

# PEGMATITES

*NATURE'S GIANT TREASURE CHEST!*



**Michael Wise**

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# An Introduction to Granitic Pegmatites

## *What is This Thing?*

### Treasure!

- a concentration of riches, often one which is considered lost or forgotten until being rediscovered.
- wealth or riches stored or accumulated, especially in the form of precious metals, money, jewels, or plate.
- any thing or person greatly valued or highly prized



## Pegmatite = Treasure!

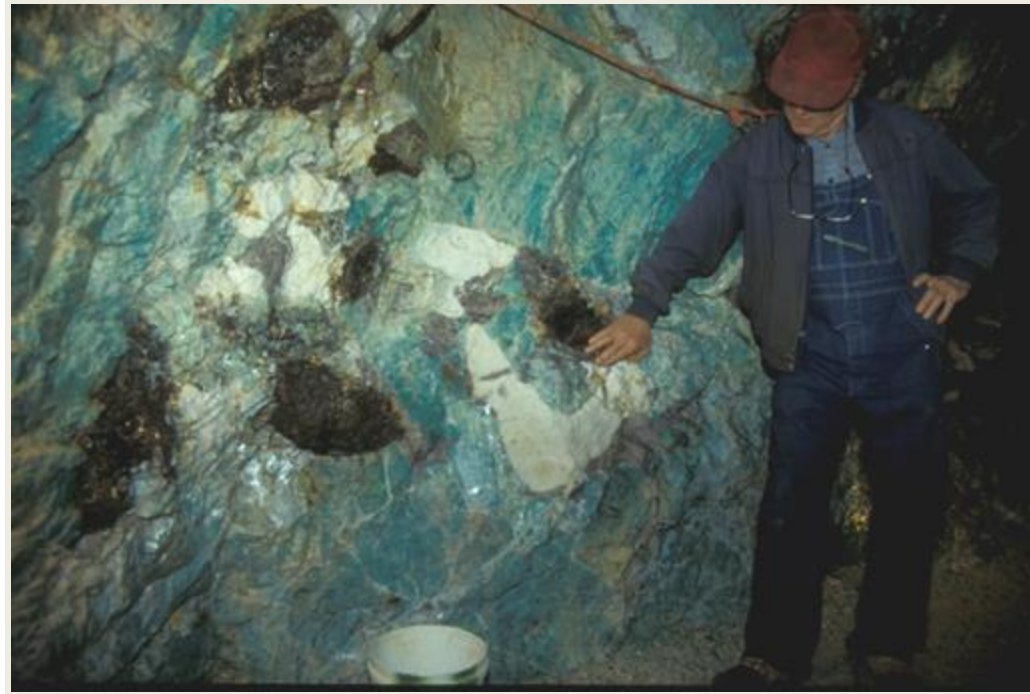


Pegmatites: Nature's Giant Treasure Chest!

# An Introduction to Granitic Pegmatites

## *What is This Thing?*

- Anatomy of Granitic Pegmatites
- Pegmatites as Ore Bodies
- Exploration for Pegmatites



# An Introduction to Granitic Pegmatites

## *What is This Thing?*

### *What is a Pegmatite?*

/ˈpegməˌtɪt/

**Pegmatite** (*sensu stricto*) – a textural term used to describe exceptionally coarse (> 2.5 cm) to gigantic-grained igneous rocks. These may include **granitic**, granodioritic, tonalitic, anorthositic, gabbroic and syenitic compositions.

### **Features**

- Generally leucocratic (light colored)
- They tend to have homogeneous to heterogeneous internal structure
- Extremely variable textures of mineral aggregates
- Some are enriched in rare-elements (e.g., lithium, beryllium, tantalum) and volatile components (e.g., H<sub>2</sub>O, F, BO<sub>3</sub>, PO<sub>4</sub>).





# An Introduction to Granitic Pegmatites

*What is This Thing?*

Granite

Pegmatite



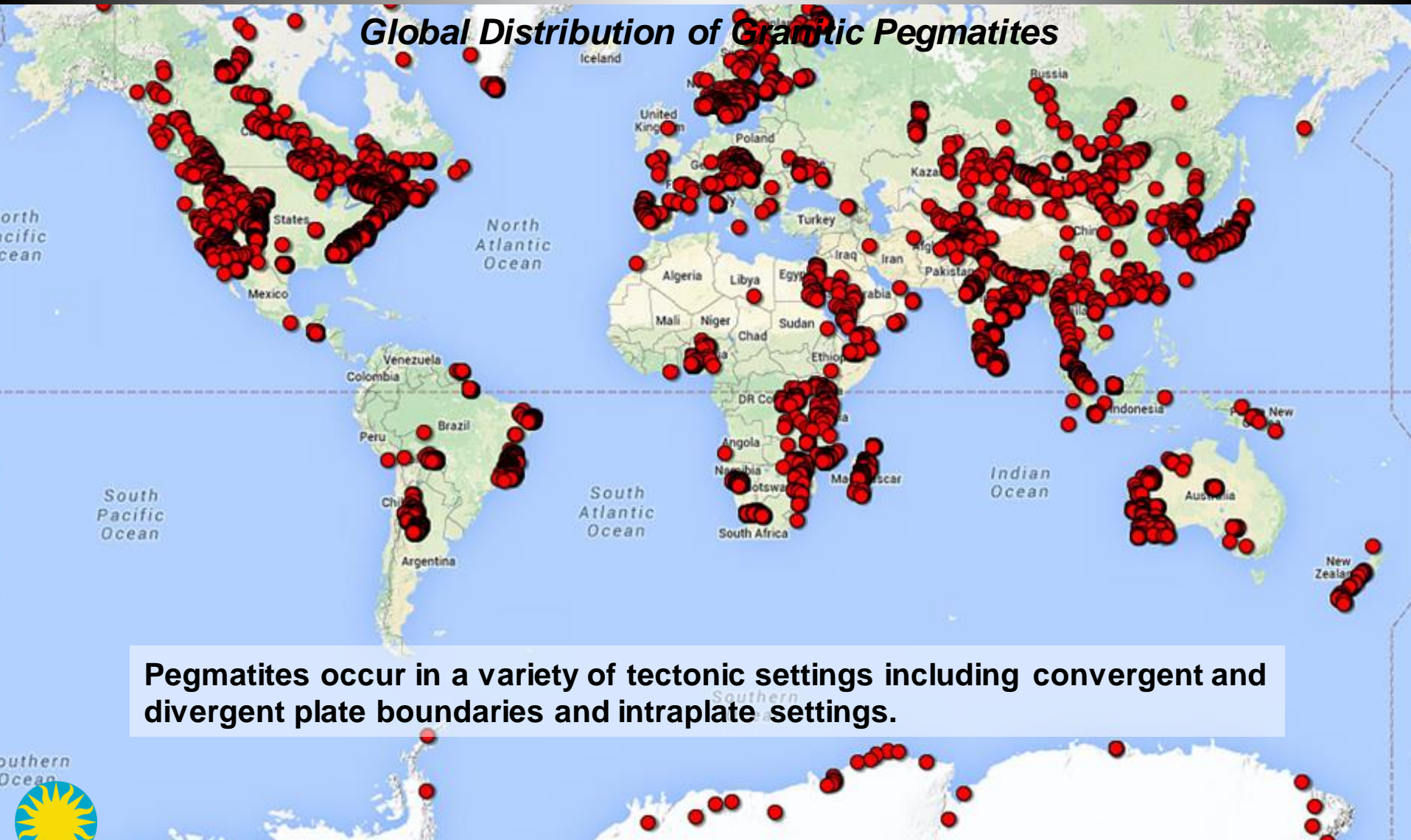
Pegmatites: Nature's Giant Treasure Chest!





# An Introduction to Granitic Pegmatites

## *Global Distribution of Granitic Pegmatites*



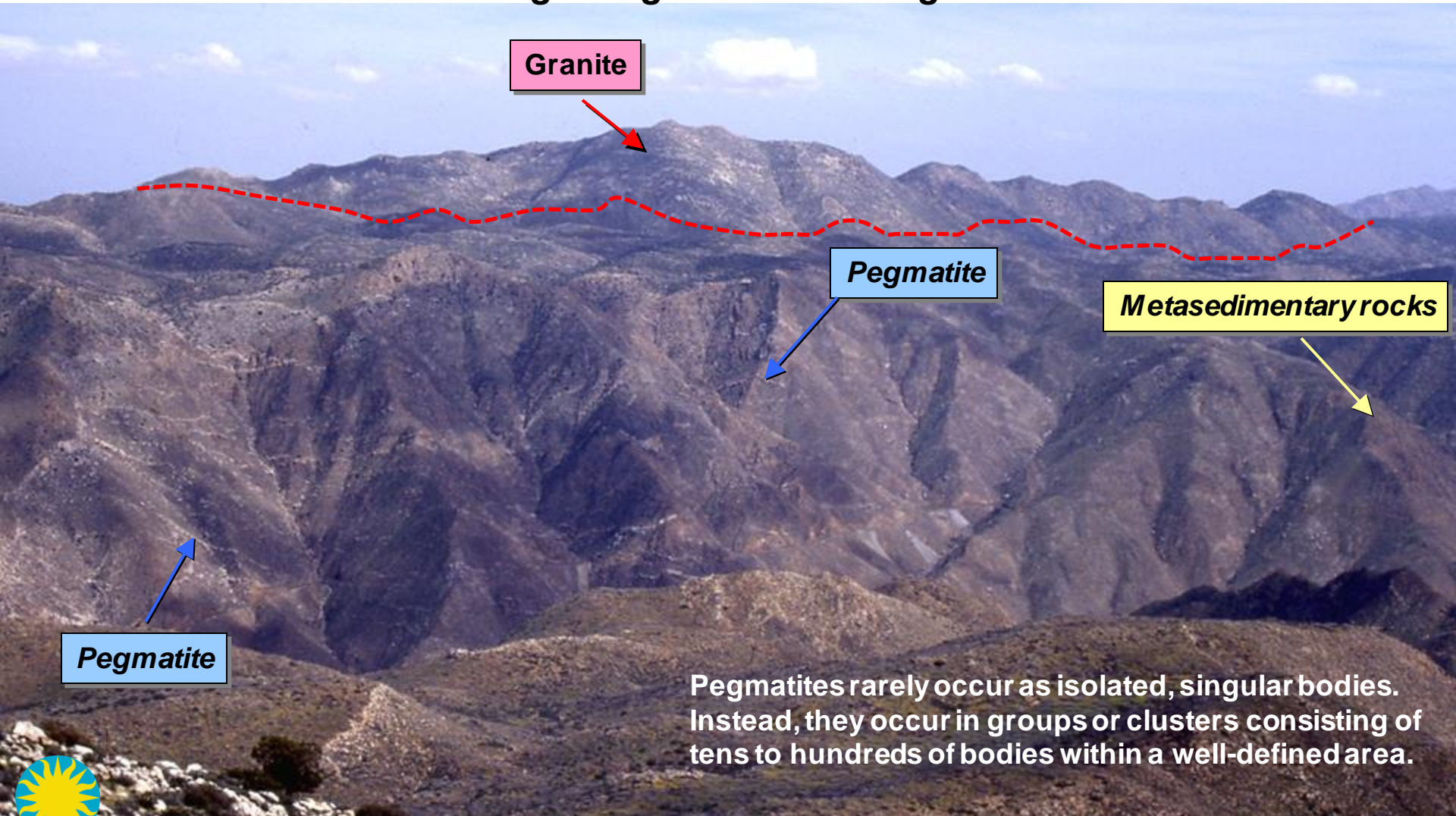
Pegmatites occur in a variety of tectonic settings including convergent and divergent plate boundaries and intraplate settings.

