Geological Assessment of Ultramafic and Mafic Rocks in Virginia: Prospects for Critical Mineral Extraction and Carbon Mineralization

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Introduction

- Carbon storage has been considered as a promising solution in offsetting greenhouse gas emissions; carbon mineralization offers an alternative form of permanent storage solution
  - Targets both in-place and mine waste rocks at the subsurface or surface
  - Fewer long-term CO_2-leakage concerns compared to saline storage methods and lower monitoring costs
- Multiple geological units in Virginia provide potential mineralization feedstocks
- The process of mineralization presents opportunities for critical mineral extraction, such as cobalt (Co) and nickel (Ni), thus adding further value to the storage process

Goal: Identify and characterize the suitable feedstocks in Virginia for carbon mineralization and mineral extraction (CMME) technology development

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CO_2 Mineralization

CO_2 reacts with rocks and minerals to form solid and stable carbonate rocks

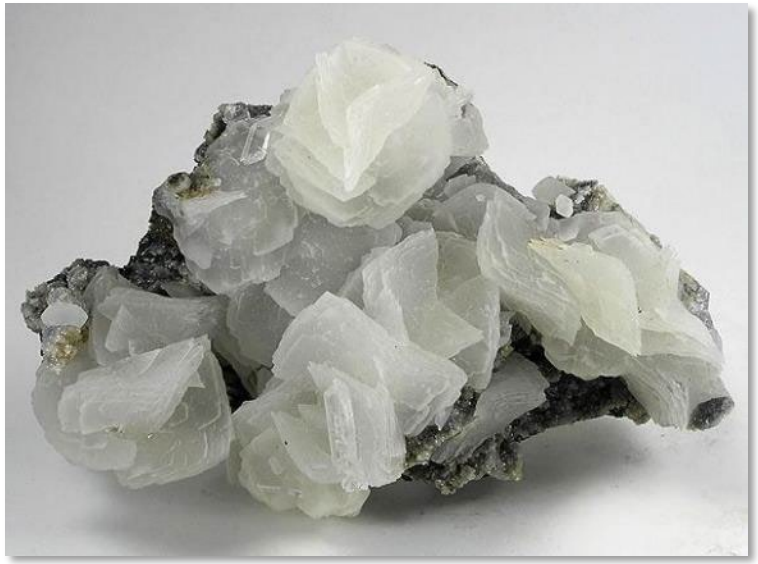
Mg^{2+}, Ca^{2+} bearing mineral + CO_2 from gas or fluid → Carbonates ($MgCO_3$, $CaCO_3$) and SiO_2

Basalt

Mine tailing

In situ: in-place rocks
Ex situ: industrial byproducts

Carbonate mineral: magnesite



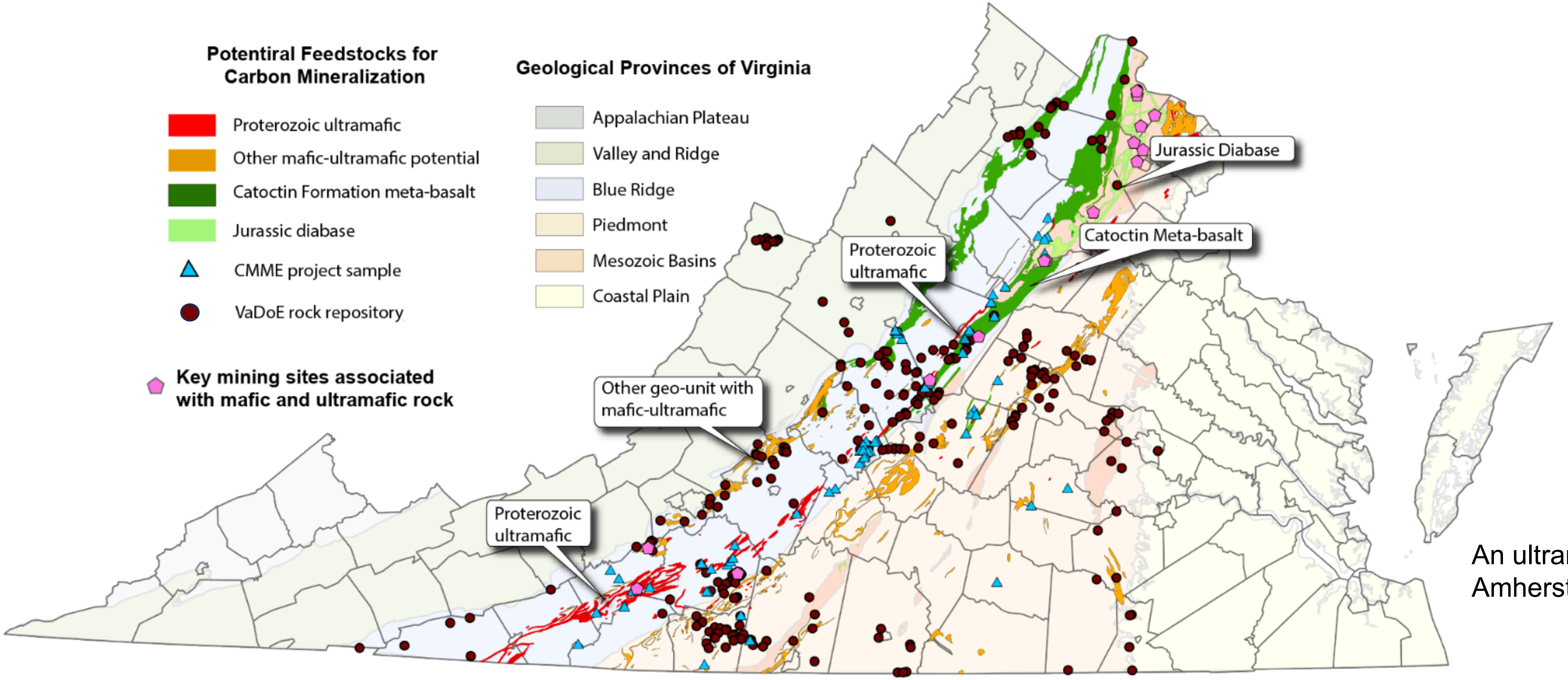
Carbonate mineral: calcite

- Minerals: **Olivine:** $(Mg,Fe)_2SiO_4$; **Pyroxene:** $(Mg,Fe)_2Si_2O_6$ to $Ca(Mg,Fe)_2Si_2O_6$; **Plagioclase:** $(CaAl_2Si_2O_8)$; **Talc:** $Mg_3Si_4O_{10}(OH)_2$; **Chlorite:** $(Mg,Fe, Al)_3(Si,Al)_4O_{10}(OH)_2$; **Amphibole:** $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
- Ultramafic and mafic rock type: Dunite, Peridotite, Soapstone (talc-schist), Basalt, Gabbro, Amphibolite

