Deep into the Chibougamau area, Abitibi Subprovince: structure of a Neoarchean crust revealed by seismic reflection profiling

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Key Points

- Seismic reflection survey of the Chibougamau area, northeastern corner of the Abitibi Subprovince, by the Metal Earth project
- The Metal Earth and Lithoprobe seismic surveys reveal that the northern part of the Abitibi Subprovince has a consistent structure ~~over its whole length (430 km)~~
- The Chibougamau area is an Archean oceanic crust ~~that~~ evolved through terrane imbrication and not through plume activity and subduction processes.

Abstract

Copper-Au magmatic-hydrothermal systems dominate in the Chibougamau area of the Neoarchean Abitibi Subprovince, whereas orogenic gold mineralization is more common in the rest of the Abitibi. Understanding differences in the metal endowment of parts of the Abitibi Subprovince requires insights into the geodynamic evolution of the Chibougamau area. This is addressed by imaging the crust using seismic reflection data acquired as part of the Metal Earth project. Seismic reflection imaged shallowly south-dipping structures in the upper-crust (e.g., deep extension of the Barlow fault) and a northward-dipping mid-crust region. The upper part of the mid-crust zone is characterized by multiple reflectors that are likely faults superimposed on a major lithological boundary. These structures were likely acquired at ca 2.70 Ga during terrane accretion prior to cratonisation. Combining the seismic data with known stratigraphic, structural and magmatic records, we propose that the study area was initially a normal (i.e., thick) Archean oceanic crust that formed at or before 2.9 Ga and that evolved through terrane imbrication at 2.73 Ga or before. This caused rapid burial of mafic rocks followed by devolatilization and partial melting of hydrated mafic rocks to produce tonalite magmas that may have mixed with mantle-derived melts to produce the diorite-tonalite suite associated with Cu-Au magmatic-hydrothermal mineralization.

Keywords: Metal Earth project, seismic reflection, Chibougamau area, magmatic evolution, geodynamic processes, mineralization

1 Introduction

Archean greenstone terranes host many of the world's major mineral resource, yet their crustal structure and tectonic history remain only partly understood. The Chibougamau seismic transect is one of 10 transects under the Metal Earth program. The latter is designed to understand the metal endowment differences of terranes with comparable surface geology; e.g., Abitibi-Wawa and Wabigoon subprovinces. Given the similar geology at surface, geophysical investigation documented herein is crucial in understanding the structure of the crust. The Chibougamau area is located in the north-eastern corner of the Neoarchean Abitibi Subprovince, in the southern part of the Superior province. Unlike other parts of the Abitibi subprovince, it is Cu-Au-endowed and it was chosen as a key area to investigate the metal endowment of the Abitibi subprovince.

The Chibougamau area is the easternmost part of the 430 km long, E-W-striking Matagami-Chibougamau greenstone belt. The eastern part of this belt had yet to be imaged by deep seismic reflection methods and, as most Neoarchean terranes, its geodynamic evolution is controversial. The Chibougamau area likely had a unique crustal evolution that led to magmatism favorable to magmatic-hydrothermal mineralizing processes and formation of the large Central Camp Cu-Au porphyry system (P Pilote et al., 1997). Porphyry-like mineralization is rare in the rest of the Abitibi Subprovince, which is mostly renowned for its orogenic gold and VMS (volcanogenic massive sulfides) ore systems (Dubé & Gosselin, 2007; Gosselin & Dubé, 2005). Chibougamau also lacks major fault zones such as the Cadillac-Larder Lake fault of southern Abitibi (Bedeaux et al., 2018). This contribution focuses on the geodynamic evolution and economic potential of the Chibougamau area, which are unraveled using new seismic reflection data combined with current stratigraphic, structural and magmatic data and interpretations for the area.

The seismic reflection profiling method provides the highest resolution image of structures at depths greater than a few kilometers within the crust (Sheriff & Geldart, 1995). Such data provide insights into, for example, lithological contacts, fault zones, altered areas (Eaton, 2006) and can thus provide invaluable insights into the structure and geodynamic evolution of the crust. Combined with surface geology data, the Metal Earth seismic profile provides insights into the structure of the Chibougamau area, its geodynamic evolution and its mineralizing systems.

2 Geological Setting

The thickest package of rocks in the Chibougamau area belongs to the ca. >2730 Ma to 2710 Ma Roy Group, which sits on ca. 2790-2760 Ma volcanic units (Chrissie and Des Vents formations) and is topped by the sedimentary units of the Opémisca Group (**Figure 1**). The Roy Group is divided into volcanic cycle 1, which consists of mafic to intermediate lava flows, and volcanic cycle 2, which consists of mafic flows topped by intermediate to felsic flows and fragmental units (Leclerc et al., 2017). In this contribution, the magmatic events that formed the Roy Group and its coeval plutons, as well as older volcanic rocks, will be referred to as the synvolcanic period, while later events that led to craton stabilization will receive the general designation 'syntectonic period'.

2.1 Stratigraphy and volcanic environment

The oldest volcanic rocks of the Chibougamau area are mafic and felsic lava flows and volcanoclastic deposits of the Chrissie and Des Vents formations, which are exposed 2 to 10 km west of the seismic profile (**Table 1**). These rocks predate the deposition of the 7-14 km thick Roy Group and Opémisca Group (Mueller et al., 1989).

Volcanic cycle 1 of the Roy Group consists mainly of mafic to intermediate lava flows of the Obatogamau Formation (Daigneault & Allard, 1990; Mueller et al., 1989) overlain by sulphide-bearing intermediate to felsic, coherent (e.g., lava dome) to clastic (pyroclastic to sedimentary units) volcanic rocks of the Waconichi Formation (Caty, 1975). The mostly effusive volcanic cycle 1 is thought to represent submarine lava plains topped by small volcanic centers (Mueller et al., 1989) locally accumulated in valleys such as, for example, the Fancamp corridor (**Figure 2**) synvolcanic structure (Legault, 2003).

In the southern part of the study area (**Figure 1**), the sedimentary rocks of the Caopatina Formation (Roy Group) are interlayered with volcanic cycle 1 rocks (Mueller et al., 1989; Mueller & Donaldson, 1992). Volcanoclastic units observed in the same area however suggest that the Caopatina Formation may be in contact with undifferentiated units of volcanic cycle 2, and recent dating indicates that it may be a syn-Opémisca basin (David et al., 2006). Dedicated studies are necessary to determine the age and origin of the Caopatina Formation, and its contact relationships with volcanic cycles 1 and 2.

The base of volcanic cycle 2 consists of mafic lava flows, interbedded thin volcanoclastic lenses and pillow breccia of the Bruneau Formation (Leclerc et al., 2011; Picard & Piboule, 1986). It is overlain by the Blondeau Formation, which is a complex assemblage of intermediate to felsic volcanic, volcanoclastic and sedimentary units (Archer, 1983; Dembele, 1984; Duquette, 1964, 1982; Lefebvre, 1991; Tait, 1987). The Blondeau Formation is intruded by the three sills of the Cummings Complex (**Table 1**), which extend over 160 km in an E-W direction (Bédard et al., 2009; Dubé, 1990; Dubé & Guha, 1987; Duquette, 1982; McMillan, 1972; Pierre Pilote, 1986; Poitras, 1984; Watkins & Riverin, 1982). The top of volcanic cycle 2 is made of the Bordeleau Formation (Caty, 1979; Dimroth et al., 1985), a concordant sedimentary unit viewed as a transitional facies between the volcanic rocks of the Roy Group and overlying sedimentary rocks (Caty, 1978; Moisan, 1992).

Volcanic cycle 2 began with effusive volcanism (Bruneau Formation) followed by the development of a basin and small sub-aerial volcanic centers (Blondeau Formation) that shed volcanoclastic material into the basin (Archer, 1983). Alternatively, the Blondeau Formation and crosscutting Chibougamau pluton have been interpreted as a large central volcano underlain by a syn-volcanic pluton, with shallow to deep marine sediments deposited on the apron of the volcano (Dimroth et al., 1985; Mueller, 1991).

