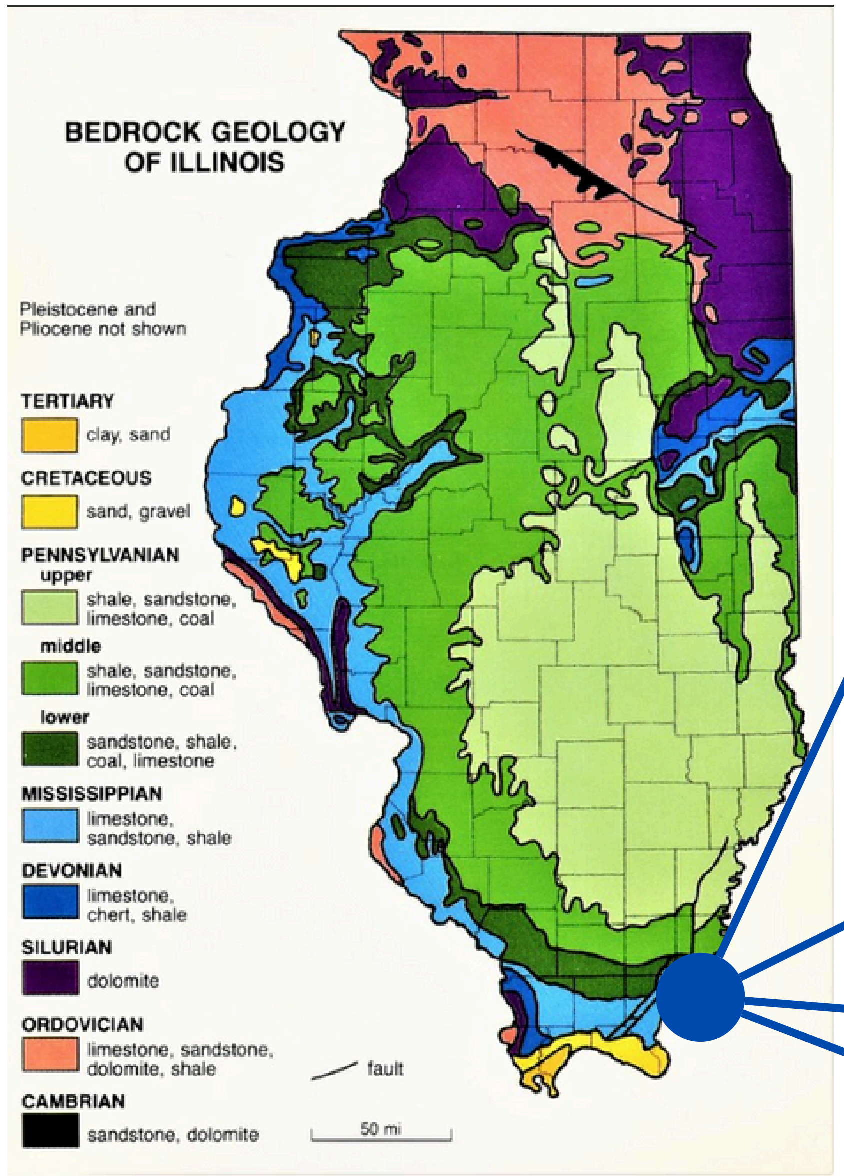
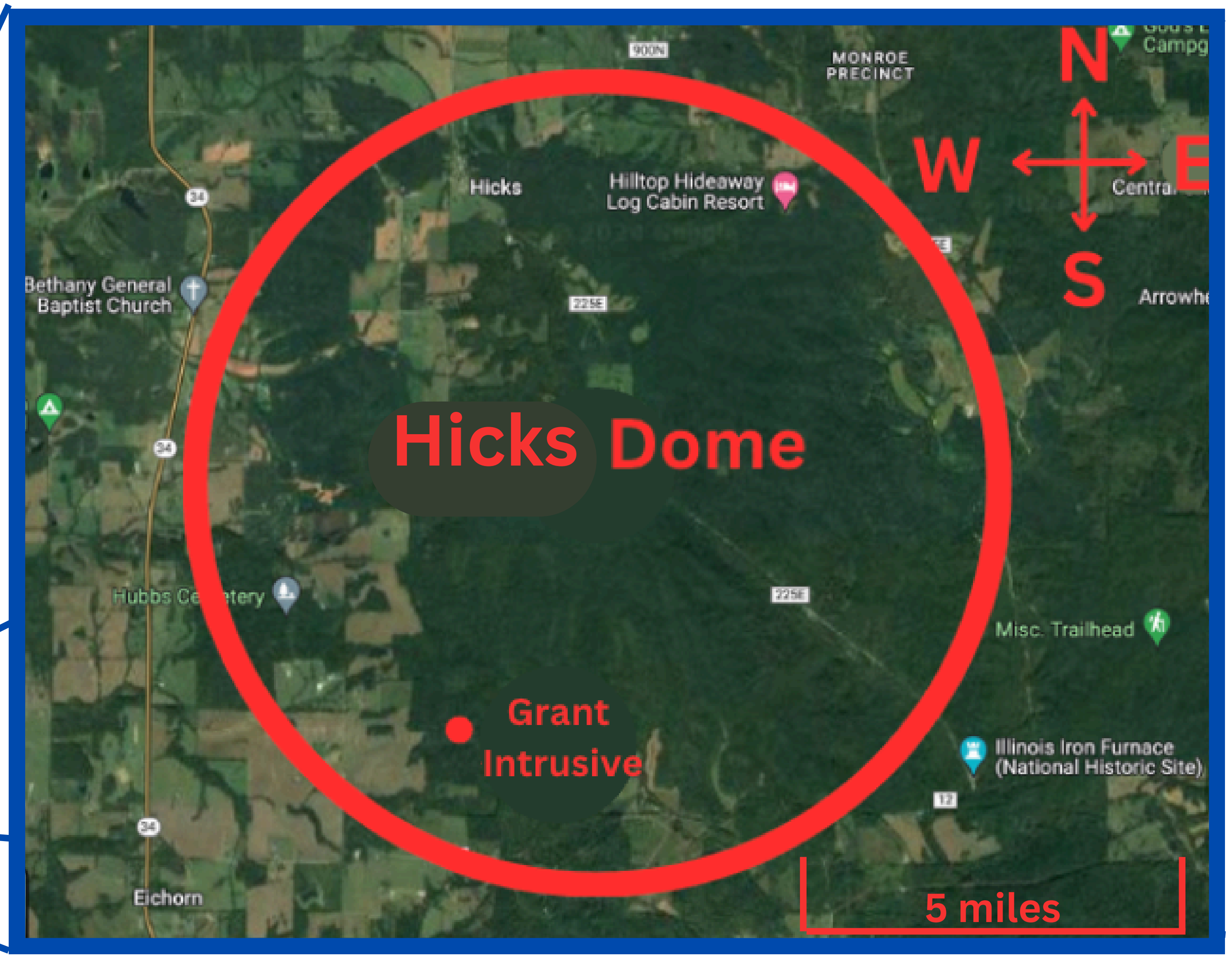
Petrological and Geochemical Analysis of the Grant Intrusive Breccia within Hicks Dome, Hardin County, Illinois





Presented By: Aaron Beirl

Southern Illinois University Carbondale - School of Earth Systems and Sustainability

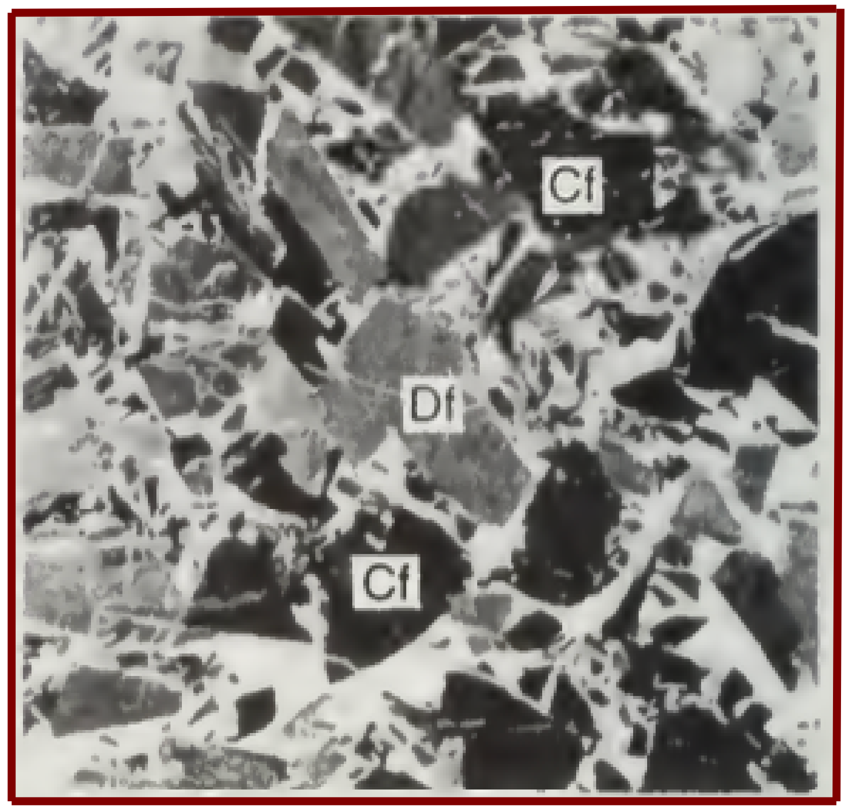
09/23/2024

Background Information on Grant Intrusive

- Part of the Hicks Dome crypto-volcanic structure
  - Explosive emplacement but cooled rapidly
  - Formed in multiple events?
- Contain's amalgamations of alkaline, carbonatitic, and ultramafic gabbros
  - Elevated concentrations of iron (Fe), magnesium (Mg), calcium (Ca), and potassium (K), compared to SiO_2
- Classified as a lamprophyric dike / shatter breccia **(Bradbury and Baxter, 1992)**
- Ore deposits are hypothesized to contain concentrations of titanium (Ti), barium (Ba), and thorium (Th), as well as heavy rare earth elements (HREEs), such as yttrium (Y) and scandium (Sc)
- Reynolds et. al.'s petrographic analysis confirmed the presence of magnetite (Fe_3O_4) coated with ilmenite ($FeTiO_3$)
- Suggested that Ti- saturation occurred during initial magma placement, crystalized during rapid cooling

(Reynolds et al. 1997)

Shatter Breccia



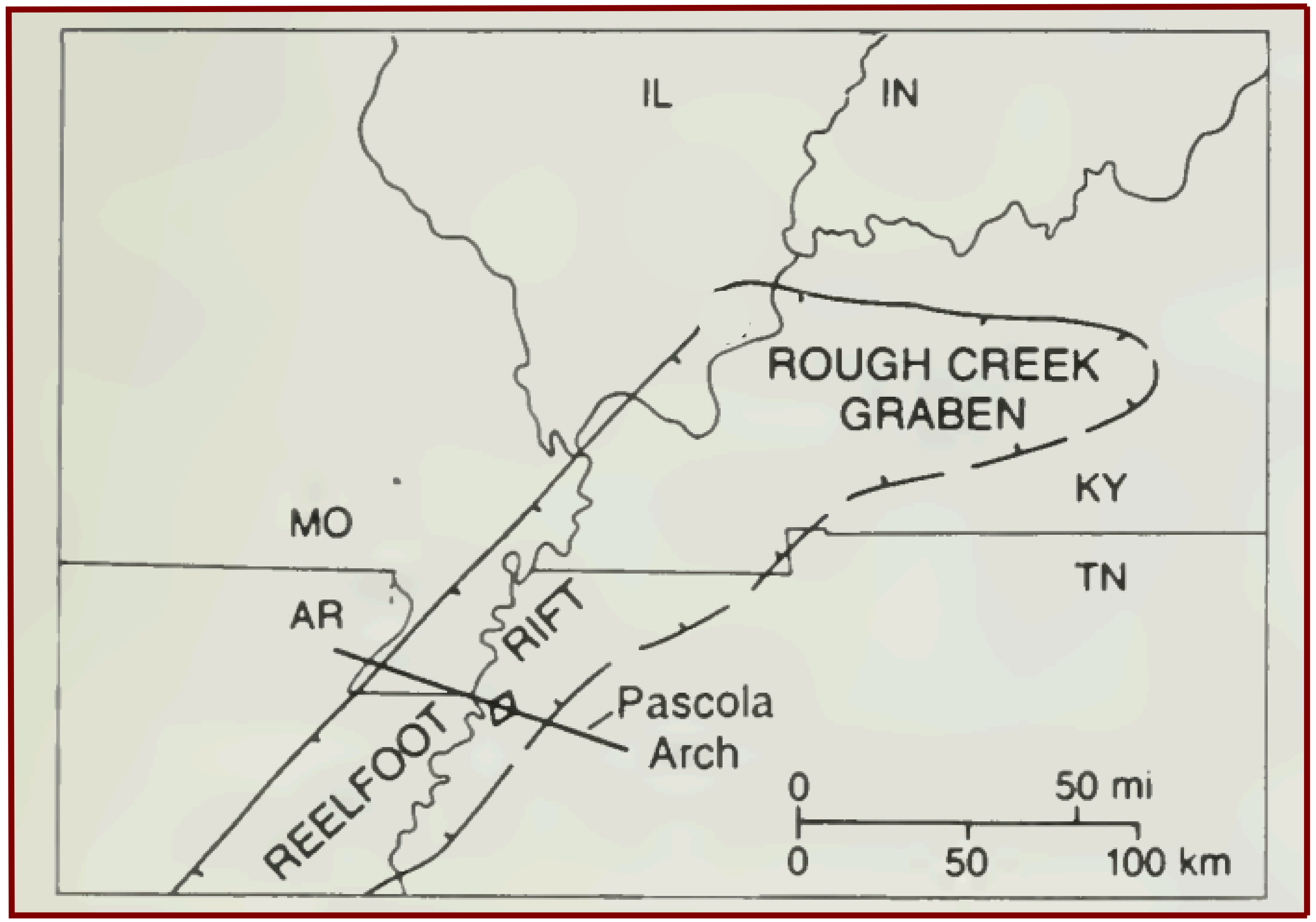
Cf = Carbonaceous Shale
Df = Dolomite Fragments
(Bradbury and Baxter, 1992)

Timeline of Events

1. **PЄ -> Є(~1Ga)**

a. Breakup of Rodina fomed the Reelfoot Rift and Rough Creek Graben

Map of Reelfoot Rift / Rough Creek Graben



(Bradbury & Baxter, 1992)

(Reynolds et al. 1997)