Blondes et. al., 2019; Image source: https://www.usgs.gov/; https://vtdigger.org/

Suitable Mafic and ultramafic rocks in VA

- Ultramafic rocks of Proterozoic age
- Meta-basalt of Proterozoic age
- Mafic diabase rocks of Jurassic age
- Other mafic-ultramafic units in Blue Ridge and Piedmont geologic provinces

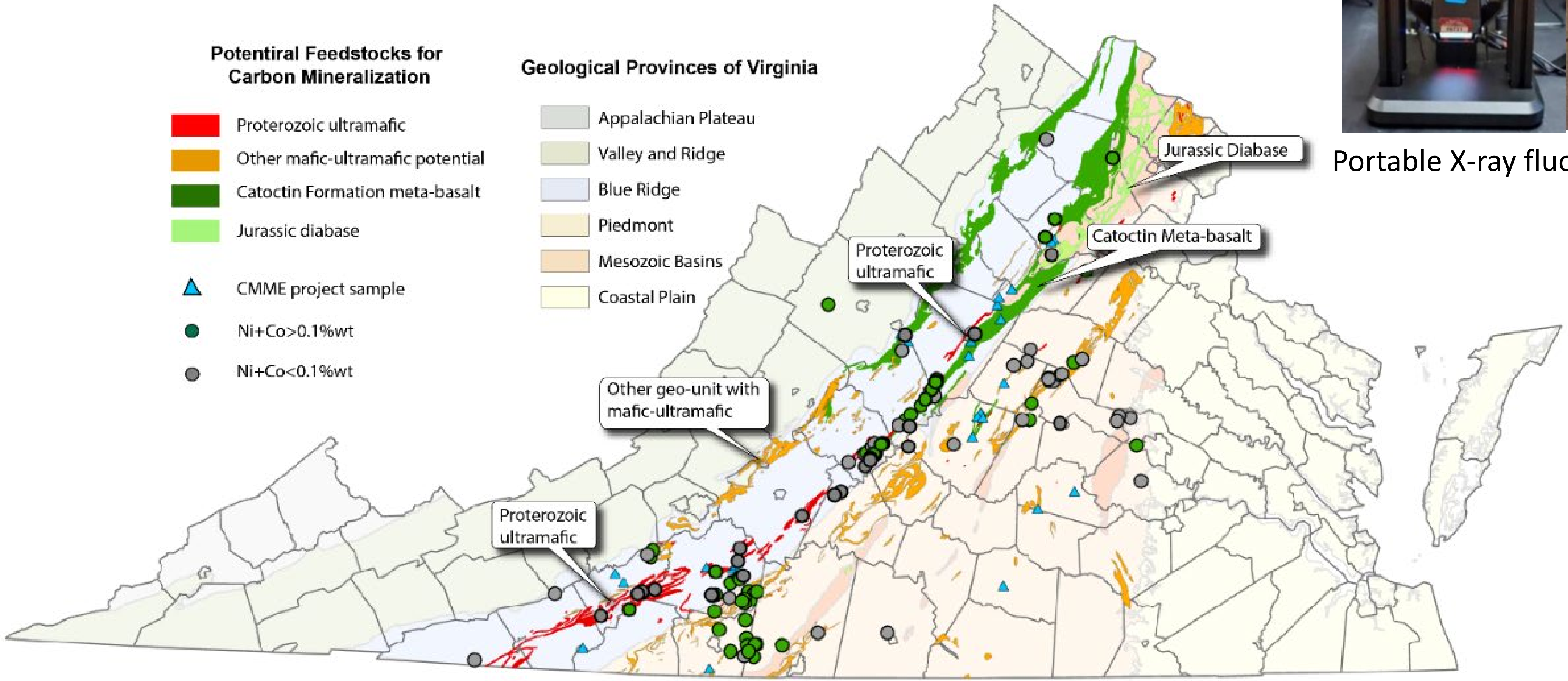


