

**Carbonatites to Alkali Granites –
Petrogenetic Insights from the Chilwa and
Monteregian Hills-White Mountain Igneous
Provinces**

G. Nelson Eby

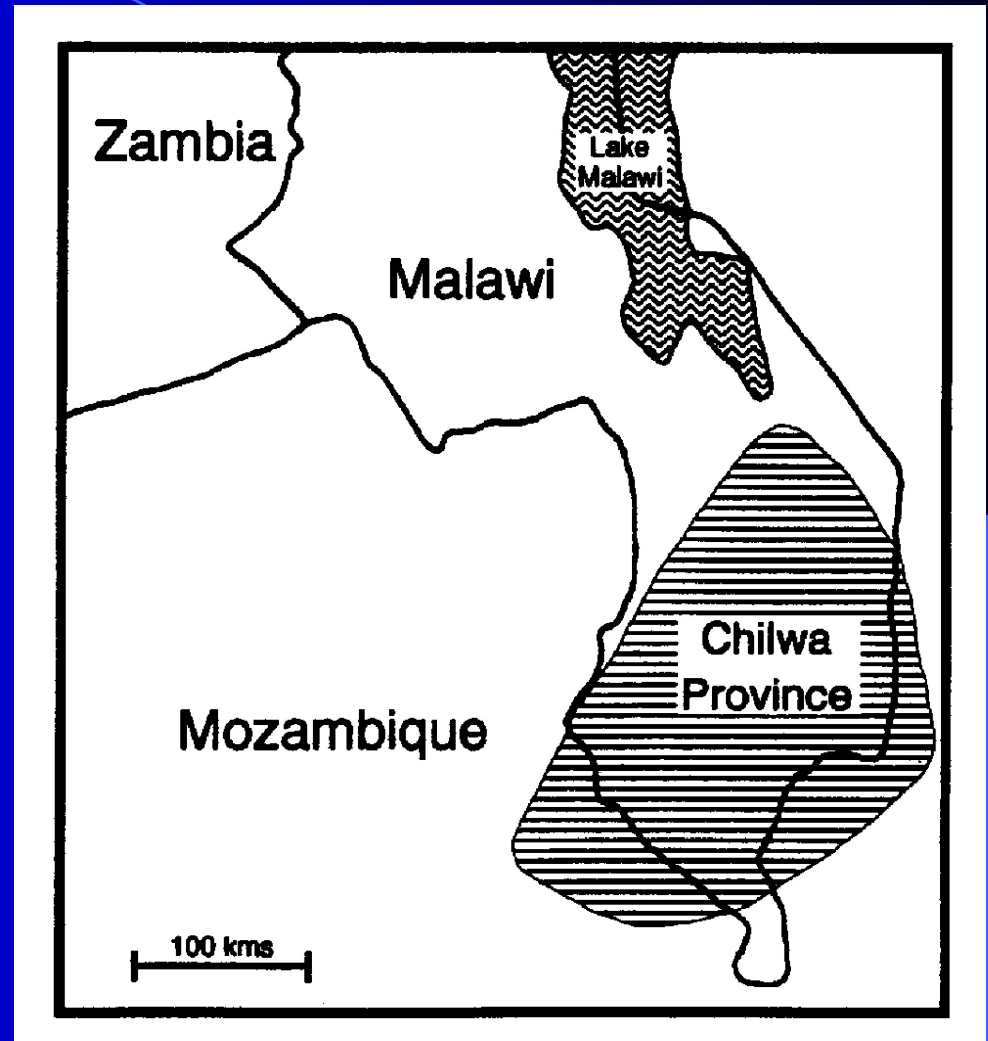
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Lowell, MA, USA

