; Brophy, 1987; Ellis and Hearn, 1990; Ellis, 1995). Mineralization occurs as galena (PbS) and ruddy brown sphalerite (ZnS). Ninety-seven (97) individual deposits have been defined within the Pine Point mining camp, but only about half (46) of these have been mined. Almost all producing deposits were

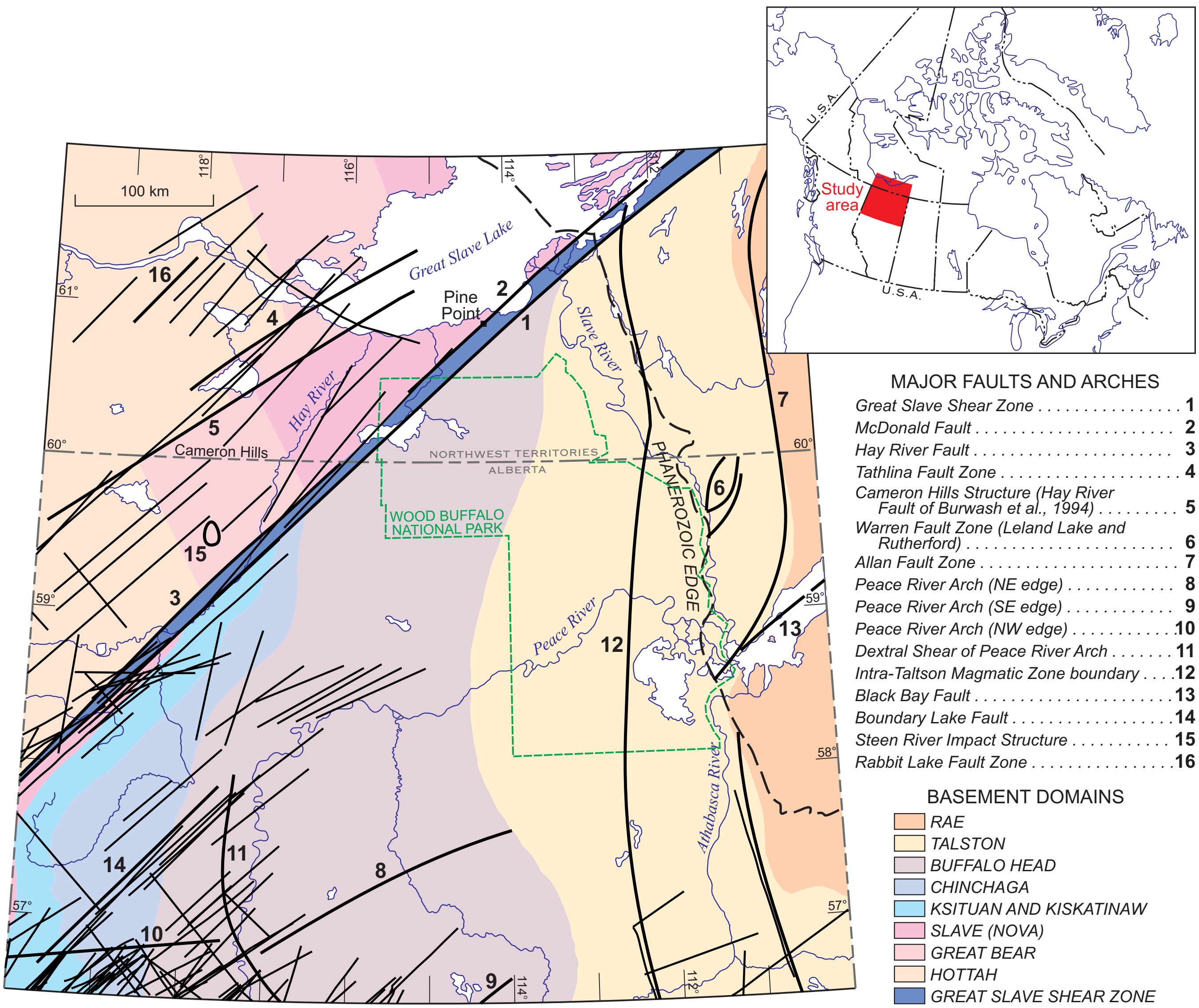


Figure 1. Study area for Targeted Geoscience Initiative (TGI) project number 232-110-010009. Known faults (Pană et al., 2001; Williams, 1977), basement domains, and other major structural features, such as the Steen River impact structure, are shown. The projection parameters adopted for GIS maps used in this project are followed here (Universal Transverse Mercator projection Zone 11 in northern hemisphere using the 1983 North American Datum).

near surface and were mined by open pit methods. Underground mining of the many slightly deeper deposits was largely precluded by economic considerations.

Several aspects of this deposit warrant recognition. It is situated 500 to 600 km east of the Cordilleran disturbed belt or mountain front. The deposit itself conforms in most respects to the classic "Mississippi Valley Type" (MVT) lead-zinc deposits (e.g. Sangster, 1995) in that the mineralization tends to occur as carbonate-hosted stratiform bodies or at least in masses that are of limited vertical extent with little or no evidence of direct structural control on the development of individual orebodies or on the style of mineralization within orebodies, and there is no association with known igneous bodies (Rhodes et al., 1984). These are salient characteristics of the type MVT deposits in the classic Tri-State District of the southern United States (Gregg, 1985; Sangster, 1995). Pine Point is also similar to the classic MVT deposits in its strong association with white dolospar, which is intimately intergrown with ore minerals and which has largely replaced limestone host rock (Gregg, 1985).

However, in the important aspect concerning the degree of structural control, the Pine Point deposit does not conform to the commonly accepted Tri-State District model for MVT lead-zinc deposits. Unlike deposits in the Tri-State District, the Pine Point deposit is situated immediately adjacent to the northwest side of a prominent, crustal-scale structure, the Great Slave Shear Zone (Fig. 1). This raises the possibility that there was some measure of direct structural control on ore deposition at Pine Point. Some workers have suggested that proximity to the Great Slave Shear Zone was an important factor in the development of the Pine Point deposit (Nelson et al., 2002) and that there was even a subregional structural control on the distribution of orebodies at Pine Point by a local set of east-west faults extending westward from the Great Slave Shear Zone to Pine Point (Skall, 1975). Recently, however, some degree of regional structural control has also been suggested for the classic Tri-State MVT district lead-zinc deposits and there is a growing appreciation that fluid movements responsible for MVT mineralization tended to be focused along faults bordering rift basins, such as the Reelfoot Rift, which are near the Tri-State MVT deposits (e.g. Keller et al., 2000).

Following the growing perception that structural features may have influenced, or focused, the subsurface movement of mineralizing fluids, the purpose of this report is to identify structures, mainly faults or fault zones, that could have acted as potential subsurface fluid conduits. Similarly, such structures may have played a role in the migration and emplacement of hydrocarbons. Regional faults in many subsurface settings have been suggested also to have influenced, or localized, the regional development of white, coarse-crystalline dolospar (e.g. Hurley and Budros, 1990) that is the common associate of MVT lead-zinc deposits and which is a favoured reservoir rock for petroleum reservoirs. Many faults, or fault zones have been previously identified and delineated in the Interior Plains of northern Alberta and southern Northwest Territories (Pană et al., 2001; Fig. 1). Figure 1 provides a background framework of previously identified linear structural elements, many of which have been interpreted to be faults or fault zones.

On Figure 1, major faults or fault zones are emphasized with bold linework and are cited by name. The defining criteria for all faults, fault zones, and structures illustrated are described briefly in Pană et al. (2001), although only the more recent references are cited. Williams (1977) is also a key reference for this study, because of its descriptions of the Rabbit Lake and Tathlina fault zones, supported by structure contour maps. These faults, unlike many other subsurface faults, display surface offsets of several kilometres, documented on geological maps (Douglas, 1974). In addition, the Tathlina Fault Zone corresponds to a sharp aeromagnetic boundary (e.g. Aspler et al., 2003). Most of the faults displayed on Figure 1 have been inferred from inflections on subsurface contour maps. Only a few faults, or fault zones, such as the Tathlina Fault Zone, have been corroborated by multiple criteria. Also shown on this figure is the large Wood Buffalo National Park straddling the border between the Northwest Territories and Alberta. This park area is a large "data gap" where no petroleum borehole data are available.

In this study, the "Hay River Fault" of Burwash et al. (1994; Fig. 1, no. 5) has been renamed the Cameron Hills Structure for reasons of clarity and because a major part of this structure passes through the Cameron Hills (Fig. 1) of the southern Northwest Territories. The "Hay River Fault" of Burwash et al. (1994) is different from the Hay River Fault as originally defined by Sikabonyi and Rogers (1959) (see also Ross et al., 1994), and which is the southward continuation of the McDonald Fault along the northwest side of the Great Slave Shear Zone into Alberta (Fig. 1).

One new structural feature is described in this study. The "Enterprise Structure" is a possible fault zone extending northeast at a low angle across Hay River (Fig. 2). It is named here after the hamlet of Enterprise, which is located along Hay River in the Northwest Territories.

Types of data used in this study include subsurface formation tops from well boreholes, publicly available seismic data from the southern Northwest Territories (Fig. 2, 3), and geophysical potential field data. Each of these types of data has advantages and limitations for structural interpretation.

Structure surface maps are constructed by using formation tops, particularly for platform carbonate units, such as the top of the Slave Point Formation, that have planar, approximately isochronous contacts in the subsurface, or by using interregional unconformities, such as the base of Phanerozoic unconformity or the unconformity at the base of the Watt Mountain Formation (Fig. 4, 5). Abrupt departures from regional trends displayed by these maps can be used to infer the existence of faults, or other subsurface structures (e.g. Williams, 1977). The usefulness of this type of data is directly dependent on the spatial density and homogeneity of well control.

