**Companion Report to accompany**

# Bedrock Geologic Map of the Lake Francis 7.5' Quadrangle, New Hampshire

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**Introduction**

This area is a sparsely populated by year-round residents, but with many part-time residents and visitors. It is a favorite location for recreation – both winter and summer/fall activities. Forestry has been a major industry in the region for many years.

The first mention of its geology is found in Charles Hitchcock's 1877 Geology of New Hampshire and his map folios. Subsequent mapping was performed nearby by Billings (1956), his students (Hatch, 1963; Green, 1964, 1968; Myers, 1964), and later in the quadrangle by Converse (1977), Jahrling (1983) and Bothner, Jahrling and Moench (unpublished mapping 1980 – 1990). The USGS published a regional map ($2^{o}$ sheet) in 1995 (Moench et al., 1995 and references therein) and a modified version of that regional map was included in the Geologic Map of New Hampshire (Lyons et al., 1997). The bedrock geology of northeastern Vermont was compiled by Ratcliffe et al. (2011). Geophysical maps are available in Bothner et al. (1997).

The bedrock geology of southern Quebec that is adjacent to the New Hampshire border was mapped in the last decade by Tremblay et al. (2015) and Perrot (2019).

The aim of this project is to provide modern bedrock geological maps of northernmost New Hampshire which can be used for both practical and scientific applications. The Lake Francis Geologic Map is the second of 5 geologic maps that will cover the 1926 Indian Stream 15' quadrangle. The Geologic Map of the Pittsburg 7.5' Quadrangle (Bothner et al., 2020) was completed in September, 2020. Mapping in the Cowen Hill Quadrangle is already underway. Further refinement of this map is anticipated as the remaining maps in Northern New Hampshire are completed.

***Regional Bedrock Geologic Setting***

Northernmost New Hampshire is underlain largely by low grade metamorphic Silurian and Devonian rocks of the Connecticut Valley - Gaspe Trough (CVGT) as shown in Figure 1. The CVGT is fault-bounded on the west by Ordovician and older rocks of Taconic and Grenville orogenic belts and on the east by the Bronson Hill – Boundary Mountain belt (BHA). The CVGT recorded initial extensional tectonics as well as compressional tectonics as island arcs and microcontinents collided with

North America during the Siluro-Devonian Salinic Orogeny and the Late Devonian Acadian Orogeny.

The late Paleozoic Alleghanian orogenic and Mesozoic Atlantic rifting events are poorly represented at this latitude with the exception of plutons and dikes of White Mountain affinity.

### *Geology of the Lake Francis Quadrangle*

#### Surficial Geology

This mapping effort did not focus on the surficial geology of the Lake Francis Quadrangle. The surficial geology consists of Quaternary sediments of fluvial and glacial origin. Glacio-fluvial gravel accumulations are found along streams in the area as well as on elevated terraces above current stream or river beds and are are frequently mined for road materials. Glacial striations throughout the quadrangle record a consistent transport direction of ~ 140° (S40°E). Large erratics are common particularly along Carr Ridge, which appears to be a lateral moraine.

#### Bedrock Geologic Summary

The bedrock geology consists of a few unmetamorphosed Mesozoic felsic and mafic dikes and of older Silurian and Devonian bedrock. The Silurian and Devonian bedrock consists of low-grade metamorphic slates, siltstones, sandstones and volcaniclastic sediments as well as metamorphosed intrusive and extrusive rocks. The mafic extrusive rocks are comprised of metabasalts and metabasaltic andesites, which were extruded as lava flows, pillow lavas, hyaloclastites, and lapilli tuffs. The felsic extrusive rocks are comprised of metadacites and metarhyolites, which consist of flows and tephra deposits (lapilli tuffs and ignimbrites). The intrusive rocks consist of diabase dikes and sills, and granitic sills and a small plutonic body.

Structurally, at least two major deformational episodes are recognized: 1) the upper Silurian-Lower-Devonian Salinic Orogeny (with both extensional and compressional events) and 2) the Late Devonian Acadian Orogeny compressional event. These deformations folded the older bedrock first in isoclinal folds and then refolded the bedrock into more open folds (e.g., Perrot, 2019, Perrot et al., 2018).

This map includes field data collected from 1976 through 2021. The field data includes structural, mineralogical and lithological data, new geochemical analyses, and five new age determinations. Data from surface exposures constrain the cross-section that shows the interpreted distribution of rock units in the subsurface. Key photos are also included to provide examples of different rock types, geometries and textures.

**Geochronology**

No fossils have been discovered in the Lake Francis Quadrangle. An Emsian? fossil was discovered to the west in the Pittsburg Quadrangle (Hueber et al., 1990).

Crystallization and detrital zircon U-Pb age assignments were determined for meta-igneous and meta-sedimentary rocks in the area using data from GeoSep Laboratories, the IsoPlotR program and analytical methods described by Vermeescht (2021a, 2021b). Five new determinations were made in the Lake Francis Quadrangle as part of this work. Additional ages were available from the Pittsburg Quadrangle (Bothner et al., 2020), the southern Quebec (Perrot, 2019, Perrot et al., 2017, 2018, 2020) and the Second Lake Quadrangle (Dorais et al., 2017). Zircon age determinations are summarized in Table 1.

U-Pb age determinations on whole rock samples were made in the Second Connecticut Lake on a sample from the East Inlet Pluton by Lyons et al. (1986), and from a sample on Round Top Mt in the Lake Francis Quadrangle by Moench et al. (1995).

***Crystallization ages: Table 1***

Two samples: IS2020-151RV (biotite metagranite sill) and IS2020-94 (meta-ignimbrite) were analyzed and both yielded approximately the same crystallization ages: 411 ± 7 (2$\sigma$) Ma and 411 ± 3 (2$\sigma$) Ma respectively.

These ages are significantly younger than whole rock age dates from the East Inlet Pluton (430 ± 4 Ma – Lyons et al., 1986) in the Second Lake Quadrangle and from Round Mt in the Lake Francis Quadrangle (Moench et al., 1995). These ages are also younger than the zircon crystal age dates from felsic metavolcanics on the southern shore of Second Lake (432 ± 8 Ma – Dorais et al., 2017).

The older ages from the whole rock age dates are not surprising as metavolcanic samples from the Lake Francis Quadrangle contain significant zircon populations with older inherited ages, which likely would skew a whole rock age determination.

***Detrital Zircon ages: Table 1, Figure 2A & B***

Age date determinations from detrital zircons are typically used for two purposes:

- Establishing the maximum depositional age of the sample. The actual age of the sample can be younger, if the younger sediment did not contribute sufficient numbers or appropriate sizes of zircon crystals. For example, we noted that some of the pelitic metasediments in our area contained few and typically < 10 micron zircon crystals.
- Establishing sedimentary provenances with clusters of zircon ages indicating derivation from different sedimentary sources.

Three samples in the Lake Francis Quadrangle contained zircon crystals of multiple ages that were analyzed as "detrital" zircon samples.

- IS2020-112 was a metavolcaniclastic unit that contained lapilli that were typically < 3 cm. The maximum depositional age was determined to be 408 ± 6 ($2\sigma$) Ma.
- IS2020-207A – this sample had very small zircon crystals and very few young zircon crystals with high discordances yield an maximum depositional age of 443 ± 16 ($2\sigma$) Ma. Removing the high discordancy samples, yielded a maximum depositional age of 603 ± 17 ($2\sigma$) Ma
- IS2019-242 – only recovered 13 zircons from this sample, very few young zircons, maximum depositional age of 459 ± 16 ($2\sigma$) Ma.

***Stratigraphy***

We recognized three formations in the quadrangle –the Ironbound Mountain (tentatively), the Gile Mountain and the Frontenac Formation. The latter is separated into four members (3 meta-igneous units and 1 metasedimentary). A correlation chart showing the overall age relationships is shown in Figure 2A. Age dates from the Lake Francis Quadrangle indicate that the Frontenac Formation is approximately co-eval with the Gile Mountain Formation. However the sedimentary source terranes were different for the Frontenac and the Gile Mountain Formations (Figure 2B).