**Pegmatites: Nature's Giant Treasure Chest!**



# The Genesis of Granitic Pegmatites

*In The Beginning There Was Magma/Melt!*



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# An Introduction to Granitic Pegmatites

## *Pegmatites of the United States*

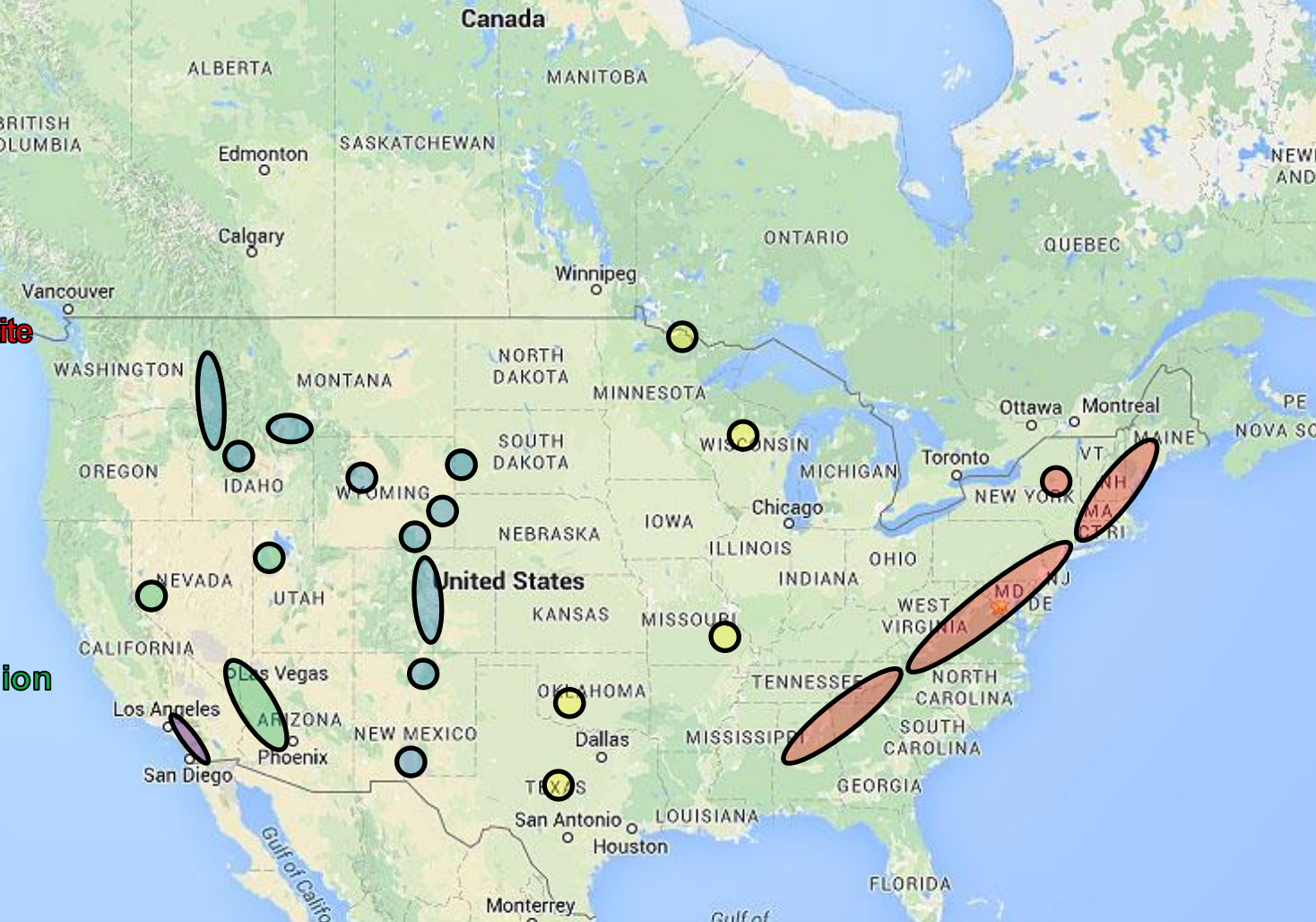
**Appalachian Pegmatite Province**

**Midwestern Region**

**Rocky Mountains Region**

**Basin and Range Region**

**Southern California Pegmatite Province**



**Pegmatites: Nature's Giant Treasure Chest!**





# The Genesis of Granitic Pegmatites

*How To Make a Pegmatite – A Very Oversimplified Process!*

Pegmatite Melt  
Genesis

Crystallization of Rock-  
forming Minerals



*e.g., quartz  
feldspars  
micas*



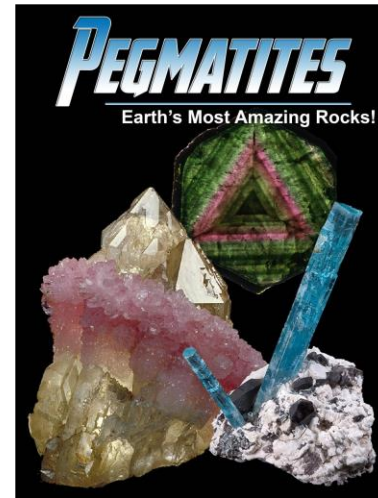
Crystallization of Rare-  
Element Minerals



*e.g., beryl (Be)  
tantalite (Ta)  
spodumene (Li)*



Decreasing  
Temperature  
(Cooling of Melt)



Extremely Cool  
Rocks!

# The Genesis of Granitic Pegmatites

*In The Beginning There Was Magma/Melt!*

## Two Models for Pegmatite Genesis

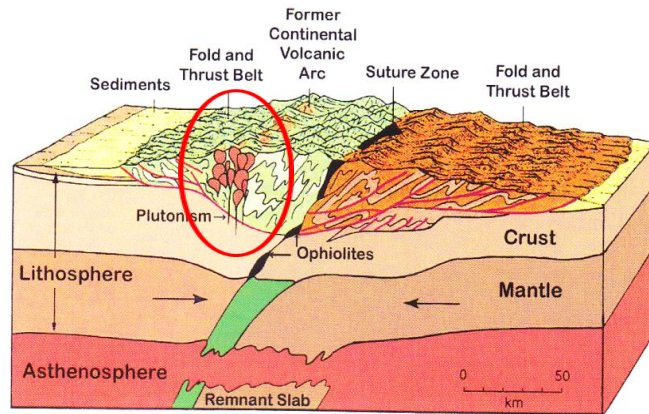
1. Late-stage product of granite crystallization (Fractional Crystallization)
2. Partial melting of pre-existing metamorphic rocks (Anatexis)



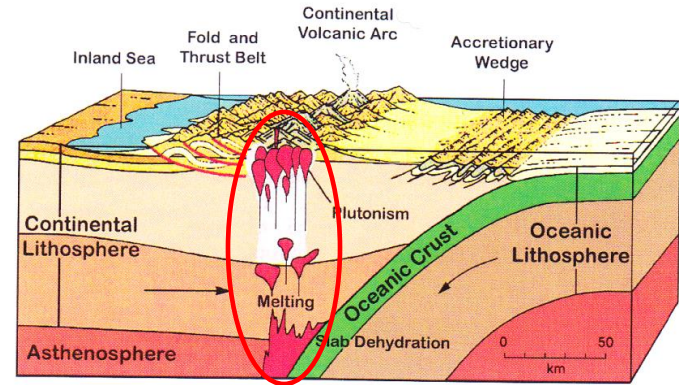
*Pegmatite crystallization temperatures ~450° to 300° C (842 to 572° F).  
Pegmatite crystallization pressures ~1.5 to 5 kb (~5 to 20 km)*

# The Genesis of Granitic Pegmatites

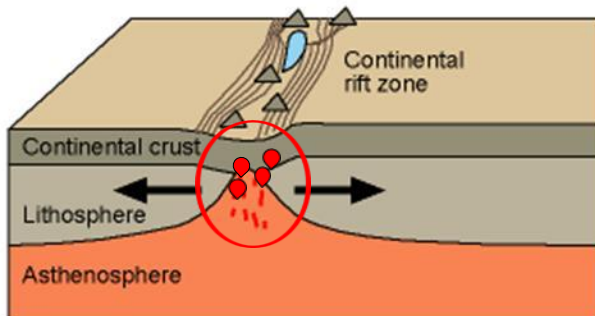
*In The Beginning There Was Magma/Melt!*



Collision zones:  
Continental crust–Continent crust



Collision zones:  
Continental crust– Oceanic crust



Rift zones:  
Pulling apart of lithospheric plates



# The Genesis of Granitic Pegmatites

*In The Beginning There Was Magma/Melt!*

Late-stage product of granite crystallization



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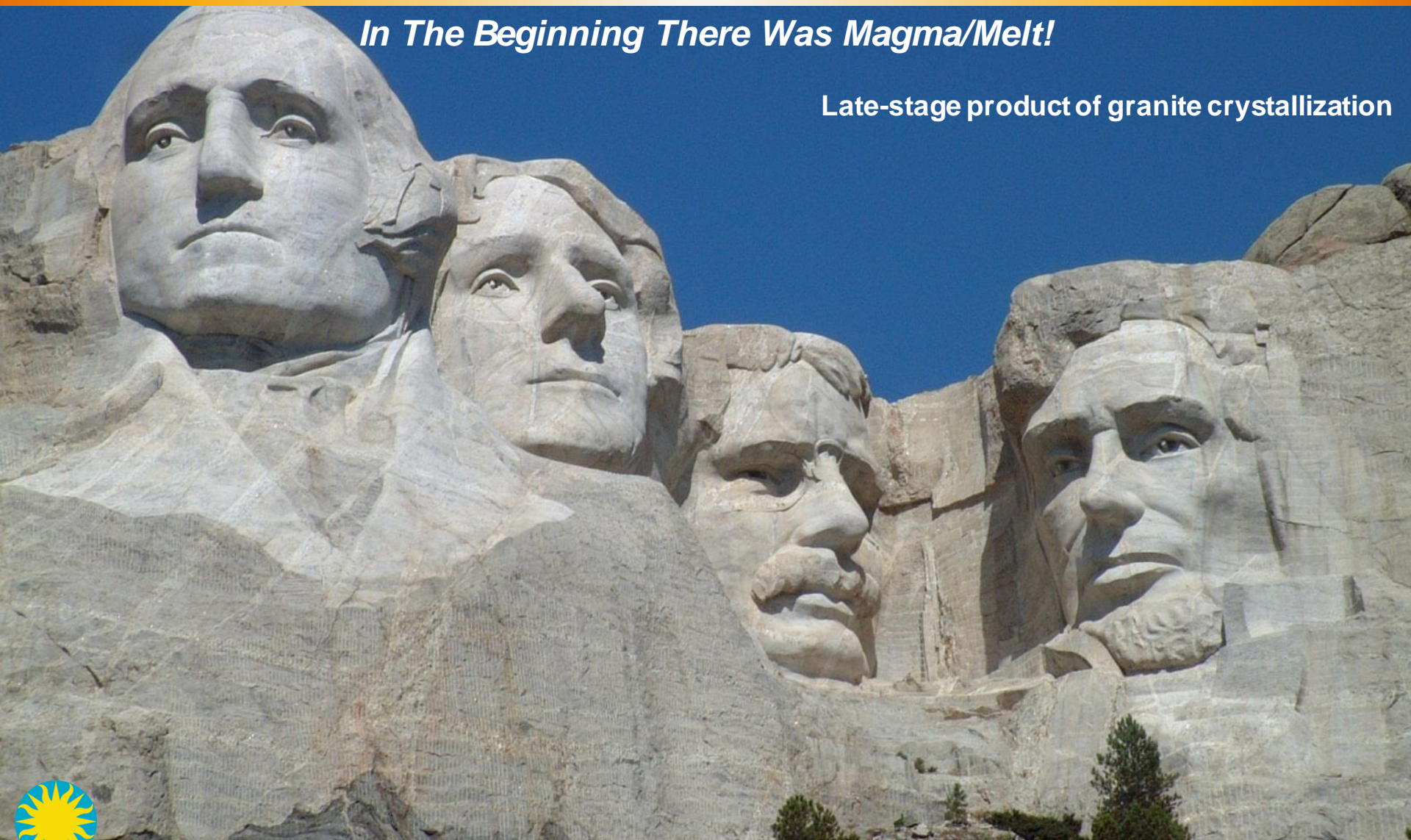
**Pegmatites: Nature's Giant Treasure Chest!**



# The Genesis of Granitic Pegmatites

*In The Beginning There Was Magma/Melt!*

Late-stage product of granite crystallization



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**Pegmatites: Nature's Giant Treasure Chest!**



# The Genesis of Granitic Pegmatites

*In The Beginning There Was Magma/Melt!*



Partial melting of pre-existing metamorphic rocks



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**Pegmatites: Nature's Giant Treasure Chest!**



# The Genesis of Granitic Pegmatites

*In The Beginning There Was Magma/Melt!*



Partial melting of pre-existing metamorphic rocks

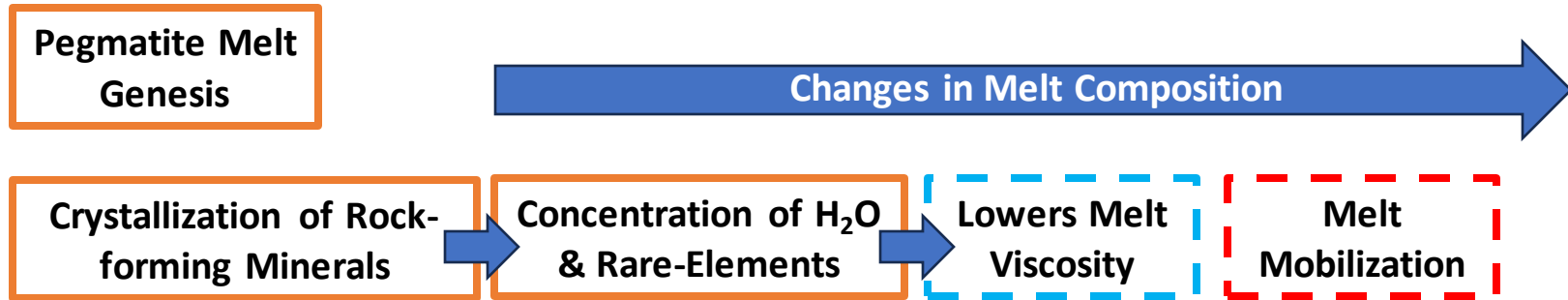


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**Pegmatites: Nature's Giant Treasure Chest!**

