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GEOPHYSICAL REASSESSMENT OF THE ROLE OF ANCIENT LINEAMENTS ON THE DEVELOPMENT OF THE WESTERN MARGIN OF LAURENTIA AND ITS SEDIMENT-HOSTED Zn-Pb DEPOSITS, YUKON AND NORTHWEST TERRITORIES

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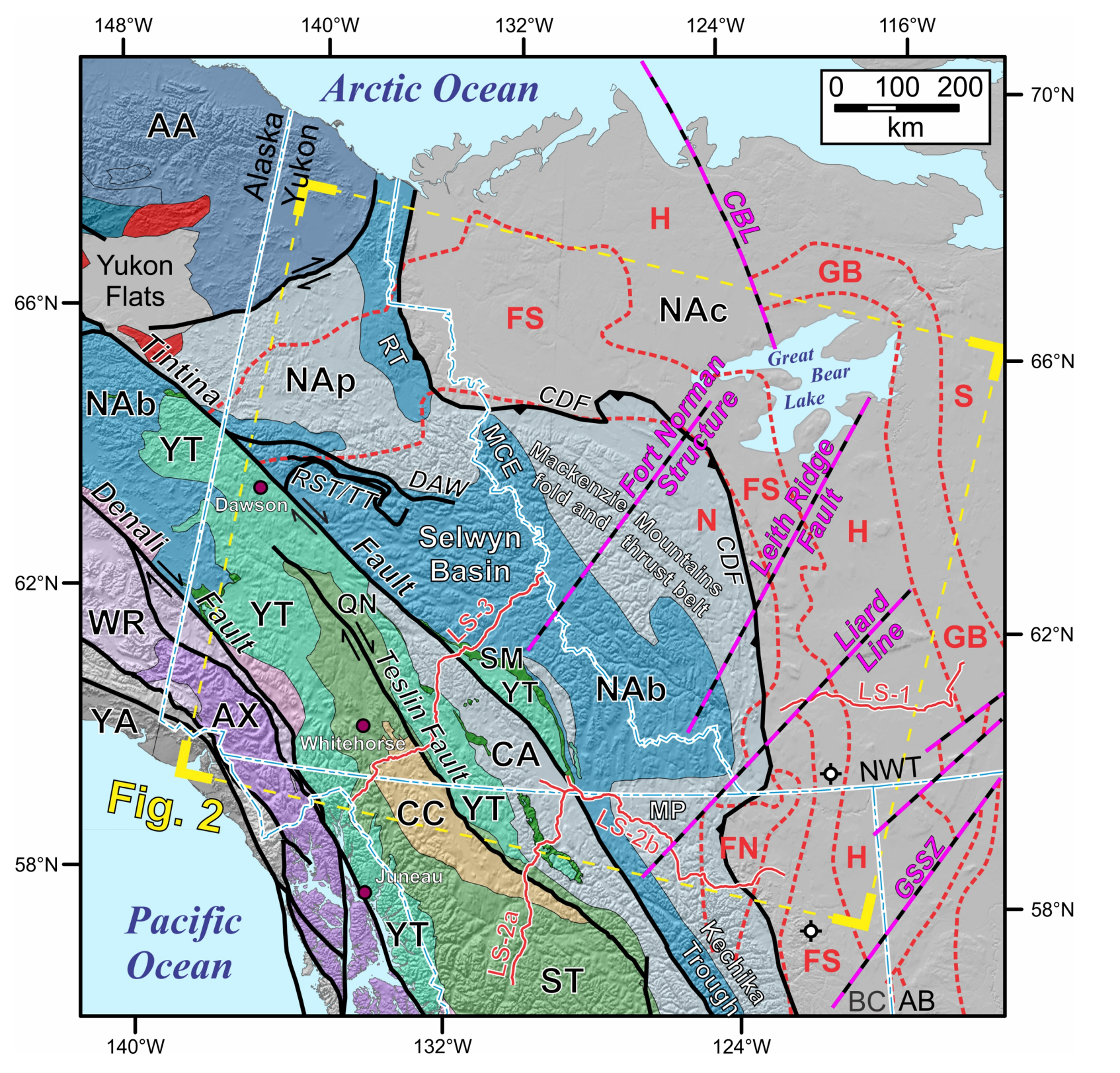

Fig. 1. Northern Cordilleran tectonic elements (modified from [1]). Purple-black lines - previously interpreted cratonic lineaments[2, 3]. Red-white solid lines show Lithoprobe (SNORCLE) lines [4, 5]. Yellow box shows the location of the study region.

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I acknowledge that this presentation took place on the traditional, ancestral, and unceded territory of the Coast Salish Peoples, including the xʷməθkʷəy̓əm (Musqueam), Sḵwx̱wú7mesh (Squamish), Stó:lō, and Səl̓ílwətaʔ/Selilwitulh (Tsleil-Waututh) Nations.

Abstract

The role of crustal lineaments in the development of the western margin of Laurentia, Selwyn basin and associated sediment-hosted Zn-Pb deposits (clastic-dominated, Mississippi-Valley-type) in Yukon and NWT, are reassessed through a new 3-D inversion strategy applied to new compilations of gravity and magnetic data. Regionally continuous, broadly NE-trending crustal lineaments including the Liard line, Fort Norman structure, and Leith Ridge fault, were interpreted as having had long-standing influence on craton, margin, and sedimentary basin development. However, multiple tectonic overprints including terrane accretion, thrust faulting, and plutonism obscure the region's history.

The Liard line, related to a transfer fault that bounds the Macdonald Platform promontory, is refined from the integration of the new geophysical models with published geological data. The geophysical models support the continuity of the Fort Norman structure below the Selwyn basin, but the presence of Leith Ridge fault is not supported in this area. The ENE-trending Mackenzie River lineament, traced from the Misty Creek Embayment to Great Bear Lake, is interpreted to mark the southern edge of a cratonic promontory. The North American craton is bounded by a NW-trending lineament interpreted as a crustal manifestation of lithospheric thinning of the Laurentian margin, as echoed by a change in the depth of the lithosphere-asthenosphere boundary. The structure is straddled by Mississippi Valley-type Zn-Pb occurrences, following their palinspastic restoration, and also defines the eastern limit of mid-Late Cretaceous granitic intrusions. Another NW-trending lineament, interpreted to be associated with a shallowing of lower crustal rocks, is coincident with clastic-dominated Zn-Pb occurrences.