Many intrusive bodies (primarily metadiabase dikes or sills, and biotite granite) are mapped largely within the Frontenac and are described in detail in the Summary of Map Units on the map itself. The metamorphosed biotite granite may have been the source for the felsic metavolcanic rocks and ignimbrites as it has approximately same age and geochemistry.

Figures 3 and 4 show characteristic metasediments and metavolcaniclastics for the Gile Mountain and Frontenac Formations respectively. Figure 5 shows examples of pillowed metabasalts and a metadiabase intrusive. Figure 6 shows examples of metavolcaniclastic /meta-lapilli tuff unit from the north shore of Lake Francis,and of a metaignimbrite from Cedar Stream. Figure 7 shows an example of the metamorphosed biotite granite plutonic body on Tromley Hill with an inset of a thin-section with myrmekitic features from a similar outcrop on Round Top Mt, and an example of thin biotite granitic sills within a metabasalt on the south shore of First Connecticut Lake.

***Structure***

Broadly speaking, the phyllites and siltstones of Gile Mountain Formation exposed on the eastern flank of the shallow northeast plunging Beaver Brook anticline (the axis is in the Pittsburg Quadrangle) dominate the western portion of the quadrangle. This eastern limb is truncated by the west-directed Monroe Fault located east of the Lake Francis Dam.

Three faults are proposed in the map area – faults are very rarely exposed in outcrop in northern New Hampshire – the Lake Francis Quadrangle is no exception. Two of the faults, the Monroe and Deadwater Ridge Faults are shown on the Bedrock Geologic Map of New Hampshire (Lyons et al., 1997). The third tentatively proposed fault (here called the Cedar Stream Fault) is a normal fault that separates the Frontenac from a possible Ironbound Mountain equivalent in the southeastern corner of the quadrangle. All three faults were folded during the Acadian Orogeny.

The Monroe Fault separates the Gile Mountain Formation to the west from the Frontenac Formation to the east. Although ages of the two formations are quite similar (based on zircon age dating), the lithogies are distinct both in terms of volcaniclastic input, metaigneous units and the different sourcing based on zircon age distributions (Figure 2B). The second proposed fault is the Deadwater Ridge

Fault, another high-angle reverse fault separating the Frontenac metasediments to the west from the Frontenac metabasalts to the east. Both the Monroe Fault and the Deadwater Ridge Faults are consistent with geophysical modeling (gravity and magnetic) of the subsurface geometry (Jahrling, 1983). The proposed Cedar Stream fault is a normal fault (mapped as the Deer Pond Fault on the NH Geological Map (Lyons et al., 1997)) based on the inferred existence of the Ironbound Mountain Formation in the southeastern corner of the Lake Francis Quadrangle. The Ironbound Mountain Formation correlation is based on a lithologic comparision made over the years (e.g., Lyons et al., 1997), but is not supported by any age data. Our attempt in 2021 to date these rocks was unsuccessful due to the lack of zircon grains.

Abundant minor folds were identified that may be related to the formation of the Beaver Brook Anticline/Syncline pair in the Pittsburg Quadrangle but we also recognize the possibility of a more complex refolded nappe structure. These regional structures are present in both the Central Maine terrane and CVGT farther south in New England, often at higher metamorphic grade. We lack evidence of a regional inverted limb at this latitude.

Three deformation events, D1, D2, and D3 are recognized in the area. Rare isoclinal F1 folds, often with well-preserved graded beds (Pittsburg Quad, Cowen Hill), are refolded about tight, asymmetric generally westerly inclined, shallow northeasterly and southwesterly plunging mesoscopic F2 folds. Abundant F2 folds crop out along the northern shoreline of Lake Francis (Figure 8) at both large and small scales with low plunges (ca. $10^{o}$). Late S3 cleavage in more pelitic layers sparingly represents D3.

***Frontenac and Gile Mountain Igneous Geochemistry***

In collaboration with Professor M.J. Dorais (BYU), we are investigating the whole rock geochemistry of the Frontenac metaigneous rocks to better understand the origin, tectonic setting and possibly develop a geochemically based igneous stratigraphy. Analytical results were received in early September. Figure 9 shows all data (separated into groups assigned by rock type and location) on two standard geochemical plots. Three preliminary results are: 1) metabasalts near the Monroe Fault appear chemically distinct from other metabasalts, 2) the metaignimbrite in Cedar Stream is nearly identical in composition with one of the metamorphosed biotite granite samples, and 3) the meta-lapilli tuff sample from the north shore of Lake Francis has a rhyolite composition.

### *Economic Geology*

As might be expected, in a submarine volcanic environment, there were a few signs of hydrothermal activity and associated mineralization. The most prominent example was a very small volcanogenic “massive” sulfide located on the southeastern shore of Lake Francis (Figure 10), with the word “massive” in quotes due to the very small size. The dominant sulfide is pyrite with some minor chalcopyrite as seen in a polished thin section from the sulfide-rich chlorite schist. The field and hand sample photos and an interpretive sketch map are shown in Figure 8. Due to the nearly vertical dips, the sketch map represents a cross-sectional view of the exhalative system.

### *Acknowledgements*

We thank Josh Keeley of NHGS for his help with base map generation (Lidar and topographic), map layout and all things ARC-related and Rick Chorman, NH State Geologist and Shane Csiki (the new NH State Geologist), for continuing support of this STATEMAP project. We also benefited from a field visit with Bob Marvinney, State Geologist of Maine, and very helpful conversations with Morgann Perrot, Alain Tremblay as well as Lori Summa and David Awwiller. Paul O’Sullivan, GeoSep, Moscow, ID, analyzed zircons from metasedimentary and metaigneous rocks by LA-ICP-MS to determine U-Pb ages. Professor Michael Dorais (BYU) arranged for the the geochemical analysis of the metaigneous rocks and provided helpful commentary. Chris and David Craigue kindly arranged lodging in Pittsburg, NH.

## *References Cited*


Billings, M.P. 1956, Geology of New Hampshire, Part II: Bedrock Geology, New Hampshire Planning and Development Commission. Concord, New Hampshire (and geologic map, 1955, scale 1:250,000).

Bothner, W.A, Kucks, R.P., Jahrling, C.E.,II, Carnese, M.J., and Moench, R.H.,1997, Complete Bouguer gravity and aeromagnetic maps of the Lewiston and Sherbrooke 1° x 2° quadrangles, Maine, New Hampshire, and Vermont: U.S.Geological Survey Miscellaneous Field Studies Map I-1898-F, scale 1:250,000.

Bothner, W.A., Converse, D.R., Jahling, C.E., II, and Koch, P.S., 2020, Bedrock Geologic Map of the Pittsburg 7.5' Quadrangle, New Hampshire. Bedrock Geologic Map Open-File Series GEO-008-024000-SMOF

Converse, D.R., 1977, Reconnaissance Geology of the Indian Stream Area Northern New Hampshire: BSE thesis, Princeton University, 127 p.

Dorais, M.J., Marvinney, R.G., Markert, K., 2017. The age, petrogeneis and tectonic significance of the Frontenac Formation basalts, northern New Hampshire and western Maine. Am. J. Sci. 317 (9), 990–1018.

Green, J.C., 1964, Stratigraphy and Structure of the Boundary Mountain Anticlinorium in the Errol Quadrangle, New Hampshire: Geological Society of America Special Paper 77, 78 p.

Green, J.C., 1968, Geology of the Connecticut Lakes Parmachenee area, New Hampshire and Maine: Geological Society of America Bulletin, v. 79, p. 1601–1638

Hatch, N.L., 1963, Geology of the Dixville quadrangle, NH: NH Department of Resources and Economic Development, Bulletin 1, Concord, NH, 81 p, map scale 1:62,500.

Hitchcock, C.H, 1874. 1877, 1878, Geology of New Hampshire, Concord, NH. 3 volumes.

Hueber, F.M, Bothner, W.A., N. L. Hatch Jr, S.C. Finney, and J. N. Aleinikoff, 1990, Devonian Plants from Southern Quebec and Northern New Hampshire and the Age of the Connecticut Valley Trough The American Journal of Science 290, no. 1–6 p. 360–95.

Jahrling, C.E., II, 1983, Geophysical, structural, and stratigraphic relations across the Monroe line and related contacts in the Indian Stream area, northern New Hampshire: Durham, NH, University of New Hampshire M.S. thesis, 106p.