Timeline of Events

1. **P€ -> €(~1Ga)**

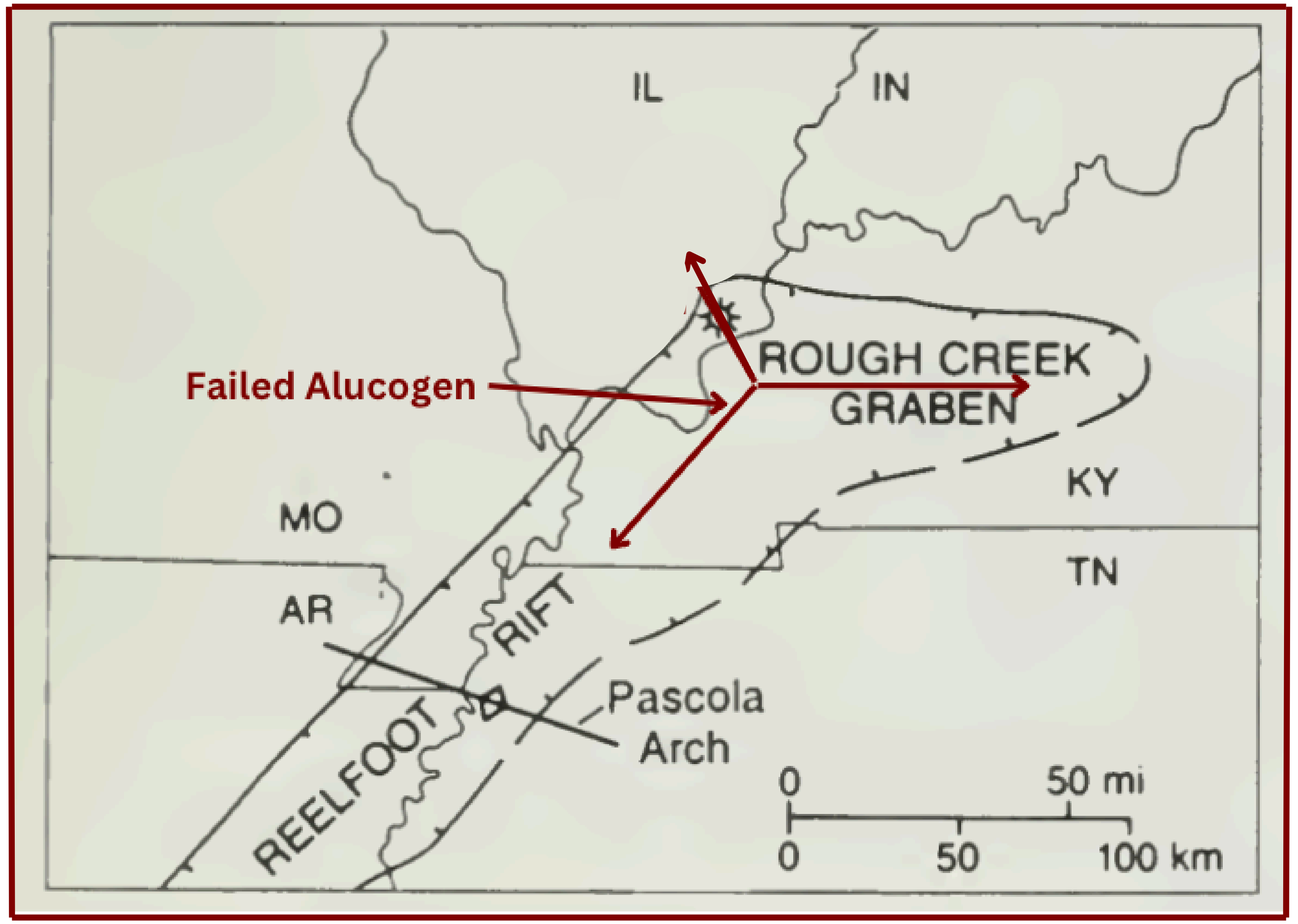
a. Breakup of Rodina fomed the Reelfoot Rift and Rough Creek Graben

↓

2. **Late Pa ->Early PR (~290 mya)**

a. North American plate is deformed by the breakup of Pangea

Map of Reelfoot Rift / Rough Creek Graben



(Bradbury & Baxter, 1992)

(Reynolds et al. 1997)

Timeline of Events

1. **PЄ -> Є(~1Ga)**

a. Breakup of Rodina fomed the Reelfoot Rift and Rough Creek Graben

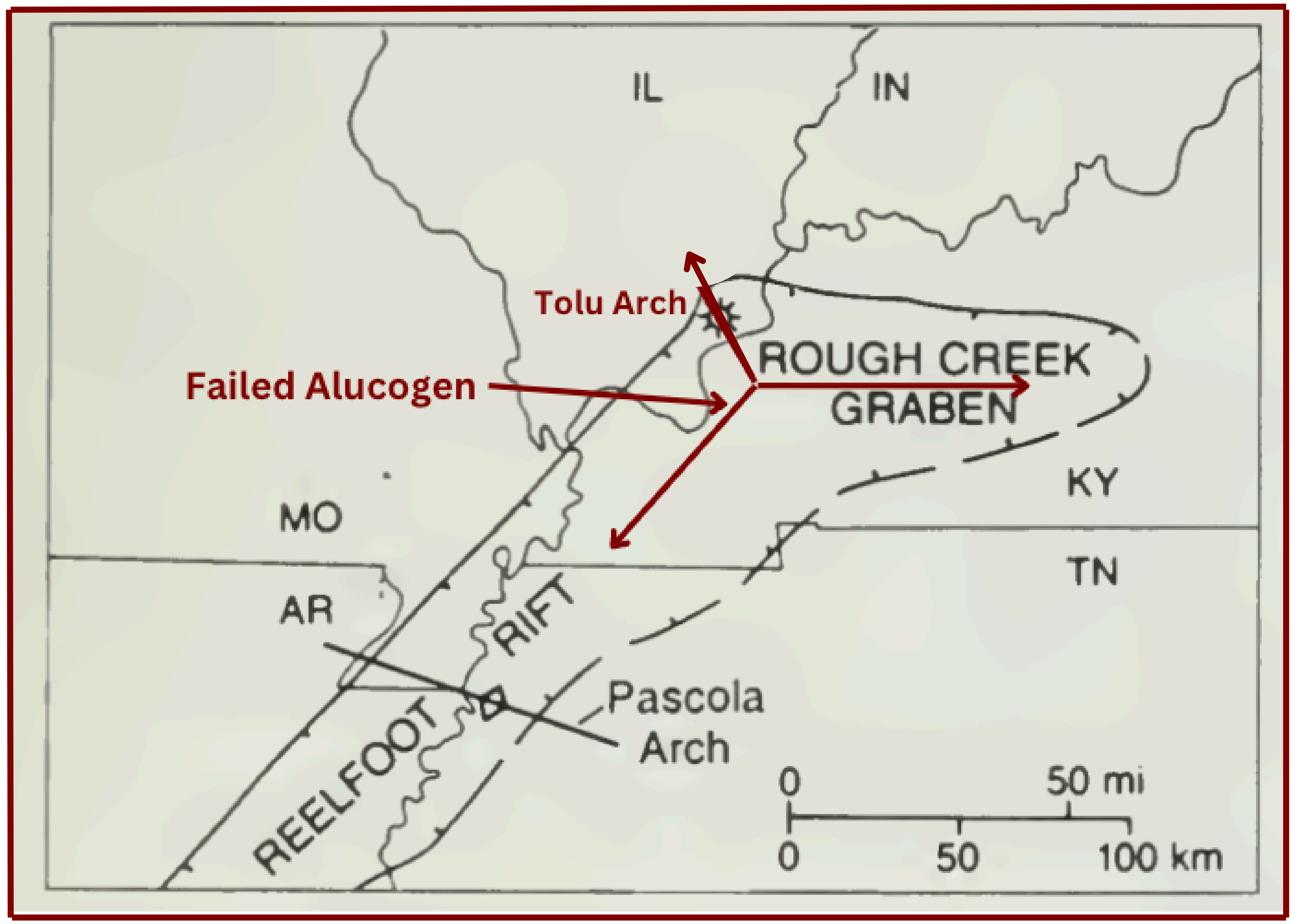
↓

2. **Late Pa ->Early PR (~290 mya)**

a. North American plate is deformed by the breakup of Pangea

b. Tolu Arch forms

Map of Reelfoot Rift / Rough Creek Graben



(Bradbury & Baxter, 1992)

(Reynolds et al. 1997)

Timeline of Events

1. P€ -> €(~1Ga)

a. Breakup of Rodina fomed the Reelfoot Rift and Rough Creek Graben

↓

2. Late Pa ->Early PR (~290 mya)

a. North American plate is deformed by the breakup of Pangea

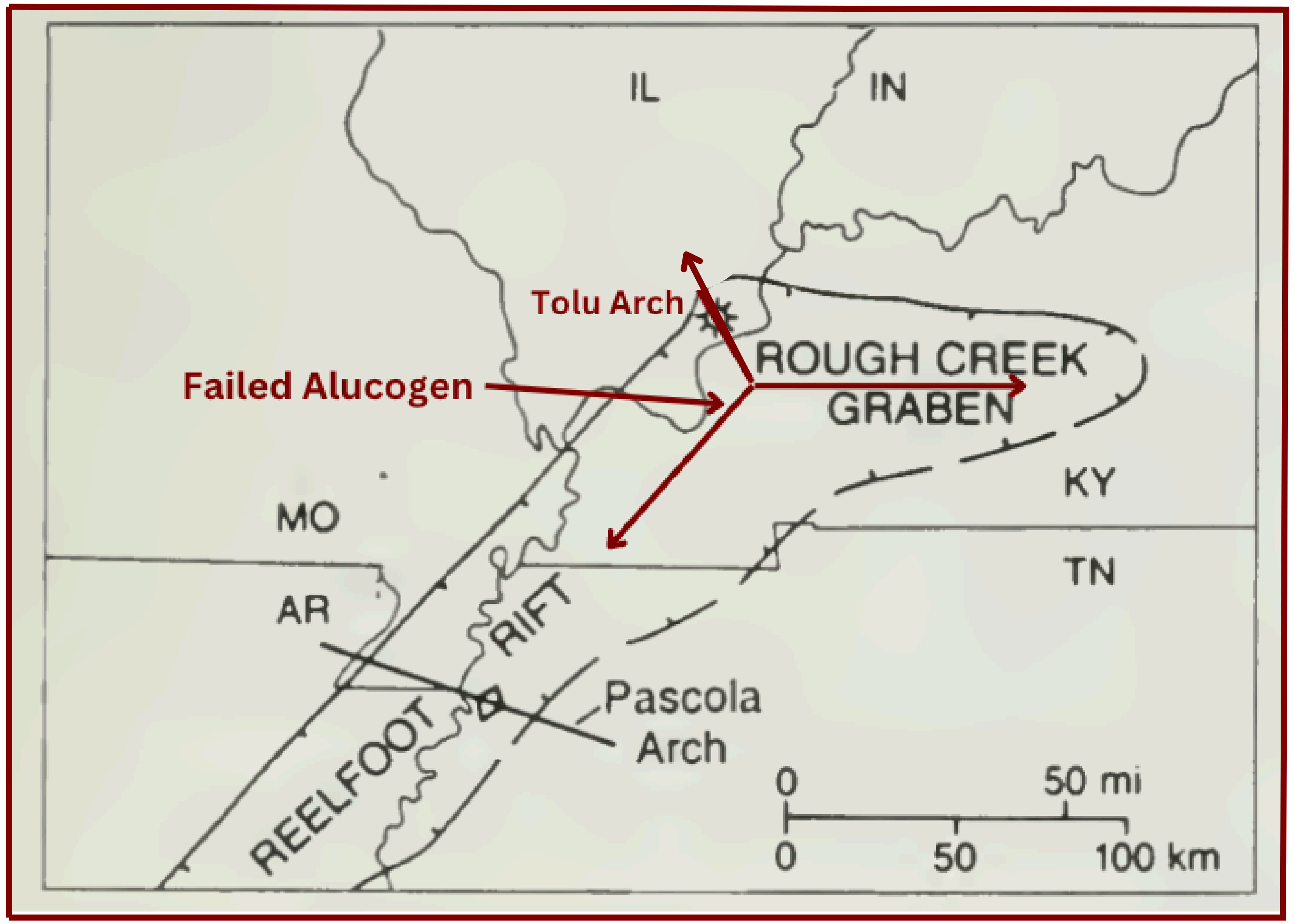
b. Tolu Arch forms

↓

3. Middle PR (~272 mya)

a. Grant Intrusive (G.I.) forms

Map of Reelfoot Rift / Rough Creek Graben



(Bradbury & Baxter, 1992)

(Reynolds et al. 1997)

Timeline of Events

1. P€ -> €(~1Ga)

a. Breakup of Rodina fomed the Reelfoot Rift and Rough Creek Graben

↓

2. Late Pa ->Early PR (~290 mya)

a. North American plate is deformed by the breakup of Pangea

b. Tolu Arch forms

↓

3. Middle PR (~272 mya)

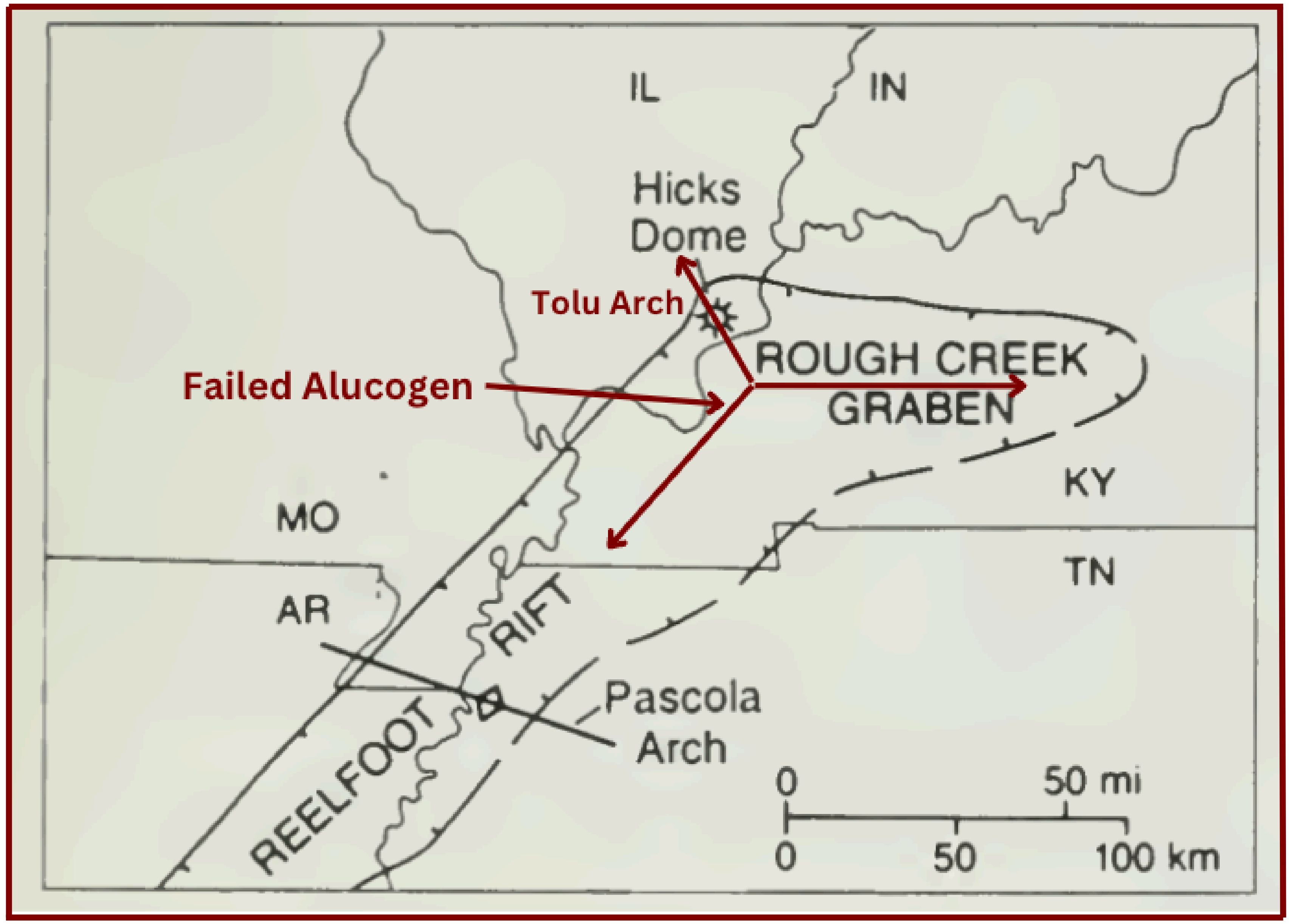
a. Grant Intrusive (G.I.) forms

↓

4. Middle PR (~270 mya)

a. Hicks Dome intrudes

Map of Reelfoot Rift / Rough Creek Graben



(Bradbury & Baxter, 1992)