An ultramafic outcrop, Amherst County, VA

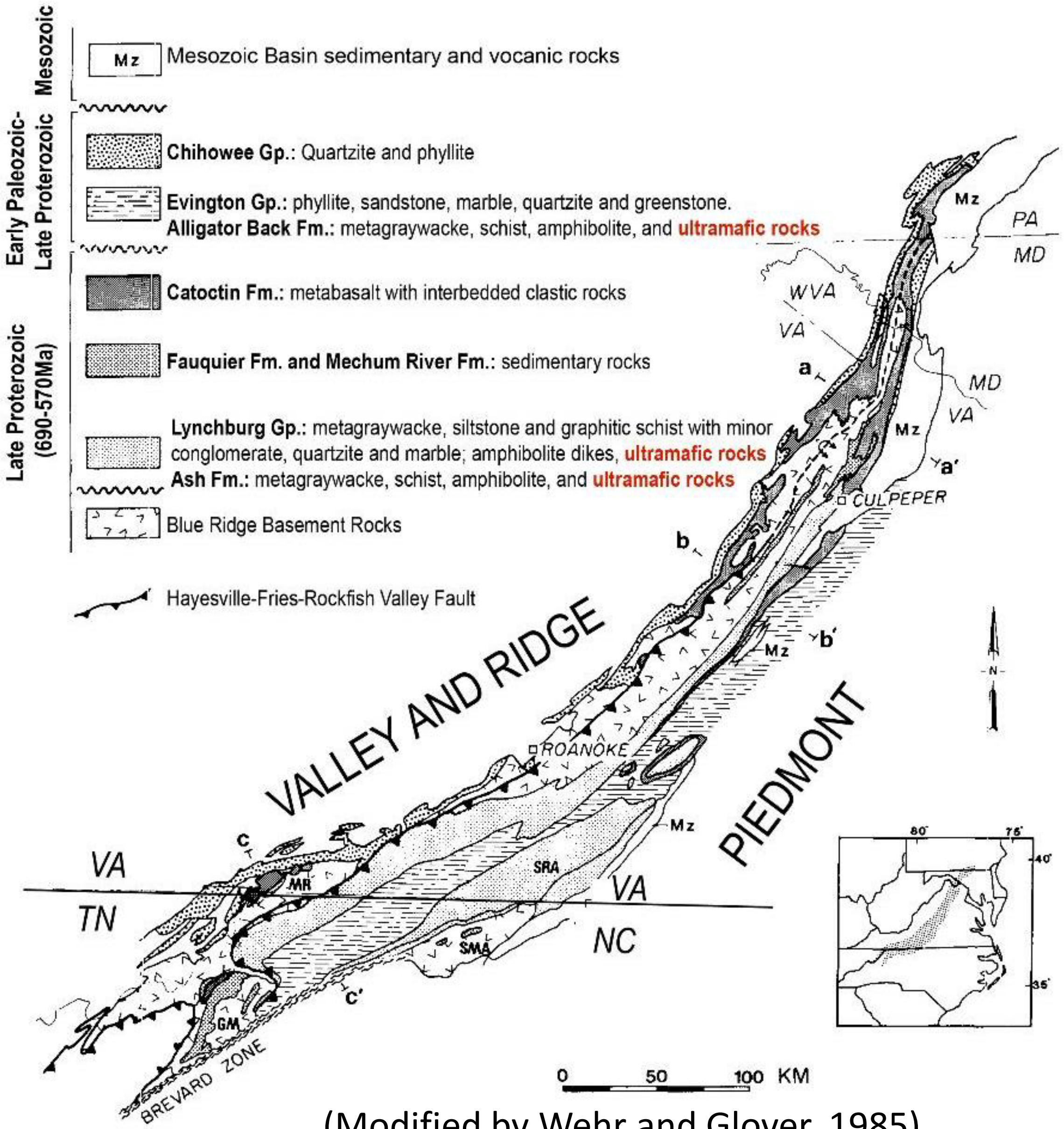
Preliminary geochemical screenings

- ultramafic rocks exhibited elevated concentrations of nickel and cobalt with reconnaissance PXRF analysis

Portable X-ray fluorescence instrumentation



Geologic Setting



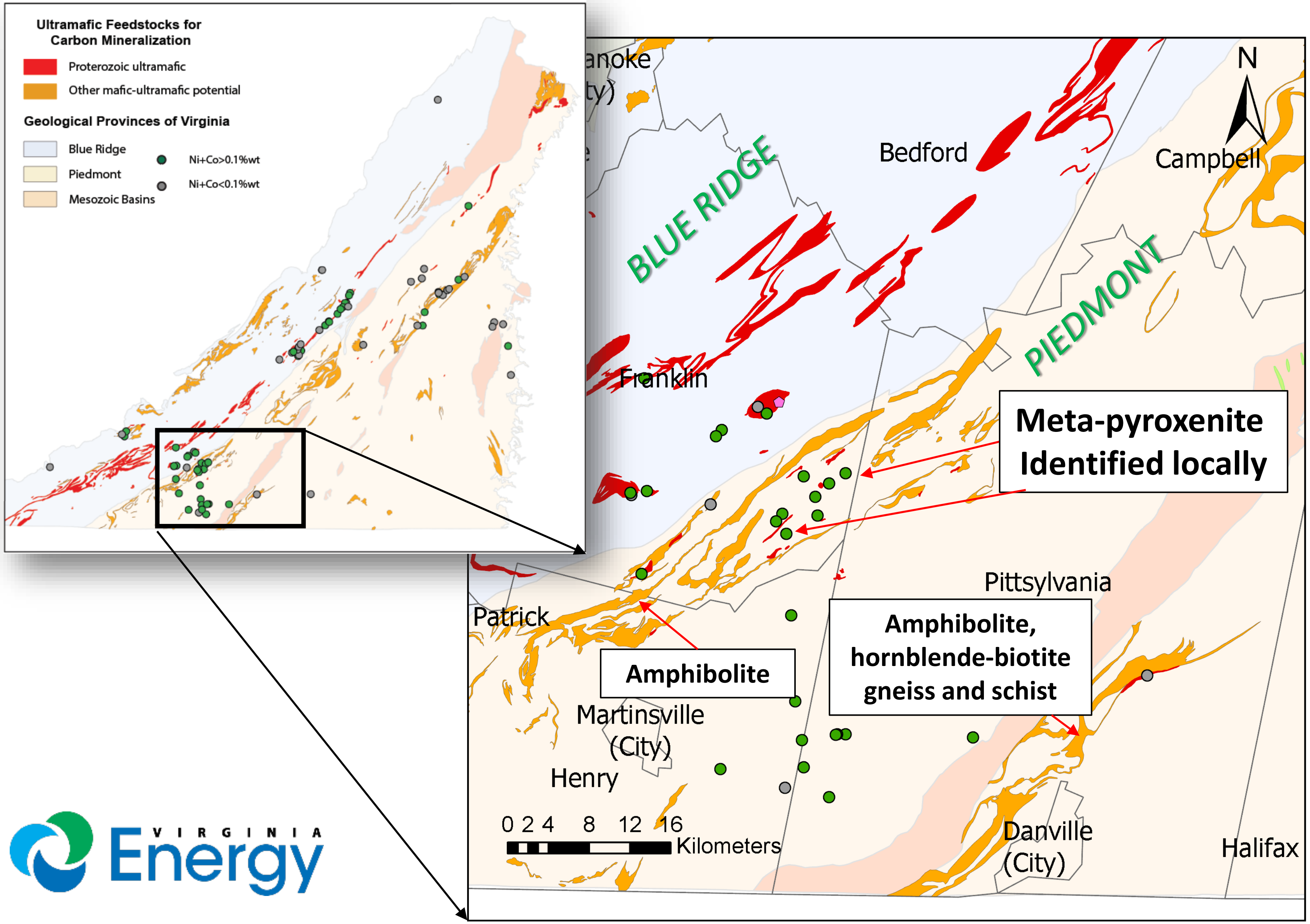
(Modified by Wehr and Glover, 1985)