Lyons, John B., John N. Aleinikoff, and Robert E. Zartman, 1986,Uranium-Thorium-Lead Ages of the Highlandcroft Plutonic Suite, Northern New England American Journal of Science 286, no. 6, p. 489–509.

Lyons, J.B., Bothner, W.A., Moench, R.H., and Thompson, J.B., Jr., 1997, Bedrock Geologic Map of New Hampshire: U.S. Geological Survey Map, scale 1:250,000, 2 sheets.

McWilliams, C.K., Walsh, G.J., Wintsch, R.P., 2010. Silurian-Devonian age and tectonic setting of the Connecticut Valley-Gaspe trough in Vermont based on U-Pb SHRIMP analyses of detrital zircons. American Journal of Science 310, p. 325–363.

Meyers, P.B, Jr.,1964, Geology of the Vermont portion of the Averill Quadrangle, Vermont: Vermont Development Department, Bulletin 27, 69p. scale 1:62,500.

Moench, RH, et al., 1995, Geology of the Lewiston-Sherbrook Area, Maine, New Hampshire, Vermont, United States, and Quebec, Canada:: US Geological Survey Map I-1898D, scale 1:250,000 and pamphlet.

Perrot, M., 2019. Évolution tectonique des bassins sédimentaires tardi-à post-taconiens des Appalaches du sud du Québec et du nord du Vermont (PhD Thesis). Université du Québec à Montréal.
Perrot, M., Tremblay, A., David, J., 2017. Detrital zircon U-Pb geochronology of the Magog Group, southern Quebec–stratigraphic and tectonic implications for the Quebec Appalachians. American Journal of Science 317, 1049–1094.
Perrot, Morgann, Tremblay, A., Ruffet, G., and David, J., 2018, Detrital U-Pb and 40Ar/39Ar geochronology of the Connecticut Valley – Gaspé trough, southern Quebec and northern Vermont – Transitional tectonism from Salinic to Acadian orogenic cycles: Tectonophysics, v.745, p. 430-452.
Perrot, M., Tremblay, A., Ruffet, G., Labrousse, L., Gervais, F., and Caroir, F., 2020, Diachronic Metamorphic and Structural Evolution of the Connecticut Valley–Gaspé Trough, Northern Appalachians." Journal of Metamorphic Geology 38, no. 1 p 3–27
Ratcliffe, N.M., Stanley, R.S., Gale, M.H., Thompson, P.J., and Walsh, G.F., 2011, Bedrock Geologic Map of Vermont: U.S. Geological Survey Scientific Investigation Map 3184, scale 1:100,000
Tremblay, A., De Souza, S., Perrot, M., Theriault, R., 2015. Géologie des Appalaches du Québec, Feuillet Sud-Ouest, regions de Montérégie, Cantons de l'Est, Centre-du Québec et Chaudière-Appalaches. Ministère des Ressources Naturelles du Québec, MB 2015-2011, 1:300,000.
Vermeesch, P., 2021a, Maximum Depositional Age Estimation Revisited, Geoscience Frontiers 12, p. 843–50.
Vermeesch, P., 2021b, On the Treatment of Discordant Detrital Zircon U–Pb Data." Geochronology 3, no. 1 p. 247–57.

# Figures & Tables

## Figure 1 – Regional geology

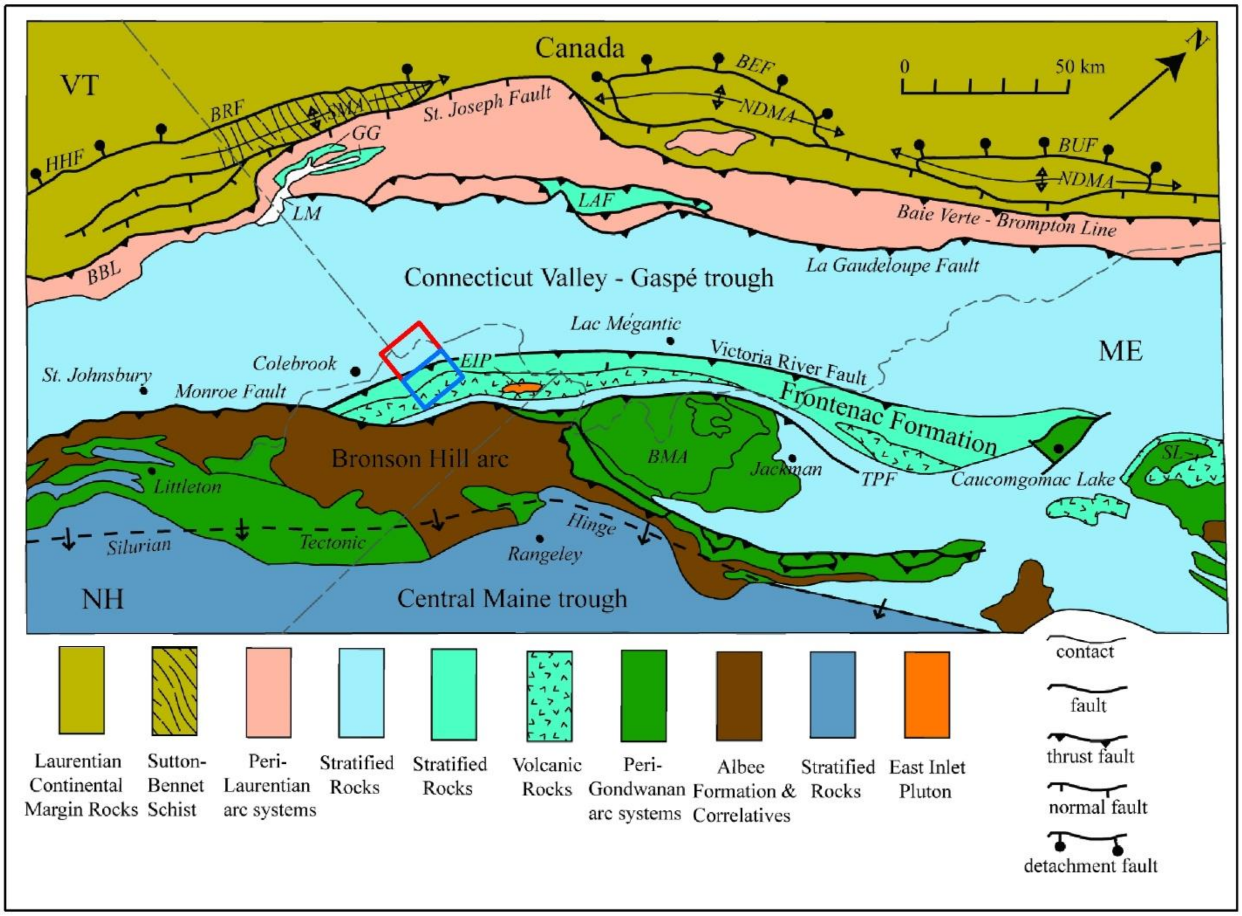


**Figure 1**. Simplified geologic map (modified after Dorais and others, 2017) showing the location of the Lake Francis Quadrangle (blue) and Pittsburg Quadrangle (red) at the southeastern border of the Connecticut Valley – Gaspé Trough. The Bronson Hill arch separates the CVGT from the Central Maine Trough. The Monroe fault is extended northerly to join the Victoria River (Belle) fault in Quebec and separates the Frontenac Formation from rocks of the CVGT in northern NH. EIP, East Inlet pluton; BMA, Boundary Mountains arch, BRF, Brome fault; BUF, Buckland fault; GG, Glenbrooke Group; HHF, Honey Hollow fault; LAF, Lac Aylmer Formation; LM, Lake Memphremagog; NDMA, Note Dame Mountains anticlinorium; SMA, Sutton Mountains anticlinorium; SL, Spider Lake; TPF, Thrasher Peaks fault

