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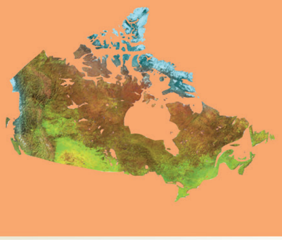

Magnetic modelling in the St. Mary Block, Purcell anticlinorium, Canadian Cordillera, British Columbia

M.D. Thomas

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Critical review

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Abstract: The St. Mary Block is a broad half anticline within the Purcell anticlinorium, southeast Cordillera, formed largely of the sedimentary Mesoproterozoic Aldridge and Creston formations, the former intruded by mafic Mesoproterozoic Moyie sills. The Creston Formation is generally associated with a relatively strong magnetic field that includes prominent linear highs. Elsewhere the field is relatively weak and little perturbed. A northeastward-increasing regional magnetic gradient spans much of the northeastern half of the block.

Modelling of magnetic profiles provides insight into upper crustal structure. Modelled sections, some 5–6 km deep, crossing the northwestern half of the area consistently display northwest-dipping (45° to 65°) magnetic units. Magnetic unit boundaries coinciding with faults, e.g. Perry Creek Fault, support a view that faults are northwest-dipping, contrary to an opinion advocating vertical faults. Modelling in localities coinciding with the Kitchener Formation suggests the presence of underlying older Creston Formation at shallow depth, and questions a conformable relationship between the two formations.

Some prominent linear magnetic highs within the Aldridge Formation are modelled as vertical sheet-like bodies, having relatively high magnetic susceptibilities uncharacteristic of the formation. These are interpreted to be gabbroic intrusions distinct from Moyie sills intrusions that generally do not produce a noticeable magnetic high. The northeastern half of the St. Mary Block displays a northeastward-increasing magnetic field. A magnetic model partially constrained by a seismic-reflection model indicates the increase relates to decreasing depth of the basement from roughly 20 km at the outset of the gradient to about 11 km near the Rocky Mountain Trench fault.

Résumé : Le bloc de St. Mary forme un large demi-anticlinal à l'intérieur de l'anticlinorium de Purcell, dans le sud-est de la Cordillère. Il est principalement constitué de roches sédimentaires du Mésoprotérozoïque attribuées aux formations d'Aldridge et de Creston. Des intrusions mafiques du Mésoprotérozoïque, les filons-couches de Moyie, sont encaissées dans la Formation d'Aldridge. À la Formation de Creston est associé un champ magnétique relativement fort, marqué par des crêtes prononcées d'aspect linéaire. Ailleurs, le champ est relativement faible et peu perturbé. Un gradient magnétique régional en hausse vers le nord-est s'étend à une grande partie de la moitié nord-est du bloc.

La modélisation de profils magnétiques nous informe sur la structure de la croûte supérieure. Les coupes modélisées traversant la moitié nord-ouest de la région, dont certaines s'étendent jusqu'à des profondeurs de 5 à 6 km, montrent des unités magnétiques s'inclinant systématiquement vers le nord-ouest (de 45° à 65°). La coïncidence des limites d'unités magnétiques avec des failles (p. ex. la faille de Perry Creek) soutient l'opinion voulant que les failles soient inclinées vers le nord-ouest plutôt qu'être verticales comme on l'a avancé. La modélisation réalisée à des endroits coïncidant avec la Formation de Kitchener laisse croire à la présence sous celle-ci, à faible profondeur, de la Formation de Creston plus ancienne et remet en question la relation de concordance entre ces deux formations.

Quelques crêtes magnétiques prononcées d'aspect linéaire à l'intérieur de la Formation d'Aldridge sont modélisées sous la forme de feuillets verticaux présentant des susceptibilités magnétiques relativement élevées, qui ne sont pas caractéristiques de cette formation. Selon notre interprétation, ces crêtes magnétiques seraient des intrusions gabbroïques distinctes des filons-couches de Moyie qui, en général, ne produisent pas de crêtes magnétiques notables. La moitié nord-est du bloc de St. Mary présente un champ magnétique en hausse vers le nord-est. Un modèle magnétique partiellement encadré par un modèle de sismique-réflexion indique que la hausse est liée à la remontée du socle, qui passe d'environ 20 km, à l'amorce du gradient, à 11 km, près de la faille du sillon des Rocheuses.

INTRODUCTION

The St. Mary Block is a broad, northeast-plunging half anticline in the central part of the Purcell anticlinorium, southeast Canadian Cordillera, dominated by metasedimentary units of the Mesoproterozoic Aldridge and Creston formations, and with a presence of Cambrian sedimentary formations (Fig. 1). The Aldridge Formation is widely intruded by Mesoproterozoic mafic Moyie sills. The crustal structure within the block has been examined by two principal seismic-reflection traverses (Van der Velden and Cook, 1996). These authors' 'profile 5 south' extended east-northeast along strike within the belt of Creston Formation on the northwest flank of the block close to the Perry Creek Fault and is devoid of reflections in the uppermost 3 km of the section. Seismic profile 10-1 ran northeast across the northeastern tract of the Middle Aldridge Formation close to the Moyie River Fault, displaying horizontal to gently dipping reflections below depths of 1 km to 2 km. Reesor (1996) presented three geological sections, maximum vertical extent 1700 m, crossing the western and/or northwestern portion of the St. Mary Block.

The presence of prominent linear magnetic anomalies within the St. Mary Block provides a means to supplement the information provided by Reesor (1996) and Van der Velden and Cook (1996) by investigating upper crustal structure through magnetic modelling. The linear anomalies are prevalent along the northwest flank of the block, permitting study of this limb of the half anticline. A prominent linear magnetic high within the expanse of the Middle Aldridge Formation, conspicuous also by it anomalous northward trend, and a regional northeastward-increasing magnetic gradient spanning the northeastern segment of the Aldridge Formation and younger formations as far east as the Rocky Mountain Trench fault are also modelled to determine their geological significance.

GEOLOGY

The St. Mary Block is formed principally of Mesoproterozoic metasedimentary rocks belonging to the Aldridge Formation and succeeding Creston Formation, with narrow belts of the Kitchener Formation also present (Fig. 1). The Aldridge Formation is composed largely of turbidite units that include arenite, siltite, and argillite units deposited in an intracontinental rift (Lydon et al., 2000), and the succeeding Creston Formation represents a rift-sag sequence (Lydon, 2000) that includes siltstone, argillite, quartz arenite, and quartz wacke. The Kitchener Formation is a dominantly carbonate formation that includes dolomitic siltstone and carbonaceous, silty dolomite and limestone (Höy, 1993).

The St. Mary Block is a broad, northeast-plunging half anticline between the Hall Lake Block to the north and Moyie Block to the south (Fig. 1), and separated from them, respectively, by the St. Mary and Moyie faults (Benvenuto and Price, 1979). The Moyie Fault separates the Mesoproterozoic Creston Formation and younger formations to the southeast from the older Aldridge Formation to the northwest. According to Höy (1993) it is a right-lateral reverse fault dipping 60° to 70° northwest and a zone of intense shearing attaining several hundred metres in width. The St. Mary Fault is one of several faults, including the Moyie Fault, attributed to regional contraction, the development of which probably commenced before the middle Cretaceous; the Moyie Fault may be somewhat younger (Cook and Van der Velden, 1995). Geological maps present it as a thrust fault with its upthrust side to the north, e.g. Brown and MacLeod (2011a) and Brown et al. (2011a). The fault is portrayed as a thrust fault dipping roughly 30° northeastward in an interpretation (Van der Velden and Cook, 1996) of seismic-reflection line profile 5 south (Fig. 1), though no reflections are present in approximately the uppermost 3 km of the seismic image, and really are poorly defined to a depth of about 5 km near the fault.

To the west and east, respectively, a schematic geological map (Benvenuto and Price, 1979) showed the St. Mary Block bounded by a portion of the St. Mary Fault trending southwest where the fault swings away from its more general west-southwest trend, and by the Rocky Mountain Trench fault. The western boundary is now probably better defined by the St. Mary–Hall Lake Fault (Fig. 1).

The southeastern half of the block is dominated by a broad, northeast-trending belt of Aldridge Formation, some 13 km to 18 km wide, significantly intruded by Moyie sills formed predominantly of gabbro and diorite (Höy, 1993). The northwestern half is dominated by the Creston Formation, which contains several narrow units of the succeeding Kitchener Formation that typically have a thrust fault contact to the northwest and stratigraphic contact to the southeast, a pattern well illustrated in geological cross-section I-I' of Reesor (1996). This composite belt ranges generally in width from about 9 km in the southwest to 15 km in the northeast. The northwest corner of the St. Mary Block is occupied by a triangular unit of Cambrian rocks belonging to the Cranbrook and Eager formations that unconformably overlie sedimentary rocks of the Kitchener Formation; the unit attains a maximum width about 10 km.

The northwestern half of the St. Mary Block is characterized by several extensive subparallel thrust and normal faults that generally are terminated northward at or just before the St. Mary Fault (Fig. 1). Two exceptions are the Perry Creek Fault and fault F2 (Fig. 1), which offset the St. Mary Fault. Benvenuto and Price (1979) noted that "The moderately northwest-dipping beds in the northwest flank of the half anticline are disrupted by a series of northwest-dipping normal and reverse faults…." These northwestern faults typically trend between roughly north and 012° in the area of Cambrian rocks and between about 020° and 030° in the area of Creston and Kitchener formations; formation

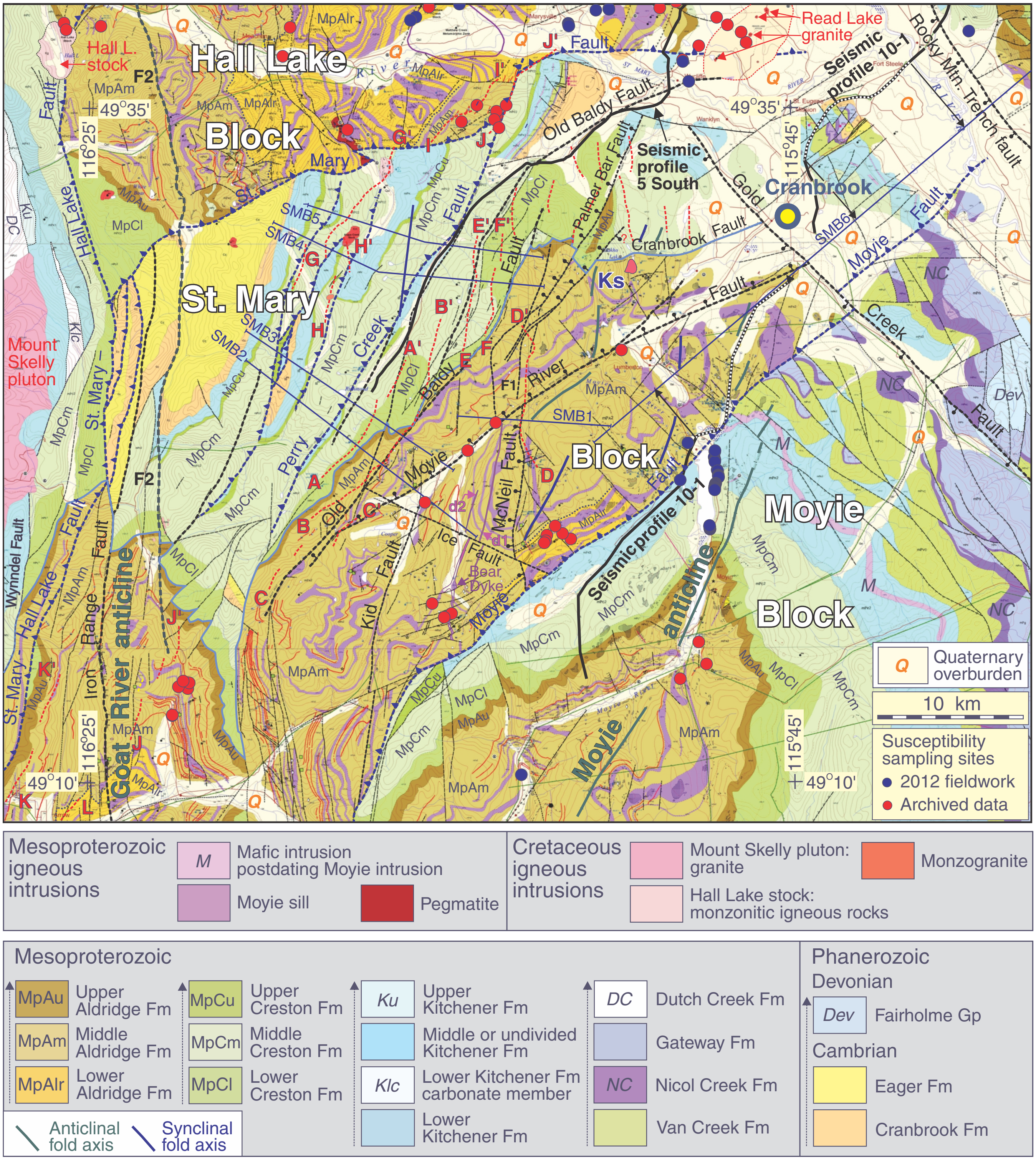

Figure 1. Geology map of St. Mary Block and flanking regions of Hall Lake and Moyie blocks compiled from 1:50 000 maps by Brown and MacLeod (2011a, b), Brown et al. (2011a, b, c) and Glombick et al. (2011). Magnetic susceptibility measuring and/or sampling sites are plotted. Lines of modelled magnetic profiles are indicated by blue lines with accompanying label, e.g. SMB1, SMB2. Red dashed lines labelled A-A', etc. trace the paths of linear anomalies outlined in Figure 2. Sections of seismic profile 10-1 (solid black line) projected to line of magnetic profile SMB6 to help constrain modelling are depicted as dashed black and white lines; black arrows define limits of projection on SMB6. Ks = Kiakho stock.

units have similar trends. The convention for direction followed here is the right-hand rule in which directions are measured in degrees clockwise from north (000°).