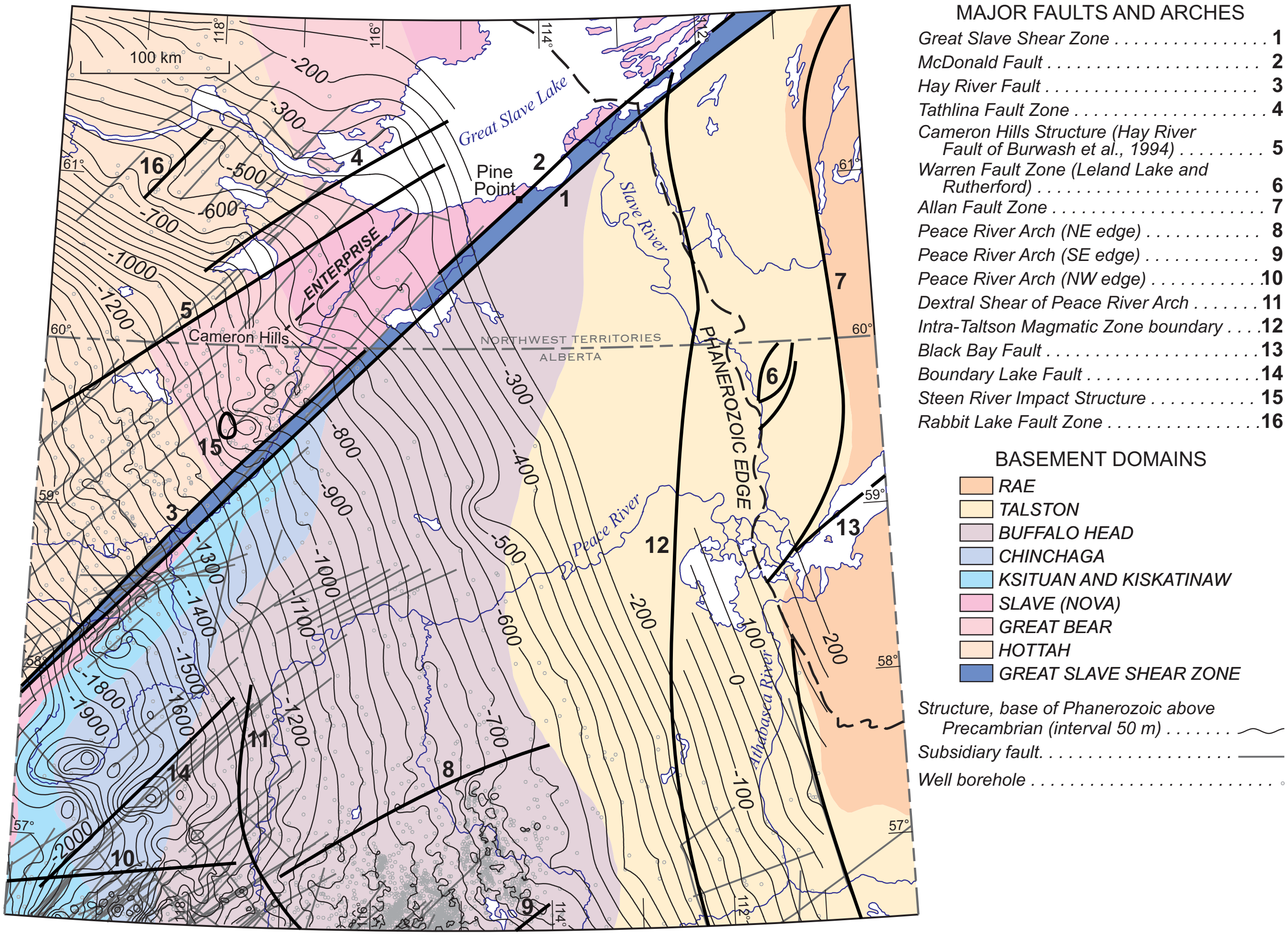


Figure 2. Structure surface map of the base of Phanerozoic unconformity above the Precambrian. A uniform southwestward dip is particularly evident southeast of the Great Slave Shear Zone. The contour interval is 50 m. The Enterprise and Cameron Hills structures are named in this study.

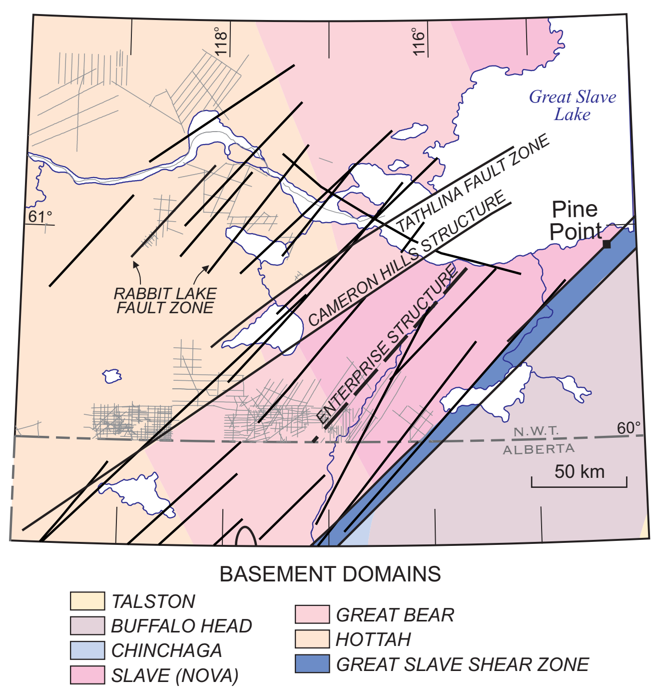
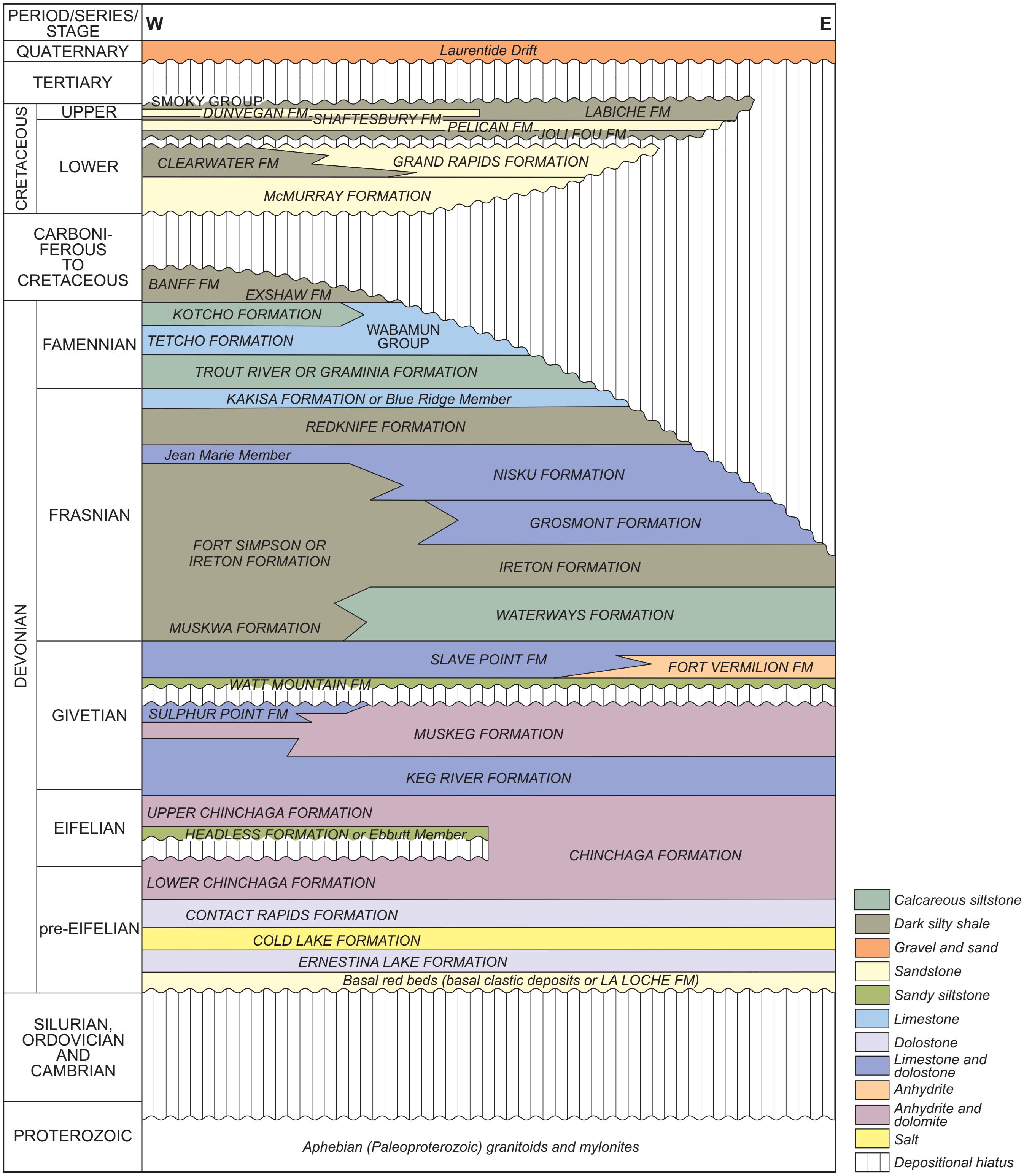
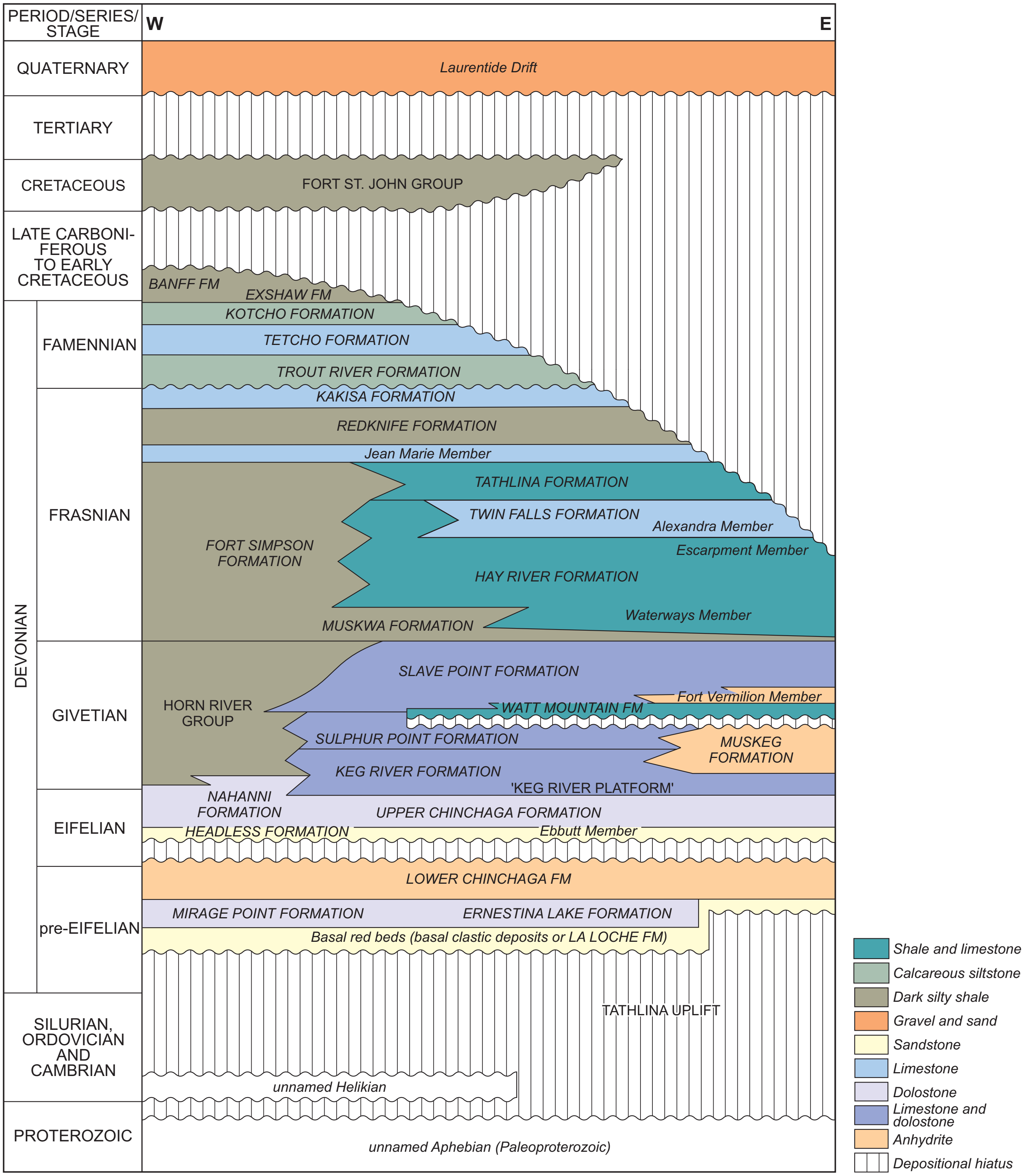


Figure 3. Map of publicly available seismic within the TGI project study area. Previously mapped faults and basement domain boundaries are shown (see Fig. 1). The Enterprise Structure extending northeast near Hay River is a new feature named in this study. The Cameron Hills Structure (formerly the "Hay River Fault" of Burwash et al., 1994) has been renamed here (see text for discussion).



