Canadian Tectonic Group field workshop 2021

The Larder Lake – Cadillac fault zone and vein formation and deformation in the Abitibi greenstone belt

Rouyn-Noranda

October 1st to 3rd

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Thanks for your support!!!

UQÀM Département des sciences de la Terre et de l'atmosphère

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YORBEAU RESOURCES INC

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HARFANG EXPLORATION

Rouyn-Noranda – Val-d'Or 2021 CTG workshop

The 2021 CTG Fall workshop will be held in the Abitibi greenstone belt of Quebec, the largest and one of the best exposed Neoarchean supracrustal belts in the Superior Province. In addition to being the main source of precious metals in Canada, it has been the focus of ongoing research efforts to unveil the complex stratigraphy and tectonic evolution of the Archean Earth for over a century. The field trip will take place between the mining towns of Rouyn-Noranda and Val-d'Or, along the Larder Lake – Cadillac fault zone, which marks a tectonic boundary between the Abitibi and Pontiac subprovinces. This area has a long mining history, with dozens of base and precious metal deposits, and very well-exposed supracrustal rocks, including bimodal volcanic rocks of the Blake River Group, and alluvial-fluvial to turbiditic clastic rocks of the Timiskaming Group. The two-day field trip will focus on exceptional exposures showing : 1- the primary and secondary features, stratigraphic relationships, and polyphased deformation of the supracrustal rocks in the vicinity of the Larder Lake – Cadillac fault zone, and 2- the setting and structural controls of auriferous veins. The trip will start in the Rouyn-Noranda area, with two N-S transects across the Larder Lake – Cadillac fault zone, which will be followed by a selection of stops along highway 117 on the way to Val-d'Or. The transects will allow discussions about fault kinematics, strain gradients, superimposed folding, timing of basin formation, and Archean geodynamic evolution of the Abitibi belt. The trip will also give a glimpse of the metallogenic context and mechanisms of auriferous vein formation and deformation along the famous Rouyn-Noranda – Val-d'Or gold belt. The group will convene in Rouyn-Noranda on Friday October 1st, for a 'distanced' get together at the Flavrian outdoor resort, where accommodations will be provided for Friday and Saturday nights.

Day 1, October 2nd : The Abitibi subprovince and the Larder Lake – Cadillac fault zone

Day 1 itinerary consists of two N-S sections across the Larder Lake-Cadillac fault zone, from the Abitibi subprovince to the north, to the Pontiac Group to the south. The first section is located between Rouyn-Noranda and the small mining town of Granada. From north to south, the field stops along this section (stops 1.1 to 1.5) will start in the volcanic rocks of the Blake River Group and finish in the Timiskaming Group (Fig. 1 to 3). The second section is located 10 km to the east. It will start from the south in the sedimentary rocks of the Pontiac Group at stop 1.6 (Fig. 1 and 3), and finish 3.5 km to the north, close to the site of the past-producing McWatters mine (stop 1.9). All stops are located on Figure 4.

Day 2 : Vein formation and deformation

The day 2 of the field trip will start 5 km to the NNW of the town of Cadillac, which is located along highway 117, approximately 50 km east of Rouyn-Noranda (Stop 2.1, Fig. 1C). This first stop will allow the group to have a better look at auriferous veins and deformation in the Pontiac Group immediately to the south of the LLCfz. The rest of the stops are sites where key field relationships have been documented in order to better understand the mechanisms of vein emplacement in the Malartic-Val-d'Or gold district. The field trip will end east of Val-d'Or at stop 2.5 (Fig. 1C). There is one optional stop at the site of the Spinifex ridge komatiite outcrop zone; see Champagne et al. (2004) and Houlé et al. (2017) for details.

Geological map of the southern Abitibi greenstone belt

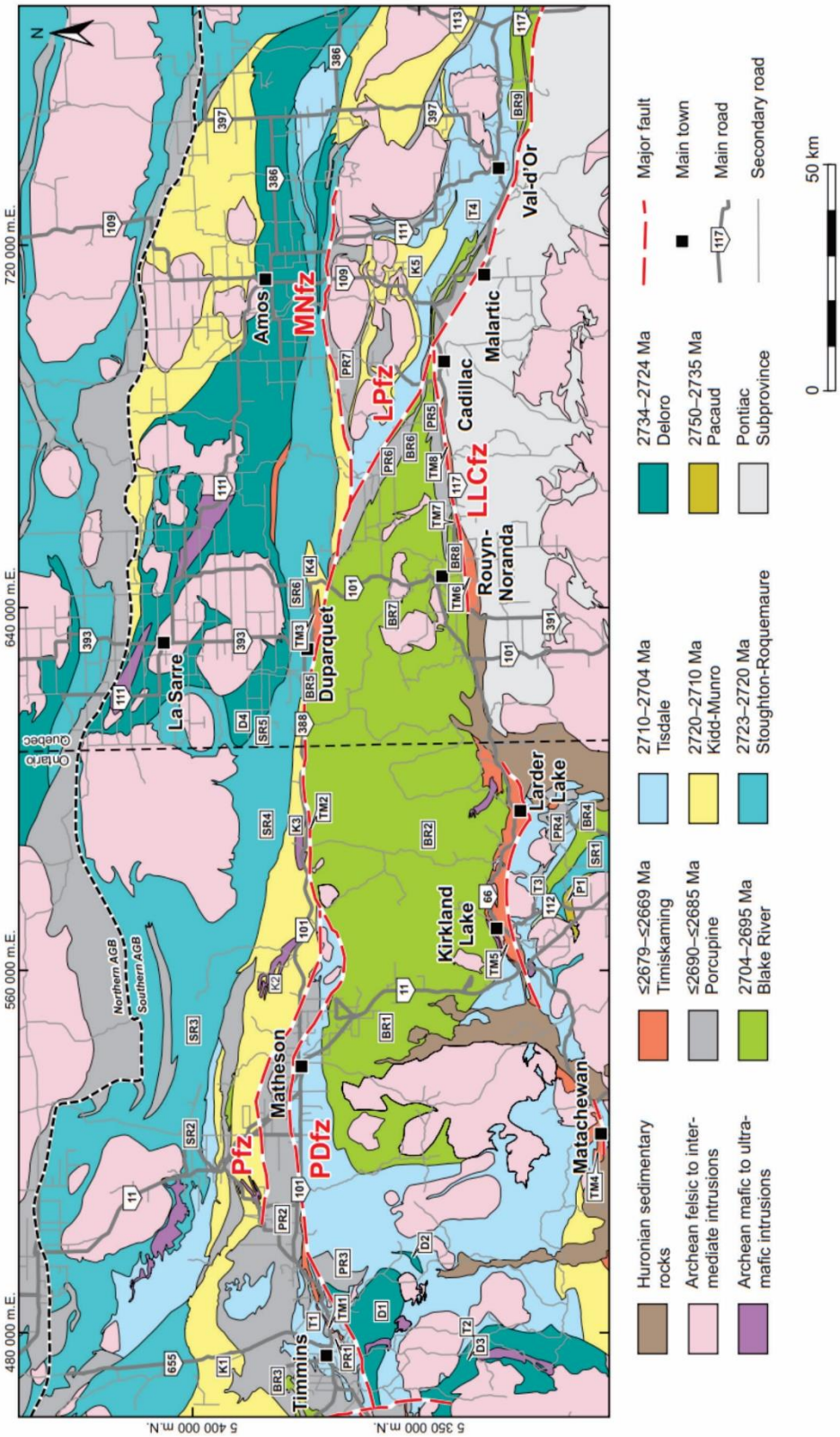


Figure 1 : Geological map of the Abitibi Greenstone belt, from Monecke et al., (2017).

Geology of the Timmins Val-d'Or gold belt

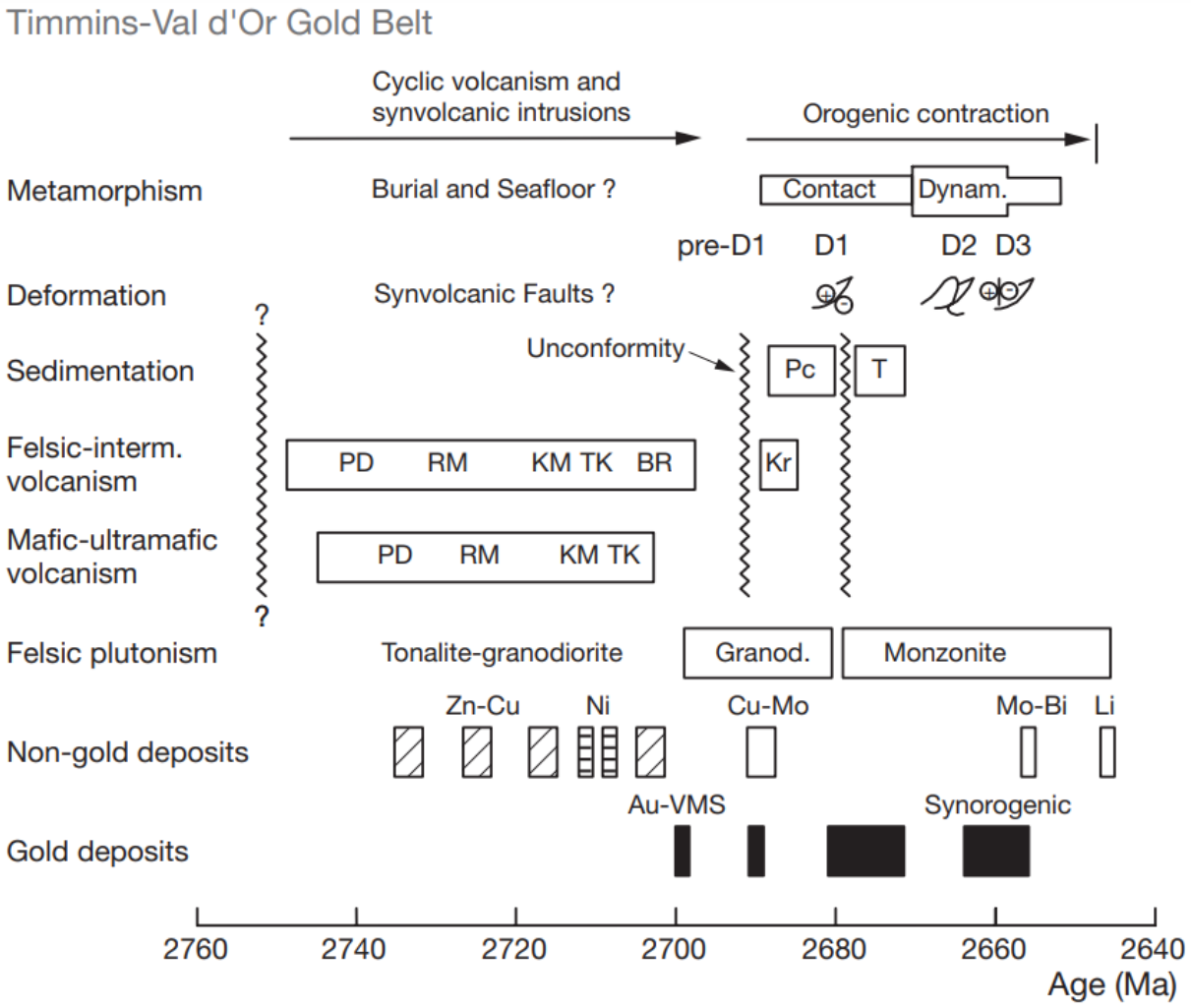


Figure 2 : Simplified tectonic and metallogenic summary of the Timmins Val-d'Or gold belt, from Robert et al. (2005). Pc – Porcupine, T – Timiskaming, Kr – Krist, PD – Pacaud and Deloro, RM – Roquemaure, KM – Kidd-Munro, TK – Tisdale – Kinojevis, BR – Blake River.

Field stop locations

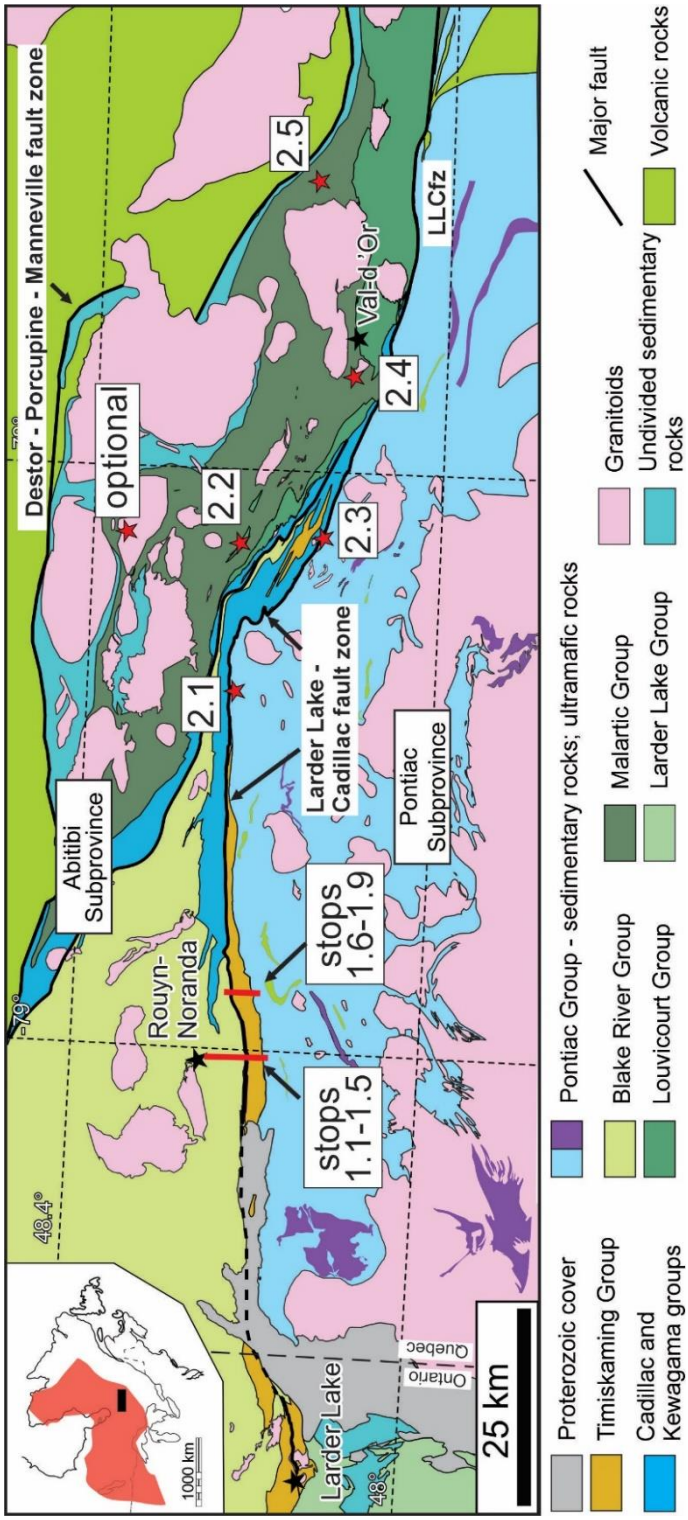


Figure 3: Modified from Bedeaux et al. (2018) and De Souza et al. (2020). The optional stop is the site of the Spinifex ridge komatiite outcrop zone; see Champagne et al. (2004) and Houlé et al. (2017) for details.