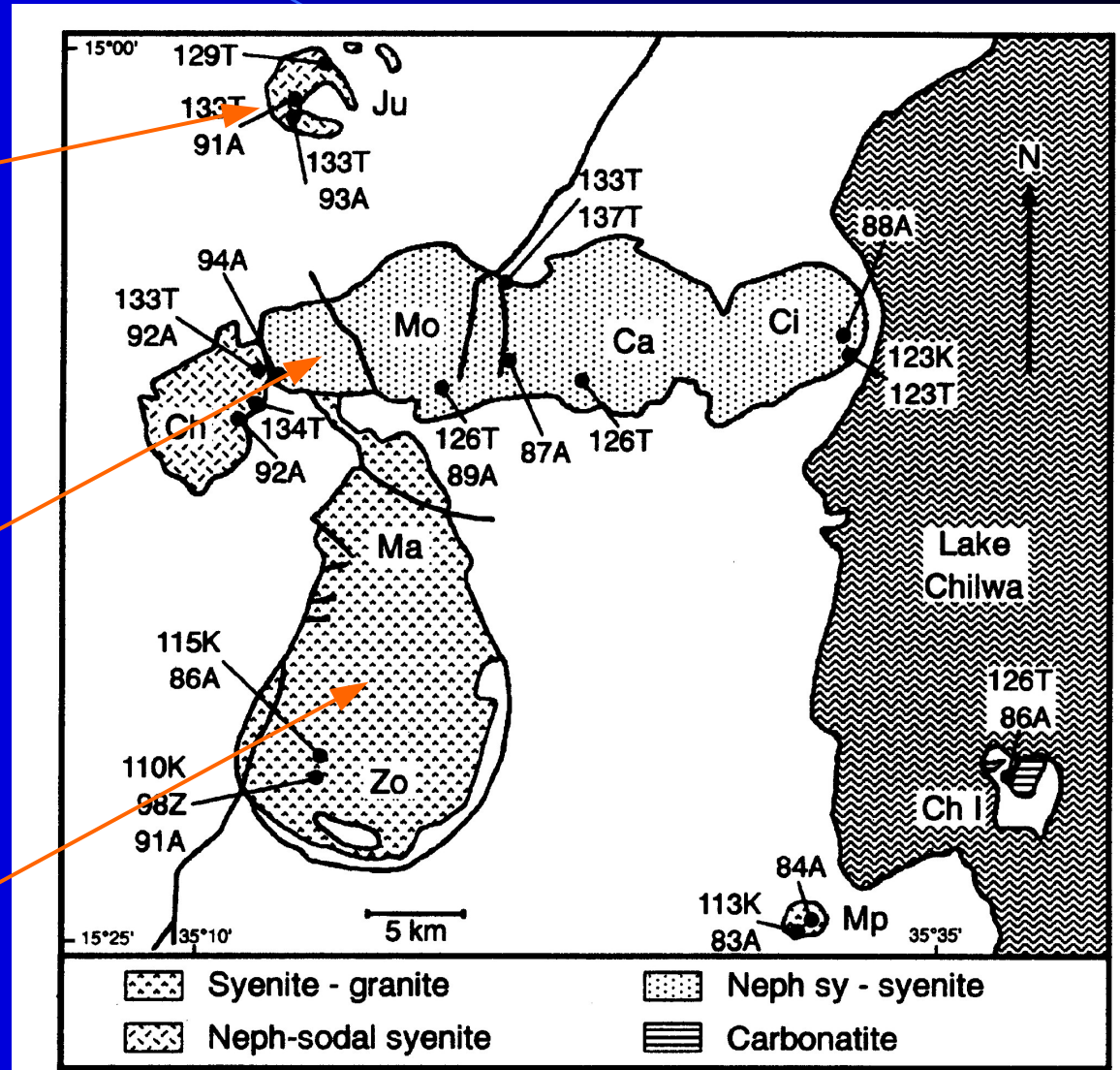
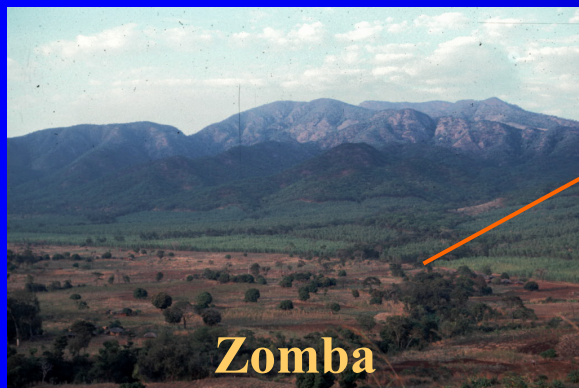
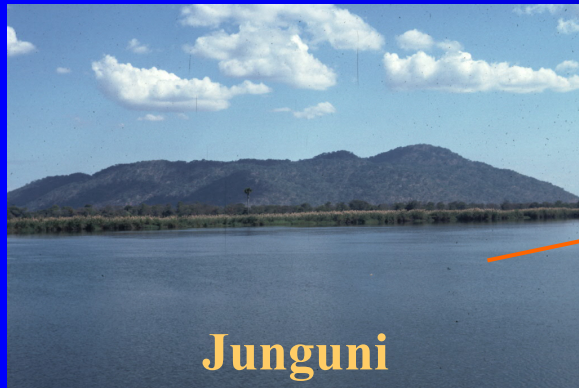
Chilwa alkaline province – Location

The Cretaceous age Chilwa Alkaline Province (CAP) is located in southern Malawi near the southern end of the present-day East African Rift System.



