

STRUCTURES AND SOUTHERN BOUNDARY ZONE OF
THE NEPEWASSI DOMAIN, CENTRAL GNEISS BELT,
GRENVILLE PROVINCE, ON

by

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***Appendix attached to paper copy (CD)**



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Abstract

A collection of structural, lithological, and geophysical data is used to estimate the location and nature of the southern boundary of the Nepewassi domain of the Central Gneiss Belt, Grenville Province. Field mapping of a teardrop-shaped structure on the West Bay of Lake Nipissing, Ontario was performed. Structural data acquired during field work was added to Lumbers' 1970 Burwash East map. The structural nature of the 'teardrop' structure and its surroundings suggest a complex history of deformation. High strain, ductile Grenvillian deformation (D1) is responsible for L-S foliation defined by mineral grain orientation and overturned folds (F1). A second, post-1235 Ma phase of deformation (D2) is responsible for the formation of gently plunging, upright ESE folds (F2) which overprinted D1 fabrics and F1 folds to form type 1 transitional to type 2 ('teardrop') and type 3 interference patterns (folding west of 'teardrop'). A boundary in which the Britt domain overthrusts the Nepewassi to the north is suggested to extend E from the Cosby batholith. Possible scenarios for relative event timing are suggested: post-1235 Ma D2 deformation followed by emplacement of the Britt, or, emplacement followed by and possibly resulting in D2 deformation.

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1.0 Introduction

The Grenville Province is a large geologic unit with characteristic high metamorphic grade and high-strain ductile deformation features. In North America, it stretches from Labrador, Canada, into the Midwest US, cropping out as far south as Llano, Texas (Rivers & Corrigan, 2000). This study focuses on the Grenville in Ontario, Canada; specifically, the poorly understood relationship between the Nepewassi and Britt domains of the Central Gneiss Belt (CGB).

The aim of this thesis is to present the location of a boundary zone between the Nepewassi and Britt domains and suggest possible formation scenarios. Investigation of a teardrop-shaped structure in the Nepewassi has provided insight into the deformational history of the domain. Regional structure, taken together with geophysical data has been used to suggest the location of a domain boundary zone. Regional fabric and lithologic boundaries have been used to construct cross sections for two possible models of the boundary zone.

1.1 Regional Framework

The Grenville Province is essentially composed of a number of mid-crustal, amphibolite to granulite facies ductile thrust sheets (domains). The origin and assembly of these domains in their current configuration is linked to the convergence of Laurentia with another cratonic body, possibly Amazonia, during the assembly of the supercontinent Rodinia. The final collision of the two cratons occurred during the Grenville orogeny (1150-980 Ma). The modern crustal configuration and dominant structural signature primarily reflect compressional, and to lesser extent, extensional phases of the Grenville orogeny, an event which overprinted features related to the long pre-Grenvillian history of Laurentia and its margin (Carr et al., 2000; Culshaw et al., 1997; Rivers & Corrigan, 2000; Hynes & Rivers, 2010).

Pre-Grenvillian Laurentia, the Composite Arc Belt, and the Frontenac-Adirondack Belt

The Grenville of Ontario and Quebec is classified into three tectonic units (west to east): pre-Grenvillian Laurentia and its margins; a 'Composite Arc Belt' (CAB) composed of allochthonous sheets of 1300-1250 Ma arc volcanics and sediments; and the 'Frontenac-Adirondack Belt' (FAB) which consists of supracrustal and granitoid rock, and anorthosite of uncertain affinity (Carr et al., 2000). The CAB and FAB, which originated outboard of pre-Grenvillian Laurentia, were amalgamated by 1190 Ma and thrust over Laurentia as a single unit during 1080-1035 Ma and 1010-980 Ma phases of Grenvillian convergence (Carr et al., 2000; White et al., 2000; Culshaw et al., 2013; Slagstad et al., 2009). Pre-Grenvillian Laurentia is further divided into three tectonic subunits (west to east): L1, the Laurentian foreland of the Southern and Superior Provinces; L2 parautochthonous belt; and L3 allochthonous belt. (Fig. 1). Together the L2 and L3 belts constitute the CGB (Carr et al., 2000; Culshaw et al., 2013). The terms 'allochthon' and 'parautochthon' in this context refer to Laurentian margin (L2, L3) domains which have either moved a considerable distance (allochthonous) or remained comparatively immobile during the Grenville orogeny relative to continental Laurentia (parautochthonous) (Carr et al., 2000; Culshaw et al., 1997). The boundary between the Laurentian foreland (L1, Southern Province) and its margin (L1 and L2) is the Grenville Front (GF). The GF is taken to be the farthest exposed northwest limit of signature Grenvillian deformation and metamorphism and bounds the Grenville Front Tectonic Zone (GFTZ, Fig. 1) on the northwest (Carr et al., 2000; Culshaw et al., 1997; Culshaw et al., 2013; Rivers et al., 1989). The eastern boundary of the Laurentian margin is a boundary thrust zone separating it from the CAB (Fig. 1) (Carr et al., 2000).

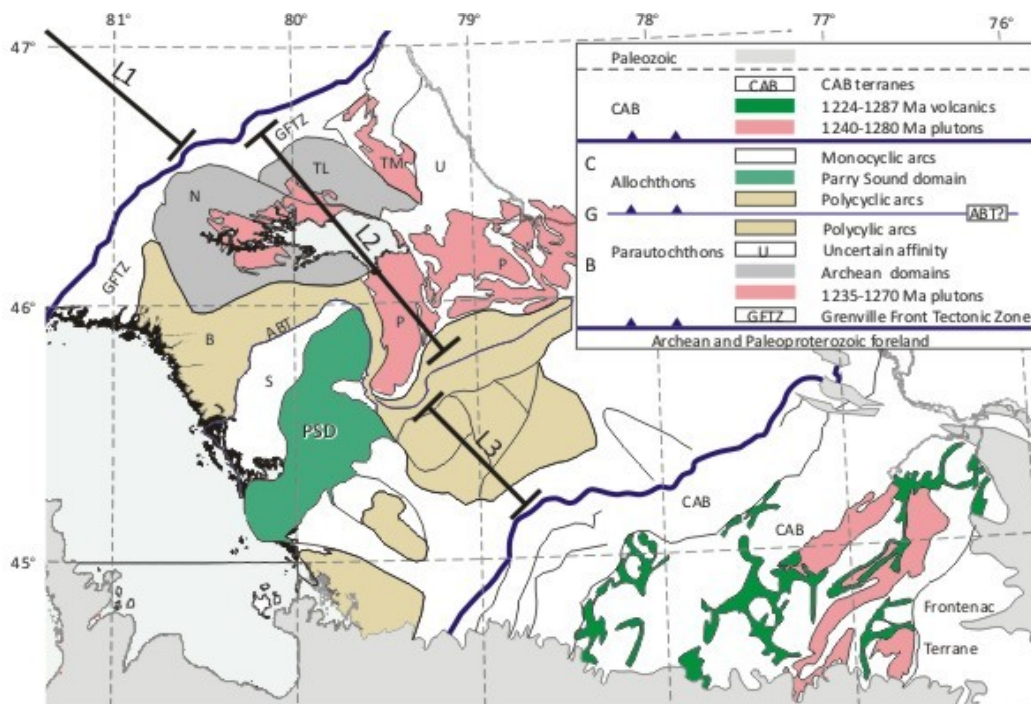


Figure 1: The CGB of Ontario. L1 Laurentian foreland, L2 parautochthonous belt, and L3 allochthonous belt labelled with extents. Abbreviations: N, Nepewassi domain; B, Britt domain; TL, Tilden Lake Domain; S, Shawanaga domain; PSD, Parry Sound Domain; P, Powassan domain; TM, Tomiko Domain. Modified from Culshaw et al., 2013.

Marginal Pre-Grenvillian Laurentia

The L2 and L3 belts are separated by a boundary thrust, the ‘Allochthon Boundary Thrust’ (ABT, Fig. 1), which is visible at surface as the northwestern boundary of the Shawanaga domain (Culshaw et al., 1997; Rivers et al., 1989; Dickin et al., 2007). Domain divisions in the CGB are made based on lithology, age, geophysical signature, and metamorphic history (Carr et al., 2000). Classification of a domain as either polycyclic or monocyclic (Fig. 1) refers to its metamorphic history. Polycyclic rocks show evidence of multiple, overprinting deformation events, including pre-Grenvillian metamorphism, while monocyclic rocks have evidence of only Grenvillian metamorphism and deformation (Culshaw et al., 1997; Rivers et al., 1989). L2 parautochthonous domains are the Britt, Nepewassi, Tilden Lake, Tomiko, and Powassan domains (Fig. 1). L3 allochthonous domains are the Shawanaga and Parry Sound domains (Fig. 1), as well as a number of poly- and monocyclic allochthonous domains E of the Parry

Sound domain that are outside of the general scope of this study (Culshaw et al., 1997; Carr et al., 2000; Ketchum & Davidson, 2000; Wodicka et al., 1996, 2000).