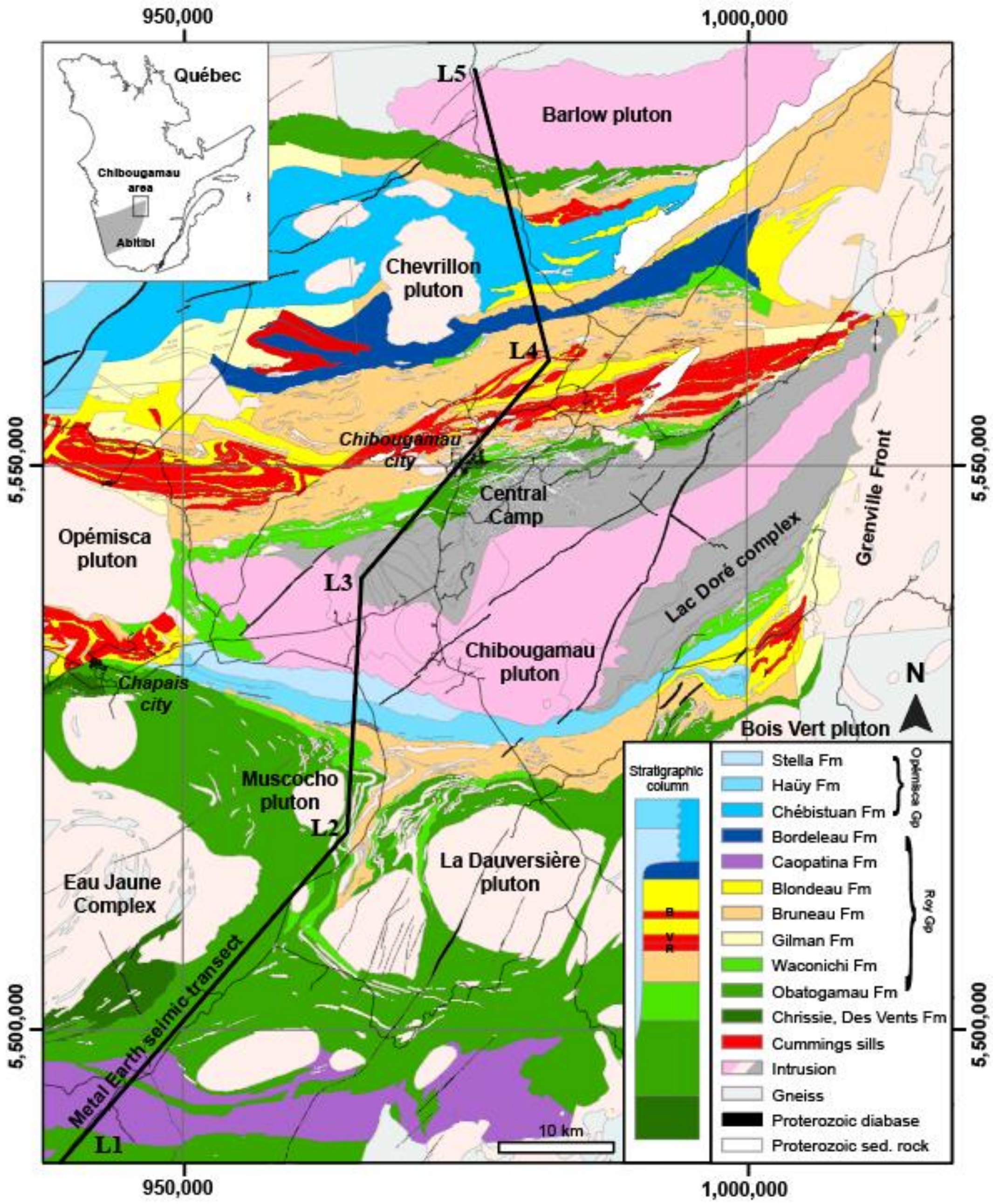

Figure 1. Geological map of the Chibougamau area, showing the main volcanic, sedimentary and intrusive phases. The geological map is modified from the Ministère de l'Énergie et des Ressources Naturelles (MERN), Québec (SIGEOM, 2018). The projection is UTM NAD83 Zone 18 N. The simplified stratigraphic column is inspired from the most recent stratigraphic interpretation (Leclerc et al., 2017). Letters B, V and R are for the Bourbeau, Venture and Roberge sills, respectively. The Caopatina Formation is not integrated to the stratigraphic column because it has a poorly constrained age and an unresolved relationship with the Opémisca Formation. The Gilman Formation belongs to a former stratigraphic interpretation recently modified using new chemical and geochronological data (Leclerc et al., 2017).

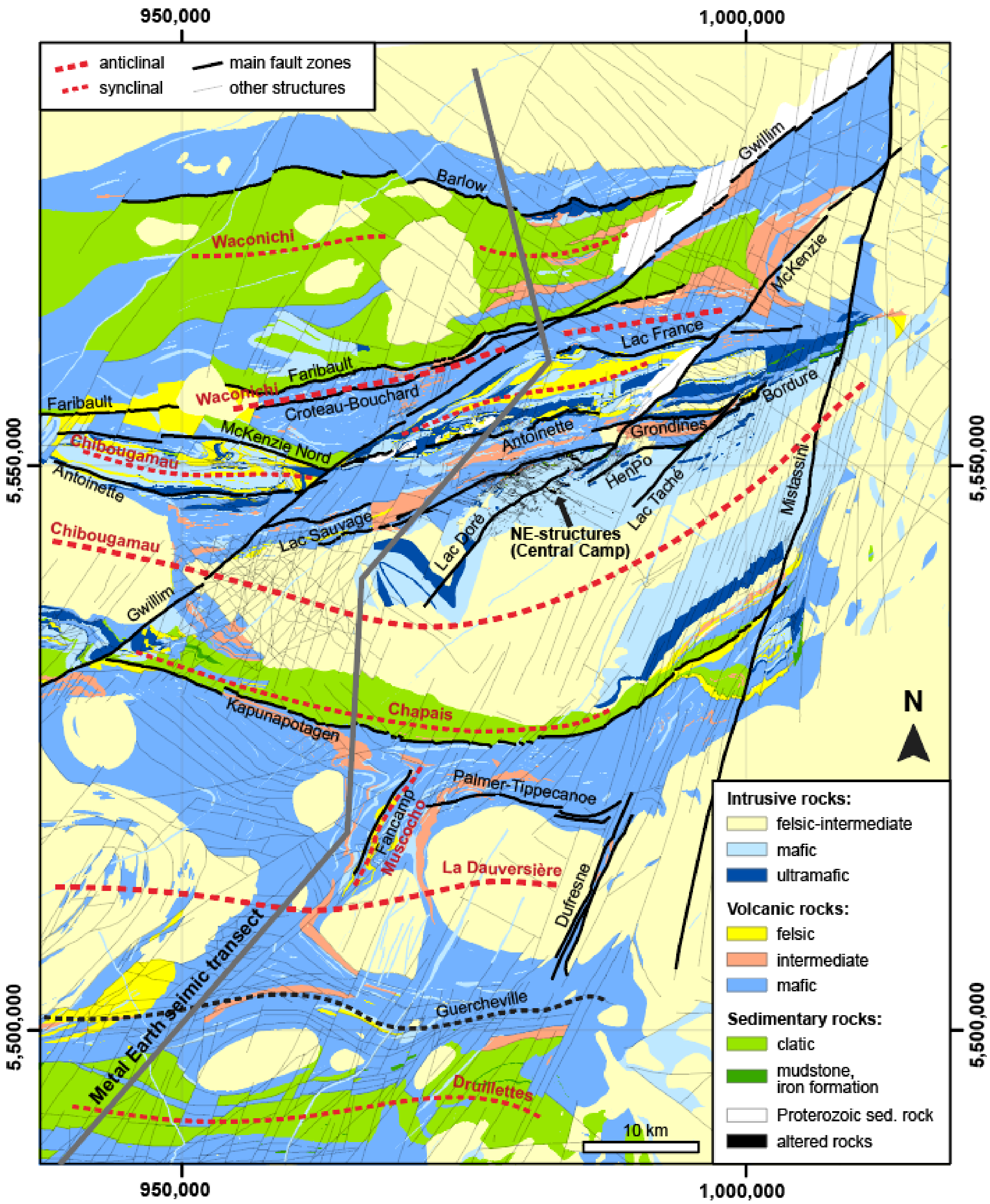

Figure 2. Lithologies and structures (SIGEOM, 2018), as well as main faults and deformation zones (Daigneault & Allard, 1990), of the Chibougamau area. The Barlow and Guercheville faults (Mueller et al., 1989) are approximately located. Most of the E-W-structures are thick deformation corridors and are drawn as thin lines for clarity. The following abbreviations are used: 'Bordure' refers to a fault located along the northern border of the Lac Doré Complex and 'HenPo' is the Henderson-Portage fault.

The Roy Group is topped by the Opémisca Group that accumulated in two sedimentary basins (Dimroth et al., 1985; Mueller, 1991; Mueller et al., 1989) (**Figure 1; Table 1**). Erosion of the volcanic islands progressively filled the basins with sediments and lava flows from the central volcanoes. This formed the Bordeleau Formation (Roy Group) and then the Opémisca Group (**Figure 2**) as basin subsidence rate decreased (Dimroth et al., 1983) and the basin evolved from marine to sub-aerial (Dimroth et al., 1985; Mueller, 1991). The southern Opémisca basin contains clasts from the Chibougamau pluton, indicating that the pluton was eroded only 15 to 18 Ma after emplacement (Daigneault & Allard, 1990).