Geological Setting, Lineaments and Structures

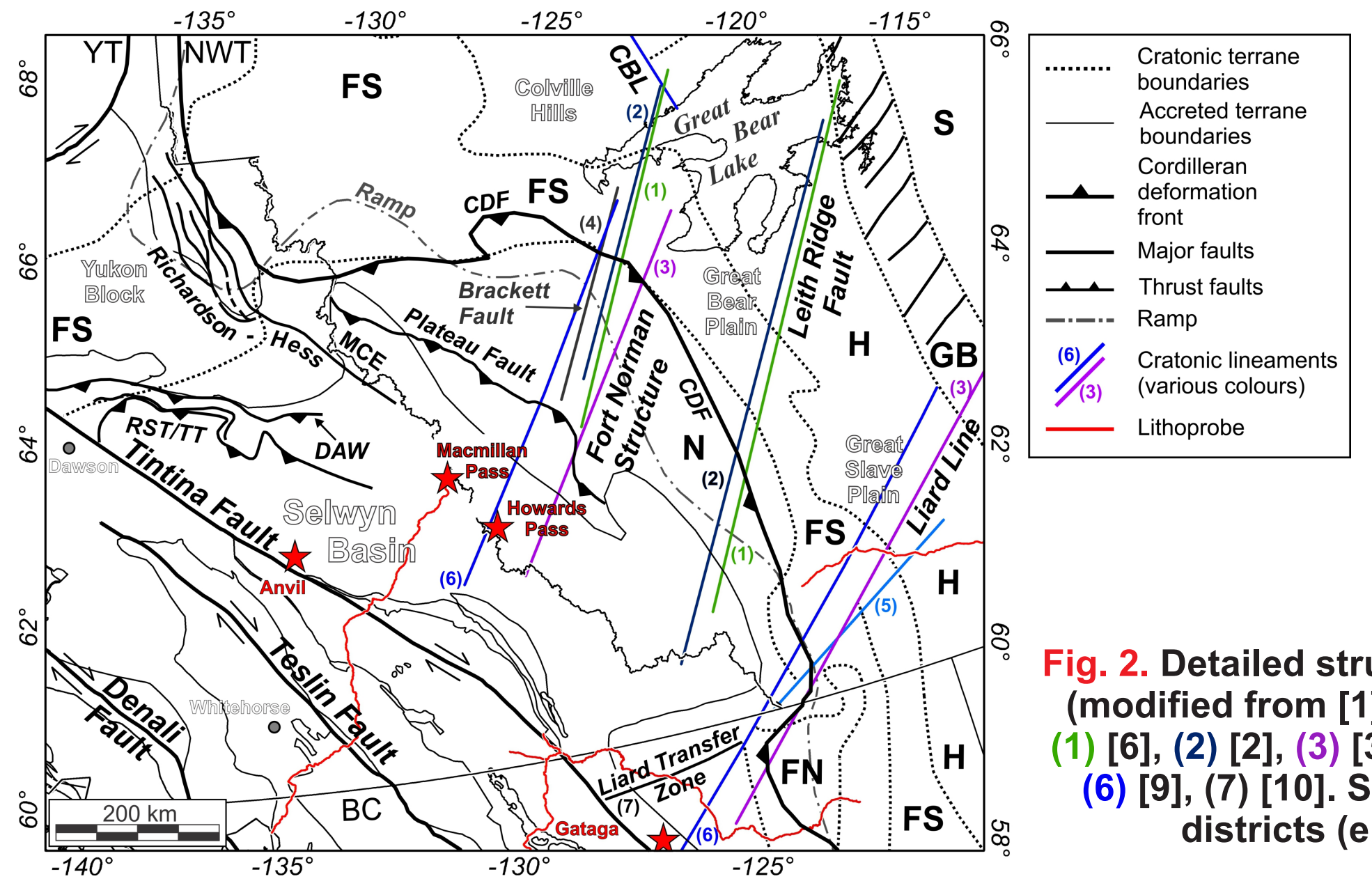


Fig. 2. Detailed structural elements (modified from [1]). Lineaments: (1) [6], (2) [2], (3) [3], (4) [7], (5) [8], (6) [9], (7) [10]. Stars CD Zn-Pb districts (e.g., [11]).