These trends in the northwest contrast markedly with those of similar features in the southeastern half of the St. Mary Block, which is formed by a broad, extensive unit of Aldridge Formation trending approximately northeast. Trends of its northwestern and southeastern boundaries, and of Moyie sills near these boundaries, are very similar. The most extensive fault within the Aldridge Formation is the Moyie River Fault, depicted as a normal fault, north-side-down (Brown et al., 2011b, c), trending 056° for the greater part of its length. The Old Baldy Fault, where it lies within the northwestern margin of the Aldridge Formation, strikes 040°, parallel to the margin. It adopts a more northerly direction within the adjacent Creston Formation to the north, similar to trends of some other faults in the northwestern half of the St. Mary Block (Fig. 1). In the northeastern portion of the Aldridge Formation, several relatively short faults trending 320° are noticeable by their 'anomalous' trend, though they parallel the Gold Creek Fault to the northeast and several faults to the east within the Moyie Block south of the Moyie Fault. A prominent fault with a general northwest trend is the Ice Fault (295°) running between the Old Baldy and Moyie faults.

MAGNETIC FIELD

A shaded map of the magnetic field of the area is shown in Figure 2, based on aeromagnetic data from the Canadian National Magnetic Database (Geoscience Data Repository for Geophysical Data; Natural Resources Canada, 2017) collected along lines spaced 805 m apart at a mean terrain

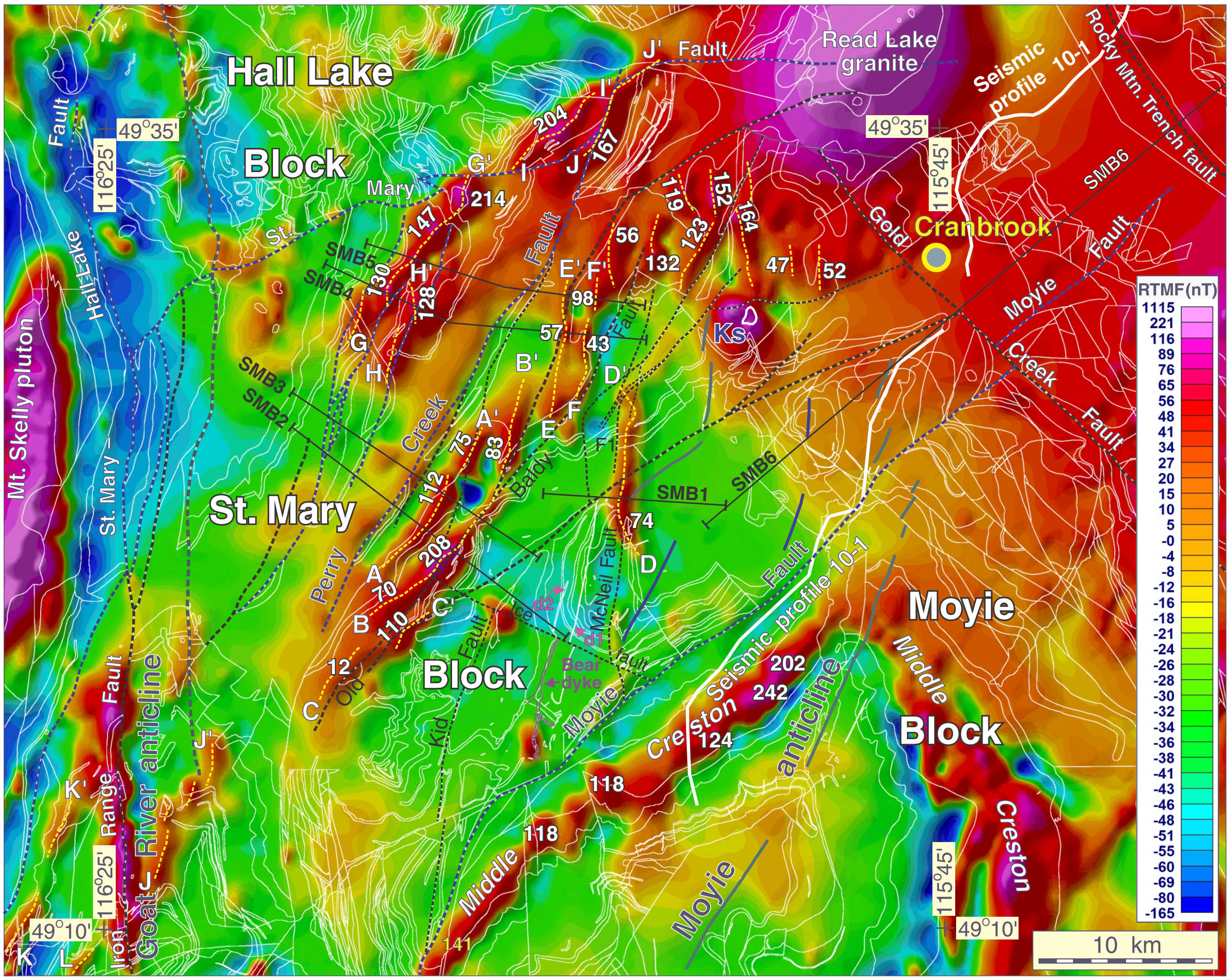

Figure 2. Residual total magnetic field map of area corresponding to that of the geology map in Figure 1. Geological contacts and faults are portrayed as white lines to provide a geological framework. Lines of modelled magnetic profiles are indicated by black lines with accompanying label, e.g. SMB1, SMB2. RTMF = residual total magnetic field, Ks = Kiakho stock.

clearance of 305 m. The two strongest magnetic highs in the area coincide with 'granitic' intrusions, the Mount Skelly pluton on the western margin and the Read Lake granite in the northeast. Prominent linear magnetic highs are associated with the flanks of the Moyie anticline and with the Iron Range Fault, where they correlate, respectively, with the Middle Creston Formation (Thomas, 2015) and principally thin (<5 m wide), massive lenses of magnetite and hematite, and wider and less brecciated magnetite-rich zones (Lowe et al., 2000). Another noticeable feature is the regionally higher magnetic field in the northeastern-eastern portion of the map, contrasted with the generally lower field over roughly the western two-thirds of the area. The change takes place along a northwest-trending belt of steeper gradients located some 14–15 km southwest of, and parallel to, the Gold Creek Fault. This will be examined by modelling along magnetic profile SMB6.

Within the western area of lower magnetic field several linear highs, albeit discontinuous, stand out. One group, comprising highs A-A', B-B', and C-C', spans the boundary between the Aldridge and Creston formations near the Old Baldy Fault (Fig. 1, 2). The linear high A-A' and northern third of B-B' fall within the Creston Formation, whereas the remainder of B-B' and C-C' lie within the Aldridge Formation. Segments of these anomalies trend generally between 025° to 045°. The northern part of B-B' has a more northerly trend of about 013°, similar to the overall trends (~006°) of the subparallel anomalies E-E' and F-F' located immediately to the east within the Creston Formation.

The linear high D-D', lying entirely within the Aldridge Formation, is conspicuous by its somewhat anomalous north-south trend and isolated location. A group of much shorter linear northward-trending anomalies lies on the Creston Formation between the north end of F-F' and Cranbrook. Near the St. Mary Fault, individual curvilinear anomalies G-G', H-H', I-I', and J-J' are superposed on a relatively broad zone of higher magnetic field trending southwest from the vicinity of the Read Lake granite. South of the fault, G-G' and H-H' both correlate mainly with the Middle Creston Formation, though it is noted that the north end of G-G' crosses a small (?)Cretaceous quartz monzonite, monzonite, granodiorite intrusion (Brown et al., 2011a), the northern extremity of H-H' touches on the south end of the (?)Cretaceous biotite monzogranite Angus Creek stock (Brown et al., 2011a, b), and the peak of the southern extent of H-H' correlates precisely with a very small (maximum width approximately 550 m) Cretaceous biotite monzogranite intrusion (Brown et al., 2011b) (Fig. 1, 2). Linear high I-I' is north of the St. Mary Fault, falling mainly within the Middle Aldridge Formation, and J-J' follows closely the Perry Creek and St. Mary faults that separate the Aldridge and Creston formations in this area.

Peak values along the various highs range from +12 nT to +214 nT, many being greater than 100 nT (Fig. 2). These compare with an estimated general background magnetic field level of about –40 nT for the area, calculated by averaging spot values within areas dominated by green shades in Figure 2. Most of the linear highs are located within the Creston Formation, and these can be explained principally by magnetic horizons within the Creston Formation as described by Lowe et al. (2000) and modelled by Thomas (2015). Sources of highs not associated with the Creston Formation present some challenges to explain, as will be seen in the section dealing with modelling of magnetic profiles.

MAGNETIC SUSCEPTIBILITIES

Magnetic susceptibilities in the area of the Purcell anticlinorium have been reported by Lowe et al. (1998, 2000) and Thomas (2013, 2015). Magnetic minerals primarily responsible for rock magnetization are magnetite and pyrrhotite, having susceptibilities of 1000–5700 × 10^{-3} SI and 3200 × 10^{-3} SI, respectively (Hunt et al., 1995); monoclinic pyrrhotite is ferrimagnetic, but hexagonal pyrrhotite is essentially nonmagnetic.

Potential sources of magnetization within the Aldridge and Creston formations

Possible sources of magnetization within the Aldridge and Creston formations were discussed briefly by Thomas (2013), who noted that reference to magnetite in detailed stratigraphic sections within these formations was rare (Höy, 1993). Magnetite has been observed, along with hematite, in thin sections of phyllitic rock samples acquired from the Lower and Upper Aldridge formations in the northern part of the Purcell anticlinorium near the White Creek batholith (Reesor, 1958). Near the Sullivan deposit, most rocks (including argillite, wacke, and arenite units) in a roughly 1 km long section of unmineralized Lower Aldridge Formation core contain magnetite, ilmenite, and pyrrhotite (Schandl et al., 2000). Thus, magnetite is present in the Aldridge Formation, but information on its abundance is lacking. The muted nature of the associated magnetic field indicates that it is insignificant.

In contrast, magnetite may be a significant contributor to magnetic anomalies in the Creston Formation (Lowe et al., 1998, 2000). Conspicuous magnetic anomalies characterize portions of the Middle Creston Formation that include green quartz arenite and arenaceous siltite, with abundant porphyroblastic magnetite (>2%) recorded in magnetic green arenite. Reesor (1958) reported abundant magnetite octahedra up to 2 mm in some beds, and octahedra at various levels within the Creston Formation in the area of the White Creek batholith. In the Yahk survey area, the Lower Creston Formation area is atypically associated with magnetic anomalies as prominent as those in areas of the Middle Creston Formation (Lowe et al., 2000). This is attributed to the common occurrence of disseminated and stringer magnetite in the fine-grained argillite that typifies the Lower Creston Formation in this area.

Pyrrhotite is seemingly abundant in the Aldridge Formation; Lowe et al. (2000) noted the pervasive nature of pyrrhotite throughout the Lower and Middle Aldridge formations. Pyrrhotite-rich argillaceous turbidite units and pyrrhotite-rich argillite and siltstone have been observed in the central part of the rift basin within the Lower Aldridge Formation and Upper Aldridge Formation, respectively (Lydon et al., 2000), and pyrrhotite-rich argillite within the Middle Aldridge Formation (Höy et al., 2000). The apparent abundance of pyrrhotite in the Aldridge Formation created an expectation that the associated magnetic field would be at a higher level than levels over younger sedimentary units containing significantly less pyrrhotite (Lowe et al., 2000). Because this expectancy is not realized, those authors concluded that the pyrrhotite was a nonmagnetic variety, which is hexagonal pyrrhotite (Thomas, 2013). Both monoclinic and hexagonal pyrrhotite types are volumetrically significant in the Sullivan ore body (Ethier et al., 1976).

Magnetic suceptibilities of rocks in the general study area

Lowe et al. (2000) discussed magnetic susceptibilities for sites within three areas (referred to as St. Mary River, Yahk, and Findlay Creek) flown by high-resolution magnetic surveys. They made 1710 measurements in the field, on outcrop, and on hand and core samples, presenting results that included the mean and range of susceptibilities and corresponding number of measurements for several geological units. Locations of measuring and sampling sites were not illustrated.