1.2 Lithology

Domains of the polycyclic CGB generally consist of pre-1600 Ma Proterozoic continental arc rocks intruded by either 1460-1430 Ma (Geon 14) or 1270-1235 Ma (Geon 12) plutons (Fig. 1). Geon 12 plutons are present in the Nepewassi, Tilden Lake, Tomiko, and Powassan domains and do not coexist with Geon 14 rocks. Archean crust in the Nepewassi and Tilden Lake domains is a minor constituent of the CGB and was intruded by Geon 12 rocks (Carr et al., 2000; Culshaw et al., 1997; Easton & Ketchum, 2002; Rivers & Corrigan 2000).

Nepewassi

The Nepewassi domain consists of Archean crust intruded by Geon 12 plutons (Chen et al., 1995; Prevec, 2004; Culshaw et al., 2013). Archean (2700-2600 Ma) crust is typically migmatitic, gray, biotite- or hornblende-quartz-feldspar orthogneiss with fine grained feldspathic orthogneiss interlayers and is restricted to the northern region of the Nepewassi domain (Lumbers, 1970; Chen et al., 1995). Geon 12 plutons include the West Bay sheet-like batholith, the St. Charles and Mercer anorthosites, and metadiabase of the Sudbury dike swarm (Prevec, 2004; Carr et al., 2000). The West Bay group includes gneissic quartz monzonite with minor granodiorite (Lumbers, 1970). Pink colour and migmatitic banding are characteristic of the West Bay group rocks. Pink West Bay granitoids are interlayered with gray migmatitic gneiss which is similar in appearance to Archean crust in the north (Lumbers, 1970). No age data exists for the interlayered gray gneiss at this time so any affinity between it and the Archean gray gneiss is uncertain. Foliation planes and lineation directions are defined by banding and mineral grain orientation, respectively.

Britt

The Britt domain includes pre-1600 Ma Proterozoic continental arc rock intruded by Geon 14 plutons (Ketchum et al., 1994; Culshaw et al., 2013; Rivers & Corrigan, 2000). Geon 14 plutons include megacrystic potassium-rich granite, monzonite, syenite, tonalite, and minor anorthosite (Lumbers, 1970; Culshaw et al., 1997). Grenvillian penetrative fabric is present throughout and foliation planes are defined by banding (Carr et al., 2000, Culshaw et al., 1997). The Britt domain was metamorphosed at upper amphibolite to granulite facies conditions following Geon 14 pluton emplacement, and pre-1600 Ma rocks have a more complex metamorphic history (outside the scope of this thesis). The minimum metamorphic age for this event is 1035 Ma (Corrigan et al., 1994).

2.0 Structure

2.1 Regional Trends

The target region for this study is the western shore of Lake Nipissing, ON, south of Lavigne ON and north of the Hwy 64/585 junction (Fig. 2). Past mapping of the Nepewassi domain has presented complex structural patterns (Lumbers, 1970). The following two structural components are evident: 1) highly strained penetrative ductile fabric associated with Grenville-stage deformation; and 2) gently plunging folds (ESE) southwest of Lavigne, ON along highways 64 and 535 (Fig. 2) (Lumbers, 1970).

Grenvillian deformation

Penetrative, high strain fabric is well-documented throughout the CGB (Carr et al., 2000; Culshaw et al., 1997; Rivers et al., 1989). It is associated with compressional and brief extensional phases of the Grenvillian orogeny (1190-980 Ma) (Carr et al., 2000). This characteristic fabric is defined by compositional banding (foliation) and preferred orientation of mineral grains (lineation). Grenvillian fabrics are gently dipping to flat lying (Carr et al., 2000). Foliation in the Nepewassi domain is fairly variable with strike angles ranging from northwest to northeast (Lumbers, 1970).

Gently plunging folds

Upright SW trending folding is well-documented throughout the CGB. Folding of high strain penetrative fabric by shallowly plunging transverse folds is a distinct characteristic of the CGB (Carr et al., 2000; Culshaw et al. 1997; Lumbers, 1970). Gently plunging, ESE trending folds are unique to the Nepewassi domain. These folds have been mapped as far north as the Northwest Bay of Lake Nipissing and as far south as West Bay (Fig. 2) (Lumbers, 1970).

2.2 The ‘teardrop’

The teardrop structure itself is on the north shore of the westernmost branch of the West Bay of Lake Nipissing (Fig. 2). It is apparent from on an early structural map of the region (Lumbers, 1970). The structure appears as a series of concentric ridges that are elongated to the east. The teardrop is approximately 3km long on its longitudinal axis (west-east) and 2km wide through its thickest section (north-south). There are several similar structures in the area (Lumbers, 1970). This structure was chosen as the focus of the study for its large size and relatively regular proportions in comparison to other teardrop-shaped features.

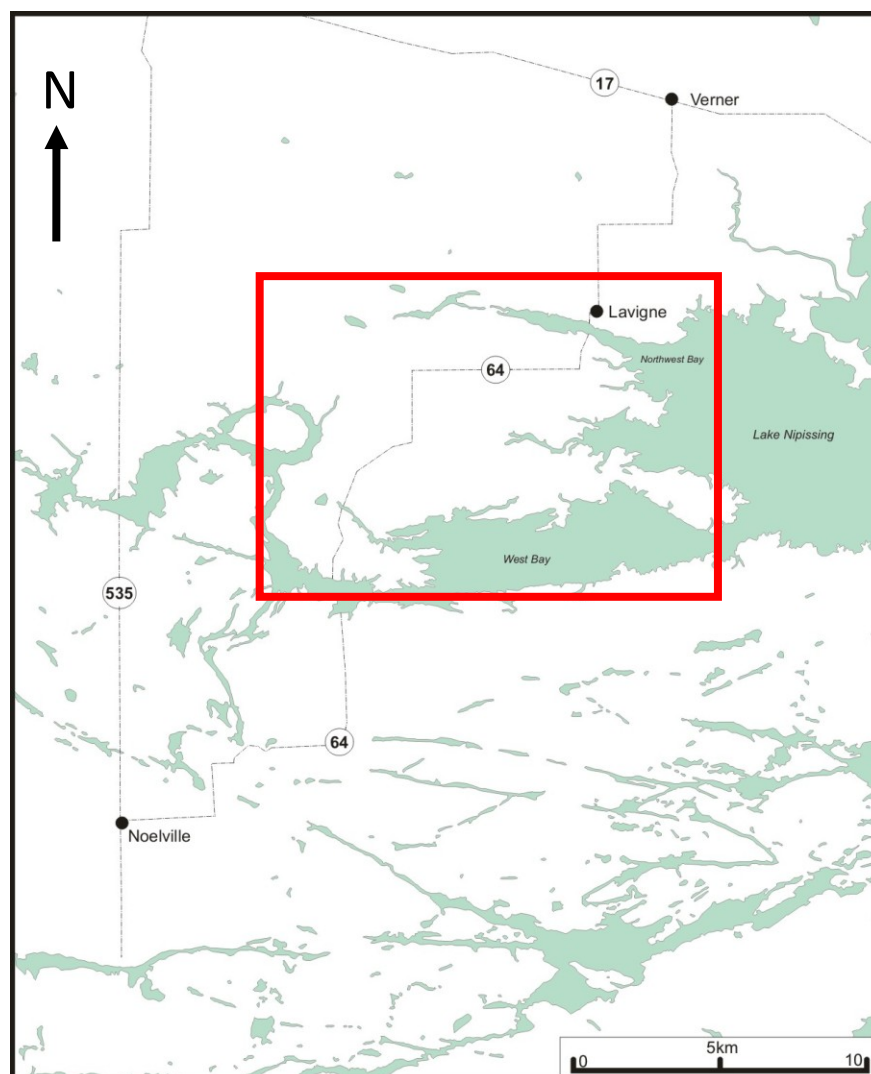


Figure 2: Location of the study area. Field work region outlined in red (vicinity of the teardrop structure).

3.0 Findings

Structural and lithologic mapping of the teardrop structure in the Nepewassi domain were carried out over a two week period. The structural (Figs 3, 4) and lithological (Fig. 7) data gathered on the teardrop were synthesized with previous work in the region. Foliation (S1) and lineation (L1) are defined by compositional banding and preferred mineral grain orientation respectively. Together S1 and L1 define an L-S fabric characteristic of the CGB. Regional foliation generally dips to the N and, following Lumbers (1970), has been plotted as form lines (Fig. 4;). These data are presented below along with a total gravity anomaly map of the region (Fig. 8).