# The Genesis of Granitic Pegmatites

*How To Make a Pegmatite – A Very Oversimplified Process!*





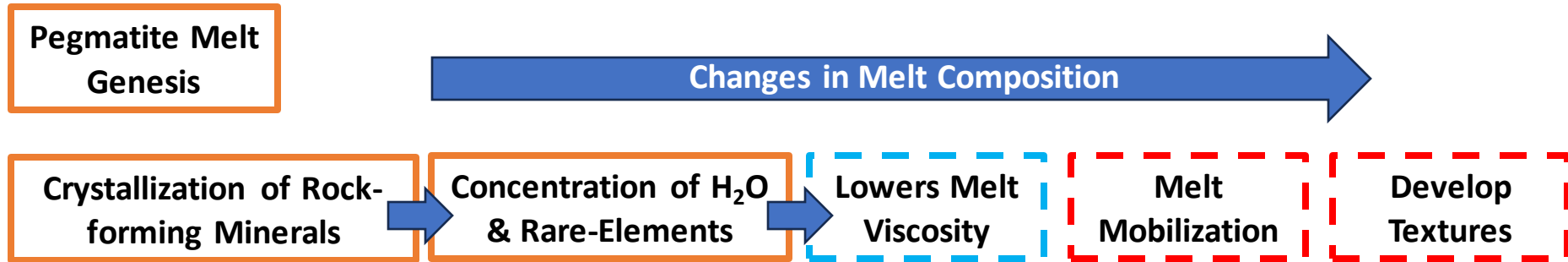
# The Genesis of Granitic Pegmatites

*In The Beginning There Was Magma/Melt!*



# The Genesis of Granitic Pegmatites

*How To Make a Pegmatite – A Very Oversimplified Process!*



# The Textures of Granitic Pegmatites

*The Bigger, The Better?*



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**Pegmatites: Nature's Giant Treasure Chest!**



# The Textures of Granitic Pegmatites



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# The Textures of Granitic Pegmatites

*The Bigger, The Better?*



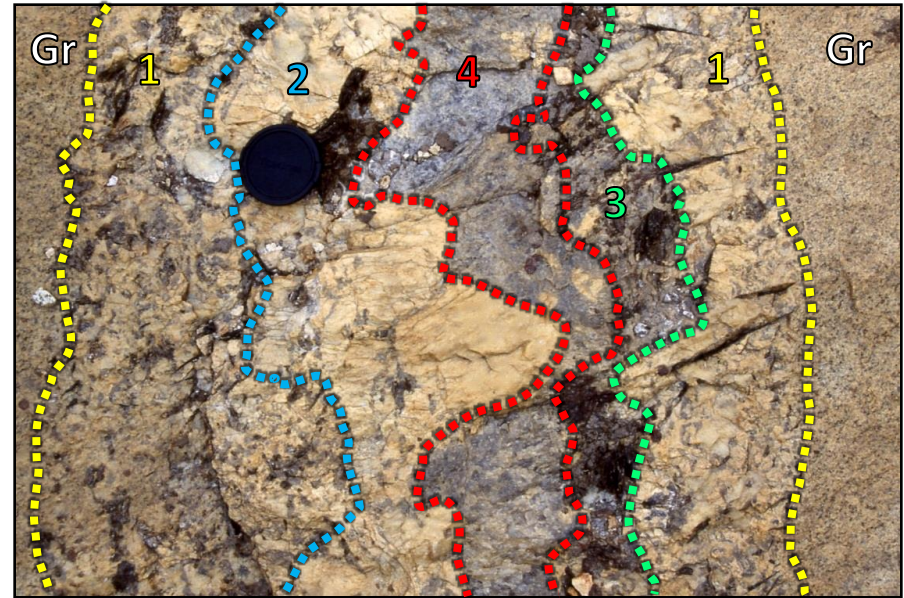


# The Textures of Granitic Pegmatites

*The Bigger, The Better?*



Unzoned pegmatite



Zoned pegmatite



# The Textures of Granitic Pegmatites

*The Bigger, The Better?*

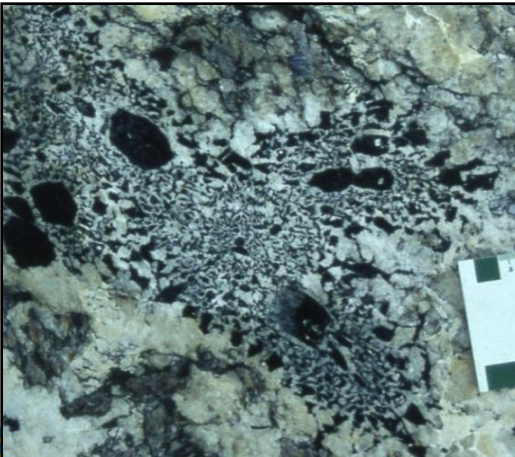
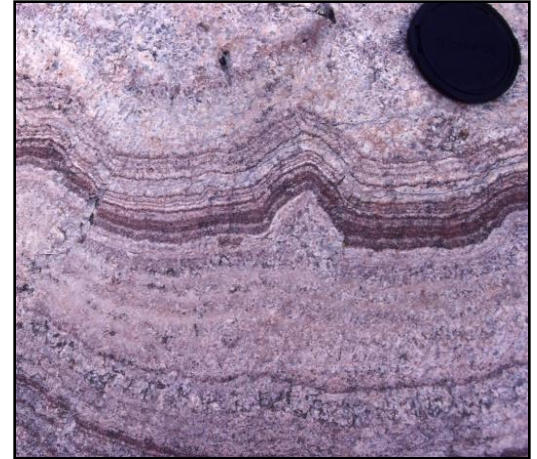
**Graphic Texture**



**Comb Structure**



**Layered Structure**





# The Textures of Granitic Pegmatites

*The Bigger, The Better?*





# The Mineralogy of Granitic Pegmatites

*Marvelously Magical Minerals!*

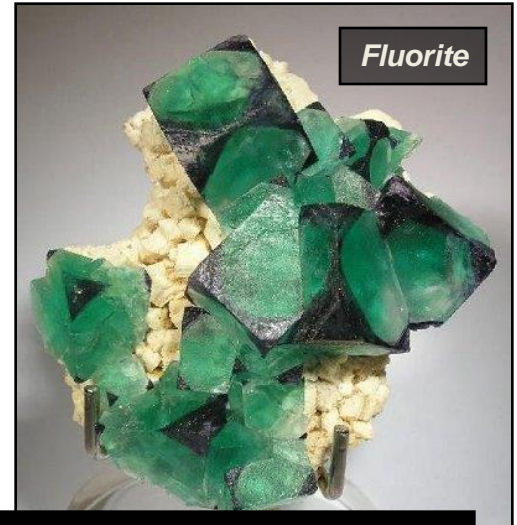
Topaz



Quartz



Fluorite



Fluorite w/Stilbite



Beryl



Pegmatites: Nature's Giant Treasure Chest!



# The Mineralogy of Granitic Pegmatites

## Marvelously Magical Minerals!

# 'Pegmatology' Periodic Table of the Elements

The periodic table is organized as follows:

- hydrogen**: Green box (H)
- alkali metals**: Yellow boxes (Li, Na, K, Rb, Cs)
- alkali earth metals**: Light blue boxes (Be, Mg, Ca, Sr, Ba)
- transition metals**: Orange boxes (Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Kr, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, I, Xe, La, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi, Po, At, Rn)
- poor metals**: Blue boxes (Al, Si, P, S, Cl, Ar, Ga, Ge, As, Se, Br, Kr, In, Sn, Sb, Te, I, Xe, Tl, Pb, Bi, Po, At, Rn)
- nonmetals**: White boxes (B, C, N, O, F, Ne, Si, P, S, Cl, Ar, As, Se, Br, Kr, Sb, Te, I, Xe, Bi, Po, At, Rn)
- noble gases**: Red boxes (He, Ne, Ar, Kr, Xe, Rn)
- rare earth metals**: Grey boxes (Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, U, Pa, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr)

Red boxes highlight the following elements:

- Nitrogen (N) - Group 15, Period 2
- Cadmium (Cd) - Group 12, Period 5
- Uranium (U) - Actinide series, Atomic number 92

Nearly 500 different minerals species are known to occur in granitic pegmatites.

Silicates, phosphates and oxides dominate over other mineral groups.

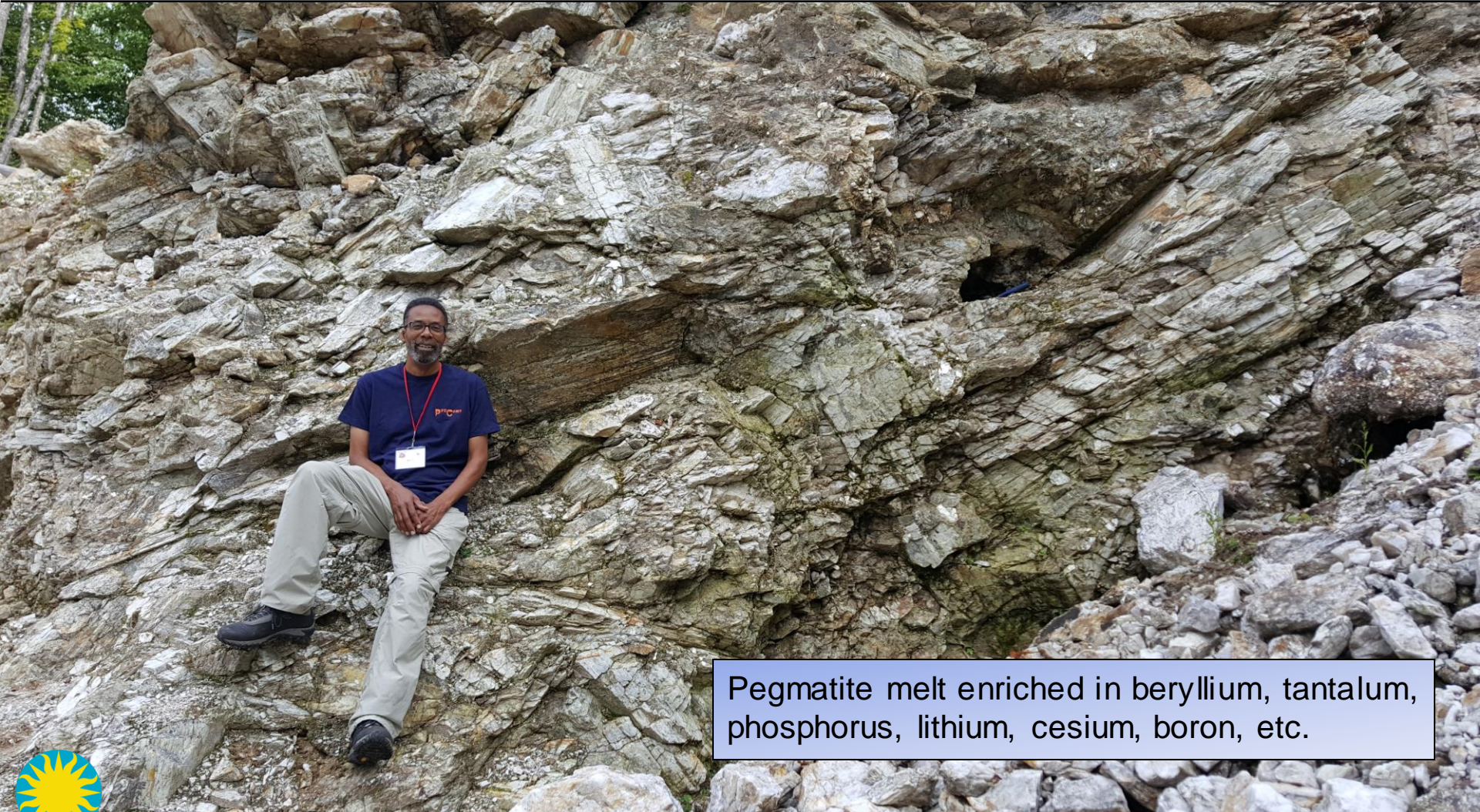
## Fluorapatite





# The Mineralogy of Granitic Pegmatites

*Marvelously Magical Minerals!*



Pegmatite melt enriched in beryllium, tantalum, phosphorus, lithium, cesium, boron, etc.



# The Mineralogy of Granitic Pegmatites

*Marvelously Magical Minerals!*



Pegmatite melt enriched in fluorine, cerium, yttrium, uranium, zirconium, niobium, titanium, scandium, etc.

# The Mineralogy of Granitic Pegmatites

## *Marvelously Magical Minerals!*

Fundamental rock-forming assemblage in granitic pegmatites is simple: quartz, microcline (potassic feldspar), and albite (sodic feldspar).