Thomas' (2013) study augmented earlier studies and attempted to examine possible geographical variations in magnetic susceptibility within geological units using measurements at, or on samples from, known locations. Two data sets satisfied this requirement: 1) field susceptibility measurements made in 2012 on outcrops at 72 sites (includes large boulders probably representative of local bedrock in a few cases, and one large hand-sample block), and 2) a small database of archived susceptibility measurements made on samples, core, and outcrops relating to 98 sites, provided courtesy of C. Lowe, Pacific Geoscience Centre, Sidney, British Columbia. The sites for these two data sets within the general study area are plotted in Figure 1, and results of this study are summarized in Table 1 (reproduced from Thomas, 2013). Key points emerging from this table are: 1) the Aldridge Formation has a very low mean susceptibility of 0.64×10^{-3} SI, consistent with the association of a generally low and gently varying magnetic field (Fig. 2); 2) the Creston Formation has a moderately strong mean susceptibility of 10.16×10^{-3} SI, consistent with the presence of associated distinct magnetic highs, and has the potential to be strongly magnetic based on the range of measured values; and 3) Moyie sills yield a small, yet significant mean susceptibility of 3.49×10^{-3} SI, indicating the possibility of associated conspicuous magnetic highs, yet 83% of a population of 47 values are 1.30×10^{-3} SI or less having a mean of 0.66×10^{-3} SI that is practically the same as the mean for the

Table 1. Summary of magnetic susceptibilities.

	2012 fieldwork			Archived			2012 fieldwork + archived		
Geological unit	N	Average ± SD	Range	N	Average ± SD	Range	N	Average ± SD	Range
Reade Lake stock	38*	1.41±4.05	0.05-16.00	6	6.13±8.16	1.26-22.12			
Mt. Skelly pluton	8	11.13±4.74	6.31-18.27						
Kitchener Fm	11	0.14±0.02	0.11-0.17						
Lower Aldridge Fm	7	0.36±0.23	0.18-0.80	45	0.71±0.43	0.13-1.80			
Middle Aldridge Fm	7	0.20±0.08	0.08-0.31	23	**0.74±0.39	0.13-1.63			
L & M Aldridge Fm	14	0.28±0.18	0.08-0.80	68	0.72±0.41	0.13-1.80	82	0.64±0.42	0.08-1.80
Creston Formation	31	2.06±3.66	0.15-18.00	19	***7.49±8.26	0.13-25.10	54	10.16±25.48	0.13-150.80
Moyie sills	17	1.64±4.16	0.42-17.78	30	4.54±14.12	0.13-77.70	47	3.49±11.56	0.13-77.70
Moyie sills (values ≤ 1.30)	16	0.63±0.12	0.42-0.91	23	0.68±0.33	0.13-1.30	39	0.66±0.26	0.13-1.30

N = number of outcrops and/or rock samples upon which susceptibility measurements were made.

L = Lower, M = Middle.

Averages and standard deviations (SD) are based on the average of the N average values obtained at a particular outcrop and/or on a rock sample from a particular outcrop. They do not represent the average value of all individual measurements made on that particular rock unit, except in the case of 2012 fieldwork measurements on the Reade Lake stock. Susceptibility values are in the unit of ($\times 10^{-3}$) SI.

*In this case N = number of individual measurements made on 1 outcrop.
**2 anomalously high values of 3.90×10^{-3} SI and 27.6×10^{-3} SI are not included in the derivation of these values.
***4 anomalously high values ranging from 31.4×10^{-3} SI to 150.8×10^{-3} SI are not included in the derivation of these values.

Moyie sills statistics for values ≤ 1.30×10^{-3} SI are for strong modal groups of low values.

Aldridge Formation; the latter similarity is reflected in the weak or absent magnetic signatures associated with many sills (Fig. 2).

Within the area of interest, susceptibility sites are widely distributed, with most targeting Aldridge Formation or Moyie sills (Fig. 1). Sites on the Creston Formation are restricted to small areas in the northern apex of the Moyie anticline and near the Read Lake granite and intersection of the St. Mary and Perry Creek faults. Apparently, there is no information on susceptibilities of the Creston Formation in the broad expanse of this formation between the St. Mary and Old Baldy faults which is crossed by modelled magnetic profiles SMB2, SMB3, SMB4, and SMB5. Modelling must therefore rely on measurements made in adjacent areas of the Purcell anticlinorium.

MAGNETIC MODELS

The locations of profile lines for modelling are plotted in Figure 1 (geology map) and Figure 2 (magnetic map). Five profiles are located within the St. Mary Block, oriented generally perpendicular to the prevailing geological strike, and one very extensive profile runs longitudinally northeastward along the eastern portion of the St. Mary Block continuing to the vicinity of the Rocky Mountain Trench fault. In all models a background magnetic susceptibility of 0.65×10^{-3} SI has been assumed based on susceptibility measurements discussed by Thomas (2013, 2015). This is based on the wide distribution of the Middle Aldridge Formation in the study area that contains significant amounts of Moyie sills in some areas. Mean susceptibilities for the Lower and Middle Aldridge formations (combined) and for Moyie sills, respectively, have been determined to be 0.64×10^{-3} SI and 0.66×10^{-3} SI (Table 1).

Modelling has been constrained by the magnetic susceptibility data and near-surface geological sections interpreted from the available 1:50 000 scale geological maps. In the case of profile SMB6, seismic data and their interpretations (Van der Velden and Cook, 1996) provided an additional constraint for modelling.

Model SMB1

Profile SMB1 crosses a distinct, approximately 10 km long, linear magnetic high trending roughly 005° (D-D' in Fig. 2), attaining a peak value of 74 nT south of the Moyie River Fault, equivalent to an amplitude of greater than 110 nT relative to the adjacent background field. The northward trend of the high is somewhat anomalous with respect to trends of some other relatively extensive and distinct linear anomalies in the St. Mary Block. Along profile SMB1 the high peaks 67 nT above background levels at its western end (Fig. 3). The profile runs approximately east-west for 10 600 m, traversing Middle Aldridge Formation and passing very close to some narrow, north-northeast-trending subparallel Moyie sills to the south (Fig. 1). Noticeably three of these sills are transected by an extensive (>12 km), very narrow Moyie intrusion (d1 in Fig. 1) trending 011°, suggestive of a dyke-like geometry and a later episode of intrusion. A less extensive, parallel dyke-like intrusion (d2) lies roughly 1100 m to the west. Both d1 and d2 are offset sinistrally approximately 360 m along the Ice Fault. The offset portion of d2 south of the Ice Fault apparently links with the Bear dyke (Fig. 1).

The somewhat sinuous normal McNeil Fault (Brown and Woodfill, 1998) runs closely parallel to these dyke-like intrusions, crossing the magnetic profile just south of the normal Moyie River Fault (Brown et al., 2011b) (Fig. 1). North of the latter fault the southern portion of a fault designated as F1 runs subparallel to the McNeil Fault, and although its south end is almost 700 m north of the Moyie River Fault (Brown et al., 2011b), it appears to be sinistrally offset from the McNeil Fault by some 350 m along the Moyie River Fault. It is possible that F1 extends southward to the Moyie River Fault, and that it was at one time continuous with the McNeil Fault. Fault F1 terminates two Moyie sills trending roughly 055° west of the fault and a single sill having a similar overall trend east of the fault. Fault F1 follows the western edge of the linear magnetic high for about 3 km, whereas the McNeil Fault lies generally along or very close to the axis of the high.

The source of this magnetic high is problematic given that it is located within a broad expanse of Middle Aldridge Formation, which is generally characterized by low magnetic susceptibilities (Lowe et al., 2000; Thomas, 2015; Table 1). Unlike the Creston Formation that contains significantly magnetic layers, e.g. green arenite (Lowe et al., 1998, 2000), a magnetic stratigraphic source within the Aldridge Formation is seemingly ruled out.

Moyie sills are distributed throughout the widespread Middle Aldridge Formation of St. Mary Block, but their magnetic signatures are weak and generally an associated signature is not discernible. Brown and Woodfill (1998) believed that the Bear dyke, located between the Ice and Moyie faults, not far from their point of intersection (Fig. 1, 2), is an exception, claiming a correspondence with a distinct oval magnetic high defined by relatively high-resolution industry data collected at 200 m line spacing. Comparison of the positions of the dyke, as located on a relatively recent 1:50 000 scale geology map (Brown et al., 2011b), and the only high in the area of the dyke as defined by lower resolution data collected at 805 m line spacing (Fig. 2) shows the high positioned along the margin of the southern end of the dyke. Notwithstanding Brown and Woodfill's (1998) observations, it is proposed that this high is not related to the Bear dyke, a Moyie intrusion as mapped by Brown et al. (2011b). This conclusion is based on the noted universal lack of a noteworthy magnetic signature of any of the many Moyie intrusions in this area of the St. Mary Block. If the source is the Bear dyke, it would seem to be a very atypical example of a Moyie intrusion in terms of its magnetic properties. It

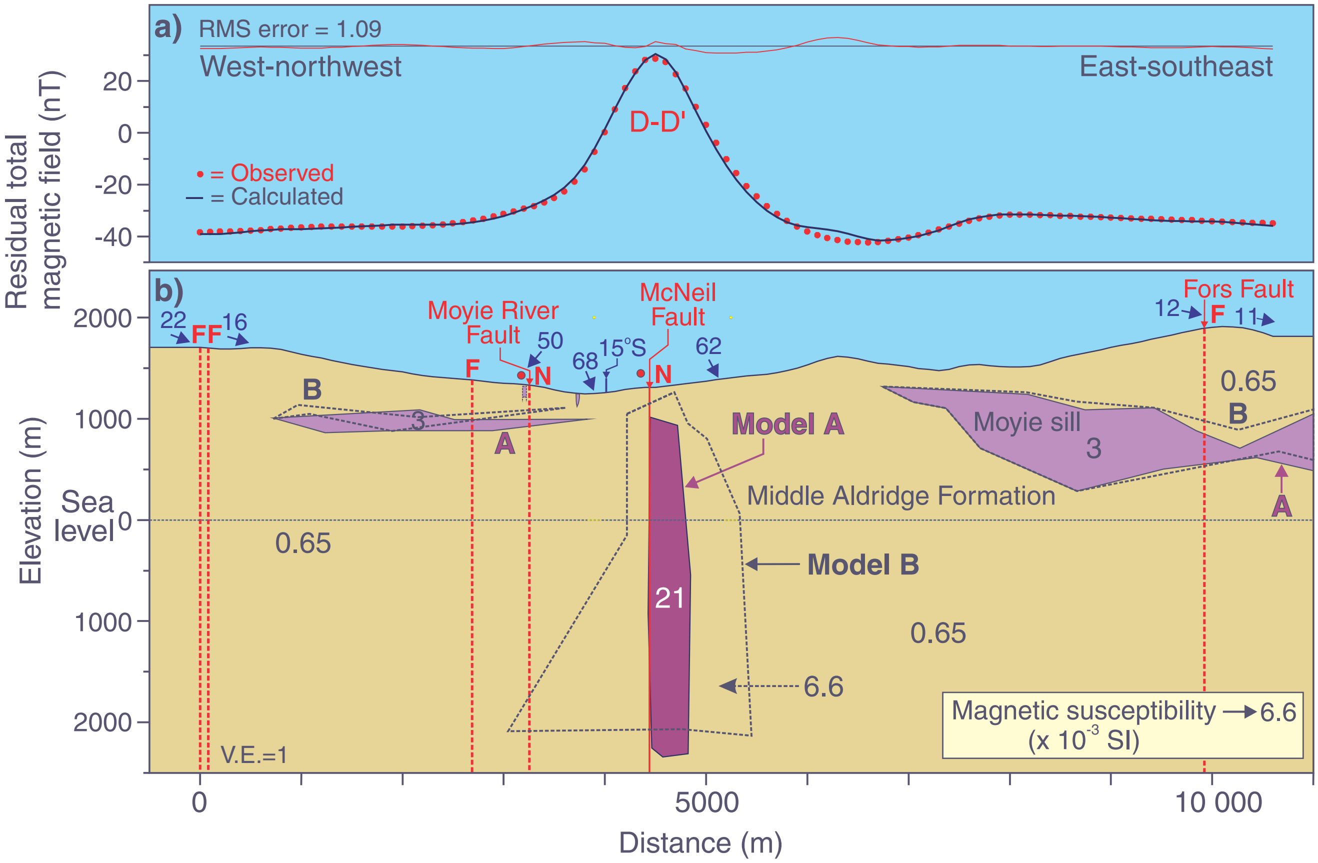

Figure 3. a) Observed magnetic profile and calculated model profile for Model A in (b) along line SMB1. **b)** Magnetic models A and B. Geology based on 1: 50 000 scale maps by Brown et al. (2011b, c). Dips are displayed with blue arrows and are apparent dips along the line of the section; dip measurements taken at positions of tails of arrow. F = fault undefined; N = normal fault, red dot to side of N depicts the downthrown side.

is assumed that the close association of the Bear dyke and magnetic high is fortuitous, and that the source of this high is a gabbroic intrusion that is not a Moyie intrusion.

