A-type Granites: Characteristics and Petrogenesis will provide an overview of the identification and petrogenesis of A-type granites. In terms of volume the so-called A-type granites comprise a minor component of the granite spectrum. However, the meaning of the term A-type granite, and the significance of this granite type in terms of tectonic setting, has spawned a large number of scientific studies. It is generally accepted that A-type granites form in extensional or post-orogenic environments. A variety of (often controversial) discriminant diagrams have been developed to identify A-type granites. Comparison of data for granites classified as A-type by these various methods reveals that there are in fact chemical and mineralogical characteristics that do distinguish A-type granites. While these granites are often iron-rich, compared to Mg, this is not always the case. Compositionally the most common A-type granite is metaluminous but a number are peralkaline and less frequently peraluminous. Various geothermometers indicate that A-type magmas generally have higher temperatures than those formed during subduction or collision. In terms of tectonic setting, it is reasonable to divide the A-type granites into two groups: (1) those formed in a purely anorogenic setting versus (2) those formed following a period of continent-continent collision. The identification of A-type granites requires carefully scrutiny of all available data, both chemical and geological, and an open mind when considering petrogenetic possibilities.
A-type Granites: Characteristics and Petrogenesis

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The A-type Granitoids

- Defined by Loiselle and Wones (1979)

- \( A \) stands for Anorogenic or Anhydrous or the first letter of the alphabet. The last choice removes the necessity of debating the meaning of \( A \).

- Magmas are emplaced in post-collisional or within plate settings, i.e., an extensional environment.

Characteristics of A-type Granitoids

1. Non-orogenic setting
2. Subaluminous to peralkaline, sometimes peraluminous
3. For rocks of intermediate silica content, A-type granitoids generally have higher total alkalis and lower \( \text{CaO} \) than other granitoids.
4. High \( \text{FeO}_T/\text{MgO} \)
5. A characteristic mineralogy consisting of iron-rich mafic silicates (annite, ferrohendenbergite, ferrohastingsite, fayalite), and in peralkaline suites alkali-rich mafic silicates (aegirine, arfvedsonite, reibekite) and perthitic feldspars.
The Alphabet Soup – is A-type granitoid a useful classification?

- Classifications are useful to the extent that they help us organize our observations/ideas.

- Classifications are a short-hand that can be used to convey a general description of geologic observations.

- One can define a group of granitoids, in terms of geologic setting and chemistry, that are distinct from other granitoids. In this instance the A-type classification is useful.

- However, a classification should not lead to rigid thinking.

- As geologists we still need to maintain our world view of multiple working hypotheses/processes.

- A-type granitoids, while similar in many respects, can apparently arise via different petrogenetic pathways. The challenge is to elucidate these pathways.
Summary of Chemical Characteristics for A-type Granitoids

The data base consists of 40 plutons/provinces and the A-type granitoids in the data base encompass a wide range of compositions.

- All the granitoids plot in the Within Plate and A-type fields on standard discriminant diagrams.
- In terms of Al and alkalis, the granitoids are peralkaline, metaluminous, and peraluminous
- Most of the granitoids are alkali-calcic to alkalic
- Most of the granitoids are Ferroan, but some are Magnesian (Frost et al., 2001, classification)
- The granitoids show a wide range in $T_{Zr}$ saturation temperatures, from 700 to 1000+ °C.
A-type granitoids: normative mineralogy and major element chemistry

Frost et al. (2001)

Frost et al. (2001)
A-type granites: Zircon saturation temperatures and trace element characteristics

Whalen et al. (1987)

Pearce et al. (1984)
A-type granitoids - Examples


3) White Mountain Igneous Province. Basalts, andesites, rhyolites, syenites and metaluminous and peralkaline granites. Associated in space and time with the silica-undersaturated sequences of the Monteregian Hills Alkaline Province. Cretaceous. Has been linked to the Meteor hotspot (Eby).

4) Early Carboniferous granitoids of the proto-Andean Foreland (Sierras Pampeanas, Argentina). Metaluminous to peraluminous. Emplaced after a long period of orogenic magmatism. Extensive shearing and emplacement of the plutons is fault controlled (Dalhquist et al., 2010).
Six peralkaline granite massifs, confined to the margins of the Keivy terrane

- Sheet-like bodies with thickness of a 100-500 m and of vast exposed areas (100-1300 km²)
- Spatial and temporal association with massif-type anorthosite bodies
Chemical characteristics and $T_{Zr}$ for the granitoids of the Keivy alkaline province

Eby (2002)
Granitoids 2654 – 2674 Ma
Anorthosites 2659 – 2663
Nepheline gabbro – 2682 Ma

The feldspathic rocks and the gabbro-anorthosites show antithetical REE patterns which suggests they may represent evolved liquids and cumulates, respectively.
Zozulya and Eby (2008) proposed that the alkaline granitoids were the result of protracted fractional crystallization of a subalkaline/alkaline basalt magma. The anorthosites represent the cumulates. Nd isotope data indicate that the basaltic magma(s) were derived from an enriched mantle source which was a result of the subduction process in the adjacent Kolmozero-Voron’ya greenstone belt which evolved in the period 2.92-2.83 Ga.
Petrogenesis of the Keivy Alkaline Province

• Extensional (rift) setting.