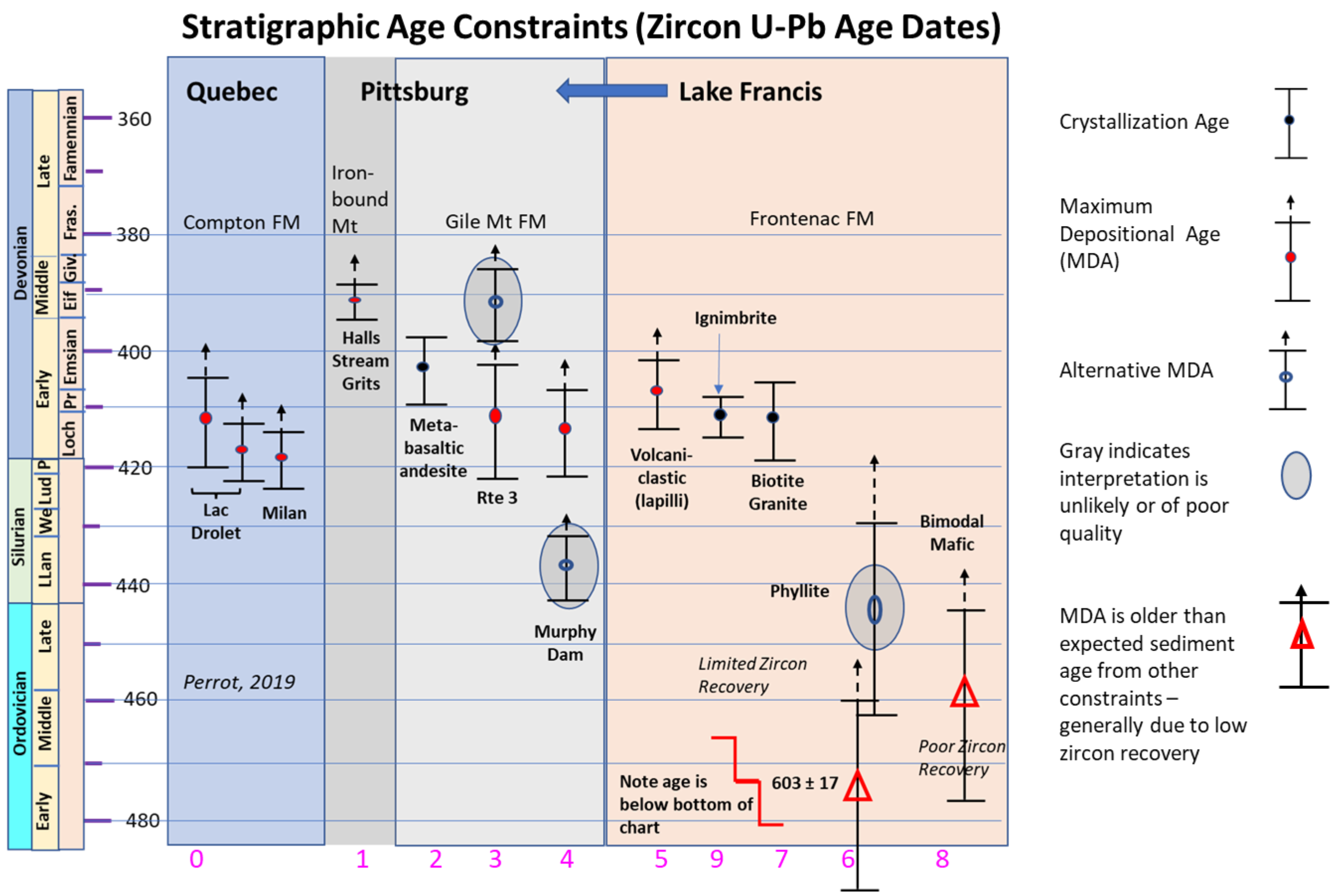


**Figure 2: A)** Zircon age determinations. Quebec dates are from M. Perrot (2018), the remainder are analyses of U-Pb from LA-ICPMS analysis conducted by GeoSep Laboratories. Two types of age determinations are shown – 1) crystallization ages and 2) maximum depositional ages (MDAs). It is important to understand that MDAs only provide an upper bound but not a lower bound for the depositional age – for two samples, the MDA is much older than the sediment age from other constraints, due to low zircon recovery). The age results are shown with 2$\sigma$ uncertainty. In some cases, the data can support alternative interpretations for the MDAs – either due to limited number of zircons or issues with data quality. Note that a gray circle is added to indicate if an alternative interpretation is considered unlikely or of poor quality. Magenta numbers reference entries in Table 1.

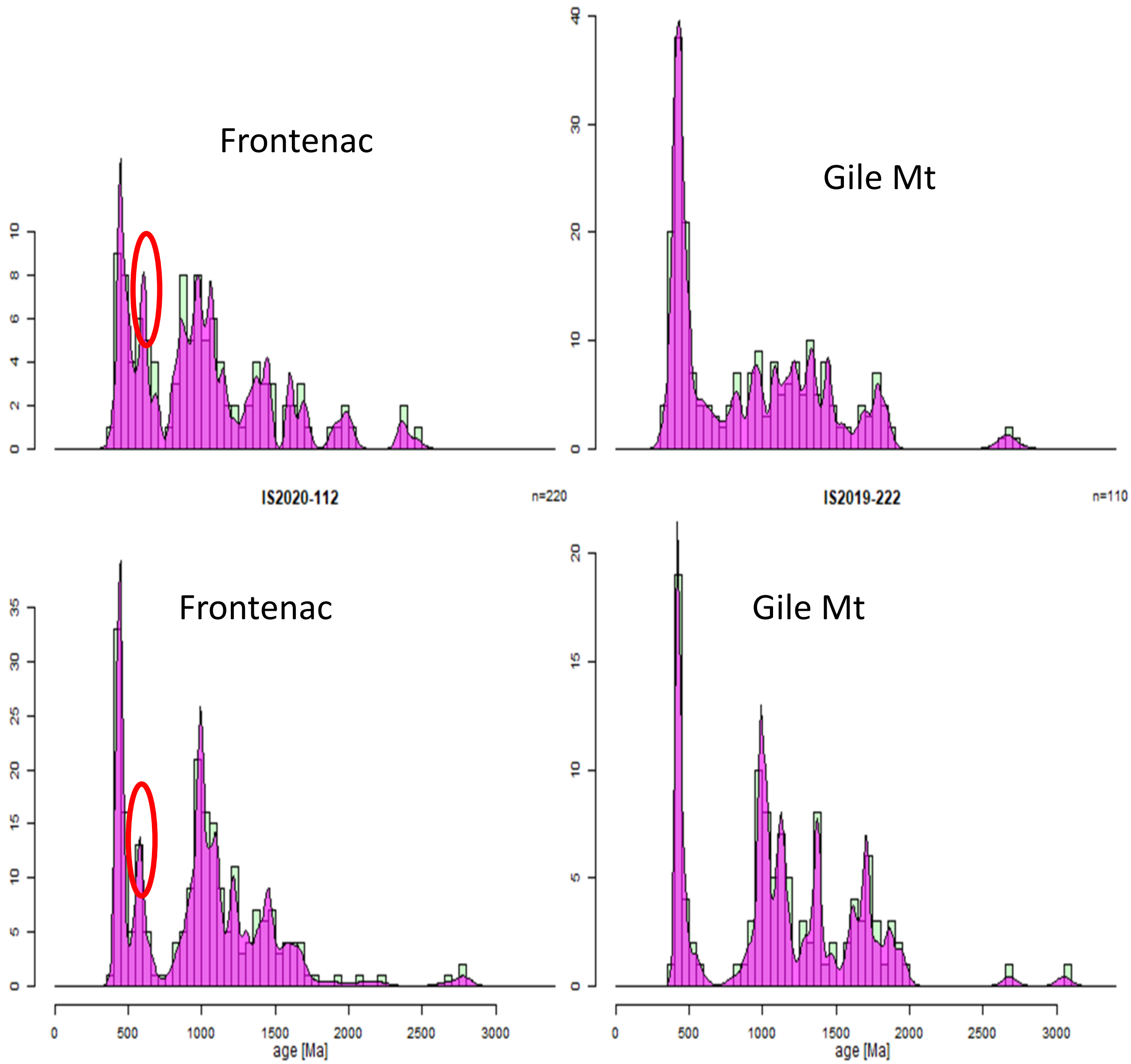


**Figure 2: B)** Zircon age distribution in 2 Frontenac and 2 Gile Mt samples. The most obvious difference between the two formation is the lack of a ~ 582 Ma peak in the Gile Mt sandstones suggesting a different source provenance for the Frontenac Formation at that time.