Geology of the Chilwa Alkaline Province

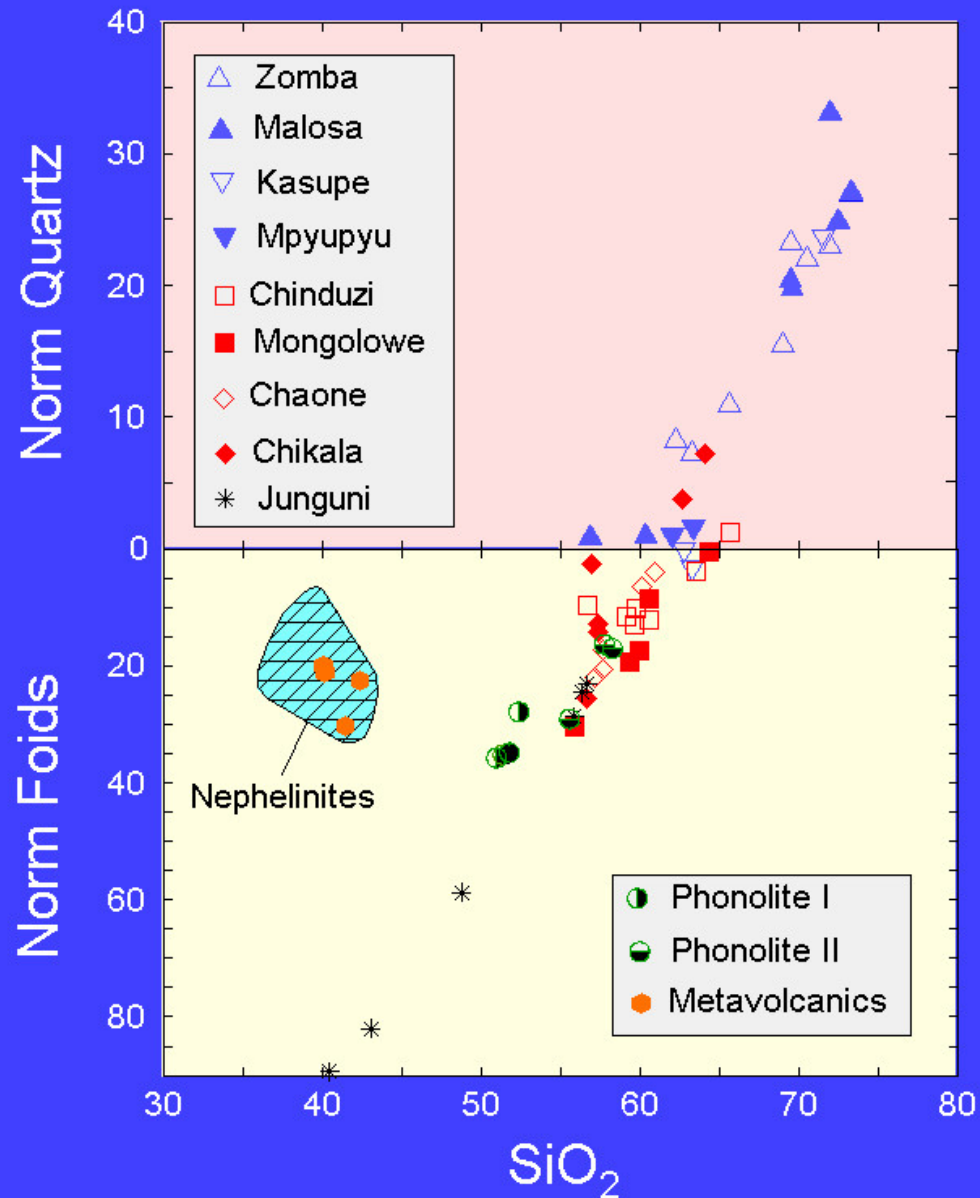
Lithologies: carbonatite, neph-sodal syenite, neph syenite, syenite, granite



Degree of silica saturation for the major plutonic and volcanic units

Felsic rocks vary from strongly silica-undersaturated nepheline-sodalite syenites to alkali granites.