Blue Ridge Province

- Ultramafic rocks are occurred as elongated lenses and belts (up to ~60 km) within the meta- sedimentary and meta-volcanic rocks
- Lynchburg Formation: dikes and sills of chlorite schist, pyroxenite, within metagraywacke, siltstone, amphibolite dikes, and graphitic schist
- Ashe and Alligator Back Metamorphic Suites: lenses of ultramafic rocks (ophiolitic fragments) within metagraywacke, schist, and amphibolite

Part of our research data is supporting current USGS study: Becker et. al., 2024: SEGSA Presentation 32 - 9 (Top of the Plaza)

Geologic Setting



Piedmont Province

- Small lenses of talc-chlorite schist within mélange phyllite and schists
- Southwest Piedmont: small pods and lenses of altered and deformed pyroxenite, dunite, and peridotite in high grade gneiss, schists, and amphibolite

Witt et al, 2021; Butler 1985

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Field study

Chlorite schist

Altered ultramafic outcrop, Franklin County

Soapstone, Nelson County

Altered ultramafic, Patrick County

Rock repository of meta-pyroxenite, Pittsylvania Co.

Meta-pyroxenite, Amherst County

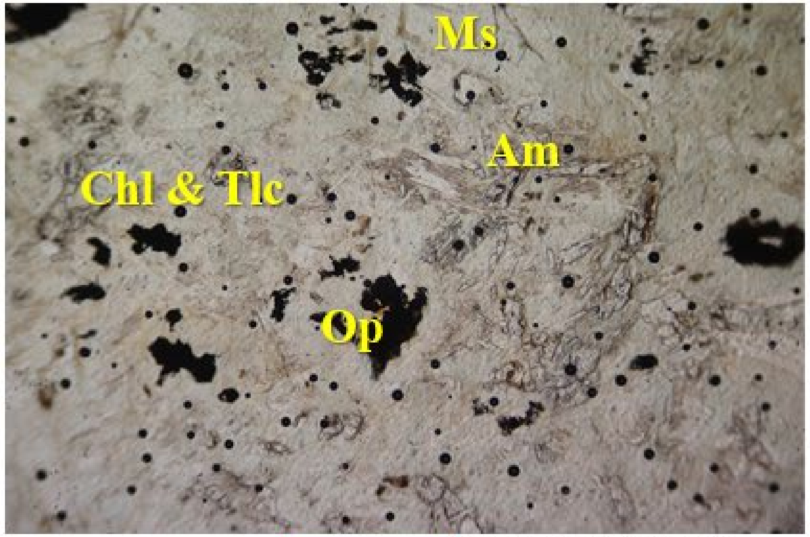
Meta-pyroxenite with asbestos fiber, Lynchburg

Meta-pyroxenite

Mineralogy: Chlorite schist

Chl-chlorite; Tlc-talc, Op-opaque mineral, Calc-calcite, Ms-muscovite, Am-amphibole, Px-pyroxene

PPL



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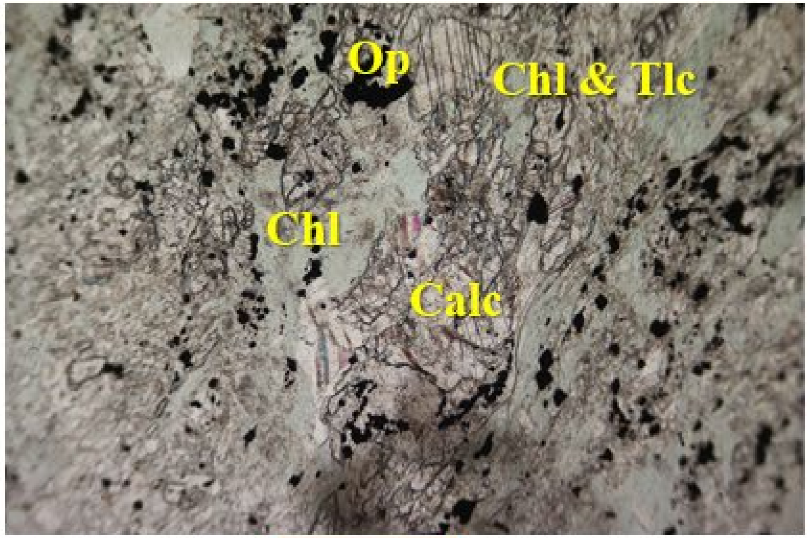

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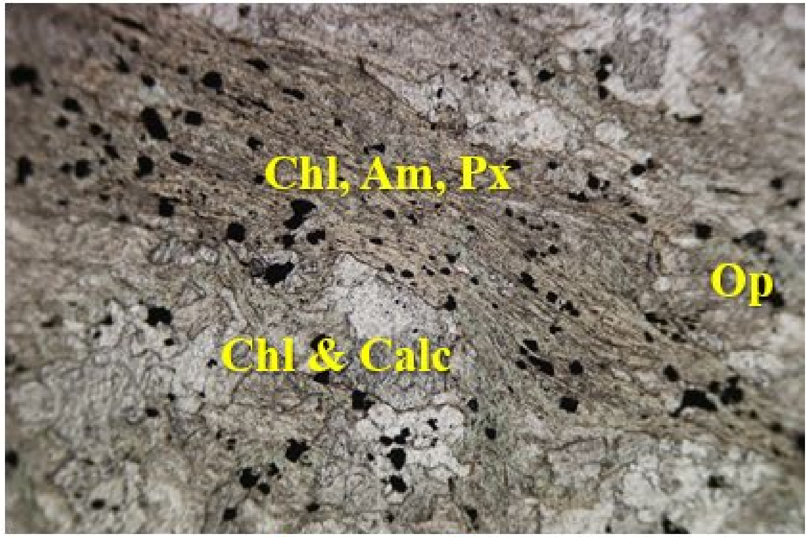