The Presqu'ile Dolomite has replaced large parts of the Sulphur Point and Slave Point formation limestone. In the Cretaceous succession the thin 'Fish Scales Zone' marks the boundary between Upper and Lower Cretaceous at the base of the Shaftesbury Formation. Groups of formations in the Devonian include: the Elk Point Group, comprising strata between and including Devonian basal clastic deposits, Granite Wash or La Loche and the Watt Mountain; the Beaverhill Lake Group, comprising the Slave Point, Waterways and their equivalents; the Woodbend Group, comprising the Ireton, Grosmont and their equivalents; the Winterburn Group, comprising strata between and including the Nisku and Trout River; and the Wabamun Group, including the Tetcho and Kotcho. Groups of formations in the Cretaceous include: the Mannville Group, comprising strata between and including the McMurray and the Grand Rapids; the Colorado Group, comprising strata between and including the Joli Fou and LaBiche, and the undifferentiated Smoky Group.

Figure 4. Stratigraphic nomenclature and schematic stratigraphic relationships along an east-west transect across northern Alberta.



The Presqu'ile Dolomite has replaced large parts of the Sulphur Point and Slave Point formation limestone. Farther west, the Presqu'ile Dolomite merges with the Manetoe Dolomite which has replaced parts of the Nahanni and Landry formation limestone (Landry equivalent to upper part of Lower Chinchaga). The La Loche Formation is a basal Devonian unit that is commonly called Basal Clastics, or Granite Wash in well descriptions. The Mirage Point Formation occurs where the basal clastic deposits are thick and include carbonate and evaporite correlative with, and similar to, the Ernestina Lake.

Groups of formations in the Devonian include: the Elk Point Group comprising strata between and including Devonian basal clastic deposits, Granite Wash or La Loche and the Watt Mountain; the Beaverhill Lake Group, comprising the Slave Point, Waterways and their equivalents; the Grumbler Group, comprising strata between and including Twin Falls and Kakisa; and the Horn River Group, including bituminous limestone and shale, and other unnamed shales. The Alexandra Member is the basal member of the Twin Falls Formation. The Fort St. John Group is the sole Cretaceous group.

Figure 5. Stratigraphic nomenclature and schematic stratigraphic relationships along an east-west transect across southern Northwest Territories in the Slave Plain east of Trout Lake.

Grids of petroleum industry seismic lines permit a more direct means of assessing the character of the Keg River to Slave Point interval in the shallow subsurface west of Pine Point and Buffalo Lake (Fig. 3). The detailed work of Rhodes et al. (1984) at Pine Point provides a physical model or analogue for the internal stratigraphy of possible mineralized intervals within the Keg River to Slave Point succession in the subsurface west of Pine Point. At Pine Point, the lateral continuity of beds within the Keg River to Slave Point succession has been severely disrupted by the large tabular and prismatic lead-zinc orebodies that locally extend stratigraphically upward from the base of the Keg River Formation to within the lower part of the Slave Point Formation. Stratigraphic disruptions similar to these can be identified in the subsurface along some seismic lines west of Pine Point. Detailed structural mapping of subsurface contacts based on seismic data is presented in another paper in this volume and inferences concerning fault development based on this data is presented there (MacLean, 2006). Interpretations of selected seismic lines from more prospective areas near Pine Point are shown here to document particular structures and to illustrate variations in the internal stratigraphy of the Keg River to Slave Point stratigraphic interval that may be analogous to Pine Point stratigraphy.

Geophysical potential field data used in this study included the residual total magnetic field and the first vertical derivative of the residual total magnetic field. The first vertical derivative of the total magnetic field was selected to emphasize subvertical magnetic contrasts in the Precambrian basement because the vertical derivative passes through very pronounced maxima and minima across steeply dipping magnetic contacts (Hood, 1965). Most of this data was acquired at data acquisition line spacings of more than 1000 m, which, in the most prospective region immediately southwest of Pine Point, is generally less than the depth to Precambrian basement. This grid spacing is probably too broad to discern typically very low intra-Phanerozoic magnetic contrasts but it is adequate to characterize contrasts with wavelengths of a kilometre or greater in the sub-Phanerozoic basement (e.g. Prieto, 1998). The part of the study area south of 60° has recently been the subject of a comprehensive regional-scale investigation of potential field signatures of Precambrian basement domains (Pilkington et al., 2000) and is not repeated here.

Magnetic data are used in preference to gravity data in this study because the magnetic signal is influenced primarily by magnetization contrasts at, or near, the basement surface whereas the gravity signal has contributions from the entire lithosphere from the surface to the mantle (Pilkington et al., 2000; Prieto, 1998). The underlying interpretive assumption is that abrupt changes in the magnetic signal highlighted by the vertical derivative may correlate with basement structures. Basement magnetic contrasts were correlated with basement-involved faulting visible on seismic lines in the region immediately southwest of the Pine Point deposit on Great Slave Lake where the post-Precambrian Phanerozoic cover is thin.

STRUCTURE AND ISOPACH DATA

Figures 2 and 6–11 are a series of structure and isopach maps incorporating formation-top information from wells across the entire project area. These maps also display all previously identified faults included in the compilation of Pană et al. (2001) and the Precambrian basement domains of Ross et al. (1994). In addition to the assemblage of previously identified faults compiled by Pană et al. (2001), three fault traces included in the Rabbit Lake Fault Zone of Williams (1977) and one additional fault trace identified in this study occurring immediately west of the Rabbit Lake Fault Zone have been included in the set of fault traces illustrated on the maps (e.g. Fig. 1) of this study. These additions to the compilation of Pană et al. (2001) are discussed in more detail below.

There is considerable variation in the density of well control across the study area. Areas of more active exploration and petroleum development, such as the Peace River Arch region in the southwest corner of the study area, contain relatively dense well control. The Rainbow Lake oilfields of northwestern Alberta found immediately northwest of the Great Slave Shear Zone represent the other extensive region of dense well control. In contrast to these regions, the northern and central parts of the study area have sparse well control, particularly in Wood Buffalo National Park (Fig. 1) of northern Alberta and southernmost Northwest Territories. Nonetheless, the series of subsurface structure contour and isopach maps presented here are derived from much more subsurface information than previous analyses of regional fault development based upon sparser well control (e.g. Sikabonyi and Rodgers, 1959).

The base of Phanerozoic structure map displays a moderately uniform southwestward dip of about 4.2 m per km southeast of the Great Slave Shear Zone (Fig. 2). Northwest of the Great Slave Shear Zone the base of Phanerozoic structure map displays more variable southwestward dips and also displays a marked change in structural strike from northwestward near the Great Slave Shear Zone and the McDonald Fault to a much more east-west orientation north of 61° latitude (Fig. 2). In spite of the obscuring effect of regional variations in the density well control, there is a discernable difference in fault distributions across the Great Slave Shear Zone. The region lying northwest of the Great Slave Shear Zone contains relatively uniformly distributed northeast-trending faults or fault zones. Southeast of the shear zone, documented faults tend to be restricted to the Peace River Arch region.

Differences in the development of faulting in regions north and south of the Great Slave Shear Zone, may, in large part, be related to the distinctly different Proterozoic histories of these regions. In Paleoproterozoic time (ca. 1.9 Ga), the Archean Slave microcraton is interpreted to have collided with the Archean Churchill Province of ancestral North America (Gibb, 1978; Hoffman, 1987; Henderson et al., 1990). In this interpretation, profound dextral transcurrent motion occurred along the southern plate boundary of the

Slave microcraton. This dextral motion of up to 700 km formed the intensely sheared Great Slave Shear Zone (Hoffman, 1987). Additional, postcollisional dextral brittle displacement of about 70 to 90 km has also occurred along the McDonald Fault, which bounds the northeast side of the Great Slave Shear Zone.

If the interpretations of Gibb (1978), Hoffman (1987), and Henderson et al. (1990) are correct then the Great Slave Shear Zone is a crustal-scale kinematic boundary. North of this boundary, strong eastward-directed and/or northeastward-directed stresses caused development of numerous transcurrent northeast and northwest-trending faults in the Paleoproterozoic Wopmay Province flanking the west side of the Slave Province. Hoffman (1987) suggested that these faults developed as the result of the later collision between the Great Bear (Fig.1) and Fort Simpson Domain magmatic arcs in a post 1.85 Ga Proterozoic event. South of this boundary, eastward-directed stress was much less with a consequently much lesser development of Proterozoic faulting. It seems reasonable to suggest that times of high Phanerozoic stresses (e.g. Laramide Orogeny) may have reactivated these older faults in Phanerozoic time.

Structural and isopach data northwest of the Great Slave Shear Zone

Northwest of the Great Slave Shear Zone there are many pronounced inflections, or abrupt changes in contour directions for groups of contours in local areas. Many of these contour inflections can be related to previously identified or named faults. The Cameron Hills Structure coincides with a pronounced deflection of base of Phanerozoic contours along parts of its length (Fig. 2). Deflection of structure contours across the Cameron Hills Structure is less obvious on the Watt Mountain and Slave Point structure maps (Fig. 6, 7) but is a little more apparent on the Jean Marie and Grosmont structure maps (Fig. 8, 9). The base of Phanerozoic to Jean Marie top isopach map provides some corroborative evidence for the continuation of the Cameron Hills Structure to the southwest where this zone separates abrupt thickness changes of this isopach interval (Fig. 10). The Cameron Hills Structure also coincides with an apparent dextral offset of the Slave, Great Bear, and Hottah Precambrian basement domains (e.g. Aspler et al., 2003) and was originally defined on this basis, as the "Hay River Fault" of Burwash et al. (1994).