• The alkaline granites are the product of extended fractional crystallization of a basalt magma. Isotope data indicates that there was some crustal contamination.

• Zircon saturation geothermometry indicates temperatures of approximately 1000°C for the peralkaline granites. The high temperatures of the magmas may be due to higher heat flow during the Archean.

• The magma source was enriched mantle. This enrichment occurred during an earlier period of subduction.

• The peralkaline granites represent a net addition of mantle derived material to the crust.
Geology of the Cretaceous Chilwa Alkaline Province

Lithologies: carbonatite, nepheline-sodalite syenite, nepheline syenite, syenite, granite
Chemical characteristics and $T_Zr$ for the Chilwa syenites and granites

Eby (2002)
Felsic rocks vary from strongly silica-undersaturated nepheline-sodalite syenites to alkali granites.

Mafic rocks are silica-undersaturated basanites and nephelinites.
Y/Nb vs Yb/Ta diagram

The metabasanites and olivine nephelineites plot in the OIB field.

The blue vector indicates the effect that crustal contamination would have on these ratios.

The red vector indicates the effect that F- and/or CO$_3$-rich fluids would have on these ratios.
The majority of the CAP samples fall in the depleted mantle field. Samples that plot outside this field lie along a possible AFC curve.
Petrogenesis of the Chilwa Alkaline Province

- Extensional (rift) setting.
- Both silica undersaturated and silica saturated sequences are associated in space and time.
- Nephelinites and basanites are part of the petrogenetic sequence.
- Zircon saturation geothermometry indicates temperatures of 900 - 1000°C for the syenites and granites.
- An AFC model can be used to relate both the silica undersaturated and silica saturated rocks starting with a silica undersaturated mafic melt. The syenites and granites were emplaced last and show the greatest amount of crustal contamination.
- The magma source was depleted mantle that was enriched shortly before or simultaneously with the melting event.
There are two periods of anorogenic granitoid magmatism (White Mountain province) in New England, USA, at \(~180\) Ma and \(~120\) Ma. This magmatism is well after amalgamation of the North American craton and is precursor to the opening of the North Atlantic Ocean. Rocks of a correlative age to the younger period of White Mountain igneous activity, but forming a silica-undersaturated suite (Monteregian Hills), are found in proximal Quebec, Canada.
The Ossipee Ring Complex – an example of Cretaceous White Mountain magmatism

Quench texture in fine-grained granite

High level intrusion, classic ring-complex structure

Bimodal volcanics + quartz syenites and granites

Coarse-grained biotite granite
Chemical characteristics and $T_{Zr}$ for the Ossipee rhyolites and granites
The mafic rocks plot in the OIB and WPB fields on various discrimination diagrams. In the Y/Nb vs Yb/Ta diagram the Ossipee basalts plot towards the IAB field (but still within the OIB field), an indication of minor crustal contamination.
Petrogenesis of the Ossipee Ring Complex

• The Monteregian Hills – White Mountain magmatism has been related to a hotspot trace. This trace continues with the New England Seamount Chain.

• In a west to east direction the magmatic activity changes from silica undersaturated magmas to silica saturated magmas. This transition corresponds with an increase in crustal thickness.

• Mafic magmas associated with the Cretaceous White Mountain plutons show isotopic evidence of crustal interaction.

• Zircon saturation geothermometry indicates temperatures of ~900°C for the rhyolites and ~ 800°C for the granites.

• An AFC model can be used to relate the basalts and rhyolites. The granites show isotopic evidence of a greater amount of crustal interaction than the rhyolites.