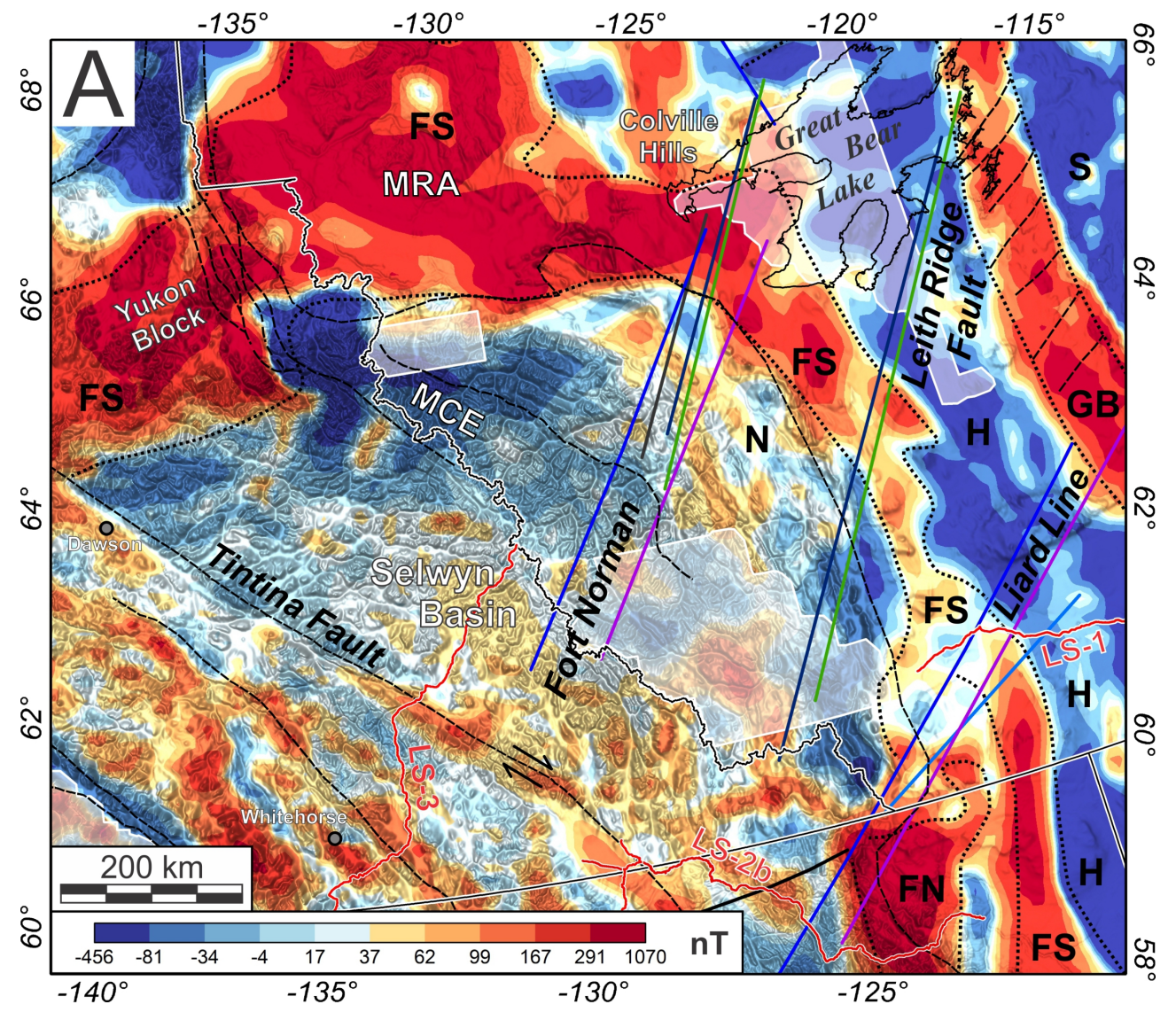


Fig. 3A. Aeromagnetic anomaly, upward continued 4 km, overlain on topography. Translucent polygons show high elevation data (e.g., [12]). See Fig. 2 for lineament key.

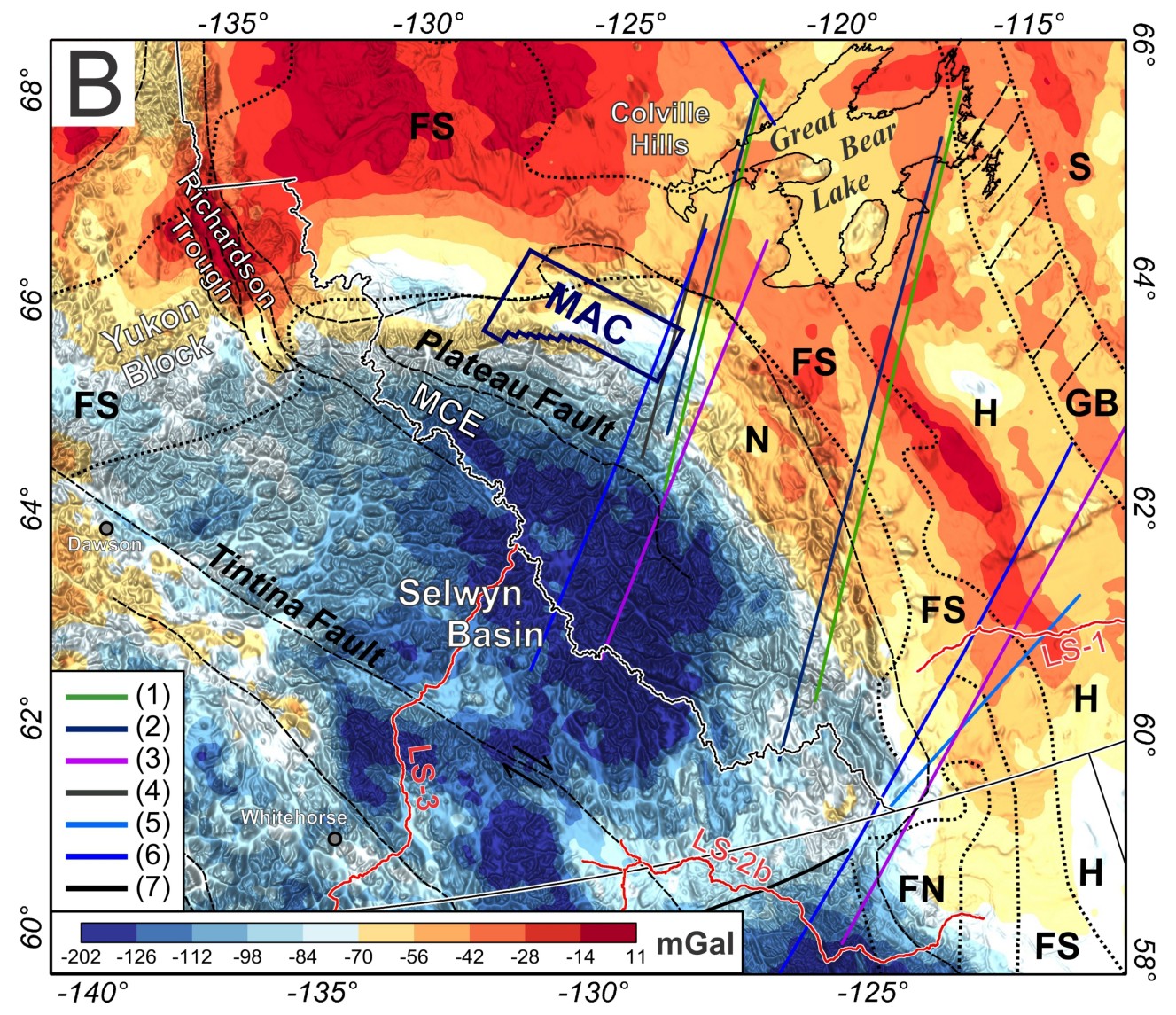


Fig. 3B. Bouguer anomaly overlain on topography. MAC shows the location of the Mackenzie airborne gravity survey [13]. See Fig. 2 for lineament key.