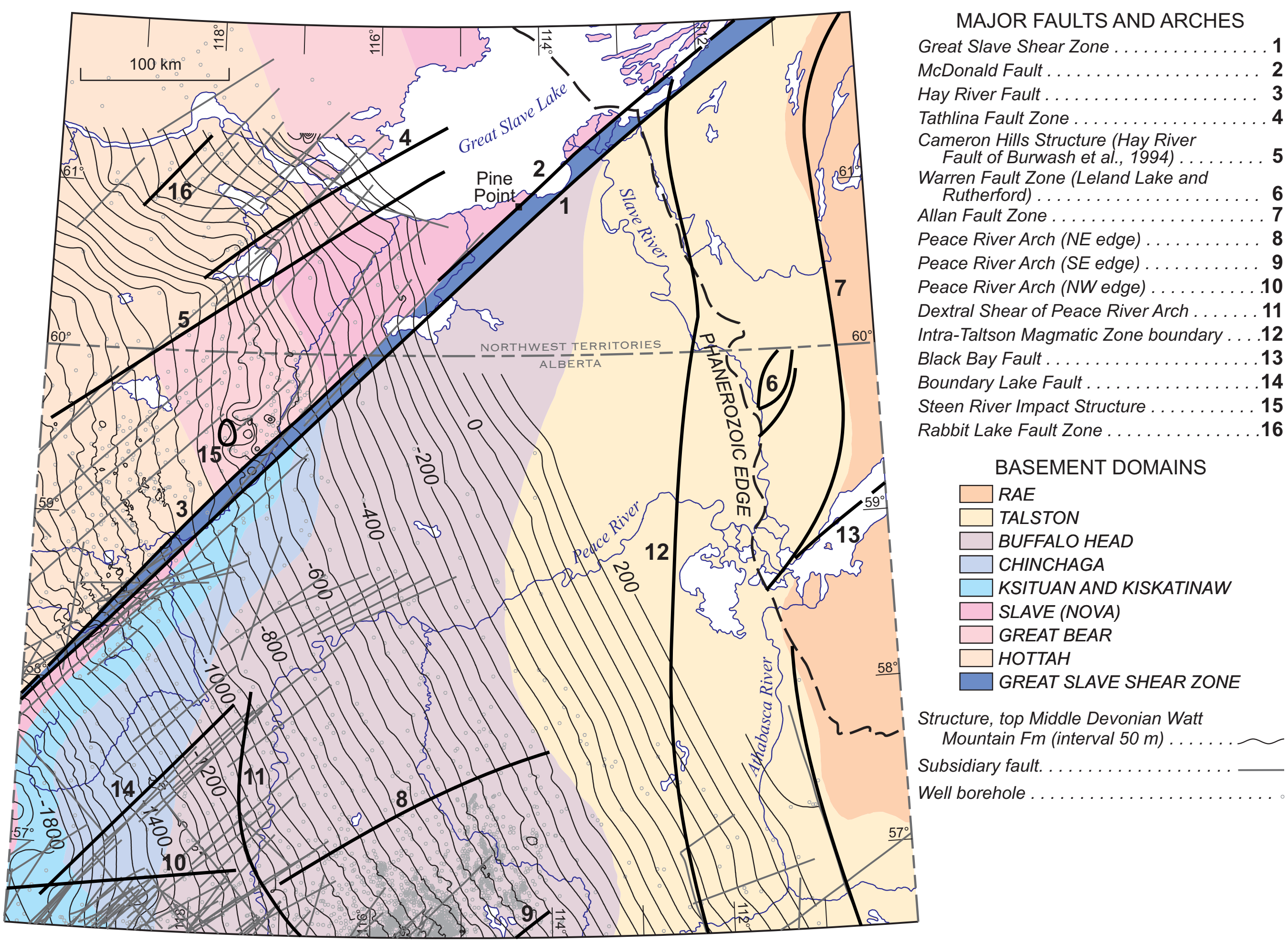


Figure 6. Structure surface map of the top of the Middle Devonian Watt Mountain Formation. The contour interval is 50 m.

Between the Cameron Hills Structure and the McDonald Fault along the Great Slave Shear Zone lies a region with numerous small northeast-trending faults (Fig. 2, 6–10). Most of these coincide with contour deflections on the base of Phanerozoic structure map as well as on the stratigraphically higher structure maps, particularly in the region of the Rainbow oilfields in northwestern Alberta (59 to 60° latitude; see Barss et al., 1970). The Steen River Impact Structure, dated at 95 Ma (Carrigy, 1968), lies at the northeast and southwest ends of two individual faults (Fig. 2). Northeast of the Steen River Impact Structure northeast-trending faults also coincide with basement contour deflections subparallel to Hay River (Fig. 2) as well as with more subdued contour deflections at all mapped higher stratigraphic levels (Fig. 6–10).

Contour deflections are particularly prominent along an axis subparallel to Hay River itself (Fig. 2, 3) between the Cameron Hills Structure and the McDonald Fault. Several previously published faults (Fig. 2; Sikabonyi and Rogers, 1959) lie close to this contour deflection axis, which is shown as a dashed line on Figure 2. It is likely that some degree of post-Precambrian faulting and/or flexure occurred approximately along this axis, which is named here the "Enterprise Structure" after the small hamlet of Enterprise located along the Enterprise Highway that extends northeast to the city of Hay River at the mouth of Hay River on Great Slave Lake. The axis of this basement structure crosses Hay River at a shallow angle (Fig. 2).

Northwest of the Cameron Hills Structure, the Tathlina Fault Zone (Williams, 1977) is another major northeast-trending structure (Fig. 2, 3). It is one of very few faults in the Interior plains that has a documented offset of the surface map pattern of Upper Devonian formations (Twin Falls to Trout River formational succession) along the northwest side of Tathlina Lake (Douglas, 1974; Fig. 3) as well as inferred offsets of Paleozoic strata in the subsurface (Williams, 1977). Like the Cameron Hills Structure, the Tathlina Fault coincides with an apparent dextral offset of basement domains (Fig. 1, 2; Aspler et al., 2003).

West of the Tathlina Fault lies an array of four previously identified northeast-trending faults that together comprise the Rabbit Lake Structure, or Rabbit Lake Fault Zone (Williams, 1977; Fig. 3). The westernmost of these is identified as the

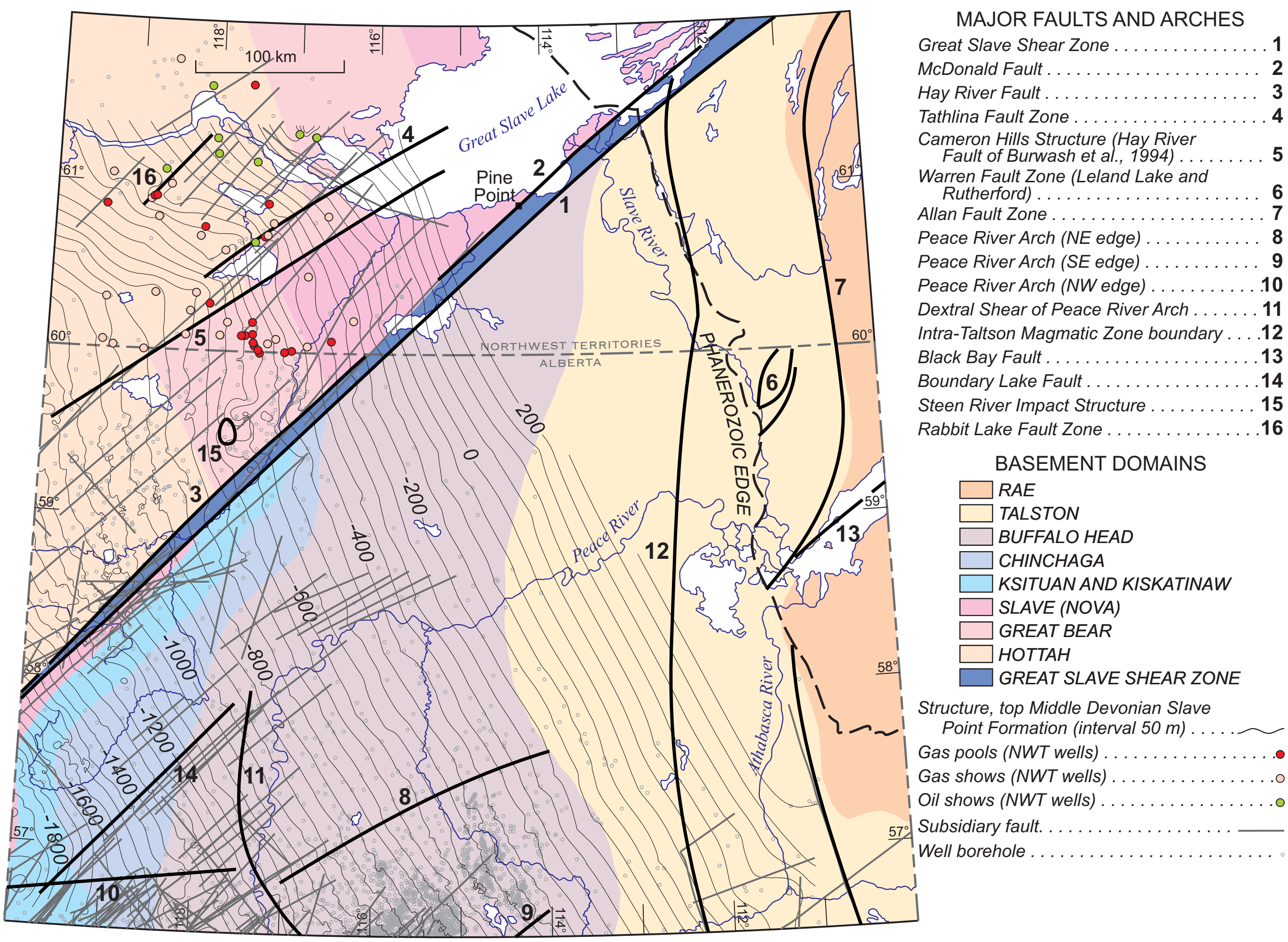


Figure 7. Structure surface map of the top of the Middle Devonian Slave Point Formation. The contour interval is 50 m. Also indicated are gas pools, gas shows, and oil shows in Northwest Territories wells. These all occur within the Keg River to Slave Point succession, with most occurring within the Slave Point.

Rabbit Lake Fault Zone on subsurface maps (e.g. Fig. 1, 2). All of these previously described faults coincide with abrupt contour deflections (Fig. 2, 6–9). The fault trace drawn immediately west of the Rabbit Lake Fault Zone of Williams (1977) on these maps is inferred from contour deflections on all structure and isopach maps shown here. This fault should probably be regarded also as part of the Rabbit Lake Fault Zone. The Rabbit Lake Fault Zone is not included in the compilation of Pană et al. (2001).

Additional data from a series of shallow-structure test holes (J.C. Sproule and Associates, 1956; 1957: Tables 1 and 2) provide further evidence for the presence of faults along the Tathlina and Rabbit Lake fault zones. A structure contour map of the top of the Kakisa Formation west of Tathlina Lake, shown in Figure 11a, shows a steep southeastward dip that coincides with the Rabbit Lake Fault Zone. The pronounced structural dome in the northwest corner of the map and northeast of the Rabbit Lake Fault Zone, is the Rabbit Lake Anticline of Williams (1977). The structure contour map of the top of the Twin Falls Formation around Tathlina Lake, shown in Figure 11b, also displays strong contour deflections along the Tathlina Fault Zone.

Some of these faults and fault zones have played a role in the development of oil and gas pools in fault-related structural traps within the Keg River to Slave Point succession. A gas pool is contained in a structural dome (Rabbit Lake Anticline) flanking the west side of the Rabbit Lake Fault Zone (Williams, 1977; Fig. 7).

Unfortunately, well density drops off abruptly east of 116° longitude (e.g. Fig. 7), which greatly hampers interpretation in the shallow subsurface of the critical region prospective for accessible near-surface lead-zinc mineralization immediately west and south of the Pine Point deposits. It is reasonable, however, to assume that many fault zones northeast of the Great Slave Shear Zone have eastward continuations beyond areas where subsurface corroboration from well control is possible.