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**Figure 3:** A) Gile Mt metasiltstones and phyllites (IS2018-1) on southwestern shore of Lake Francis. Sedimentary features (scours) are complicated by the intense shearing nearby. B) Finely layered Gile Mountain gray phyllites and metasiltstones exhibiting partial turbidite sequences (IS2020-136).

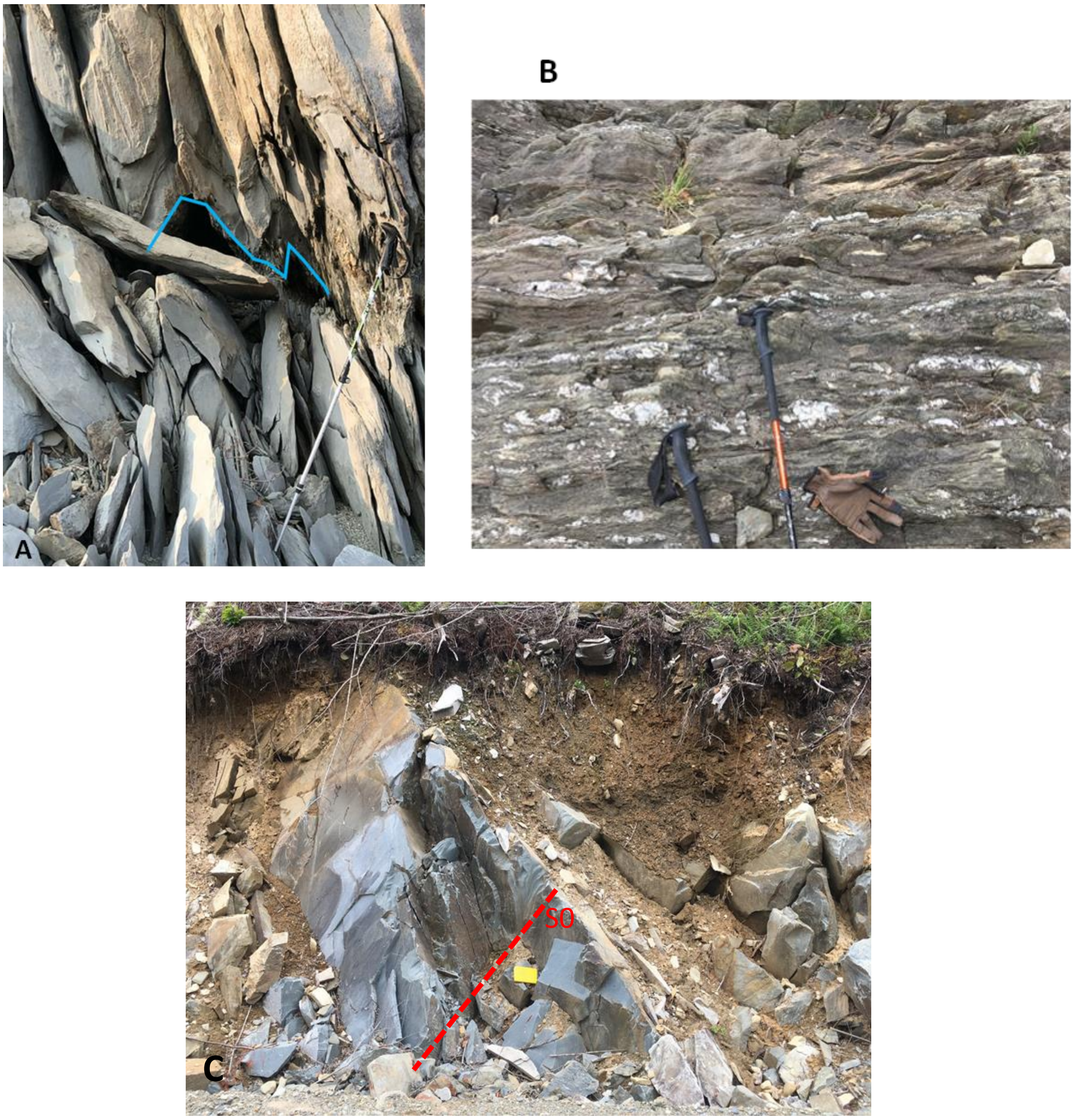


**Figure 4: A)** Folded Frontenac volcaniclastic sediment on north shore of Lake Francis (IS2020-116), **B)** Frontenac Phyllite (IS2021-216A) along shore of 1st Connecticut Lake with abundant quartz veining. **C)** Thick-bedded Frontenac metasiltstone (Sherman Loop, IS2021-242) with bedding (S0) well displayed.

**Figure 5** : A) Frontenac Pillowed metabasalt (IS2020-215) crops out on the north shore of Lake Francis.  Large pillow underneath the trekking poles clearly tops upwards (east),  B) Frontenac Metadiabase (IS2020-213) photos showing metadiabase with interesting flow structures (in some cases pillows) and adjacent to the fine-grained flow structures is coarse-grained (> 3-5 mm) metadiabase indicating intrusion into a metabasalt pile.

**A**

**B**

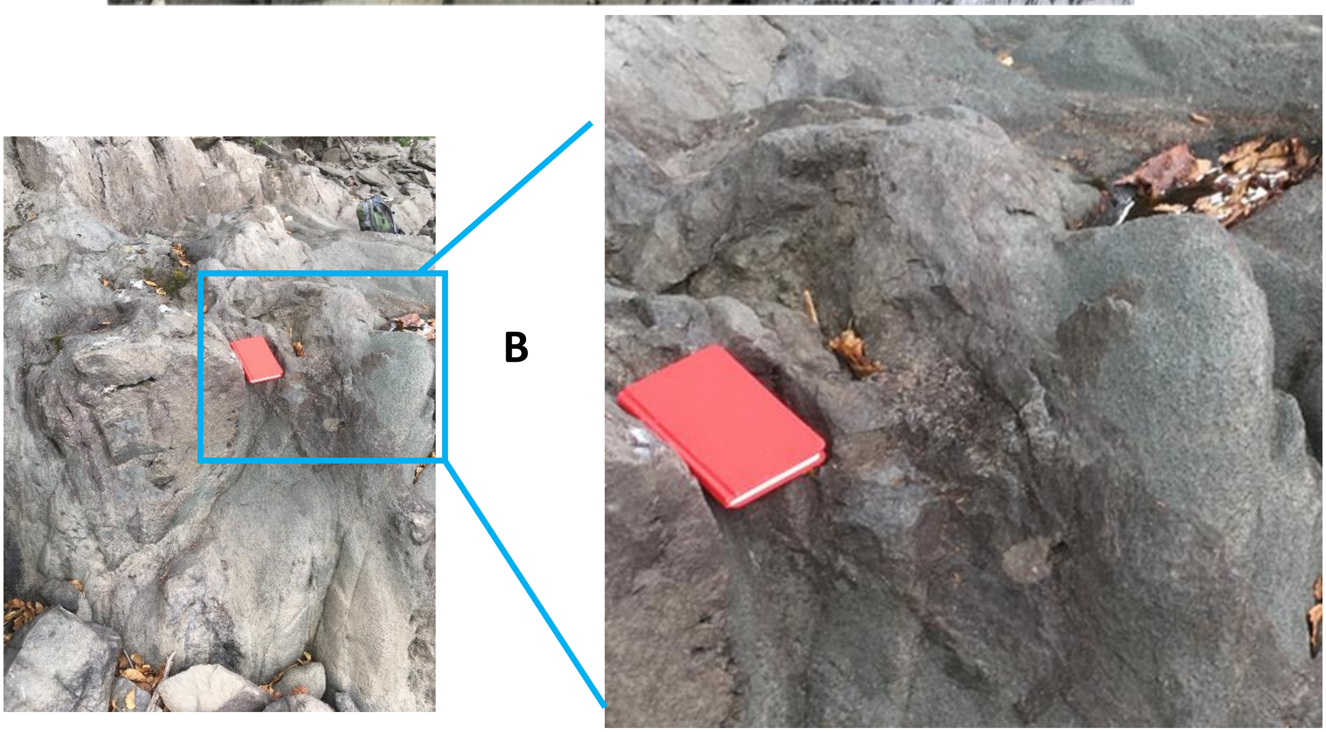


**Figure 6: A)** Meta-Lapilli tuff /tuffaceous sediment on north shore of Lake Francis (IS2020-112, maximum depositional age 408 ± 6 Ma) – geochemistry suggests a rhyolitic composition. **B)** Metaignimbrite outcrop in Cedar Stream (IS2020-94B). Geochemical composition is similar to metabiotite granite and zircon age is 411 ± 3 Ma.

