Michael Wise
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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!
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?

/'pɛɡməˌtɪt/

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., H₂O, F, BO₃, PO₄).
Pegmatites occur in a variety of tectonic settings including convergent and divergent plate boundaries and intraplate settings.
Pegmatites rarely occur as isolated, singular bodies. Instead, they occur in groups or clusters consisting of tens to hundreds of bodies within a well-defined area.
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
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—Continental 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
The Genesis of Granitic Pegmatites

In The Beginning There Was Magma/Melt!

Late-stage product of granite crystallization
In The Beginning There Was Magma/Melt!

Partial melting of pre-existing metamorphic rocks
The Genesis of Granitic Pegmatites

In The Beginning There Was Magma/Melt!

Partial melting of pre-existing metamorphic rocks
The Genesis of Granitic Pegmatites

How To Make a Pegmatite – A Very Oversimplified Process!

Pegmatite Melt Genesis

Changes in Melt Composition

Crystallization of Rock-forming Minerals

Concentration of H₂O & Rare-Elements

Lowers Melt Viscosity

Melt Mobilization
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!

Pegmatite Melt Genesis

Crystallization of Rock-forming Minerals

Concentration of H$_2$O & Rare-Elements

Changes in Melt Composition

Lowers Melt Viscosity

Melt Mobilization

Develop Textures
The Textures of Granitic Pegmatites

The Bigger, The Better?
The Textures of Granitic Pegmatites

The Bigger, The Better?

Pegmatites: Nature's Giant Treasure Chest!
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

Graphic Texture

Comb Structure

Layered Structure

The Bigger, The Better?
The Textures of Granitic Pegmatites

*The Bigger, The Better?*
The Mineralogy of Granitic Pegmatites

Marvelously Magical Minerals!

- Topaz
- Quartz
- Fluorite
- Fluorite w/Stilbite
- Beryl
Nearly 500 different minerals species are known to occur in granitic pegmatites. Silicates, phosphates and oxides dominate over other mineral groups.
Pegmatite melt enriched in beryllium, tantalum, phosphorus, lithium, cesium, boron, etc.
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!

Quartz var. milky

Quartz var. rose

Quartz var. smoky

Quartz var. amethyst

Fluid inclusions

Mn (Manganese), P (Phosphorus), inclusions

Radiation

Fe (Iron), Radiation

Pegmatites: Nature's Giant Treasure Chest!
The Mineralogy of Granitic Pegmatites

Marvelously Magical Minerals!

- Muscovite
- Annite (Biotite)
- Almandine
- Fluorapatite
- Zircon
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)

Muscovite

Lithian muscovite

Lepidolite

Rose muscovite

Pegmatites: Nature's Giant Treasure Chest!
The Mineralogy of Granitic Pegmatites

Marvelously Magical Minerals!

Photo credit: © Elliott/Fine Minerals International

Rhodochrosite
Epidote
Jeremejevite
Monazite
Londonite
The Mineralogy of Granitic Pegmatites

How To Make a Pegmatite – A Very Oversimplified Process!

1. Pegmatite Melt Genesis
2. Crystallization of Rock-forming Minerals
3. Concentration of $\text{H}_2\text{O}$ & Rare-Elements
4. Lowers Melt Viscosity
5. Crystallization of Rare-Element Minerals
6. Depletes melt of Rare-elements
7. Melt Mobilization
8. Reduces $\text{H}_2\text{O}$ solubility
9. Exsolve $\text{H}_2\text{O}$
10. Pocket Formation?

Changes in Melt Composition

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

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)?*

Pegmatites with miarolitic cavities are extremely rare! Typically develop in pegmatites that crystallize at low pressures (~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!

1. Pegmatite Melt Genesis
2. Crystallization of Rock-forming Minerals
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8. Crystallization of Rare-Element Minerals
9. Depletes melt of Rare-elements
10. Reduces H₂O solubility
11. Exsolve H₂O
12. Pocket Formation?
13. Replacement & Alteration

Pegmatites: Nature's Giant Treasure Chest!
The Mineralogy of Granitic Pegmatites

Endgame!

- Lithian micas + clays replacing elbaite
- Epidote replacing microcline
- Kaolinite
- Cookeite

Kaolinized pegmatite with 150 ppm Ta (pXRF)
The Mineralogy of Granitic Pegmatites

Endgame!