A similar conclusion is reached in the case of another roughly oval magnetic high located near the intersection of the Ice and Kid faults (Fig. 1, 2) that also lies close to a mapped Moyie sill. Its peak is located about 400 m from the sill. A map of the first vertical derivative of the magnetic field shows that the axis of the anomaly extends northwest across the sill. A shallow drillhole (K97-01-254) (Schetselaar et al., 2015) just 79 m deep, positioned within the peak area of the high approximately 125 m east of the sill intersected 10.6 m of gabbro at the bottom of the hole. Is this truly Moyie gabbro or an unrelated magnetic gabbro? Most of the remainder of the core was clastic sedimentary or fault rocks. Another drillhole (SMC-95-1-2), 1067 m deep, roughly 150 m northeast of the limit of the magnetic high and positioned on the Moyie sill penetrated a total of 245 m of gabbro, 175 m of which was at a depth of less than 200 m. If magnetic, it would be expected that it would produce a discernible magnetic signature, but such is not present. Clastic sedimentary rocks of the Middle Aldridge Formation make up most of the rest of the core. It is apparent that the Moyie sill, in that location at least, is relatively nonmagnetic. This, and the fact that the long axis of the oval magnetic high is virtually perpendicular to the trend of the Moyie sills in this area suggest a source other than sills. This anomaly and that near the Bear dyke have similar dimensions and have amplitudes relative to the local background magnetic fields of about 117 nT and 136 nT, respectively.

In considering possible sources for the linear anomaly D-D', its peak amplitude of 74 nT, while noticeably less than those of the oval magnetic highs, does hold the possibility that it is related to a gabbroic intrusion. The linearity of the magnetic high and its close proximity to the McNeil and F1 faults suggests a steep magnetic dyke, the location of which may be influenced by these faults.

A dyke-like model (A) is shown in Figure 3. A vertical body, roughly 270 m to 420 m wide, extending to a depth of about 3600 m provides a close match to the observed magnetic profile. Its upper surface lies between 300 m to 400 m below ground surface, and it has a relatively strong magnetic susceptibility of 21 × 10^{-3} SI. It lies along the eastern side of the McNeil Fault, schematically shown to be vertical. Broad, low-amplitude magnetic highs to either side (western one is barely discernible) are attributed to buried subhorizontal Moyie sills, the presence of which is not inconsistent with the geology. The sills were assigned a realistic magnetic susceptibility of 3 × 10^{-3} SI. An attempt to model a dyke having a steeply dipping upper surface, yielding a wedge shape that might be more consistent with emplacement controlled by steep faulting, was unsuccessful. A match of the peak of the high was more easily achieved with the flatter top surface shown (Fig. 3), and a shallow depth was also a requirement. The amplitude of the high was less sensitive to changes in the depth of the lower surface of the dyke. Changes as much as ±1000 m had very little influence on the calculated profile in the area of the peak, thus highlighting the phenomenon of ambiguity in modelling magnetic data, particularly when rigid constraints are unavailable.

The problem of ambiguity is further illustrated with a different model (B, Fig. 3) of similar vertical extent, but having significantly lower susceptibility, in this case 6.6 × 10^{-3} SI. The lower susceptibility requires that the model is less deeply buried and widens with increasing depth. The model includes subhorizontal Moyie sills to complete an acceptable match to the observed magnetic profile, which is as good as the match for the dyke model (A).

The McNeil fault zone is poorly exposed, but at one locality along an adjacent northeast-trending shear zone albite-altered, iron-oxide breccia resembling mineralization along the Iron Range Fault (Stinson and Brown, 1995) is present (Brown and Woodfill, 1998). Such mineralization takes the form of lenses of massive hematite and magnetite up to 3 m wide that are generally surrounded by wider zones of hematitic breccia. A prominent linear magnetic anomaly running along the Iron Range Fault is attributed to this mineralization (Lowe et al., 2000). The similar northward trend of the Iron Range and McNeil (and F1) faults and the common presence of iron-oxide breccia and an associated prominent magnetic anomaly, collectively, may have significance for mineral exploration along the McNeil and F1 faults.

Model SMB2

Profile SMB2, 20 km long, is one of two parallel profiles crossing southwest-trending linear magnetic highs A-A' and B-B' close to the boundary between the Aldridge and Creston formations (Fig. 1, 2). These highs display as two narrow and apparently mutually interfering highs near the centre of the profile (Fig. 4a). The linear high A-A' falls exclusively within the Creston Formation, with the related peak in the profile centred on the Lower Creston Formation and attaining a value approximately 93 nT above an assumed background level at the northwest end of the profile. Linear high B-B' surprisingly correlates with the Middle Aldridge Formation with one section centred on the Old Baldy Fault. In the profile it is represented by a peak attaining roughly 193 nT above background, reflecting the culmination of values along this linear anomaly.

Northwest of these highs, over mainly the Middle Creston Formation, a long wavelength, markedly asymmetrical, low-amplitude (~33 nT) high peaks near the Perry Creek Fault and gradually diminishes toward the northwest end of the profile. Southeast of the principal highs a small, relatively broad, flat-topped high seems to correlate with Moyie sills; its amplitude is only about 16 nT relative to local background in this section of the profile.

The two central peaks are both explainable by narrow, steeply northwest-dipping units (Fig. 4b). The unit linked to the northwestern peak, on magnetic anomaly A-A' (Fig. 2), is compatible with mapped geology, correlating with a unit of Lower Creston Formation. Its susceptibility of 7 × 10^{-3} SI is consistent with the range of values for the Creston Formation (Table 1). Lowe et al. (2000) noted that the Lower Creston Formation near Yahk, formed of fine-grained argillite, commonly contains stringer and disseminated magnetite. The unit explaining the southeastern peak, on magnetic anomaly B-B' (Fig. 2), is geologically perplexing. It is not modelled to the surface, because relatively nonmagnetic Aldridge Formation, yielding consistently weak susceptibilities throughout the Purcell anticlinorium, is mapped at surface, yet modelling requires the upper surface of the unit to be quite shallow. Its susceptibility is a large 25 × 10^{-3} SI, consistent with the range of values determined for the Creston Formation (Table 1). Similar large values were derived for several modelled units within the Creston Formation on the flanks of the Moyie anticline, the largest ranging from 16 × 10^{-3} SI to 22 × 10^{-3} SI (Thomas, 2015). This modelled unit has magnetic susceptibilities typical of magnetic components of the Creston Formations, but lies within relatively nonmagnetic Aldridge Formation. It may therefore be related to a gabbroic intrusion similar to that proposed as the source of linear high D-D', also located within the Aldridge Formation. Adding to the confusion is the fact that the linear magnetic high B-B' (Fig. 2) on which this peak is located apparently continues northeastward crossing from the Aldridge Formation into the Creston Formation (Fig. 1, 2), in which area a modelled Creston Formation unit would make geological sense. There is a short disconnect between the north-northeastern and south-southwestern segments of linear high B-B' near the Old Baldy Fault, and it is possible that the alignment of the two segments is fortuitous, and that they are related to different sources.

If the unit is indeed related to a magnetic unit of the Creston Formation, the dilemma is to interpret a structure that would permit the outlined geometrical relationships. The Old Baldy Fault was described as a northwest-side-down normal fault with normal movement occurring late in its history (Brown and Woodfill, 1998). A marked contrast in the nature of the Aldridge Formation takes place across the fault with a total absence of Moyie sills northwest of the fault. Here geology is relatively simple with a stratigraphic section from Middle Aldridge Formation, through Upper Aldridge Formation, Lower Creston Formation, and Middle Creston Formation dipping consistently and relatively

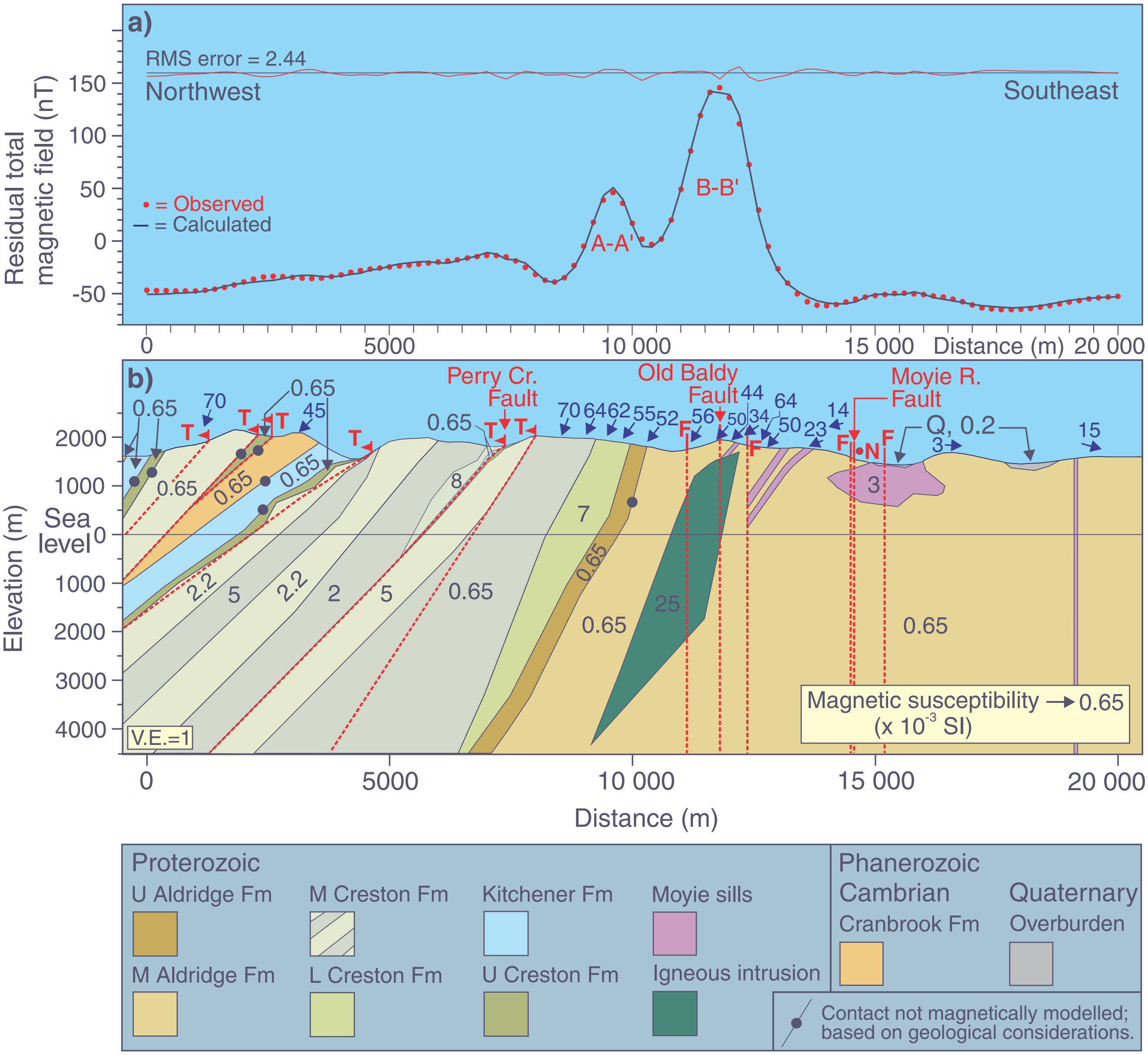

Figure 4. a) Observed magnetic profile and calculated model profile for model in (b) along line SMB2. **b)** Magnetic model; geology based on 1:50 000 scale map by Brown et al. (2011b). Dips are displayed with blue arrows and are apparent dips along the line of the section; dip measurements taken at positions of tails of arrow. U = Upper; M = Middle; L = Lower; F = fault undefined; N = normal fault, red dot to side of N denotes the downthrown side; T = thrust fault, triangle denotes upthrust side.

steeply (generally >50°) northwest (Fig. 4b). Such a geological scenario offers little room for a structural model that could emplace a magnetic unit of Creston Formation in the manner displayed in Figure 4b.

Linear anomaly B-B' has been examined by Brown and Woodfill (1998) who commented that much of the exposure in the area of the anomaly is unaltered Middle Aldridge Formation with rare to no Moyie sills, but did note that locally magnetic sills are present on the David property 330 m southeast of the Old Baldy Fault. Sills in this area are very narrow and it not anticipated that they would contribute greatly to the linear anomaly. Brown and Woodfill (1998) further suggested that a Cretaceous intrusion at shallow depth could produce the anomaly. Such a source would obviate the need for complex structural interpretations. The Cretaceous quartz monzonitic Kiakho stock (Höy, 1993) is one such intrusion producing a strong magnetic anomaly (~340 nT amplitude), though this is a more typical oval shape (Fig. 2), rather than the elongate form of the anomaly along B-B'.