(Reynolds et al. 1997)

Timeline of Events

1. PЄ -> Є(~1Ga)

a. Breakup of Rodinia formed the Reelfoot Rift and Rough Creek Graben

↓

2. Late Pa ->Early PR (~290 mya)

a. North American plate is deformed by the breakup of Pangea

b. Tolu Arch forms

↓

3. Middle PR (~272 mya)

a. Grant Intrusive (G.I.) forms

↓

4. Middle PR (~270 mya)

a. Hicks Dome Intrudes

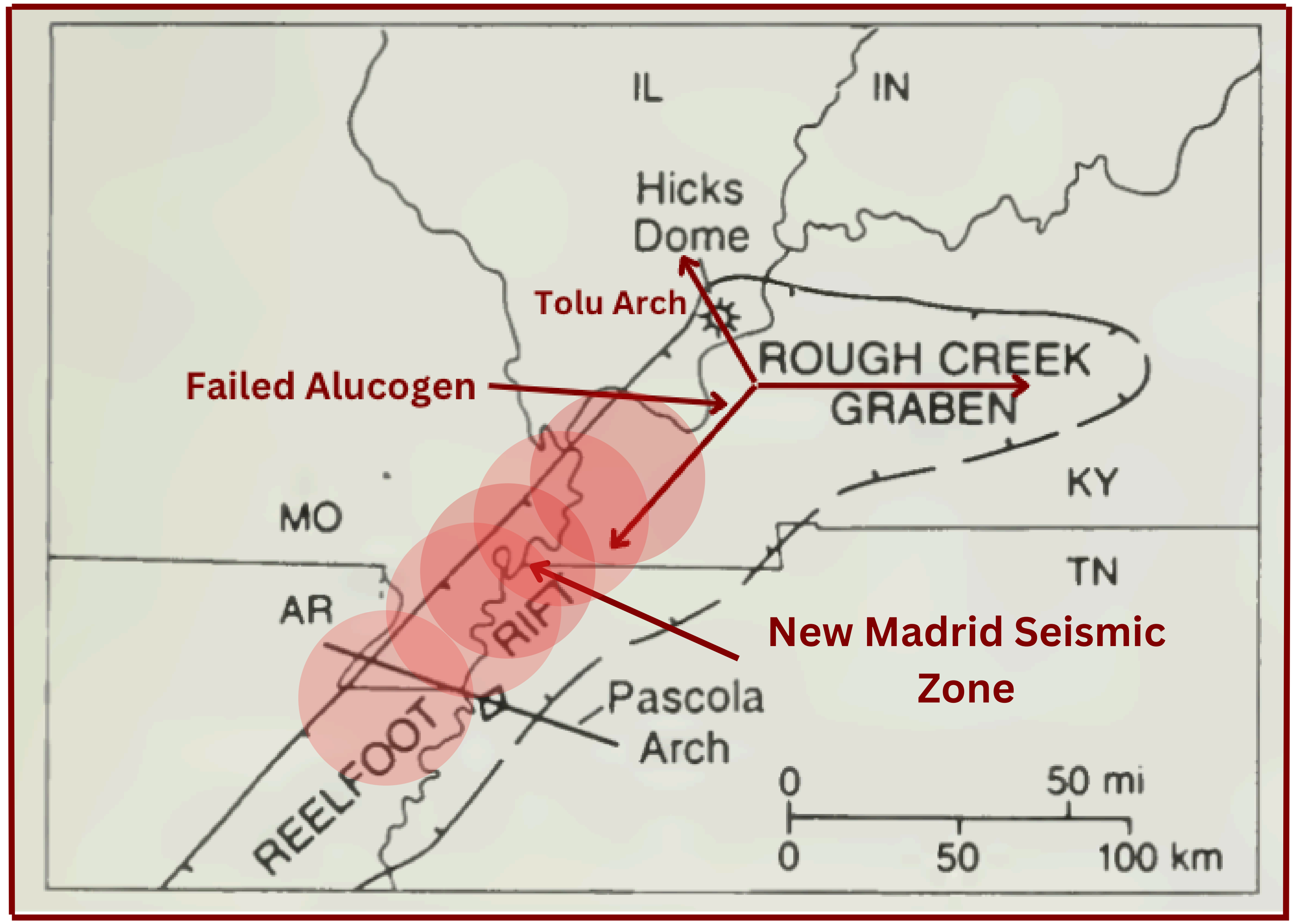
↓

5. Late JP -> Early K (~145 mya)

a. New Madrid Fault System forms above dormant Reelfoot Rift

(Reynolds et al. 1997)

Map of Reelfoot Rift / Rough Creek Graben



(Bradbury & Baxter, 1992)

Purpose of Study

- Critical elements are necessary for the production of alloys utilized in the manufacturing of aerospace satellites, automobiles, and medical equipment
- Grant Intrusive serving as a continental ore deposit could assist in decreasing our dependance on other countries for these essential elements
- The United States Department of Energy defines a critical material as:

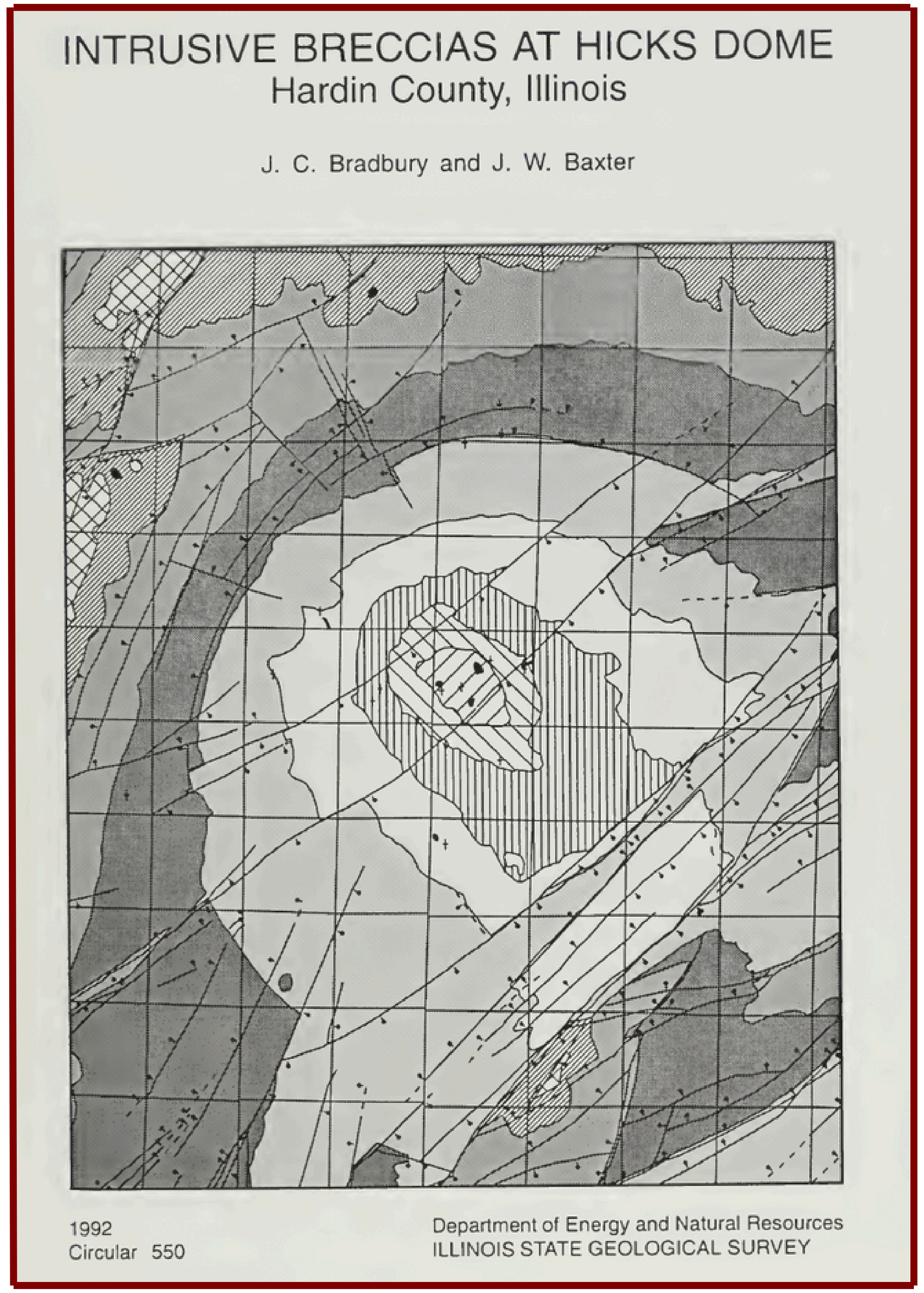
> Section 7002(a)(2) of the Energy Act of 2020 defines "critical materials" to be: (A) Any non-fuel mineral, element, substance, or material that the Secretary of Energy determines (i) has high risk for supply chain disruption; and (ii) serves an essential function in one or more energy technologies, including technologies that produce, transmit, store, and conserve energy [referred to here as a critical material for energy]; or (B) a critical mineral [as designated by the Secretary of the Interior].[1] The Final 2023 DOE Critical Materials List includes the following:

(The Federal Register, 2023)

Limitations of Study

- Not a lot of literature of Hicks Dome, let alone Grant Intrusive
  - Only two studies have focused on characterizing Grant Intrusive (Bradbury and Baxter, 1992) and (Reynolds et al., 1997)
  - Lots of uncertainty / disagreement between hypotheses

- Research area located over private and government properties



Paleomagnetic and $^{40}Ar/^{39}Ar$ Results from the Grant Intrusive Breccia and Comparison to the Permian Downeys Bluff Sill—Evidence for Permian Igneous Activity at Hicks Dome, Southern Illinois Basin

By Richard L. Reynolds, Martin B. Goldhaber, *and* Lawrence W. Snee

EVOLUTION OF SEDIMENTARY BASINS—ILLINOIS BASIN
Jennie L. Ridgley, *Project Coordinator*

U.S. GEOLOGICAL SURVEY BULLETIN 2094–G

A multidisciplinary approach to research studies of sedimentary rocks and their constituents and the evolution of sedimentary basins, both ancient and modern

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

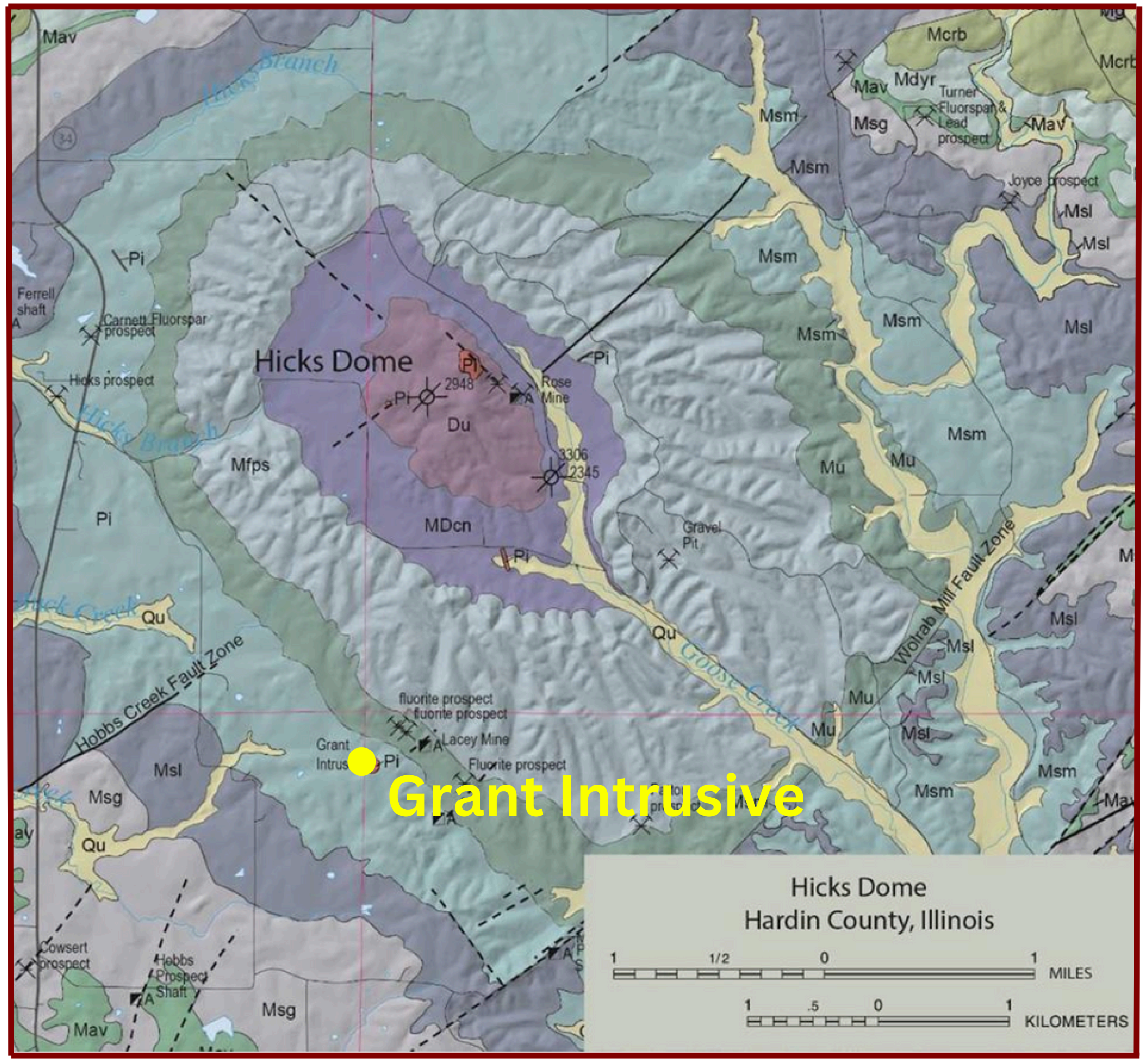
Project Hypothesis

- Grant Intrusive contains economic concentrations of Ti, Ba, Th, and HREEs
    - Ore minerals include apatite, barite, ilmenite, and xenotime-(Y)
    - Ores minerals are incorporated into the matrix as well as weathering products