Secondary Beryllium Minerals from the Alteration of Beryl

**Beryl**

\[ \text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18} \]

- **Acidic fluids**
  - *pH* ~ 2 to 3
  - Quartz

- **pH ~ 4 to 5**
  - Bertrandite
    \[ \text{Be}_4\text{Si}_2\text{O}_7\text{(OH)}_2 \]
  - Euclase
    \[ \text{BeAlSiO}_4\text{(OH)} \]
  - Phenakite
    \[ \text{Be}_2\text{SiO}_4 \]
  - (+/- quartz, kaolinite)

- **pH ~ 7**
  - Bavenite
    \[ \text{BeAl}_2\text{Si}_2\text{O}_4\text{(OH)} \]
  - (+/- feldspars, micas, quartz)

- **pH ~ 8 to 9**
  - Milarite
    \[ \text{KCa}_2\text{Al}_2\text{Si}_{12}\text{O}_{30} \cdot 0.5\text{H}_2\text{O} \]
  - Bityite
    \[ \text{CaLiAl}_2\text{(AlBeSi}_2\text{)}\text{O}_{10}\text{(OH)}_2 \]
  - (+/- micas, zeolites, montmorillonite)

- **pH ~ 10 to 11**
  - Epididymite
    \[ \text{NaBeSi}_3\text{O}_7\text{(OH)} \]
  - Eudidymite

*Be, Al, Si, O, Na, Ca, Li, K, Al, Be, Si*
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

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.
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

Beryl variety Aquamarine
(crystal prior to creating the Dom Pedro)

Dom Pedro Aquamarine
10,363 cts
Gift of Jane Mitchell & Jeffery Bland
## Granitic Pegmatites As Ore Bodies

### Sources of Gem Materials

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

Muscovite

Pegmatites: Nature's Giant Treasure Chest!

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

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

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

Quartz

Microcline

Muscovite
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.
Cesium is recovered from the mineral pollucite ($\text{Cs}_2\text{Al}_2\text{Si}_4\text{O}_{12}\cdot2\text{H}_2\text{O}$) 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.
Columbite-tantalite, (Fe,Mn)(Nb,Ta₂)O₆: 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, LiAlSi₂O₆: Lithium-ion batteries are one of the most popular types of rechargeable battery for portable electronics.
What is This Thing?

Rocky Mountains Region
Southern California Pegmatite Province
Basin and Range Region
Midwestern Region
Appalachian Pegmatite Province

Pegmatites of the United States

Lithium-rich pegmatite districts

Granitic Pegmatites As Ore Bodies

Pegmatites: Nature’s Giant Treasure Chest!
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).
## Granitic Pegmatites As Ore Bodies

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<th>Black Hills area South Dakota Pegmatite Minerals</th>
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<tbody>
<tr>
<td>Albit e</td>
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<tr>
<td>Allani te</td>
</tr>
<tr>
<td>Allaudite</td>
</tr>
<tr>
<td>Almandine</td>
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<tr>
<td>Amblygonite</td>
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<tr>
<td>Apatite-F</td>
</tr>
<tr>
<td>Arrojadite</td>
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<tr>
<td>Arsenopyrite</td>
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<tr>
<td>Autunite</td>
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<tr>
<td>Bertrandite</td>
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<tr>
<td>Beryl</td>
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<tr>
<td>Biotite</td>
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<tr>
<td>Brazilianite</td>
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<tr>
<td>Cassiterite</td>
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<tr>
<td>Chrysoberyl</td>
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<tr>
<td>Columbite</td>
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<tr>
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<tr>
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<td>Eucryptite</td>
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- **Apatite-F**: King Lithia mine
- **Cassiterite**: White cap mine
- **Heterosite**: White Elephant mine
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**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

Lots of untested potential indicated by unexplained soil and litho-plex.
Pegmatites: Nature's Giant Treasure Chest!

Exploration For Pegmatite Deposits

Fractionation Indicators

- 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

Fractionation, Volatile enrichment, Complexity of zoning, Extent of replacements.

Schematic Representation of Regional Zoning (Trueman & Cerny 1987).
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
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)**
Patterns of element enrichment

- **K-feldspar**
  - Primitive pegmatites
  - Highly evolved pegmatites

- **Muscovite**
  - Primitive pegmatites
  - Muscovite
  - Lithian Muscovite
  - Lepidolite
  - Highly evolved pegmatites

- **Beryl**
  - Primitive pegmatites
  - Highly evolved pegmatites
Patterns of element enrichment

**Nb-Ta Oxides**

- **TAPIOLITE**
- **IXIOLITE**
- **Spd**
- **Bighill Lake**
- **Faulkner Lake**
- **Riber pegmatite**
- **No Spd**
- **Blaisdell Lake**
- **Harding Lake**
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).
Exploration For Pegmatites Deposits

Preliminary Assessment of Black Hills Granites
Exploration For Pegmatites Deposits

Preliminary Assessment of Black Hills Granites
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

I

II

III

K/Rb

Li (ppm)

Bob Ingersoll

Helen Beryl

Etta

Edison

Tin Mountain

Pegmatites: Nature’s Giant Treasure Chest!
Pegmatites Rule!

The End!