Table 1. Stratigraphy of the Chibougamau area

Stratigraphy	Major rock types	Thickness	U/Pb age
Pre-Roy Group			
Chrissie Fm[1]	Mafic to felsic lava flows,	?	~2759 Ma [1] [2]
Des Vents Fm	volcanoclastic deposits	2-2.5 km [2]	~2791 Ma [3]
Roy Group – cycle 1			
Obatogamau Fm	Mafic to intermediate lava flows	2-4 km [2, 4]	?
Waconichi Fm	Coherent to clastic, mafic to felsic, volcanic rocks	2.4 km [5]	~2730-2726 Ma [3, 6]
Roy Group – cycle 2			
Bruneau Fm	Mafic flows mostly	?	2724 Ma [7]
Blondeau Fm	Intermediate to felsic, volcanic to sedimentary deposits	2-3 km (north) to 0.5 km (south) [4, 8, 9]	<2721 Ma [10]
Bordeleau Fm	Volcanoclastic deposits, arenite, conglomerate		
Cummings sills	Three Ultramafic to mafic sills	<500 m, 250-1000 m, 450-750 m [9]	2717 Ma [3]
Roy Group (?)			
Caopatina Fm	Pelitic to siliciclastic sedimentary rocks	?	<2707 Ma [11] and older?
Opémisca Group			
Stella Fm	Sandstone, conglomerate		<2692 to
Haüy Fm	Sandstone, conglomerate, shoshonitic lava flows	<4 km	<2704 Ma [10, 12]
Chébistuan Fm	Sandstone, conglomerate		

[1] Fm stands for Formation

[2] References in the table: [1] (David et al., 2011); [2] (Mueller et al., 1989); ; [3] (Mortensen, 1993); [4] (Daigneault & Allard, 1990); [5] (Caty, 1975); [6] (Leclerc et al., 2011); [7] (D. Davis et al., 2014); [8] (Archer, 1983); [9] (Duquette, 1982); [10] (Leclerc et al., 2012); [11] (David et al., 2006); [12] (David et al., 2007).

The Chibougamau area also contains intermediate to felsic intrusions. During the synvolcanic period, these intrusions are tonalite-trondjhemite-granodiorite (TTG) suites such as the Eau Jaune Complex (**Figure 1**) and tonalite-trondjhemite-diorite (TTD) suites such as the ca. 2714-2718 Ma Chibougamau pluton that is characterized by multiple magma pulses and a poorly defined internal organization (Mathieu & Racicot, 2019). The ~2728 Ma Lac Doré Complex layered intrusion (Mortensen, 1993), which is a dominantly mafic complex with a coherent magmatic stratigraphy (Allard, 1976; Mathieu, 2019), also formed during the synvolcanic period.

Magmatism, in the syntectonic period, may postdate or may be coeval with the main sedimentary deposits (**Figure 3**). Only the shoshonitic lava flows observed in the Haüy Formation, Opémisca Group (**Table 1**), are clearly syn-sedimentary units (Piché, 1985). Other plutons intrude the Roy and Opémisca groups (e.g., Muscocho and Chevrillon plutons; **Figure 1**). These include the 2696 Ma Barlow pluton (W. J. Davis et al., 1995), which is expressed by tonalite and monzodiorite cutting across the contact between the Abitibi and Opatica subprovinces (Racicot et al., 1984). The geometry of these and additional intrusions were investigated in detail as part of the Metal Earth project, using gravity inversion, and showed that the main intermediate to felsic intrusions crossed by the studied transect (Chibougamau and Barlow plutons) extend to the upper- to mid-crust contact (Maleki Ghahfarokhi, 2019).

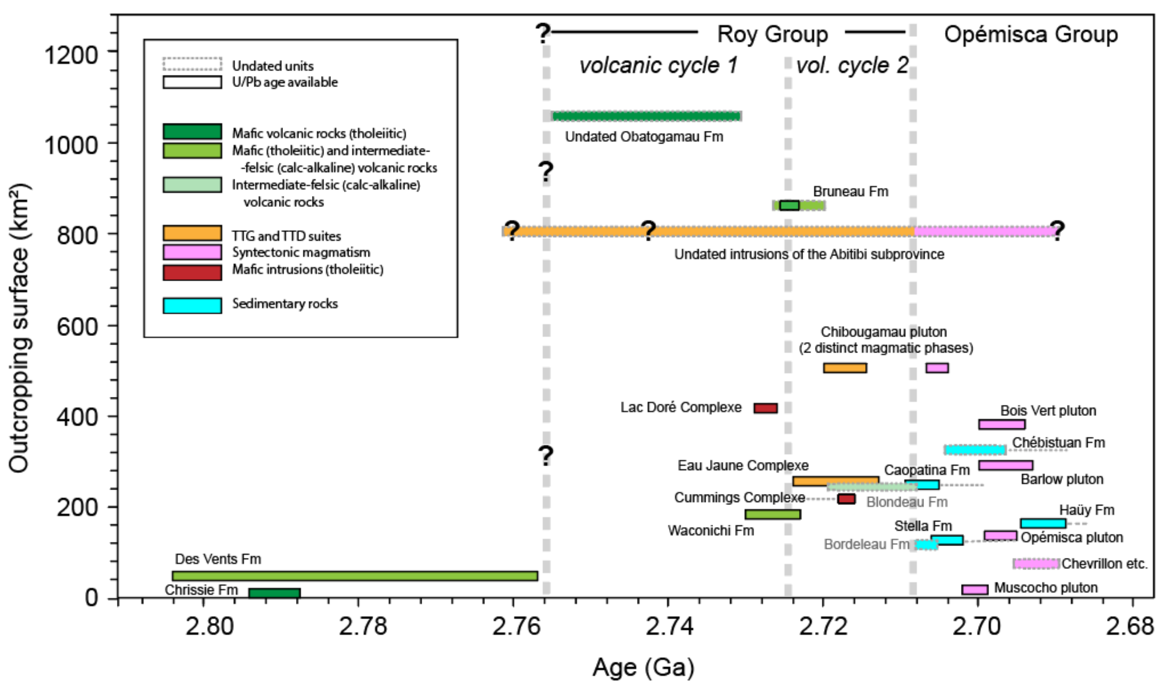

Figure 3. Binary diagram showing the surface area occupied by the main lithologies on **Figure 1** against the radiogenic ages available in the MERN dataset (SIGEOM, 2018). A total of 30 U/Pb ages (9 of which in the Waconichi Formation) where compiled from the MERN database (SIGEOM, 2018) and an approximate age is attributed to the undated units. Magmatic affinities were compiled for the volcanic rocks (Leclerc et al., 2017; Potvin, 1991) and, for intrusive rocks, was attributed as follows: 1) large-volume synvolcanic intrusive complexes dominated by tonalite and/or diorite are given the general designation TTG and/or TTD suites; and 2) other plutons with variable volumes (e.g. monzodiorite, granodiorite) are designated ‘syntectonic intrusions’. The following abbreviations are used: ‘Fm’ stands for Formation; ‘Chevrillon etc.’ refers to the

Chevrillon pluton and to the other intrusions emplaced in the Chébistuan Formation. Note that undated plutonism and volcanism (e.g. Obatogamau Formation) may not be as continuous as is suggested by the diagram.

2.2 Magmatic evolution

The Chibougamau area is characterized by a synvolcanic period that lasted > 90 Myr, followed by a 20 Myr syntectonic period (**Figure 3**), as is usual in greenstone belts around the world (Laurent et al., 2014). Magmatic activity was likely episodic during both synvolcanic and syntectonic periods. According to SiO_2-content, mafic and intermediate to felsic volcanic rocks dominate volcanic cycles 1 and 2, respectively (Leclerc et al., 2011, 2017).

Using the TAS (Le Bas et al., 1992), the AFM (Irvine & Baragar, 1971) and the Th/Yb vs Zr/Y (Ross & Bédard, 2009) diagrams, it was determined that the mafic lava flows (basalt to basalt-andesite) of the Roy Group and older units of the Chrissie and Des Vents formations have tholeiitic affinities (Leclerc et al., 2011, 2017). On REE and multi-element diagrams normalized to primitive mantle, they have flat patterns (Leclerc et al., 2017). On the other hand, intermediate to felsic extrusive rocks of the Roy Group and older units have major element contents akin to those of calc-alkaline rocks and are enriched in the most incompatible elements, such as Th and La (Leclerc et al., 2017). Some of these rocks, however, display less fractionated trace element profiles and correspond to differentiated tholeiitic magma (Leclerc et al., 2017).

The only intrusive complex clearly coeval with volcanic cycle 1 (i.e., Lac Doré Complex) has a tholeiitic affinity (**Figure 3**). During volcanic cycle 2, tholeiitic intrusions also formed (e.g., Cummings sills) (Bédard et al., 2009), while several TTG and TTD suites intruded the volcanic pile. The onset of tonalite-dominated magmatism (TTG and TTD) is unconstrained in the Chibougamau area (**Figure 3**). The duration of syntectonic magmatism also needs to be evaluated by geochronological investigations, which is beyond the scope of this paper. As in other greenstone belts, synvolcanic magmatism is K-poor (TTG suite), while the magmas of the syntectonic period contain more K (shoshonite flows, granodiorite, monzonite). Syntectonic magmatism is sub-alkaline in the Chibougamau area, with only the shoshonite flows of the Haüy Formation displaying an alkaline affinity.

2.3 Structural Geology

The Chibougamau area underwent four deformation events (Daigneault & Allard, 1990). As for the rest of the Abitibi Subprovince, the first three events occur at ~2.70 Ga during terrane assembly of the subprovince during the Kenoran orogeny (Dallmeyer et al., 1975). The D_1 deformation event is characterized by N-S to NNW-striking open synforms without associated axial planar cleavage (Daigneault et al., 1990). These folds are thought to have formed during reactivation of synvolcanic structures such as the Fancamp corridor (**Figure 2**) (Legault, 2003).