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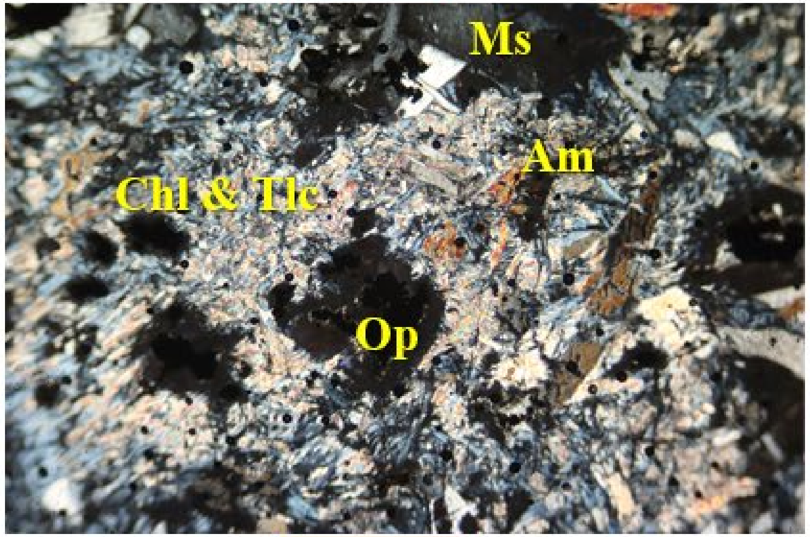

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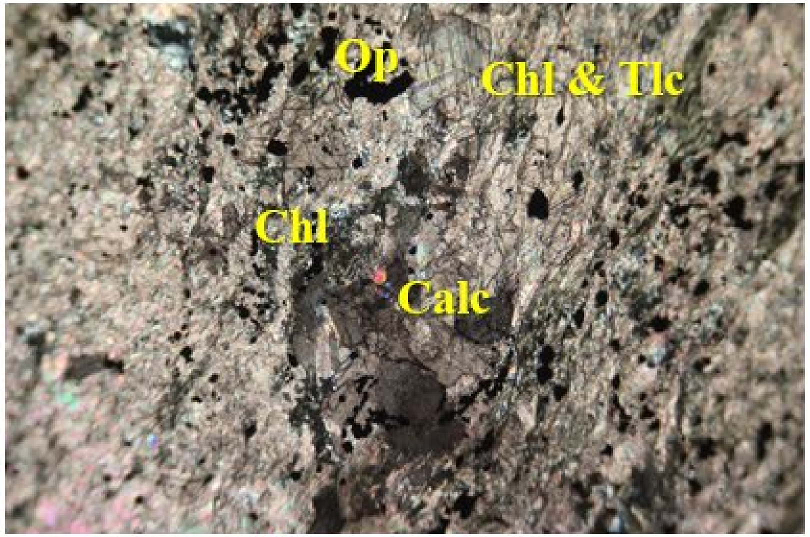

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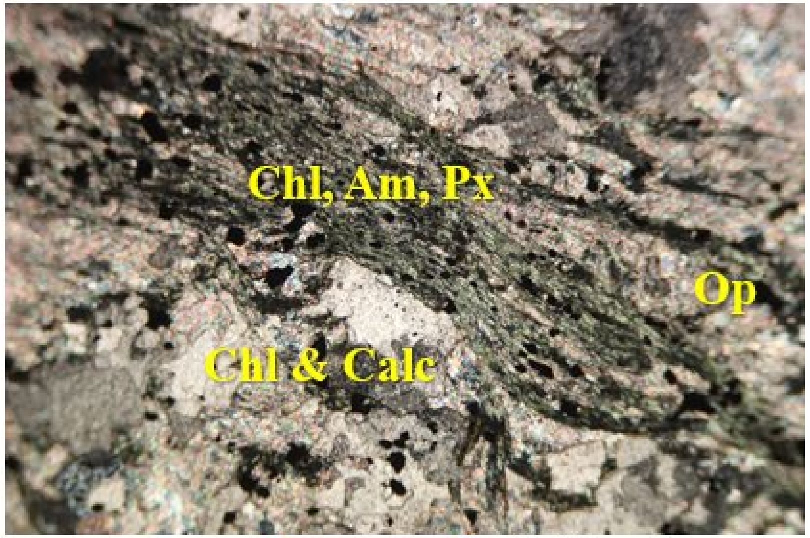

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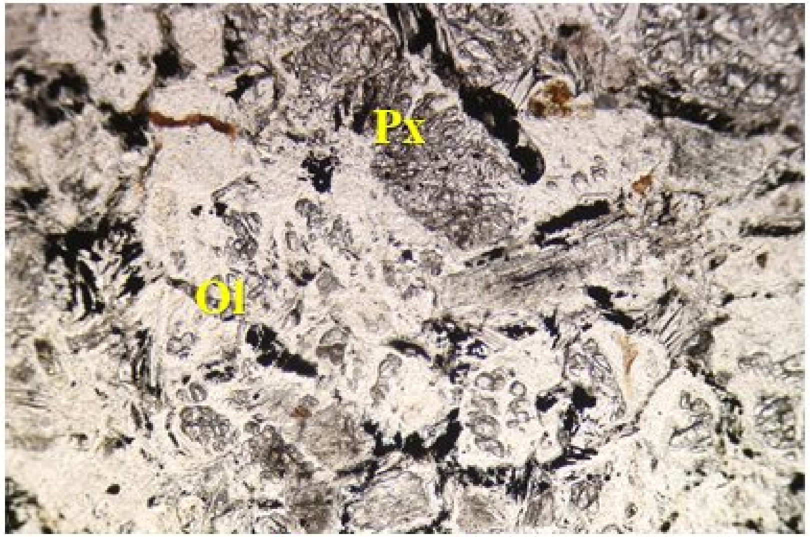
Mineralogy: Meta-pyroxenite