The broad asymmetric magnetic high to the northwest of the central highs is attributed to a series of generally relatively weakly magnetic units within the Middle Creston

Formation. The weakest magnetic units produce no magnetic response as they have the same magnetic susceptibility as that of the 'background' magnetic susceptibility of 0.65×10^{-3} SI assigned to the Middle Aldridge Formation, a value also applied to the Kitchener Formation and the Cambrian Cranbrook Formation. Other Middle Creston Formation units have susceptibilities ranging from 2×10^{-3} SI to 8×10^{-3} SI. All units dip northwest at angles ranging from about 45° to 60° in concert with mapped surface dips. Exceptions are very near-surface gentle dips of unit contacts near the Perry Creek Fault and the adjacent fault to the northwest (dips of 21° and 15°, respectively). It is believed that these gentle dips may be local artifacts related to relatively rugged topography in these localities. Dips of faults in this northwestern portion of the model have been modelled as being parallel or subparallel to dips of magnetic unit contacts. A choice of dipping faults is influenced by Benvenuto and Price's (1979) claim that moderately northwest-dipping beds on the northwest flank of the St. Mary Block half anticline are disrupted by northwest-dipping normal and reverse faults. This picture differs from that of Reesor (1996) who showed these faults to be vertical in sections across this general area. The weak magnetic high southeast of the Moyie River Fault is explained by a Moyie intrusion about 850 m thick having a susceptibility of 3×10^{-3} SI.

Model SMB3

Profile SMB3 is 17.2 km long and runs parallel to profile SMB2 crossing the two linear magnetic highs A-A' and B-B', and two other distinct highs northwest of A-A' (Fig. 2). From northwest to southeast the highs have amplitudes of 49 nT, 57 nT, 150 nT, and 60 nT, respectively, relative to a presumed background level at the southeast end of the profile (Fig. 5). The most prominent high (A-A') coincides with a unit of the Lower Creston Formation, which is uniquely the modelled source of the high A-A' in profile SMB2, having a moderately high susceptibility of 7×10^{-3} SI (Fig. 4). In the case of profile SMB3, the high A-A' is attributed to relatively magnetic rocks distributed in the upper part of the Lower Creston Formation and lower part of the Middle Creston Formation (Fig. 5). Most of these have a susceptibility of 9×10^{-3} SI, with one thin horizon attaining 11.5×10^{-3} SI.

The two highs to the northwest are located over the Middle Creston Formation and are modelled as relatively weakly magnetic layers within susceptibilities ranging from 2.2×10^{-3} SI to 3.51×10^{-3} SI. These are compatible with susceptibilities (generally 2×10^{-3} SI to 5×10^{-3} SI; 8×10^{-3} SI for one layer) for relatively magnetic layers modelled in SMB2 to the southwest. Dips of Middle Creston Formation magnetic layers within the northwestern part of SMB3 are noticeably steeper (~70°) than those within SMB2 (~45°), which is perhaps surprising given that the profile lines are only about 2 km apart; however, the nature of the profiles across the Middle Creston Formation differ significantly, with that for SMB2 being smoother and more amenable to modelling in terms of gentler dips, and there is limited dip information northwest of the Perry Creek Fault.

The southeastern magnetic high B-B' is imperfectly explained by a vertical sheet-like body up to about 460 m wide adjacent to the Old Baldy Fault. It has the highest modelled susceptibility in the model (14×10^{-3} SI). It is capped, arbitrarily, by a shallow-dipping Moyie sill. It is imperfectly modelled in the sense that the modelled magnetic profile, locally, does not match very well the observed profile. This seems to be caused mainly by the presence of a distinct magnetic low between A-A' and B-B' that cannot be reproduced by a variety of geometries applied to the sheet-like body and to the magnetic Creston Formation units correlating with the high A-A'. The low is centred immediately northeast of the profile line and has a peak amplitude of about −100 nT relative to the magnetic field level at the southeast end of the profile, though is only about −15 nT along the profile itself. In plan view the low is approximately tear-shaped (Fig. 2) and has maximum southwest-northeast and northwest-southeast dimensions of about 1900 m.

The shape and negative character of this tear-shaped anomaly suggest that it may be related to a steeply dipping, cylindrical mafic intrusion having a reversed component of remanent magnetization. The anomaly is positioned on a unit of Lower Creston Formation, so any such intrusion must be buried, but not deeply. The latter unit sits in the core of a syncline defined by a unit of the Upper Aldridge Formation in the geological section depicted in Figure 5, but this portrayal is somewhat misleading as the rocks in this locality dip steeply northeast away from the line of section, i.e. the syncline plunges to the northeast.

The stratigraphy of the Middle Proterozoic Belt–Purcell Basin includes horizons characterized by both normal and reversed magnetizations (Elston et al., 2002). For the present area of interest, information on reversed magnetizations is provided for the "Purcell Lavas," which are correlated with the Nicol Creek Formation (Fig. 1). Reversed magnetizations have also been reported for Cretaceous and Eocene igneous rocks in the Canadian Cordillera. For example, Wynne et al. (1998) reported reversed magnetizations for subaerial volcanic rocks of the 70 Ma Eocene Carmacks Group in Yukon, and Bardoux and Irving (1989) noted reversed magnetizations in the 50.5 Ma Eocene Trepanier porphyry and dacite. Such data, therefore, are permissive of the possible presence of a Cretaceous or Eocene plug-like intrusion.

A vertical intrusion is modelled (Fig. 5b) centred within the small near-surface syncline cored by Creston Formation. It is approximately 250 m wide at surface, narrowing slightly downward, has a strike length of 1600 m, and depth of at least 5000 m. The large difference in surface dimensions arises because the profile crosses the magnetic low near its edge (Fig. 2) where it narrows significantly,

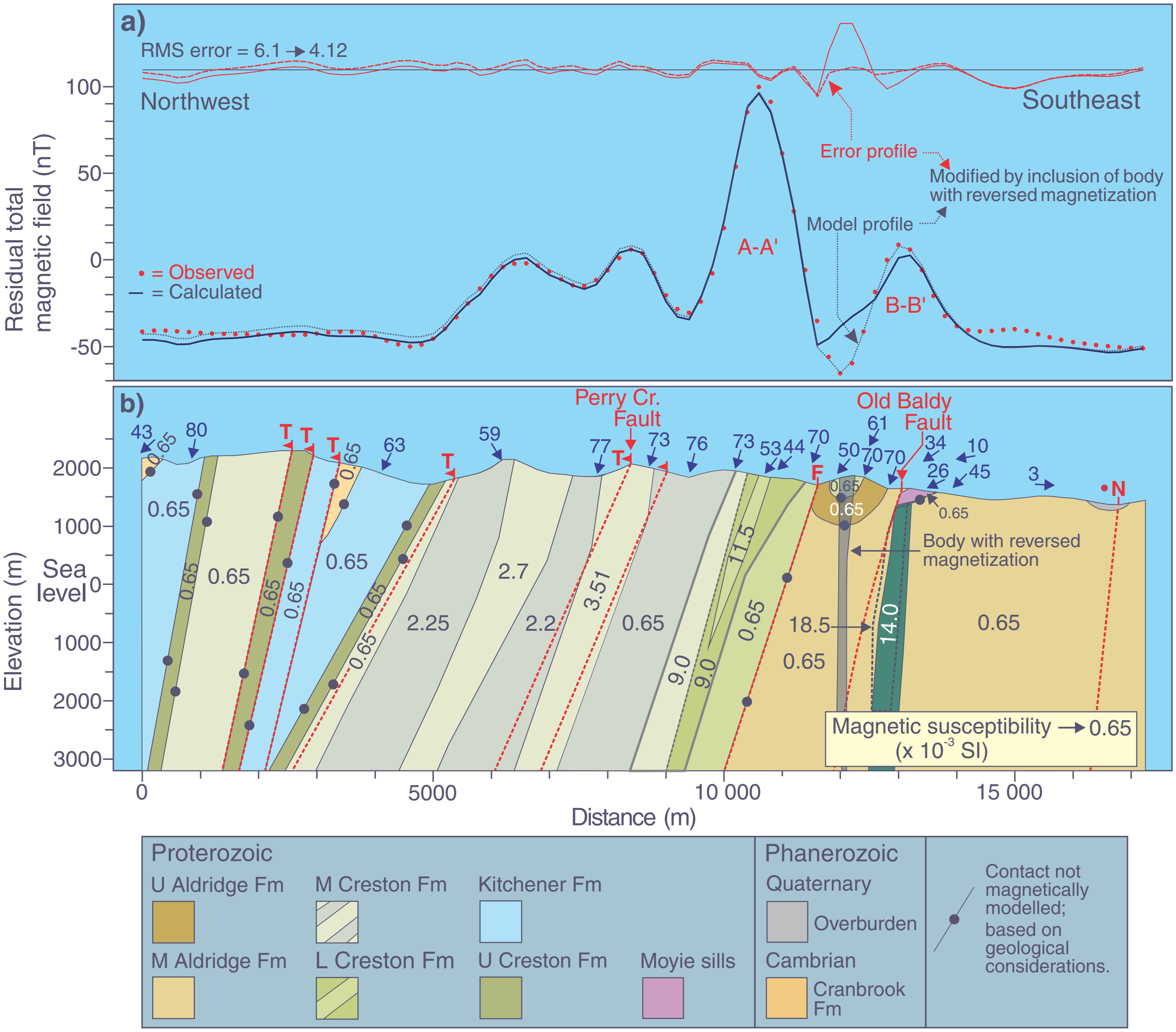

Figure 5. a) Observed magnetic profile and calculated model profile for model in (b) along line SMB3. **b)** Magnetic model; geology based on 1:50 000 scale map by Brown et al. (2011b). Dips are displayed with blue arrows and are apparent dips along the line of the section; dip measurements taken at positions of tails of arrow. U = Upper; M = Middle; L = Lower; F = fault undefined; N = normal fault, red dot to side of N denotes the downthrown side; T = thrust fault, triangle denotes upthrust side.

and the finite strike length perpendicular to the profile used in modelling is much larger to accommodate the width of the low in this direction. The modelled intrusion is not, therefore, a cylindrical plug that might have been generated in 3-D modelling. Nevertheless, the modelled unit serves to demonstrate that a vertical intrusion having a component of reversed magnetization is consistent with the magnetic signatures. The unit has a reversed remanent component of magnetization having an intensity of 0.3 A/m, and inferred inclination and declination of –90° and 0°, respectively; a component of induced magnetization is not assigned. The match between observed and modelled profiles is marginally improved overall from a root mean square error of 6.1 to 4.12, but is greatly improved locally in the area of the magnetic low between A-A' and B-B'. Inclusion of the plug requires that the susceptibility of the nearby vertical sheet modelled to explain the high B-B' be increased from 14.0 × 10^{-3} SI to 18.5 × 10^{-3} SI, and very slight modifications to its shape.

Model SMB4

Profile SMB4 runs east-southeast for 8 km then swings roughly 095°, ending at 19.4 km. It crosses the belt of higher magnetic field trending southwest from near the Read Lake granite on which are superposed linear highs G-G' and H-H' (Fig. 2). Apparently, these two highs and adjacent highs to the east coalesce to produce this zone of positive magnetic signature. The profile extends from Cambrian sedimentary rocks in the west-northwest to Middle Aldridge Formation metasedimentary rocks in the east, passing across mainly Middle Creston Formation metasedimentary rocks that are juxtaposed with several bands of Kitchener Formation metasedimentary rocks (Fig. 1) (Brown et al., 2011a, b). Some of these bands are bounded to the west-northwest by thrust faults that may be northwest-dipping (Benvenuto and Price, 1979).

In the model (Fig. 6) the peaks on the west-northwest part of the profile, corresponding to linear anomalies G-G' and H-H', are superposed on a broad magnetic high that extends across most of the profile west-northwest of the Perry Creek