The D_2 deformation event is coeval with peak greenschist facies metamorphism. Most regional folds in the Chibougamau area formed during the D_2 event, including the

E-W-striking Waconichi, Chibougamau, Chapais and Druillettes synclines and the Waconichi, Chibougamau and La Dauversière anticlines (**Figure 2**). Several of those synclines are deformed sedimentary basins, whereas the Chibougamau anticline has been inflated, or domed, by magmatic injections (Chibougamau pluton), which were emplaced in the hinge of the anticline and further deformed during D_2.

The folds have a subvertical and E-W-striking axial plane cleavage, which locally wraps around plutons that acted as resistant cores during the deformation. A near-vertical stretching lineation lies along the cleavage plane (Daigneault & Allard, 1990). Deformation is most intense around the plutons, along contacts between the Roy and Opémisca groups, in corridors spatially associated with gold showings (**Figure 4**), and within the contact zone between the Abitibi and Opatica subprovinces (Daigneault & Allard, 1990; Leclerc et al., 2017).

The formation of the regional folds and the intensification of their axial plane cleavage along lithological contacts was accompanied by the formation of E-W-striking reverse faults, although some of these faults may be older structures that were reactivated during D_2 (**Figure 2**). For example, the Barlow fault is interpreted as a basin-bounding syn-sedimentary fault that was reactivated as a reverse fault during D_2 (Dimroth et al., 1986). Other basin-bounding faults, such as the Kapunapotagan fault, are chloritised, sericitised and carbonatized (ankerite-rich) fault planes.

The D_3 deformation event, which correspond to the waning stage of the main deformation event (D_2), reactivated the east-west-striking faults as transcurrent strike-slip faults. The D_4 deformation event represents the ~1.1 Ga Grenville orogeny (Baker, 1980). It resulted in the formation of NNE-striking faults in the Chibougamau area and amphibolite grade metamorphism near the Grenville front (Kline, 1985) (**Figure 1**).

3 Methodology and results

3.1 Acquisition of seismic reflection data

Seismic transects across the Superior craton were done ~30 years ago as part of the Lithoprobe program (Calvert & Ludden, 1999; Percival & West, 1994; White et al., 2003). Lithoprobe's mandate was to image the crust and crust-mantle boundary. The program emphasized deep signal penetration, resulting in low near-surface resolution of reflectors. The more recent Discovery Abitibi seismic surveys obtained better near-surface resolution but were restricted to a few areas (Ayer et al., 2008; Snyder et al., 2008).

The Metal Earth program used existing roads and survey designs that provided greater lateral and vertical seismic wave resolution of near-surface and deeper crustal structures (Cheraghi et al., 2019). Overlaps between Lithoprobe and Metal Earth seismic profiles show better resolution of the upper crust along the Metal Earth seismic profiles (Naghizadeh et al., 2019). The Metal Earth seismic surveys were acquired as regional (R1) and high-resolution (R2) surveys. The geometrical attributes of both surveys, as well as the processing performed to produce the migrated profile (**Figure 5a**), is published elsewhere (Cheraghi et al., 2018; Naghizadeh et al., 2019).

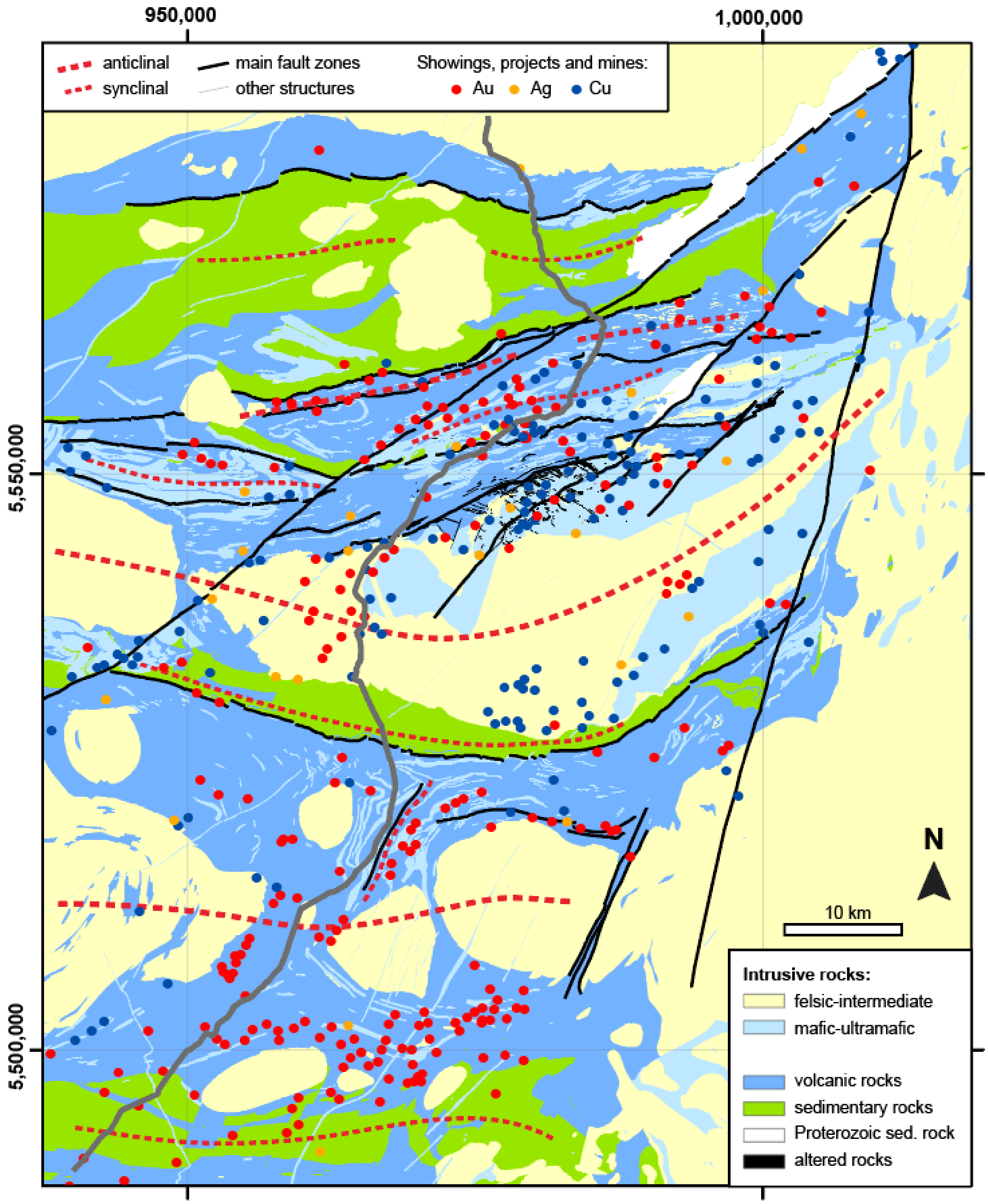

Figure 4. Main lithologies, structures and Au-Cu-Ag-showings of the Chibougamau area (SIGEOM, 2018). A part of the Au showings aligns parallel to the main E-W faults and deformation zones, such as the Guercheville, Plamer-Tippecano, and Antoinette – Croteau – Lac France faults zones. Other Au showings, as well as most Cu showings and mines, are spatially associated with the Chibougamau pluton (porphyry-style of mineralization) (P. Pilote, 1995; P. Pilote et al., 1998) and the Cummings sills (Opemiska-style of mineralization) (Leclerc et al., 2012).

The R1 Chibougamau survey presented here does not overlap with previous Lithoprobe or Discovery Abitibi profiles and provides new insights into deep structures. The profile is 113 km long and extends from the Barlow pluton in the north (Abitibi-Opatica Subprovince contact) to the Caopatina basin in the south. Data were acquired along forest roads (162 km length) and were projected onto four straight segments (113 km total length) during processing (**Figure 1**). This profile provides a complete section of the eastern extremity of the E-W-striking Matagami-Chibougamau greenstone belt.

3.2 Reflectors, geological units and faults

Seismic waves are sensitive to physical properties of rocks, particularly seismic wave propagation and density. The seismic wavelength, typically 100-5000 m in crystalline rocks, determines the resolution and thus the scale at which reflectors between contrasting rock types can be observed (Eaton et al., 2010). Typical vertical resolution is one-quarter of the seismic wavelength. Lateral resolution varies with depth and is a few kilometers in the mid- to lower crust. Lateral continuity of reflectors is uncommon in ancient crystalline rocks, and where observed are significant major structures (Eaton et al., 2010).

In the Chibougamau area, most structures and lithological units strike E-W so the seismic transect was designed to roughly follow N-S roads (**Figure 2**). A notable exception is in the Chibougamau syncline, where the road and transect are sub-parallel to lithological contacts. As a result, seismic reflectors are less visible south of this inflection; i.e., south of the L4 marker (area D, **Figure 5b**). Another exception is the Fancamp corridor area (L2 marker), where the lithological contacts are oriented NNE-SSW and are sub-parallel to the seismic profile (**Figure 2**). In these areas, the interpretation of the seismic data is challenging and questionable (**Figure 6**).