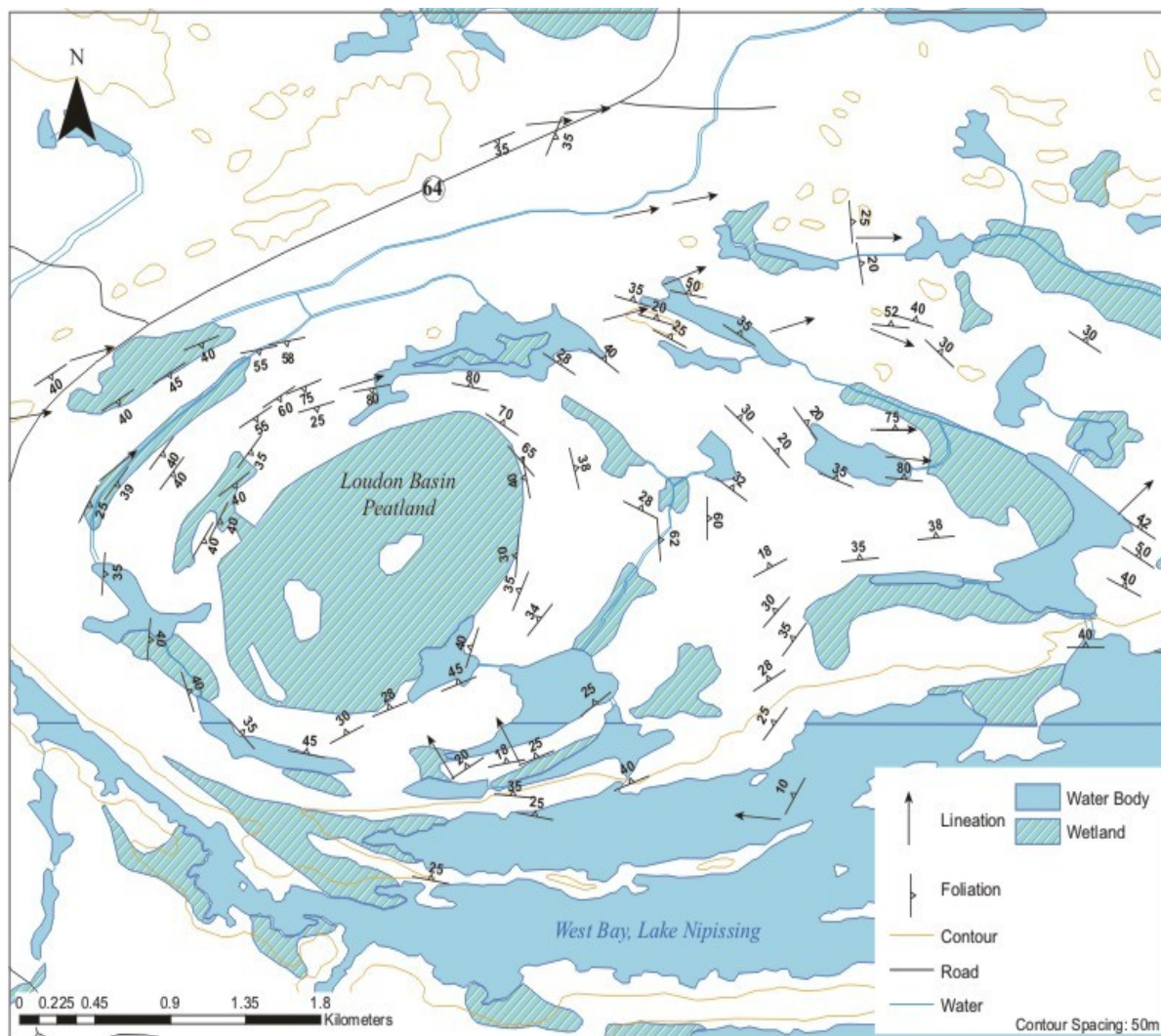


Figure 3: Measured foliations and lineations taken during field work for this study (see Appendix for field notes). The extent of this region is outlined in Fig. 2.

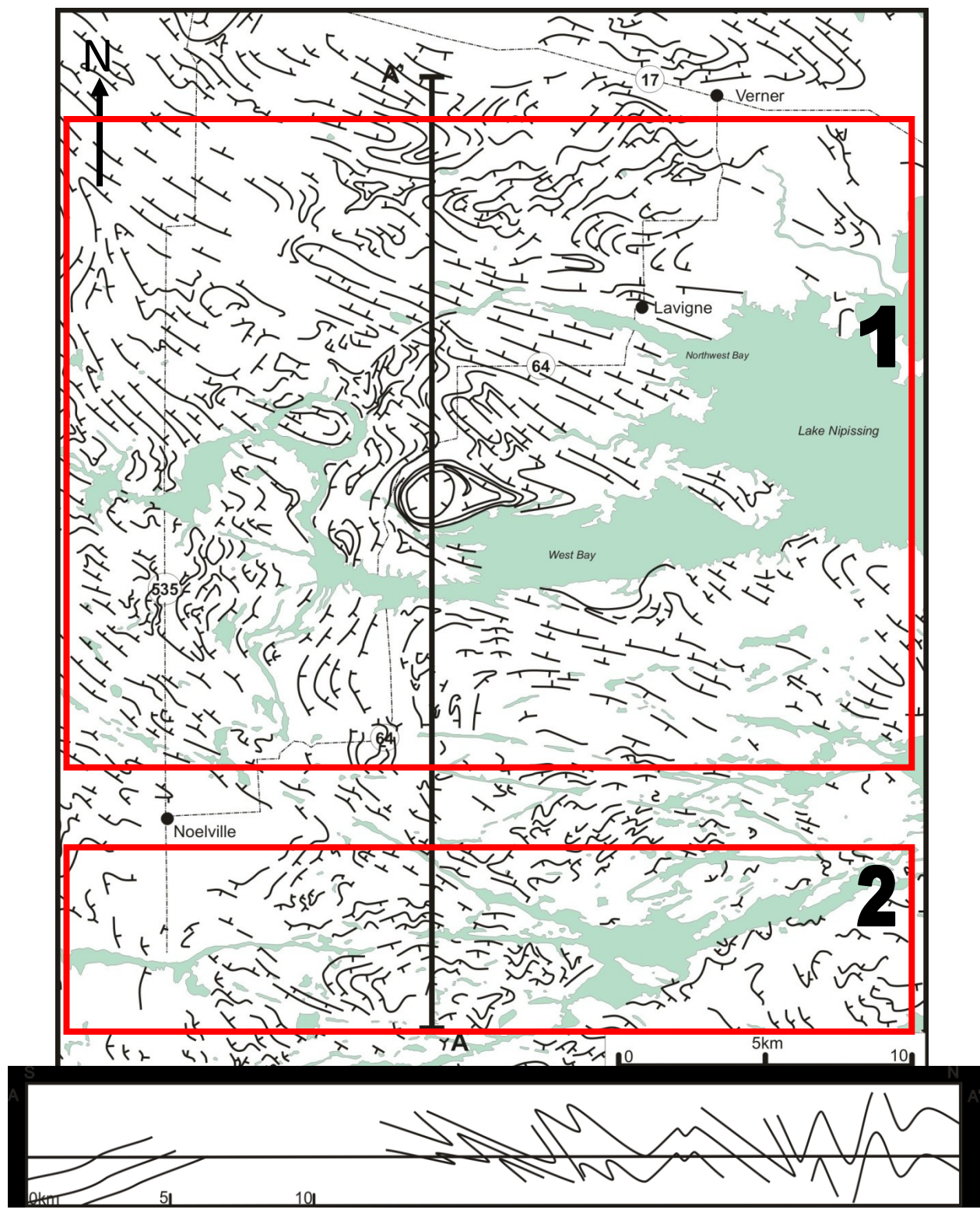


Figure 4: Structural form lines in the study area with schematic cross section based on form lines. Foliation in area 1 is generally N-dipping while area 2 is generally S-dipping (stereonet projections for each area in Figs 5-6). Adapted from Lumbers (1970).