Location of Day-1 field stops

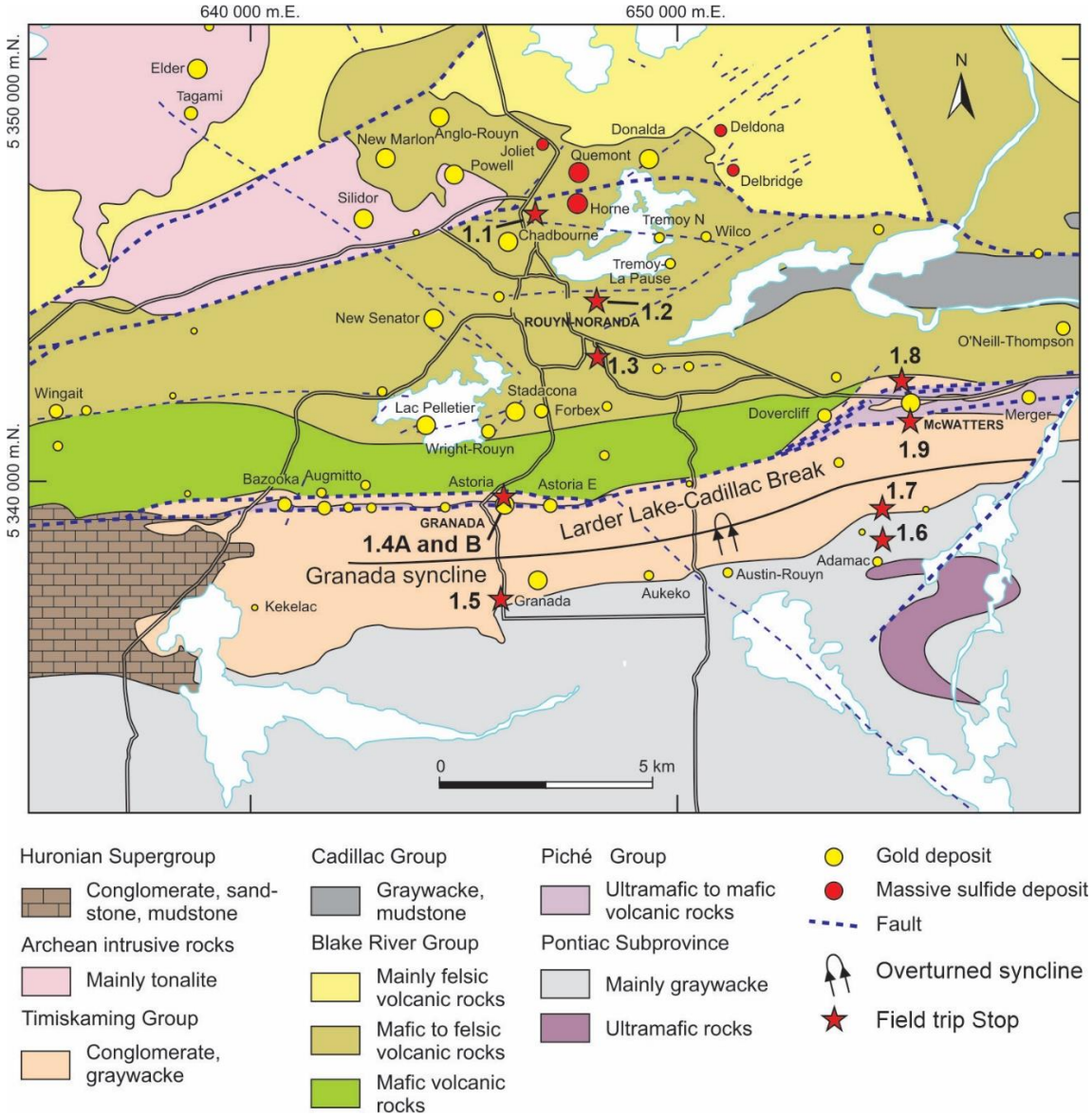


Figure 4: Geological map of the Rouyn-Noranda area. This map was modified from Poulsen (2017) to add the trace of the Granada syncline and of the day-1 field trip stops.

Day 1 : The Abitibi subprovince and the Larder Lake – Cadillac fault zone

Stop 1.1 : Horne West outcrop – Primary features in volcaniclastic rocks

UTM NAD1983 zone 17: 646 490 mE / 5 346 275 mN

The Horne West outcrop zone of stop 1.2 is located to the west (< 1 km) of the past-producing (1927-1976) Horne mine and smelter complex (Fig. 4). The Horne mine produced 260 t of gold, and 1.13 Mt of copper (Kerr and Mason, 1990), and it represents the largest Au-rich vms in the world, and one of the largest vms deposits (Dubé et al., 2007). The Horne West outcrop was mapped and described in great detail as part of the TGI program of the Geological Survey of Canada (Fig. 1.1; Monecke et al., 2008; Monecke et al., 2013). The following description is largely inspired from their work.

The north part of the stripped outcrop shows a succession of felsic volcanic and volcaniclastic rocks that belong the Blake River Group, the youngest of the volcanic assemblages in the Abitibi subprovince (Figs. 1 and 3; (2704-2695 Ma). It represents one of the best sections of the Horne mine area stratigraphy, with well preserved primary features. The detailed facies analysis has shown that the lower part of the stratigraphy consists of a flow banded rhyolite that locally contains mafic xenoliths ranging in size from few cm to over one m, generally with irregular margins. The rhyolite locally shows well developed polygonal fractures (Fig. 1.1B). A sample of rhyolite yielded a U-Pb crystallization age of 2702.2 ± 0.9 Ma, which is interpreted as a crystallization age (McNicoll et al., 2014). Hence, these felsic rocks represent some of the oldest rocks of the Blake River Group. The rhyolite is overlain by a volcaniclastic succession composed of lithic sandstone and breccia. Fragments are mainly of rhyolitic composition and some are pyrite-rich. These volcaniclastic rocks are massive to laminated with normal graded bedding that indicates younging to the north. Erosional surfaces and channels are common. Locally, cobble-size fragments set in finer grained laminated sandstone show beddings sags in the underlying layers (Fig. 1.1C), thus suggesting these fragments may have landed in non-lithified substrate, possibly as ballistic clasts. Toward the northern margin of the outcrop zone, the volcaniclastic rocks include a distinctive unit containing sulphide-rich clasts that reach up to 50 cm (Fig. 1.1D). The rocks are variably sericitized and they locally contain pinkish sub-mm garnet giving a distinctive color in altered surface. These field observations strongly suggest that the Horne West zone represents a proximal facies association, with strong potential for important VMS-style mineralization in areas surrounding the Horne mine and Horne West mineralized zone.

The site of the Horne mine and mineralized zones at depth, below the level of past underground mining, are currently the focus of an important exploration project by Ressources Falco. Figure. 1.1E shows a 3D model of the underground workings of the Horne mine, and the Horne 5 deposit. The original geometry of the Horne 5 deposit was significantly modified by stretching, shearing and transposition (Krushnisky et al. 2020) along the E-W-trending foliation also present on the Horne west outcrop. The Horne 5 deposit is estimated to contain proven and probable ore reserves of 80.9Mt at an average grade of 2.37g/t of gold-equivalent. It is estimated to contain 6.13 Moz of gold-equivalent (Ressources Falco; https://www.falcores.com/fr/).

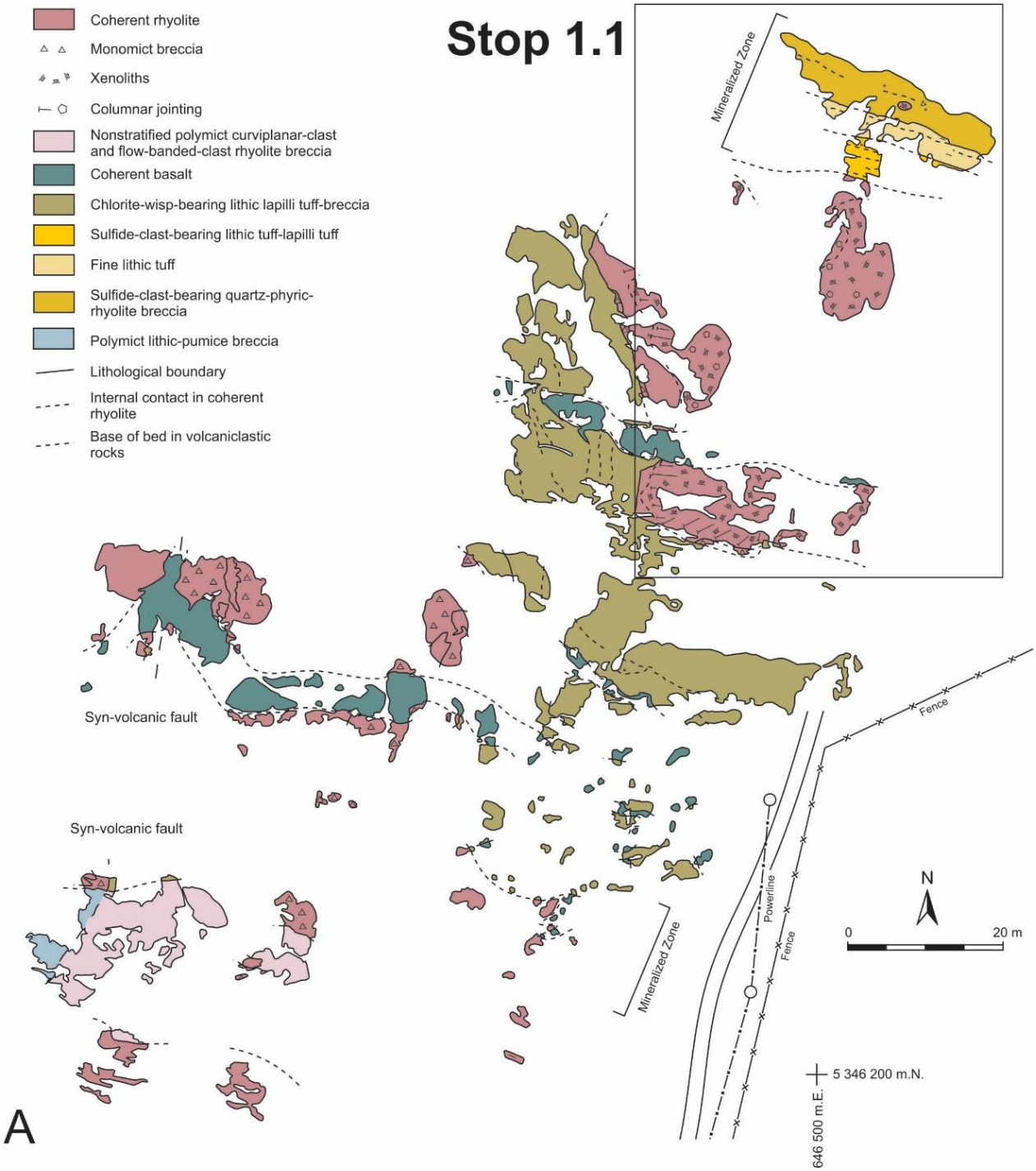
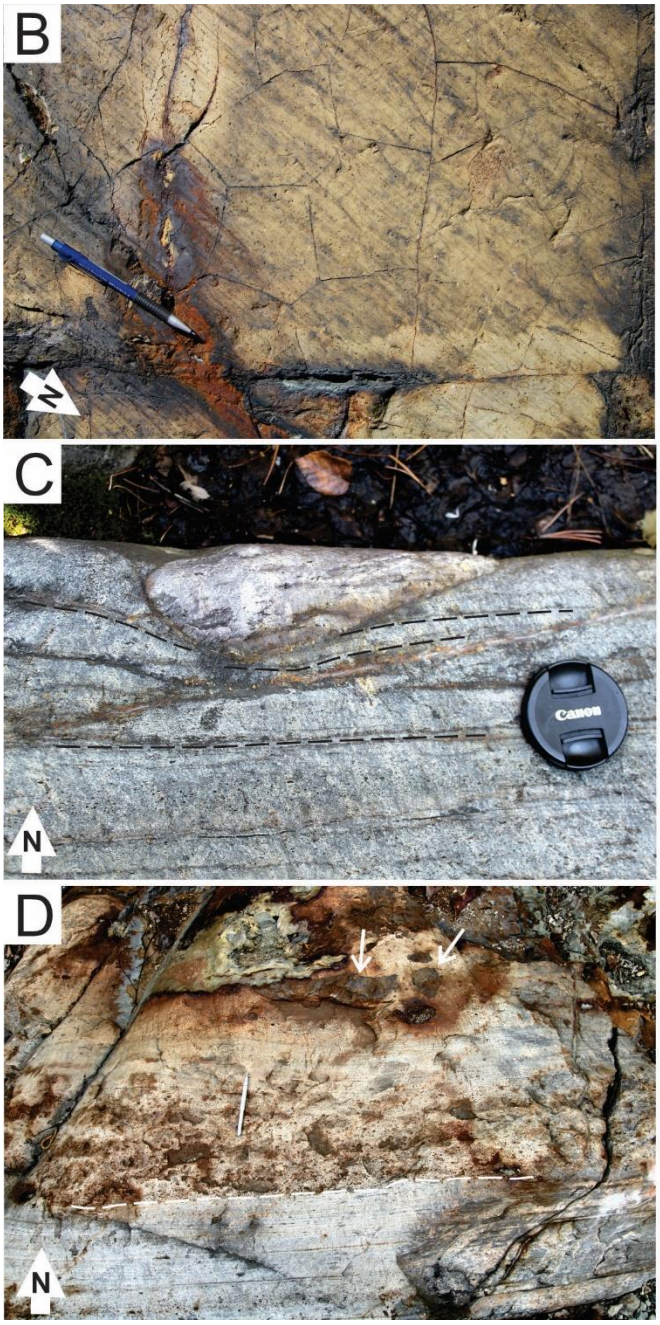


Fig. 1.1: A) Geologic map of the Horne West outcrop zone, modified from Monecke et al. (2017). Stop 1.1.