Prominent reflectors were identified visually on the seismic profile and correlated with surface geological units and faults. Additional constrains come from subsurface modeling of rock units using gravity, magnetic and conductivity data (Maleki Ghahfarokhi, 2019). Interpretations of the seismic profiles were done independently by D. Snyder, P. Bedeaux and L. Mathieu and are presented in **Figure 6.**

All interpreted seismic profiles display multiple shallowly dipping reflectors. In the first interpretation by D. Snyder, reflectors or clusters of reflectors interpreted as large-scale shear zones are emphasized (**Figure 6a**). The second interpretation by P. Bedeaux focuses on contacts between major package of rocks, including the lower crust, mid-crust and upper metavolcanic-sedimentary supracrustal rocks and intrusions (**Figure 6b**). The third interpretation by L. Mathieu includes all reflectors and presents a more detailed interpretation of the upper crust using the mapped extent and known thickness of the main lithological units (**Figure 6c**).

3.3 Interpretation of seismic reflection data

The general structure of the seismic profile (**Figure 5b**) consists in: 1) an upper-crust region extending to 3 to 10 km depth (A), characterized by sub-horizontal reflectors with limited N-S extents, with one notable exception dipping at 33° in the northern part of the profile; 2) a mid-crust region that extends down to 20 or 30 km depth (B), where the most prominent reflectors are concentrated; 3) a lower-crust region (C) that contains few prominent reflectors; and 4) an area (D) where interpretation is challenging (see previous section). The mid-crust section has an apparent shallow dip (4° to 23°) directed toward the north, except in the northernmost part of the profile, where it dips toward the south at 19° (**Figure 5b**).

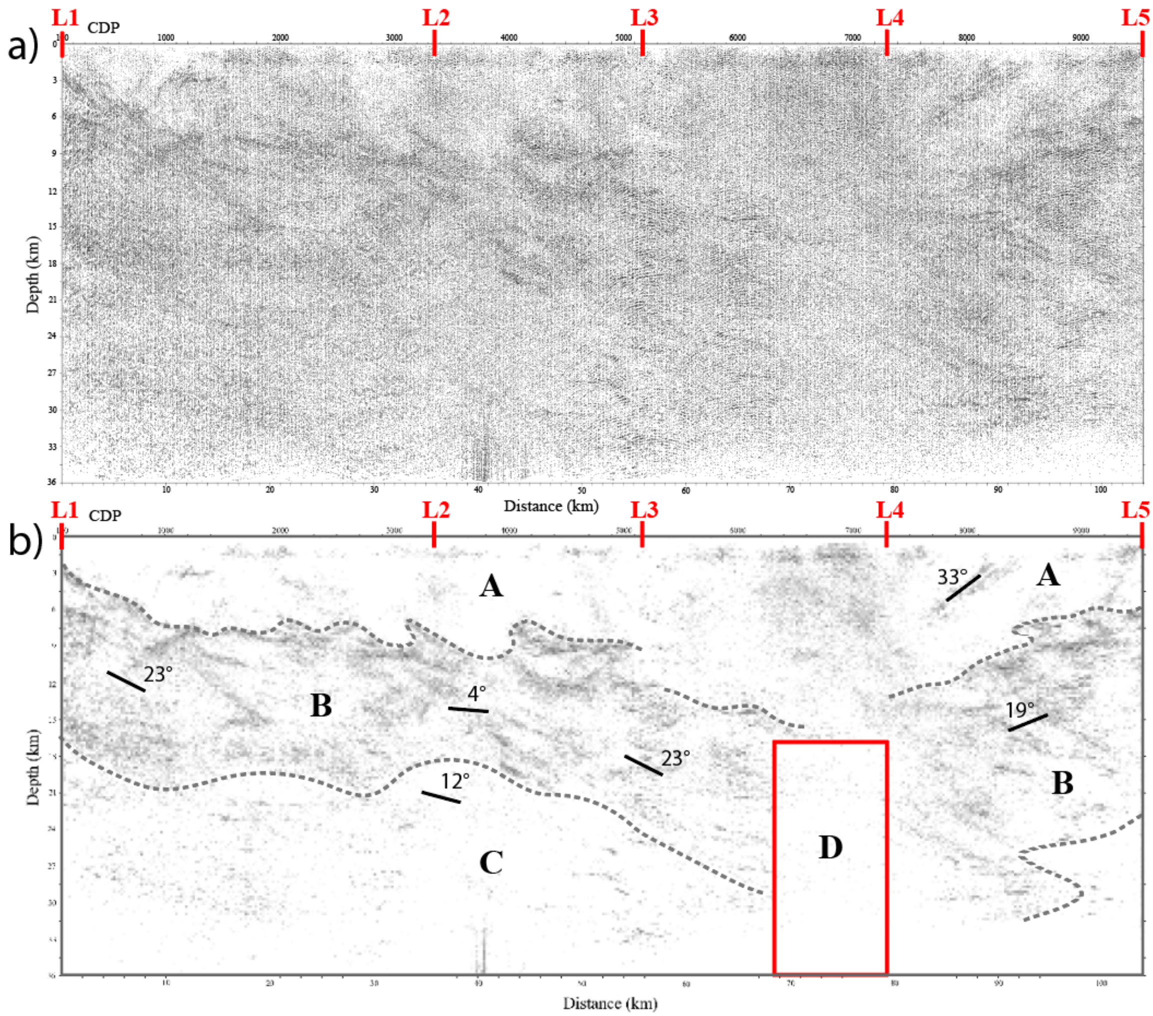

Figure 5. The Metal Earth R1 seismic profile of the Chibougamau area (a). The image has been down-sampled (1 pixel for each 10*10 pixels) and its luminosity-contrast has been modified as to highlight the main reflectors (b). Markers L1 to L5 are located on **Figure 1** and zones A to D are described in the text. Zone B has irregular apparent dip, and a general dip of 12°N in most of the section.

Interpretations of the Metal Earth seismic profile emphasize the main reflectors and how they relate to known faults, folds and lithological contacts at surface (**Figure 6**). The first detailed interpretation (D. Snyder; **Figure 6a**) shows the main reflectors as large-scale shear zones. Disruption zones are also drawn in the upper-crust, where rock packages with contrasting compositions may be in contact. One of these disruption zones separates a northern area (Opatica Subprovince) from supracrustal rocks in the Chibougamau area. The Moho is located at about 30-33 km depth, where reflectivity decreases (**Figure 6a**). This is in agreement with Moho depth determined by regional teleseismic studies (Darbyshire et al., 2017). The main intrusive complexes are located where main reflectors are lacking and using the results of gravity modelling (Maleki Ghahfarokhi, 2019).

The second detailed interpretation (P. Bedeaux; **Figure 6b**) divides the section into three regions. The upper region comprises several reflectors, including one prominent cluster of reflectors that dip 33° toward the south and that correlate to the Barlow Fault at surface. Other shallow reflectors are broadly sub-horizontal and are located in the Barlow pluton and in the gneisses of the Opatica Subprovince. The supracrustal rocks are drawn as a folded volcano-sedimentary succession with limited northward and southward extents, which is thickest (14 km thick) in the Chibougamau and Waconichi synclines area. The mid-crust region is characterized by a large number of shallowly north-dipping reflectors (**Figure 6b**). It underlies both the Opatica and Abitibi subprovinces with increasing thickness to the north. Additional reflectors dip toward the south and these concentrate in the upper- and mid-crust regions and near the contact between the Opatica and Abitibi subprovinces. These reflectors are interpreted as late normal faults that offset the northward-dipping reflectors.

The third detailed interpretation (L. Mathieu; **Figure 6c**) also divides the profile into upper-, mid- and lower-crust regions based on the distribution and orientations of the main reflectors (**Figure 5b**). The upper-crust region is mostly made of lava flows of the Obatogamau Formation and, possibly, undifferentiated older volcanic rocks (**Figure 6c**). This part of the profile contains abundant reflectors that dip shallowly toward the north and south (concave reflectors) and that correlate with the large-scale folds in the Chibougamau area (**Figure 2**). The Barlow fault correlates with clusters of reflectors that dip toward the south (**Figure 6c**). The Kapunapotagan fault is traced based on the truncation of shallowly dipping reflectors as a major sub-vertical structure that extends downward to the upper- to mid-crust contact. Both the Barlow and Kapunapotagan faults are spatially associated with sedimentary basin-bounding structures. The mid-crust section is drawn as two imbricated regions, representing the Abitibi and Opatica subprovinces, using the distribution of the main reflectors (**Figure 6c**). Multiple imbricated reflectors are observed in the upper part of the mid-crust region, which are drawn as structures superimposed on a major lithological contact; i.e., contact between volcano-sedimentary supracrustal rocks and mid-crustal rocks.