Structural and isopach data southeast of the Great Slave Shear Zone

Southeast of the Great Slave Shear Zone, deflections of structure contours are less pronounced than northwest of the Shear Zone. This is particularly true of the Watt Mountain and Slave Point structure contour maps (Fig. 6, 7). These

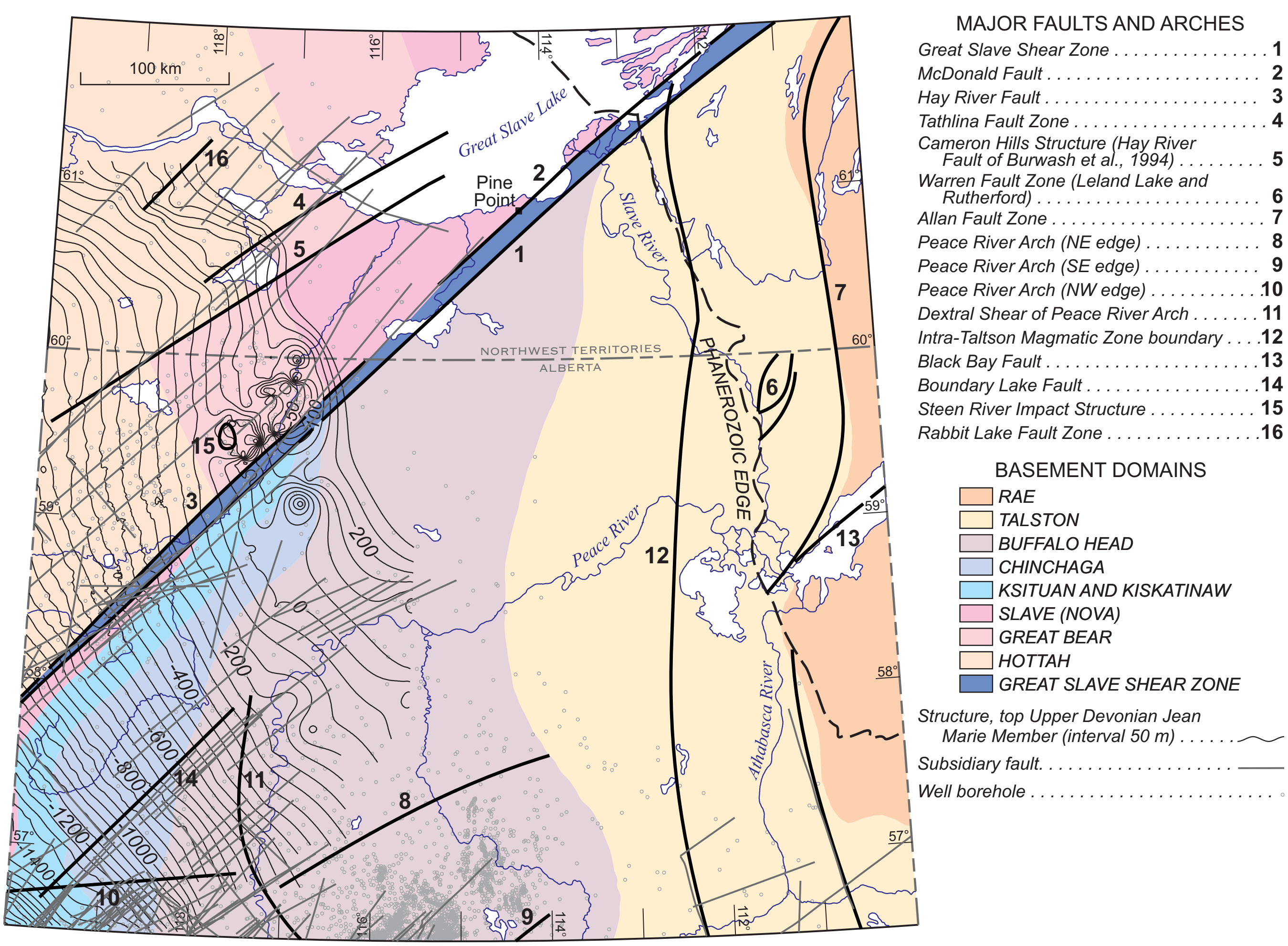


Figure 8. Structure surface map of the top of the Upper Devonian Jean Marie Member. The contour interval is 50 m.

Table 1. Structure test-hole data for the top of the Twin Falls Formation in the Tathlina Lake area reported in Sproule and Associates (1956, 1957)

Station number	Year	Location		KB		TD		Twin Falls Formation*		
									Metres	
		Latitude	Longitude	Feet	Metres	Feet	Metres	Feet	Depth	Subsea
1	1956	60.74580	117.45420	882	268.8	374	114.0	660	201.2	67.7
2	1956	60.71330	117.40330	920	280.4	295	89.9	580	176.8	103.6
3	1956	60.75170	117.37000	873	266.1	132	40.2	437	133.2	132.9
7	1956	60.75170	117.28420	860	262.1	124	37.8	404	123.1	139.0
8	1956	60.78500	117.33000	809	246.6	321	97.8	322	98.1	148.4
10	1956	60.74580	117.37170	877	267.3	161	49.1	430	131.1	136.2
14	1956	60.74750	117.33000	873	266.1	508	154.8	418	127.4	138.7
19	1956	60.78830	117.28250	816	248.7	227	69.2	187	57.0	191.7
22	1956	60.77000	117.36670	845	257.6	122	37.2	505	153.9	103.6
23	1956	60.50420	117.09667	944	287.7	300	91.4	615	187.5	100.3
29	1956	60.53670	117.00080	966	294.4	123	37.5	493	150.3	144.2
31	1956	60.81330	117.21830	803	244.8	151	46.0	134	40.8	203.9
32	1956	60.85670	117.27920	794	242.0	147	44.8	113	34.4	207.6
33	1956	60.85330	117.25000	803	244.8	124	37.8	107	32.6	212.1
34	1956	60.85170	117.21991	809	246.6	144	43.9	112	34.1	212.4
36	1956	60.84580	117.16250	846	257.9	127	38.7	117	35.7	222.2
37	1956	60.84170	117.13330	856	260.9	155	47.2	98	29.9	231.0
38	1956	60.81170	117.16250	818	249.3	161	49.1	172	52.4	196.9
1	1957	60.77691	117.32870	811	247.2	145	44.2	236	71.9	175.3
2	1957	60.79109	117.32870	811	247.2	289	88.1	393	119.8	127.4
3	1957	60.79225	117.29977	776	236.5	151	46.0	149	45.4	191.1
4	1957	60.79861	117.25203	767	233.8	188	57.3	154	46.9	186.9
7	1957	60.81366	117.19213	779	237.4	171	52.1	132	40.2	197.2
8	1957	60.78414	117.32870	767	233.8	151	46.0	85	25.9	207.9
9	1957	60.83145	117.28067	759	231.3	212	64.6	155	47.2	184.1
10	1957	60.83058	117.19097	781	238.1	144	43.9	95	29.0	209.2
11	1957	60.82248	117.14902	800	243.8	147	44.8	117	35.7	208.2
12	1957	60.80208	117.28183	766	233.5	141	43.0	141	43.0	190.5
13	1957	60.83073	117.24769	767	233.8	170	51.8	147	44.8	189.0
14	1957	60.82928	117.21875	770	234.7	161	49.1	125	38.1	196.6
15	1957	60.80990	117.28067	756	230.4	197	60.0	221	67.4	163.1
16	1957	60.78111	117.32870	809	246.6	153	46.6	221	67.4	179.2
17	1957	60.79601	117.29977	783	238.6	155	47.2	179	54.6	184.0
18	1957	60.79977	117.29977	765	233.1	202	61.6	289	88.1	145.0
19	1957	60.80353	117.29977	761	232.0	203	61.9	280	85.3	146.6
20	1957	60.81626	117.26476	762	232.3	206	62.8	209	63.7	168.6

*Stratigraphic marker "X" in J.C. Sproule and Associates (1956, 1957) is five feet above top of the Twin Falls Formation in the Briggs N. E. Tathlina Lake No. 1 well. Consequently, five feet were added to the "X" marker elevations at all test holes to obtain the elevations of the top of the Twin Falls Formation at those holes.

Table 2. Structure test-hole data for the top of the Kakisa Formation in the Rabbit Lake area reported in Sproule and Associates (1956, 1957)

Station number	Year	Location		KB		TD		Kakisa Formation*		
									Metres	
		Latitude	Longitude	Feet	Metres	Feet	Metres	Feet	Depth	Subsea
5	1955	60.91667	118.76244	1044	318.2	1018	310.3	452	137.8	234.2
6	1955	60.96565	118.61320	970	295.7	651	198.4	349	106.4	181.6
8	1955	61.03941	118.88157	872	265.8	533	162.5	168	51.2	33.8
9	1955	60.98311	119.01046	931	283.8	664	202.4	436	132.9	210.1
12	1955	60.91216	119.12204	996	303.6	150	45.7	734	223.7	402.3
19	1955	60.84291	119.03835	1059	322.8	599	182.6	758	231.1	497.9
20	1955	60.81644	118.98373	1083	330.1	955	291.1	897	273.4	527.6
21	1955	60.97185	118.74221	953	290.5	613	186.8	327	99.7	155.3
23	1957	60.94764	118.76662	1029	313.6	328	100.0	58	17.7	-35.7
24	1957	60.95608	118.74802	1021	311.3	139	42.4	120	36.6	11.4
25	1957	60.97072	118.69921	965	294.0	176	53.6	160	48.8	103.2
27	1957	60.94200	118.77615	1033	314.9	102	31.1	78	23.8	-23.8
46	1957	60.93519	118.76214	1040	317.1	213	64.9	88	26.8	-11.8
97	1957	61.00619	118.63947	908	276.9	296	90.2	53	16.2	-23.8
98	1957	61.03491	118.56741	912	278.1	296	90.2	-38	-11.5	-87.2

*Stratigraphic marker "F" in J.C. Sproule and Associates (1956, 1957) is eight feet above top of the Kakisa Formation in the Briggs Rabbit Lake No. 1 well. Consequently, eight feet were added to the "F" marker elevations at all test holes to obtain the elevations of the top of the Kakisa Formation.

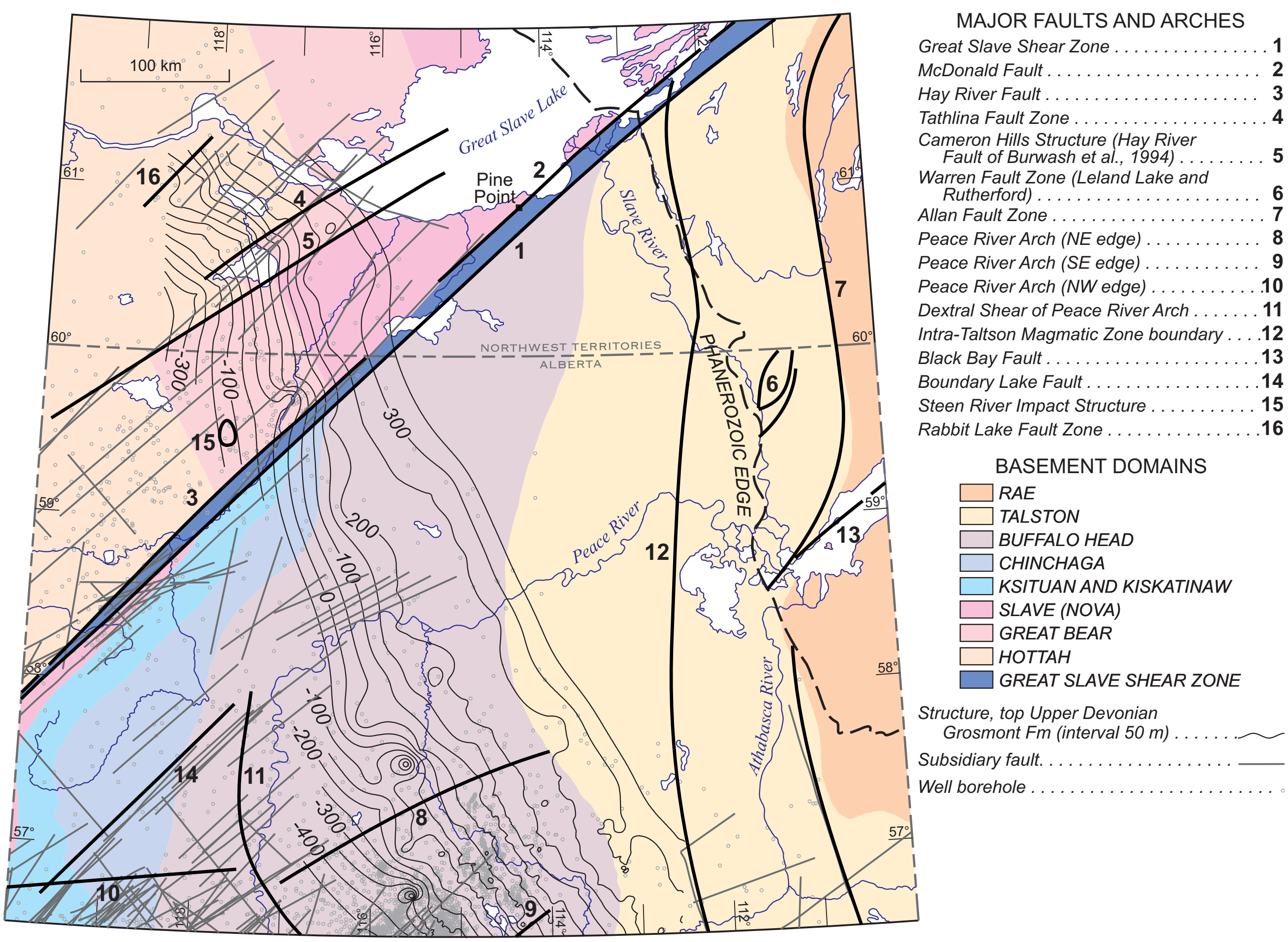


Figure 9. Structure surface map of the top of the Upper Devonian Grosmont Formation. The contour interval is 50 m.