Project Goals

1. Identify minerals hosting critical material elements

Crater Explorer



(Charles O'Day)

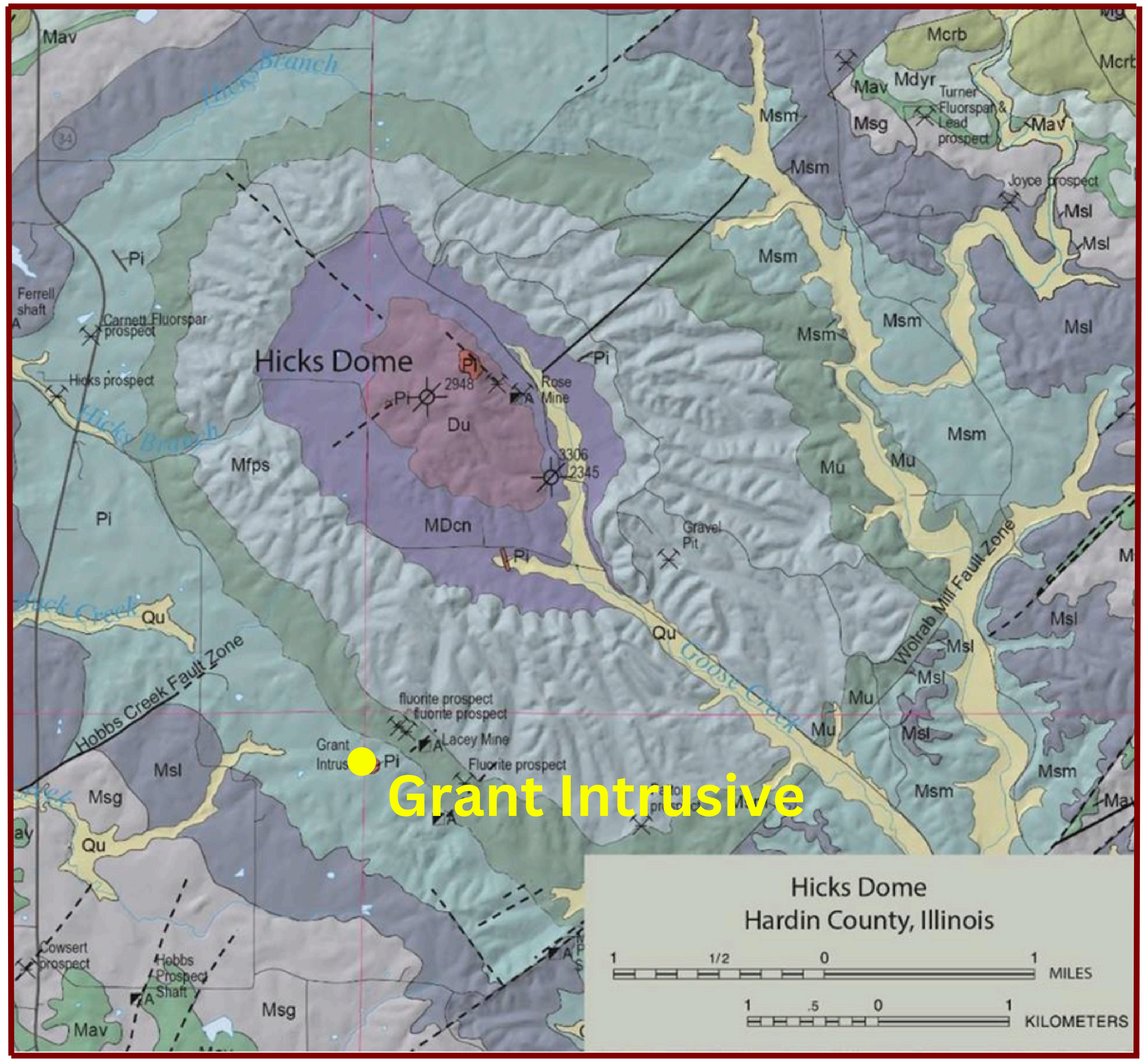
Project Goals

1. Identify minerals hosting critical material elements

↓

2. Map igneous bodies within the subsurface

Crater Explorer



(Charles O'Day)

Project Goals

1. Identify minerals hosting critical material elements

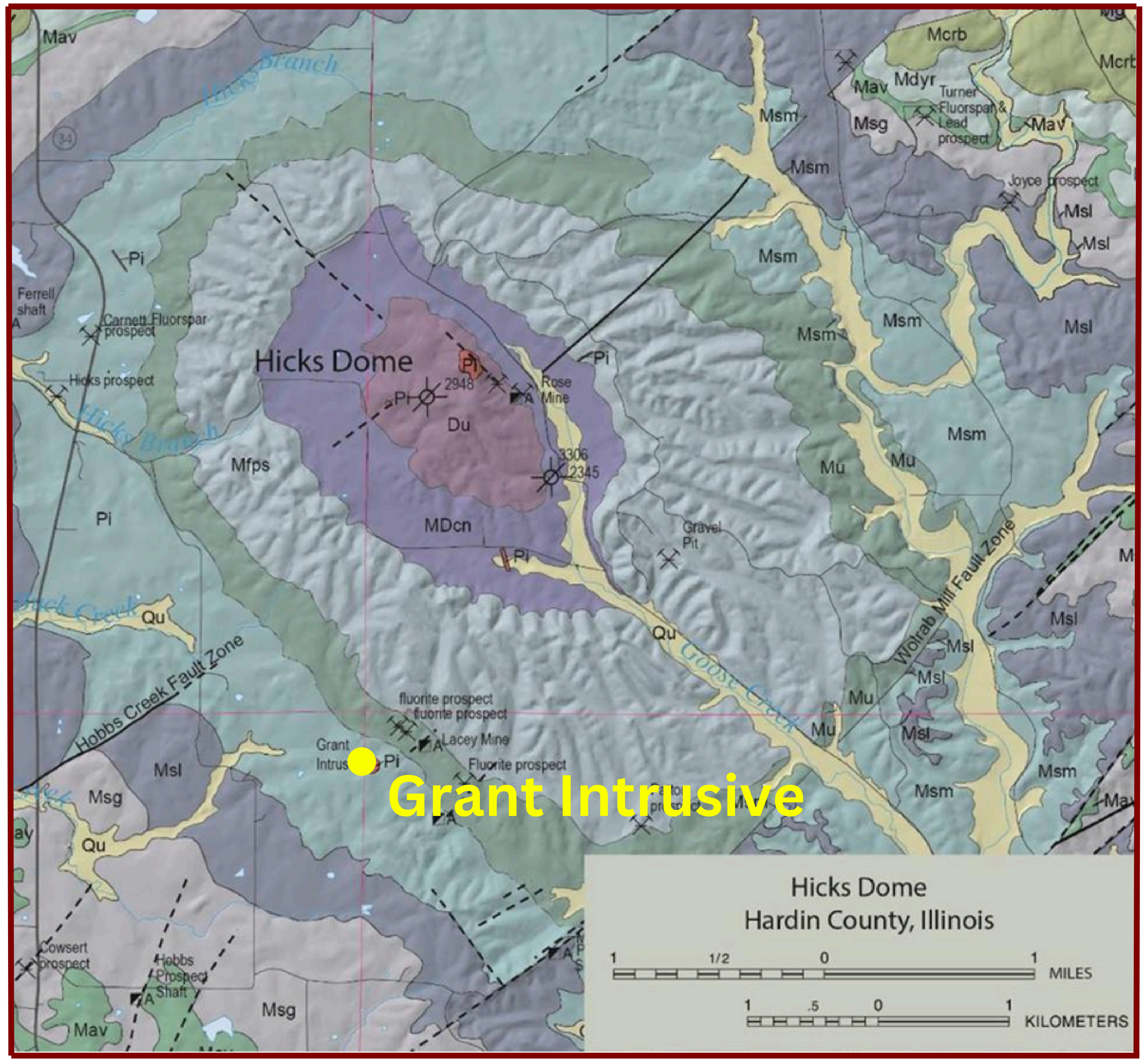
↓

2. Map igneous bodies within the subsurface

↓

3. Determine Ore Grade

Crater Explorer



(Charles O’Day)

Project Goals

1. Identify minerals hosting critical material elements

↓

2. Map igneous bodies within the subsurface

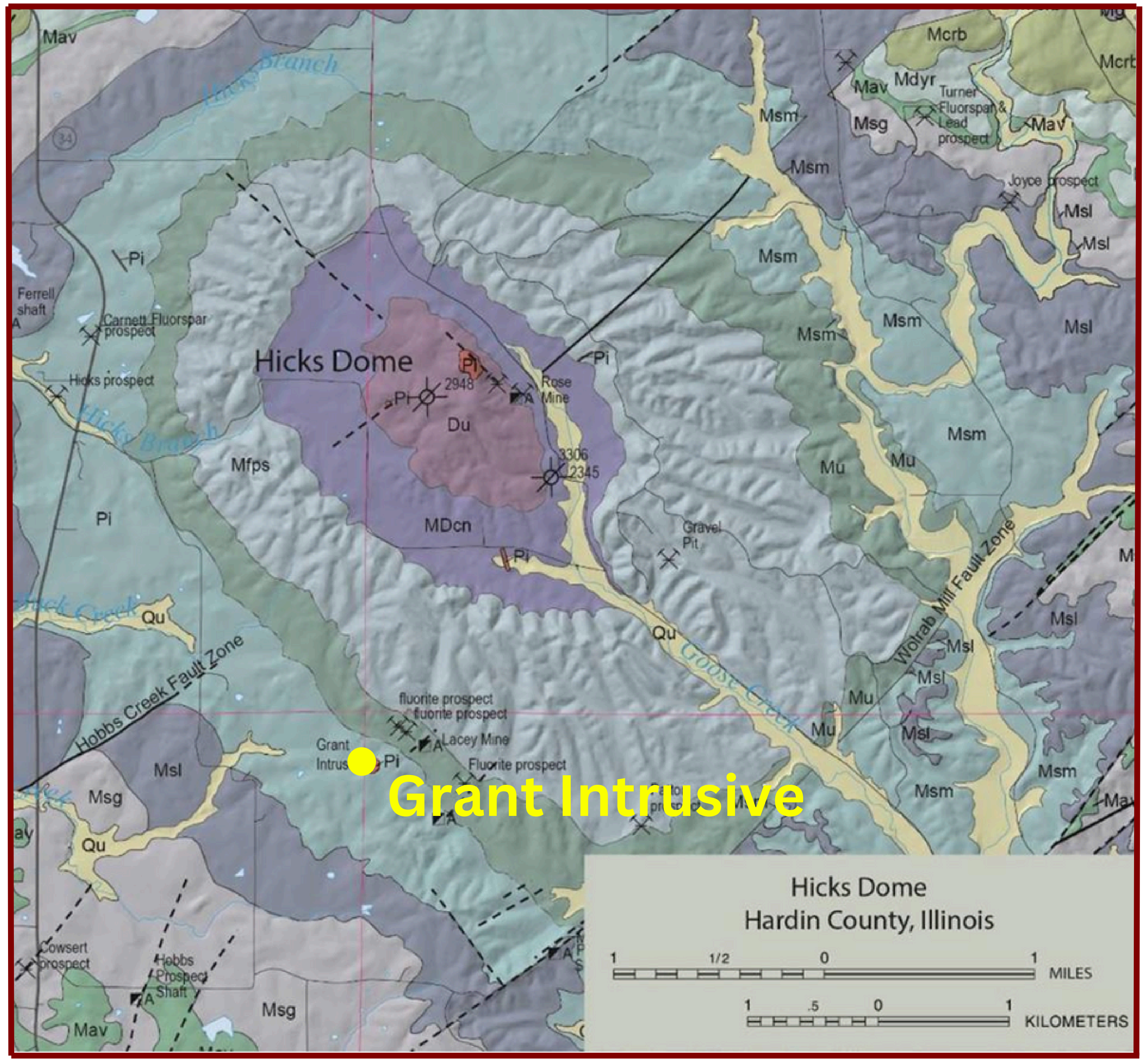
↓

3. Determine Ore Grade

↓

4. Infer economic ore concentrations

Crater Explorer



(Charles O'Day)

Methodologies

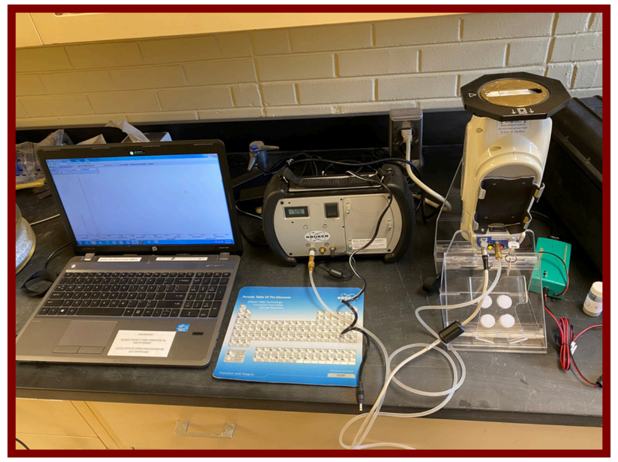
Methods To Date:

- X-Ray Fluorescence (XRF)
  - To determine bulk geochemistry and ore grade
- Scanning Electron Microscope (SEM) with Energy Dispersive Spectroscopy (EDS)
  - To identify critical elements

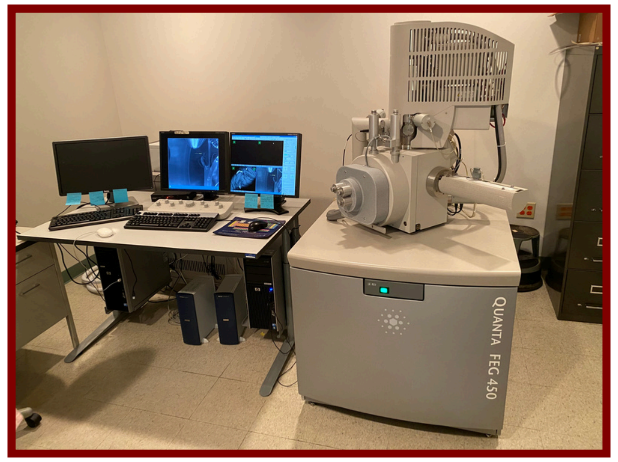
Future Methods:

- X-Ray Diffraction (XRD)
  - To identify mineral identities
- Optical Petrographic Analysis
  - To confirm rock and mineral identities
- Dual Censor Cesium Vapor Magnetometer
  - Map ore localities within the subsurface