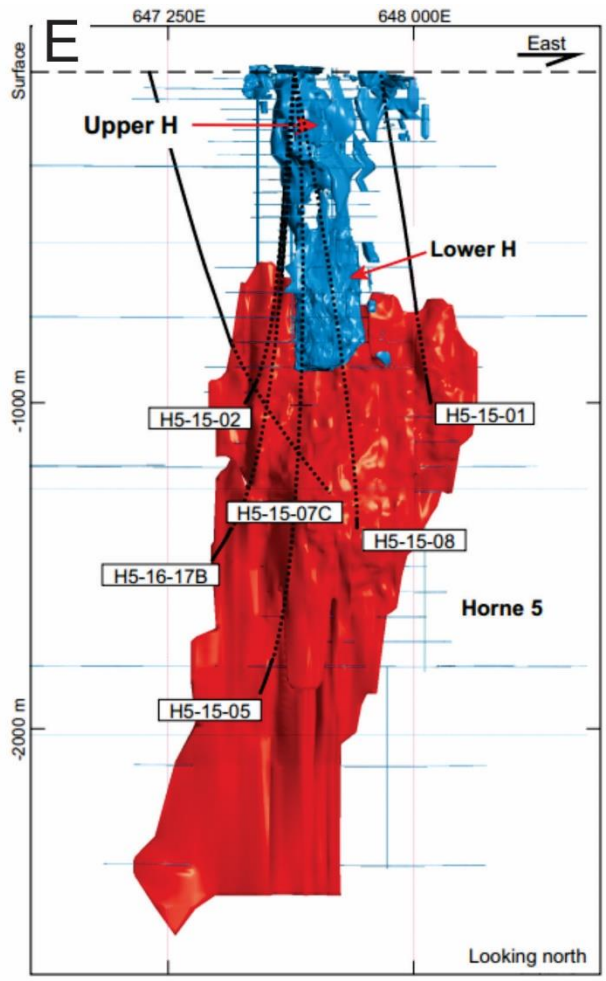


Fig. 1.1: Continued B) Columnar jointed rhyolite; C) Volcaniclastic rock with felsic clast showing sag structure in underlying sandstone; D) Massive sulphide clasts (white arrows) in normally graded felsic volcaniclastic rock younging to the north; E) 3D model of the Upper H and Lower H Horne mine workings (blue) and the Horne five deposit (red), from Krushnisky et al. (2020).

Stop 1.2 : Cap d'Ours –Rhyolite breccia of the Blake River Group

UTM NAD1983 zone 17: 648 150 mE / 5 344 200 mN

Cap d'Ours is a large outcrop zone located in the town of Rouyn-Noranda (Fig. 4). It exposes rhyolitic rocks of the Glenwood volcanic complex, which belongs to the Rouyn-Pelletier Formation. This outcrop zone was described by Gauthier (1980), Tassé et al. (1982), and more recently by Genna (2009), and Moore (2015). The volcanic complex mainly consists of monomictic fragmental rhyolite interpreted as autoclastic flow breccia, and of a massive lobate facies with distinct flow banding (Fig. 1.2A). The flows are intruded by quartz-phyric rhyolite dikes interpreted as endogenous dome facies (Genna, 2009; Moore et al., 2014; Moore, 2015). Two samples from the felsic dikes yielded U-Pb zircon crystallization ages of 2701.9 ± 1.4 Ma and 2702.2 ± 3 Ma

(Mueller et al. 2012). Along its eastern margin, the Glenwood volcanic complex is bounded by a swarm of NE-trending dikes, which are interpreted to mark the synvolcanic Glenwood fault. The Glenwood volcanic complex is thought to have formed on the margin of the New Senator caldeira, one of the caldeira complexes of the Blake River Group (Mueller et al., 2012). The volcanic rocks and dikes are affected by a penetrative ENE-trending foliation and a moderate to strong subvertical stretching lineation. The contact between the rhyolite dikes and flows is folded (Fig. 1.2B), and shows that, although very well-preserved, primary volcanic features have been modified during regional deformation.

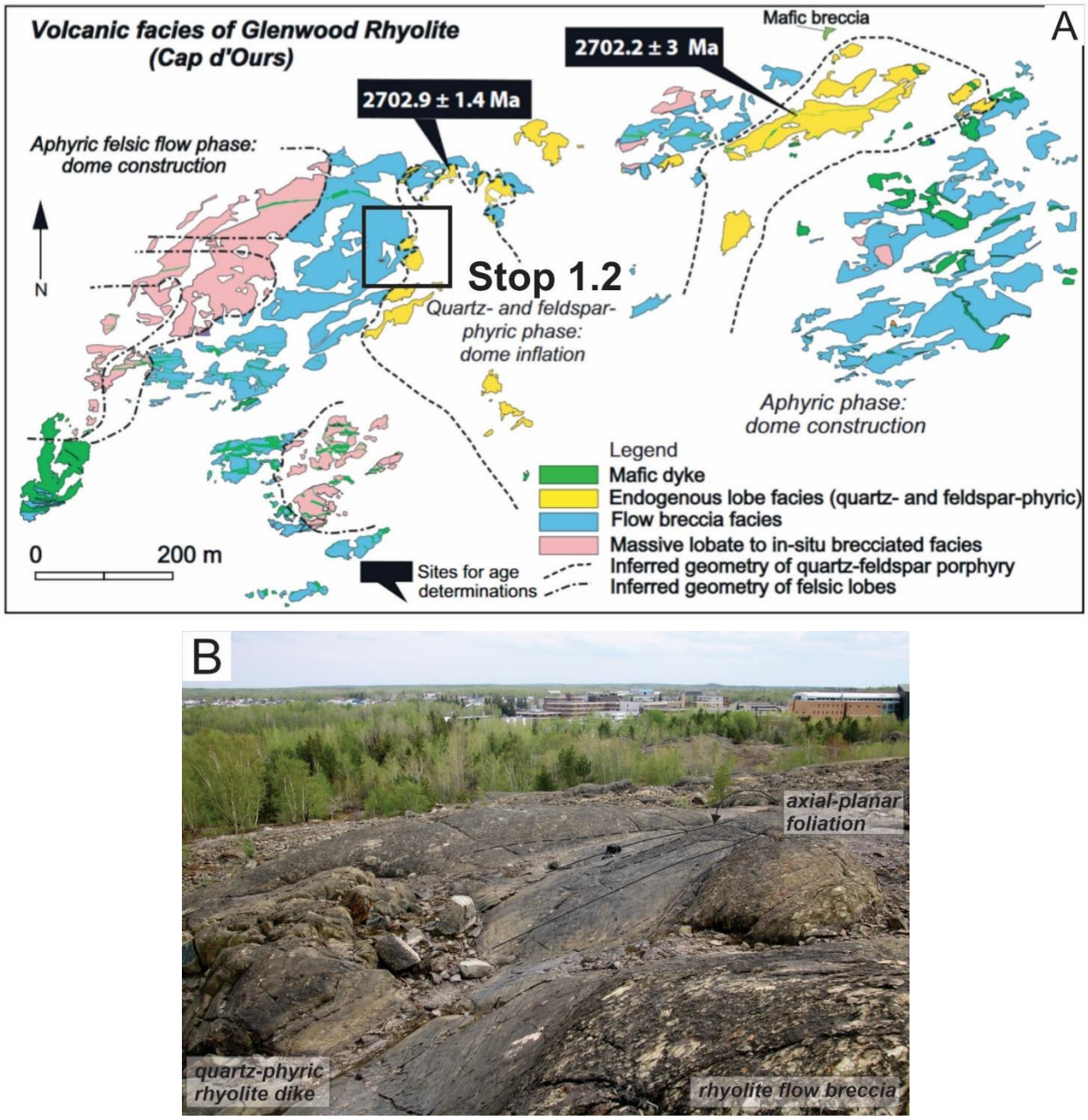
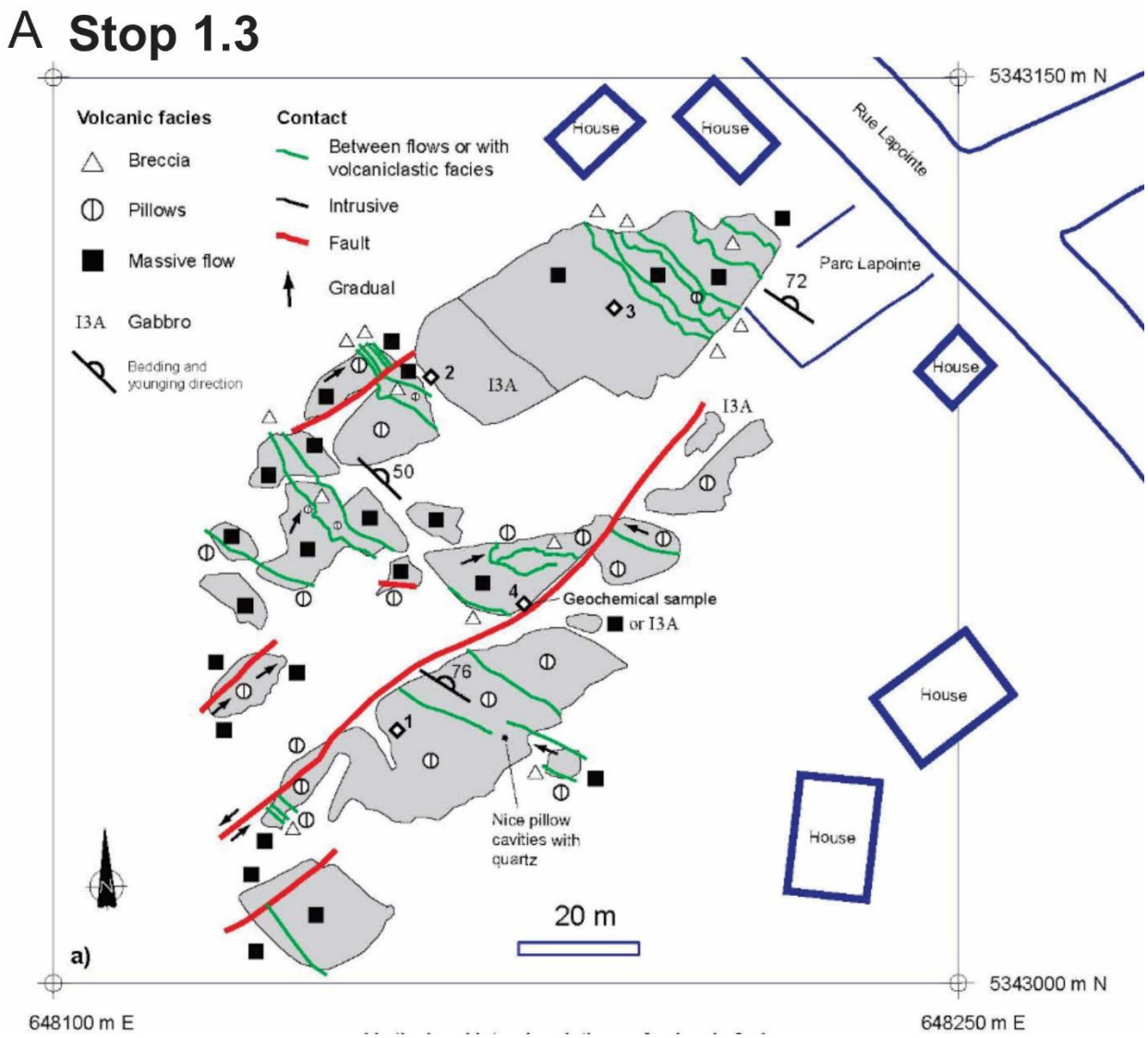


Fig. 1.2: A) Geologic map of the Cap d'Ours outcrop zone; from Mueller et al. (2012); B) Folded contact between rhyolite flow breccia and crosscutting quartz-phyric rhyolite dike. Stop 1.2.

Stop 1.3 : Parc Lapointe – Basaltic flows of the Blake River Group

UTM NAD1983 zone 17: 648 170 mE / 5 343 045 mN

The parc Lapointe outcrop zone shows excessively well preserved mafic volcanic flows and volcaniclastic rocks. Goutier (2017) provided a brief summary and a geological map of the outcrop zone (Fig. 1.3A). They are metamorphosed at sub-greenschist facies and were used by Dimroth et al. (1978) to define the architecture of Archean mafic flows of the Blake River Group (Fig. 1.3B). Complex flow units show a massive base that grades laterally and vertically into pillowed flows, breccia and hyaloclastite (Fig. 1.3C-D). Coarse to fine grained gabrro sills are also present. The flows are NW-striking, steeply dipping and younging toward the NE, as indicated by pillow morphology, flow-top breccia and nicely preserved pillow cavities (Fig. 1.3E). The outcrop zone is located in a regional E- to NE-trending fold hinge zone. Discrete m-thick shear zones are developed at high angle to the flows and these shears mark discontinuities in the individual flow units.



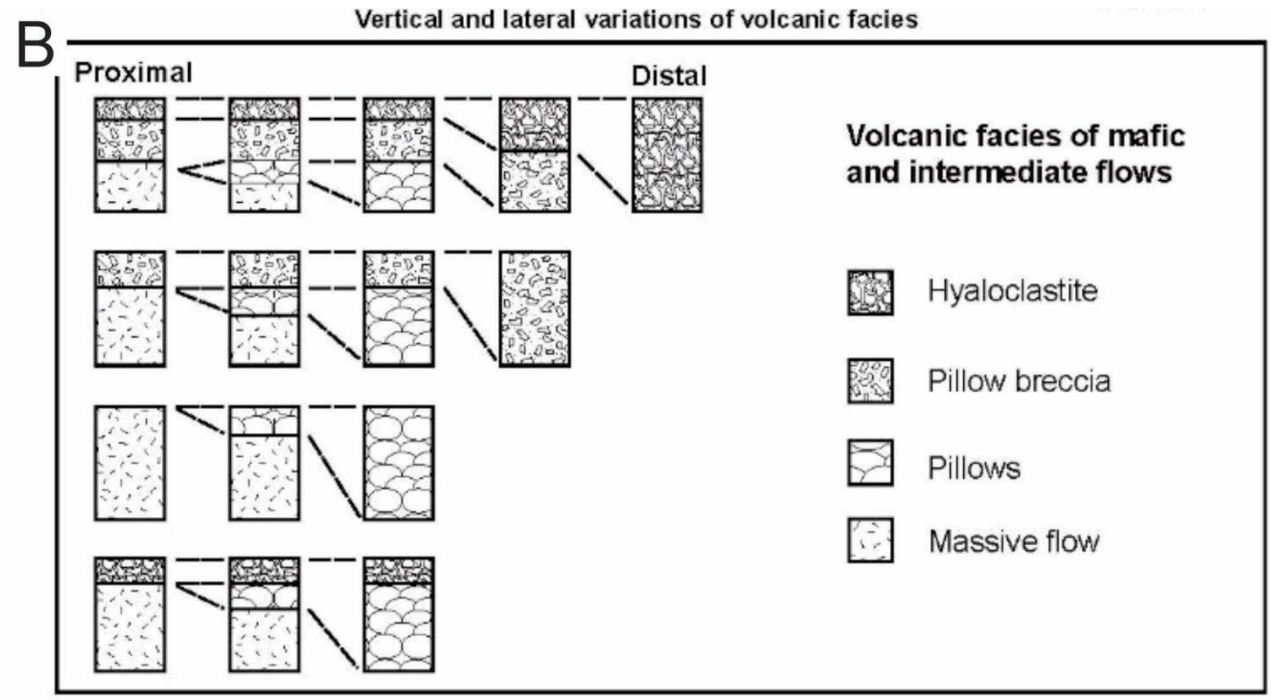


Fig. 1.3: A) Detailed outcrop map of basaltic lava flows at parc Lapointe, from Goutier (2017); B) Vertical and lateral facies variation of the flows, from Goutier (2017), after Dimroth et al. (1978); C) hyaloclastic breccia at flow top and overlying massive flow; D) detail of hyaloclastic breccia with cuspate fragments; E) stacked intrapillow cavities. Stop 1.3.