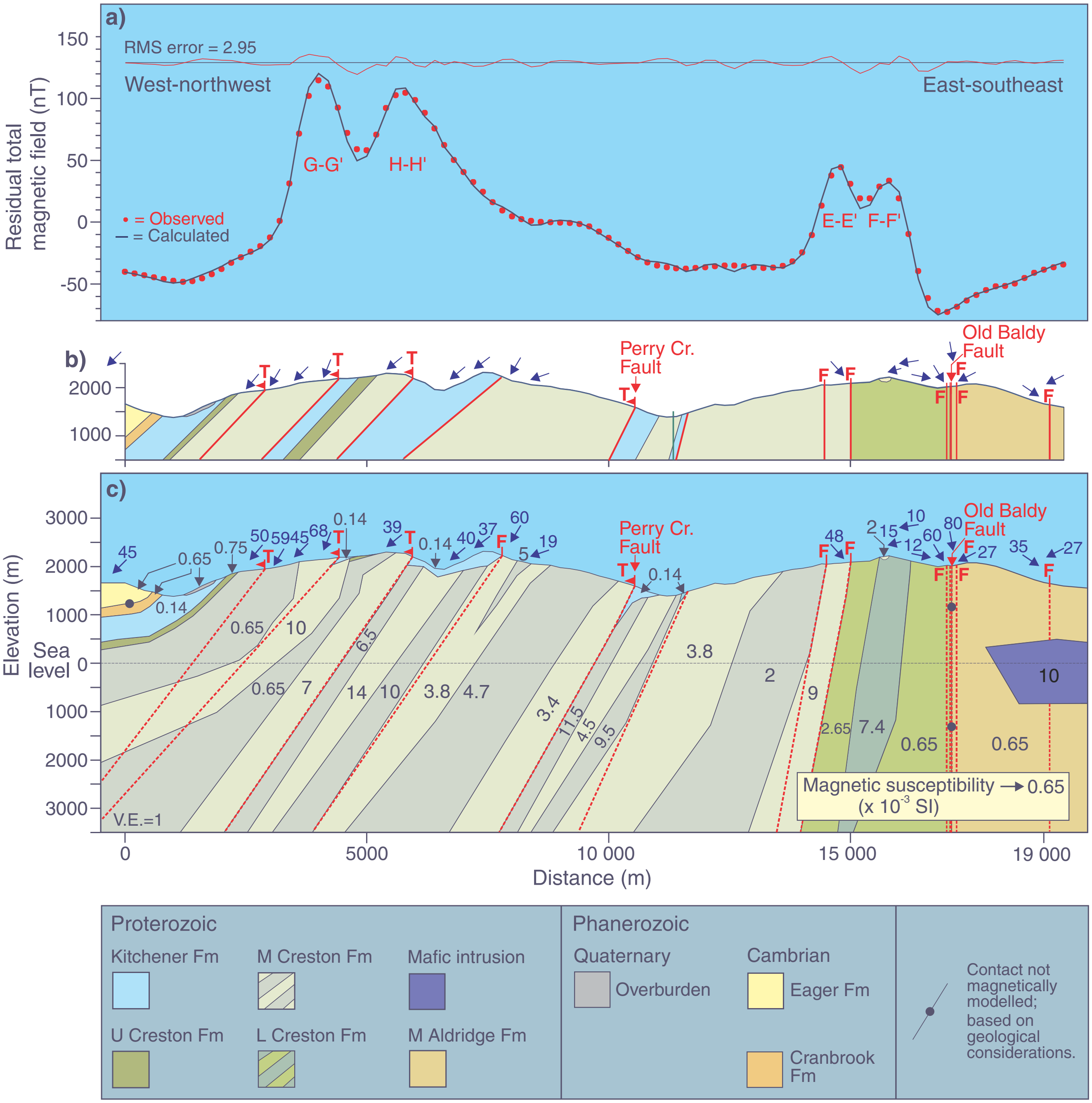

Figure 6. a) Observed magnetic profile and calculated model profile for model in (c) along line SMB4. **b)** Geological section interpreted from 1:50 000 scale geological maps by Brown et al. (2011a, b, c). **c)** Magnetic model; geology based on 1:50 000 scale maps by Brown et al. (2011a, b, c). Dips are displayed with blue arrows and are apparent dips along the line of the section; dip measurements taken at positions of tails of arrow. U = Upper; M = Middle; L = Lower; F = fault undefined; T = thrust fault, triangle denotes upthrust side.

Fault. These peaks have amplitudes of about 163 nT and 153 nT, respectively, relative to the lowest part of the profile near the west-northwest end. Both peaks fall on the Middle Creston Formation, not far from adjacent units of Kitchener Formation to the east-southeast. Near the east-southeast end of the profile two smaller peaks, corresponding to linear anomalies E-E' and F-F', having amplitudes of about 93 nT and 82 nT, respectively, also correlate with the Creston Formation. Peak E-E' falls on the Middle Creston Formation, whereas peak F-F' is located roughly at the junction between the Middle and Lower Creston formations. In this area, a narrow northward-directed incursion of Middle Creston Formation invades a broader belt of Lower Creston Formation (Fig. 1) (Brown et al., 2011b). Interpretation of the geological map suggests that the Lower Creston Formation underlies the Middle Creston Formation at shallow depth, continuing west as far as a normal fault, and that the source of F-F' is within the Lower Creston Formation.

The close spatial correlations of the principal magnetic peaks with the Creston Formation and recognized magnetic characteristics of the formation, both Middle and Lower, prompted an approach to modelling based on a west-northwest-dipping succession of metasedimentary layers within the Creston Formation. Several mapped bedding dips in the west-northwestern half of the profile support this approach, though dips are scarce in the central part of the profile and rather more variable in direction and magnitude near the Old Baldy Fault. It has been noted, also, that portions of linear highs G-G' and H-H' are underlain by Cretaceous ‘granitic’ rocks, a peak of one section of H-H' coinciding precisely with a small circular intrusion (Fig. 1, 2). Notwithstanding a potential contribution from such granitic rocks, sedimentary layers within the Creston Formation are favoured as the principal source of magnetic anomalies in the model.

The model displays a series of west-northwest-dipping units of mainly Middle Creston Formation metasedimentary rocks. Dips range generally from about 52° to 61° in the west-northwestern half, slightly steeper than most dips depicted on geological maps (Brown et al., 2011a, b) that range from 37° to 68°. Steeper modelled dips of unit boundaries, up to about 80°, are observed near the Old Baldy Fault, though the few mapped dips in this area range from 10° to 48°; steeper dips of 60° and 80° are mapped only very close to the fault. At the west-northwest end of the model, dips become gentler into the area of Kitchener Formation and Cambrian rocks, a requirement to match the small magnetic low in this part of the profile. A broad unit of Kitchener Formation coinciding with the east-southeastern flank of peak H-H' has been thinned dramatically from what would have been expected from a conformable relationship with the older underlying Creston Formation, but thinning is necessitated by a need for more strongly magnetic rocks closer to the surface. This unit of Kitchener Formation thins to disappearance less than 3 km to the southwest of the profile line (Fig. 1), which supports its termination at no great depth along the line itself. The nature of its base, in presumed contact with the Middle Creston Formation and truncating steeply dipping magnetic units of the formation according to the model, is open to question, but appears to be structural rather than stratigraphic in nature.

The large west-northwestern peaks G-G' and H-H' are explained mainly by a series of magnetic layers within the Middle Creston Formation having susceptibilities ranging from 6.5×10^{-3} SI to 14×10^{-3} SI. A narrow band of Upper Creston Formation located in the low between the peaks is speculated to be very thin and truncated to the west beneath the Kitchener Formation by a fault, and has little influence on the magnetic field. The east-southeastern peaks E-E' and F-F' are explained by relatively thin and near-vertical units of Middle Creston Formation and Lower Creston Formation, respectively, having moderately large susceptibilities of 9×10^{-3} SI and 7.4×10^{-3} SI, rivalling values under the west-northwestern peaks. Of concern is the incompatibility between the steeply modelled units and gentle mapped surface dips ranging from just 10° to 15°. It is true that very few dips are mapped in the area of the E-E' and F-F' peaks, but nevertheless they raise questions about the viability of the modelling. On the other hand it would be more difficult to model the peaks without involving units having steep contacts.

Between the two groups of peaks susceptibilities in the Creston Formation range generally from 2×10^{-3} SI to 4.7×10^{-3} SI with just a few units having the low value of 0.65×10^{-3} SI typical of the characteristically weakly magnetic Aldridge Formation. Noticeably, two Middle Creston Formation units near the Perry Creek Fault having significantly stronger magnetic susceptibilities of 11.5×10^{-3} SI and 9.5×10^{-3} SI, rivalling those of units associated with the principal peaks, are not associated with peaks. In one case, the top of the unit is buried beneath a wedge of Kitchener Formation having a median thickness of about 200 m that suppresses the magnetic signature. In the second case, the unit intersects the surface, but is only 120 m to 180 m wide over the uppermost 1 km and flanked by units having moderately sizable susceptibilities (3.8×10^{-3} SI and 4.5×10^{-3} SI), all of which serve to reduce the magnetic impact of this unit.

An east-southeastward increase in the magnetic field at the east end of the profile, culminating in a weak linear magnetic high approximately 30 nT amplitude, is modelled by a buried body having a moderately high susceptibility of 10×10^{-3} SI. The high peaks roughly 1200 m from the end of the profile, is roughly 3 km long, oriented 030° and lies within the Aldridge Formation between two normal faults (Brown et al., 2011c). Modelling of this anomaly further east (not displayed in Fig. 6) indicates that the body may rise to within less than 100 m below the surface. It has been argued previously (model SM1) that Moyie sills are probably not very strongly magnetized, and so this unit probably does not represent such a sill. As for model SMB1, it is speculated that the body is a gabbroic intrusion that is not a Moyie intrusion.

Model SMB5

Profile SMB5 runs subparallel to SMB4, roughly 2 km to 3 km to the north, crossing virtually the same geological units along strike traversed by SMB4, though Cambrian rocks are not present at the west-northwest end. A major difference in the profiles is the absence of a peak related to linear magnetic high H-H' (Fig. 2) in profile SMB5 (Fig. 7), present in profile SMB4 (Fig. 6), though a small peak (P) associated with a small en echelon linear anomaly is present. A strong peak, amplitude approximately 180 nT, relative to the lowest point of the profile, reflects linear anomaly G-G'. This amplitude compares closely with the 173 nT amplitude observed for G-G' along profile SMB4. Near the east-southeast end of the profile, the peak corresponding to

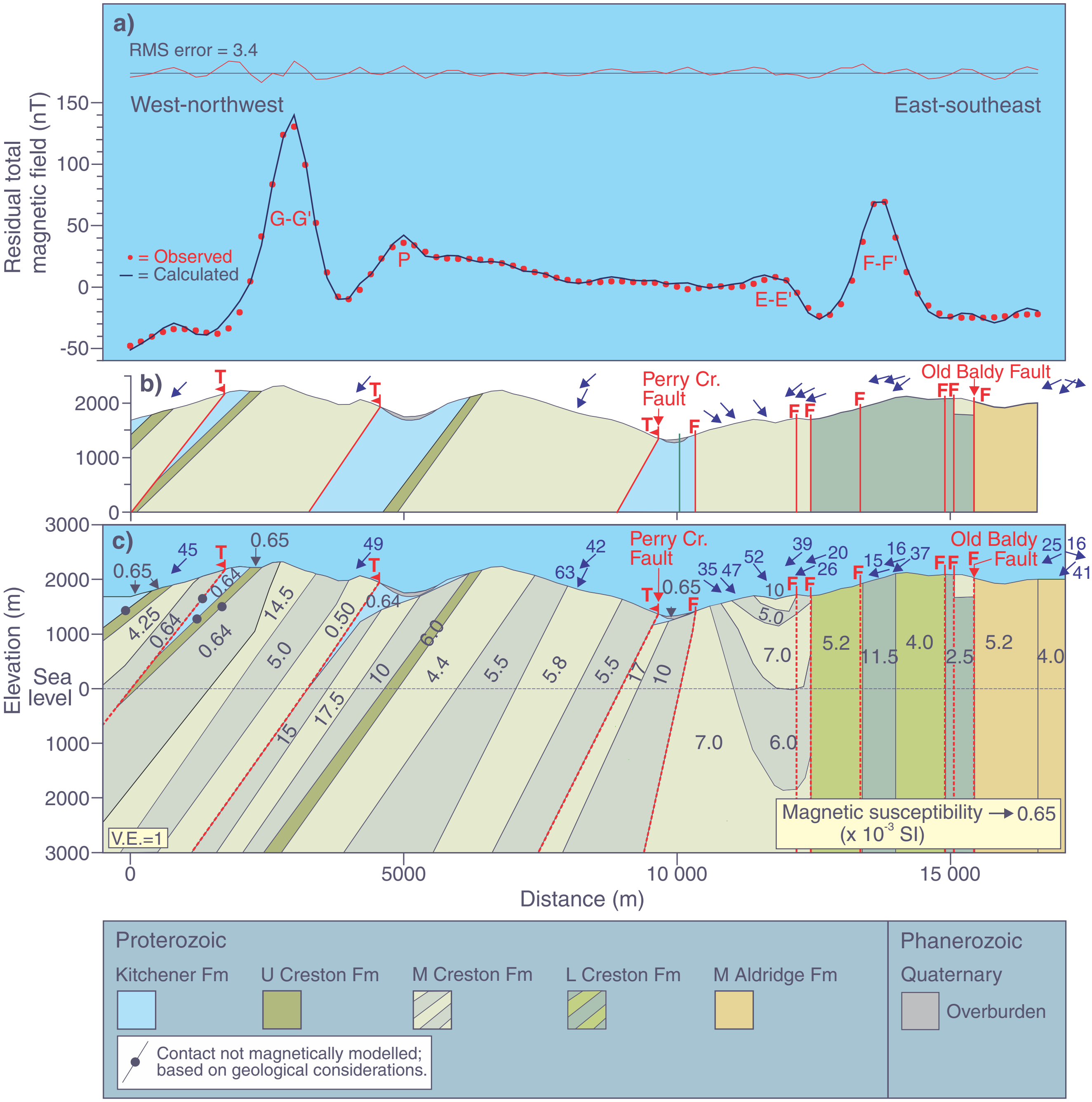

Figure 7. a) Observed magnetic profile and calculated model profile for model in (c) along line SMB5. **b)** Geological section interpreted from 1:50 000 scale geological maps by Brown et al. (2011a, b, c). **c)** Magnetic model; geology based on 1:50 000 scale maps by Brown et al. (2011a, b, c). Dips are displayed with blue arrows and are apparent dips along the line of the section; dip measurements taken at positions of tails of arrow. U = Upper; M = Middle; L = Lower; F = fault undefined; T = thrust fault, triangle denotes upthrust side.

linear anomaly E-E' is present, but very weak, whereas F-F' is prominent with an amplitude of 93 nT relative to the local background.