Bruker AXS Hand Held XRF



FEI Quanta FEG450 SEM with EDS



Rigaku Ultima 4 XRD

Samples Analyzed

G.I. # 4

G.I. #7

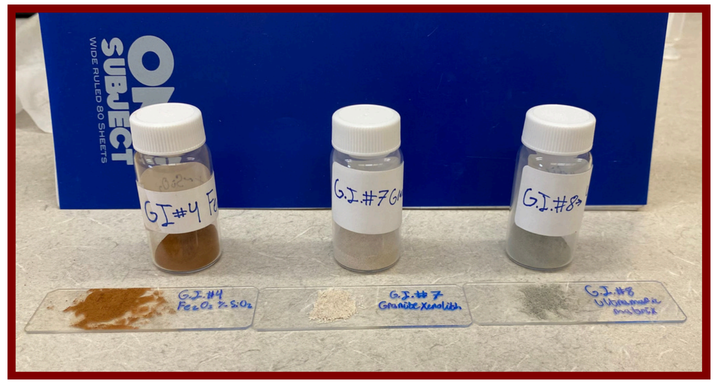
G.I. #8

G.I. # 9

G.I. # 10

G.I. # 11

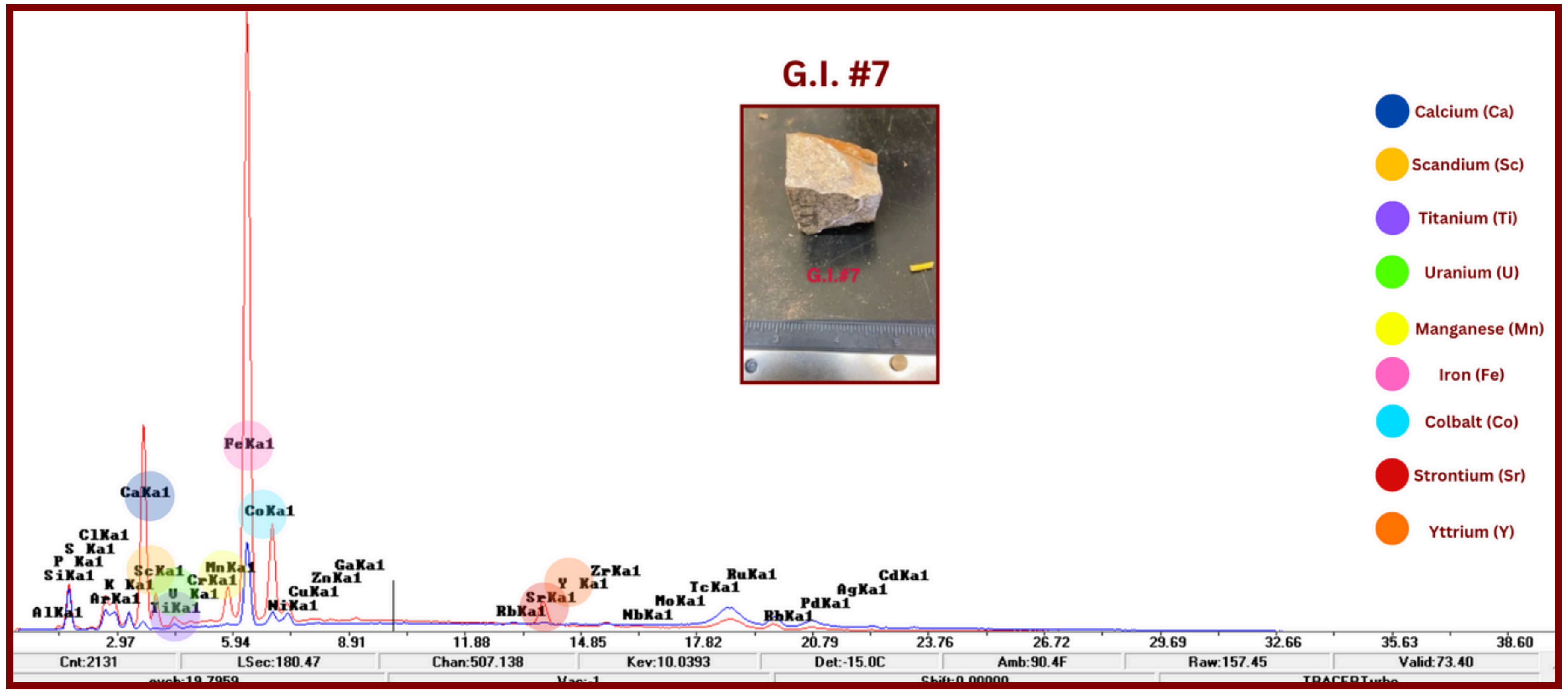
G.I. # 12

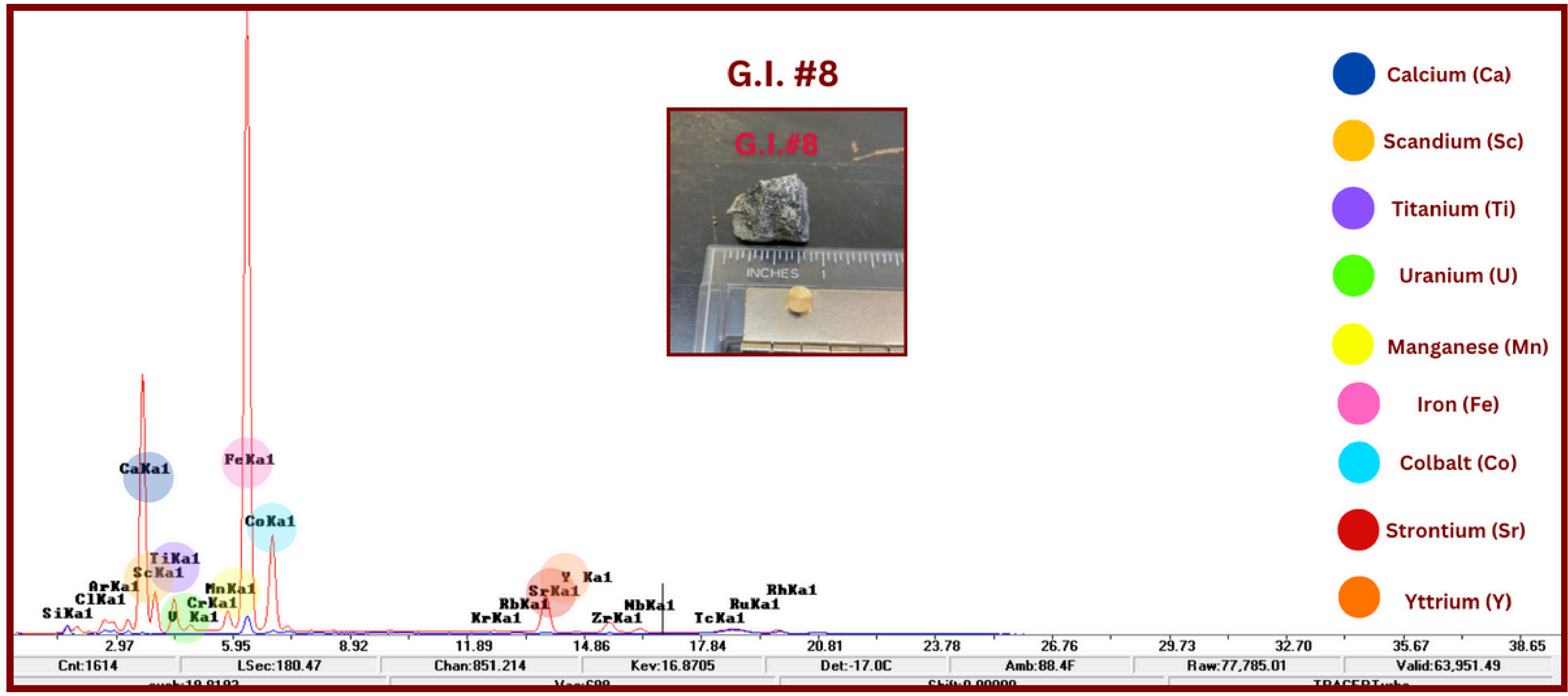


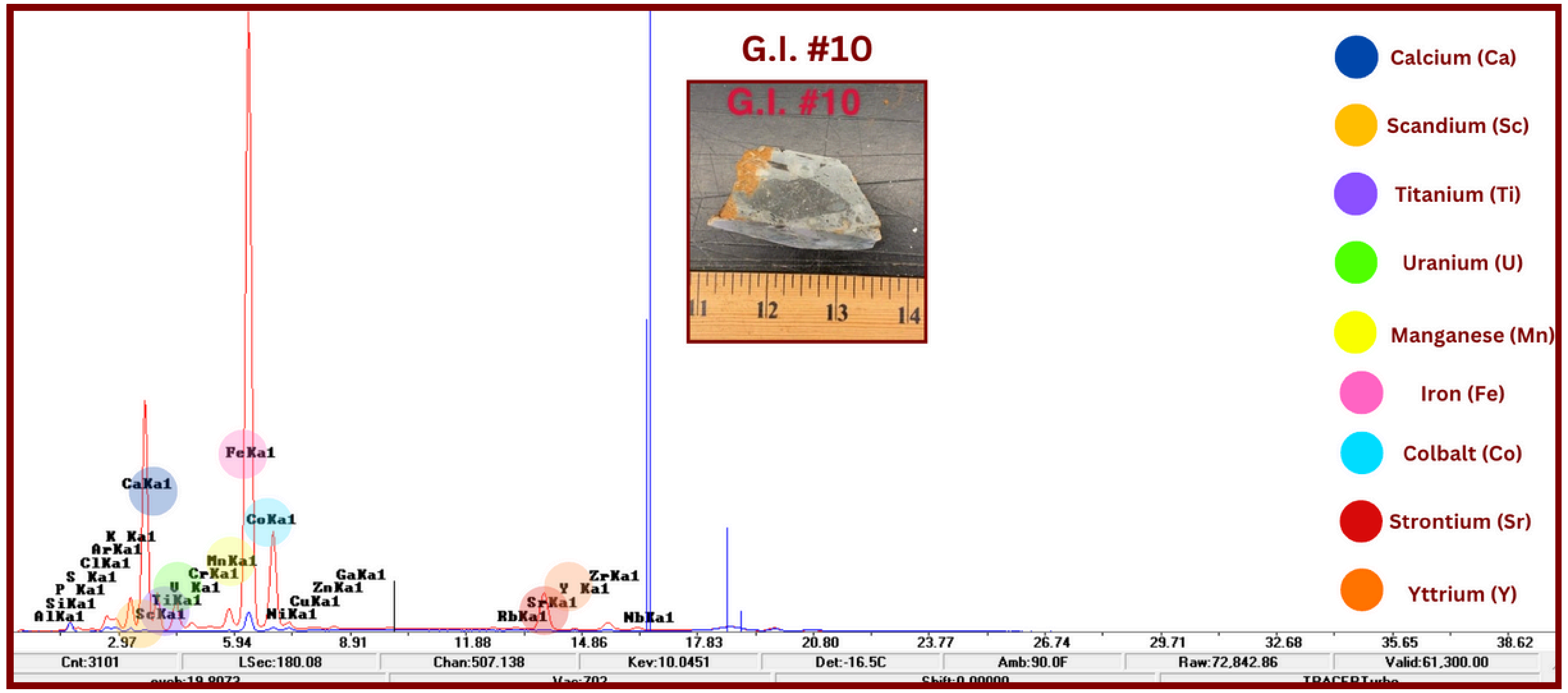
Rock samples provided by the Illinois State Geological Survey (ISGS)

ILLINOIS STATE GEOLOGICAL SURVEY
PRAIRIE RESEARCH INSTITUTE

X-Ray Fluorescence (XRF)







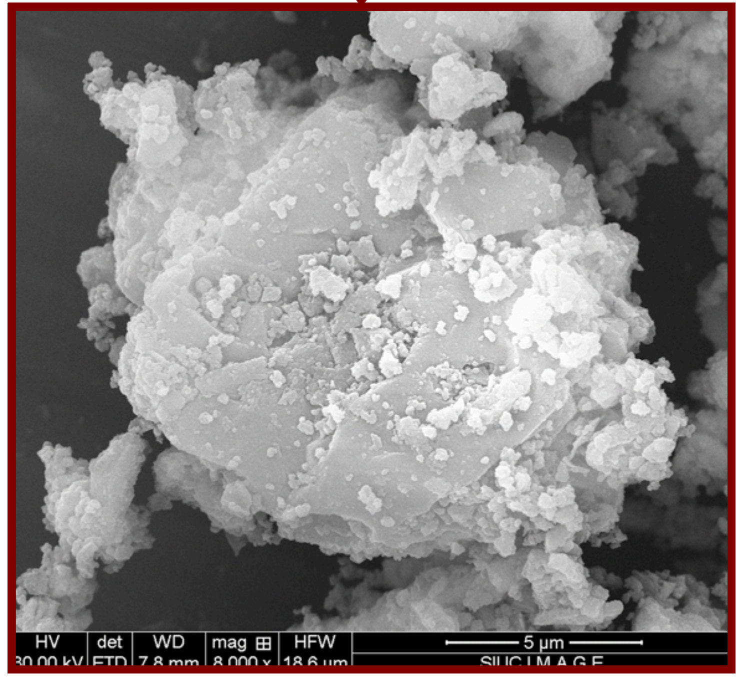
Impulse[*10^6]

Energy [KeV]

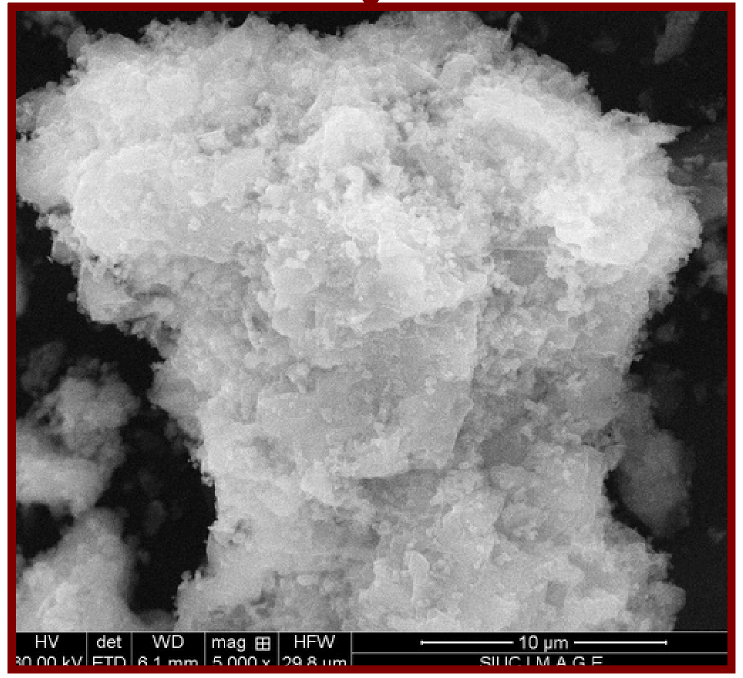
- Notable Peaks for cobalt (Co) and strontium (Sr)
- Peaks for titanium (Ti), uranium (U), scandium (Sc), and yttrium (Y) are less predominant but still present

Scanning Electron Microscope (SEM)