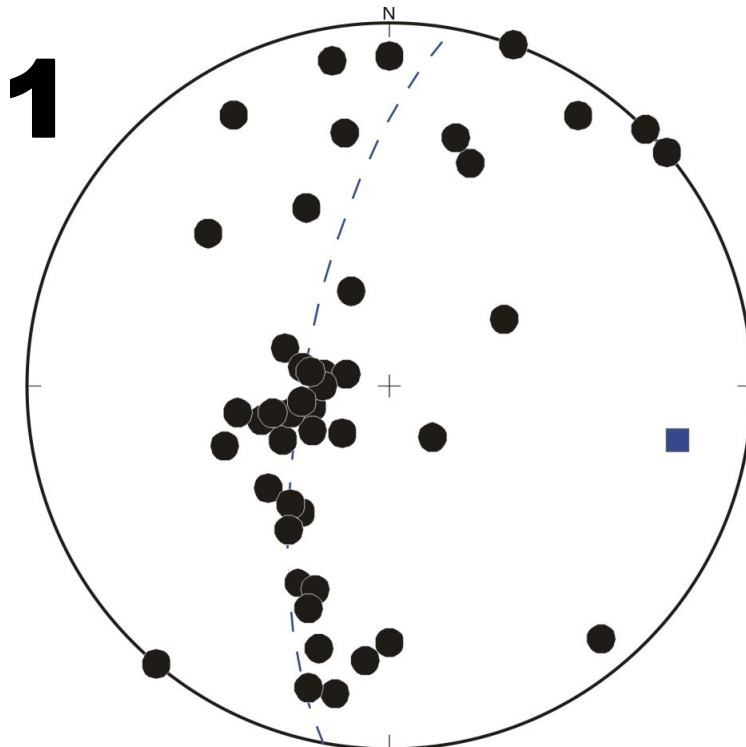


Figure 5: Poles to planes of foliations along Highways 64 and 535 in area 1, N of Noelville (Fig. 4; Appendix). From Culshaw, (personal communication, 2013).

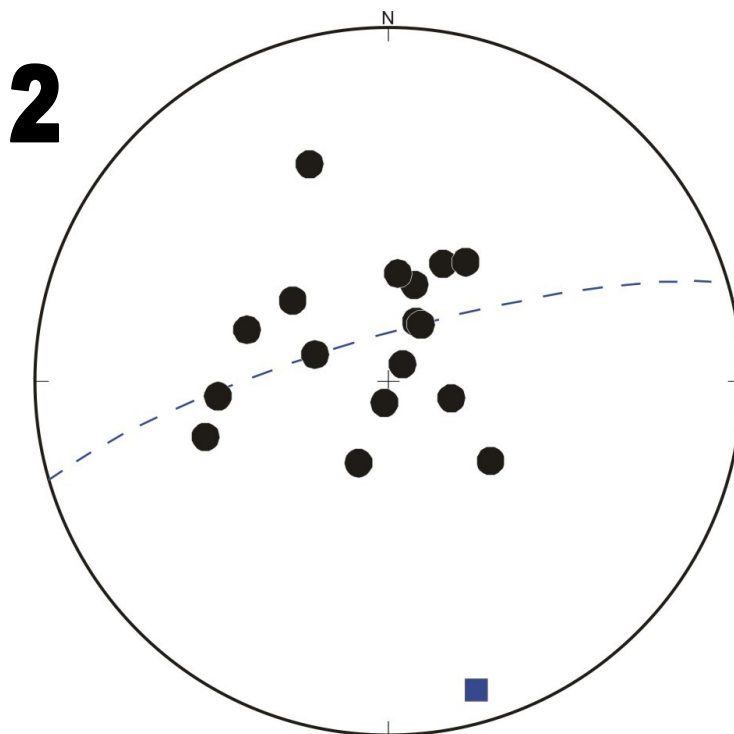


Figure 6: Poles to planes of foliations for roadside stations in area 2, S of Noelville (Fig. 4; Appendix). From Culshaw (personal communication, 2013).

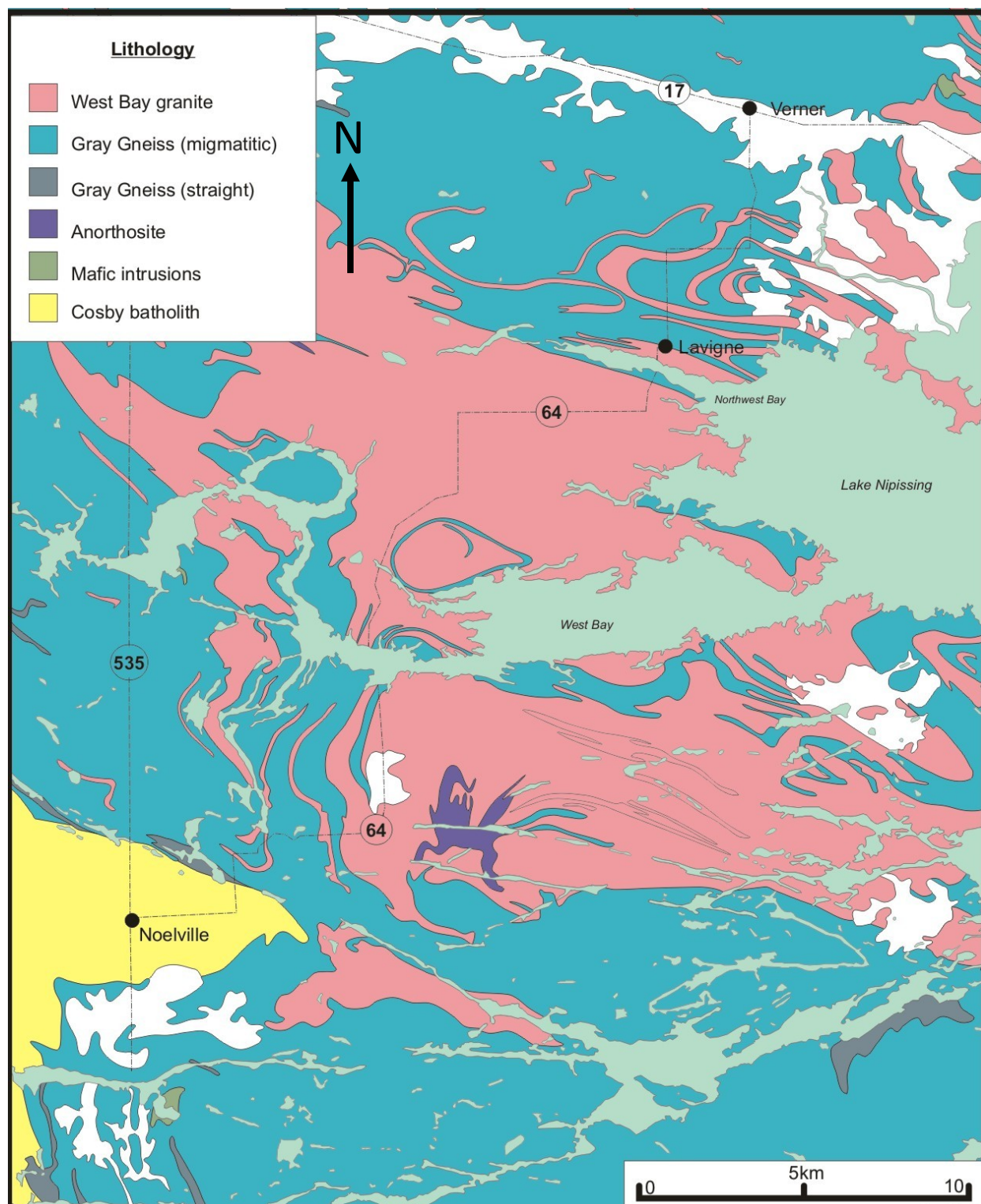


Figure 7: Lithological map of the study area. Adapted from Lumbers (1970).