maps display a remarkably uniform trend of structure contours across the entire contoured region southwest of the shear zone. The only exception to this generalization occurs in the extreme southwest corner of the study area in the heart of the Peace River Arch region. Here, pronounced contour deflections occur in a small area containing abundant faults in the centre of the Peace River Arch area.

In the region between the Peace River Arch and the Great Slave Shear Zone, the base of Phanerozoic structure contours display some large undulations that may represent paleotopography on the base of Phanerozoic erosional unconformity surface (Fig. 2). This is particularly evident in the southwest corner of the study area immediately north of the Peace River Arch, where several basement "highs" on the erosion surface lie beneath the relatively planar, southwest-dipping top of Watt Mountain and Slave Point surfaces (Fig. 2, 6, 7). Faulting or other deformation responsible for the development of these local highs must have predated deposition of the Watt Mountain Formation. Possibly, these basement highs reflect the latest Proterozoic to Cambrian rifting event that affected western North America (Aitken, 1993).

Other faults, such as in the group of closely spaced northeast-trending faults centred at 116°W longitude and 58°3'N latitude, coincide with some very slight contour deflections on the base of Phanerozoic (Fig. 2) and on the Watt Mountain, Slave Point, and Jean Marie structure maps (Fig. 6, 7, 8). It is possible that small post-Devonian movements along these faults caused these slight contour deflections.

Similar small contour deflections on these maps occur across northeast-trending faults at the south end of the Taltson Basement Domain in the extreme southeast corner of the study area (Fig. 2, 6, 7).

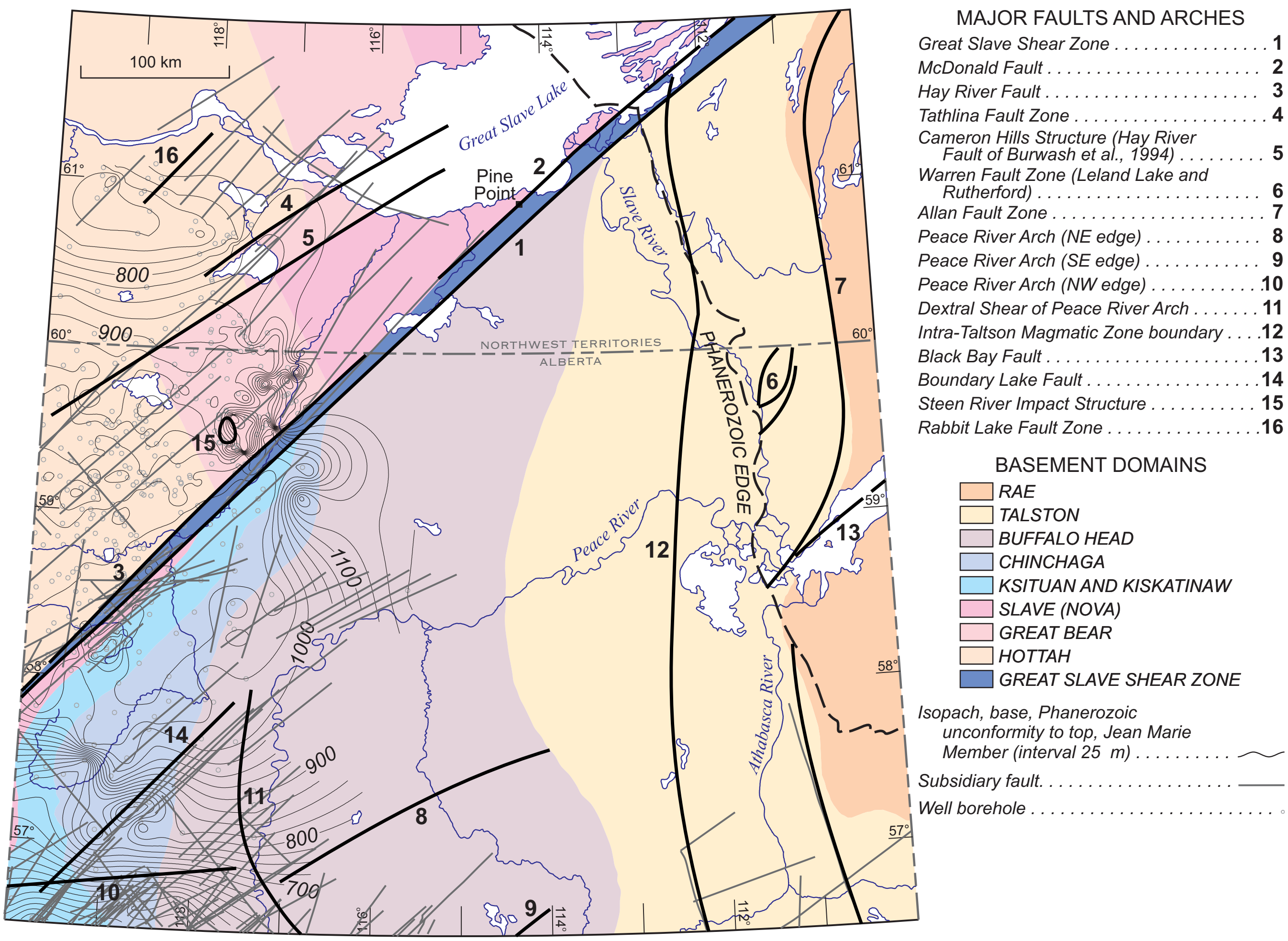


Figure 10. Isopach map of the stratigraphic interval bounded by the base of the Phanerozoic unconformity and the top of the Jean Marie Member. Well control southeast of the Great Slave Shear Zone is not sufficient to define thickness trends. Northwest of the shear zone thickness changes provide some indication that movements across the dominantly northeast-trending faults occurred during deposition of this stratigraphic interval. The contour interval is 25 m.

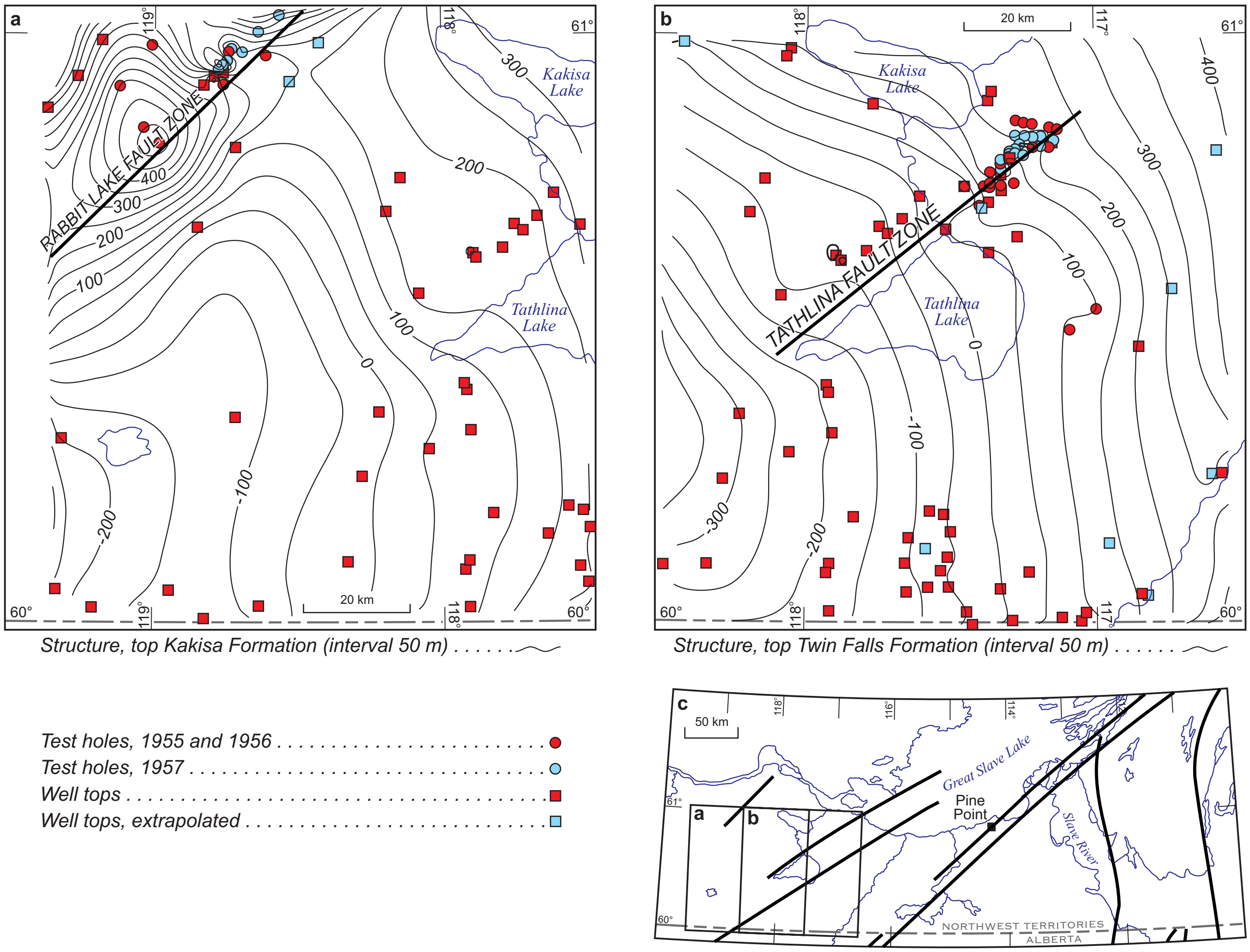


Figure 11. Structure contour maps of the top of the Kakisa Formation **(a)** in the Rabbit Lake area and of the Twin Falls Formation and **(b)** in the Tathlina Lake area. These maps incorporate additional data derived from shallow test holes drilled in 1955, 1956, and 1957 (J.C. Sproule and Associates, 1956, 1957) along with well information. Contour interval is 50 m. The regions covered by these more detailed structure maps are shown in **(c).**

Reflection seismic lines

Figure 3 shows the complete, publicly available seismic coverage in the study area obtained from the National Energy Board (NEB) of Canada. This coverage is restricted to the Northwest Territories and no seismic data are publicly available for the Province of Alberta. Maclean (2006), in a companion report in this publication, presents a series of detailed seismic time-structure maps across areas covered by all these seismic grids.