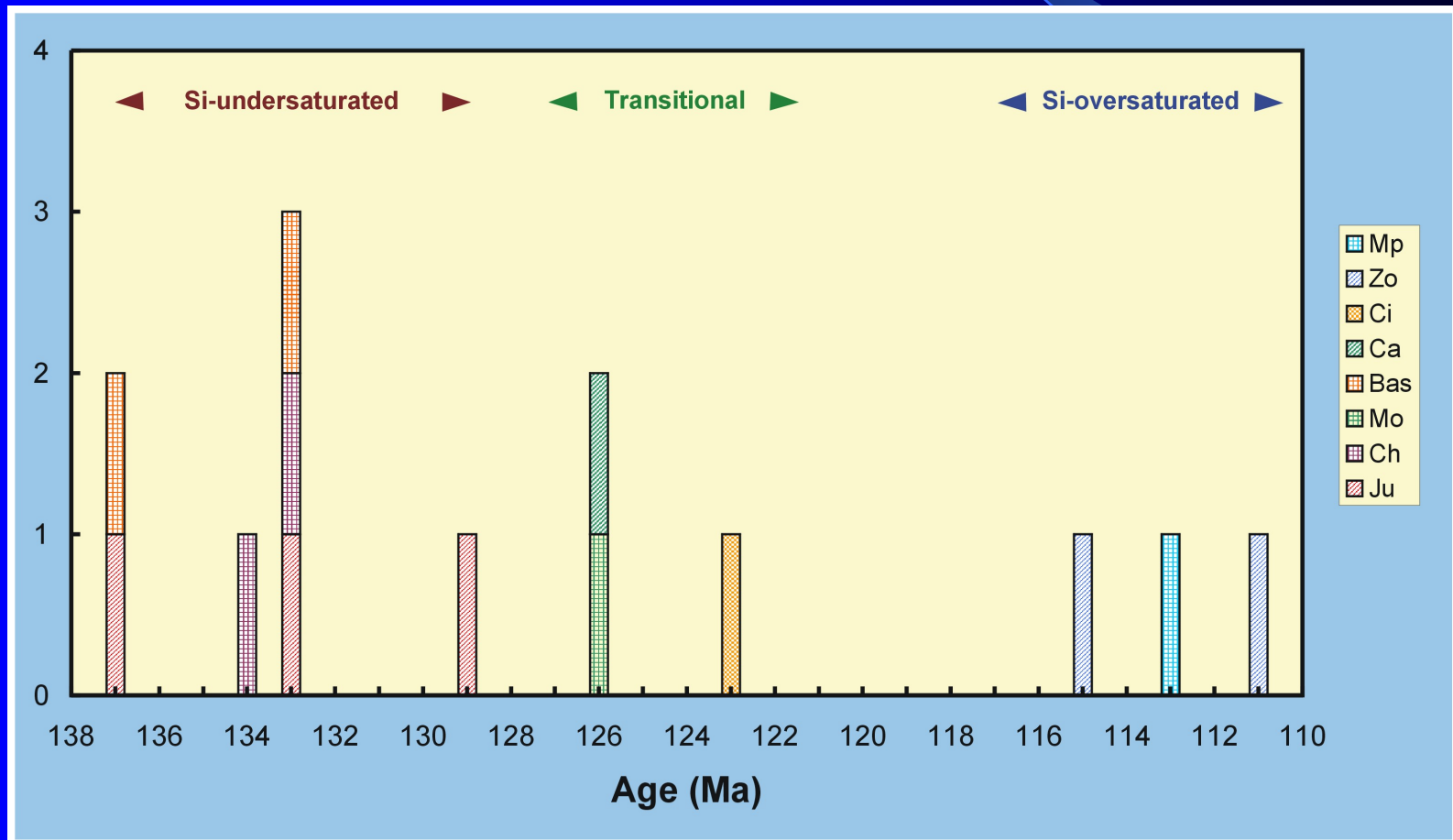
Mafic rocks are silica-undersaturated basanites and nephelinites.