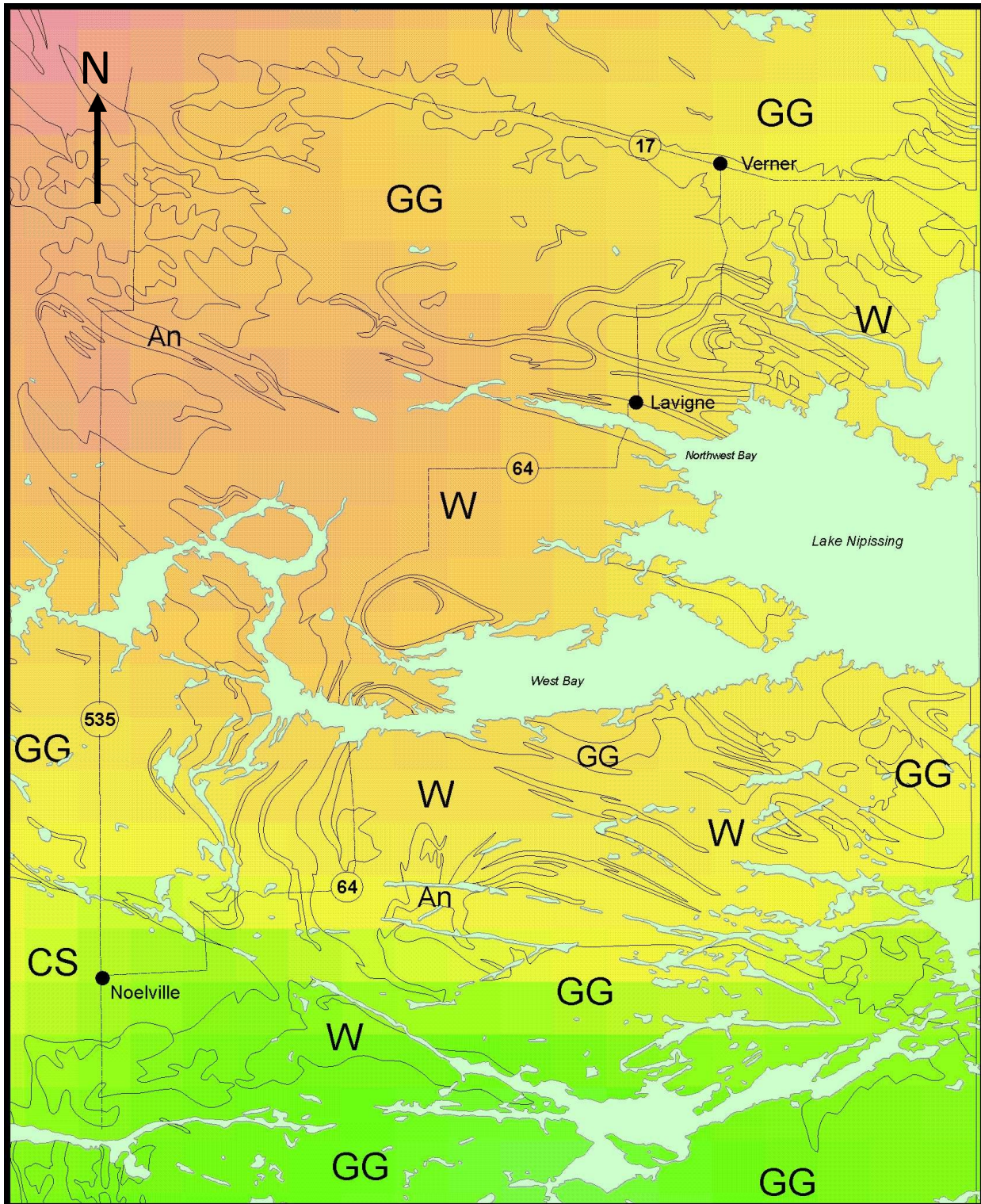


Figure 8: Total gravity anomaly for the study region. Values are higher N of Noelville (yellow, orange) and lower S of Noelville (green). Abbreviations: An, anorthosite; CS, Cosby batholith; GG, gray gneiss; W, West Bay granites. Gravity anomaly data from NRC (GeoGratis).

4.0 Interpretation

4.1 Fold Superposition

The map pattern of S1 in the teardrop (Fig. 3) structure is strikingly similar to one of several fold interference patterns presented by Ramsay (1967). The scheme of fold interference used here considers rock possessing a complex deformation history consisting of two folding events. These two events are analyzed in terms of the angles (α and β , respectively) between the first generation axial plane and the second generation displacement vector in the axial plane (a_2), and between the first and second generation (b_2) fold axes (after Ramsay, 1967). Three basic types of fold interference are defined for use as qualitative first approximations when interpreting fold orientation from map pattern: Type 0 ($\alpha, \beta=0^\circ$), identical fold superposition; Type 1 ($\alpha>0^\circ, \beta=90^\circ$), or “dome-and-basin” type; Type 2 ($\alpha=90^\circ, \beta>0^\circ$), or “boomerang” type; and Type 3 ($\alpha>0^\circ, \beta=0^\circ$), or “hook-shaped” type (Fig. 9) (Fossen, 2011; Ramsay 1967). The pattern presented for a transitional Type 1 to Type 2 pattern closely resembles the surface geometry of the teardrop structure (diagram D, Fig. 9).

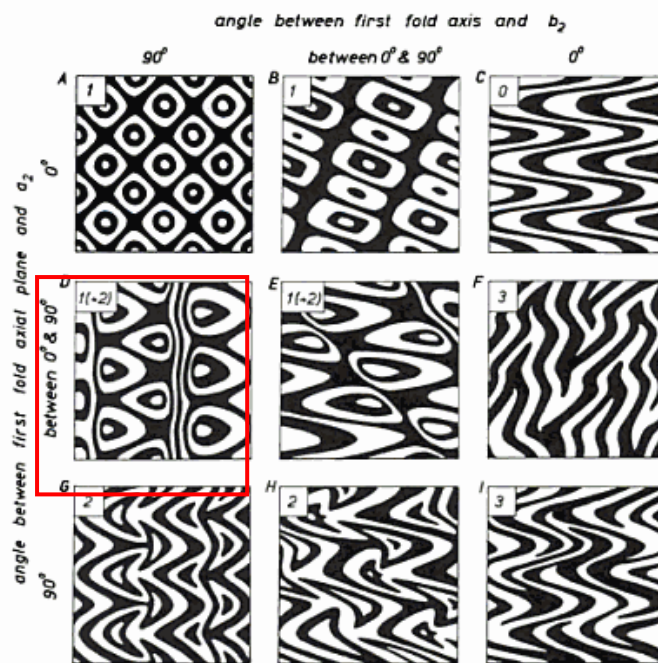


Figure 9: Fold interference models based on Ramsay's classification. Diagram D closely resembles the teardrop structure. Angle between first fold axial plane and a_2 (α) and between first fold axis and b_2 (β) discussed in text. From Ramsay (1967).

The teardrop is the result of complex deformation consisting of at least two folding events. The geometry of the F1 and F2 fold pattern is seen in a Type 1 transitional to Type 2 fold interference pattern from Ramsay's classification. The F1 axial plane (a_1) is at some oblique angle to the F2 displacement vector (a_2) and the first and second fold axes (b_1, b_2) are perpendicular. The dominantly N-dipping S1 surfaces seen in the form line map and illustrated in the schematic cross section above (Fig. 4) suggest furthermore that a_2 was inclined and that the F2 axial plane strikes ESE. On the basis of the interference diagram (Type 1-2 transition pattern) and ESE strike direction of F2 axial planes (Fig. 4, 7), it can be assumed that there is a first fold axis of NNE or SSW (90° to ESE); and that the first fold axial plane is at $\sim 45^\circ$ to a_2 . Given the inclination of the F2 axial plane (Fig. 4), the F1 axial plane is gently inclined. From this interpretation it can be concluded that we have an early D1 event causing recumbent folding towards the GF, with gently inclined axial planes and NNE trending fold axes. D1 is followed by a later (D2) event causing inclined F2 folding with ESE-striking axial planes (Fig. 7). Assuming that the high strain L-S fabric in the Nepewassi was deformed by both events, it is reasonable to suggest that D1 was a high strain, ductile event creating S1 and L1 which were then re-folded by later F2 folds.

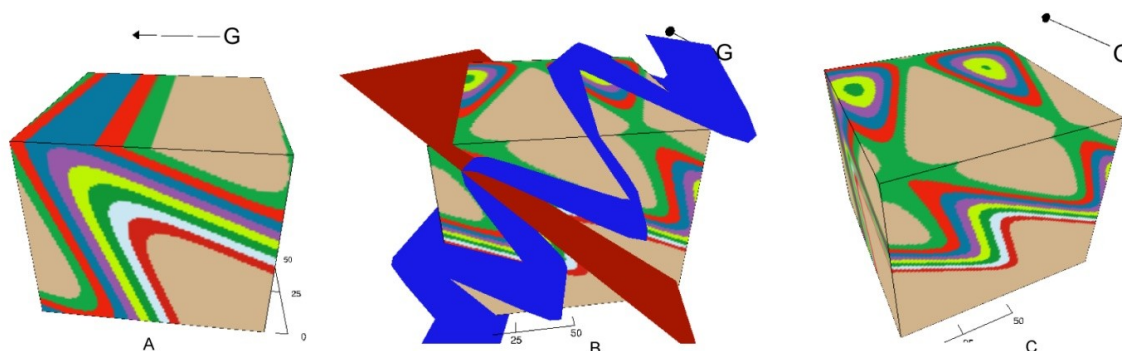


Figure 10: Schematic block models developed representing progression through D1 (diagram A) and D2 (diagram B) deformation period, with final superposition model (diagram C). G indicates the direction towards the GF. From Culshaw, (personal communication, 2013).