Quartz



Microcline



Albite



# The Genesis of Granitic Pegmatites

*Marvelously Magical Minerals!*



Fluid inclusions



Radiation



Mn (Manganese),  
P (Phosphorus),  
inclusions



Fe (Iron),  
Radiation



# The Mineralogy of Granitic Pegmatites

*Marvelously Magical Minerals!*





# The Mineralogy of Granitic Pegmatites

*Marvelously Magical Minerals!*

## Color Varieties of Beryl

Goshenite: colorless to white

Aquamarine: blue

Heliodor: yellow to greenish-yellow

Morganite: pink

**Emerald: dark green**



# The Mineralogy of Granitic Pegmatites

*Marvelously Magical Minerals!*



Li (Lithium)





# The Mineralogy of Granitic Pegmatites

*Marvelously Magical Minerals!*

**Rhodochrosite**



Photo credit: © Elliott/Fine Minerals International

**Epidote**



**Jeremejevite**



**Monazite**



**Londonite**

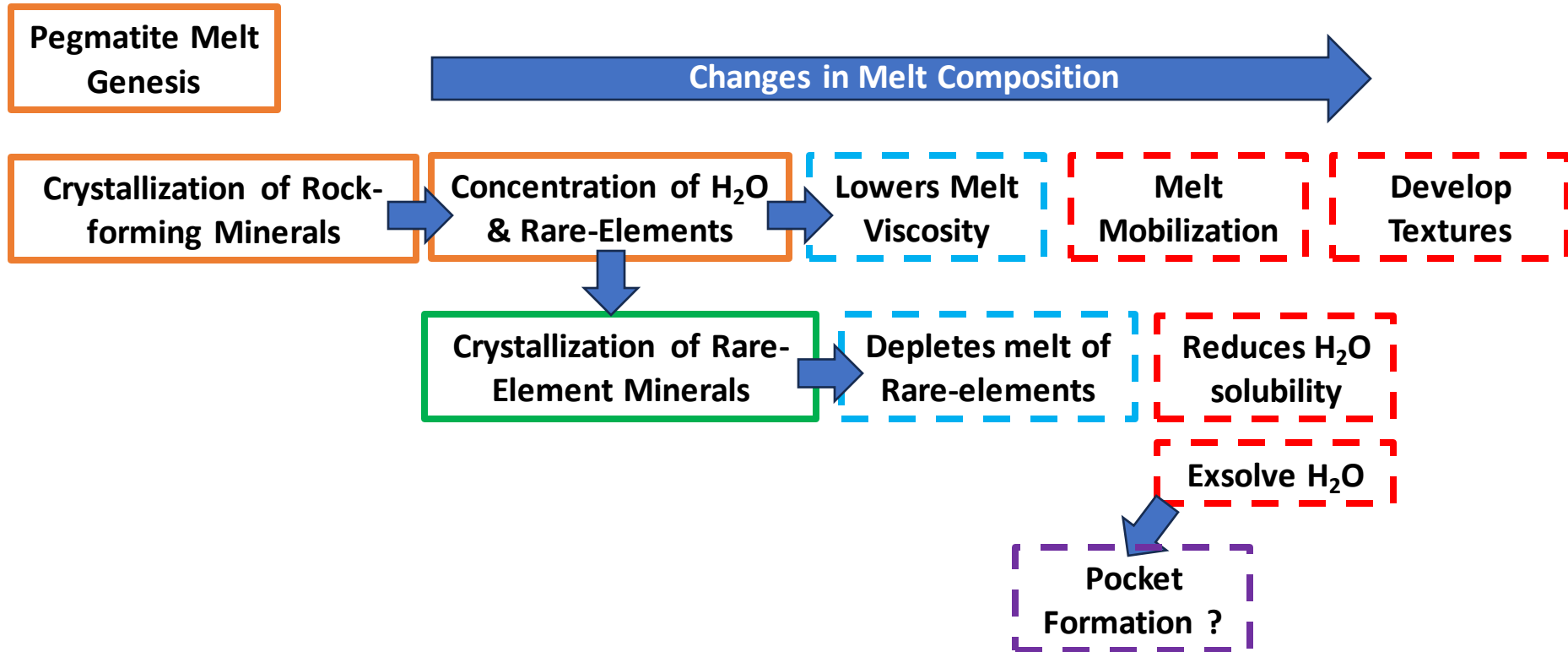


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# The Mineralogy of Granitic Pegmatites

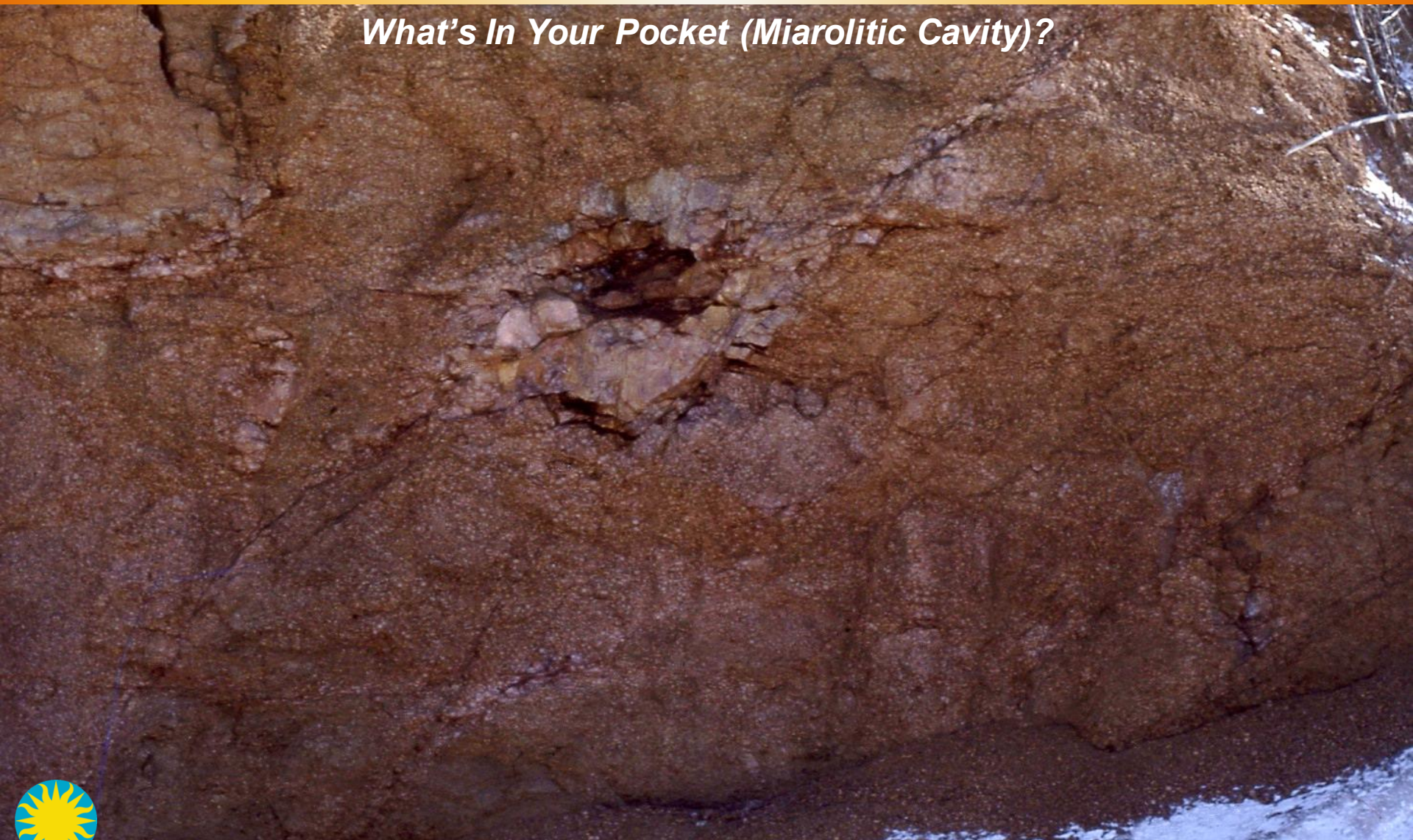
*How To Make a Pegmatite – A Very Oversimplified Process!*





# The Late Stages of Granitic Pegmatites?

*What's In Your Pocket (Miarolitic Cavity)?*



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# The Late Stages of Granitic Pegmatites?

## *What's In Your Pocket (Miarolitic Cavity)?*



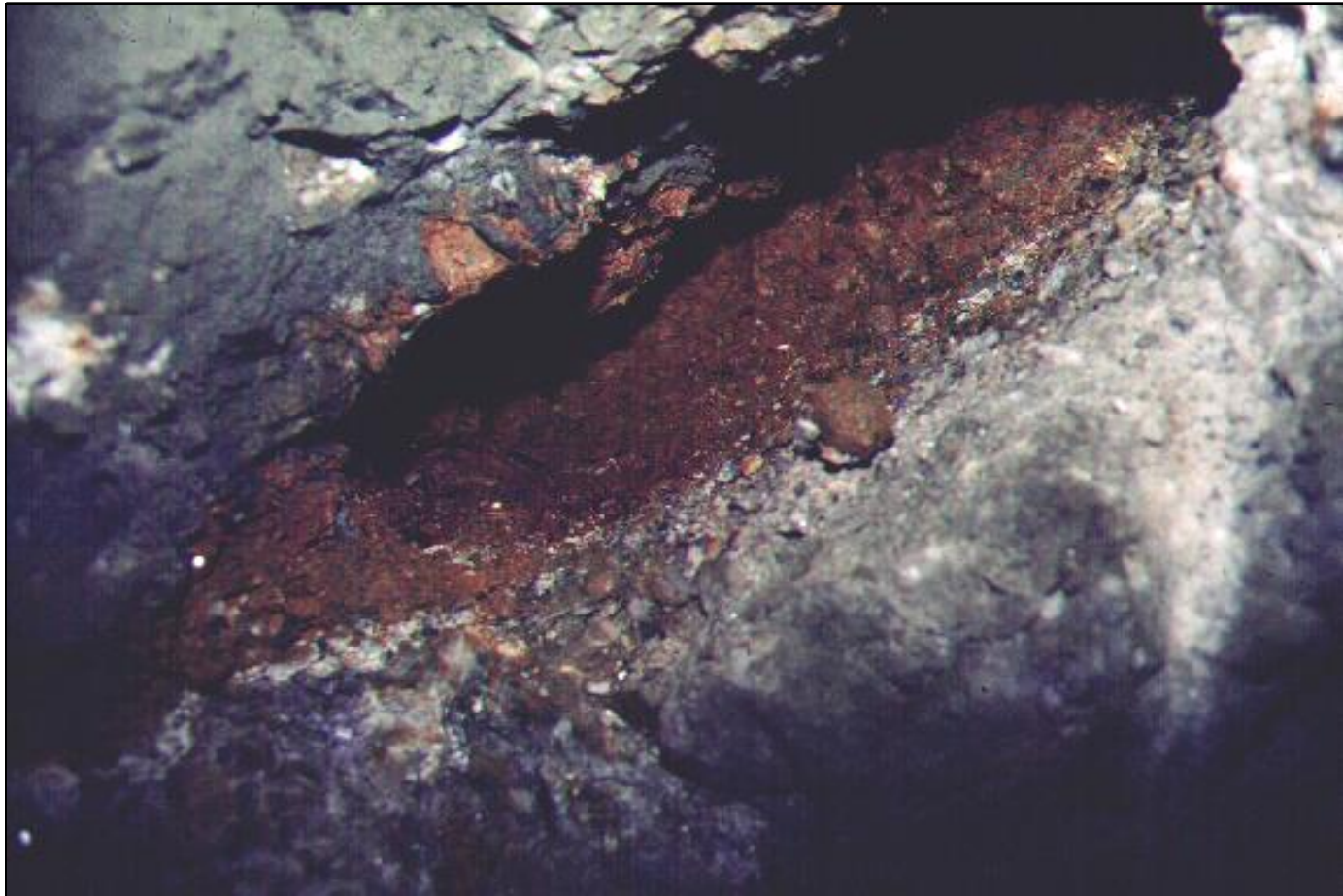
Pegmatites with miarolitic cavities are extremely rare! Typically develop in pegmatites that crystallize at low pressures ( $\sim 1.5 - 2$  kb).





# The Late Stages of Granitic Pegmatites?

*What's In Your Pocket (Miarolitic Cavity)?*



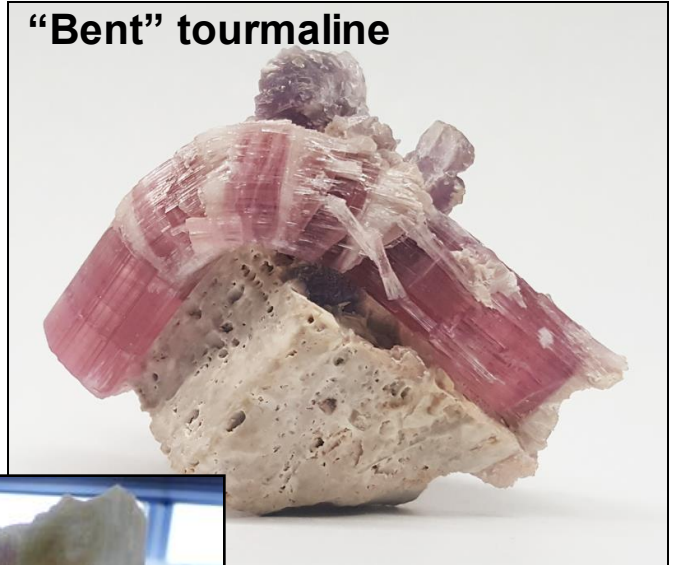
# The Late Stages of Granitic Pegmatites?