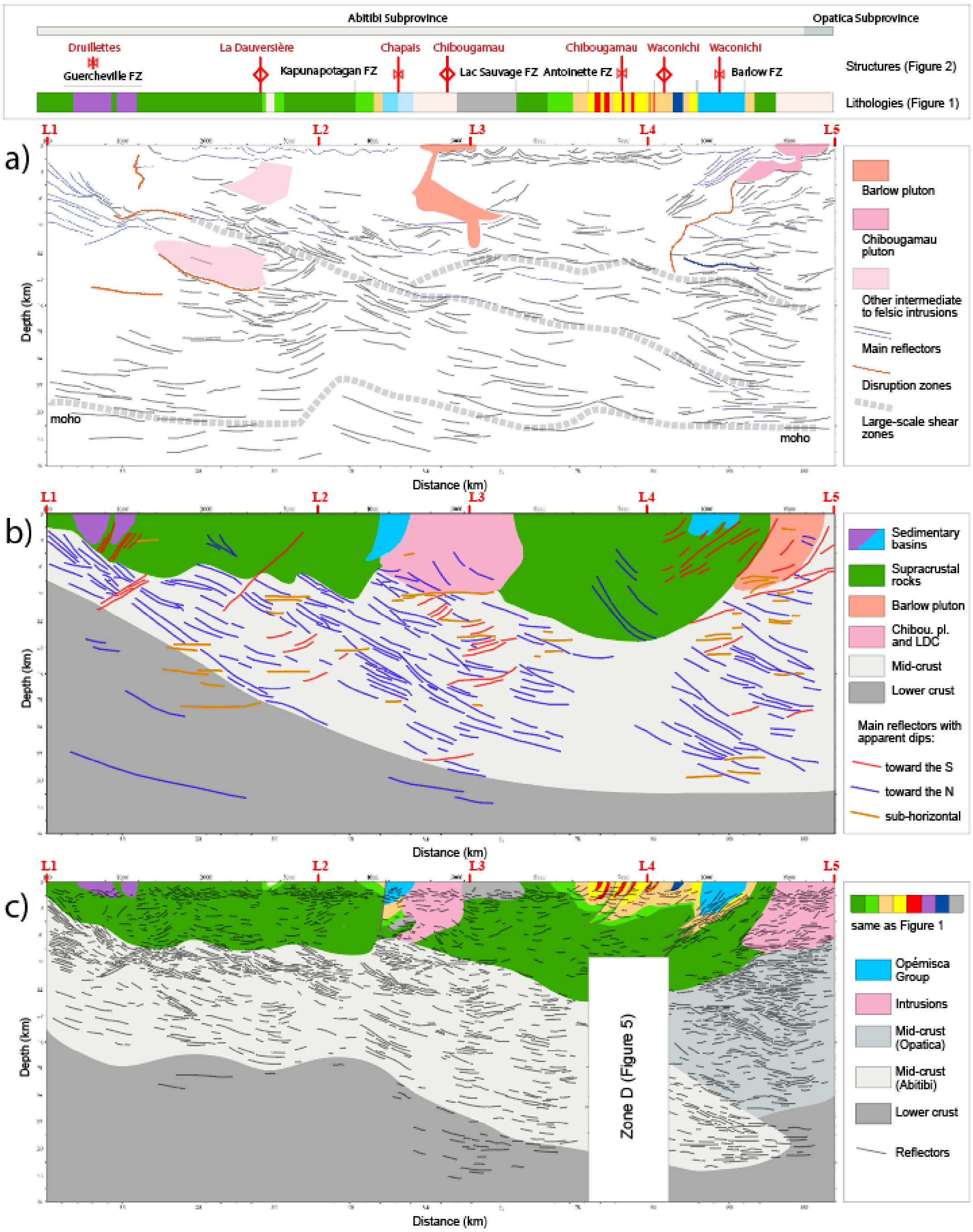

Figure 6. Interpreted seismic profile showing the main reflectors and possible extensions of surface geology at depth. The seismic profile was interpreted by (a) D. Snyder, (b) P. Bedeaux and (c) L. Mathieu. The stratigraphic units, lithologies and structures intersected by the Metal Earth seismic profile (top of the figure) were extracted from the MERN dataset (SIGEOM, 2018) using the ArcGIS software, and served as a basis to interpret the seismic profile. Zone D (**Figure 5**) was not interpreted by all the authors due to a lack of clear reflectors in the part of the seismic profile that is parallel to stratigraphy. The abbreviation ‘Chibou. Pl. and LDC’ stand for the ‘Chibougamau pluton and Lac Doré Complex’ magma intrusions.

4 Discussion

The architecture of the southern Superior Province is interpreted on Lithoprobe seismic profiles in terms of imbricated terranes with large syn-accretionary faults and possibly fossil subduction zones that displaced the Moho. This reflected the prevalent view at the time of subduction-driven plate tectonics during the Archean (Clowes et al., 1998; Ludden & Hynes, 2000). Indeed, subduction can juxtapose lithologies of different provenances and shove supracrustal rocks deep beneath the crust (Fountain & Salisbury, 1981). However, as discussed in this section, other geodynamic processes have been proposed for the Archean and processes other than subduction may explain the reflectors on the Chibougamau seismic profile.

4.1 Interpreting the crystalline crust with seismic reflection data

A difficulty that arises when interpreting seismic profiles of the crystalline crust is that reflectors may correspond to lithological contacts (layers, sills) and/or structures, including fluid-filled fractures (Lacroix & Sawyer, 1995), as well as contacts between rocks with different alteration styles or metamorphic grades (Eaton, 2006). For example, the Lithoprobe program obtained strong reflectivity at laterally continuous lithological contacts characterized by large impedance contrasts; e.g., gabbro-rhyolite contacts (Adam et al., 1998; Eaton et al., 2010) and mafic sills intruding intermediate composition rocks in the mid-crust (Calvert & Ludden, 1999). In the Chibougamau area, the Cummings sills (gabbro) intrude into the Blondeau Formation (felsic) and are expected to produce strong reflections. These rocks are, however, intersected by several faults in the Waconichi syncline area, possibly explaining their unremarkable reflectivity.

On the Chibougamau seismic profile, the most prominent reflectors are observed at the contact between supracrustal rocks of the upper-crust region (zone A on **Figure 5b**) and the mid-crust region (zone B). This is interpreted as a major lithological contact, with supracrustal rocks underlain by an intrusion-dominated zone (**Figures 6b, c**). The latter zone may contain numerous intrusions to supracrustal rocks contacts that may have been superimposed by faults during deformation.

In other areas imaged by the Lithoprobe program, faults and shear zones tend to form stronger reflectors than lithological contacts (Calvert & Ludden, 1999; Eaton et al., 2010; Snyder et al., 2008). The same may apply to the Chibougamau Metal Earth profile. Laterally extensive reflectors are usually interpreted as crustal thrusts (Lacroix & Sawyer, 1995), while reflective extensional structures are inferred in only a few areas (Calvert & Ludden, 1999). Similarly, compressional structures seem to dominate in the Chibougamau profile.

The upper- to mid-crust reflectors, on the Chibougamau profile, are imbricated and mostly dip toward the north. Because the Chibougamau area is located next to the Grenville front, it is possible that some of the faults associated with these reflectors formed during the Grenville Proterozoic orogeny about 1.5 Ga after craton stabilization. However, the general attitude and distribution of these reflectors resemble those observed in the Matagami area, 250 km to the west (Calvert & Ludden, 1999), thus the mid-crust reflectors of the Chibougamau profile are likely related to Neoarchean deformation as previously interpreted.

The Chibougamau profile also shows distinct mid- and lower-crust regions (**Figure 5b**). The mid- to lower-crust contact is clearly imaged by most seismic profiles around the world, as it is a major metamorphic and sometimes compositional boundary (Salisbury & Fountain, 2012). In the Chibougamau area, this contact is at greater depths in the northern part of the profile (**Figure 5b**) and so it is unlikely to be a metamorphic boundary only and is likely a major compositional boundary.

4.2 Structure of the crust

The Chibougamau area has been interpreted by some as a volcanic island arc, which evolved from an immature oceanic arc to a mature arc crossed by multiple batholiths (Dimroth et al., 1985; Mueller et al., 1989). Other interpretations suggest that the exposed rocks represent a 10 km thick supracrustal sequence that was deposited on an older sialic crust of unknown origin (Daigneault & Allard, 1990) and that may be dominated by locally outcropping tonalitic gneisses, such as the Lapparent massif west of the Eau Jaune Complex (**Figure 1**) (Chown & Mueller, 1992). The Metal Earth seismic profile shows that the supracrustal sequence is 5 to 14 km thick and that it represents an upper crustal region that differs from the mid- and lower-crustal regions (**Figure 6**).

The mid- and lower-crust areas may consist of synvolcanic intrusions related to the evolution of pre-Roy Group supracrustal sequence, or may correspond to an older crystalline basement (Chown & Mueller, 1992). Isotopic data suggests that the Abitibi Subprovince is composed mainly of juvenile volcanic rocks (W. J. Davis et al., 2000). This is more compatible with a continuous lower to upper crust that underwent a progressive maturation during TTG and subsequent magmatism. However, the Pilbara craton also has juvenile isotopic signatures, but it is underlain by older crust (Petersson et al., 2019). By analogy, an older crustal root for the Abitibi Subprovince cannot be fully excluded. Solving how the mid- to lower-crust formed requires dedicated geochemical investigations that are beyond the scope of this paper, as seismic data cannot constrain the age of the crust.