Am-amphibole, Px-pyroxene, Opx-orthopyroxene, Ol-olivine altered, frac-fracture

PPL



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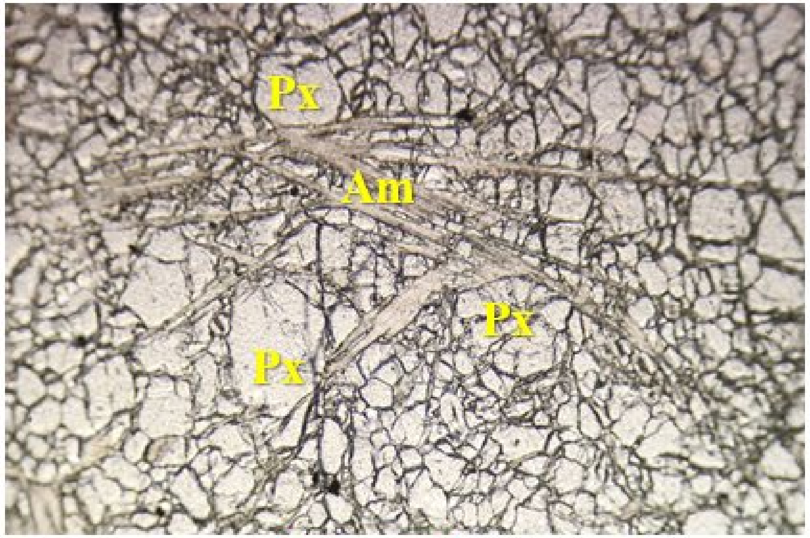

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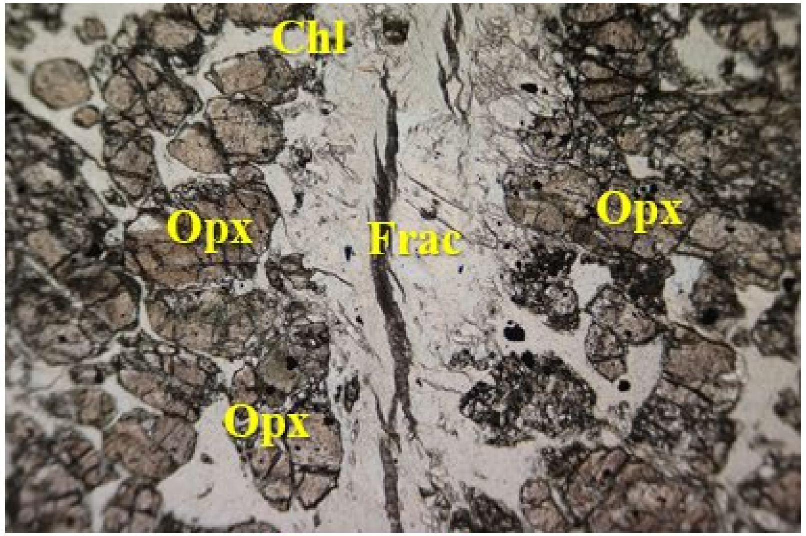

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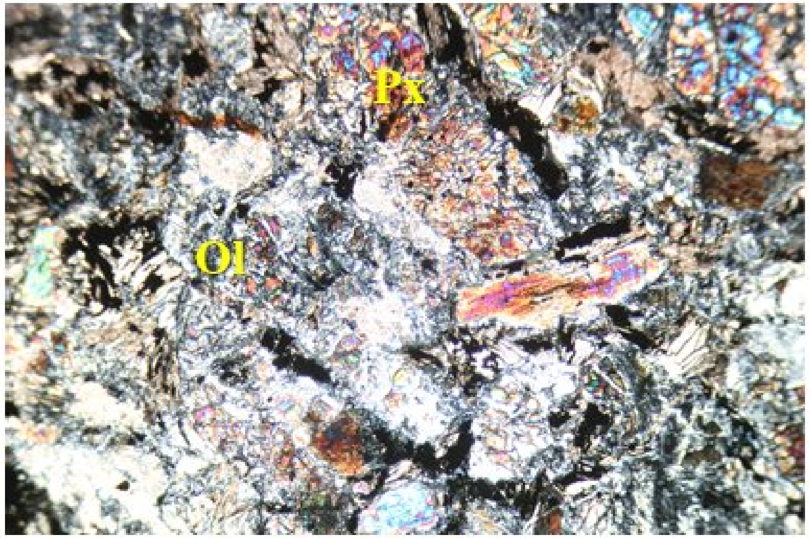

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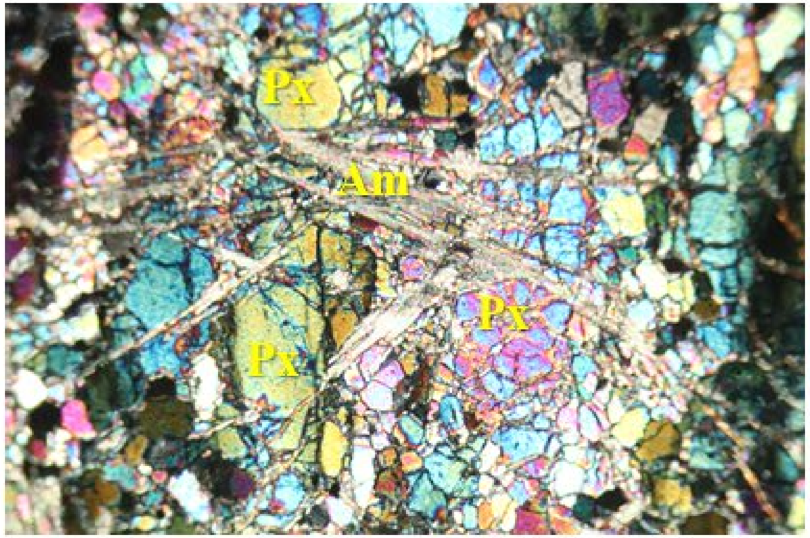

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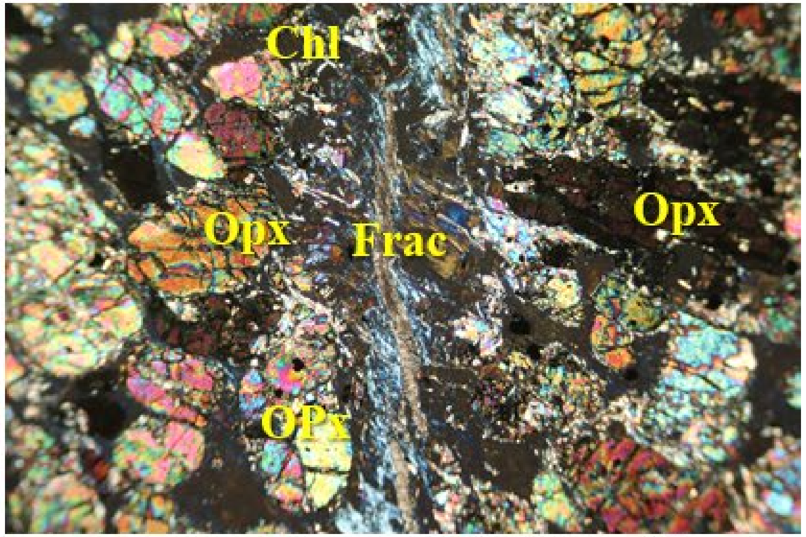