*What's In Your Pocket (Miarolitic Cavity)?*

Fibrous “hairy” tourmaline



“Bent” tourmaline

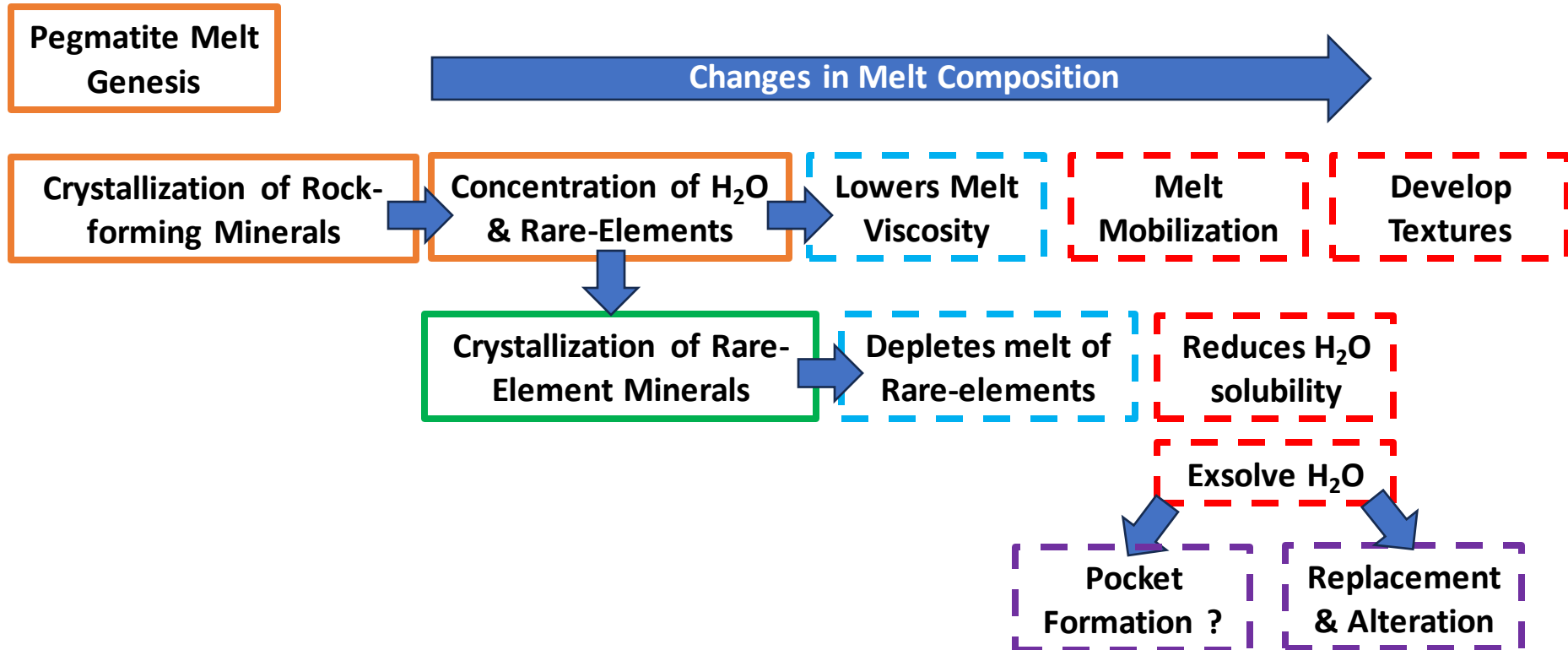


Stages of etched (corroded) tourmaline



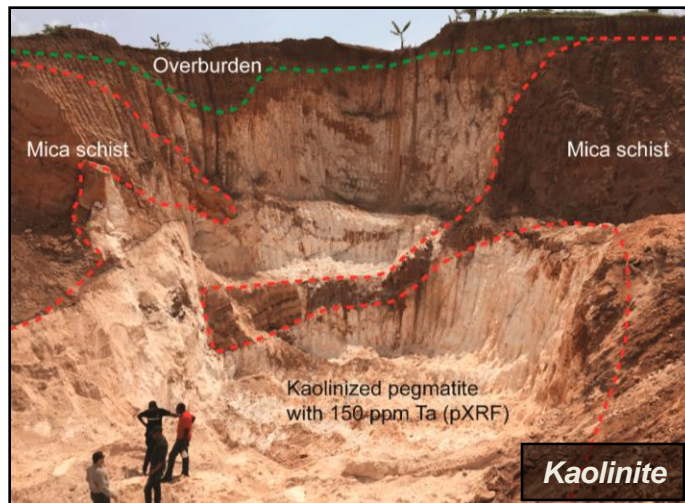
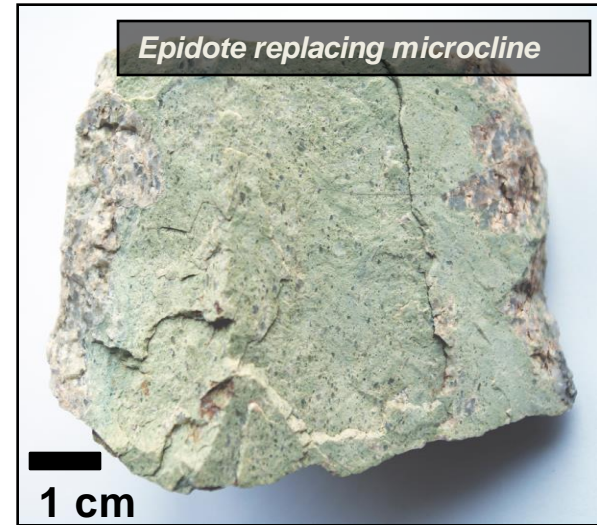
# The Mineralogy of Granitic Pegmatites

## *How To Make a Pegmatite – A Very Oversimplified Process!*



# The Mineralogy of Granitic Pegmatites

*Endgame!*

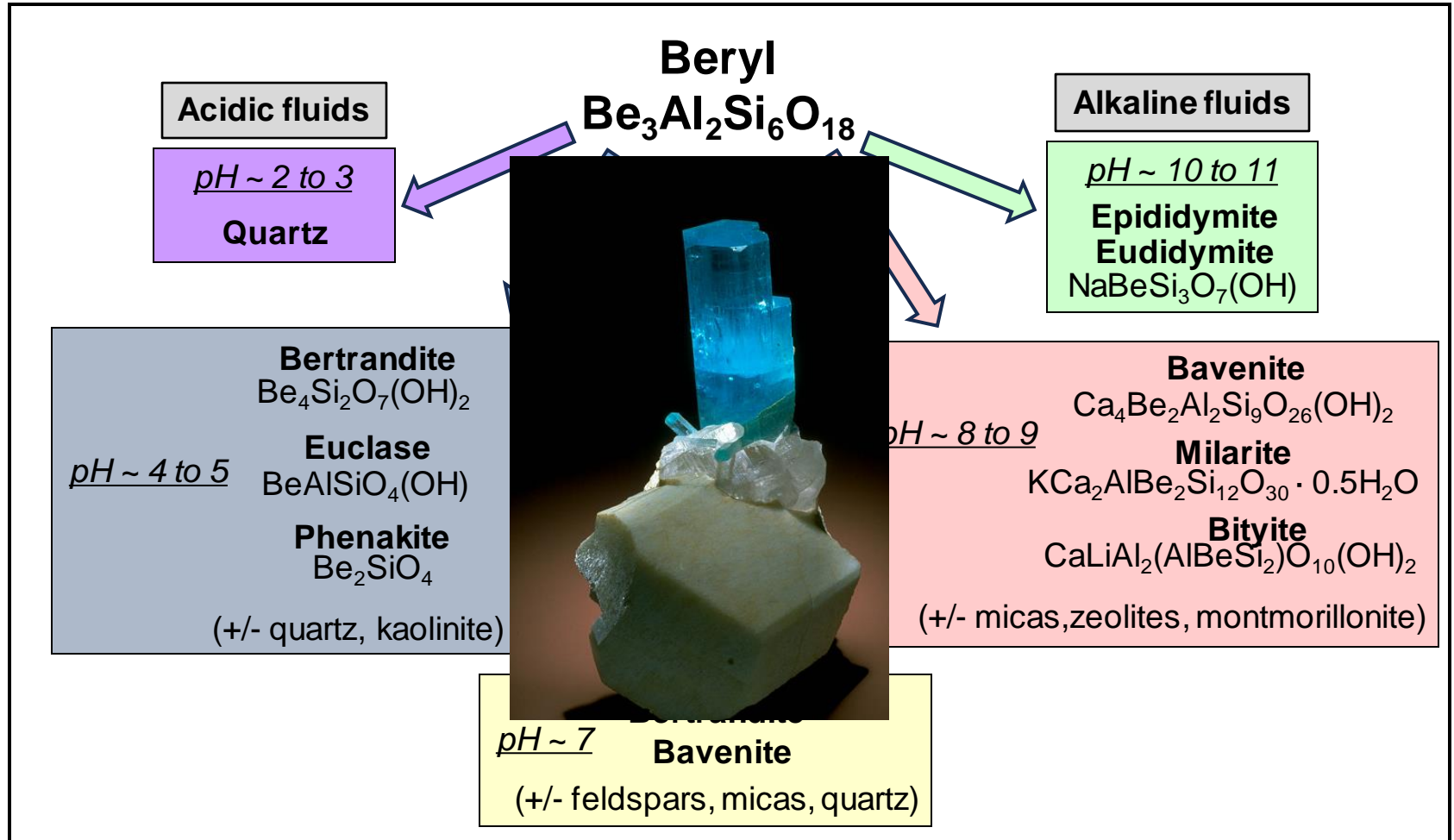




# The Mineralogy of Granitic Pegmatites

## Endgame!

Secondary Beryllium Minerals from the Alteration of Beryl



# Granitic Pegmatites As Ore Bodies

- Sources of Collectable Mineral Specimens
- Sources of Gem Materials
- Sources of Architectural Materials
- Sources of Industrial Minerals
- Sources of Rare Elements





# Granitic Pegmatites As Ore Bodies

## Collectables



Smithsonian Institution  
National Museum of Natural History

## Pegmatites: Nature's Mineralogical Museum

Pegmatites are igneous rocks, like granites, but with very large mineral grains. Well-known for their diversity of mineral species, pegmatites are arguably the world's most mineralogically interesting rock types. Pegmatites can contain an assortment of collector-quality, gem-grade, industrial and scientifically important minerals. This case highlights some of the interesting pegmatite minerals from the Smithsonian's Mineral and Gem Collection.

Blair Valley pegmatites, CA

Blair Valley pegmatites, CA



Smithsonian

Pegmatites: Nature's Giant Treasure Chest!

# Granitic Pegmatites As Ore Bodies

## *Sources of Gem Materials*



Pegmatite is used in **gemstone mining** because of it has large crystal minerals. Gem minerals found in pegmatite include amazonite, apatite, aquamarine, beryl, chrysoberyl, emerald, garnet, kunzite, lepidolite, spodumene, topaz, tourmaline, zircon, and many others.



# Granitic Pegmatites As Ore Bodies

## *Sources of Gem Materials*



# Granitic Pegmatites As Ore Bodies

## Sources of Gem Materials

Mineral species	Gem variety	Colors
<b>Beryl</b>	<i>Aquamarine</i>	blue and green
	<i>Emerald</i>	green
	<i>Goshenite</i>	colorless
	<i>Heliodor</i>	yellow
	<i>Morganite</i>	pink to orange
<b>Topaz</b>		colorless, blue, brown
<b>Elbaite (Tourmaline Group)</b>	<i>Achroite</i>	colorless
	<i>Canary</i>	yellow
	<i>Indicolite</i>	blue
	<i>Paraiba</i>	blue, green
	<i>Rubellite</i>	red to pink
	<i>Verdelite</i>	green
<b>Spessartine (Garnet Group)</b>		orange
<b>Spodumene</b>	<i>Kunzite</i>	pink to purple
		green





# Granitic Pegmatites As Ore Bodies

## *Sources of Architectural Materials*



Pegmatite are used as **architectural stone**. If the pegmatite is sound and attractive, it might be cut into slabs and polished for building facing, countertops, tile or other decorative stone products and sold commercially as a “granite.”