Age versus degree of silica saturation

Sequence of emplacement:

- Basanites + neph-sodal syenites (138-132 Ma)
- Neph syenites + syenites (129-123 Ma)
- Syenites + granites (115 – 111 Ma)



Major lithologies of the Chilwa Province

- **Metavolcanics (basanites) and olivine nephelinites**
- **Nepheline- sodalite syenites and nepheline syenites**
- **Syenites and alkali granites**

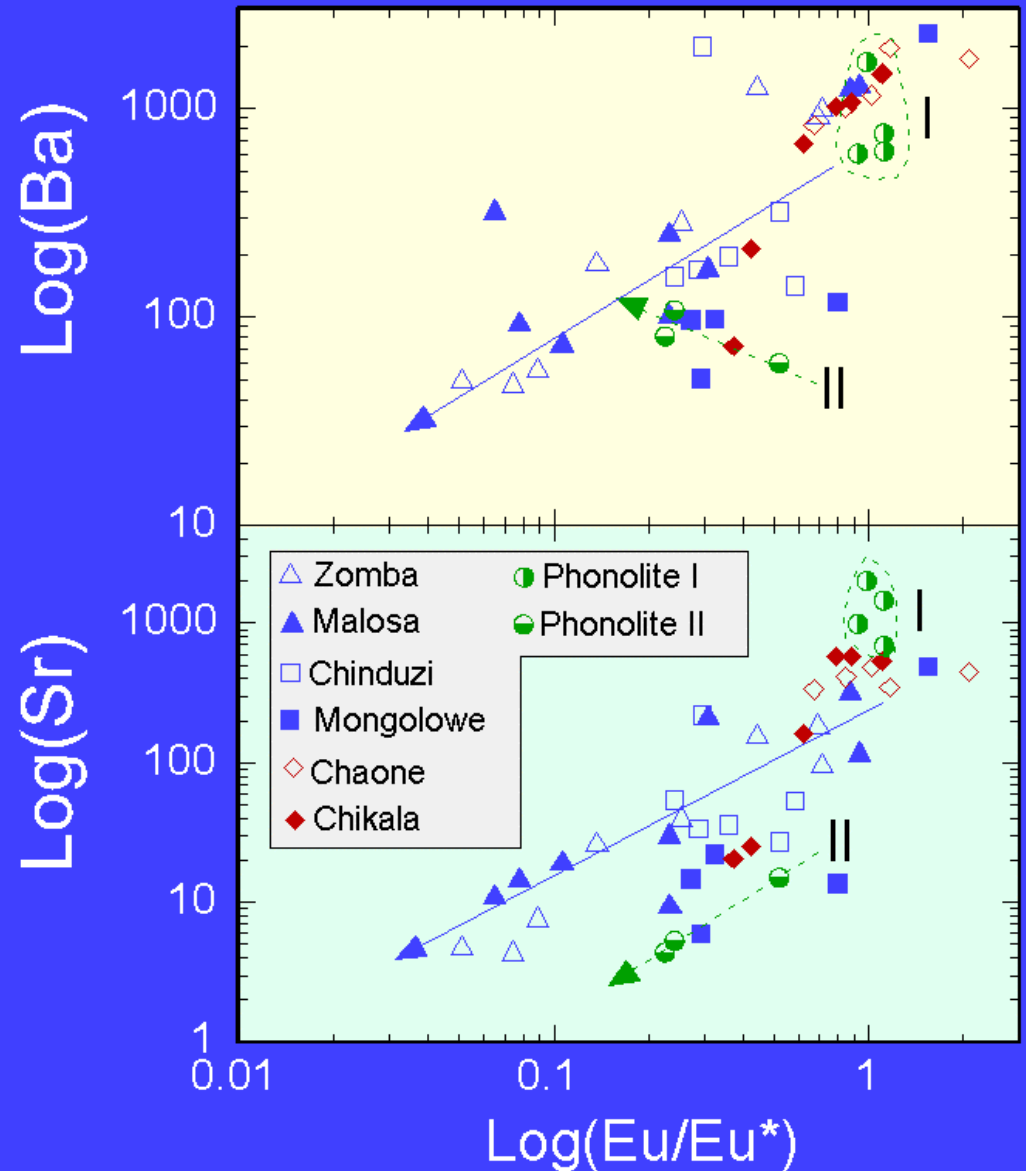
Sequence of emplacement

- **Lava flows (basanites) and nepheline-sodalite syenites**
- **Nepheline syenites and syenites**
- **Syenites and alkali granites**