Stop 1.4 : Granada – Astoria mine site and the Larder Lake – Cadillac fault zone

The Astoria mine site is located in the small mining town of Granada to the south of Rouyn-Noranda (Fig. 4). It exposes mineralized veins and contact relationships across the Larder Lake – Cadillac fault zone (LLCfz; Fig. 1.4A). The site is relatively well known, since it was previously described and mapped by Wilson (1962), Goulet (1978), Gauthier et al. (1990), Diop (2011), Poulsen (2017), Bedeaux (2018) and Chapon (unpublished data). This stop is subdivided into two main outcrop zones, 1.4A and 1.4B. The former shows the contact zone between the Blake River and Timiskaming groups. The second exposes the auriferous quartz-carbonate veins and breccias of the Astoria gold deposit, as well as mafic to ultramafic volcanic rocks of the Piché Group and bounding faults. The site is currently part of a flagship exploration project operated by Yorbeau Ressources.

The Granada-McWatters area, and specifically the site of the Astoria mines, exhibits key relationships to interpret the chronology of deformation events in this part of the Abitibi greenstone belt. As presented below, field observations indicate that volcanic rocks of the Abitibi subprovince may have undergone deformation prior to, and after the sedimentation of the Timiskaming Group. Hence, these clastic sedimentary rocks and the underlying unconformity can be used to establish a relative chronology of structures. In the sections that will follow, D_1 will refer to structures formed prior to the deposition of the Timismkaming Group. D_2 refers to the penetrative schistosity or cleavage that is mostly oriented E-W and contains a moderate to strong down-dip stretching lineation. We will also note that at least two generations of crenulations and related folds are superimposed on D_2.

1.4 A : Blake River – Timiskaming contact zone

UTM NAD1983 zone 17: 645 960 mE / 5 340 054 mN

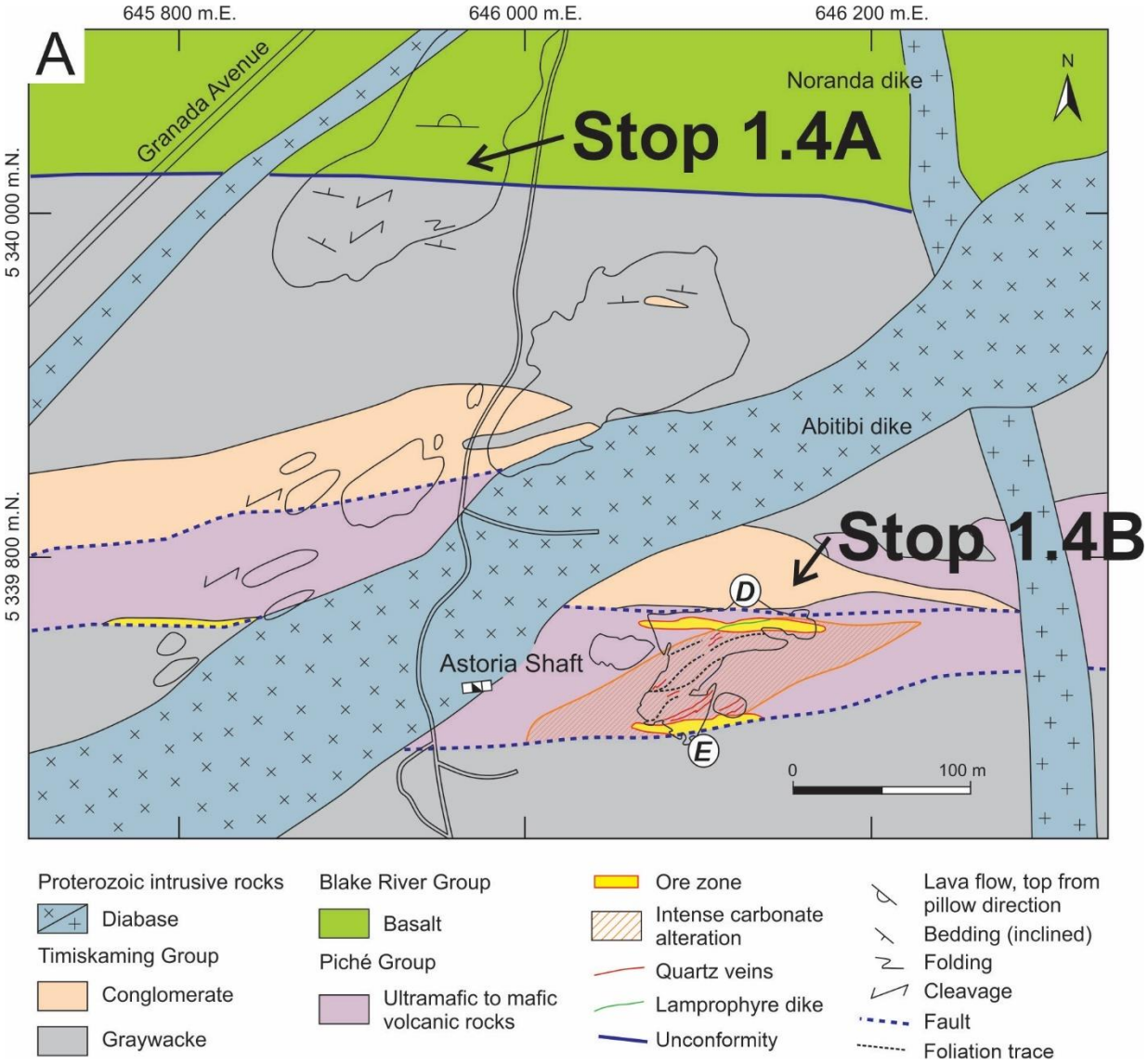
Stop 1.4A is located on a prominent hill, approximately 50 m west of the trail leading to Stop 1.4B. There, the volcanic rocks of the Blake River Group are mainly represented by pillowed basaltic flows and volcanic breccia. Although the rocks are highly strained, unequivocal north-directed younging of the volcanic pile is determined based on the morphology of the pillows (Fig. 1.4B). To the south, turbiditic graywacke and siltslate of the Timiskaming Group are in sharp contact with volcanic breccia of the Blake River Group. South of this contact the sedimentary rocks show graded bedding and refracted cleavage clearly indicating that the sedimentary succession is younging toward the south (Fig. 1.4C). The relationships across the contact zone suggest that it represents an unconformity, and that the volcanic rocks of the Blake River Group were deformed prior to the sedimentation of the Timiskaming Group. Light grey quartz veins in the turbidites are subparallel to a penetrative S_2 foliation, and both are overprinted by an E- to NE-striking crenulation cleavage that is axial-planar to asymmetric Z-type folds.

1.4B : Larder Lake – Cadillac fault zone (LLCfz)

UTM NAD1983 zone 17: 646 110 mE / 5 339 770 mN

Stop 1.4B is a large stripped outcrop on the LLCfz and the auriferous vein system of the Astoria gold exploration project. The north part of the outcrop shows highly strained polymictic conglomerate of the Timiskaming Group in contact with strongly foliated mafic-ultramafic volcanic rocks of the Piché Group (Fig. 1.4D). The volcanic rocks were variably altered to carbonate-chlorite-talc and are locally fuchsitic.

Sedimentary rocks of the Timiskaming Group also occur to the south of the Piché Group, but are instead composed of finer grained conglomerate, sandstone and mudrock. Both the northern and southern contacts of the Piché Group are faulted and north-dipping. The foliation in the mafic-ultramafic rocks is oriented NE to NNE and is oblique to the northern and southern contacts. At the scale of the outcrop, the trace of the foliation defines a sigmoidal shape. A down-dip stretching lineation is well developed in the Timiskaming Group to the south (Fig. 1.4E). However, shallow-plunging slickenlines and numerous shear bands indicating a dextral sense of shear are widespread in the ultramafic rocks (Fig. 1.4F). Also, conglomerates located along the northern contact display clear evidence of dextral shearing (Fig. 1.4G). The site of the Astoria mine is a good example of the quartz-pyrite-arsenopyrite auriferous veins and breccias developed in association with strongly carbonatized mafic and ultramafic rocks along the LLCfz. The two main mineralized zones are located in the Piché Group, close to its northern margin, and along its southern contact with the sedimentary rocks, which are also locally mineralized (Fig. 1.4A). Mafic Proterozoic dikes are locally associated with contact metamorphism.



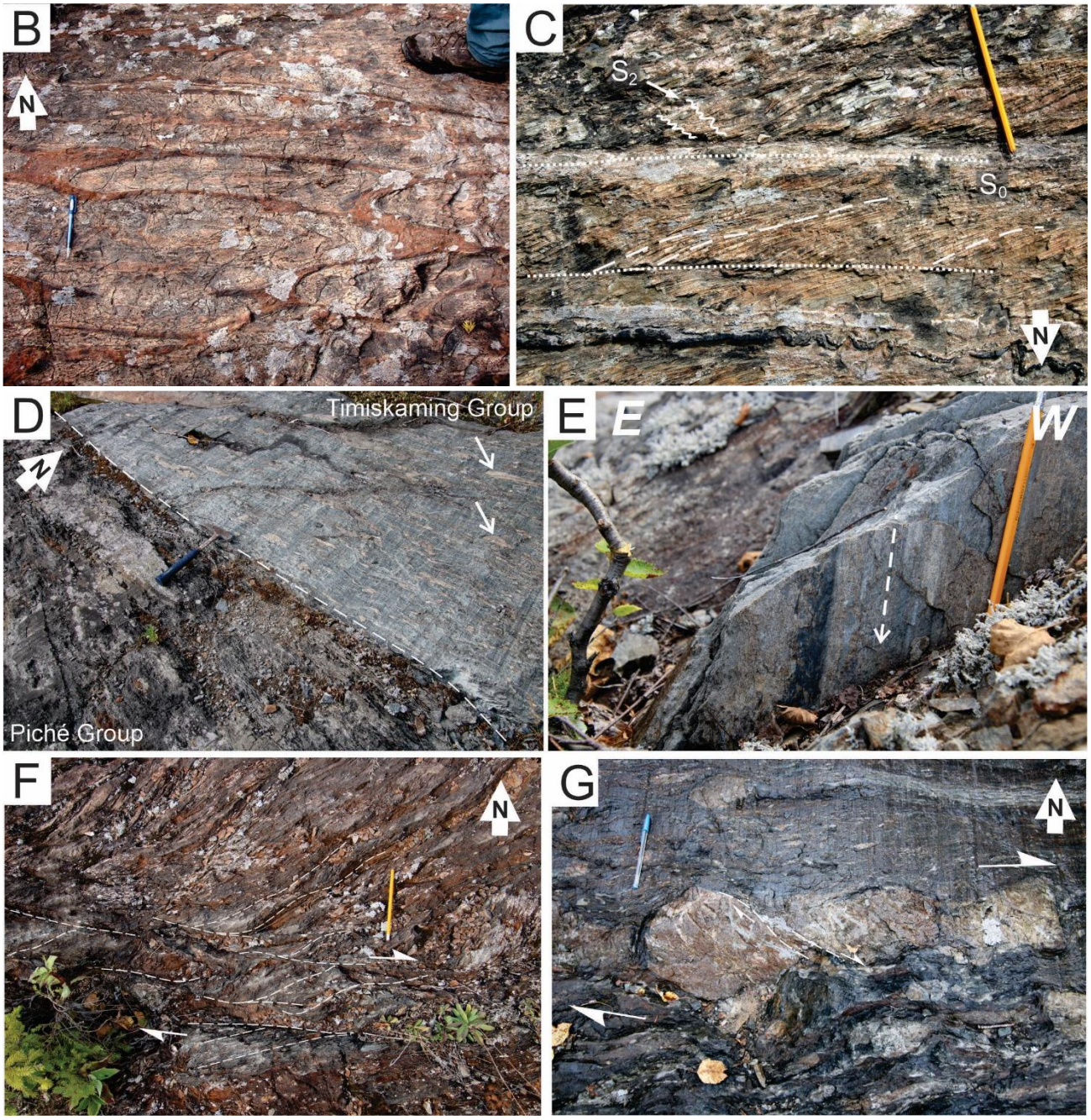


Fig. 1.4: A) Geological map of the Astoria mine area; the map was modified from Poulsen (2017), after Wilson (1962), Goulet (1978) and Gauthier et al., (1990). Note the position of photos D and E; B) Flattened pillow basalts of the Blake River Group, with younging to the north; C) Turbidite in which S_2 (crenulate line) is strongly affected by a north-trending crenulation cleavage that is refracted (stippled line) and indicates younging to the south. D) Faulted hangingwall contact between Timiskaming Group conglomerate (north) and Piché Group (south); white arrows point at clasts; E) Down-dip stretching lineation in conglomerate of the Timiskaming Group (Granada Formation), immediately to the south of the Piché Group; F) Dextral shear bands in hydrothermally (ankerite-talc-chlorite) altered ultramafic rocks of the Piché Group; G) Dextral sense of shear indicated by shear band-type boudin in Timiskaming Group conglomerate. A-C are for stop 1.4A, and D-G are for stop 1.4B.

Stop 1.5 : Granada road cut – Timiskaming conglomerate in shear zone

UTM NAD1983 zone 17: 646 000 mE / 5 337 695 mN

Stop 1.5 is a roadside outcrop located in the Timiskaming Group (Fig. 4), in a unit of clast-supported polymictic boulder conglomerate belonging to the Granada Formation (Fig. 1.5A). The Granada Formation is preserved in a south-verging overturned syncline located to the south of the LLCfz (Goulet, 1978; Daigneault et al., 2002; Diop, 2011). This major structure is defined as the Granada syncline and has been recognized over a strike length of at least 20 km (Fig. 4). Stop 1.5 is located close to the southern margin of this structure, and to the contact with the Pontiac Group to the south.