Only seismic lines located south of 61°N latitude, as shown in Figure 12, have been examined in this study. This includes several grids of industry seismic that are crossed by several grids of major northeast-trending faults, such as the Tathlina Fault, the Hay River Fault Zone, and the Enterprise Structure, which lie northwest of the Great Slave Shear Zone and west of Pine Point. Seismic lines that have been interpreted in detail for this study are shown in red on Figure 12. A northeast trending, graben-like structure, which brackets seismic line P28-9e-8009-8017 and has been documented by MacLean (2006), coincides with the Enterprise Structure immediately north of 60°.

Interpreted seismic lines show many examples of where the Slave Point and sub-Slave Point Paleozoic succession has been structurally deformed or exhibits a loss of continuity, or changes in character or disappearance of internal reflectors (Fig. 12).

In the western part of the region displayed in Figure 12, there are many locations where the sub-Slave Point succession has been involved in compressional deformation that has clearly offset the top of the Slave Point. One of these locations is illustrated towards the west end of seismic line C54-1e-13. Here, several reverse faults have offset the base of Phanerozoic unconformity as well as the overlying Devonian succession including the Slave Point, Muskwa, and Waterways formations (Fig. 13). This faulting does not affect overlying Devonian markers, such as the Jean Marie Member

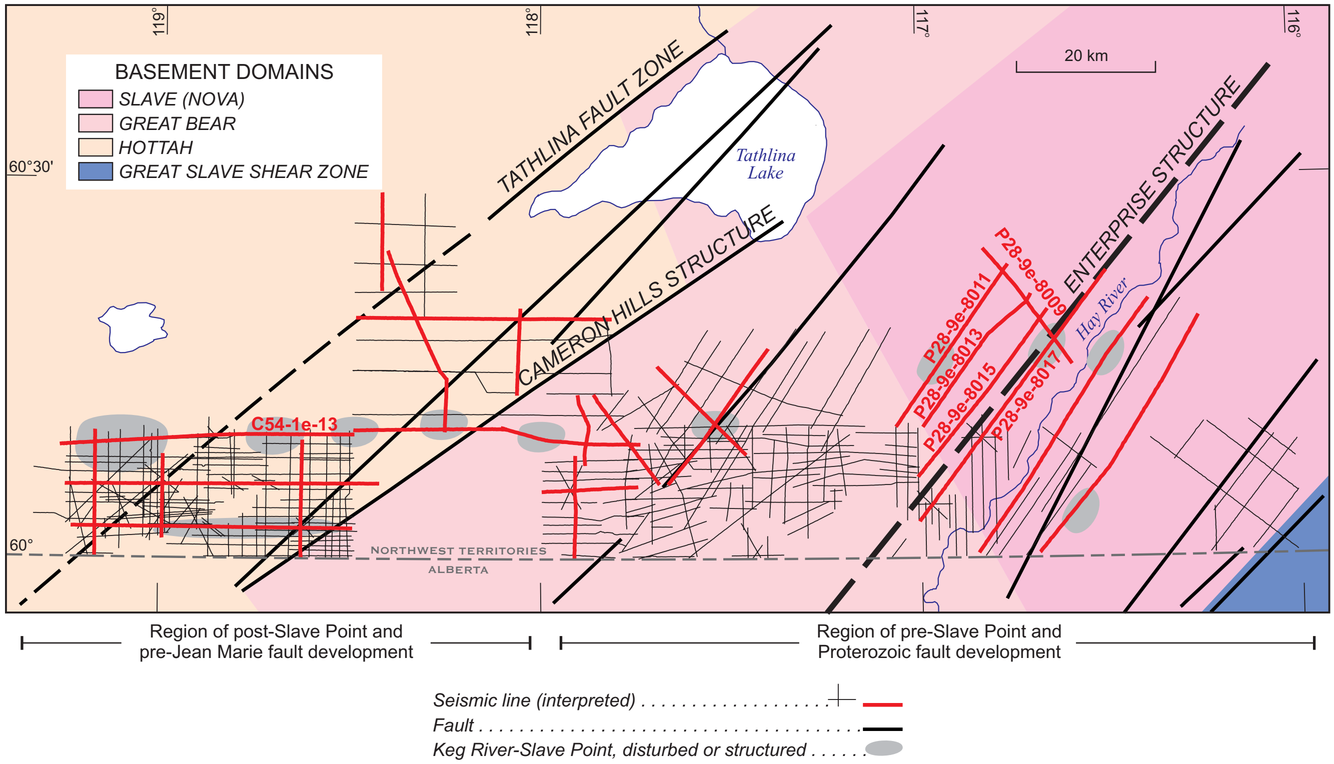


Figure 12. Seismic coverage south of 61° north latitude. Seismic lines that have been interpreted are shown in red. Small regions of structured or disturbed Slave Point and sub-Slave Point strata are shown. Disturbed stratigraphic intervals are defined as those with discontinuous internal seismic reflectors.

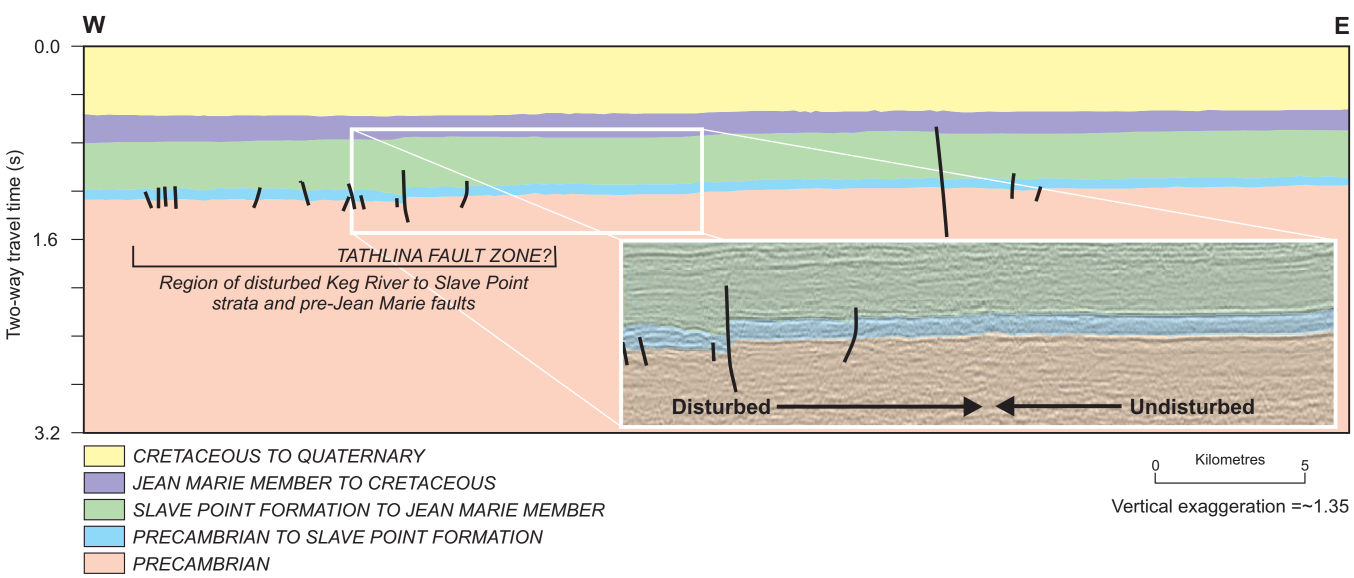


Figure 13. Seismic line C54-1e-13 on the west side of Cameron Hills (Fig. 12) shows that the top of the Slave Point and Muskwa/Waterways formations (represented by the blue Precambrian to Slave Point interval) have been offset at several places by high-angle reverse faults. The overlying Jean Marie Member is unaffected by these faults, indicating that they were active only in early Late Devonian time before Jean Marie deposition. Slave Point and sub-Slave Point Paleozoic strata exhibit discontinuous internal reflectors in the vicinity of these faults as shown in the inset bitmap.