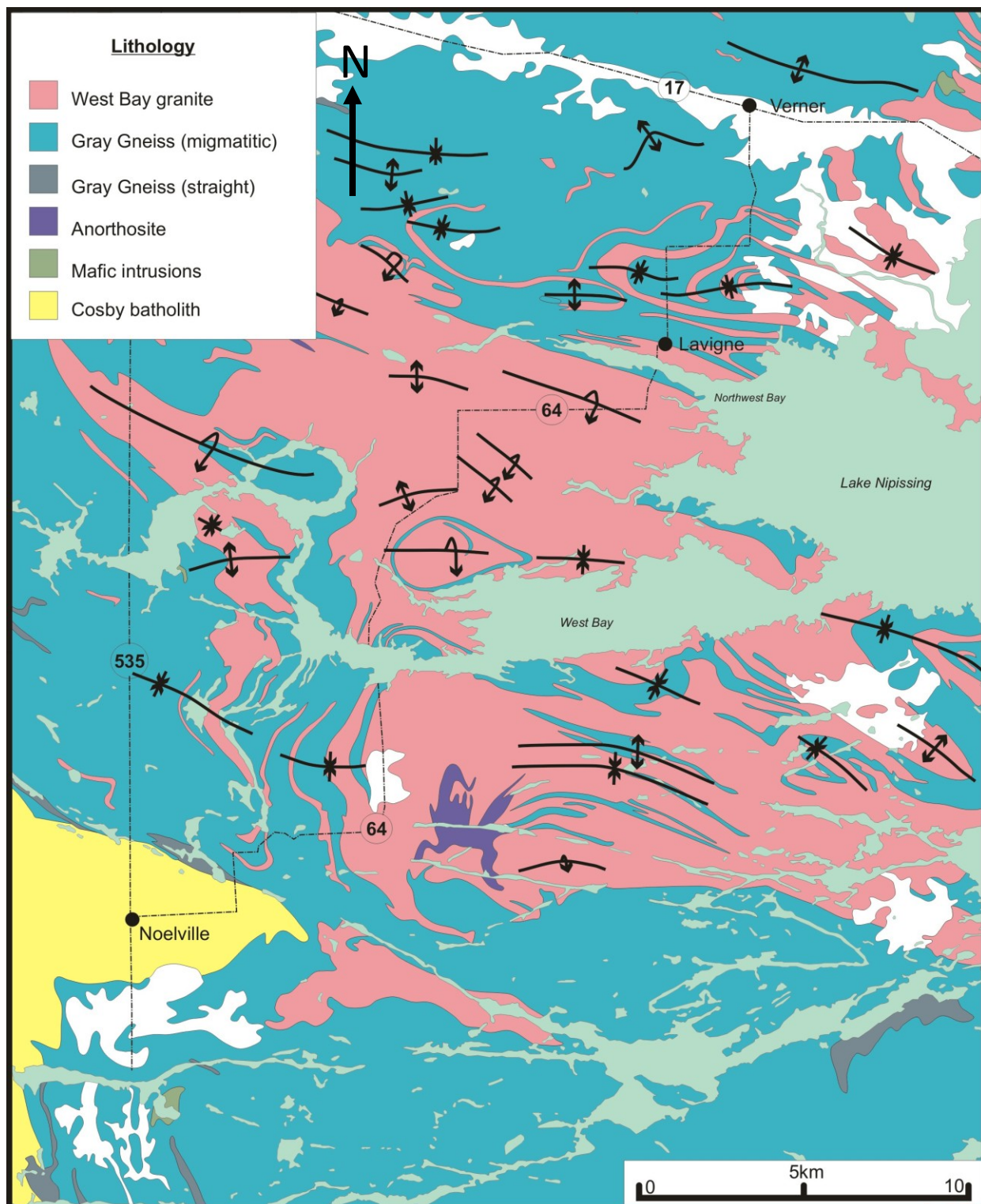


Figure 11: Lithological map of study area (Fig. 4) with F2 synclines, anticlines, and overturned folds. Adapted from Lumbers (1970).

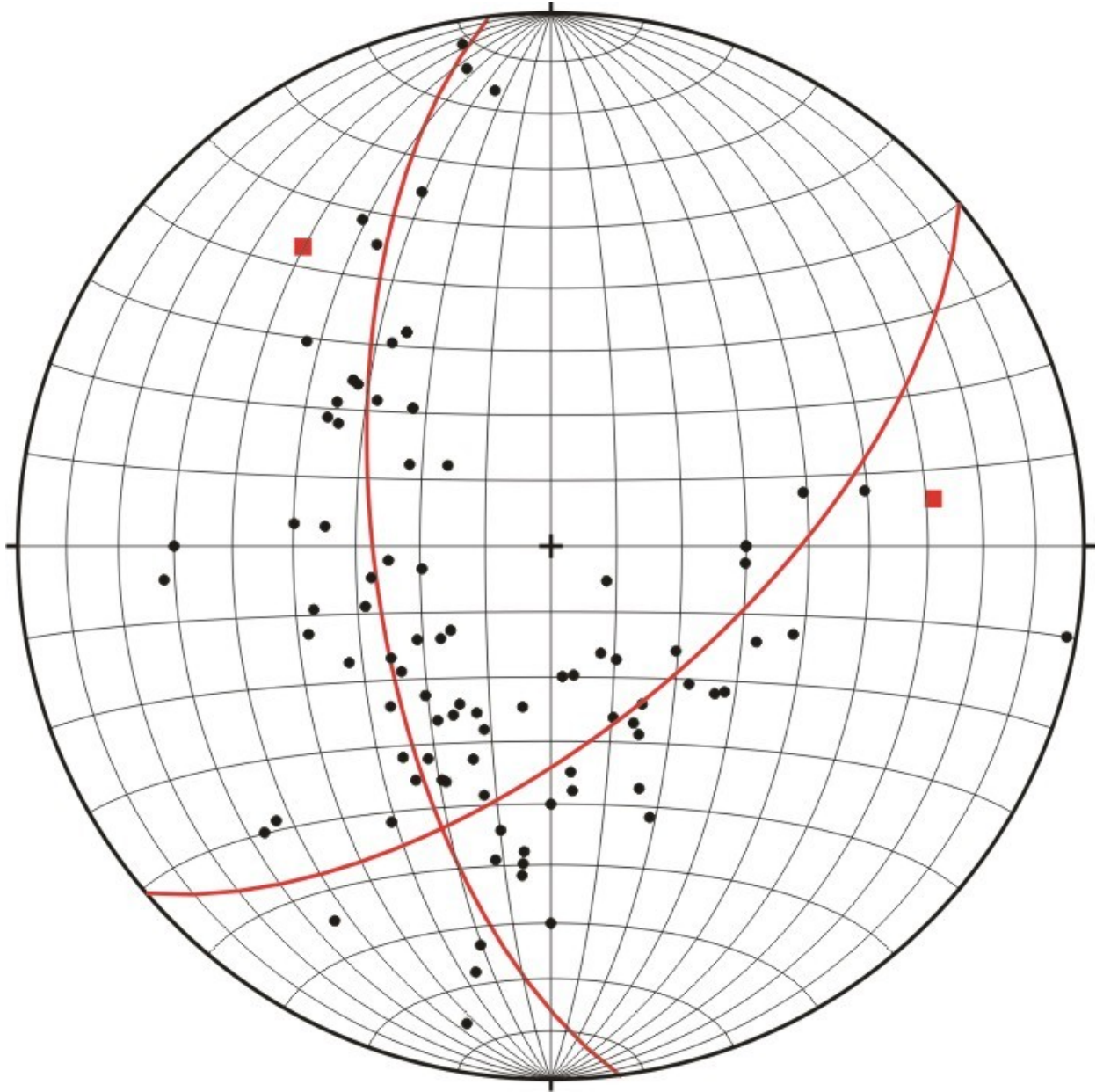


Figure 12: S1 foliation field measurements from the teardrop structure for this study (Appendix) represented as poles to planes. Lines of best fit and beta points (inferred hinge) for two apparent groups have been drawn: one dominant girdle and ENE-plunging beta point, and a loosely grouped girdle and ~NW plunging beta point.

There are two groups of S1 planes observed in the teardrop structure: the dominant girdle with a beta point plunging to the ENE and a loosely spaced girdle with a beta point plunging more steeply to the NW (Fig. 9). In the context of the complex deformation history described above, each orientation may be associated with a deformational period. In this case, the ENE-plunging beta point might be associated

with the F2 folds while the NW-dipping beta point might be associated with F1 folds. This association is uncertain, however, as re-working by F2 folds has caused significant alteration in the original F1 structure.