• The basaltic magma were derived from an OIB-like source.
These $A_2$ granitoids are slightly to strongly peraluminous, are associated with shear zones, and are emplaced shortly after a long period of orogenesis.
Geology of the individual plutons and their relationship to the TIPA shear zone

Dahlquist et al. (2010)
Chemical characteristics and $T_{Zr}$ for the Argentina granitoids
Trace (and major) element data indicate that the individual plutons evolved through fractionation of alkali feldspar, apatite, and FeTi oxide.
### Nd isotope data for Carboniferous granites

<table>
<thead>
<tr>
<th>Pluton/complex</th>
<th>$\varepsilon_{\text{Nd}}$</th>
<th>$T_{\text{DM}}$ (Ga)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Árboles</td>
<td>-0.8 to -2.6</td>
<td>0.96 – 1.30</td>
</tr>
<tr>
<td>Huaco</td>
<td>-2.4 to -3.2</td>
<td>1.25 – 1.40</td>
</tr>
<tr>
<td>San Blas</td>
<td>0.6 to -4.8</td>
<td>1.04 – 1.38</td>
</tr>
<tr>
<td>Zapata</td>
<td>-2.6 to -3.9</td>
<td>1.20 – 1.70</td>
</tr>
<tr>
<td>Early Ordovician</td>
<td>-4.8 to -8.5</td>
<td>1.5 – 1.7</td>
</tr>
<tr>
<td>granites</td>
<td></td>
<td></td>
</tr>
</tbody>
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A simple isotope mixing model, using as one end member the Early Ordovician granites as a potential crustal protolith and as the other end member asthenospheric mantle (CHUR) gives the following result:

63% asthenospheric mantle and 37% continental lithosphere

(Dahlquist et al., 2010)
• The granitoids were emplaced at the end of a long period of orogenic activity which ended with an extensional phase.

• The extension led to ensialic back-arc rifting with asthenospheric upwelling and melting of underplated basaltic material (Alasino et al., 2011, Hutton VII).

• Emplacement was controlled by a pre-existing shear zone.

• Zircon saturation geothermometry indicates temperatures of 880°C to 700°C and there is an excellent correlation between decreasing $T_{Zr}$ and increasing $SiO_2$.

• Magmatic evolution of each pluton was controlled by fractional crystallization of alkali feldspar, apatite, and Fe-Ti oxides.

• Simple isotopic mixing calculations indicate that the magmas were mixtures of asthenospheric (63%) and crustal (37%) material. Hence there is a significant mantle component.

Summarized from Dalhquist et al. (2010).
The previous 4 examples represent the variety of granitoids that fall in the A-type category. Several generalities can be derived from these examples.

1) Zircon saturation temperatures range between 800 and 1000°C. Hence these are high temperature melts with low water content. This is illustrated by the projection of the compositions for the granitoids into the haplogranite system. The compositions of the granitoids from the four examples fall well off the water saturated minima.
2) Primitive mantle normalized spider diagrams indicate that (a) feldspar (negative Ba, Sr and Eu anomalies), apatite (negative P anomaly) and Fe-Ti oxides (negative Ti anomaly) were fractionated from the magmas; (b) the presence of small to relatively significant positive Pb anomalies indicate that crustal contamination played a role; and (c) Nb-Ta and Zr-Hf anomalies indicate an enriched mantle source for the mafic melts that played a role in the petrogenesis of the granites.
3) The hotspot and rift related Ossipee and Chilwa granitoids show clear evidence of an OIB-like source. In the case of the Argentina granites there is evidence of a significant crustal component. The Archean rift-related Kola granitoids overlap with the OIB field, but largely fall in the area dominated by crustal compositions. Note that in the case of both the Kola and Argentina granitoids there is also a possible IAB-like end-member. In all of these cases, the data suggest the involvement of both mantle and crustal material, to varying degrees, in the petrogenesis of the granitoids.
4) Maximum $T_{Zr}$ for Ossipee granites (OG), Ossipee rhyolites and Argentina granitoids (A), Chilwa syenites and granites (C), and Kola peralkaline granites (K) plotted versus a variety of geotherms. Matching the tectonic setting to the appropriate geotherm and magma temperature shows that the required melting temperatures exceed those that could be reasonably expected at an appropriate depth. Hence the role of mantle derived mafic magmas, to provide heat and/or material seems essential in the generations of these A-type granitoid melts.
Conclusions

• The A-type granites define a distinct group within the granite family.

• They are, essentially without exception, crystallized from high temperature melts. This requires high temperatures in the source regions and such high temperatures are not normally achieved in the crust. Hence, the involvement of mafic magmas, or high mantle heat flow, is a necessity.

• A variety of chemical parameters indicates that the granitic magmas are derived by fractional crystallization of feldspars, apatite, and FeTi oxides from more primitive melts. The high Ga/Al ratios that are typical of A-type granites may be a result of extensive feldspar fractionation.

• In most cases a satisfactory petrogenetic model involves AFC processes starting with relatively mafic magmas. These mafic melts can be derived directly from the mantle or by re-melting of underplated mafic material.

• No single petrogenetic model can be used to describe the formation of A-type granites.
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