**A** Biotite granite cliff **B** Felsic sills in Frontenac metabasalt

**Figure 7:** **A)** Intrusive biotite granite forms large cliffs on Tromley Hill (IS2021-117). **B**) Biotite granite forms sills in the Frontenac metabasalt along the southern shore of the 1st Connecticut Lake (IS2021-17) and particularly in Cedar Stream / S Tromley Hill area (typically 1-3 m scale), where the contacts are knife sharp. Zircon crystallization age is 411 ± 7 Ma. **C)** Thin section inset of "graphic" biotite granite with well-developed myrmekite from Round Top Mt (IS2020-144).

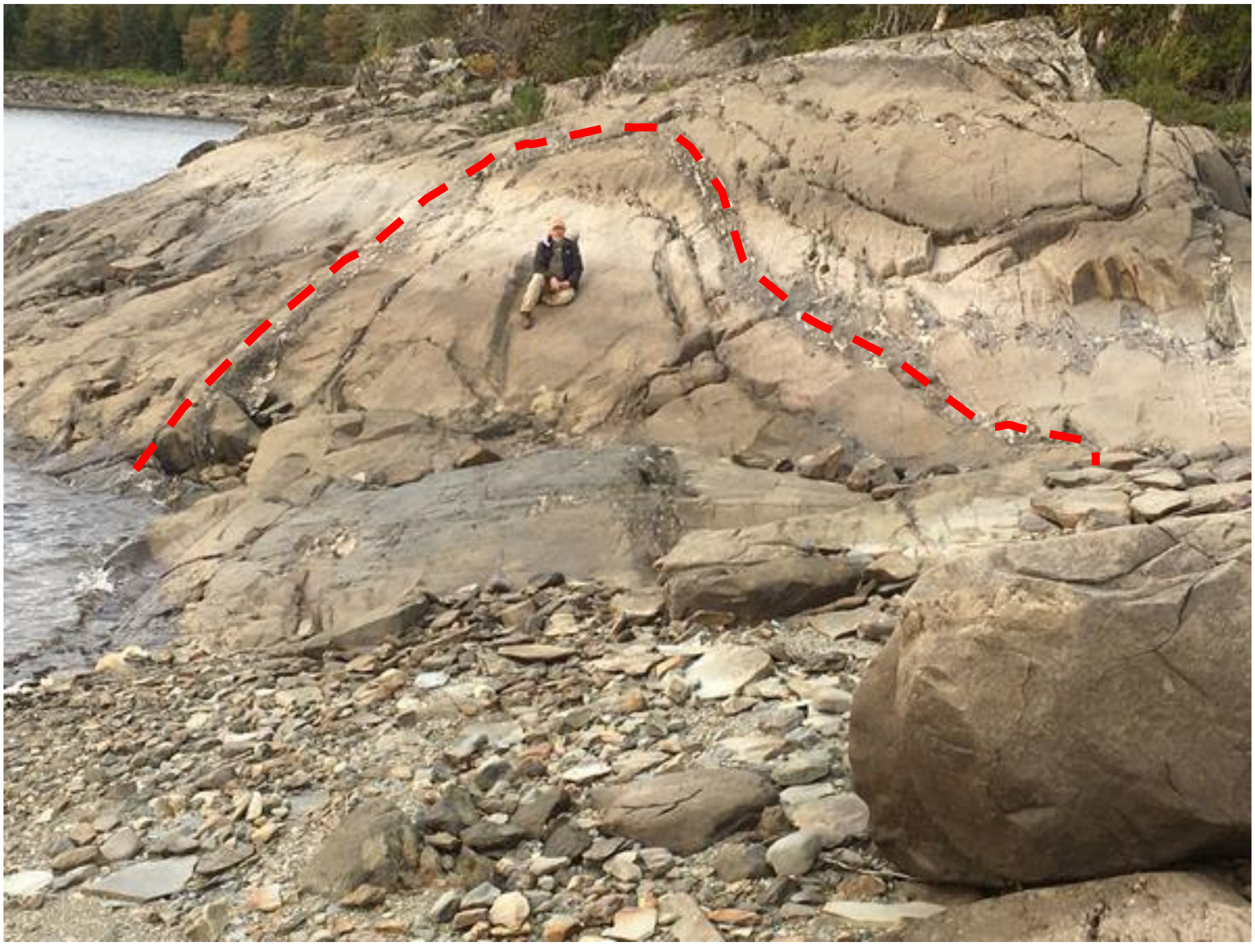

**Figure 8:** Large-scale open fold (F2) in Frontenac metavolcaniclastic sediment (IS2020-115). Note the quartz veining that outlines the fold. Folds of this size are rarely exposed in this area.