Event timing can be constrained by the age of the West Bay granite, a Geon 12 pluton. The West Bay granite records L-S fabric with F2 folding indicating that both D1 and D2 have a maximum age of deformation of ~1235 Ma (Carr et al., 2000; Culshaw et al., 1997; Easton & Ketchum, 2002; Rivers & Corrigan 2000). Given this time reference it can be assumed that both events occurred during Grenvillian-phase deformation (1150-980 Ma) because there is no evidence for any major post-Grenvillian deformation phase. The N region of the study area is described here as showing evidence for multiple periods of Grenvillian-phase deformation (polyphase), as opposed to the S region which only shows evidence for a single event of Grenvillian-phase deformation (monophase).

4.2 Nepewassi-Britt Boundary Zone

A significant amount of structural, lithological and geophysical evidence suggest an E-W running boundary near the Cosby batholith. Across this boundary there is a contrast in gravity anomaly data (Fig 11), change in the dominant trend of L-S fabric (~N dipping to ~S dipping), and Geon 12 plutons are completely absent from the S area (Fig. 12). Furthermore, as discussed previously, there is evidence for polyphase Grenvillian deformation to the N of the boundary while the S area shows monophase Grenvillian deformation. This zone is assumed here to be the boundary between the Nepewassi and Britt domains. The Nepewassi-Britt relationship is taken to be a boundary thrust in which the Britt has overthrust the Nepewassi domain consistent with the S-dipping foliation of the Britt in the study area (Fig. 4). This is a reasonable assumption because boundary thrust relationships are present between most CGB domains.

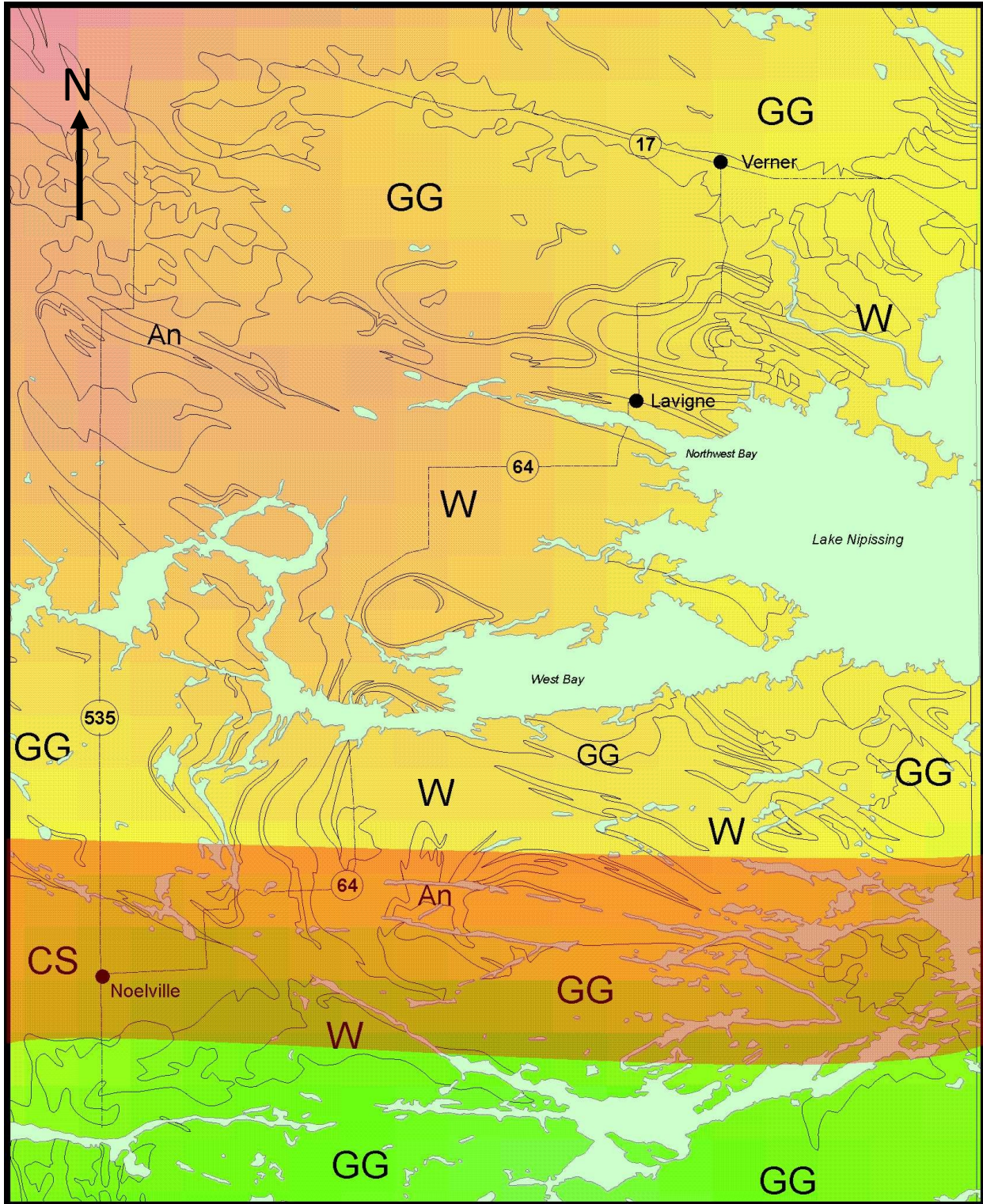


Figure 13: Total gravity anomaly as in Fig. 8 with interpreted Nepewassi-Britt boundary zone highlighted, separating the high value region (N) from the low value region (S).

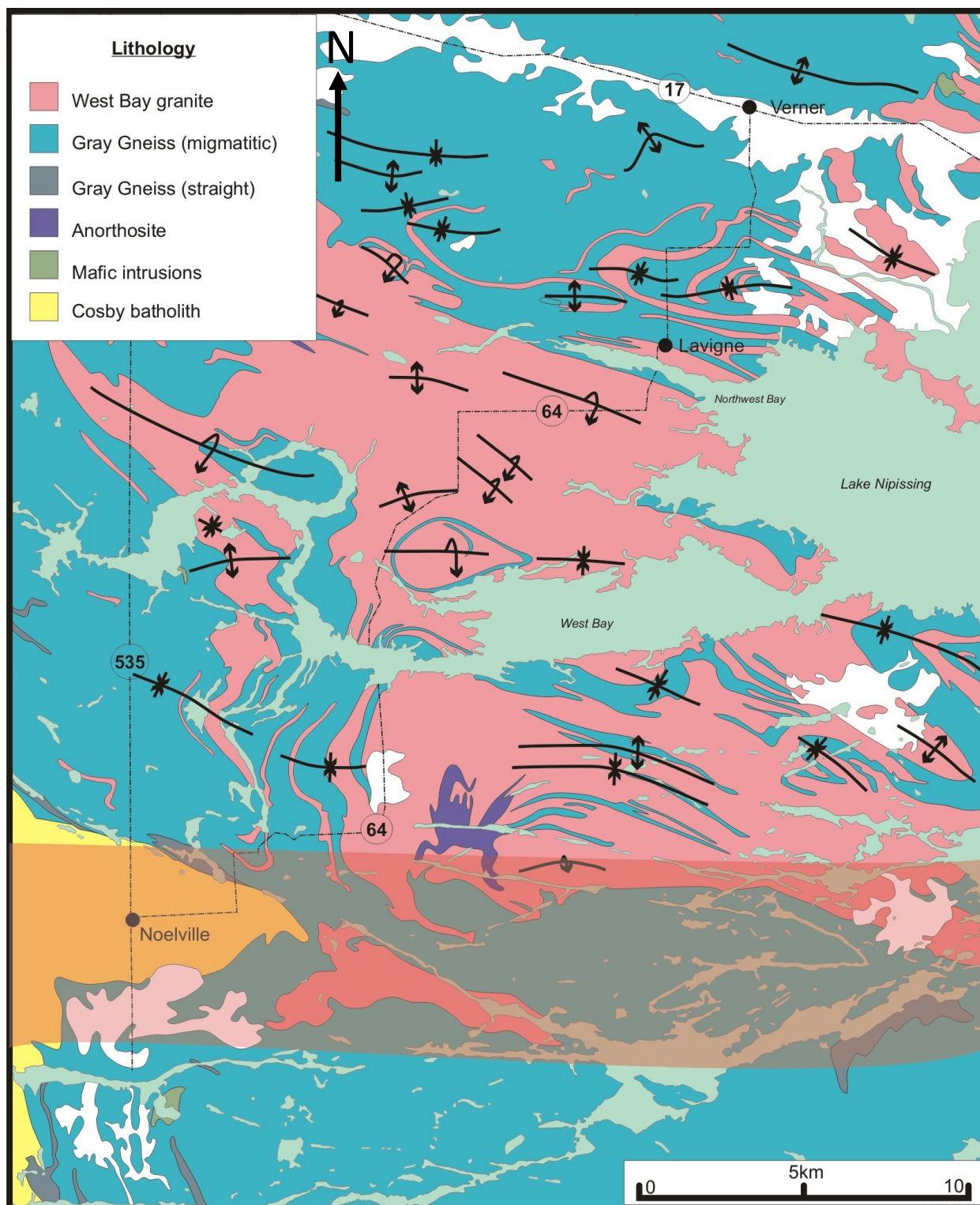


Figure 14: Lithologic and structural map (Fig. 11) with interpreted Nepewassi-Britt boundary zone.