In crustal cross-sections of convergent tectonic orogens around the World, the crust-mantle transition tends to be blurred by large anorthosite bodies (Fountain & Salisbury, 1981; Salisbury & Fountain, 2012). This transition is not sharply defined in the Chibougamau area and could also be occupied by underplated mafic to ultramafic bodies. Other magmatic bodies, as well as plagioclase- and amphibole-rich cumulates, may also occur at different levels in the crust, as anorthosite-rich intrusions (e.g., Lac Doré Complex) are observed in the Chibougamau area and as TTG suites are dominated by amphibole and plagioclase fractionation (Moyen & Martin, 2012). The magmatic systems of the Chibougamau area are, however, not associated with strong reflections.

Also, most crustal cross-sections around the World have a complex fine-scale layering (lenticular granitoid bodies, deeply buried sedimentary sequences, etc.) that may cause deep reflections (Fountain & Salisbury, 1981). This may represent the imbrication of terranes with contrasting compositions; e.g., reconstruction of the Triassic Ivrea-Verbano zone, Italy (Khazanehdari et al., 2000; Rutter et al., 1999). The Lithoprobe seismic sections also comprise an Abitibi mid-crust region composed of imbricated metasedimentary and igneous rocks interpreted as accretionary complexes along primary suture zones (Bellefleur et al., 1995; Calvert & Ludden, 1999). A similar interpretation could be proposed for the mid-crust region of the Chibougamau profile (**Figure 6a**), which thickens to the north either as one continuous package of rocks (**Figure 6b**) or as an imbrication of two terranes (**Figure 6c**). Interpretation of the mid-crust section remains uncertain, as this part of the crust is dominated by anastomosing reflectors likely representing faults that obliterated lithological contacts. Nonetheless, the Chibougamau profile has a very different, more homogenous, architecture than that of the Ivrea-Verbano zone, with no evidence of imbricated sedimentary packages.

The 500 km long Kapuskasing uplift, which separates the Abitibi and Wawa subprovinces, may be a closer analogue. The Kapuskasing uplift formed due to NE-directed crustal-scale thrust faulting (Percival & McGrath, 1986) during the Neoarchean (Duguet & Szumylo, 2016). This uplift exposes a section across the lower crust consisting of an upper sequence of supracrustal rocks cut by plutons (0 to <10 km thick), a middle sequence of gneissic batholiths with tonalite and granodiorite intrusions (< 10 to ~20 km), and a lower sequence (20 to >25 km) of granulite gneisses (Percival & Card, 1983; Percival & West, 1994).

The Chibougamau profile may have a similar crustal architecture as the Kapuskasing uplift. Its A, B and C regions (**Figure 5b**) may correspond with the upper, middle and lower sequence of the Kapuskasing uplift. Region A would correspond to the supracrustal rocks sequence of the Kapuskasing uplift, region B to intermediate to felsic intrusions enclosed by supracrustal rocks, and region C to granulite facies gneisses. The mid-crust reflectors are likely faults that formed during imbrication of the Abitibi and Opatica subprovinces (**Figure 6**), during terrane assembly and cratonisation of the southern Superior Province (D_2 deformation event also referred to as the Kenoran orogeny).

4.3 Comparison to the Lithoprobe seismic profiles

The Abitibi Subprovince has a constant crustal thickness of 35-40 km and is thinner adjacent to the Grenville Front as a consequence of post-Grenville orogeny extension (Ludden et al., 1993). Thinner crust is confirmed by the Metal Earth seismic profile, with the Moho located at 30-33 km depth in the Chibougamau area. Also, the Lithoprobe seismic profiles were used to interpret the Pontiac, Abitibi and Opatica subprovinces as sequences of metasedimentary and metaplutonic rocks imbricated during subduction-driven horizontal tectonics (Ludden et al., 1993).

The Chibougamau profile has similar features has those of the Abitibi Lithoprobe profiles. Besides the three distinct layers of crust that characterize all Lithoprobe profiles (Lacroix & Sawyer, 1995; Ludden et al., 1993; Percival et al., 1989), the gently northward-dipping reflectors observed in the mid-crust of the Chibougamau Metal Earth profile are similar to those observed on Abitibi Lithoprobe line 28/29/48, located 250 km to the west in the Matagami area (Bellefleur et al., 1995; Calvert & Ludden, 1999; Lacroix & Sawyer, 1995). These reflectors are thought to form by underthrusting and accretion of the Abitibi beneath the Opatica Subprovince (Calvert & Ludden, 1999). A similar interpretation of the mid-crust region can be proposed for the Chibougamau area (**Figure 6a, c**). The northern part of the Abitibi Subprovince (Matagami-Chibougamau greenstone belt) has thus probably a consistent structure over its whole length (430 km). Also, the general structure of the mid-crust is likely a consequence of the N-S shortening event that lead to collision (Lacroix & Sawyer, 1995).

The steeply-dipping faults at surface have been linked to flatter structures at depth on most Lithoprobe profiles (Ludden & Hynes, 2000). Shallow-dipping faults are also observed at surface (Lacroix & Sawyer, 1995) and may be represented by the gently-dipping reflectors that underlie the Barlow fault in the Chibougamau section (**Figure 6**). The Lithoprobe sections included an upper crust (< 6-9 km depth) characterized by listric thrusts and imbricated rock packages, a mid-crust (3-12 to 12-25 km depth) dominated by low-angle thrusts, ramps and culmination folds, and a less-reflective lower-crust (>12-25 km) with a similar structure (Lacroix & Sawyer, 1995). A similar interpretation can be proposed for the Chibougamau area (**Figure 6a**). Alternatively, the main reflectors may be interpreted as faults with limited extents locally superimposed on lithological contacts (**Figure 6b, c**).

These structures have been compared to the upper crust imbricated fan geometry observed in modern orogens (Lacroix & Sawyer, 1995). The Abitibi Subprovince, however, differs from typical high-level thrust belts by the abundance of penetrative foliation, folds and ductile-brittle faults; it has a deeper and more ductile aspect (Lacroix & Sawyer, 1995). In the light of the new seismic data, such remarks also apply to the Chibougamau area.

4.4 Implications for the geodynamic setting of the Chibougamau area

The Abitibi Subprovince represents juvenile and thickened lithospheric crust whose origin remains hotly debated. As postulated previously (Ludden & Hynes, 2000), the unique thermal regime of the Archean (Herzberg et al., 2010) may be one of the main factors that led to a crustal evolution distinct from what can be observed in modern geodynamic settings.

In that sense, the notions of 'oceanic crust', 'subduction setting' and 'orogeny', among others, as we understand it today may not be directly applicable to the Archean. For example, the Abitibi Subprovince could be viewed as an oceanic plateau resulting from mantle plume activity (Benn & Moyen, 2008), which was subducted and melted to produce TTG magmas (Martin et al., 2014). Although it is not easy to subduct oceanic plateau, there are modern examples in circum-Pacific (Bierlein & Pisarevsky, 2008). Alternatively, the basalts of the Abitibi Subprovince may have formed by partial melting of the hot ambient upper mantle rather than a plume (Herzberg et al., 2010). The Abitibi may represents a typical, >30 km thick, Archean oceanic crust that progressively evolved, through hydration, metamorphism and melting (to form TTG suites), toward a cratonic nucleus (Herzberg & Rudnick, 2012). In both scenarios, the Abitibi crust is initially thick and dominantly mafic, so these scenarios fail to explain the many distinctive features imaged on the seismic profile.

Another line of evidence is the magmatic record. In the Chibougamau area, mantle melts dominate volcanic cycle 1 (tholeiitic basalts, Lac Doré Complex) and continued during volcanic cycle 2 (Bruneau Formation, Cummings sills). There is no evidence for a depleted mantle source (i.e., no LILE- and LREE-depletion on the multi-element and REE diagrams), as is generally the case in Archean provinces (Moyen & Laurent, 2017). These type of magmas can be generated by modern plume but for the Archean period, this could also point to high degree of partial melting (30%) of a hot ambient mantle (Herzberg et al., 2010; Herzberg & Rudnick, 2012). The latter hypothesis is favored as the Chibougamau area lacks evidences of plume activity such as komatiite (Parman & Grove, 2005).

Archean geodynamic models may be divided into those that embrace the actualism principle and those that reject it. In other words, some models stipulate that ancient lithosphere behaved as today's stiff lithosphere, while others advocate for a much weaker lithosphere (Gapais et al., 2009; E Sizova et al., 2010). A subduction setting is the cornerstone of "actualistic" models, and these models typically invokes flatter subduction zones than those present today to explain the absence of a metasomatized mantle wedge in the Archean (Abbott et al., 1994; Chown et al., 1992; Kerrich & Polat, 2006). Other models stipulate that subduction tectonics began late, may be as late as the Neoproterozoic (Stern, 2005), and variants such as the 'hot subduction' model have been proposed for the Archean (Moyen & Laurent, 2018).