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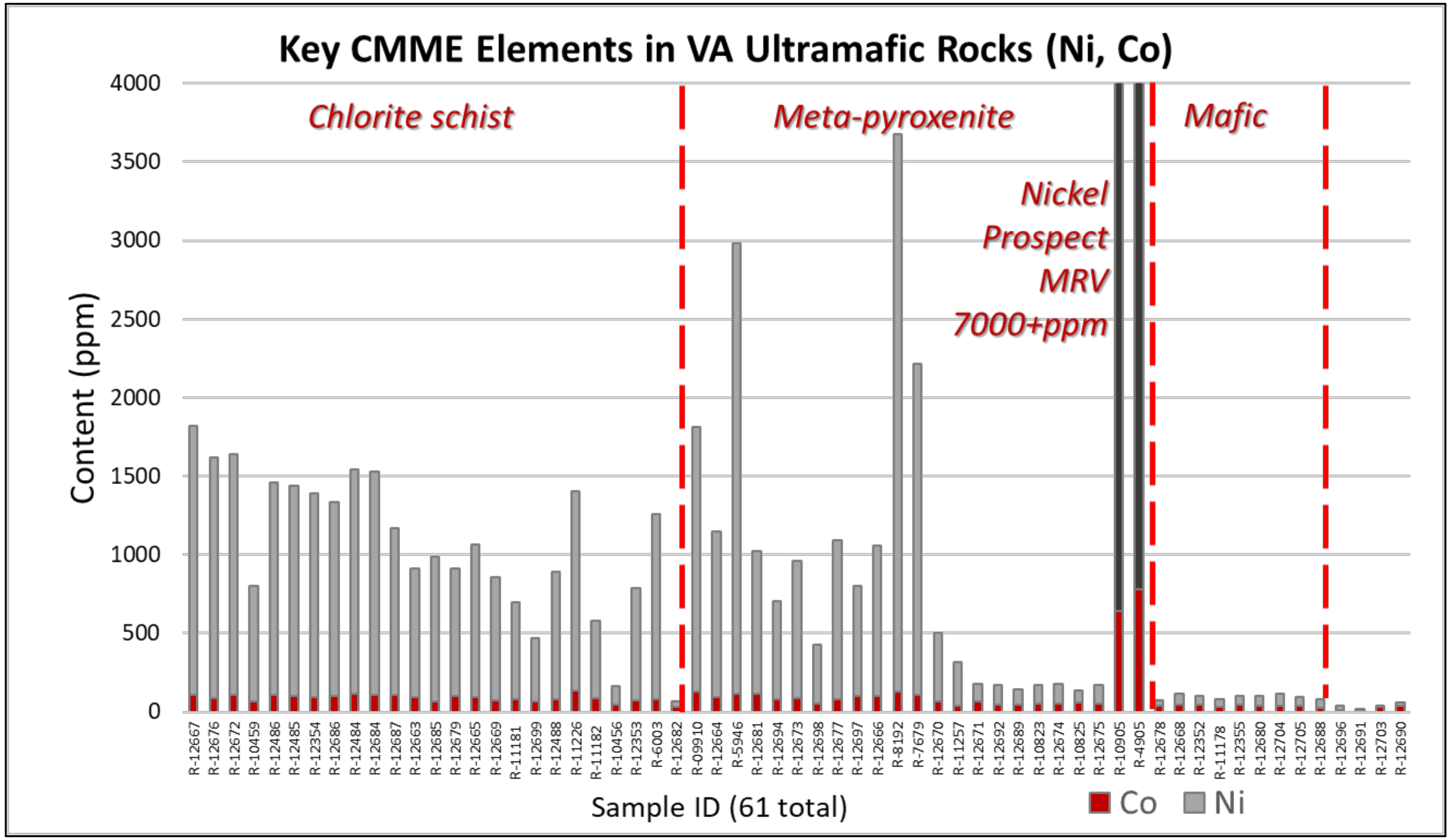
Geochemistry: CMME potentials



Concentration of CMME-associated elements from major and trace element analysis at commercial labs

<u>Mineral extraction (ME) threshold</u>:

Ni+Co> 0.1wt% (1000ppm), ideally >0.5wt% (5000ppm)

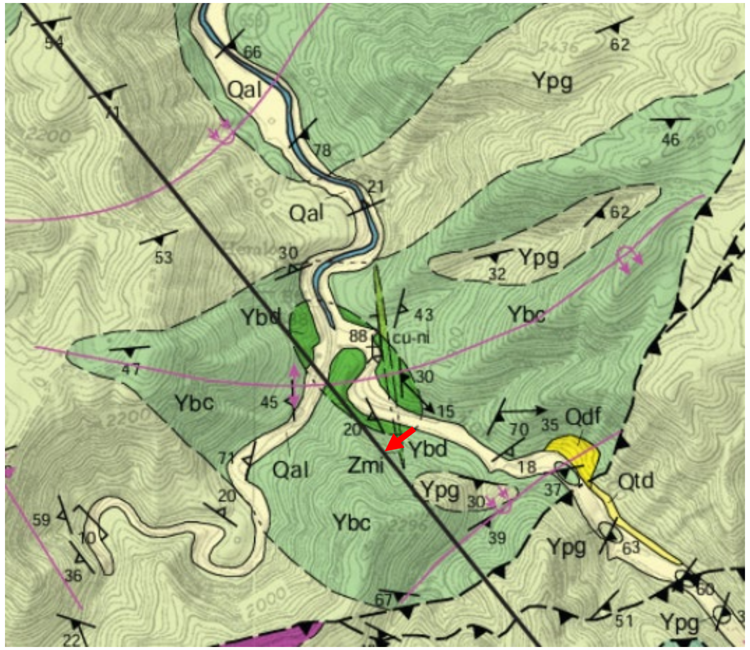
- Ultramafic rocks generally exhibit elevated Ni and Co concentrations: chlorite schist samples often exhibit Ni concentration >0.1wt%; Ni concentration in meta-pyroxenite varies but some demonstrate significant potential
- Co concentrations are generally less than 200 ppm