At stop 1.5, the foliation is moderately dipping to the north and clasts are variably flattened and stretched depending on their composition and texture. Primary sedimentary structures are not preserved and some of the clasts show evidence of shearing, including symmetric and asymmetric strain shadows (Fig. 1.5B), boudinage, and sigmoidal clasts. Locally, clasts appear to be affected by a slight antithetic rotation and synthetic shear fractures suggesting a reverse sense of shear (Fig. 1.5C). This is consistent with sparse shallow dipping extensional quartz veins, the regional correlation of this shear-related fabric with S_2 and steeply plunging isoclinal F_2 folds suggesting a N-S compression. Nevertheless, a definite interpretation of shear sense is complicated by the heterogeneous nature of the conglomerate. Daigneault et al. (2002), Diop (2012) and Bedeaux et al. (2017) have interpreted this outcrop as an extensional shear zone related to the late uplift of the Pontiac Group relative to the Abitibi subprovince in the hanging wall.

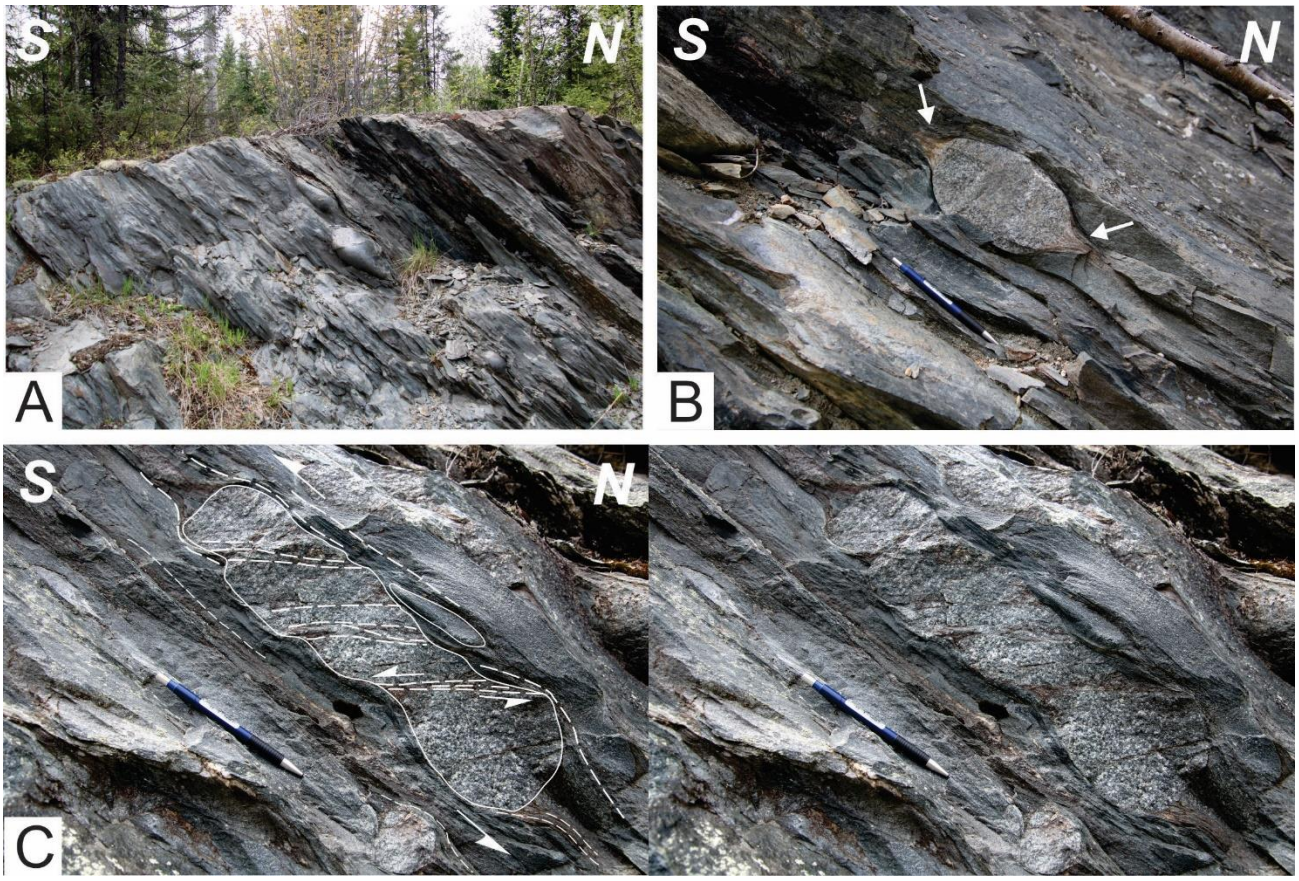


Fig. 1.5: A) Deformed Timiskaming Group conglomerate of the Granada Formation along the southern margin of the Granada syncline; B) Strain shadows associated with a deformed clast; C) left : annotated photograph of deformed clast with shear fractures indicating a reverse sense of shear; right : initial photograph. Stop 1.5.

Stop 1.6 : Polyphased deformation in the Pontiac Group

UTM NAD1983 zone 17: 654 980 mE / 5 338 726 mN

This outcrop is relatively small and was recently exposed on the roadside (Fig. 4). It consists of phyllitic metasedimentary rocks attributed to the Pontiac Group. It shows tight, east-trending folds with an axial-planar foliation that overprints a penetrative N-S schistosity (Fig. 1.6B). The style of folding and associated fabrics is reminiscent of the first phase of deformation that postdates the Timiskaming Group, and is defined herein as D_2. This could imply that the earlier schistosity represents an early phase of deformation and metamorphism that predates the Timiskaming sedimentation and therefore correlates with D_1 deformation. The Pontiac Group, between the Quebec-Ontario border and the Malartic-Val-d'Or area, shows evidence of folding and of a penetrative metamorphic fabric that predates the S_2 schistosity and associated F_2 folds. This was also suggested by Goulet (1978), Sansfaçon (1986), Camiré and Burg (1993), De Souza et al., (2015, 2017), Perrouty et al. (2017), and Rehm et al. (2021). This interpretation would imply that the Pontiac Group was deformed and metamorphosed shortly after its deposition (ca. 2685-2682 Ma; Davis, 2002), prior to the deposition of the Timiskaming Group (≤2679 Ma; Monecke et al., 2017).

– By the way, say hi to the gnomes, they are busy fishing, taking selfies, and painstakingly guarding the outcrop (Fig. 1.6B) –

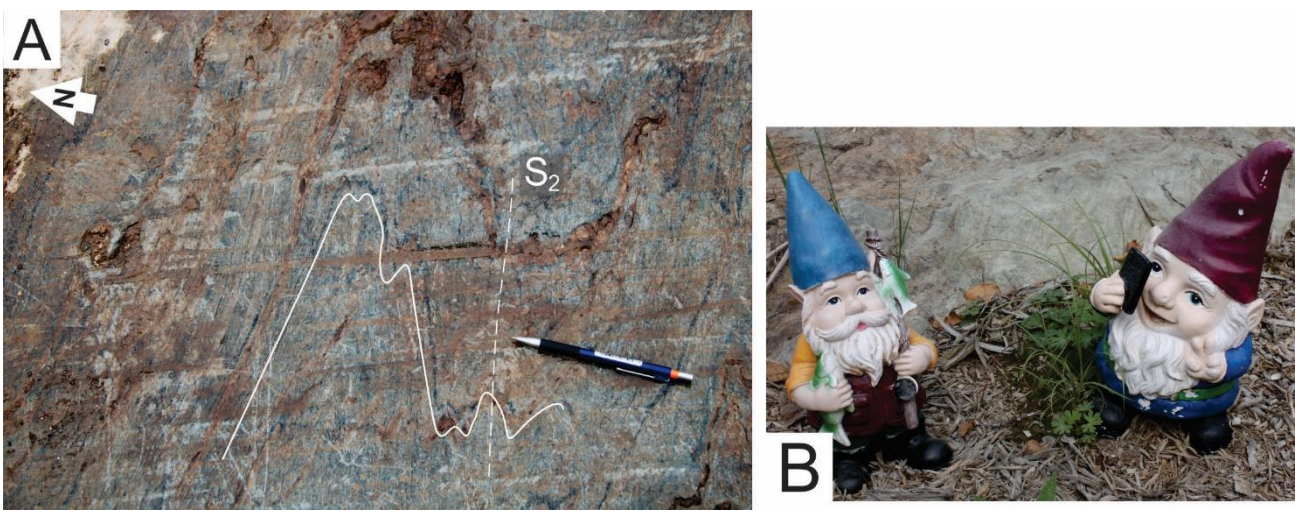


Fig. 1.6: A) Phyllitic metasedimentary rocks of the Pontiac Group showing an early N-S schistosity (full line) that is tightly folded by east-trending F_2 folds and related axial-planar fabric (S_2; stippled line); B) company for your rock observation.

Stop 1.7 : Lineated Timiskaming conglomerate

UTM NAD1983 zone 17: 654 890 mE / 5 339 600 mN

As for stop 1.5, this outcrop is located along the southern margin of the Timiskaming Group, less than 20 m to the north of the contact with the underlying Pontiac Group (Fig. 4). At this site, the Timiskaming Group is represented by highly strained clast-supported polymictic conglomerate. The clasts are flattened, but they

are also stretched, with an aspect ratio that exceeds 10 : 1, even for the more competent clasts consisting of granitoid (Fig. 1.7A). The stretching lineation is down-dip and contained within the north-dipping S_2 foliation, which is tightly folded, and crenulated by a shallowly dipping crenulation cleavage (Fig. 1.7B).

Outcrops of stops 1.5 and 1.7 both indicate that this contact zone between the Timiskaming and Pontiac groups is a complex deformation zone. Nevertheless, regional stratigraphic and structural relationships in the McWatters-Granada area are consistent with the southern margin of the Granada Formation representing a a shear zone possibly developed along an unconformity where strain was subsequently partitioned during N-S shortening.

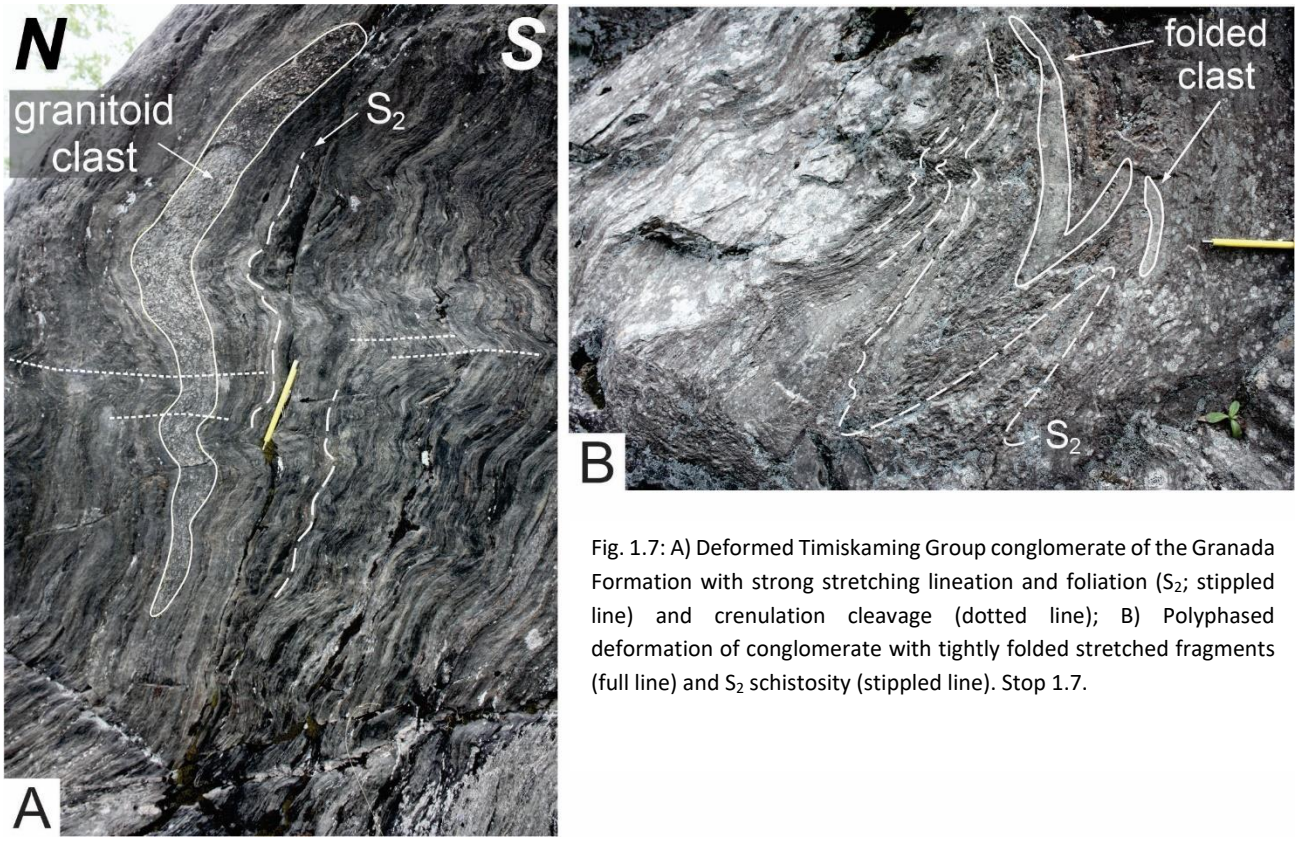


Fig. 1.7: A) Deformed Timiskaming Group conglomerate of the Granada Formation with strong stretching lineation and foliation (S_2; stippled line) and crenulation cleavage (dotted line); B) Polyphased deformation of conglomerate with tightly folded stretched fragments (full line) and S_2 schistosity (stippled line). Stop 1.7.