# Granitic Pegmatites As Ore Bodies

*Sources of Architectural Materials*

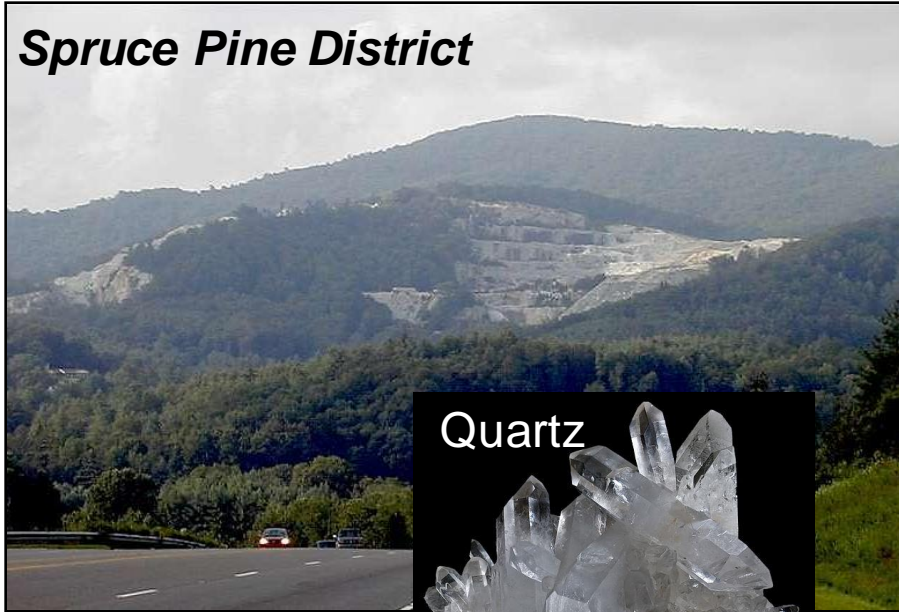




# Granitic Pegmatites As Ore Bodies

## *Sources of Industrial Materials*

### ***Spruce Pine District***



**Quartz**



High purity quartz is used in new applications and markets including solar panels, semiconductors, and fiber optic cables.

**Microcline**



Feldspar is an important ingredient in the manufacture of glass, ceramics, and as fillers and extenders in applications such as paints, plastics and rubber.



**Muscovite**



Cosmetics, insulators, caulks, sealants, paints, lubricants, brake pads...etc.

# Granitic Pegmatites As Ore Bodies

## *Sources of Critical & Strategic Elements*

***Greenbushes mine***



**Cassiterite**



Pegmatite is used for **rare mineral mining**. These minerals can be commercial sources of beryllium, bismuth, boron, cesium, lithium, molybdenum, niobium, tantalum, tin, titanium, tungsten, and many other elements.



# Granitic Pegmatites As Ore Bodies

## Sources of Critical & Strategic Elements *Beryllium*



Although beryllium production is dominated by the rhyolite hosted bertrandite, beryl ( $\text{Be}_3\text{Al}_2\text{Si}_3\text{O}_{18}$ ) from pegmatites continues to be a lesser, but local, source of beryllium.

Beryllium-based alloys are in components of aerospace, automotive, and electronic devices.

# Granitic Pegmatites As Ore Bodies

## Sources of Critical & Strategic Elements *Cesium*

Cesium is recovered from the mineral pollucite ( $\text{Cs}_2\text{Al}_2\text{Si}_4\text{O}_{12} \cdot 2\text{H}_2\text{O}$ ) which is found in highly evolved, rare-element pegmatites.

The oil sector is the largest consumer of cesium. The market consists of cesium-based brines for high temperature-high pressure application drilling fluids and fine chemicals. Because of its photoemissive properties, Cs is also used in solar photovoltaic cells.





# Granitic Pegmatites As Ore Bodies

## Sources of Critical & Strategic Elements *Tantalum & Lithium*



Columbite-tantalite,  $(\text{Fe}, \text{Mn})(\text{Nb}, \text{Ta}_2)\text{O}_6$ : Tantalum has a wide variety of industrial uses but the most significant is in electronics for tantalum capacitors that they can be incorporated into electronic devices such as mobile phones.



Spodumene,  $\text{LiAlSi}_2\text{O}_6$ : Lithium-ion batteries are one of the most popular types of rechargeable battery for portable electronics.

# Granitic Pegmatites As Ore Bodies

## *Pegmatites of the United States*

*Lithium-rich pegmatite districts*

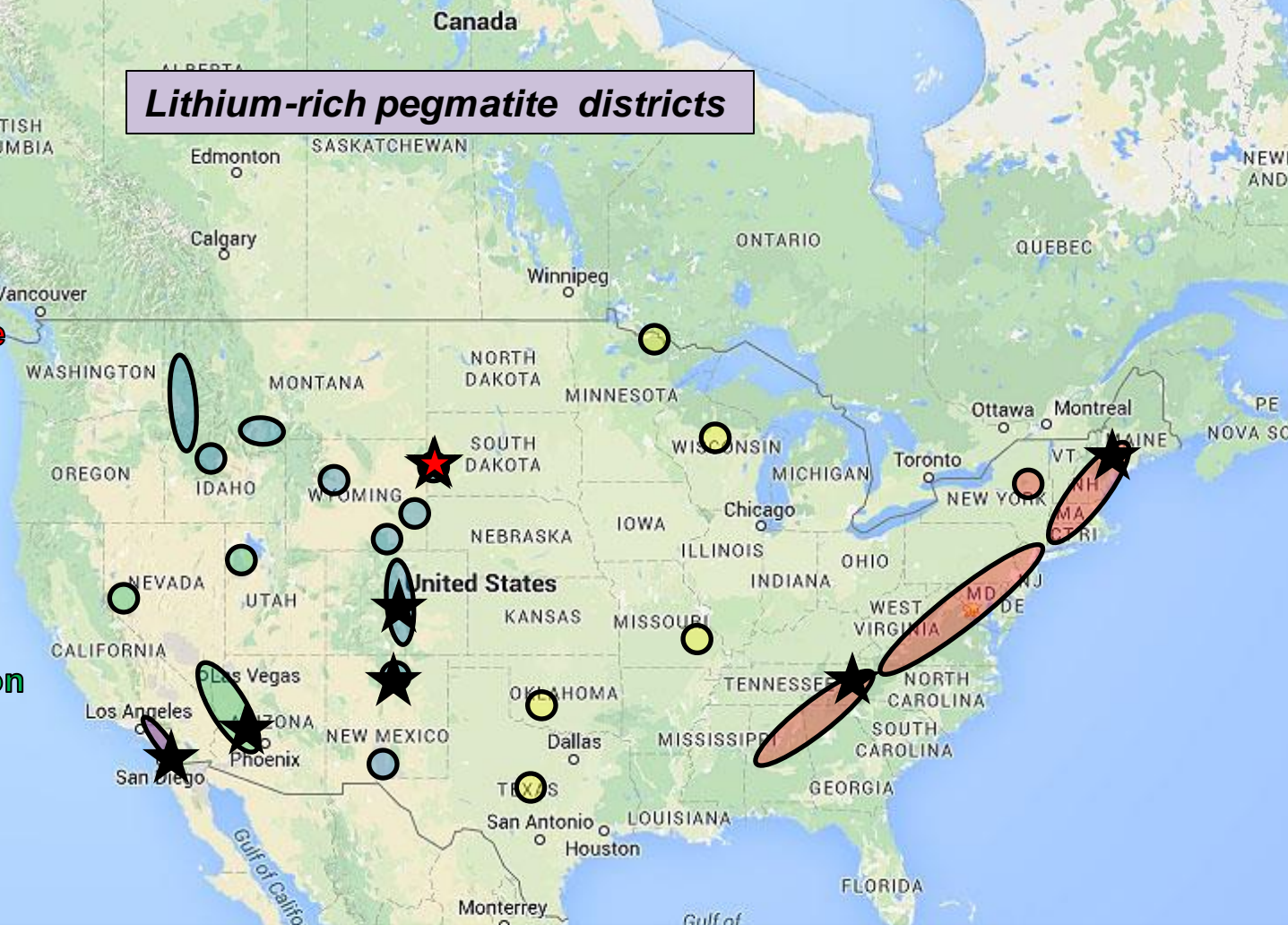
**Appalachian Pegmatite Province**

**Midwestern Region**

**Rocky Mountains Region**

**Basin and Range Region**

**Southern California Pegmatite Province**



**Pegmatites: Nature's Giant Treasure Chest!**



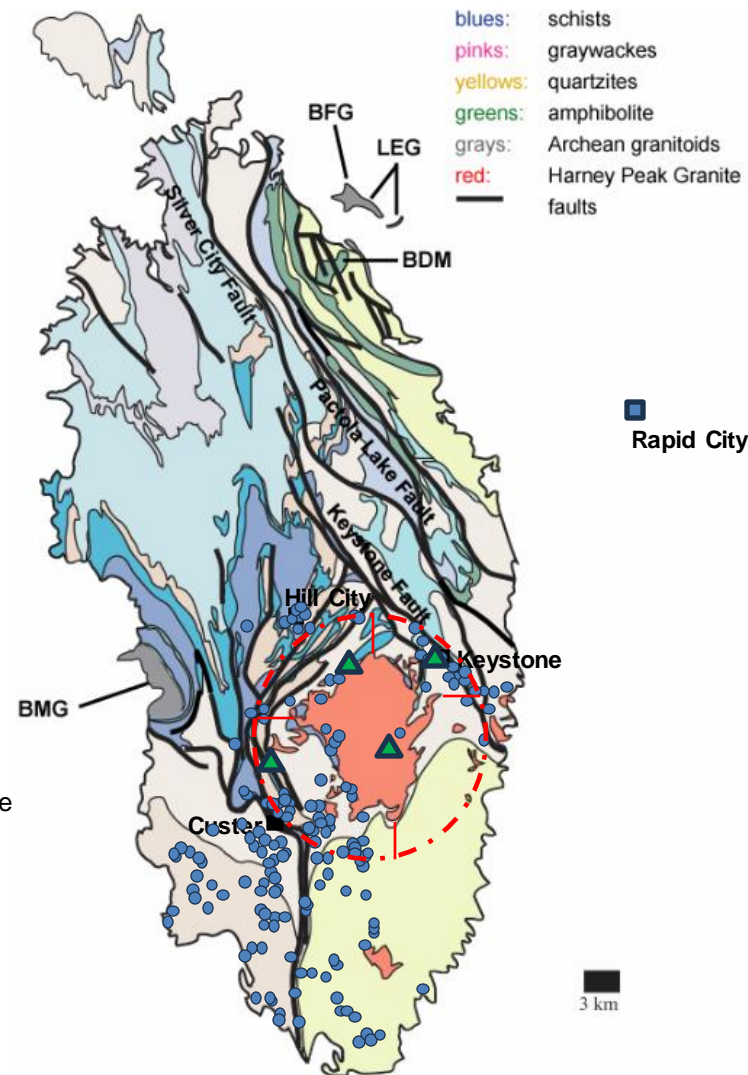
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# Granitic Pegmatites As Ore Bodies

Generalized geologic map of the Black Hills crystalline core with pegmatites and regionally important structures. Modified from Allard and Portis, (2013) and Redden et al. (1990).

- Harney Peak Granite
- ▲ Pegmatitic Granite
- Pegmatites



# Granitic Pegmatites As Ore Bodies

**Black Hills area South Dakota Pegmatite Minerals**

Albite	Fairfieldite	Petalite
Allanite	Ferrisicklerite	Pollucite
Allaudite	Goethite	Quartz
Almandine	Goyazite	Rutile
Amblygonite	Graftonite	Schorl
Apatite-F	Heterosite	Scorzalite
Arrojadite	Holmquistite	Sicklerite
Arsenopyrite	Lepidolite	Spessartine
Autunite	Lithiophilite	Spodumene
Bertrandite	Lollingite	Strengite
Beryl	Microcline	Tantalite
Biotite	Microlite group	Tapiolite
Brazilianite	Mitridatite	Torbernite
Cassiterite	Molybdenite	Triphillite
Chrysoberyl	Monazite-Ce	Triplite
Columbite	Montebrasite	Triploidite
Elbaite	Montmorillonite	Uraninite
Eosphorite	Muscovite	Uranophane
Eucryptite	Orthoclase	Wodginite
		Zircon



**Apatite-F:** King Lithia mine



**Cassiterite:** White cap mine



**Heterosite:** White Elephant mine





# Granitic Pegmatites As Ore Bodies

## Black Hills area South Dakota Pegmatite Minerals

Albite	Fairfieldite	Petalite
Allanite	Ferrisicklerite	Pollucite
Allaudite	Goethite	Quartz
Almandine	Goyazite	Rutile
<b>Amblygonite</b>	Graftonite	Schorl
Apatite-F	Heterosite	Scorzalite
Arrojadite	Holmquistite	Sicklerite
Arsenopyrite	<b>Lepidolite</b>	Spessartine
Autunite	Lithiophilite	<b>Spodumene</b>
Bertrandite	Lollingite	Strengite
<b>Beryl</b>	Microcline	<b>Tantalite</b>
Biotite	Microlite group	<b>Tapiolite</b>
Brazilianite	Mitridatite	Torbernite
<b>Cassiterite</b>	Molybdenite	Triphillite
Chrysoberyl	Monazite-Ce	Triplite
<b>Columbite</b>	Montebrasite	Triplodite
Elbaite	Montmorillonite	Uraninite
Eosphorite	Muscovite	Uranophane
Eucryptite	Orthoclase	Wodginite
		Zircon