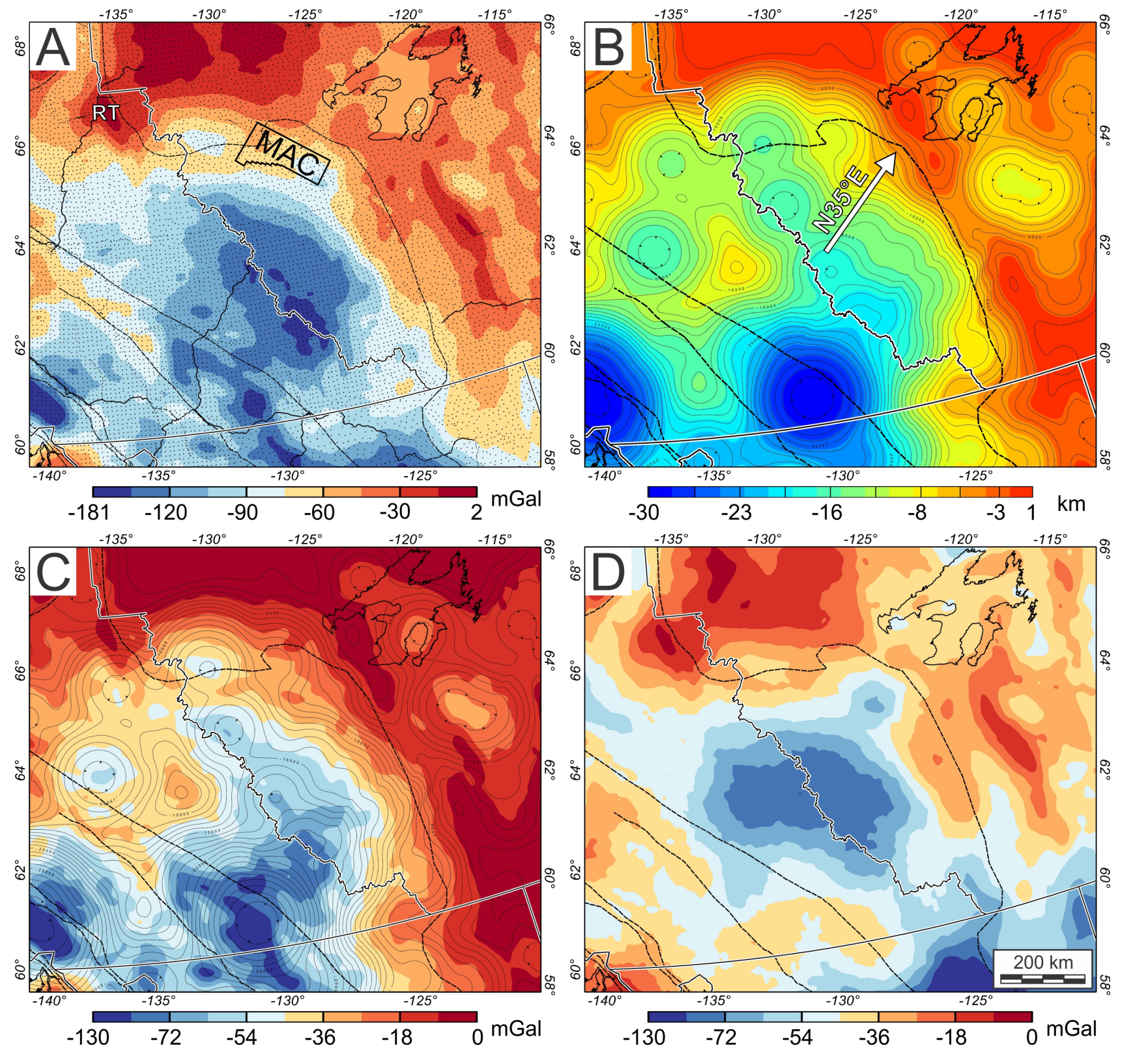
Details of the tectonic history of the western margin of the North American craton (Laurentia) in NW Canada, formed from the progressive accretion of 2.3-1.8 Ga magmatic arcs and microcontinents (summarised by [9]). However, the structure of the Laurentian craton and its relationship to the tectonic development of the northern Cordilleran orogen are obscured by a lack of exposure, and burial beneath the Neoproterozoic to early Paleozoic continental margin sedimentary rocks, including Selwyn basin. The tectonic processes that formed the Cordilleran orogen of western Canada include terrane accretion, regional plutonism and metamorphism, development of the Selwyn basin and Mackenzie Mountains fold and thrust belt (MMFTB), and large offset strike-slip faults (e.g., [9] and the references therein [14-15]). Notably, ancient crustal lineaments (Figs. 1, 2) are interpreted as having had long-standing tectonic influence on the development of the craton, its western margin and overlapping sedimentary basin, and the mineralisation therein (e.g., [9-11] [16]). Despite extensive geological and geophysical investigation (e.g., [3-5] [9] [17-20]), the structure of the Laurentian margin and its impacts on the region tectonic development are not comprehensively understood.

Previously the lineaments were ascribed to dip or strike-slip faults, inferred from regional stratigraphic relationships and potential field anomalies ([2-3] [6] [8]), which have little surface expression in Paleozoic rocks within Selwyn basin. Herein, the lineaments are redefined as representing lower crustal structures that have seen intermittent reactivation both spatially and throughout the geological history of the region. The lineaments mark the location of domain boundaries within the craton and they have had variable control on sediment thickness and facies and subsequent deformation, and provide conduits for mineralising fluids, and intrusions.

In this study, a range of potential field inversion strategies are developed and employed to model the crustal character of the western Canadian craton and its rifted Laurentian margin beneath Selwyn basin. The study builds on that of Hayward (2019) [15], which modeled the N35°E décollement beneath the Selwyn basin, related to the MMFTB. Specifically, the character of regional lineaments, interpreted to have played an important role in the development of Selwyn basin and its mineralisation, yet remaining enigmatic despite prior investigation (e.g., [2-3] [6] [8] [10]), are explored.

3-D Inversion of Gravity, Magnetic and Pseudogravity data

Fig. 4. Gravity Processing



(A) Bouguer anomaly upward continued 5 km with gravity stations. (B) Model surface and décollement of the MMFTB defined geophysical modeling [15]. White arrow is estimateddirection of shortening. (C) Gravity anomaly contribution of the rocks above the model surface/décollement. (D) Residual gravity anomaly (A minus C).