G.I. #12



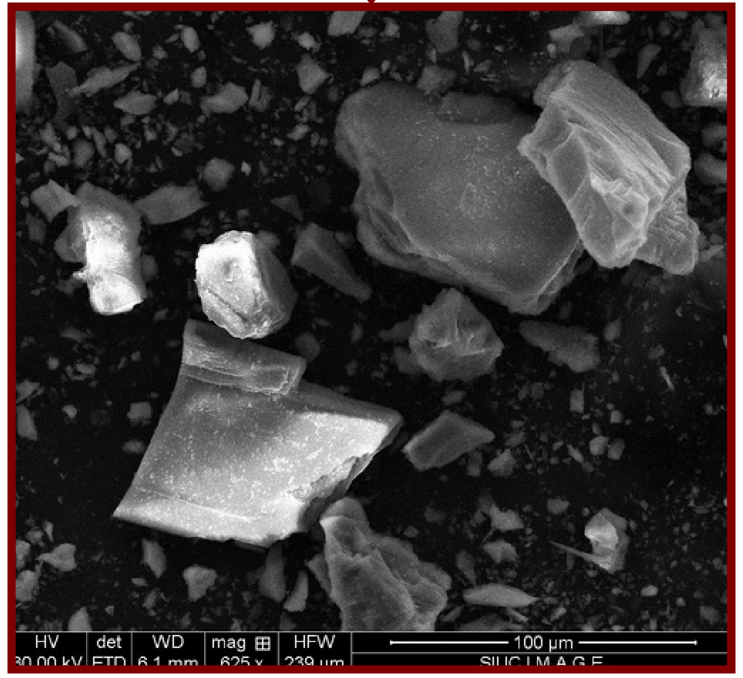
G.I. # 4



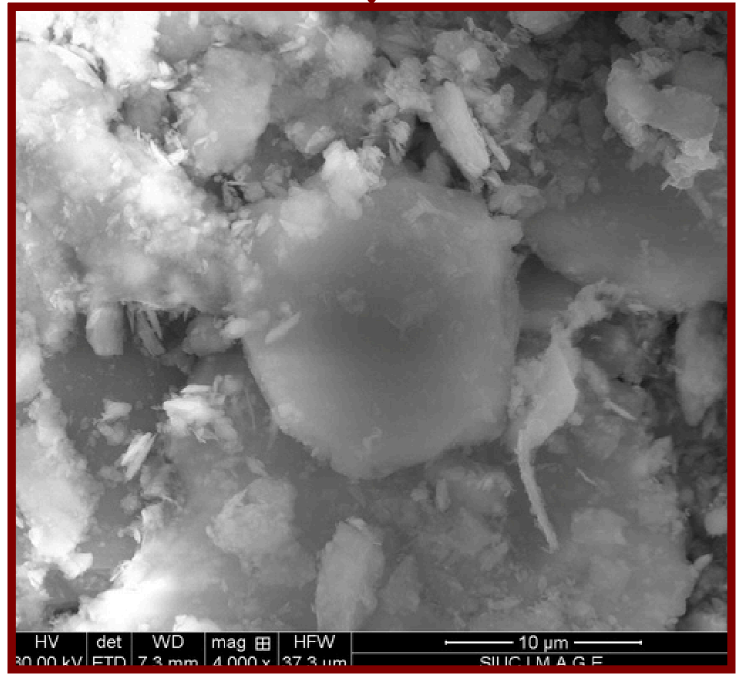
Weathering Products

- Gritty and amorphous
- Clay like material with Ilmenite

G.I. #8



G.I. #11

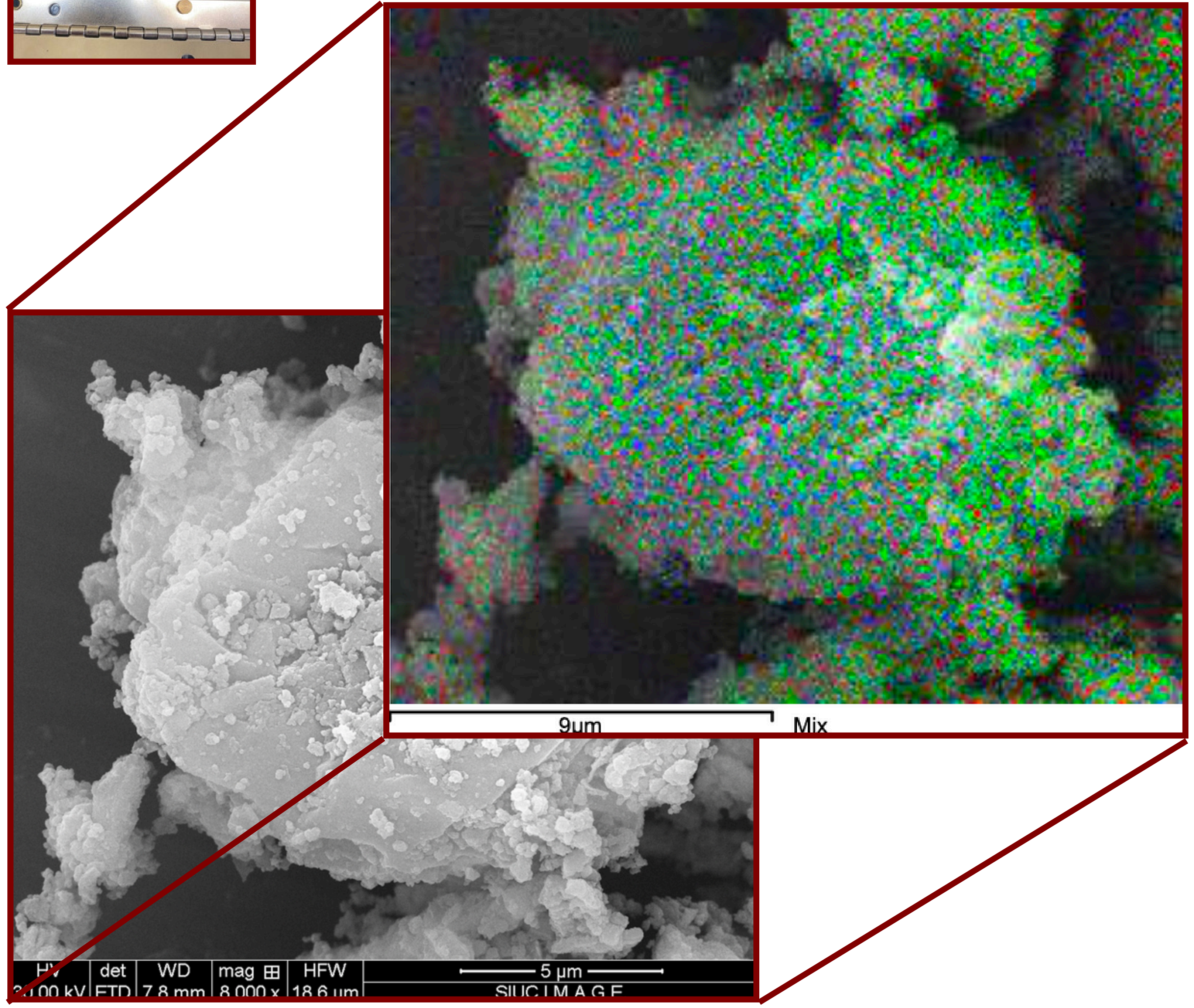


Matrix Material

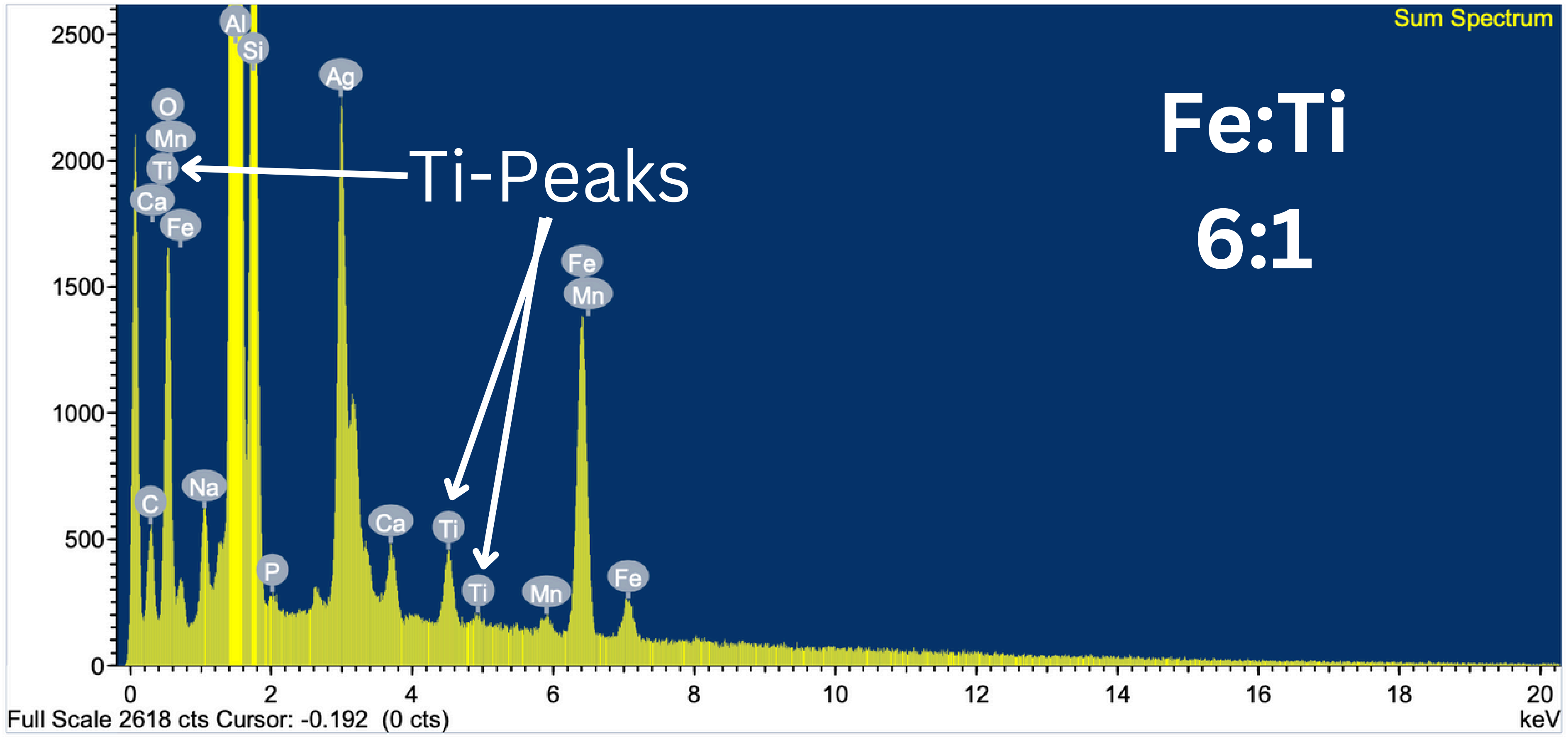
- Platy grains
- Most likely forms of amphibole (riebeckite) or biotite (phlogopite)

Scanning Electron Microscope with Energy Dispersive Spectroscopy (SEM-EDS)

G.I. #12

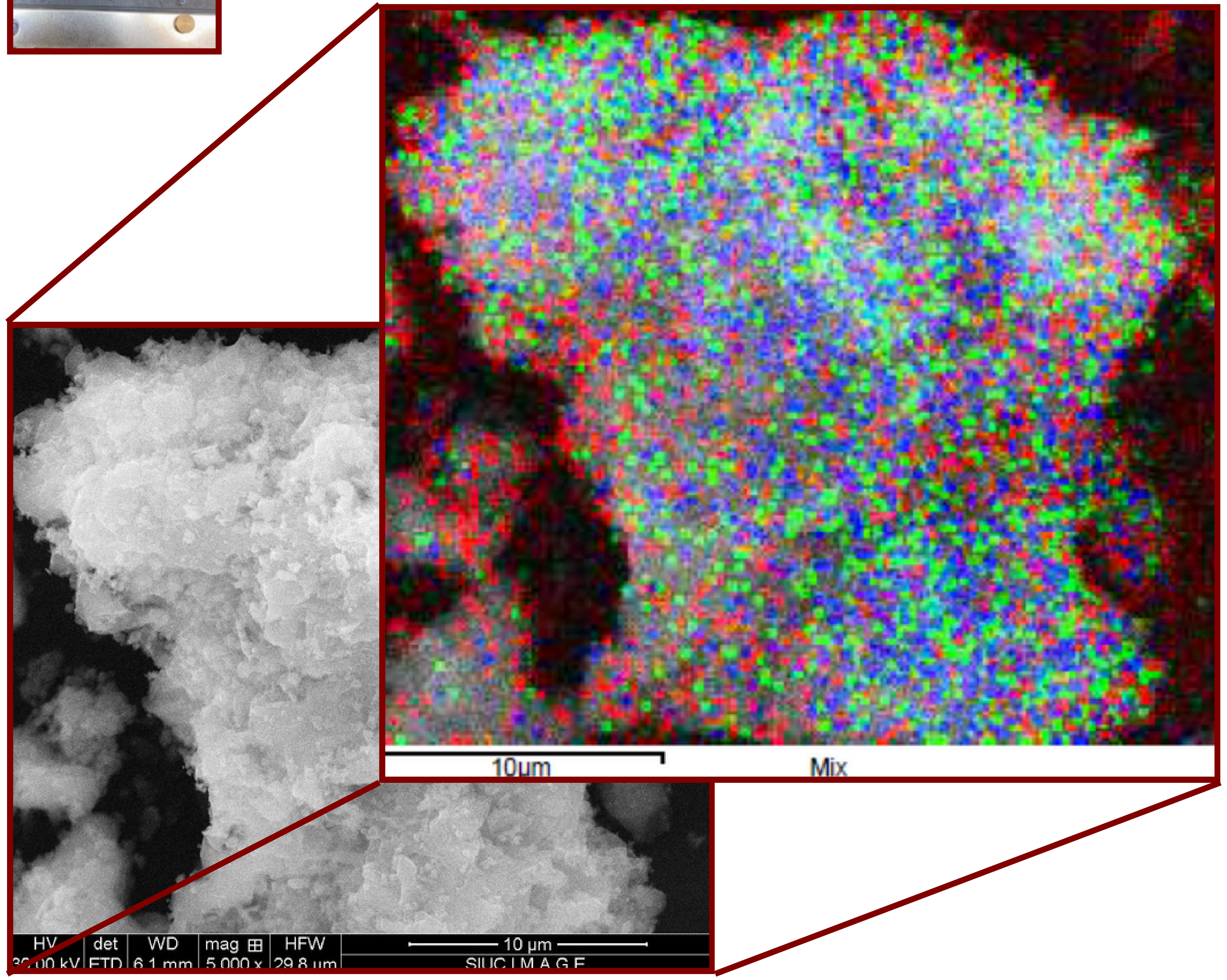


Element	App Conc.	Intensity Corrn.	Weig...	Weig... Sigma	Atomi...
C K	12.21	0.2456	15.17	1.26	26.35
O K	37.95	0.4121	28.09	0.93	36.64
Na K	2.79	0.5905	1.44	0.06	1.31
Al K	72.40	0.7065	31.26	0.59	24.18
Si K	15.28	0.4486	10.39	0.21	7.72
P K	0.51	0.6603	0.24	0.04	0.16
Ca K	1.29	0.8436	0.47	0.03	0.24
Ti K	1.59	0.7701	0.63	0.03	0.27
Mn K	0.49	0.8181	0.18	0.03	0.07
Fe K	10.91	0.8464	3.93	0.09	1.47
Ag L	20.61	0.7668	8.20	0.19	1.59
		Total:	100.00		