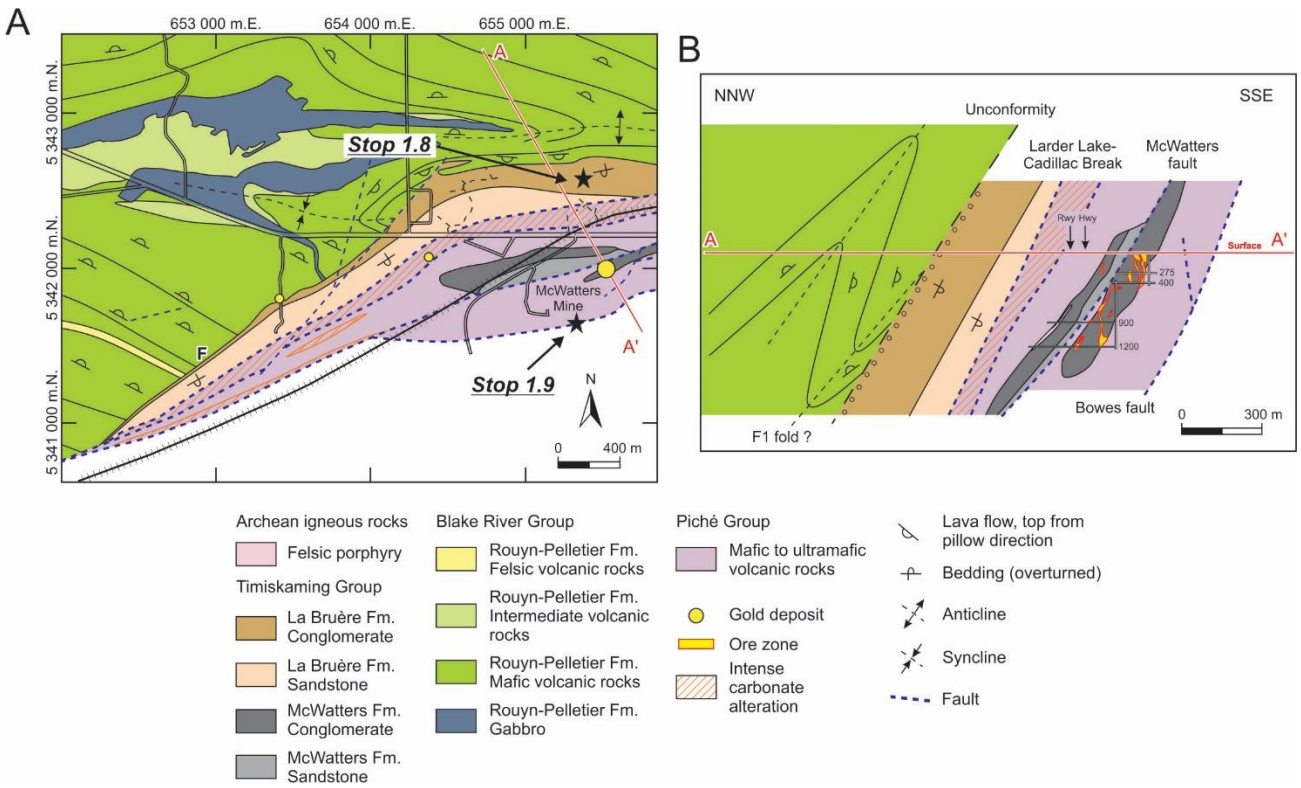
Stop 1.8 : McWatters north : The Timiskaming conglomerate of the La Bruère Formation

UTM NAD1983 zone 17: 655 380 mE / 5 342 520 mN

McWatters is a small mining town along highway 117. The McWatters mine produced gold from quartz veins located within the LLCfz. A good summary of the outcrop zone and surrounding area is given by Poulsen (2017; Fig. 1.8A and B) and Jébrak et al. (1991; Fig. 1.8C). The mineralized veins are mainly hosted in conglomerate of the McWatters Formation, which consists of mafic to ultramafic rocks, sandstone and conglomerate (Wilson, 1948; Jébrak et al., 1991). Poulsen (2017) correlated the volcanic rocks of the McWatters Formation with those of the Piché Group (Fig. 1.8A). To the north of the McWatters Formation, detrital sedimentary rocks of the Timiskaming Group belong to the La Bruère Formation. It consist of a lower unit of channelized

polymictic clast-support conglomerate that forms a fining-upwards succession with interlayered sandstone and siltslate toward the summit. The conglomerate comprises a wide variety of clasts, including jasper, iron formation, felsic volcanic and intrusive rocks, mafic rocks, as well as fuchsite-bearing lithologies (Fig. 1.8D). The conglomerate and sandstone show graded bedding and cross-bedding, all indicating younging towards the south (Fig. 1.8E). The upper turbiditic graywacke unit of the La Bruère Formation is poorly exposed on the site of stop 1.8.

The lower contact of the La Bruère Formation with the basaltic units of the Blake River Group (Rouyn-Pelletier Formation) to the north is locally exposed on a small outcrop located approximately 700 m to the WNW of stop 1.6 (Goutier and Poulsen, 2012). As mapped by Wilson (1948), Côté (1975), Goulet (1978), Jébrak et al. (1991), Goutier and Poulsen (2012) and Poulsen (2017), the contact corresponds to an angular erosional unconformity. The bedding is overprinted by a moderately north dipping S_2 cleavage that contains a down-dip stretching lineation. The bedding-cleavage relationship indicates that much of the outcrop zone is located on the overturned limb and hinge zone of a shallowly plunging F_2 fold overturned toward the south (Fig. 1.8C). Walking southward from stop 1.8, over approximately 100 m, the conglomerate is increasingly strained, ankeritized and medium gray quartz veins become abundant along the faulted south margin of the La Bruère Formation. The increasing strain, hydrothermal alteration and presence of quartz veins are indicative of the strain gradient and auriferous hydrothermalism associated with the LLCfz.



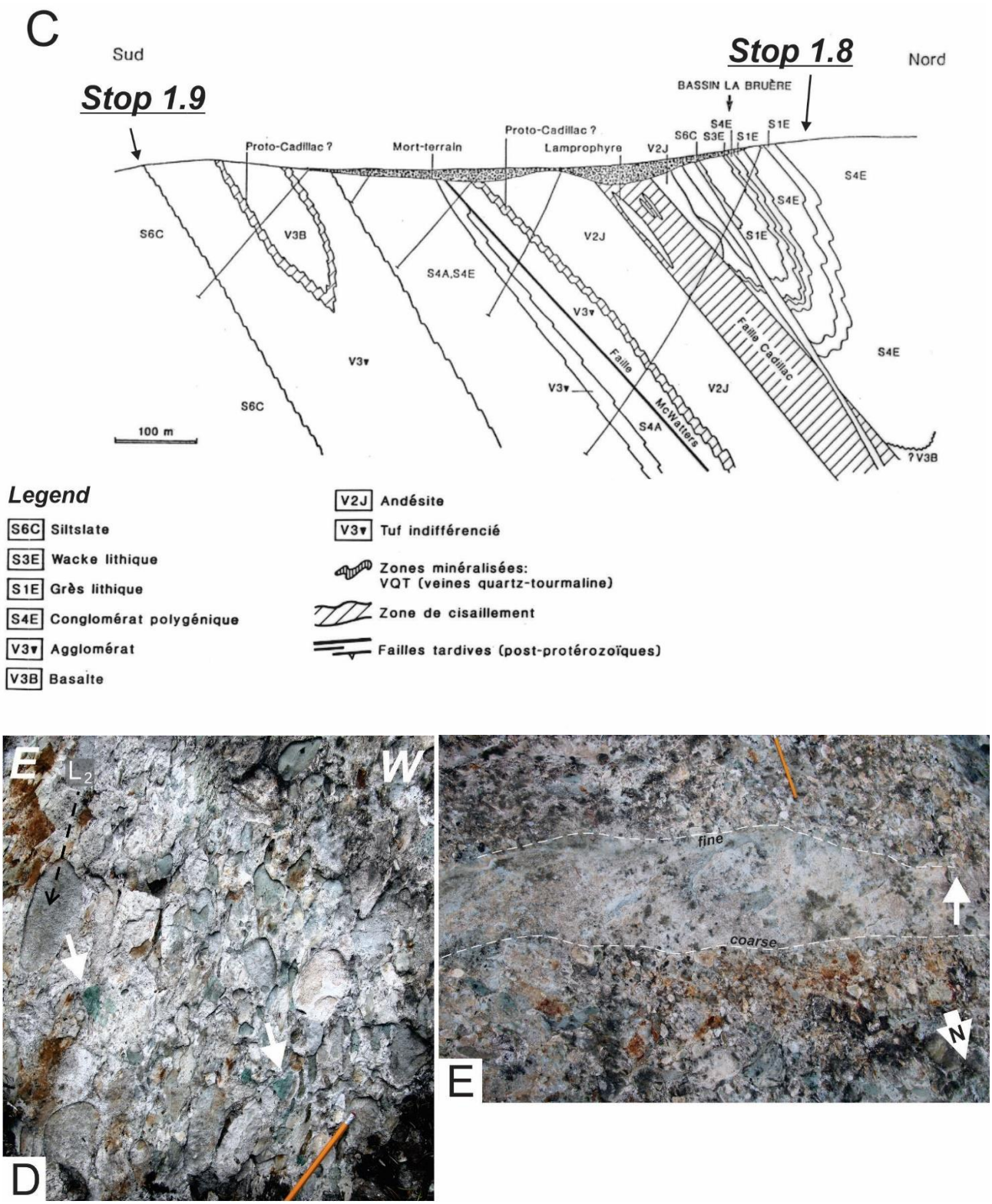


Fig. 1.8: A) Geological map of the McWatters area; modified from Poulsen (2017); Note the position of stops 1.8 and 1.9; B) Cross section of the McWatters area (From Poulsen, 2017); C) Detailed section of the McWatters deposit showing the position of stops 1.8 and 1.9; Modified from Jébrak et al. (1991); D) Polymictic conglomerate of the Timiskaming Group (La Bruère Formation) with fuchsitic clasts (white arrow) and moderate stretching lineation (stippled black arrow); E) Lenticular graded lithic sandstone in conglomerate; younging direction is indicated by the white arrow. Stop 1.8.

Stop 1.9 : McWatters trench – Bowes fault zone and superimposed folding

UTM NAD1983 zone 17: 655 560 mE / 5 341 780 mN

To the south of highway 117, and of the McWatters mine site, a stripped outcrop exposes the Bowes fault, which corresponds to the southern contact of the McWatters Formation to the north, with polydeformed turbiditic graywacke and siltstone to the south (Fig. 1.8C). Along the fault, ultramafic rocks of the McWatters Formation are strongly foliated and metamorphosed to an assemblage of chlorite-talc-carbonate (Fig. 1.9A). The sedimentary rocks are isoclinally folded (F_2) and show two generations of superimposed crenulation cleavages, as well as z-type asymmetric folds.

The isoclinal F_2 folds are associated with a penetrative schistosity (S_2) that is parallel to the Bowes fault and contains a down-dip mineral lineation, which is evident along the fault. The S_2 schistosity and the Bowes fault are both folded and affected by a NE- to E-striking crenulation cleavage that affects both limbs of the isoclinal folds (Fig. 1.9B-C). A late spaced cleavage is shallow-dipping (Fig. 1.9A). These structures can be correlated in terms of style, orientation and relative chronology with tectonic structures that were documented at stops 1.4 to 1.8. However, Goulet (1978) and Jébrak et al. (1991) have identified a penetrative bedding-parallel schistosity during their microstructural study of the turbidites. Since S_2 is the earliest tectonic fabric in the Timiskaming Group, the presence of an early penetrative schistosity casts doubts on the origin of the sedimentary rocks of stop 1.9. Goulet (1978) proposed that they may belong either to the Pontiac Group, or to the Granada Formation of the Timiskaming Group, since both units contain similar turbiditic wackes and siltstones. Nevertheless, sedimentary rocks of the Granada Formation are mapped continuously into the McWatters area and stop 1.9, thus suggesting that the turbidites belong to the Timikaming Group, and that the early schistosity could be related to bedding-parallel slip during D_2 folding.

Overall, the structural style and kinematics of the area are consistent with southward thrusting of the McWatters Formation and of the Abitibi subprovince volcanic rocks, over the Granada basin syncline and Pontiac Group. Nevertheless, underground geological mapping at the McWatters mine by Jébrak et al. (1991) has highlighted an early phase of normal faulting in ultramafic rocks along the LLCfz. Bedeaux (2018) has also interpreted a phase of normal faulting. The origin of these extensional structures remains to be better constrained. Late brittle faults are also common in the McWatters area. These are oblique or at high angle to the structural grain. The McWatters fault (Fig. 1.8C), located to the north of stop 1.9 displaces Proterozoic diabase dikes (Jébrak et al., 1991). The Davidson creek fault, 3.5 km to the east of outcrop 1.5 is a northeast-trending subvertical brittle fault that also cuts Proterozoic diabase dikes.

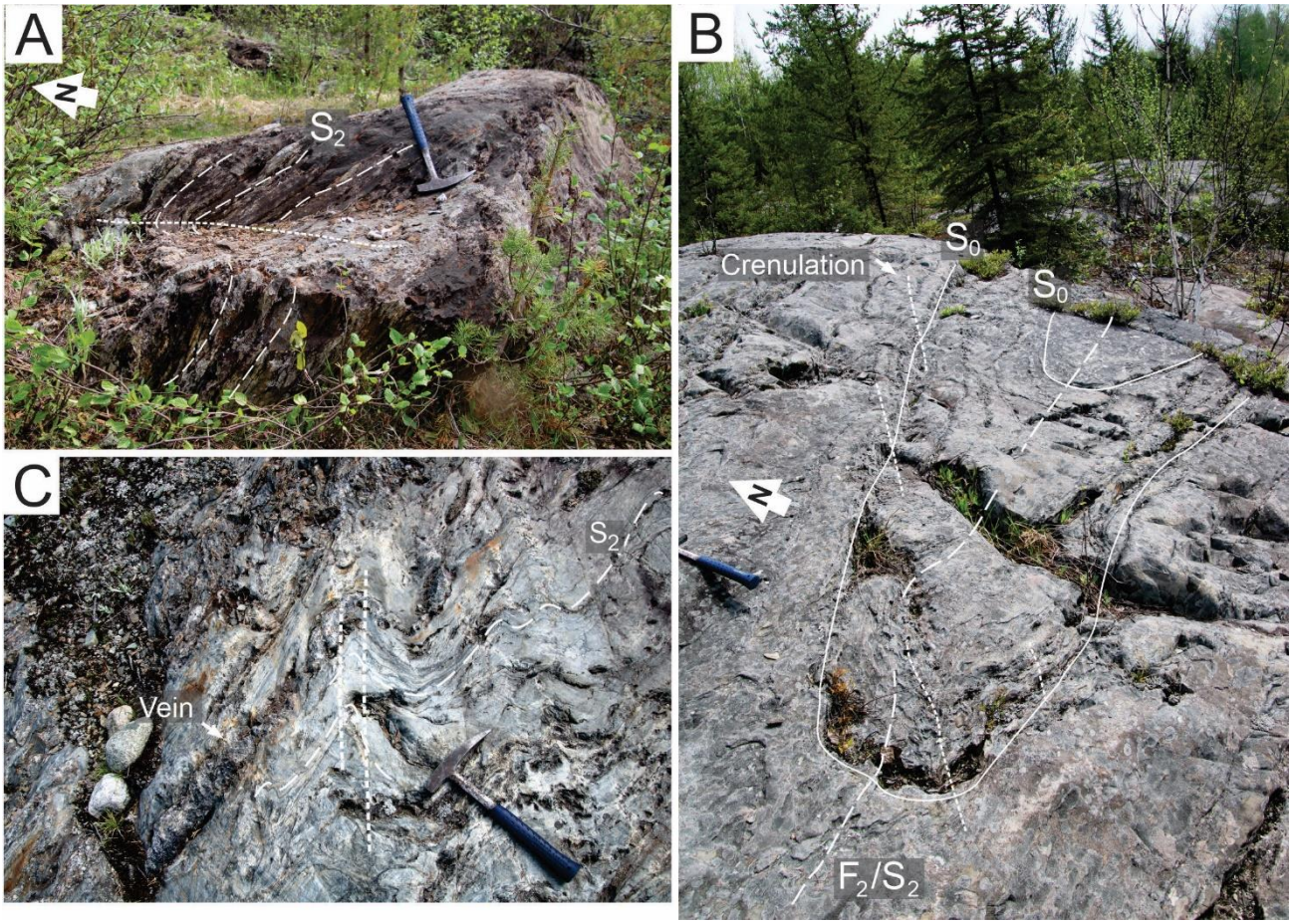


Fig. 1.9: A) Deformed volcanic rocks along the Bowes fault; and shallow-dipping crenulation; B) Isoclinally folded (F_2) turbidites of the Timiskaming Group (Granada Formation); a northeast-trending crenulation cleavage (dotted line) affects the two limbs of the folds and its axial planar cleavage (stippled line) C) asymmetric z-type folds and northeast-trending crenulation cleavage (dotted line) affecting S_2 (stippled line) and quartz veins. Hammer head points to the north. Stop 1.9.