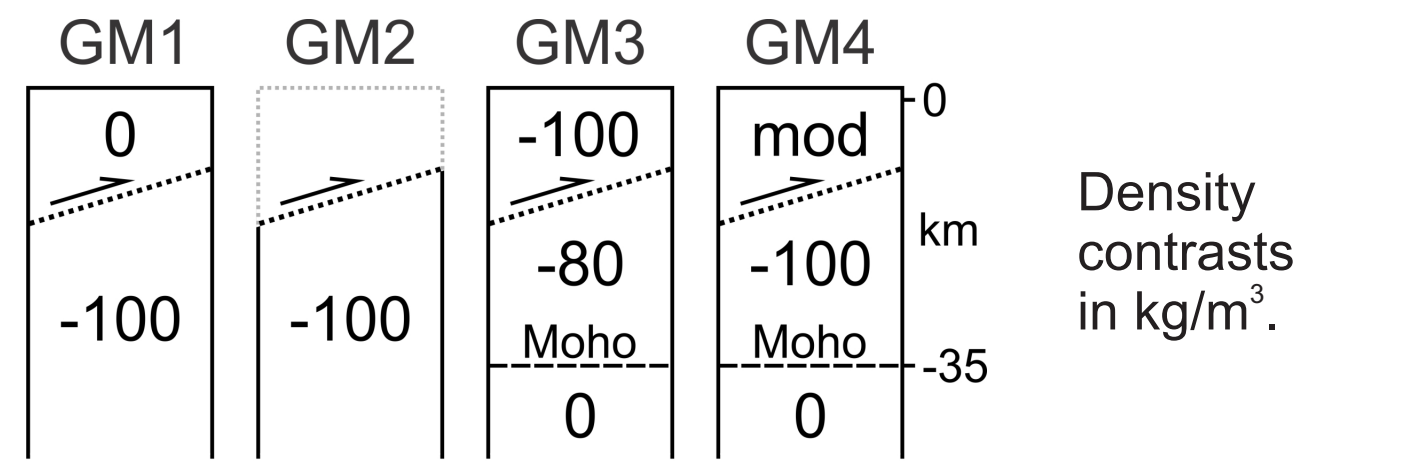
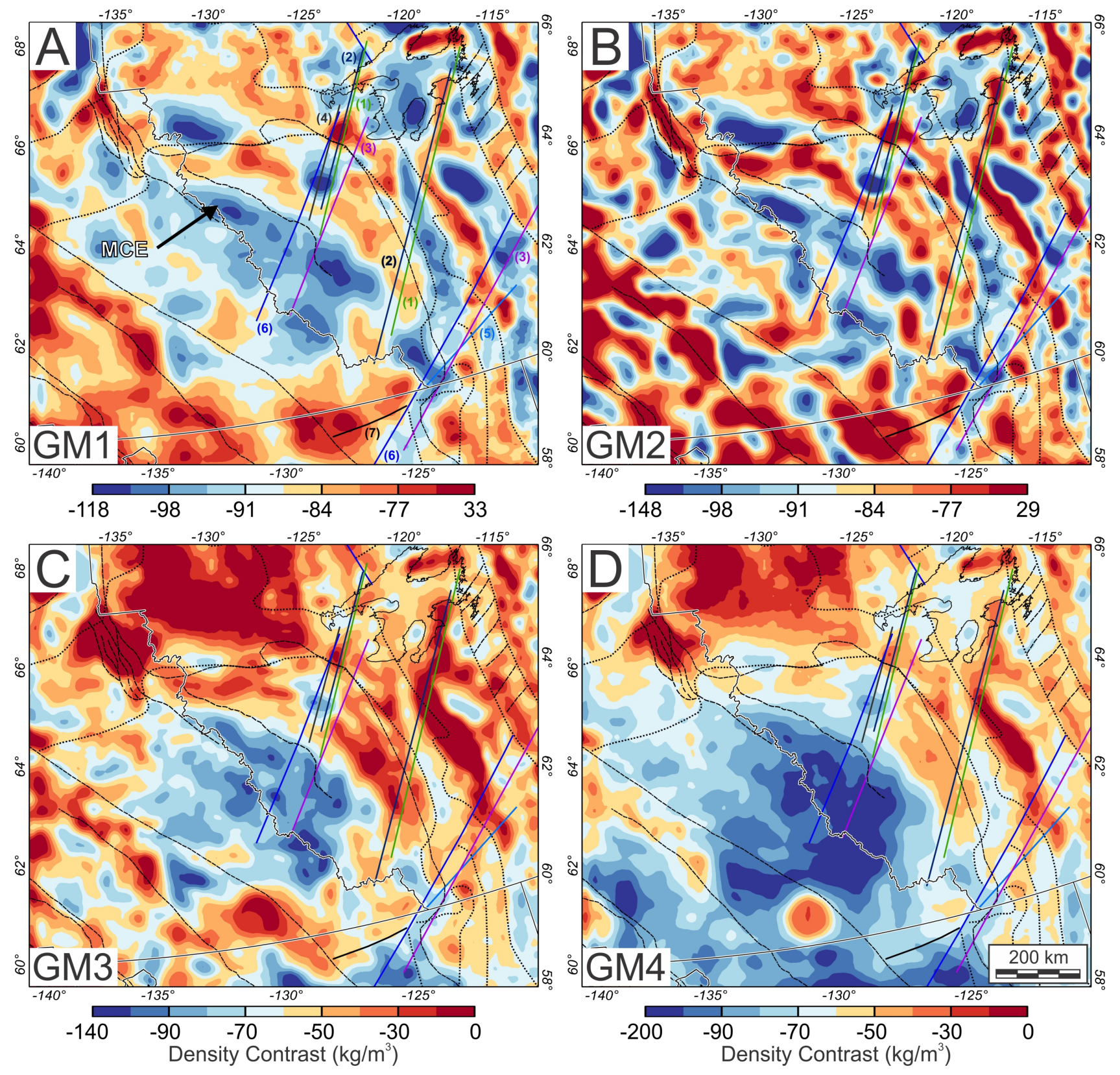


Fig. 5. Sketch of the reference models used in approaches to gravity inversion. Topography tops each model, except GM2, by the model surface/décollement (dotted lines).

Fig. 6. Gravity Inversion



Density models GM1 to GM4 from the 3-D inversion of Bouguer gravity data. Depth slices at 5 km below the model surface Fig. 4B. See Fig. 5 for reference models.

Regional gravity data [26] (~10 km station spacing), was compiled with airborne data (Mackenzie survey [13] (Fig. 3B). Data were reduced to a Bouguer density (2670 kgm^{-3}), gridded at 2 km, and upward continued 5 km to minimise shallow-sourced noise (Fig. 4A). Aeromagnetic data [27], comprising regional and high-resolution data, provide broad coverage. Gaps (translucent polygons (3A)) were patched with high altitude (~4 km) data [12], following the upward continuation of the regional data. The pseudo-gravity anomaly was calculated (Oasis Montaj - Geosoft Inc.) from aeromagnetic data and upward continued 1 km to match the Bouguer data. (Magnetic field parameters I=79º, D=33º, and F=58639 nT).