**Apatite-F:** King Lithia mine



**Cassiterite:** White cap mine



**Heterosite:** White Elephant mine



# Exploration For Pegmatites Deposits

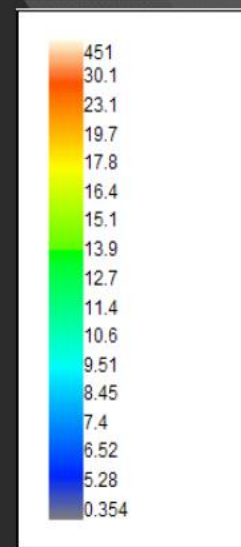
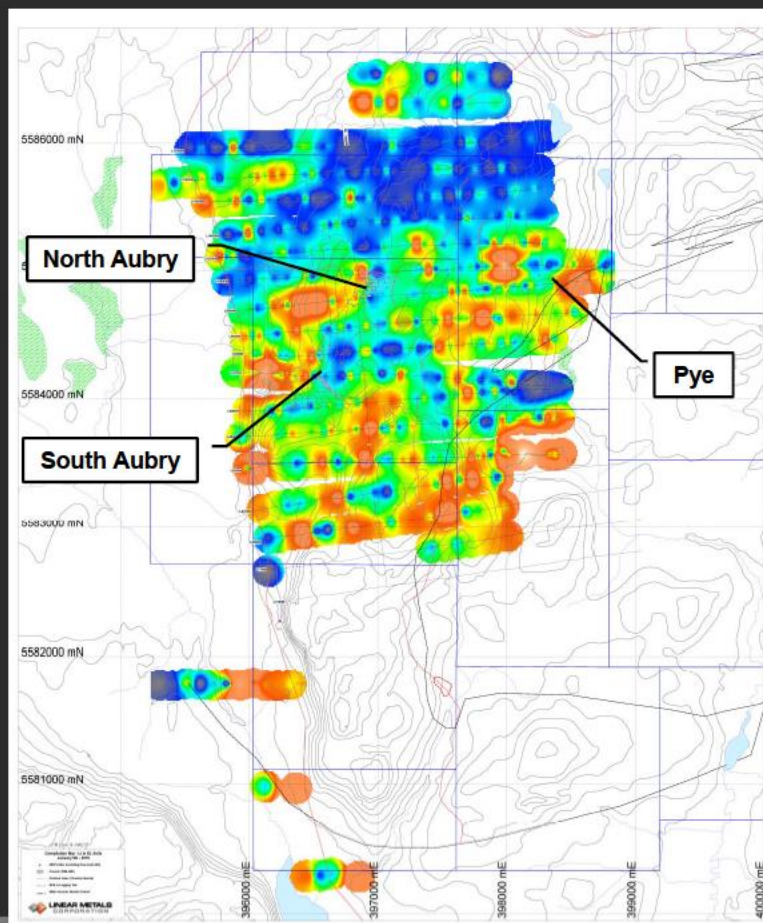
1. *Exploration for Exposed Pegmatite Fields*
2. *Search for Hidden Pegmatite Deposits*





# Exploration For Pegmatites Deposits

## Seymour Lake – Enzyme Leach Soil Results, Lithium



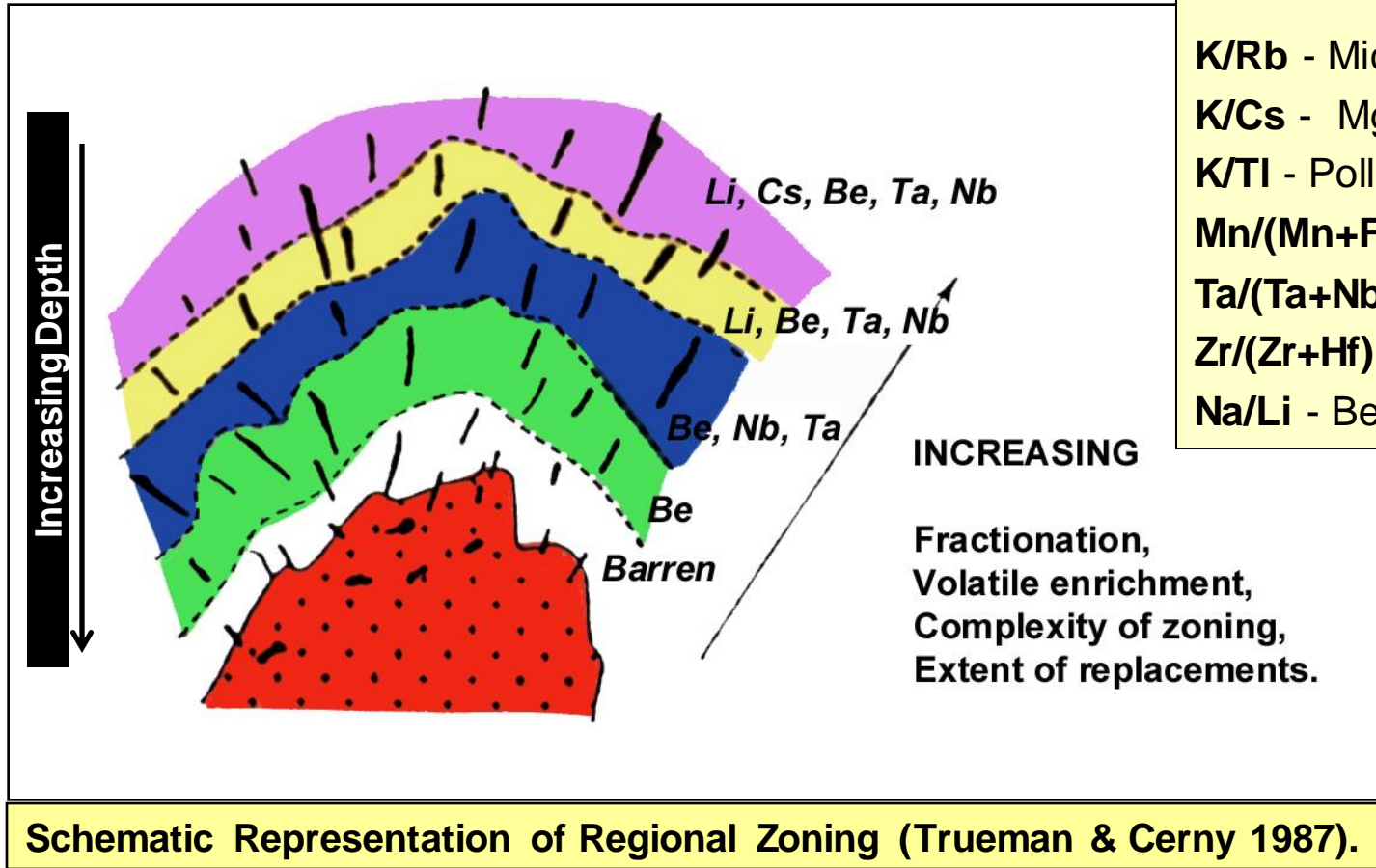
Li ppb

Lots of untested potential indicated by unexplained soil and litho



Pegmatites: Nature's Giant Treasure Chest!

# Exploration For Pegmatites Deposits



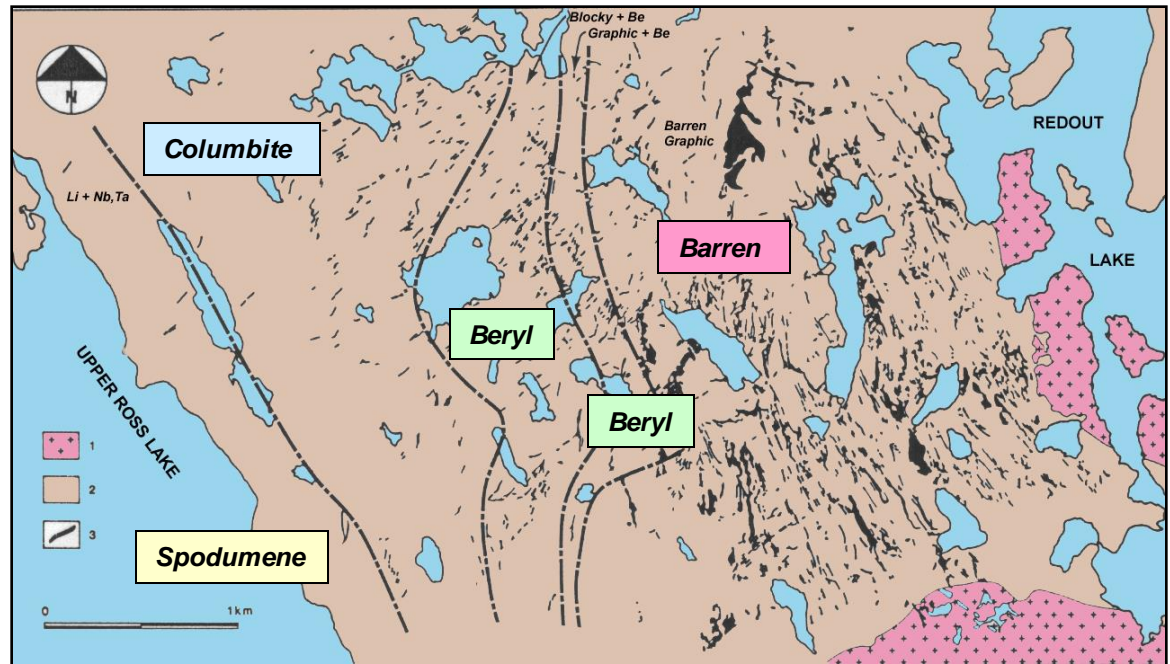


# Exploration For Pegmatites Deposits

Pegmatite groups may be associated with a particular granite body. The associated granite is often parental to the pegmatites, which tend to occur either within the granite or in a zone immediately surrounding the granite.

- Have variable textures
- Diverse mineralogy
- Extreme chemical compositions

## Distribution of the PEG Group around the Redout Granite, NWT, Canada



# Exploration For Pegmatites Deposits

## **GEOCHEMICAL INDICATORS OF RARE-ELEMENT ENRICHMENT IN GRANITIC PEGMATITES**

**K/Rb** - Microcline, Micas

**K/Cs, Mg/Li** - Micas

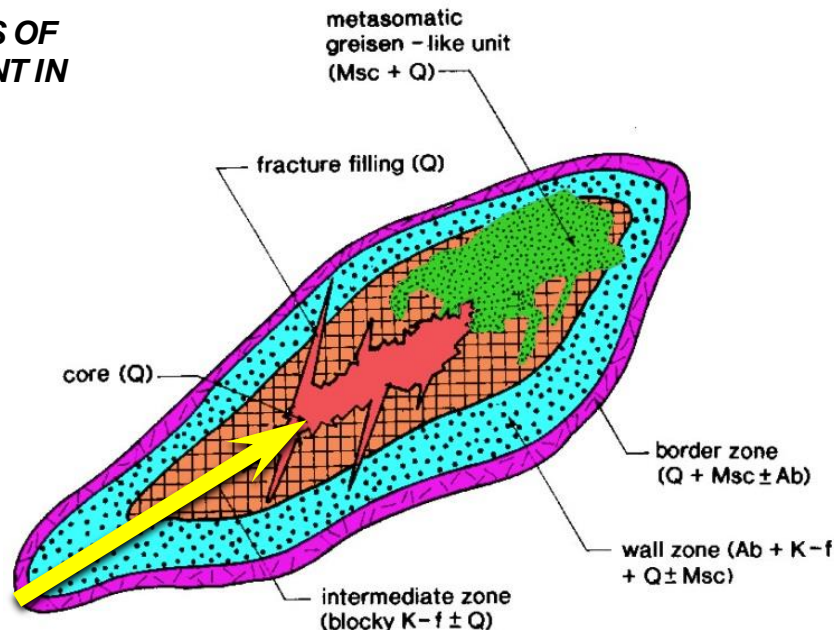
**K/Tl** - Pollucite

**Mn/(Mn+Fe)** - Garnet

**Ta/(Ta+Nb)** - Columbite

**Zr/(Zr+Hf)** - Zircon

**Na/Li** - Beryl

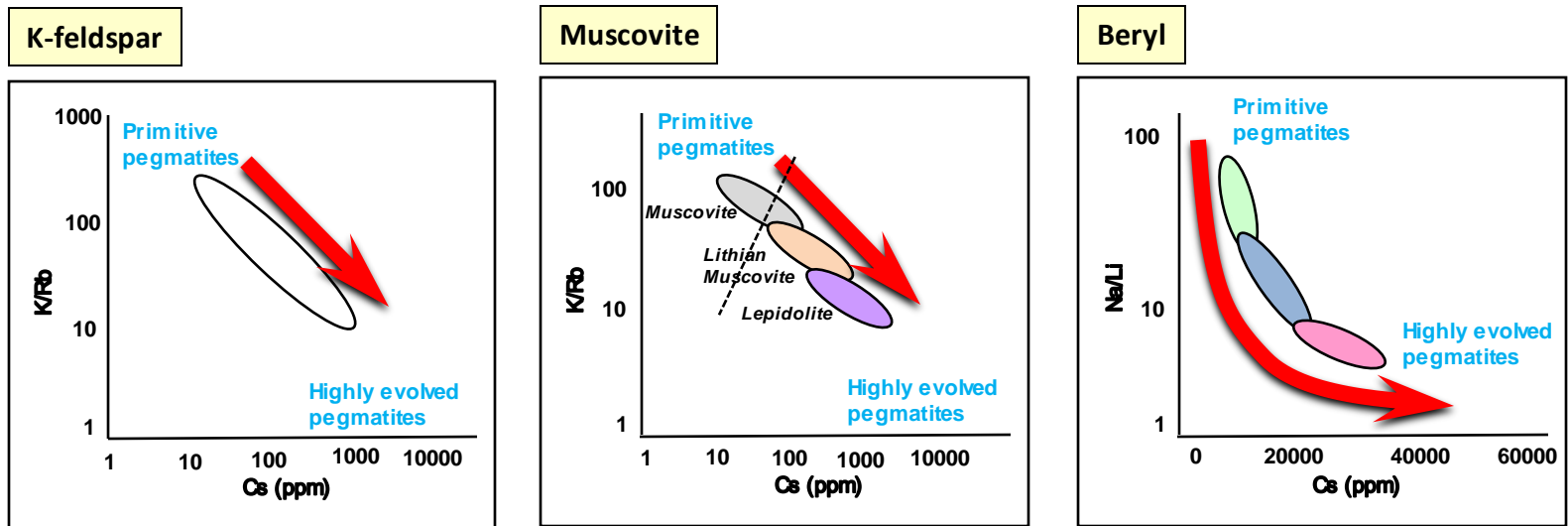


**GEOCHEMICAL INDICATORS TEND TO INCREASE FROM THE OUTER ZONES (e.g., wall zone) TO THE CENTRAL ZONES/UNITS (e.g., core)**