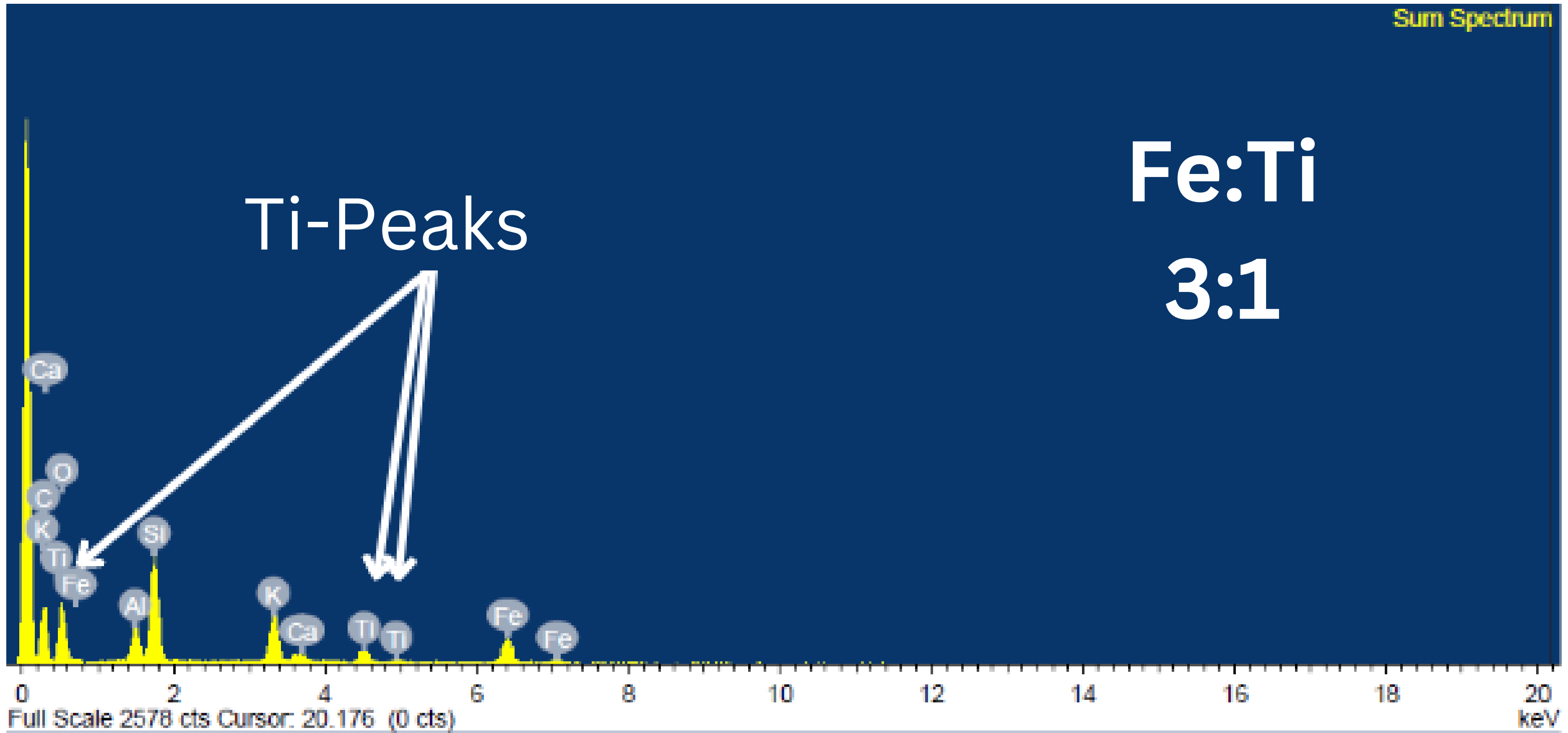
Scanning Electron Microscope with Energy Dispersive Spectroscopy (SEM-EDS)

G.I. # 4

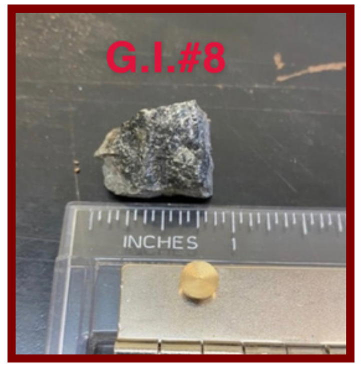


Element	App Conc.	Intensity Corrn.	Weig...	Weig... Sigma	Atomi...
C K	242.24	0.6279	46.79	7.14	57.45
O K	114.70	0.3481	39.96	5.45	36.84
Al K	9.91	0.6470	1.86	0.27	1.02
Si K	31.78	0.7426	5.19	0.71	2.73
K K	20.42	1.0484	2.36	0.33	0.89
Ca K	2.62	0.9795	0.32	0.07	0.12
Ti K	6.18	0.8299	0.90	0.14	0.28
Fe K	17.84	0.8286	2.61	0.37	0.69

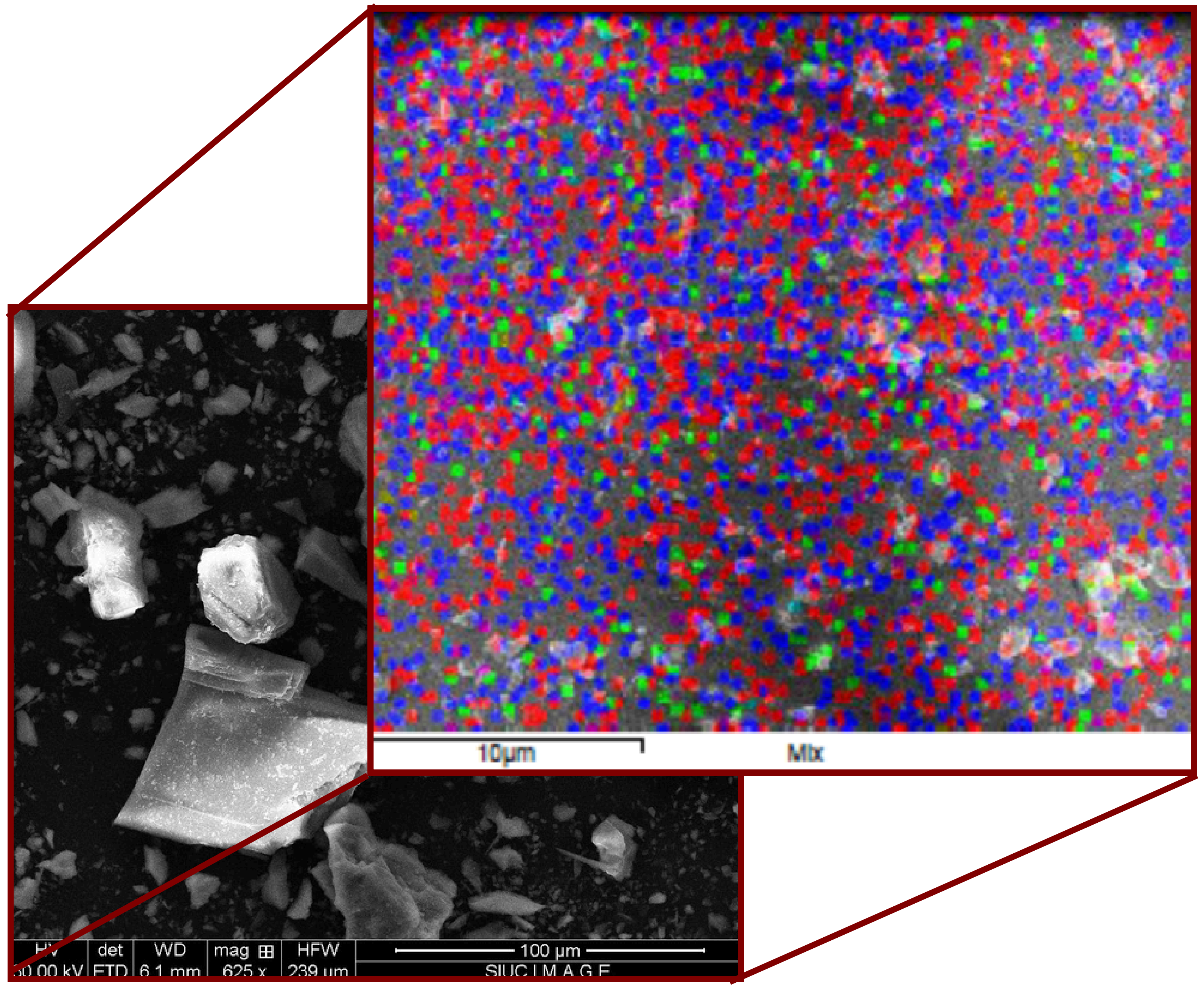
Total: 100.00



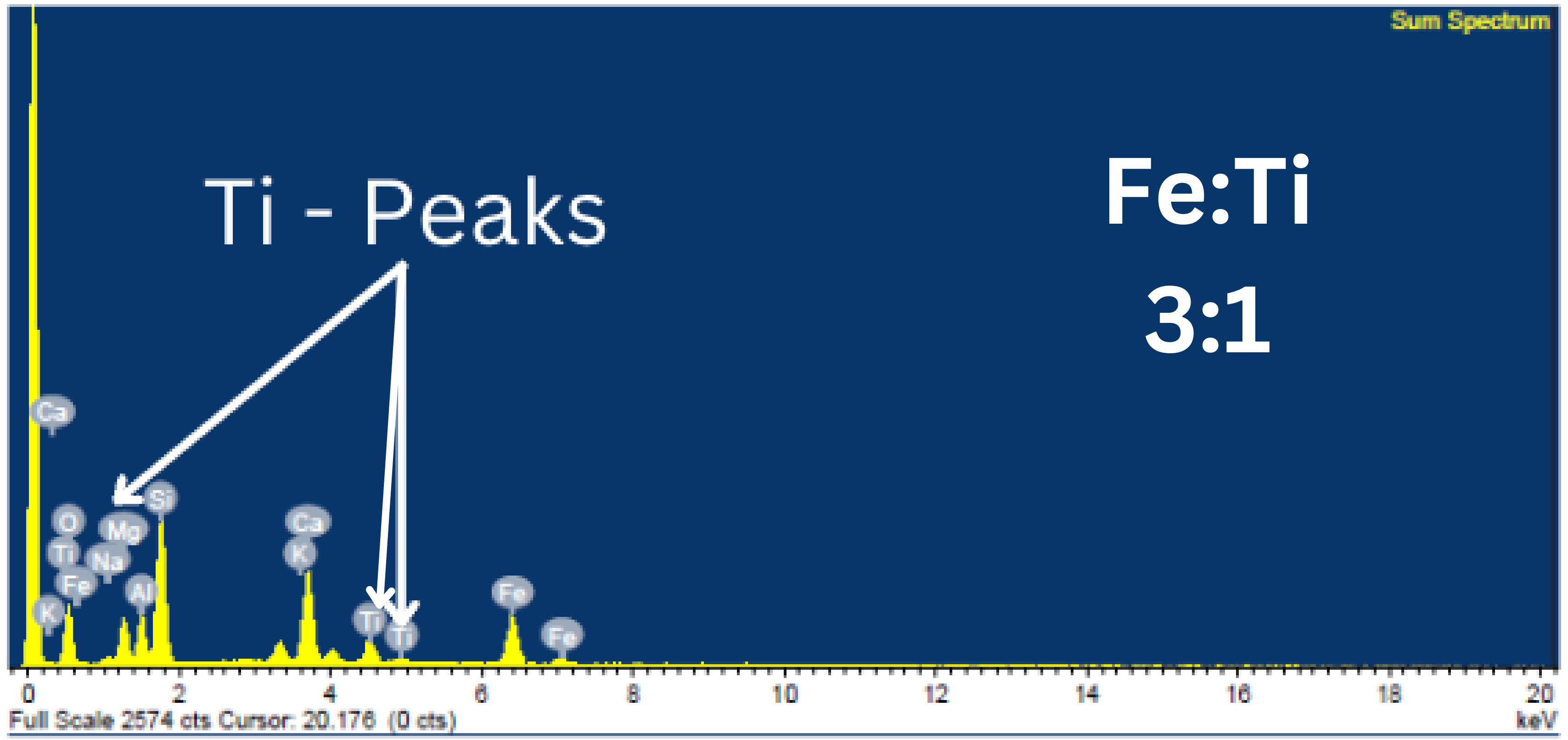
Scanning Electron Microscope with Energy Dispersive Spectroscopy (SEM-EDS)



G.I. #8

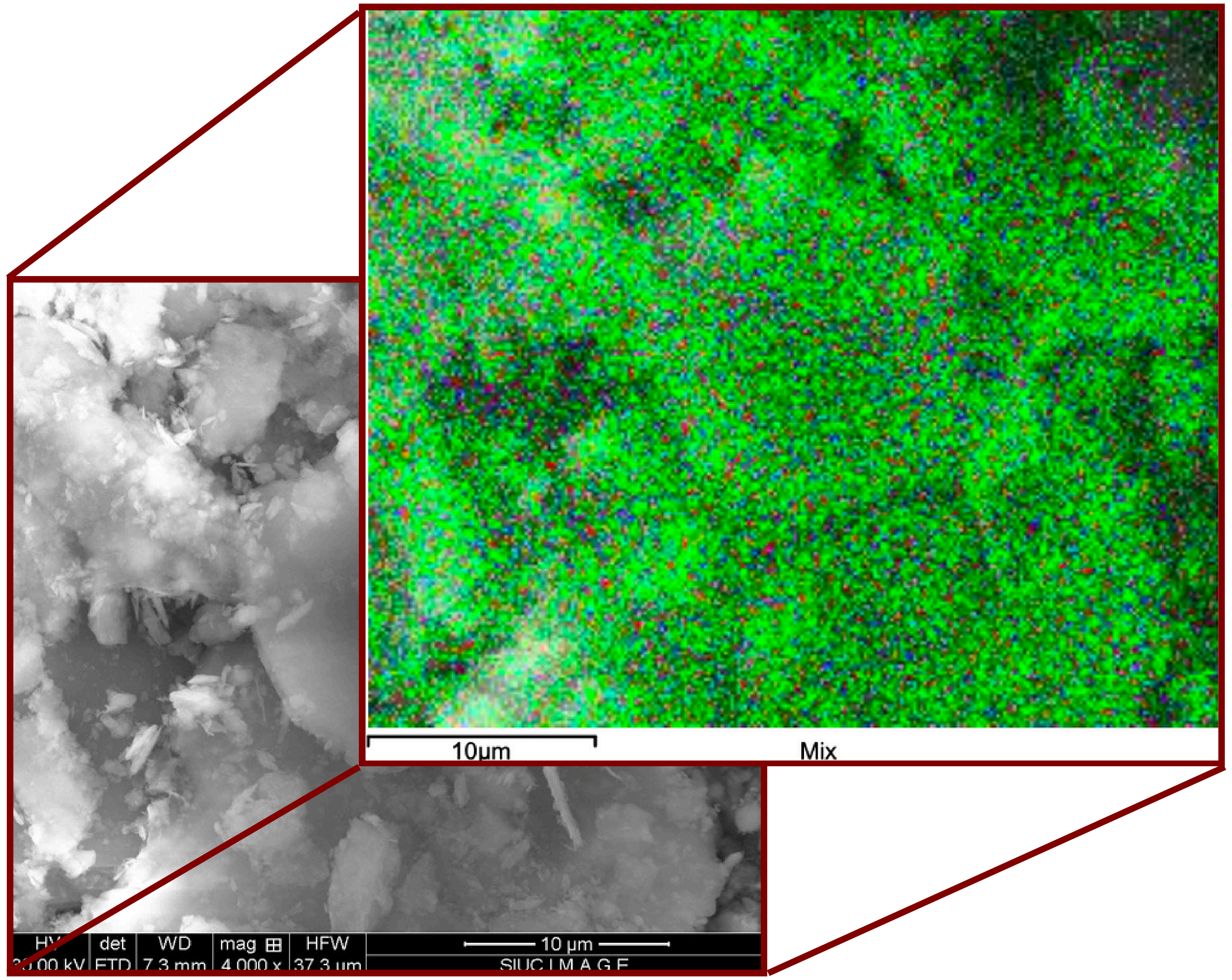


Element	App Conc.	Intensity Corrn.	Weig...	Weig... Sigma	Atomi...
O K	78.25	0.5088	47.42	1.24	64.47
Na K	2.20	0.4421	1.54	0.28	1.45
Mg K	10.34	0.4471	7.13	0.35	6.38
Al K	9.46	0.4968	5.87	0.31	4.74
Si K	30.07	0.5600	16.56	0.49	12.82
K K	5.58	0.9573	1.80	0.13	1.00
Ca K	25.63	0.9275	8.52	0.28	4.62
Ti K	6.86	0.7806	2.71	0.16	1.23
Fe K	23.00	0.8386	8.46	0.32	3.29
		Total:	100.00		