The 3-D inversion and forward modeling of gravity and magnetic data are performed using GRAV3D and MAG3D [28-29]. As potential field modeling is inherently non-unique, the data are modeled through several approaches to seek reproducible features, more likely to be accurate representations of the subsurface [30].

All models are built on an 5x5x1 km mesh, a good compromise between computational size, model resolution, and artefacts. Padding limited artefacts at model edges. Topography was defined by a 5 km grid from ETOPO1 [31]. Gravity data were extracted at original station locations (18745 stations) whilst the airborne survey stations were subsampled (3870 stations) from a 2 km cell sized grid. Magnetic and pseudo-gravity data (12733 points) were extracted from the magnetic and pseudo-gravity grids at a cell spacing of 10 km.

In order to investigate the lower crustal structure beneath Selwyn basin, gravity models include the depth to a model surface [15] delimited by the modeled depth of relatively lower density plutons and sedimentary rocks. West of the CDF, the model surface approximates the décollement at the base of an allocthonous wedge, associated with the MMFTB. The modeled décollement has an average orientation of N35°E (Fig. 4B) and shallows from a depth of ~15-25 km beneath Selwyn basin to ~11 km below the MMFTB, where it shows close agreement with geological cross-sections [15] [25] [32-33].

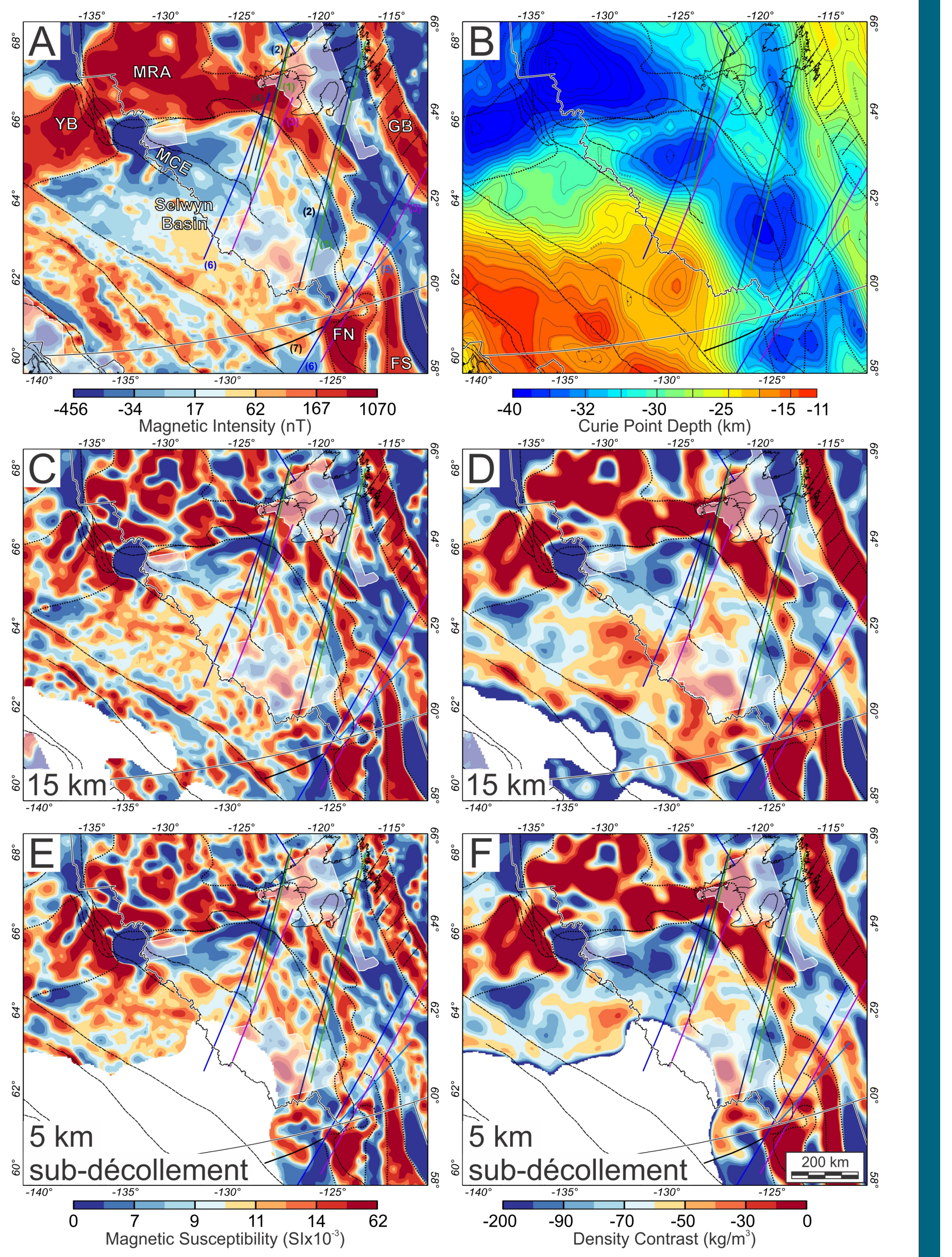
3-D gravity inversion

Four reference model/approaches to 3-D gravity inversion are illustrated in (Fig. 5). The gravity contribution of the above model surface [15] layer (Fig. 4C), was subtracted from the Bouguer anomaly (Fig. 4A) to give a residual gravity anomaly (Fig. 4D). Models GM1-2 (Fig. 6A, B) use the residual gravity anomaly. Models GM3-4 (Fig. 6C, D) use the Bouguer anomaly. In models GM3-4 only negative density contrasts were permitted and a Moho at a depth of 35 km [5] [34] was included in the reference models for GM3-4 to restrict density variations to the crust.

3-D magnetic and pseudo-gravity inversion

The magnetic and pseudo-gravity inversions (Fig. 7A, B) were constrained by simple two-layer reference models with magnetic susceptibility contrasts of 0.01 and 0.0 (SI) and density contrasts of 100 and 0 kg/m^3, respectively, with the layers separated by the Curie-point depth [35]. Integration of the model surface was not useful here due to its intersection with the Curie-point depth over a broad area.

Fig. 7. Magnetic and Pseudo Gravity Inversion



Magnetic susceptibility and pseudo-density models. (A) Magnetic anomaly. (B) Curie Point depth. (C-D) Model slices at 15 km. (E-F) Model slices at 5 km sub-décollement.