The magnetic model (Fig. 7) from roughly the Perry Creek Fault west-northwestward is dominated by steeply west-northwest-dipping units of Middle Creston Formation that are generally thin or of moderate thickness; thin units of Upper Creston Formation are also present. Dips are characteristically between about 50° and 63°, though somewhat less steep, 40° to 50° near the west-northwestern end. West-northwestward from the fault immediately east of the Perry Creek Fault approximately two-thirds of the combined thickness of Middle Creston Formation (mainly), Upper Creston Formation and Kitchener Formation has magnetic susceptibilities ranging from 0.50×10^{-3} SI to 6.0×10^{-3} SI. As expected, a unit under peak G-G' has a significantly higher susceptibility of 14.5×10^{-3} SI, and three contiguous units located under peak P have high values of 10×10^{-3} SI, 15×10^{-3} SI, and 17.5×10^{-3} SI. Although peak P is not very strong, high susceptibilities are required in this area, because the three units are partially covered by Quaternary overburden and Kitchener Formation that presumably suppress their magnetic signature. A similar requirement for higher susceptibilities applies near the Perry Creek Fault where similar cover is present, and here two contiguous units have values of 10×10^{-3} SI and 17×10^{-3} SI. As noted for the model of profile SMB4, the gently dipping base of the Kitchener Formation, apparently obliquely truncating steeply dipping magnetic units of the Middle Creston Formation, raises questions regarding the nature of the contact between the two formations.

A series of synclinally folded units having moderately high susceptibilities ranging from 5×10^{-3} SI to 10×10^{-3} SI has been modelled within the Middle Creston Formation east of the Perry Creek Fault. Although few dips and strikes are mapped along the profile (Brown et al., 2011a,b), those present within this portion of the Middle Creston Formation are compatible with the presence of a synclinal structure. A mapped fault, modelled to be vertical, is interpreted to mark the eastern limit of the syncline. Between this fault and the Old Baldy Fault, the Lower Creston Formation is depicted as a series of vertical units having susceptibilities ranging from 2.5×10^{-3} SI to 11.5×10^{-3} SI; the latter value is present in a unit correlating with the peak F-F'. As for profile SMB4, the modelled vertical units conflict with surface dips ranging from 15° to 37° and consistently directed west-northwest. Here, again, mapped dips are few, but raise questions relating to the incongruity between their magnitudes and those of contact dips in the model.

East of the Old Baldy Fault, two vertical units of the Middle Aldridge Formation are modelled. Their susceptibilities of 5.2×10^{-3} SI and 4.0×10^{-3} SI are much higher than the characteristic value of 0.65×10^{-3} SI adopted for this formation. Measurements of Aldridge Formation from this area would be required to determine if these values are reasonable, which is probably unlikely. Thomas' (2013) map of susceptibility sampling sites for the Purcell anticlinorium does not show any sites in this particular area, and the upper value reported for the range of values for the Middle Aldridge Formation is 1.63×10^{-3} SI. An east-southeastward increase in the magnetic field at the east end of profile SMB4 was attributed to a buried gabbroic intrusion that is not a Moyie intrusion within the Middle Aldridge Formation, susceptibility 10×10^{-3} SI. It is speculated that a similar explanation might apply to the eastern end of model SMB5, thus obviating the need for uncharacteristically high susceptibilities for the Middle Aldridge Formation.

Model SMB6

Profile SMB6 runs northeast from well within the St. Mary Block to the east side of the Rocky Mountain Trench fault, commencing on the core of Middle Aldridge Formation and visibly traversing the Creston and Kitchener formations northeast of the Gold Creek Fault, though much of the bedrock northeast of the fault is hidden by Quaternary cover (Fig. 1). The profile is displayed in Figure 8a and a geological section interpreted from 1:50 000 scale geological maps (Brown and MacLeod, 2011a; Brown et al., 2011c) is portrayed in Figure 8b. The definition of the thick Quaternary basin in the Rocky Mountain Trench fault is based on results of gravity modelling by Garland et al. (1961) along a profile running almost exactly along the line of SMB6.

The path of profile SMB6 was chosen to investigate the contrast between the relatively flat, smooth, and generally unperturbed magnetic field over much of the south-western portion of Middle Aldridge Formation forming the St. Mary Block, and the field that increases progressively northeastward across the northeastern portion to almost 6 km beyond the Gold Creek Fault (Fig. 2). The change commences across a conspicuous northwest-trending belt, about 3 km wide, of slightly steeper magnetic gradient that traverses the Middle Aldridge Formation and included Moyie sills, and follows a somewhat tortuous path. The belt runs for about 14 km northwestward from the Moyie Fault, terminating roughly 5 km northwest of the Moyie River Fault, though here its identification is less certain as it merges with the western flank of a prominent magnetic high related to the Cretaceous Kiakho stock (Brown et al., 2011c) (Fig. 1, 2). Values continue to increase slightly less rapidly northeastward from this initial gradient over roughly the next 20 km before the field flattens for about 6 km at a level about 95 nT above the background field to the southwest (Fig. 8a). The field then increases northeastward once again, more gently, before peaking sharply near the Rocky Mountain Trench fault.

A similar southwest to northeast contrast in the magnetic field is observed southeast of the Moyie Fault, but the steeper southwestern initial portion of the gradient in the St. Mary Block apparently is replaced along strike by a broad magnetic high extending southeast along the eastern flank of the Moyie anticline and coinciding mainly with

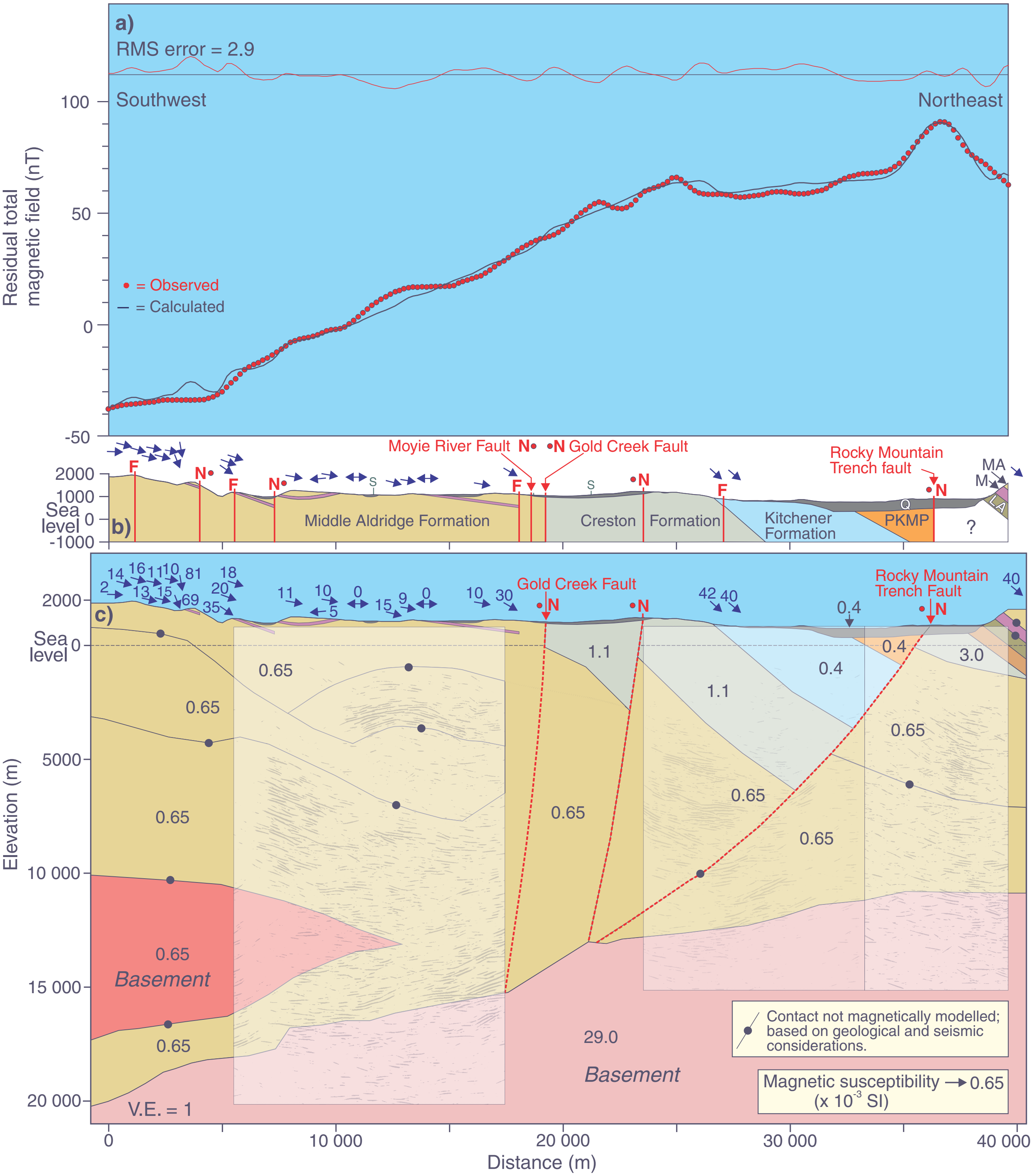

Figure 8. a) Observed magnetic profile and calculated model profile for model in (c) along line SMB6. **b)** Geological section interpreted from 1:50 000 scale geological maps by Brown and MacLeod (2011a) and Brown et al. (2011c). LA = Lower Aldridge Formation, MA = Middle Aldridge Formation, M = Moyie sills, PKMP = 'Post-Kitchener Formation MesoProterozoic rocks'. **c)** Magnetic model; geology based on 1:50 000 scale maps by Brown et al. (2011c). Dips are displayed with blue arrows and are apparent dips along the line of the section; dip measurements taken at positions of tails of arrow. F = fault undefined; N = normal fault, red dot to side of N denotes the downthrown side. Seismic sections are projected to SMB6 from portions of seismic profile 10-1 (Van der Velden and Cook, 1996), exhibiting some degree of subparallelism with SMB6. Several geological contacts are not modelled from the magnetic data, but are portrayed to present an idea of the layering within the model and are based principally on the seismic interpretation of Van der Velden and Cook (1996) and reprocessed seismic sections provided courtesy of F. Cook and K. Vasudevan, previously associated with the University of Calgary.

the Kitchener Formation. A spatially small magnetic low separates these two different expressions of the magnetic field. Nevertheless, the change from a relatively flat magnetic field in the southwest to a progressively northeastward-increasing field in the northeast is present both northwest and southeast of the Moyie Fault.

Mapped surface geology provides no helpful clues regarding the reason for the change in the field, since the geology is dominated by Middle Aldridge Formation containing Moyie sills in the area characterized by the flat magnetic field, and in the area across which the magnetic field increases. It is noted that the slightly steeper southwestern part of this regional gradient cuts across one Moyie sill, suggesting that the source of the gradient may be deeper than the sill and Aldridge Formation in immediate contact with it.

Possible insight into the cause of the change in magnetic field is afforded by the interpretation of a seismic-reflection profile interpreted by Van der Velden and Cook (1996). The profile, designated as profile 10-1, runs reasonably close to SMB6 (Fig. 1, 2), but is not everywhere closely parallel or subparallel to SMB6, diverging by as much as 6.2 km and 7.7 km, respectively, south and north of SMB6. Considering that SMB6 has a large extent of 39.6 km, however, the scale of investigation offers the possibility of extrapolating over these distances, in the hope of outlining major crustal structures along the magnetic profile. Profile 10-1 represents a combination of three individual seismic traverses, with a short gap in coverage present near Cranbrook (Fig. 1). Duncan Energy Inc. completed the traverses in 1984 and 1985, and data were later enhanced through reprocessing at the University of Calgary. F. Cook and K. Vasudevan, previously affiliated with the university, kindly provided upgraded images of the seismic images to the author. Van der Velden and Cook's (1996) interpretation is displayed in Figure 9b.