Assuming a domain boundary in which the Britt domain, showing evidence for one Grenvillian deformation event, has overthrust the Nepewassi domain; which shows evidence for two Grenvillian deformation events, two scenarios of event timing are presented. D1 and D2 are assumed to be Grenvillian on the basis of the 1235 Ma age of the Geon 12 West Bay pluton, and thus within the Grenvillian age window of 1150 to 980 Ma. Given a minimum metamorphic age for Britt deformation of 1035 Ma (Corrigan et al., 1994), that window can be further restricted (1150-1035 Ma). Therefore, there are at least two, possibly three deformation events affecting the Nepewassi domain during the 1150-1035 Ma age window: D1, followed by D2 and (or including) the emplacement of the Britt domain. The relative timing of D2 and the emplacement of the Britt remains uncertain. Three scenarios are presented here: D2 deformation, followed by later emplacement of the Britt; emplacement of the Britt directly causing D2 deformation; and emplacement of the Britt followed by later, independent D2 deformation. There are a number of problems in each of these scenarios. There is no obvious structural evidence to suggest a post-D2 deformation event associated with the Britt emplacement. Associating the Britt emplacement with D2 deformation is the simplest solution as there are no other obvious effects of the emplacement, or driving forces of D2, in the Nepewassi domain. However, this solution does not explain why the F2 folds are inclined and verging SSE. Finally, if the Britt was emplaced at some time post-D2, some effect of D2 deformation would be expected in the Britt (of which there is none). What can be concluded here is that a boundary between the Nepewassi and Britt exists at the location suggested (Figs 13, 14), and that the emplacement of the Britt domain and D2 event, which were probably associated, occurred at some time post-D1.

5.0 Conclusion

From the data presented in this thesis, it is interpreted that the Nepewassi domain records a complex, polyphase deformation history consisting of at least two Grenvillian events. The deformational history, together with geophysical and lithological signature differentiates the Nepewassi from the Britt domain. A location for the boundary zone is suggested based on these structural, geophysical, and lithological differences. The nature of this boundary is assumed to be a thrust in which the Britt domain overthrust the Nepewassi domain during its emplacement. Furthermore, potential timing scenarios have been presented based on event timing assumptions (i.e. whether the emplacement of the Britt domain pre- or post-dates D2 deformation). There are a number of unsolved problems for each of these scenarios. Assuming the Britt domain was emplaced prior to the D2 event, thrusting of the Britt to the N may have driven the D2 deformation event. If this is the case, then the S-verging attitude of the F2 folds is unexplained. If D2 has an independent cause, then the truncation of F2 folds at the domain boundary cannot be explained. Assuming the Britt domain was emplaced at a later time than the D2 event, the Britt must have originated at some unknown, relatively distant location so as not to be affected by D2. Further field work in the boundary zone region (Figs 10, 11) will be useful in providing deeper understanding of the nature of this domain boundary.

For this study, a boundary line between the Britt and Nepewassi domains has been drawn on the basis of evidence for a polyphase Grenvillian history (Nepewassi) as opposed to a monophase Grenvillian history (Britt). Supporting evidence is provided by lithology (Geon 12 plutons in the Nepewassi as opposed to Geon 14 plutons in the Britt) and geophysical data. Consideration of the other domains of the CGB in these terms may prove useful in determining various other boundaries. For instance, it would be interesting to discover if any association between polyphase Grenvillian deformation and the presence of Geon 12 plutons exists (Fig. 15). Further work in this case will include the classification of the polycyclic CGB domains under the poly- or monophase Grenvillian deformation terminology used in this thesis.

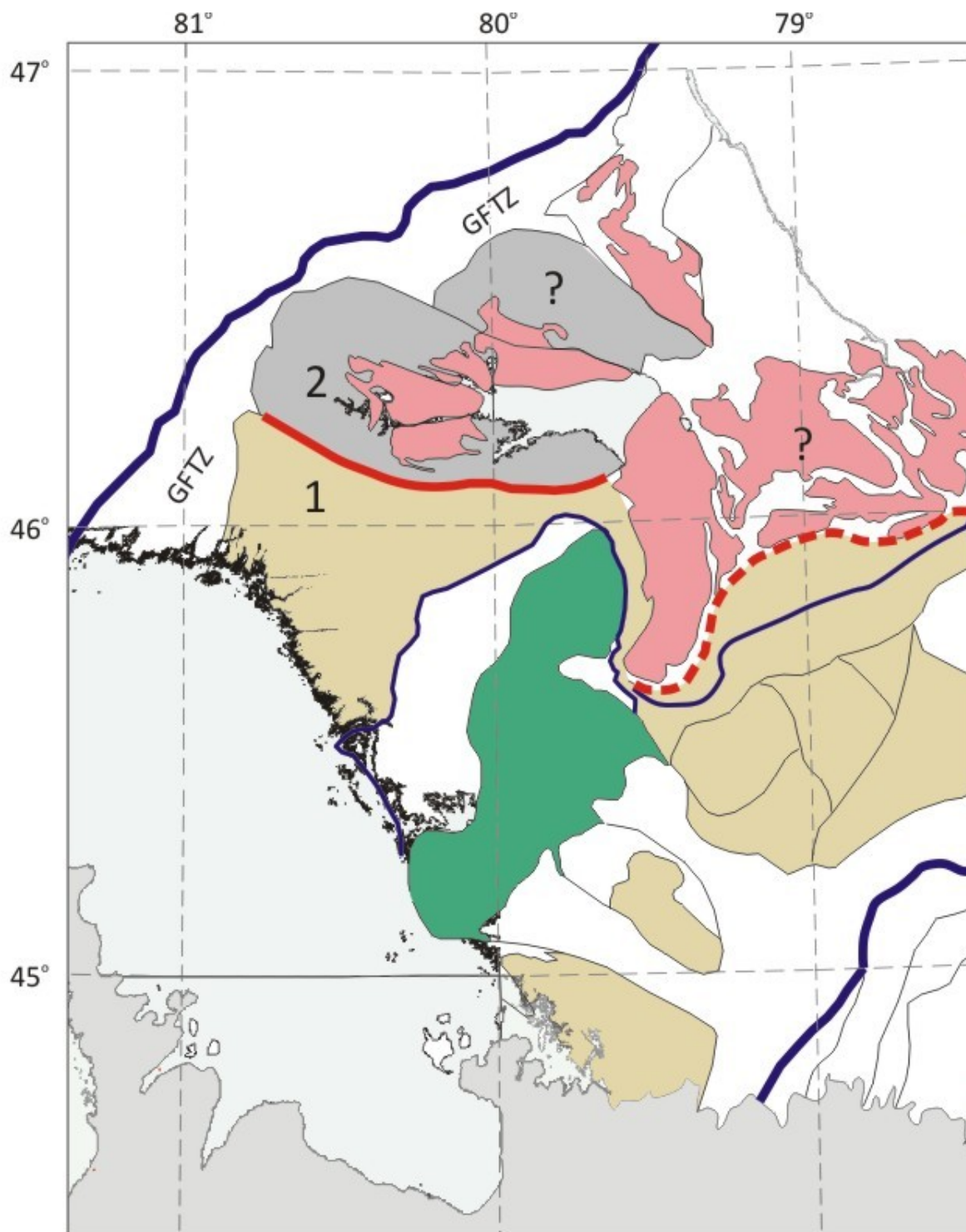


Figure 15: The CGB of Ontario (after Fig. 1). The interpreted Nepewassi-Britt boundary between polyphase and monophase Grenvillian deformation is symbolized by a red line. A dashed red line represents a possible poly-/monophase boundary under the assumption that Geon 12 plutons and polyphase Grenvillian deformation are associated. Modified from Culshaw et al. (2013).

6.0 References

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