Lineament Interpretation and Conclusions

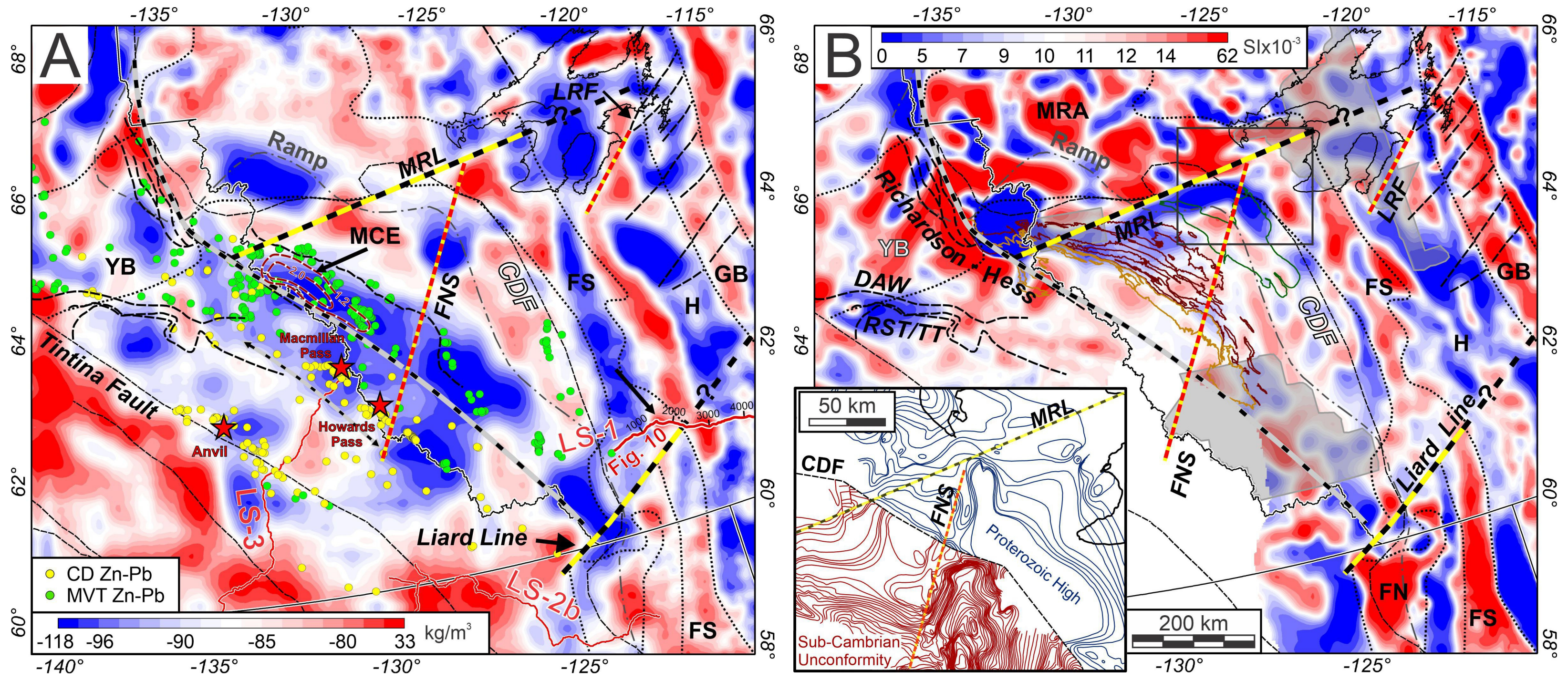


Fig. 8. Re-evaluation of lineaments of the western Laurentian margin from density and magnetic susceptibility model results.

(A) Density model GM1. Heavy yellow-black to black dashed lines show the Liard line and Mackenzie River lineament (MRL). Yellow-red dotted line shows the Fort Norman structure (FNS) and Leith Ridge fault (LRF). Black-light grey dashed lines show the NW-trending lineaments. Dark red-white dashed lines show sediment thickness (km) in the Misty Creek Embayment (MCE, [36]). Grey dot-dashed line shows the Proterozoic ramp [17] [37]. Mineral occurrences shown as yellow (CD Zn-Pb) and green (MVT Zn-Pb) circles. Red lines show Lithoprobe lines [4-5], with shotpoints related to cross-section (Fig. 10).

(B) Magnetic susceptibility. Dark and light brown polygons show mapped extent of the Proterozoic Mackenzie Mountains and Windermere Supergroups [38-39]. Inset shows the seismic time-structure relief of the sub-Cambrian unconformity and structural high of the Paleoproterozoic Hornby Bay Assemblage [21] in relation to the MRL and FNS.

Reassessment of the structure of western Laurentia applied new techniques to archival data and leads to several new conclusions. However, new geophysical data (e.g., seismic reflection), would lower uncertainty in the model results.

1. The ENE-trending Mackenzie River lineament (MRL, Fig. 8) marks a change in the character and structure of the Proterozoic crust of the western margin of Laurentia. This boundary is continuous from the Misty Creek Embayment to Fort Simpson terrane, but is tentatively interpreted to extend east into Hottah terrane. The lineament may continue west of the Richardson Trough, but there the boundary has been tectonically modified.
2. The revised location of the Liard line (LL) cleanly bisects crustal density and magnetic features including the Fort Simpson and Fort Nelson highs. To the SW, the LL was previously interpreted as a Paleozoic structure. To the NE, Lithoprobe line 1 (Fig. 10) shows a high density mid-crustal indenter of Hottah terrane and a change in lower crustal structural style of Fort Simpson terrane rocks within the collision zone. However, the lack of evidence of Paleozoic deformation suggests that the LL may not continue NE within Hottah terrane.
3. The MRL is interpreted to represent the boundary between a Laurentian rift margin embayment beneath Selwyn basin and the promontory of the Mackenzie craton to the north. The limited evidence for post-Proterozoic influence of this lineament inboard of the rift margin, with few related structural or stratigraphic relationships at surface, suggests that activity was focused to the west.
4. A NW-trending structure, that in-part merges with the Richardson-Hess fault system, is defined by a change in the geophysical character of the crust. The structure is interpreted as a fault system that is a crustal manifestation of lithospheric thinning, as echoed by a change in LAB depth ([41], Fig 9). The structure had a long-lived impact on the Laurentian margin tectonics, marking the platform to basin transition in Selwyn basin, and on the development of the Misty Creek Embayment. The structure also forms a northeastern boundary to the majority of MVT and CD deposits, following their palinspastic restoration. A second NW-trending feature to the south is interpreted to delimit a broad shallowing of lower crustal rocks, imaged by Lithoprobe line 3, and the location of CD deposits.
5. The Fort Norman structure (FNS) is interpreted to continue beneath the Selwyn basin. However, geophysical evidence is lacking for continuation of the Leith Ridge fault (LRF) west of the Hottah terrane.