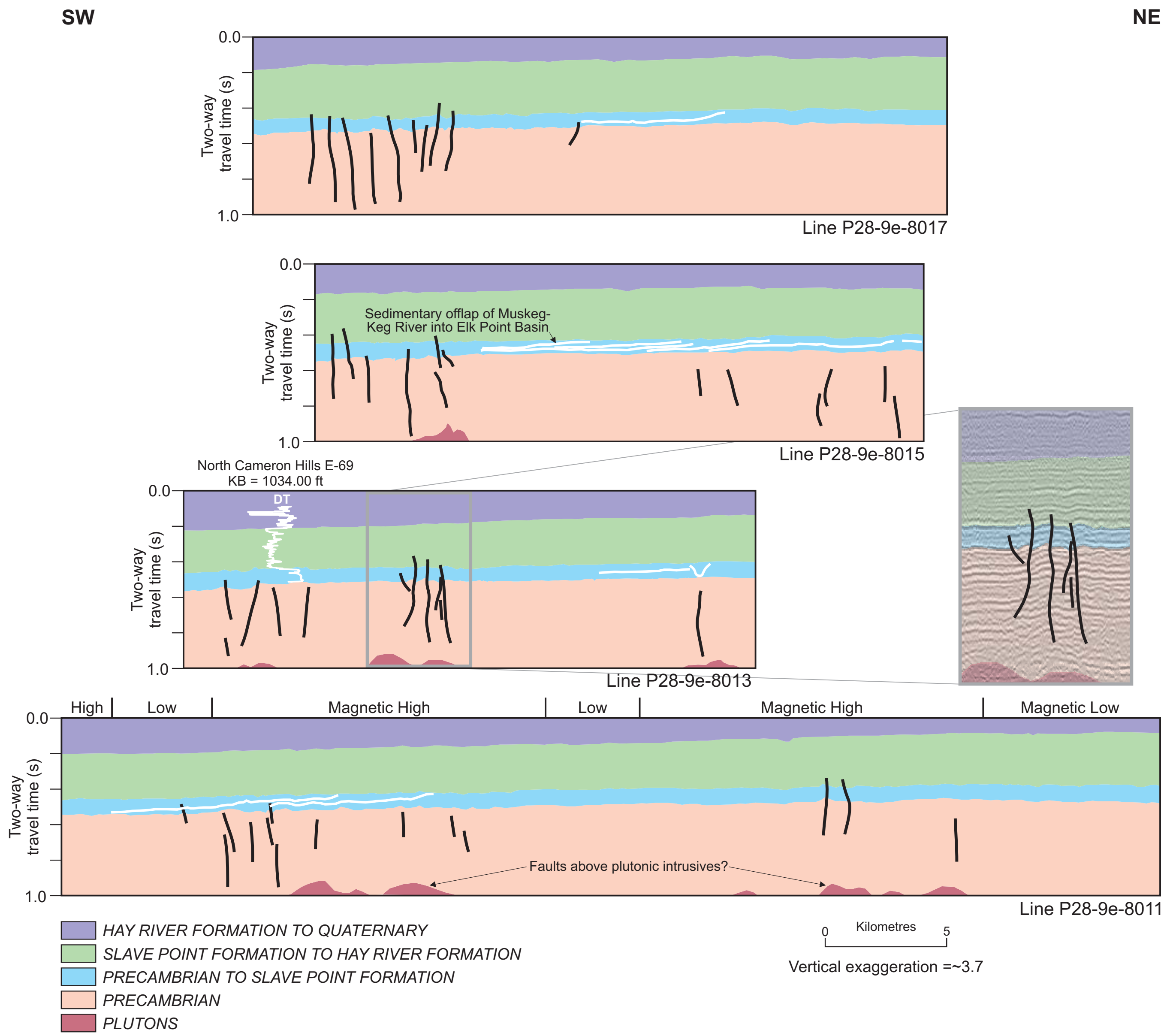
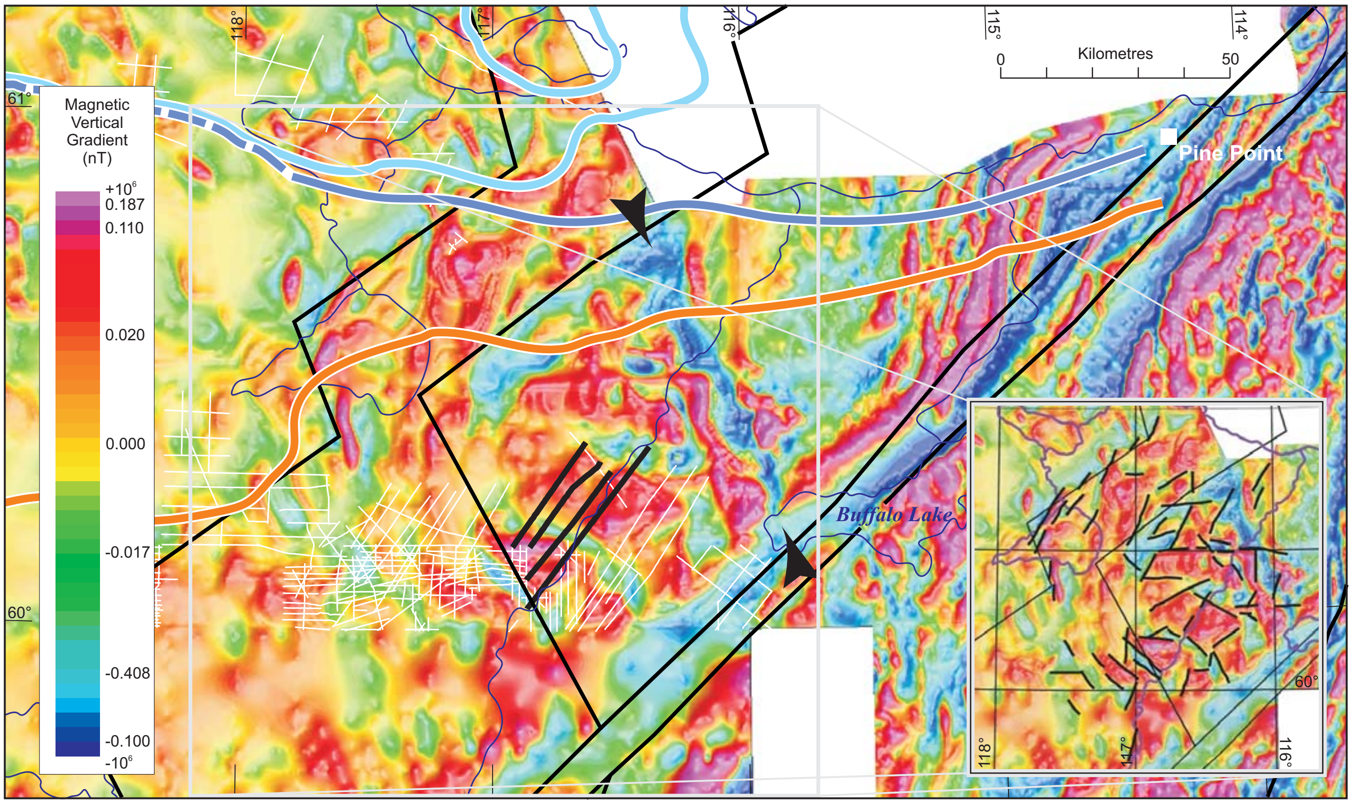


Figure 14. Interpretations for seismic lines P28-9e-8011, 8013, 8015, and 8017 immediately east of Hay River and shown on Figures 12 and 15. Subvertical Precambrian to Late Devonian aged faulting tends to be grouped above possible intrusive plutons across magnetic “highs”. Inset bitmap shows seismic character of this faulting.

or the Wabamun Group (Fig. 13). This suggests that the deformational episode responsible for this faulting followed deposition of the Slave Point and Waterways but predated Jean Marie deposition and thus is tightly constrained to an early Late Devonian time (Douglas, 1974). An alternate explanation, considered less likely, is that these faults are basement faults that were reactivated during Laramide compression but only propagated a short distance upward through the overlying section.

Tathlina Fault may coincide with one of these high-angle faults, or, the intersection of Tathlina Fault may occur at one of the irregularities along the base of Phanerozoic unconformity near the centre of the line. Most of these faults, however, can only be documented for a few kilometres and are oriented northwest to southeast (MacLean, 2006). In the region of the contractional faults, the Keg River to Slave Point succession displays hummocky, or mounded, rather discontinuous internal reflectors (Fig. 13).

Seismic lines that extend through the east side of the area shown in Figure 12 display many groups of northwest- to southeast-oriented subvertical faults within Proterozoic strata of the Great Bear and Slave basement domains near Hay River (Fig. 14) with the exception of the Enterprise Structure (Fig. 2, 12). Most of these groups of faults fall near the edge or above possible intrusive plutons at the base of the Proterozoic succession. Proterozoic “highs” on the base of Phanerozoic unconformity occur preferentially above many of these inferred plutons (Fig. 14). These highs may be the



Slave Point Limit
Keg River-Sulphur Point Limit
Muskeg Limit
Axis of possible fluid flow, northwest from Great Slave Shear Zone

Figure 15. First vertical derivative of the total magnetic field (nT = nanoteslas). Red represents maximum values and blue represents minimum values of the vertical magnetic derivative. Seismic lines P28-9e-8011, 8013, 8015, and 8017 immediately east of Hay River and shown on Figures 12 and 14 are highlighted. Subvertical Precambrian to Late Devonian aged faulting tends to be grouped above possible intrusive plutons across magnetic "highs" as emphasized in the bitmap inset. Note the strongly developed north-northwest rift-like "valley" in the vertical derivative that joins the Great Slave Shear Zone at a high angle at the western end of Buffalo Lake.

erosional remnants of Proterozoic uplifts associated with emplacement of plutons. Internal seismic reflectors within the Keg River to Slave Point succession above these uplifts are very discontinuous. At least some Late Devonian movement occurred on faults above plutonic uplifts as many of these have offset the top of the Slave Point Formation.

Aeromagnetic data

Previously, public domain aeromagnetic data within the project area has been used to assist in the delineation of basement domains (Fig. 1, 15). Recent refinements to Precambrian basement domain boundaries using total magnetic field data include Pilkington et al. (2000) and Aspler et al. (2003). As discussed previously, the vertical derivative of the magnetic field is used here for analysis because magnetic contrasts of the Precambrian basement that may be fault-related are preferentially enhanced. In this study, the area southwest of Pine Point has been selected for aeromagnetic interpretation because of its greater prospectivity for lead-zinc mineralization (Fig. 15).

There are two striking features of the aeromagnetic map shown in Figure 15. First, there is a complex array of km-long to tens of km-long linear magnetic edges that can be interpreted as the possible faulted edges of Precambrian basement immediately east of Buffalo Lake and shown in the inset map in Figure 15. Some of these faults can be documented where seismic lines cross these magnetic "edges" (Fig. 14, 15). Some part of the signal emanates from magnetic contrasts far below the top of the Proterozoic, but Euler Depth Solutions across the inset map area indicate a depth to magnetic basement ranging from 600 m to 2200 m (W. Miles, pers. comm.). This is consistent with the top of the Precambrian basement at a depth about 0.5 s two-way travel time on seismic (Fig. 14). Clearly, these faults could serve as conduits for mineralizing solutions that circulated from the Proterozoic up into the Keg River and Slave Point carbonate strata.

The second noteworthy feature of this magnetic map is the very strongly developed magnetic "low" extending north-northwest from the Great Slave Shear Zone at the west end of Buffalo Lake (Fig. 15). It is uncertain as to what this feature is but it clearly demarcates the complex rectilinear magnetic array to the southwest from the rather featureless magnetic terrain northeast of the “low”. Whatever its origin, it is probable that faults or groups of faults follow the jagged margins of this feature.

Nelson et al. (2002) described how leads in deposits, such as at Pine Point and in the subsurface at Rainbow Lake in Alberta, which both fall along the Great Slave Shear Zone, comprise a distinct, nonradiogenic population of lead isotopes unlike the “radiogenic” leads in the numerous MVT-type lead-zinc deposits scattered along the western Cordillera. They inferred that this supported deep mineralizing fluid flow focused along the Great Slave Shear Zone as a primary agent responsible for the formation of large MVT deposits such as Pine Point.

We speculate that the spectacular northwest-trending magnetic “low” extending westward from Buffalo Lake could have provided direct access for the northwest circulation of mineralizing solutions derived from the Great Slave Shear Zone itself. This situation would be somewhat analogous to the relationship within the Tri-State MVT deposits of the Viburnum Trend, where mineralizing solutions were derived from the nearby Reelfoot Rift block-faulted graben and focused along its bounding faults (Keller et al., 2000).

CONCLUSIONS

The study area of this TGI project can be divided into two structurally distinct regions separated by the Great Slave Shear Zone. Northwest of the shear zone, numerous northeast-trending faults or fault zones affected the lower Paleozoic (sub-Carboniferous) succession. Offsets across these faults have been inferred from the locations of pronounced deflections of contours on structure and isopach maps of Paleozoic units and on the base of Phanerozoic unconformity structure map. The influence of fault movements is less pronounced southeast of the Great Slave Shear Zone with the major exception of the densely faulted Peace River Arch region in the southwestern part of the study area. One new northeast-trending structure, the “Enterprise Structure” is defined in this study on the basis of structure contour deflections and by comparison with a coincident graben-like structure defined seismically by MacLean (2006).

The relative abundance of regional faults northwest of the Great Slave Shear Zone is a factor that favours the occurrence of lead-zinc deposits in the subsurface southwest of Pine Point and the development of structural traps for subsurface petroleum reservoirs. Some corroboration for this is provided by the presence of structurally disturbed Keg River to Slave Point strata along seismic lines that cross some regional faults and by the presence of zones with hummocky, discontinuous internal reflectors within these strata northwest of the Shear Zone.

Aeromagnetic data show a distinct region of possible fault-bounded, magnetically defined basement blocks west of Buffalo Lake that may have acted as conduits for the flow of mineralizing metaliferous solutions into Devonian carbonate. Anhydrite of the Muskeg Formation is present throughout this region (Fig. 15) as a required source of sulphur for metal sulphides. Magnetic data also reveal a distinct, and possibly fault-bounded and graben-like magnetic “low” extending northwest from the Great Slave Shear Zone, which may have “tapped” into the main plumbing network of the mineralizing solutions circulating within the Shear Zone and which participated in the formation of the Pine Point deposits.

ACKNOWLEDGMENTS

We would like to thank Graham Lai for his assistance with the SAMS well database at the Geological Survey of Canada (Calgary). Karen Fallas and Peter Hannigan of the Geological Survey of Canada (Calgary) reviewed the manuscript and made many useful suggestions. This paper is a contribution of the Targeted Geoscience Initiative Project number 010009 of the Geological Survey of Canada.

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