Assuming subduction-driven accretionary tectonics, the mid-crust region along the Chibougamau profile could be interpreted as Abitibi crust that was subducted northward beneath the Opatica Subprovince. An additional northward-directed subduction beneath the study area is required to shove hydrated basalts beneath the Chibougamau area to produce TTG melts. There is evidence of mid-crustal imbrication in the northern part of the seismic profile (**Figure 5**) but there is no evidence for a slab subducted beneath the study area. The study area also lacks typical 'arc magma'; i.e., mafic magma with calc-alkaline affinity derived from the hydrous melting of a mantle wedge. The only volcanic rocks with calc-alkaline affinities are intermediate to felsic in composition. By analogy with modern settings (Blum Oeste & Wörner, 2016; Wörner et al., 2018), these rocks may be crustal melts (hydrated basaltic source), with anatexis induced by the emplacement of mantle-derived magmas in the crust. Anatexis of the crust formed felsic melts that more or less hybridized with mafic mantle-derived melts to produce intermediate melts (Bédard, 2018). We argue that no evidence supports a modern-style subduction process in the Chibougamau area.

Other geodynamic models for the Archean period invoke mantle plume activity as the driving factor in the formation of Archean crust (Gerya et al., 2015). Superplume activity may have led to peak juvenile crust production at 2.75 Ga (Mints, 2017). Part of the crust may then have locally evolved (e.g., Abitibi area) within a subduction setting (Mints, 2017). The partial convective overturn model alternates between horizontal motions (plate tectonics) and stages of mantle plume-driven crustal reworking (Rey et al., 2003). The Archean subcretion model also invokes horizontal movement followed by the imbrication of crust that is too thick to subduct and that matures, melts and produces TTG magmas (Bédard, 2018; Bedard et al., 2013; Bédard et al., 2003). Another category of model stipulates that vertical movement dominate and that the crust and upper mantle were re-worked through convection, sinking of dense greenstone belts or diapir-type gravitational instabilities, i.e., sagduction (Chardon et al., 1996; François et al., 2014;

Van Kranendonk, 2011; Lin et al., 2013; Van Thienen et al., 2004). No evidence of vertically ‘dripping’ mafic rock packages is observed on the Chibougamau seismic profile, and the sagduction model may apply better to greenstone belts with components older than the juvenile Abitibi Subprovince.

Most of these models stipulate that TTG magmatism comes from the progressive maturation of the crust. Tonalites of TTG suites originate from partial melting of hydrated and metamorphosed enriched-basalts (Martin et al., 2014). The chemistry of TTG suites (HREE depletion, high Al-content) has indeed long been interpreted as the result of partial melting of hydrated basalts at depth, within the stability field of amphibole and garnet (Moyen & Martin, 2012). Subduction can introduce mafic rocks to a deep environment (Moyen & Laurent, 2018), as can delamination (Bédard, 2018; Bedard et al., 2013; Elena Sizova et al., 2015), while melting of the base of a thickened crust is another possibility (Van Kranendonk et al., 2015). A matter raised by the latter models is whether basalts hydrated by sea water can be buried fast enough to produce the H_2O-rich source of the TTG suite. Another matter that remains to be investigated is whether tonalites are HREE-depleted because they come from the melting of a basaltic source in the stability field of garnet (Moyen & Martin, 2012) or whether the HREE-depletion is mostly due to differentiation controlled by amphibole and apatite (Liou & Guo, 2019).

In the light of these geodynamic models and considering the lack of komatiite in the study area, we propose that it likely initiated as a normal Archean oceanic crust; i.e., as a thickened and dominantly mafic crust that formed at about, or before, 2.9 Ga (**Table 1, Figure 3**). Mantle-derived melts formed most of the crust, while the more felsic so-called “calc-alkaline” volcanic rocks can be explained by anatexis induced by the accumulation of mantle-derived melts in the mafic crust.

Geochronological data are sparse in the Chibougamau area. At the time of writing, there is no evidence for pre-volcanic cycle 2 TTG and TTD suites (**Figure 3**). Abundant partial melting of hydrated basalts located at depth may thus have initiated late, at or after 2.73 Ga, and ended at 2.71 Ga (**Figure 3**). We propose that collision with older crust to the north induced imbrication of several parts of the Abitibi Subprovince (of contrasting ages and thicknesses?), forming the mid-crustal imbrication observed on the seismic profile (**Figure 6c**). The imbrication induced rapid burial of hydrated mafic rocks, which may have rapidly de-hydrated to produce a ‘pulse’ of TTG magmatism that lasted no longer than 20 Myr. Other magmas (e.g., intermediate volcanic rocks, diorite of the TTD suites) may be explained by mixing between mantle-derived and TTG melts, implying that partial melting of mantle rocks continued but declined during volcanic cycle 2. This model implies that shortening, as well as imbrication between the Abitibi and Opatica subprovinces, started during the synvolcanic period and continued throughout the syntectonic period (so-called Kenoran orogeny). This formed faults and folds in the upper- and mid-crustal regions (**Figure 6**), while magmatic activity declined.

4.5 Metallogenic implications

The preliminary geodynamic model proposed in the previous section has several metallogenic implications. In the Chibougamau area, the main VMS mineralization is associated with the Waconichi Formation. Sea-floor mineralizing processes may have been favored by a decrease in the eruption rate, as the geodynamic setting evolved from oceanic (plateau basalt or typical Archean oceanic crust) to collisional. The VMS systems cluster around a major heat source, i.e., the Lac Doré Complex, which is equivalent to the Bell River Complex of the Matagami mining camp (Piche et al., 1993). Seismic data show no major difference between the structure of the crust of the Chibougamau and Matagami areas. The Chibougamau area is not, however, renowned for its VMS deposits, the Lemoine deposit excepted (Mercier-Langevin et al., 2014). There may be significant differences in the extent, efficiency and duration of both hydrothermal systems that cannot be explained by geodynamic contexts differences and that should be investigated by dedicated studies.

Chibougamau is however a Cu-Au mining camp known for its magmatic-hydrothermal deposits centered on the Chibougamau pluton (P Pilote et al., 1997). The imbrication of parts of the oceanic crust followed by rapid devolatilization and melting of mafic rocks to produce TTG suites, and possible mixing with mantle-derived melt to produce TTD, all seem favorable to the production of Cu-Au-bearing hydrous magmas. Magmas able to contribute fluids and metals to mineralizing systems also formed during the syntectonic period, e.g., MOP-II (Lépine, 2009) and Lac Line (Côté-Mantha, 2009) polymetallic mineralization. The lithosphere of the Chibougamau area seems particularly favorable to magmatic-hydrothermal systems. This is either due to abnormal abundance of sulfur and metals in the deep parts of the crust or underlying mantle rocks, or to favorable processes, such as intrusions emplaced at depths favorable for fluid exsolution and the initiation of hydrothermal processes.

Continued shortening during terrane imbrication caused additional burial and metamorphic devolatilization, producing fluids that induced orogenic gold-style of mineralization in the Chibougamau area (Leclerc et al., 2017). However, these are gold showings only and not deposits, possibly because no crustal-scale sub-vertical fault system comparable to the Cadillac-Larder Lake fault of southern Abitibi (Bedeaux et al., 2018) has efficiently channeled these fluids. Alternatively, an abundant source for Au, such as the Pontiac sedimentary Subprovince (Pitcairn & Leventis, 2017), is lacking in the Chibougamau area. Also, exploration for gold-only systems started recently in the Chibougamau area, and it is possible that with more exploration, more gold occurrences will be found. The supracrustal succession (potential source rocks) is thickest north of the town of Chibougamau, which could be the most prospective domain.

5 Conclusions

This contribution presents the first seismic reflection profiling of the Chibougamau area, north-eastern corner of the Neoarchean Abitibi Subprovince. The Chibougamau area shares many similarities with the Matagami area to the west, imaged by the Lithoprobe program in the 90s, suggesting that the northern part of the Abitibi Subprovince has a consistent structure and a uniform geodynamic evolution. Combining new seismic data with the known stratigraphy, structure and magmatic records of the Chibougamau area, we propose that it represents normal Archean oceanic crust that evolved into the Abitibi Subprovince through imbrication and collision with a crustal block located to the north. Subduction and other post-Proterozoic geodynamic settings are unlikely to apply to the Neoarchean period. This contribution proposes that the structure and magmatic systems of the Chibougamau crust result from horizontal shortening that induced terrane imbrication in a fashion that differs from modern-day subduction and collisional processes. Terrane imbrication induced rapid burial, devolatilization and partial melting of the mafic crust, giving raise to tonalite-dominated magmatism (TTG suite). Possible hybridization between TTG and mantle-derived melts gave rise to the TTD suite and associated Cu-Au porphyry-style of mineralization. Continued devolatilization provided conditions favorable to the development of orogenic gold-style of mineralization. The paucity of economic Au deposits in the Chibougamau area either reflects limited historical exploration efforts for Au-only systems or a lack of major fault systems and sedimentary source rocks akin to these observed in the southern part of the Abitibi Subprovince.

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Data availability: Archiving of the Metal Earth R1 seismic profile of the Chibougamau area (**Figure 5a**) in the EarthCube repository is underway. This data is also available as supporting information to this contribution.

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