# Exploration For Pegmatites Deposits

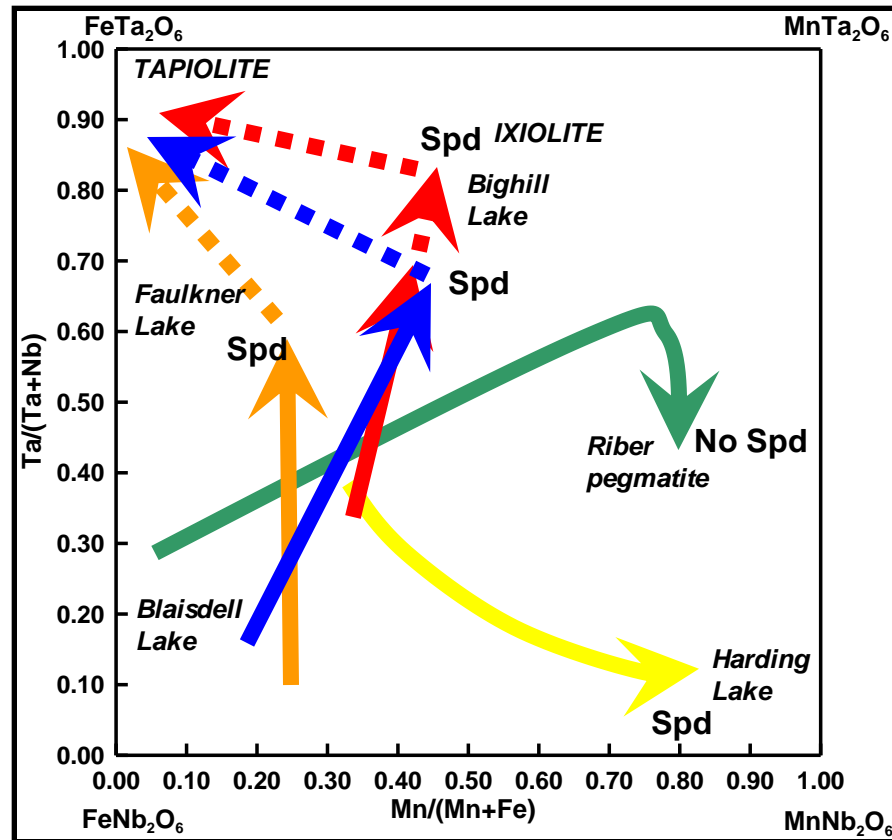
## *Patterns of element enrichment*



# Exploration For Pegmatites Deposits

## Patterns of element enrichment

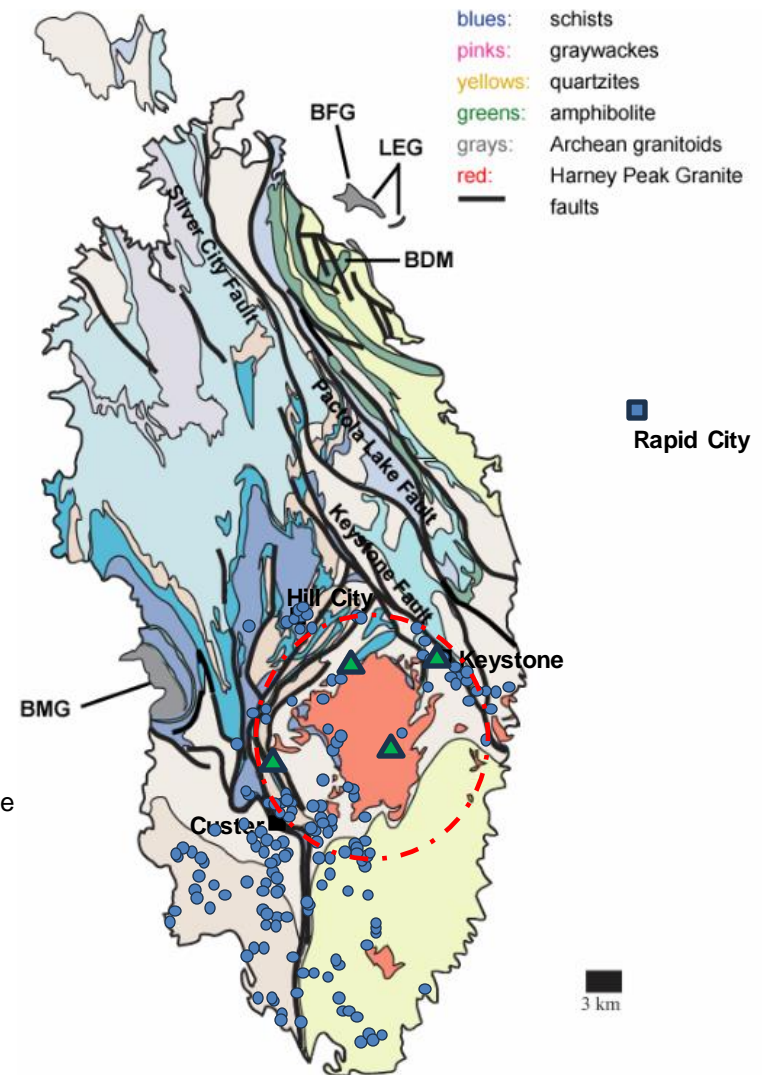
### Nb-Ta Oxides





# Exploration For Pegmatites Deposits

Generalized geologic map of the Black Hills crystalline core with pegmatites and regionally important structures. Modified from Allard and Portis, (2013) and Redden et al. (1990).



- Harney Peak Granite
- ▲ Pegmatitic Granite
- Pegmatites

# Exploration For Pegmatites Deposits

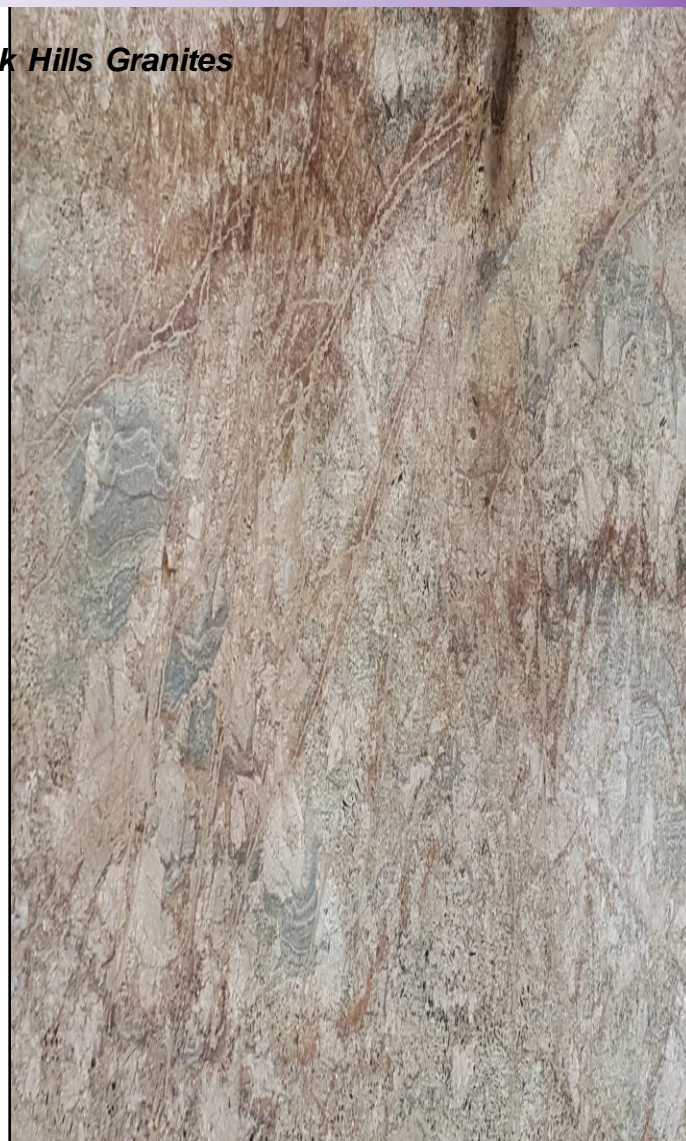


**Pegmatites: Nature's Giant Treasure Chest!**



# Exploration For Pegmatites Deposits

*Preliminary Assessment of Black Hills Granites*



Smithsonian

**Pegmatites: Nature's Giant Treasure Chest!**

# Exploration For Pegmatites Deposits

## Patterns of element enrichment

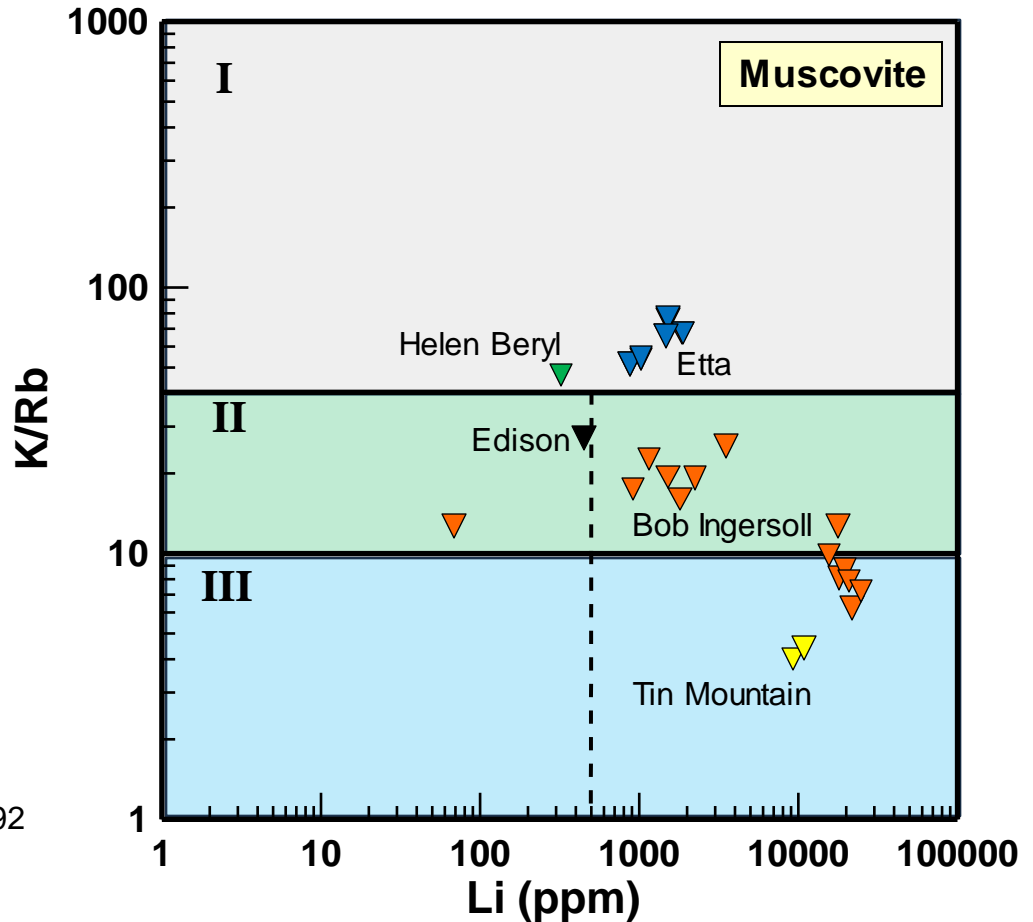
I - Non- to weakly fractionated

II - Moderately fractionated

III - Highly fractionated

Muscovite data from Jolliff et al., 1992

## Preliminary Assessment of Black Hills Pegmatites





**Pegmatites Rule!**



**The End!**



**Pegmatites: Nature's Giant Treasure Chest!**