Day 2: Vein formation and deformation

Stop 2.1: Folding and auriferous veins in the Pontiac Group

UTM NAD1983 zone 17: 692 040 mE / 5 345 300 mN

Stop 2.1 Is a large outcrop that was recently stripped and cleaned to expose thick auriferous veins and shear zones in the Pontiac Group. This site is located 2.8 km to the SSE of the LaRonde mine, a gold-rich VMS deposit that is currently mined at a depth of more than 3 km. It is also located less than 200 m to the south of the LLCfz, and 800 m to the WSW of the O'Brien mine, a past-producing (1925 to 1956, and 1970 to 1981) vein-hosted gold deposit located along the LLCfz in the Cadillac mining camp. The site is currently the property of Radisson Mining Resources.

The mineralized outcrop of stop 2.1 is particularly interesting because, although gold-bearing quartz veins are common in the Pontiac Group, the auriferous veins are rarely very large or form sufficiently dense arrays to be mined. On this site the veins locally reach a thickness of more than 2 m. They are hosted in tightly to isoclinally folded turbiditic graywacke and siltstone (Fig. 2.1). The folds are symmetrical and steeply plunging.

They are associated with a strong cleavage that is subvertical and correlates with the D_2 phase of deformation. In the hinge zone of the folds, graded bedding indicates that the turbidites are younging to the east (Fig. 2.1 A and B). The shear zones hosting the auriferous veins are not much thicker than the veins themselves. They show a biotite-calcite hydrothermal alteration, and a down-dip mineral lineation. The strong S_1 schistosity in the Pontiac Group of stop 1.6 is not well developed here. However, if you look closely, you may find a folded bedding-parallel fabric. This is often the case in the Malartic area, where an S_1 foliation is associated with pre-D_2 folding of the Pontiac Group turbidites (Sansfaçon, 1986; Perrouty et al., 2017; De Souza et al., 2017).

Fig. 2.1: A) Deformed and tightly to isoclinally folded (F_2) strata of the Pontiac Group; younging is indicated by the black arrow; B) Detail of graded bedding in Pontiac Group turbidites. Stop 2.1.

Stop 2.2 : The Malartic Lakeshore showing and vein deformation along the Rivière Héva fault

UTM NAD1983 zone 17: 711 660 mE / 5 345 980 mN

This stop is significant for our understanding of the stratigraphic and structural architecture of the volcanic pile, but also of the episodes of auriferous vein formation in the Malartic – Val-d'Or mining district. North of the town of Malartic, the volcanic rocks of the Malartic and Louvicourt groups form a south-younging succession ranging in age from 2714 to 2698 Ma (c.f. Pilote, 2013; Guay et al., 2018). Both consist of mafic, intermediate and felsic volcanic rocks, but the Malartic Group contains abundant komatiite that are absent from the Louvicourt Group (Pilote, 2013). The stripped outcrop of stop 2.2 was recently mapped in detail by Guay et al. (2018; Fig. 2.2A). It exposes a major shear zone along the Rivière Héva fault, the importance of which was recently emphasized by Guay et al. (2018), who have shown that it marks a major discontinuity in the volcanic pile. The vertical displacement along the fault must be quite significant since it juxtaposes felsic volcaniclastic rocks of the Héva Formation (ca. 2698 Ma) to the northeast and ultramafic to mafic volcanic

rocks of the Dubuisson Formation (ca. 2708 Ma) to the southwest. The felsic rocks are highly strained and show a shallow-plunging stretching lineation. Within approximately 20 m from the faulted contact, the mafic and ultramafic rocks are transformed into mylonitic schist and the ultramafic rocks are strongly metasomatized and biotite-rich. The foliation is subvertical to steeply southwest-dipping, and is molded around a tonalite stock that cuts the volcanic rocks but does not outcrop at surface. Both dip-slip and strike-slip motion have been documented based on lineation patterns. Guay et al. (2018) have explained the kinematics of the shear zone by its evolution in a transpressional regime in which deformation was initially dominated by a dip-slip motion and later overprinted by dextral shearing.

The mafic and ultramafic rocks are cut by quartz-calcite veins, which also contain variable proportions of barite, albite and traces of gold and tellurides (Guay et al., 2018). The veins show biotitized margins, and they are boudinaged and transposed into parallelism with the schistosity (Fig. 2.2B). The veins are also affected by Z-type folds and cut by diorite and granodiorite dikes (Fig. 2.2C). One of these dikes yielded a U-Pb zircon crystallization age of ca. 2694 Ma (Guay et al., 2018). This age and crosscutting relationship imply that the auriferous quartz-calcite veins were emplaced prior to the sedimentation of the Timikaming Group, and of the Cadillac and Pontiac groups. A similar timing was also established from other gold deposits in the Malartic gold camp, notably at the Norlartic mine (Couture and Pilote, 1994). Hence, an early phase of gold mineralization represented by deformed auriferous veins occurred shortly after the end of volcanism. When present in the same deposit or outcrop, these early veins are generally cut by quartz-tourmaline veins that typify some of the vein gold deposits of the Val-d'Or camp (Robert, 1994).

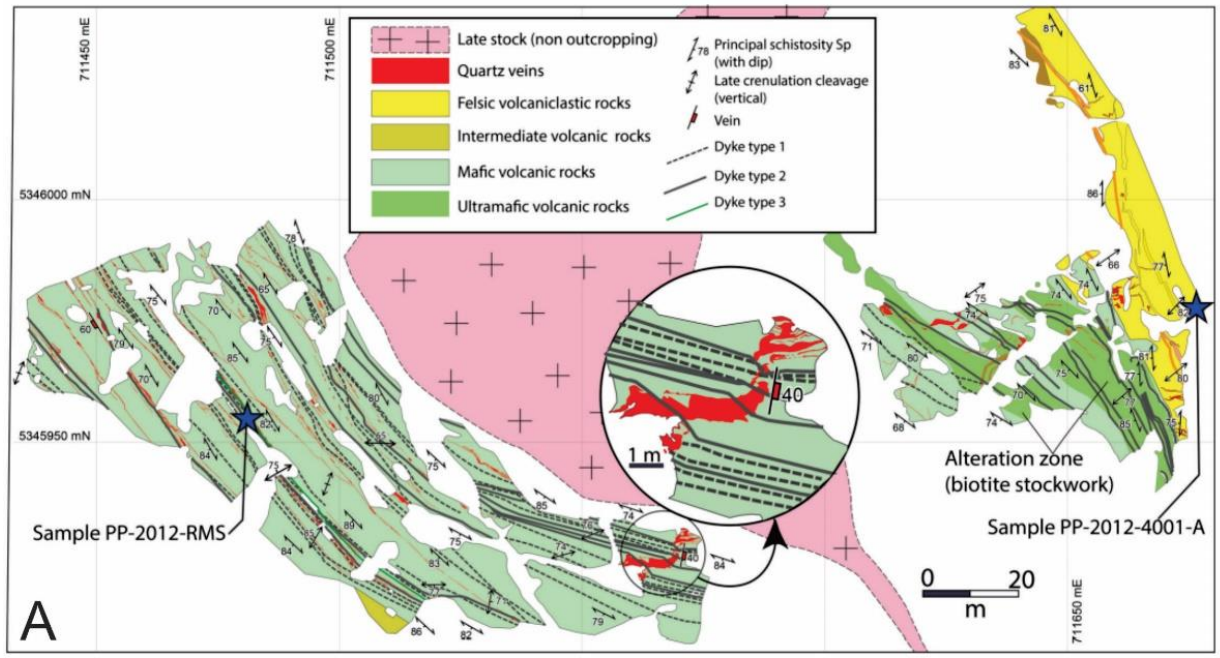
Stop 2.3 : Canadian Malartic open pit mine lookout

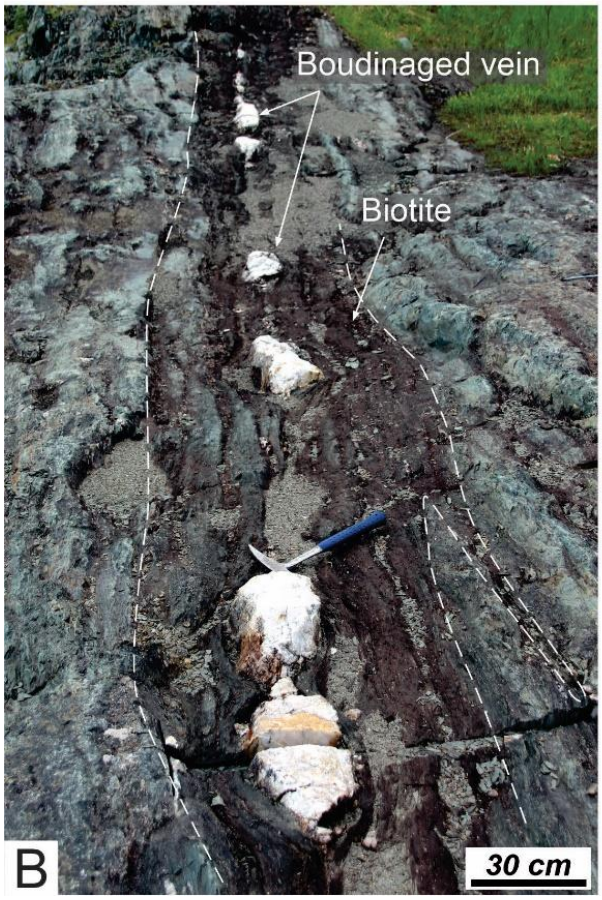
UTM NAD1983 zone 17: 714 380 mE / 5 335 040 mN

The Canadian Malartic open pit gold mine is currently the largest gold producer in Canada, with 4.8 Moz that have been produced during the first ten years of operation (2011-2019). In total, the Canadian Malartic deposit and associated mineralized zones contained at least 29 Moz of gold (past-production, resources and reserves; compiled from Trudel and Sauvé (1992) and Agnico-Eagle mines website). The ore consists of disseminated sulphides in stockworks and replacement-style mineralization, with an average grade of approximately 1 g/t. The discovery, development and mining history of the Canadian Malartic deposit is quite interesting and summarized by Wares and Prud'homme (2013) and De Souza et al. (2020).

The lookout gives a great view over the open pit mine, the geology of which is summarized in Figure 2.3A and B). It is possible to see the trace of bedding in the Pontiac Group, the main host to ore, and felsic and intermediate dikes/sills that dip moderately to steeply towards the SE in the southern part of the pit. An F2 axial surface runs across the pit, from the southeastern to the northwestern corner, but is not clearly visible due to the lack of evident marker horizons. Decommissioned mining adits from the past-producing underground mines (1935-1981) are also noticeable. Three of those can be seen on the west wall and are stacked diagonally along the Slated fault. This fault represents one of the main metallotects of the Malatic camp (De Souza et al., 2015; 2017). This brittle-ductile fault dips steeply towards the south and is recognized over a strike length of approximately 5 km. It is locally marked by discontinuous mylonite, fractured and brecciated rock, quartz veins, and by late gouge and local cataclasite that overprint the ductile fabrics. At the northern extremity of the east wall of the pit, it is possible to see the quartz monzodiorite intrusion (light

grey) that shows an apparent dip towards the north, and is cut at high angle by the Sladen fault. Two main trends of gold mineralization are recognized; one is subparallel to the F_2 axial trace and S_2 cleavage, whereas the second is parallel to the Sladen fault. The gold zones are thickest (75 to 100 m) where the Sladen fault cuts the quartz monzodiorite located in the footwall.





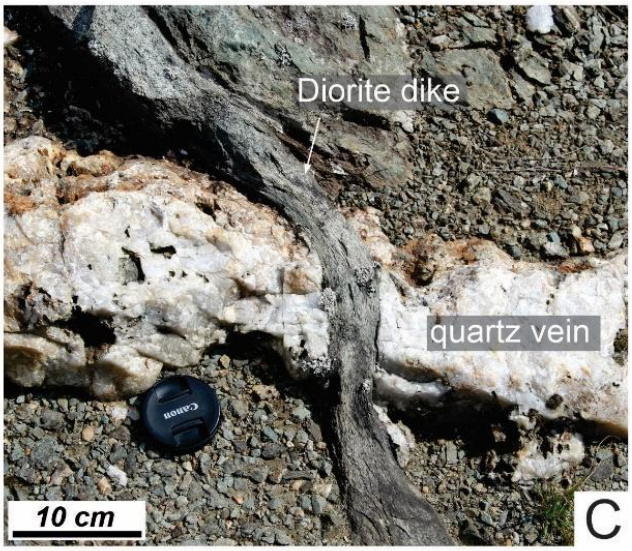


Fig. 2.2: A) Detailed geological map of the Malartic Lakeshore gold showing; The map is from Guay et al. (2018); B) Boudinaged quartz-calcite vein with biotite-rich selvages; C) Auriferous quartz-calcite vein cut by diorite dike. Stop 2.2.