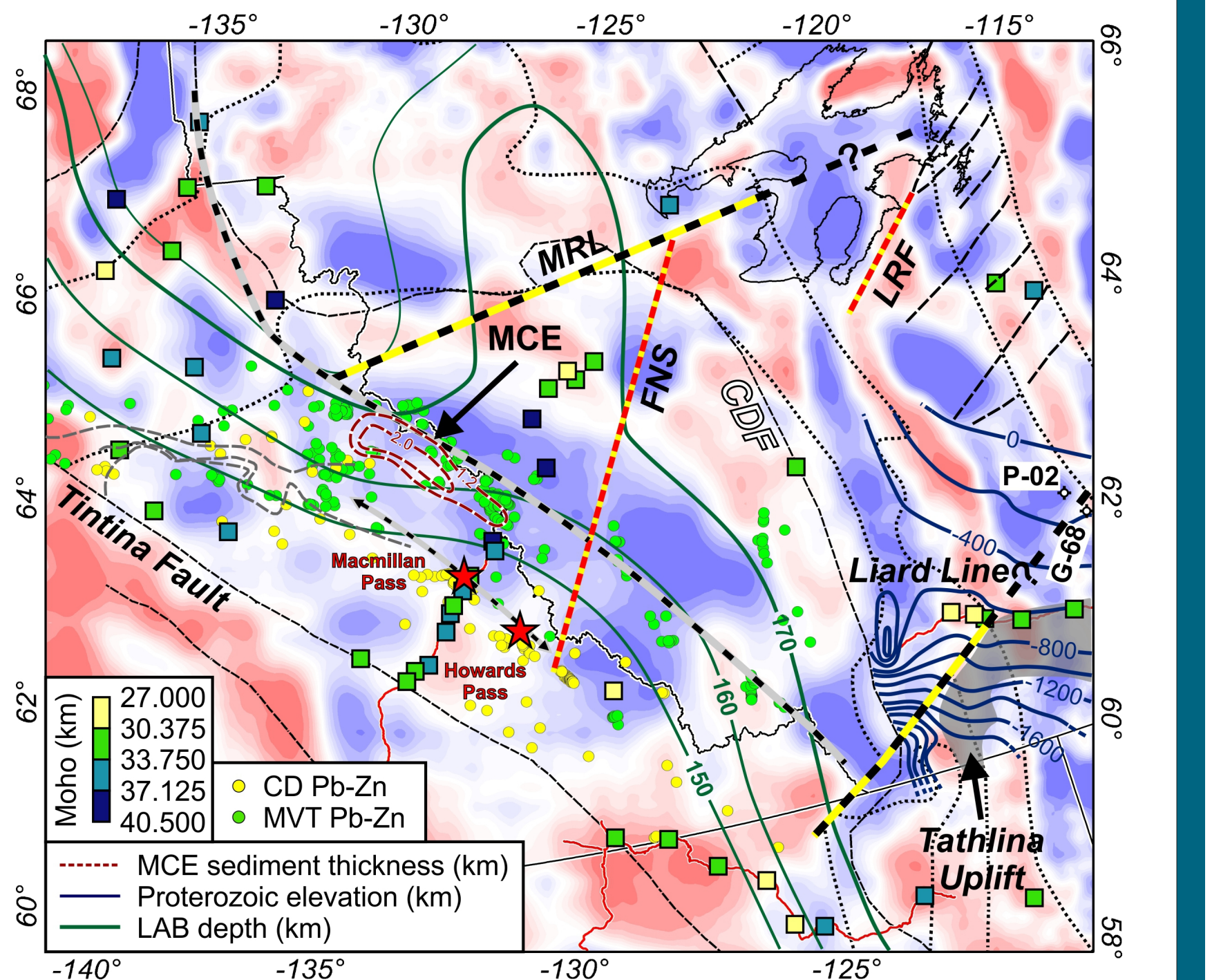


Fig. 9. Relationships of lineaments and geological/geophysical observations on model GM1. Moho depth from receiver functions [40]. Grey shade shows Tathlina uplift with blue lines showing the elevation of the Precambrian basement [20]. Palinspastically restored CD and MVT Zn-Pb mineral occurrences, and Misty Creek Embayment [36] (compare to Fig. 8A).

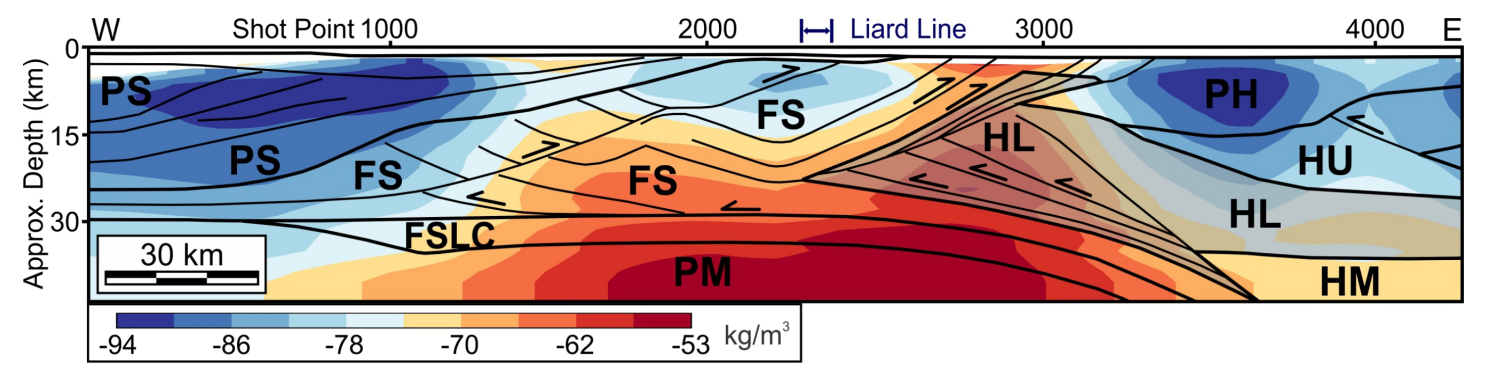


Fig. 10. Cross-section through density model GM1 along part of Lithoprobe line 1 (Fig. 8A). Structural interpretation [4]. Grey shaded area shows the indenter of Hottah terrane lower crust.

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