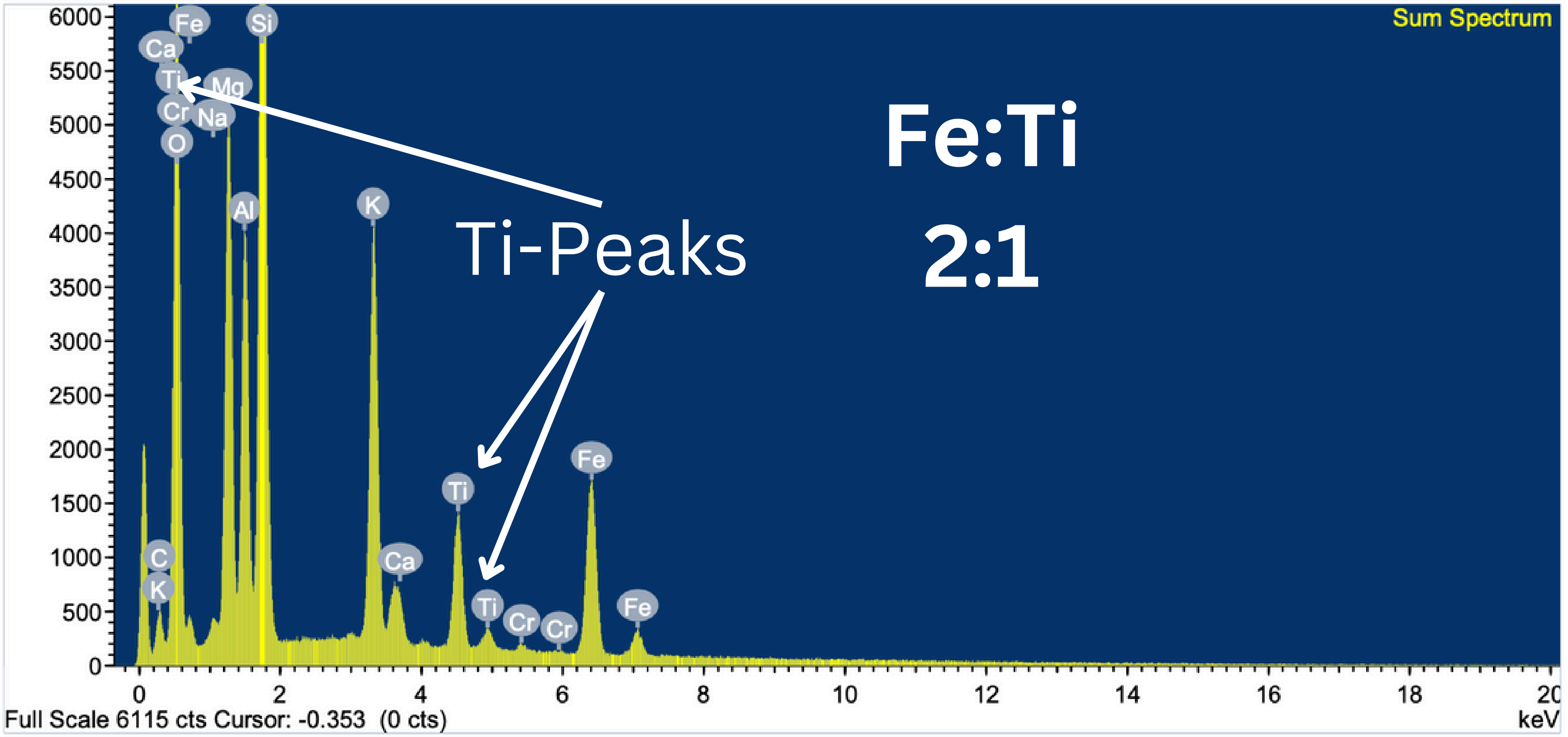
Scanning Electron Microscope with Energy Dispersive Spectroscopy (SEM-EDS)

G.I. #11



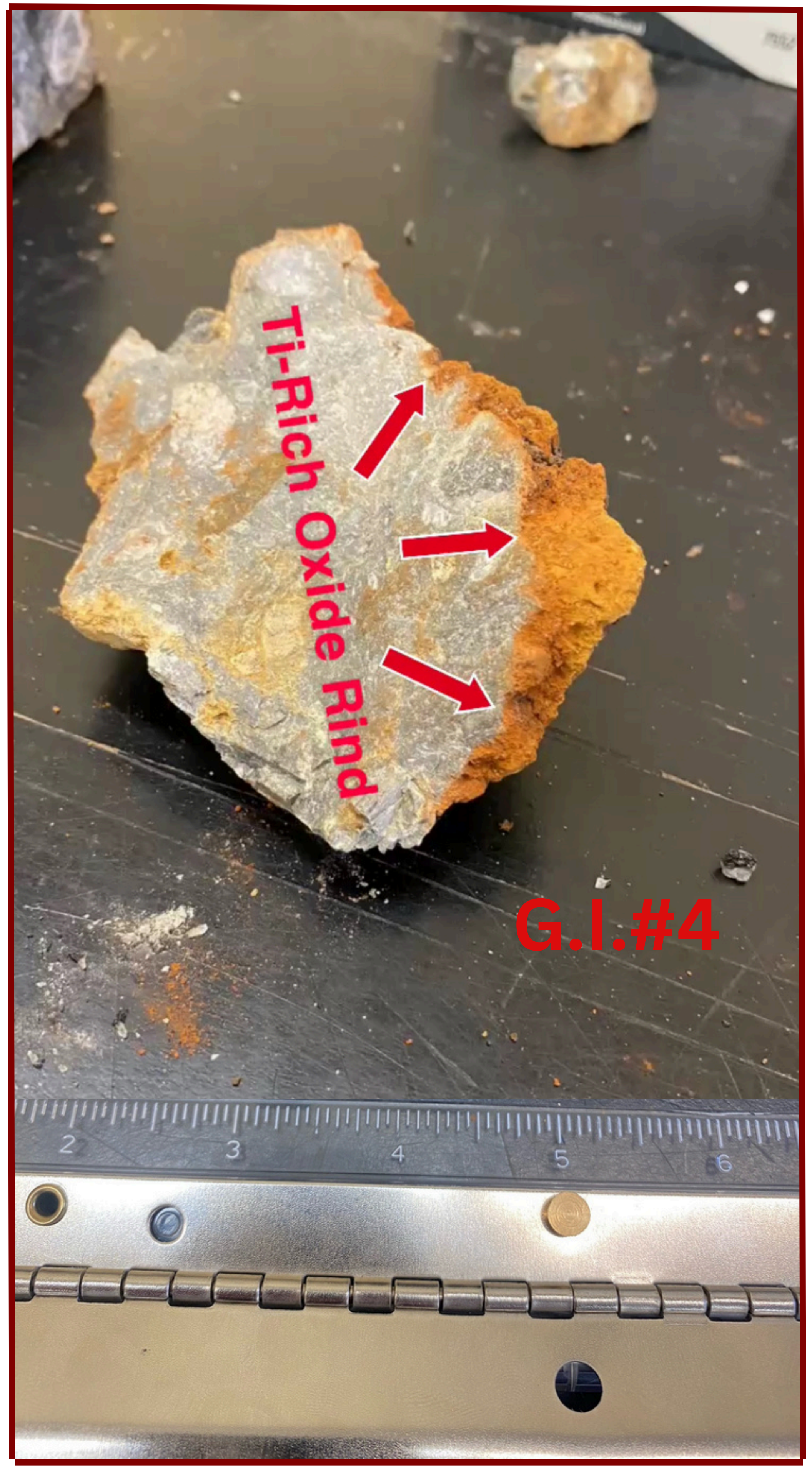
Element	App Conc.	Intensity Corrn.	Weig...	Weig... Sigma	Atomi...
C K	-15.71	0.2693	-17.18	8.26	-32.72
O K	146.94	0.6692	64.66	4.56	92.46
Na K	1.32	0.4732	0.82	0.09	0.82
Mg K	19.75	0.4853	11.98	0.85	11.28
Al K	13.73	0.4926	8.21	0.59	6.96
Si K	31.65	0.5426	17.17	1.22	13.99
K K	19.64	0.9380	6.16	0.44	3.61
Ca K	1.49	0.8873	0.49	0.04	0.28
Ti K	6.95	0.7980	2.56	0.19	1.22
Cr K	0.44	0.8315	0.16	0.02	0.07
Fe K	14.17	0.8416	4.96	0.35	2.03

Total: 100.00



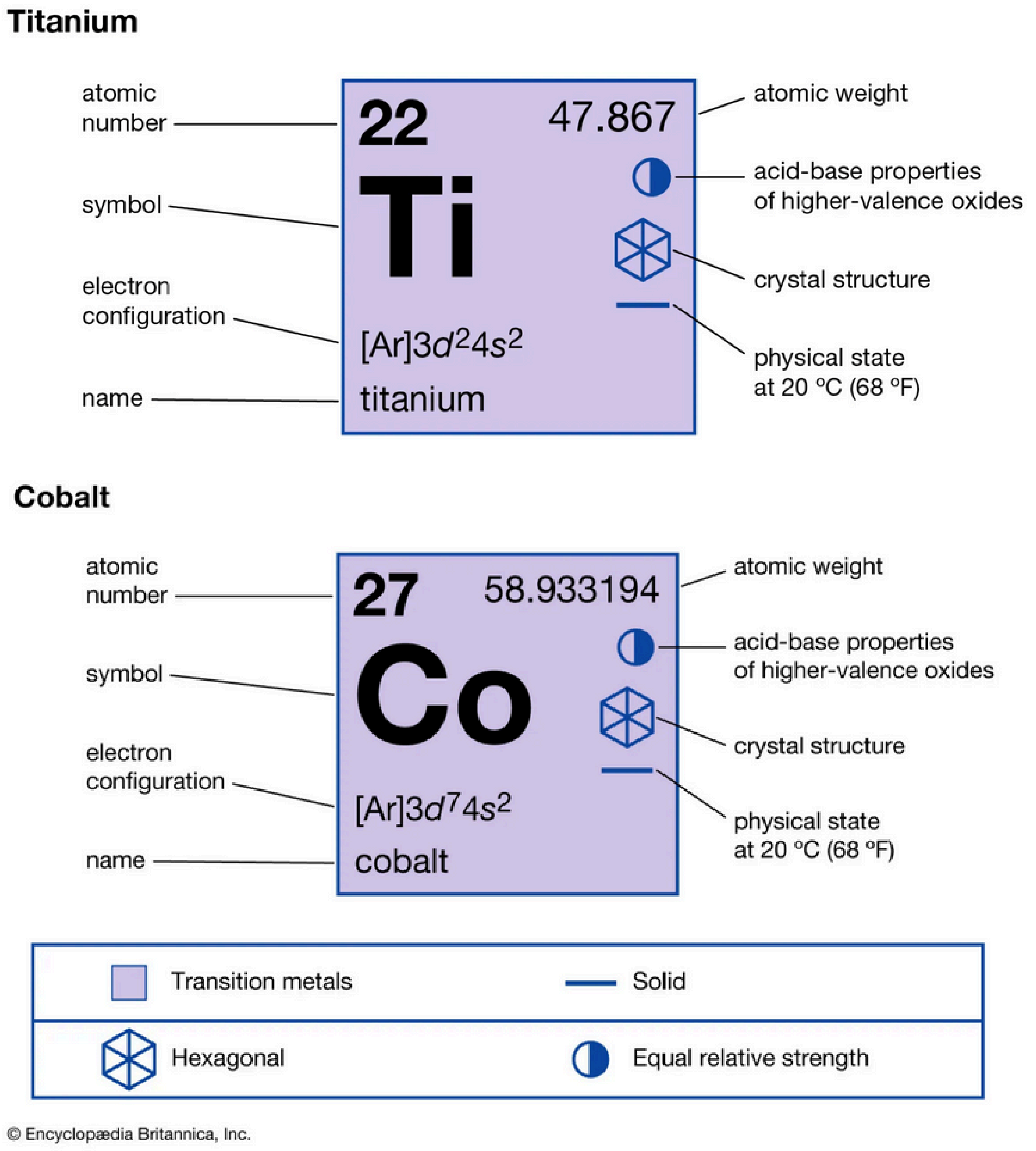
Results

- *Reynolds et. al.'s* petrographic analysis confirmed the presence of magnetite (Fe_3O_4), coated with ilmenite ($FeTiO_3$)
  - Suggested that Ti- saturation occurred after initial magma placement, during rapid cooling
- Our current results indicate Ti incorporation in the matrix material, and in the weathering products as well
- Co, Sr, and Y incorporation are localized to specific mineral phases
  - Concentrated phases may simplify extraction process



Preliminary Inferences

- Based on the differences in the:
  - mineralogical occurrence of Ti
    - In the matrix and weathering products
- Grant Intrusive Is:
  - Formed from more than one enrichment episode
  - An economic source for Ti in addition to HREE's and other critical metals.
  - Potential source of Co, but ore minerals have yet to be inferred



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Acknowledgments

- My advisors and mentors: Dr. Daniel Hummer, Dr. Harvey Henson, and Dr. Lilliana Lefticariu
- John Fox from Prescott Petrographics
- SIUC Micro Imaging and Analysis Center
- GSA and the MGPV division for travel funding

Questions?