Nickel Prospect at VA

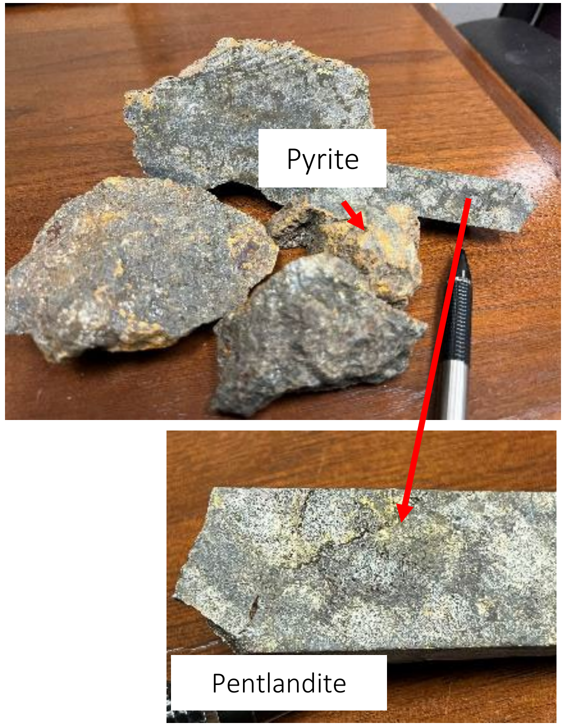
Milestone: Identified one Virginia economic mineral location that has (Ni + Co) concentrations up to 0.7 wt%

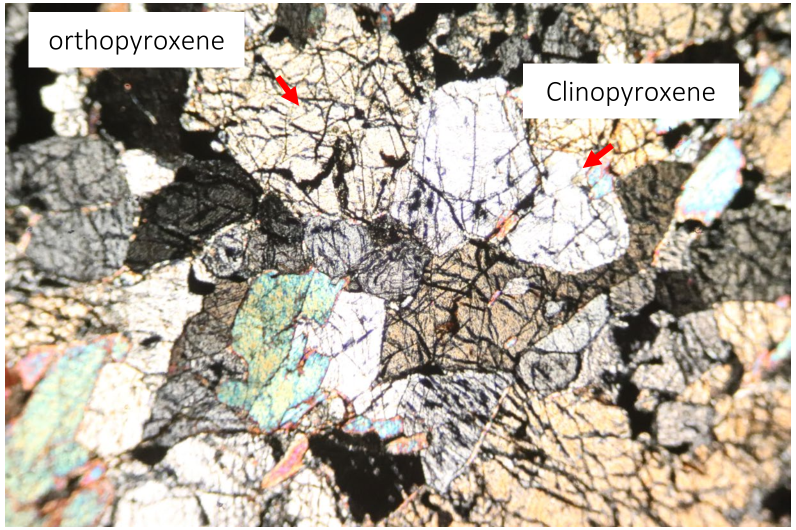
Lithology	Sulfide ores are hosted by mafic and ultramafic rocks ranging in composition from pyroxenite to gabbro
Mineral observed	Pyroxene, pyrrhotite, pentlandite, pyrite, chalcopyrite, ilmenite, magnetite, and violarite (a secondary oxidation mineral of pentlandite)
Key elements for CMME	Ni: 6480 ppm; Co: 642 ppm MgO: 16.56wt%; Fe_2O_3: 37.18wt%; CaO: 1.4wt%; SiO_2: 27.32wt%

Lick Fork Nickel Prospect, Floyd Co., VA



Nickel ore hosted by ultramafic, metadiorite, and metagabbro





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Hand specimen (left); thin section (right, 4X magnification, cross-polarized)

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Discussion

- Chlorite schist, while more widespread, tends to have lower overall Ni and Co content. Conversely, meta-pyroxenite at certain locations may host significant concentrations of Ni and Co, but with potentially limited distribution
- Both types of ultramafic outcrops pose challenges in terms of accessibility, and fresh sample acquisition. Additionally, there is a lack of studies quantifying the thickness of both mafic and ultramafic rocks. It is recommended to conduct scientific well drilling to obtain unweathered core samples and to study the thickness for CMME resource assessment
- The ultramafic and mafic rocks are lack of primary porosity but contain fractures as secondary porosity for in-situ storage through carbon mineralization

Takeaway and future investigation

- Virginia hosts a remarkable abundance of ultramafic and mafic rocks that could potentially contribute to carbon mineralization storage
- Within Virginia's ultramafic formations, two rock types have been identified which have good mineral extraction potential: chlorite schist and meta-pyroxenite
  - Chlorite schist samples have been found to have Ni concentrations greater than 0.1 wt% (1000 ppm)
  - In meta-pyroxenite samples, Ni concentrations vary, but some locations show high concentrations (~ 0.7 wt%; 6480 ppm) and future exploration potential
  - Cobalt (Co) concentrations in the chlorite schists and meta-pyroxenite are generally less than 200 ppm
- Mafic rocks samples do not indicate elevated Ni or Co concentrations, generally less than 100 ppm
- Current efforts continue by:
  - Searching for suitable ultramafic feedstocks for CMME
  - Mafic and ultramafic mapping for carbon mineralization resource assessment

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Thank You!

This study is funded by Department of Energy, ARPA-E Program through Virginia Tech: DE-AR0001710: Energy-relevant elements recovery from CO_2-reactive minerals during carbon mineralization

Acknowledgement:

- Virginia Tech: Wencai Zhang and Bin Ji
- USGS: Mark Carter and Naomi Becker
- Virginia Energy: Michelle Nelson, Nick Evans, Patrick Finnerty (Geology and Mineral Resources Program), and Willie Cochran (Mineral Mining Program)
- Activation Laboratories, Ltd.
- Quality Thin Sections

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