Of potential relevance to an explanation of the magnetic field is the northeast-dipping panel of Aldridge Formation sedimentary rocks in the centre of the section containing the group of reflections S2 (Fig. 9) attributed to Moyie sills within the sedimentary package. In the southwestern half of the section these overlie a nonreflective zone interpreted to signify the presence of sedimentary rocks belonging to the Creston and Kitchener formations (Van der Velden and Cook, 1996). Below the nonreflective zone is a thick zone characterized by many reflections (S1) that are also attributed to Aldridge Formation intruded by Moyie sills. The northeast-dipping

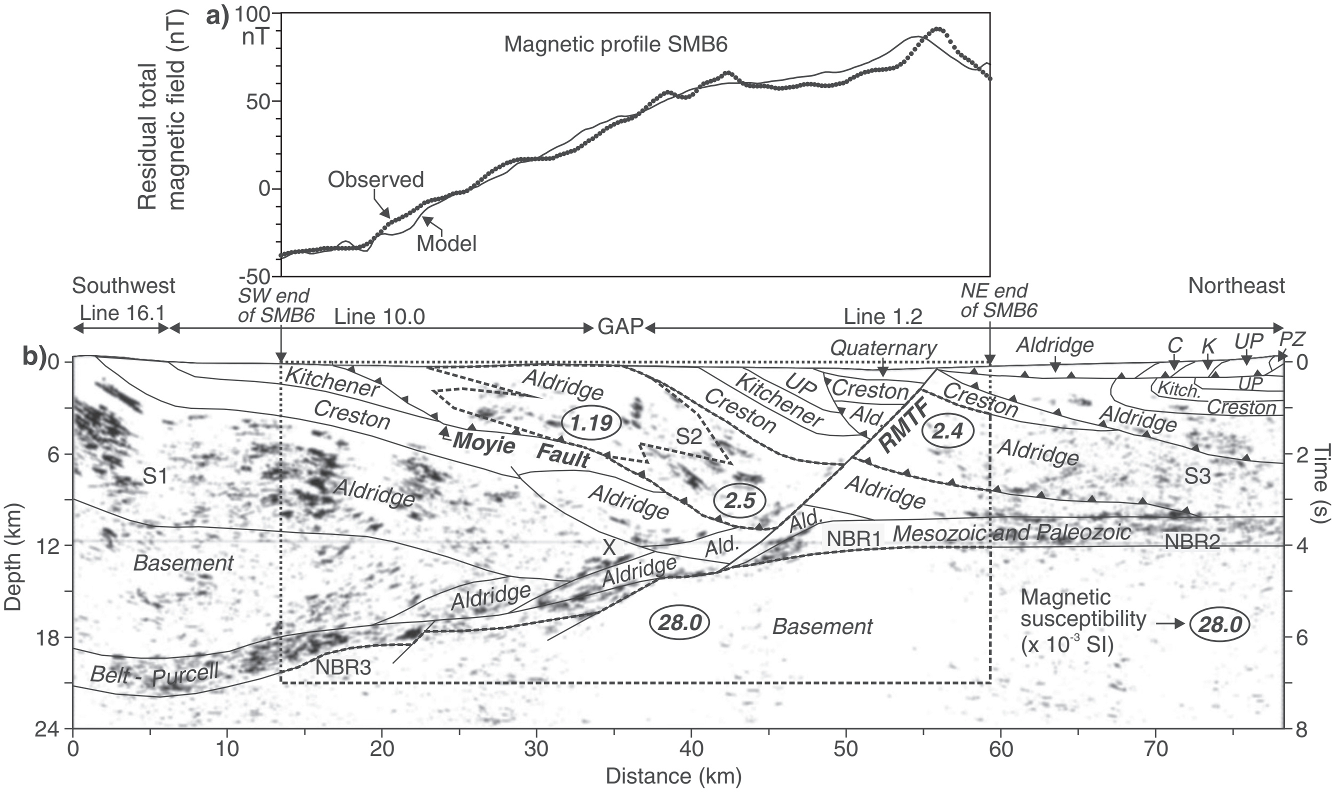

Figure 9. a) Observed magnetic profile along line SMB6 and calculated model profile for portion of seismic-reflection model in (b) within the dashed rectangular box. **b)** Seismic-reflection model along profile 10-1 of Van der Velden and Cook (1996). Magnetic susceptibilities are assigned to three units within the Aldridge Formation and to the lower basement, and all other units are assigned a uniform density of 0.65 × 10^{-3} SI. RMTF = Rocky Mountain Trench fault, C = Creston Formation, K = Kitchener Formation, UP = Upper Belt–Purcell strata, P2 = Paleozoic strata, NBR = near-basement reflections.

Aldridge Formation containing the S2 reflections initially thickens northeastward from its contact with the Kitchener Formation, and if its bulk magnetic susceptibility is higher than rock units laterally adjacent, the thickening magnetic unit could conceivably have a notable influence on the northeast increase in the magnetic field. Thomas' (2013) study of magnetic susceptibilities in the Purcell anticlinorium reported a mean value of 0.64 × 10^{-3} SI for the metasedimentary rocks of the Lower and Middle Aldridge formations and a mean value of 3.49 × 10^{-3} SI for Moyie sills, so that the Aldridge Formation significantly intruded by the sills could produce a positive magnetic expression. On the other hand, Thomas (2013) also noted that 83% of 47 measured values are 1.30 × 10^{-3} SI or less and have a mean value of 0.66 × 10^{-3} SI that differs little from the mean value of the Aldridge Formation, which is commonly reflected in the weak or absent magnetic signatures associated with many sills (Fig. 2).

The seismic model of Van der Velden and Cook (1996) was projected to the line of SMB6 and used as a template to initiate magnetic modelling of the profile (Fig. 9). The positions of the ends of line SMB6 projected at right angles to the line are indicated on the seismic model. Because the path of the seismic line is longer, the horizontal scales will differ, 45.8 km of tortuous seismic path equating with the 39.6 km length of SMB6. In spite of relatively minor registration inconsistencies and the fact that extrapolation is not everywhere strictly along strike, the template provides a useful guide to modelling profile SMB6 (Fig. 9a). In the seismic model (Fig. 9b), within the portion spanning profile SMB6, magnetic susceptibilities have been assigned to two interfingering areas within the northeast-dipping unit of Aldridge Formation associated with the group of reflections S2. The values are 1.19 × 10^{-3} SI and 2.5 × 10^{-3} SI, considered reasonable if contained Moyie sills have susceptibilities approximately equal to the mean value of 3.49 (standard deviation ± 11.56) × 10^{-3} SI determined for 47 measurements (Table 1). A value of 2.4 × 10^{-3} SI was assigned to the northeast-dipping unit of Aldridge Formation northeast of the Rocky Mountain Trench fault. As modelling proceeded it became apparent that the steep magnetic gradient dominating the southwestern and central parts of the magnetic profile, and the magnetic 'plateau' above the dipping Rocky Mountain Trench fault could not be reproduced only by the northeast-dipping units of Aldridge Formation having the noted susceptibilities that apparently are too low. If susceptibilities of portions of the units are significantly increased to 10 × 10^{-3} SI, the southwestern gradient and the peak immediately northeast of the Rocky Mountain Trench fault can be roughly reproduced, but the model profile falls short of the observed by over 100 nT near the centre of the 'plateau'. This approach of trying to satisfy the observed magnetic profile with principal sources, i.e. Moyie sills, within the Aldridge Formation was thus abandoned.

Attention turned to the basement beneath the NBR1, NBR2, and NB3 groups of reflections. This has the requisite geometry of a wedge that could generate an eastward-increasing magnetic field. Ultimately a susceptibility value of 28 × 10^{-3} SI assigned to this basement wedge, in combination with the slightly magnetic (susceptibilities of 1.19 × 10^{-3} SI, 2.4 × 10^{-3} SI, and 2.5 × 10^{-3} SI) units of Aldridge Formation, were able to provide a reasonable match of model and observed magnetic profiles (Fig. 9a). The root mean square difference between the profiles is 5.0 nT. The basement susceptibility value of 28 × 10^{-3} SI is considered realistic and may be compared with values reported by Pilkington and Percival (1999) for Precambrian rocks in the Superior Province of the Canadian Shield. They determined a mean susceptibility of 30 × 10^{-3} SI for measurements on more than 3500 samples from a 500 km by 500 km area of the Minto Block of northern Quebec. It is noted that the basement unit interpreted by Van der Velden and Cook (1996) and occupying a lower crustal position in the southwestern part of the model has a susceptibility equal to the background susceptibility of 0.65 × 10^{-3} SI, and is therefore magnetically, and perhaps otherwise, distinct from the lower basement unit.

The knowledge gained from modelling guided by the seismic model was then used to model the profile incorporating a near-surface geological section (Fig. 8b) interpreted from available 1:50 000 geological maps (Brown and MacLeod, 2011a; Brown et al., 2011c) and sections of reprocessed seismic sections along seismic profile 10-1 (Fig. 8c). Because the basement has been identified as the likely principal source of the gradient-like magnetic signature, magnetic susceptibility contrasts within the crust above basement have been kept to a minimum. Presumed Aldridge Formation forming most of this crust and a possible basement wedge within the lower part of the crust interpreted by Van der Velden and Cook (1996) have been assigned a uniform 'background' susceptibility of 0.65 × 10^{-3} SI. The main exceptions to this background value are values of 1.1 × 10^{-3} SI and 3.0 × 10^{-3} SI derived for units of Creston Formation east of the Gold Creek and Rocky Mountain Trench faults, one of which is critical to reproducing the distinct peak at the northeast end of the profile.

Patterns of seismic reflections dipping in opposite directions help constrain the path of the Rocky Mountain Trench fault (Fig. 8c). Southwest of the Gold Creek Fault, concentrations of layered reflections potentially defining Moyie sills outline layering within the relevant portions of the Aldridge Formation. The 'contacts' within the model in this area are, therefore, not strictly contacts between lithological units, but simply indicate the attitude of lithological layering in the crust. The wedge of basement is based on the seismic interpretation by Van der Velden and Cook (1996). The depth to the lower basement decreases fairly uniformly from just over 20 km at the southwest end of SMB6 to just over 15 km at the projected lower end of the Gold Creek Fault. The depth then decreases somewhat more rapidly northeastward over the next 3.7 km to a depth of roughly 13 km at the projected lower end of an unnamed normal fault, from where it decreases more slowly and uniformly to about 11 km at the northeast end of SMB6. The short, steeper section of the basement and/or suprabasement contact is likely influenced by, and links with, the Rocky Mountain Trench fault, and/or associated splay faults.

CONCLUSIONS AND DISCUSSION

Modelling of prominent linear magnetic highs in the St. Mary Block has provided insight into the structure and geology of the uppermost 5 km or so of the crust. Modelling of a regional magnetic gradient covering the northeastern half of the block complements seismic modelling of the basement surface. Most of the conspicuous highs are associated with the Creston Formation and have been modelled as moderately magnetic units, both within the Lower and Middle Creston formations, having susceptibilities consistent with measured values. The four models along the northwestern flank are composed of units dipping consistently northwest in harmony with mapped surface dips, which helped constrain modelling. The modelled dips range generally from about 45° to 75°, with steeper dips ranging from about 80° to 90° observed in some models near the Old Baldy Fault. The models indicate that the structural picture observed at surface is maintained for several kilometres into the crust.

A linear magnetic high located within the central part of the Aldridge Formation is conspicuous by its anomalous north trend and presence within rocks that are very weakly magnetic. It is modelled in terms of a buried dyke-like sheet having a relatively strong magnetic susceptibility of 21 × 10^{-3} SI. It extends over 3350 m vertically and its upper surface lies between 300 m and 400 m below ground surface. Its anomalous trend and the lack of discernible positive magnetic signatures for many Moyie intrusions in the area strongly suggest that it belongs to a different intrusive suite. The linear magnetic high, in part, coincides with the McNeil fault zone, near which albite-altered, iron-oxide breccia resembling mineralization (hematite and magnetite) along the Iron Range Fault has been reported (Brown and Woodfill, 1998). The similar trends of the Iron Range and McNeil faults and common presence of iron-oxide breccia and a strong linear magnetic anomaly may indicate potential for copper and gold along the McNeil Fault. A second sheet-like body also having a moderately strong magnetic susceptibility (14 × 10^{-3} SI) has been modelled within the Aldridge Formation along the northwestern edge of the formation near the Old Baldy Fault. The favoured interpretation for this body is that it is also a gabbroic intrusion that does not belong to the Moyie suite.

A curious result is an apparent unconformable relationship between some units of the Kitchener Formation and older Creston Formation, which is unexpected given that Höy (1993) described the relationship between the two formations as gradational. For example a broad unit of Kitchener Formation near a strong magnetic peak (H-H' in Fig. 6c) has been thinned dramatically from what would have been expected from a conformable relationship with the older Creston Formation (Fig. 6b). Here, however, strongly magnetic rocks close to the surface are required to help reproduce this peak, and since Kitchener Formation rocks have a very low magnetic susceptibility (0.14 × 10^{-3} SI, Table 1), such rocks must reside in the underlying Creston Formation. Because the magnetic units in the Creston Formation are steeply dipping, it is apparent that they must be truncated by a gently dipping lower surface of the Kitchener Formation. It is speculated that gently dipping extensional faulting may have influenced the development of this surface.

Modelling demonstrates that the prominent northeastward-increasing magnetic gradient coinciding with the northeastern half of the St. Mary Block can be reconciled with a northeastward-decreasing depth of the basement as previously delineated by a seismic-reflection model (Van der Velden and Cook, 1996). The depth decreases over a distance of 40 km from about 20 km at the outset of the gradient in the southwest within the Aldridge Formation to about 11 km in the northeast near the Rocky Mountain Trench fault. The gradient is generated exclusively by the northeast-thickening wedge of basement having a modelled magnetic susceptibility of 29 × 10^{-3} SI that contrasts with a ‘background’ susceptibility of 0.65 × 10^{-3} SI assigned to most other units.

This study has provided insight into the potential sources of several of the most prominent magnetic anomalies in the St. Mary Block, and provided a new perspective on crustal structure to a depth of about 5–6 km. It has also reinforced a seismic-reflection model proposing decreasing depth of basement northeastward toward the Rocky Mountains, and indicated that this basement is moderately to strongly magnetic, suggestive of crystalline Precambrian crust.

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