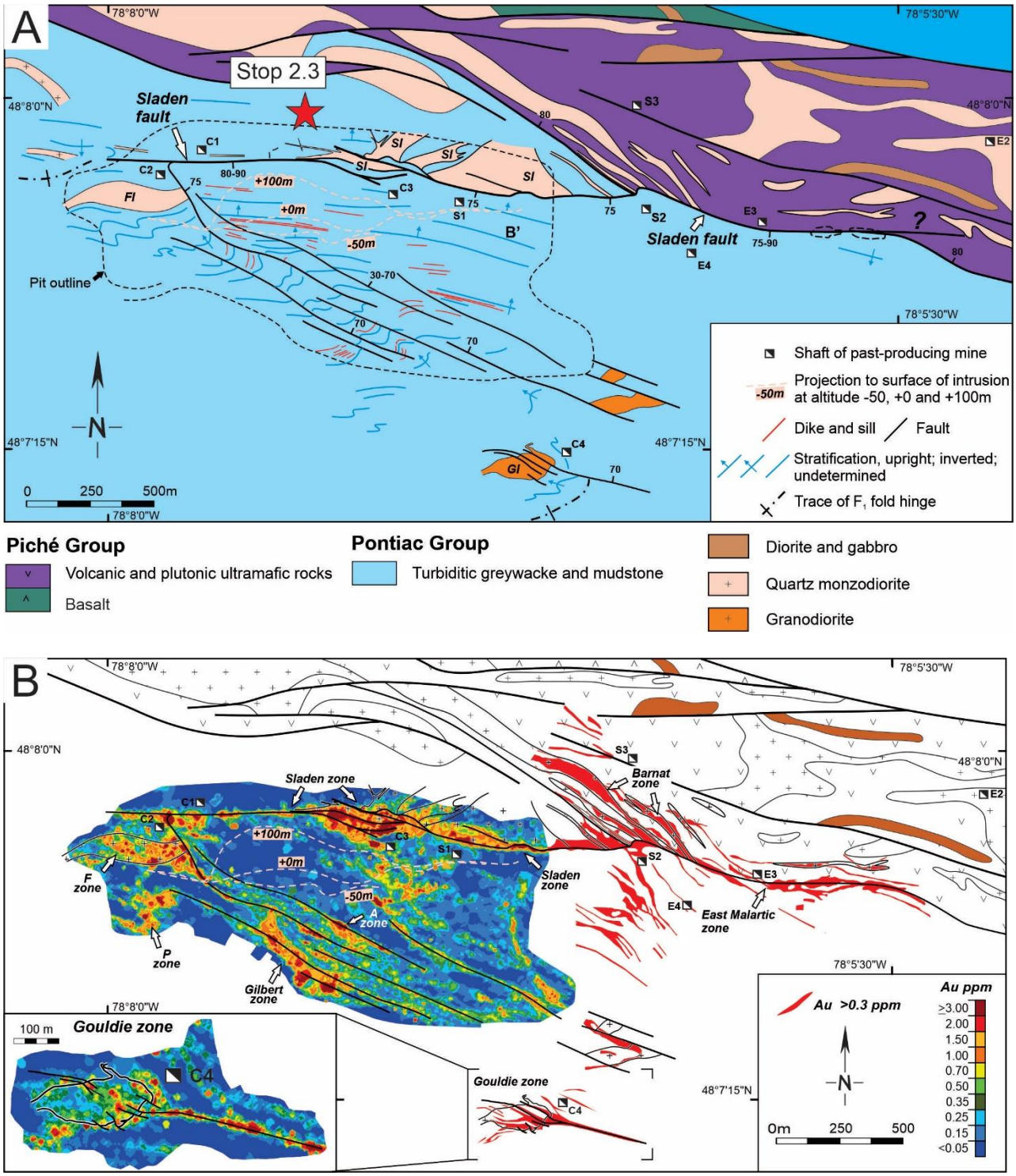
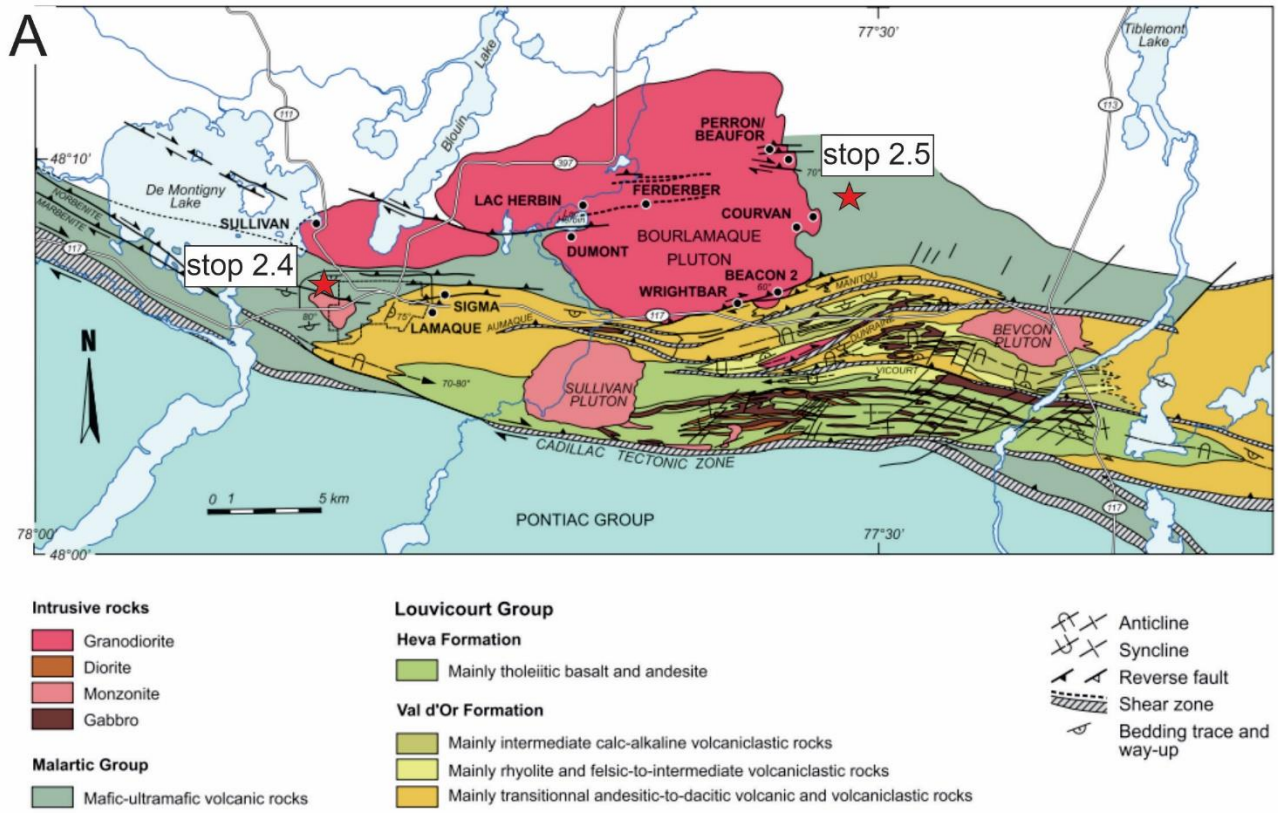


Fig. 2.3 A) Geologic map of the Canadian Malartic deposit area. The stippled pink lines represent the projection to surface of the quartz monzodiorite porphyry at +100 m, +0 m, and –50 m relative to sea level; B). Surface distribution of gold. Shaded colors correspond to an interpolation of blast hole and RC drilling assay data. Red mineralized zones represent a compilation of exploration RC and diamond drill assays. Black and white squares indicate the position of mine shafts: C = Canadian Malartic; E = East Malartic; S = Sladen-Barnat. FI = F zone intrusion; SI = Sladen zone intrusion; GI = Gouldie zone intrusion. From De Souza et al. (2020).

Stop 2.4 : Deformed veins in Val-d'Or

UTM NAD1983 zone 18: 289 450 mE / 5 332 310 mN

Stop 2.4 is located in Val-d'Or and it can be easily accessed from highway 117, and a trail that leads towards the ESE, directly onto a stripped outcrop of the Veine no.5 gold showing (Fig. 2.4A). It is currently the property of Bonterra Resources. The site is located approximately 600 m to the WSW of the Stabel mine, which produced gold from auriferous quartz veins between 1933 and 1937. This outcrop is very large and the field visit will focus on its eastern part. The gold is hosted in one main quartz veins and associated veins, which cuts a magmatic breccia complex that was intruded into the volcanic rocks of the Malartic Group (Jacola Formation; Fig. 2.4A). The site was described in detail by Barbe (2011). The complex consists of multiple intrusive facies that include various types of diorite, monzodiorite, tonalite, and a spectacular polygenic breccia composed of a dioritic matrix and a wide variety of clast composition, size and shape (Fig. 2.4B). The veins are folded and affected by the shear-related ductile fabric (Fig. 2.4C). The shear zone that hosts the auriferous veins shows spectacular examples of shear bands, c-s fabrics and drag folds, that all suggest a dextral sense of shear (Fig. 2.4C and D). Massive ankerite veins are also present and equally deformed. A late, but deformed quartz monzodiorite dike related to the magmatic complex yielded a U-Pb zircon crystallization age of ca. 2672 Ma (David et al., 2011; Barbe, 2011), and corresponds to the youngest intrusive rocks cut by auriferous in the Val-d'Or camp. Barbe (2011) notes that field relationships suggest a close temporal relationship between the emplacement of the magmatic complex and dextral shearing.



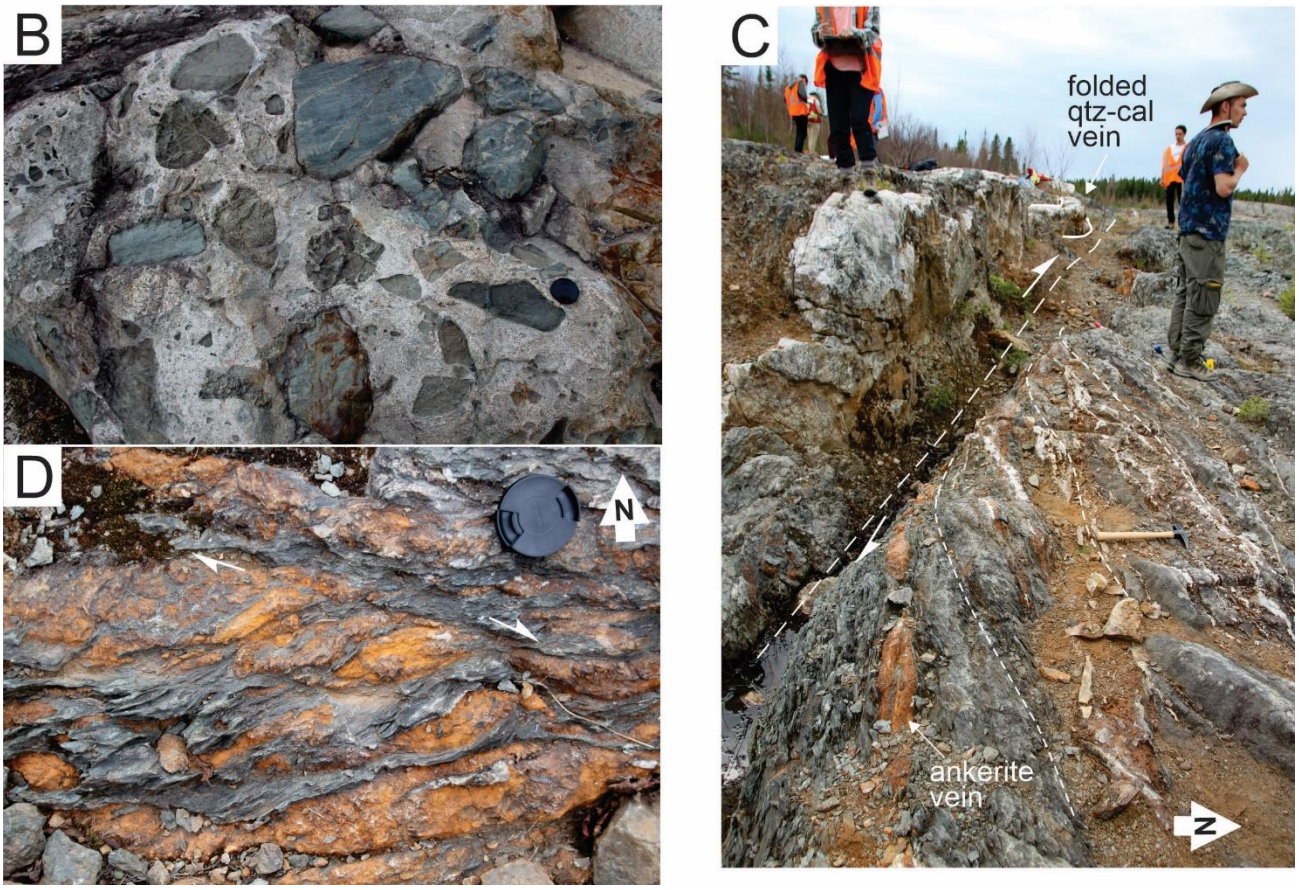


Fig. 2.4: Geology of the Val-d'Or area and location of stops 2.4 and 2.5; the map is from Tremblay et al. (2020); B) Polygenic magmatic breccia; C) folded auriferous quartz-calcite vein and shear zone at the Veine no5 showing ; D) Sheared ankerite veins in chloritic mylonitic schist.

Stop 2.5 : Lucien Béliveau stripped outcrop – quartz-tourmaline veins

UTM NAD1983 zone 18: 312 740 mE / 5 335 100 mN

Stop 2.5 is located on the site of the past-producing Lucien-Béliveau mine. It also represents the flagship exploration project of Probe Metals in the Val-d'Or. An outcrop zone close to the mine was recently stripped and shows a beautiful exposure of quartz-tourmaline veins, the hallmark of the Val-d'Or mining district (Robert et al., 2005; Dubé and Mercier-Langevin, 2020). The site is located approximately two kilometers east of the Bourlamaque pluton (Fig. 2.4A). The host rocks consist of intermediate volcaniclastic rocks belonging to the Dubuisson Formation of the Malartic Group. Bedding is NNE-trending and locally marked by a subvertical lapilli tuff horizon intercalated within the volcanic strata (Fig. 2.5A). A penetrative schistosity and associated shear zones are subvertical to steeply south-dipping, and developed at high-angle to bedding. The bedding-schistosity relationship suggests that the outcrop is located in the hinge zone of a subvertically plunging fold.

The volcaniclastic rocks are cut by north-trending mafic dikes that control, in part, the vein distribution and concentration. The veins are preferentially developed within the dikes, which are more competent than their host rocks. The shear zones and vein selvages are hydrothermally altered to chlorite-sericite-ankerite-pyrite. Two main types of veins are recognized : quartz-albite-calcite and quartz-cabonate-tourmaline veins. The former are scarce and mostly present along the contacts of mafic dikes. The quartz-tourmaline veins are

subdivided into shallow-dipping to subhorizontal extensional veins, and moderately-dipping laminated fault-fill veins with crack-and-seal structures and slickenlines indicating a reverse motion (Fig. 2.5B and C). This quartz-tourmaline vein system is representative of the fault valve process related to cyclic fracturing of the host rocks due to high fluid pressure, as presented in the classic work of Robert and Brown (1986) and Sibson et al. (1988).

Fig. 2.5: A) Mafic volcaniclastic rock of the Dubuisson Formation (Malartic Group); note the lapilli tuff horizon in the center of the photograph; B) Shallow-dipping extension veins (white arrows) and moderately-dipping fault-fill quartz-tourmaline veins; C) Slickenlined surface in fault-fill quartz-tourmaline vein.

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