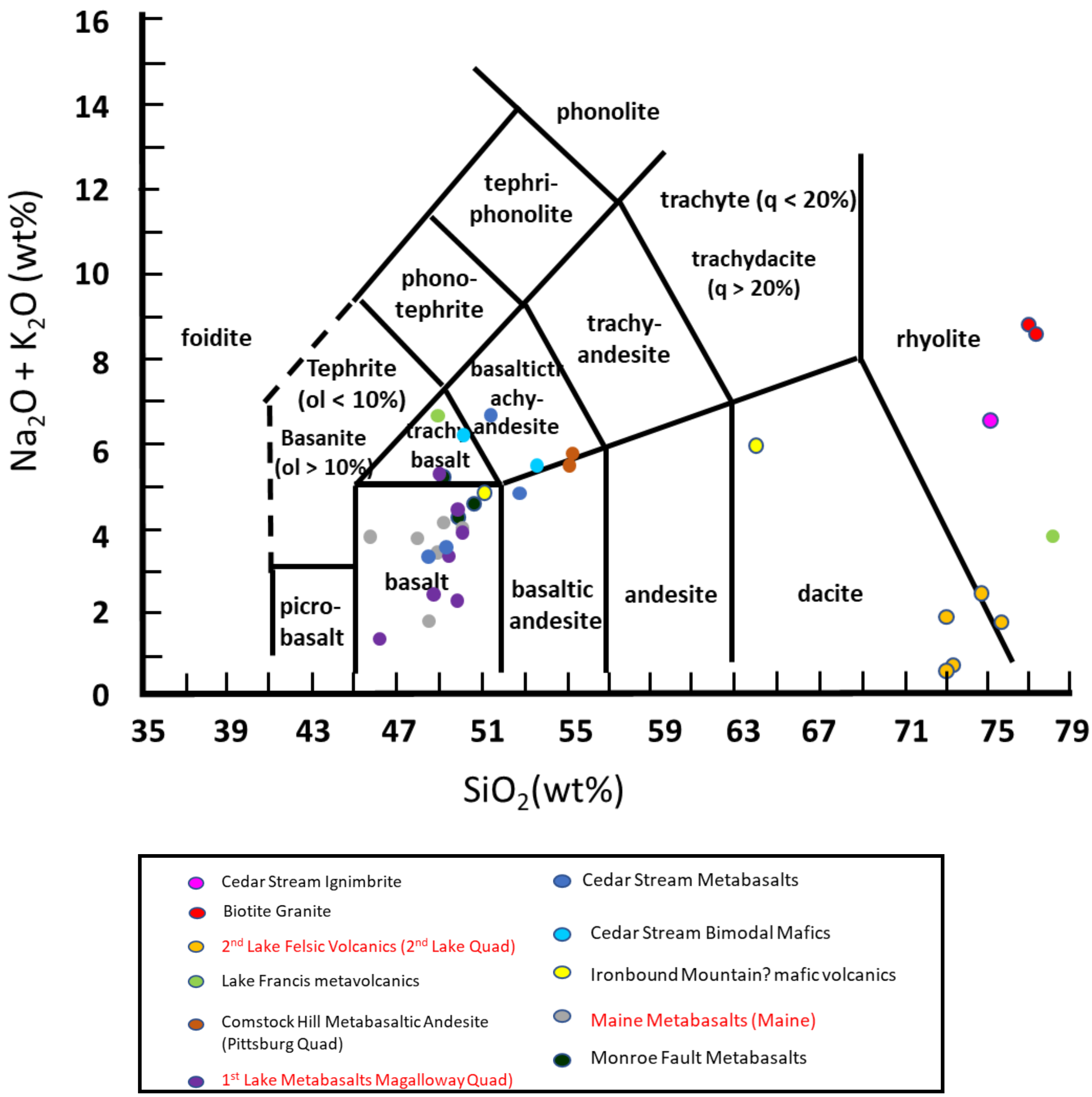


**Figure 9A: Frontenac MetaIgneous Rocks and Gile Mt metabasaltic andesite**
Major Element Chemistry – range of metabasalts, meta-basaltic andesites, dacites, rhyolites/granites.

*All red legend entries indicate data from Dorais et al., 2017; remaining data generated during collaboration with Professor M.J. Dorais (BYU)*

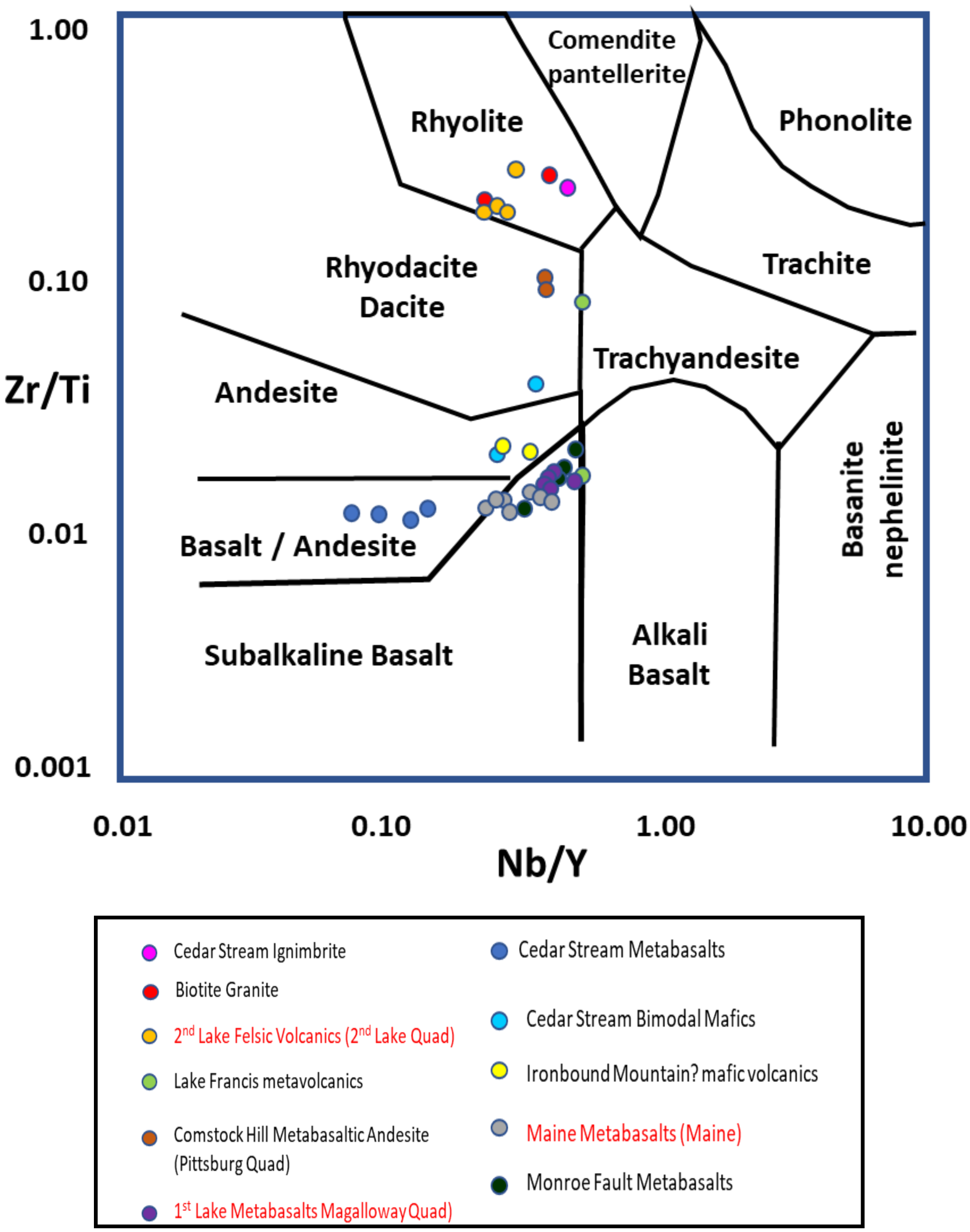


**Figure 9B: Frontenac MetaIgneous Rocks and Gile Mt metabasaltic andesite**
Trace element chemistry – see separation of metabasalts from Monroe Fault, similarity of biotite granite and metaignimbrite, unusual metabasaltic andesite from Gile Mt. (PIttsburg)

*All red legend entries indicate data from Dorais et al., 2017; remaining data generated during collaboration with Professor M.J. Dorais (BYU)*

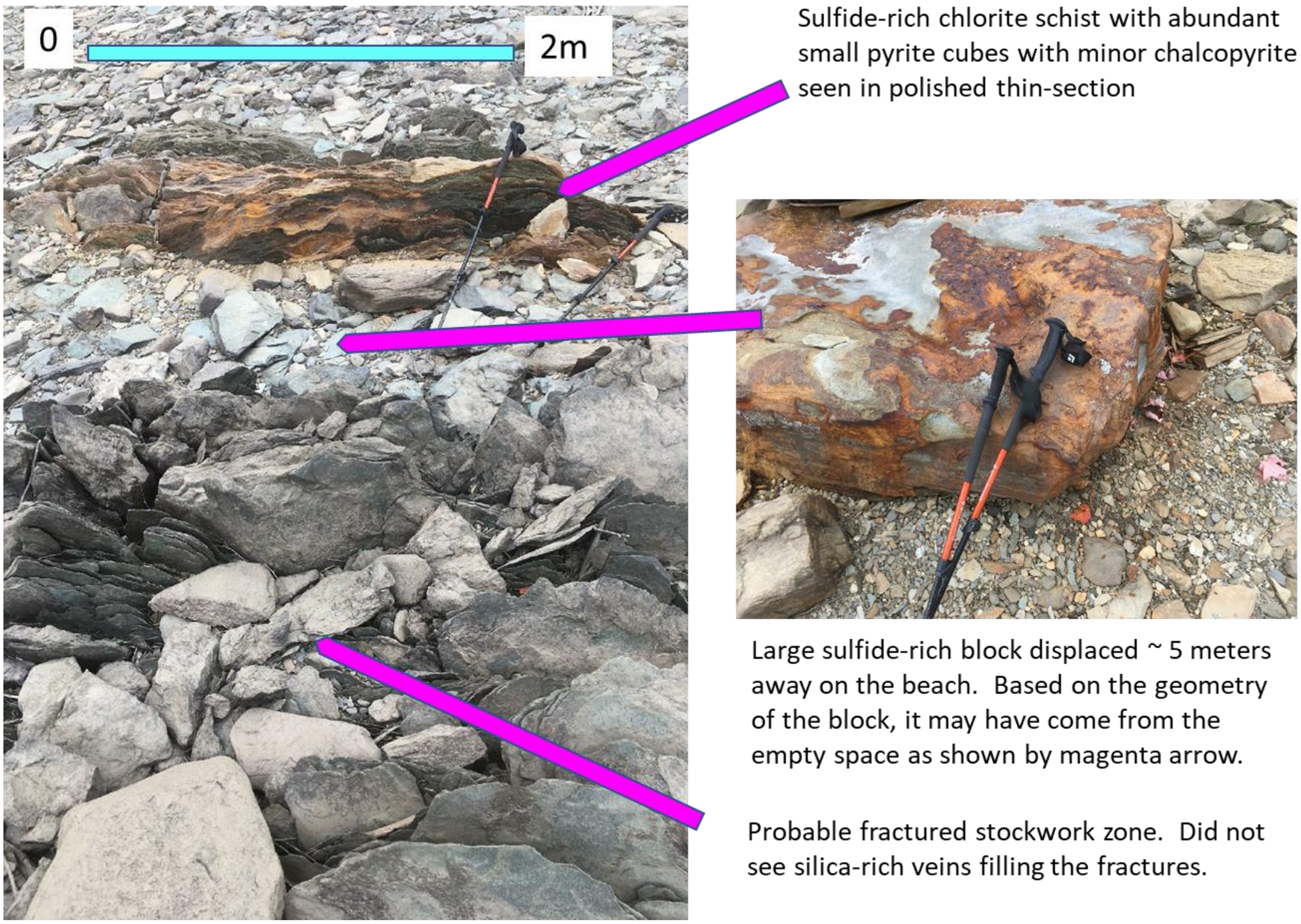


**Figure 10A: –** Exhalative Deposit (IS2020-211): Small Volcanic "Massive" Sulfide deposit: exhalative sulfide deposit (partially dismembered).

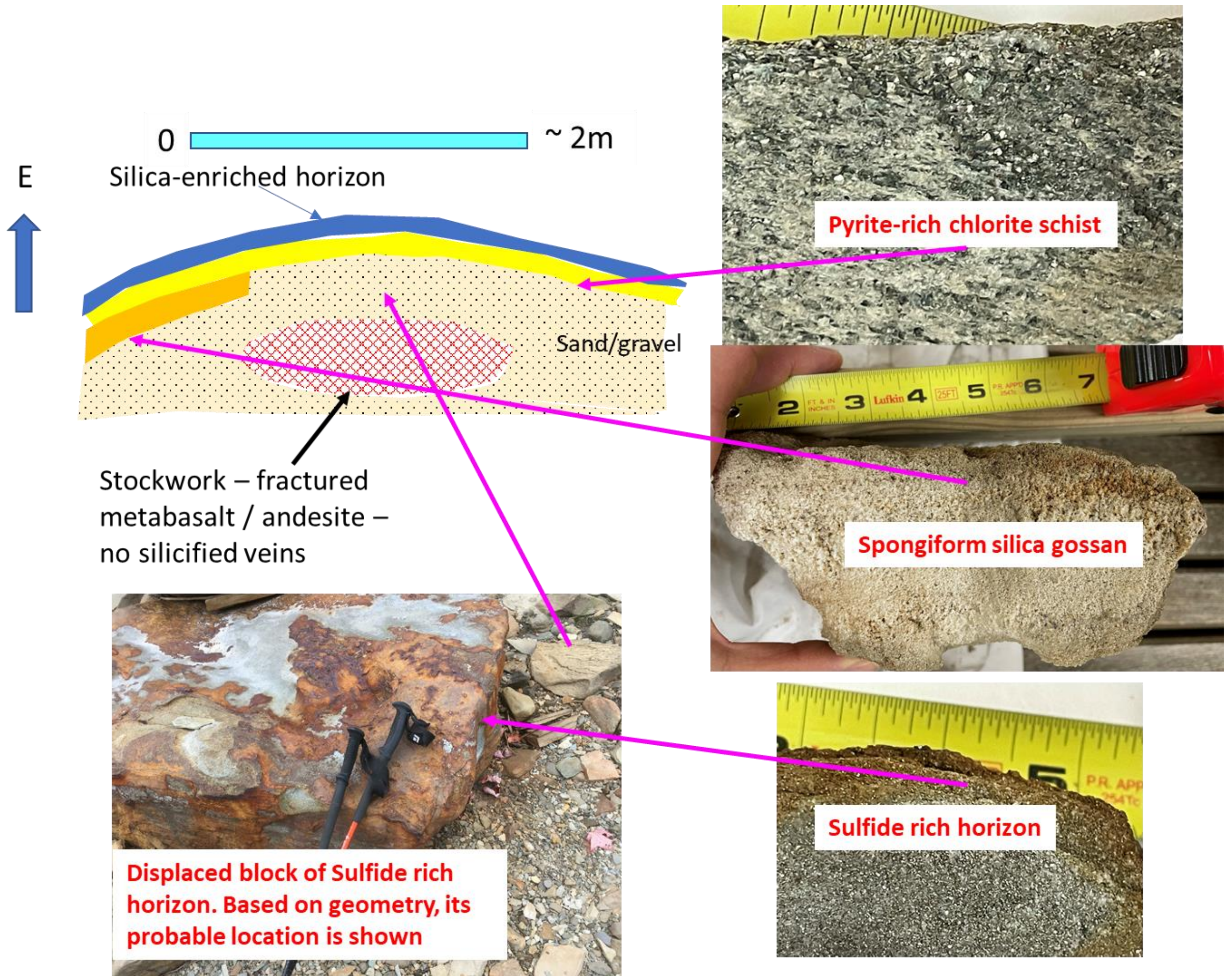


**Figure 10B:** Small Volcanic "Massive" Sulfide deposit (IS2020-211): small exhalative sulfide deposit with hand samples shown from different zones. Sketch figure tries to capture the key elements of the exhalative system.

## Table 1: Summary of Zircon U-Pb Age Dates

| Sample | Location | Formation | Crystallization Age (Ma) | Maximum Depositional Age (Ma) | Comments |
|---|---|---|---|---|---|
| 13MP26<br>0 | Quebec near NH border | Lac Drolet | | 413± 7 (2σ) | From Perrot, 2019 Ph.D thesis |
| IS2019-172<br>1 | Ridge W of Indian Stream (Pittsburg Quad) | Halls Stream Grits, Ironbound Mt | | 391 ± 2 (2σ) or 2 peak model 381-386 Ma and 397 -406 Ma | MWSD suggests two populations which may represent two events |
| IS2019-184<br>2 | Indian Stream Comstock Hill (Pittsburg Quad) | Metabasaltic Andesite | 403 ± 6 (2σ) | | Good result |
| IS20-18<br>3 | Tabor Notch Rd & US 3 (Pittsburg Quad) | Gile Mt | | 411 – 414 ± 8 - 10 (2σ)<br>Alt: 391 ± 6 (2σ) | Loc. of Emsian fossils; Difficult younger ages |
| IS2019-222<br>4 | Lake Francis Spillway (Pittsburg Quad) | Gile Mt | | 413 ± 8 (2σ) or<br>443 ± 5 (2σ) | Few young ages with discordance < 15% |
| IS2020–112<br>5 | N Shore Lake Francis (Lake Francis Quad) | Front. meta-volcaniclastics | | 408 ± 6 (2σ) | Reasonable |
| IS2020-207A<br>6 | NE Corner Lake Francis (Lake Francis Quad) | Front. meta-volcaniclastics | | 603 ± 17 (2σ) Ma<br>Alt. 443 ± 16 (2σ) Ma | Very few "young" ages and high discordances. |
| IS2020-151RV<br>7 | Cedar Stream (Lake Francis Quad) | Biotite meta-Granite | 411 ± 7 (2σ) | | Tight age distribution |
| IS2019-242<br>8 | Cedar Stream (Lake Francis Quad) | Mafic metavolcanic | | 459± 16 (2σ) | Very limited younger age data. |
| IS2020-94<br>9 | Cedar Stream (Lake Francis Quad) | Meta-Ignimbrite | 411 ± 3 (2σ) | | Tight age distribution |
| IS2020-102<br>10 | SE corner Lake Francis (Lake Francis Quad) | Metabasalt | | N/A | Did not recover any zircons |
| IS2020-56<br>11 | Lang Hill, Lovering Mt. Quad | Calcium-rich Metadiorite | | N/A | Only recovered 7 zircon grains |