The pattern is increasing silica content with decreasing age

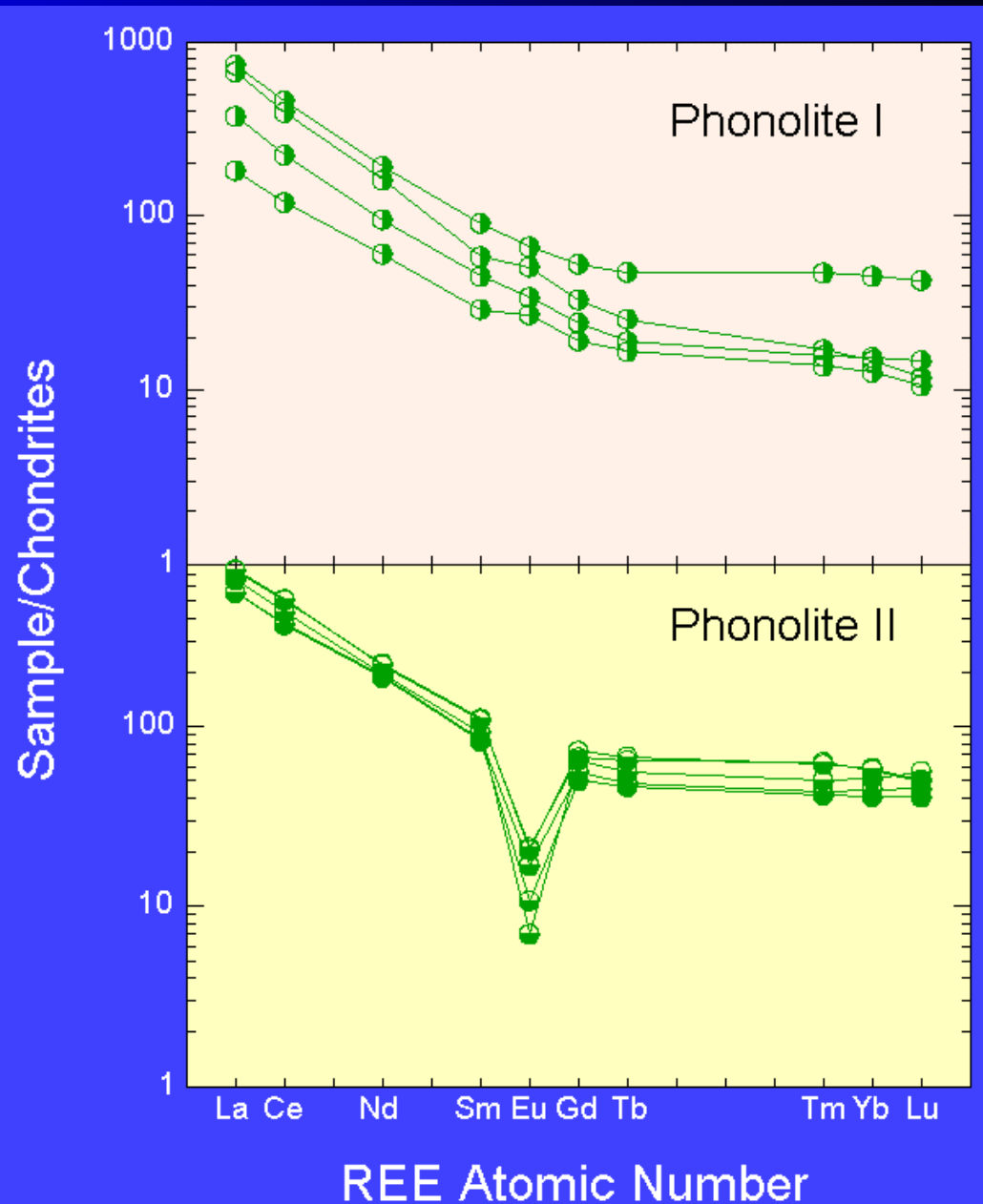
Log Eu* vs log Sr, Ba

- Two groups of phonolites can be distinguished, one that shows negative Eu anomalies, one that doesn't.
- The alkali granites and syenites (Zomba & Malosa) roughly fall along alkali feldspar + plagioclase fractionation vectors.
- Many of the nepheline syenites also show negative Eu anomalies indicating that feldspar fractionation played a role in their evolution.



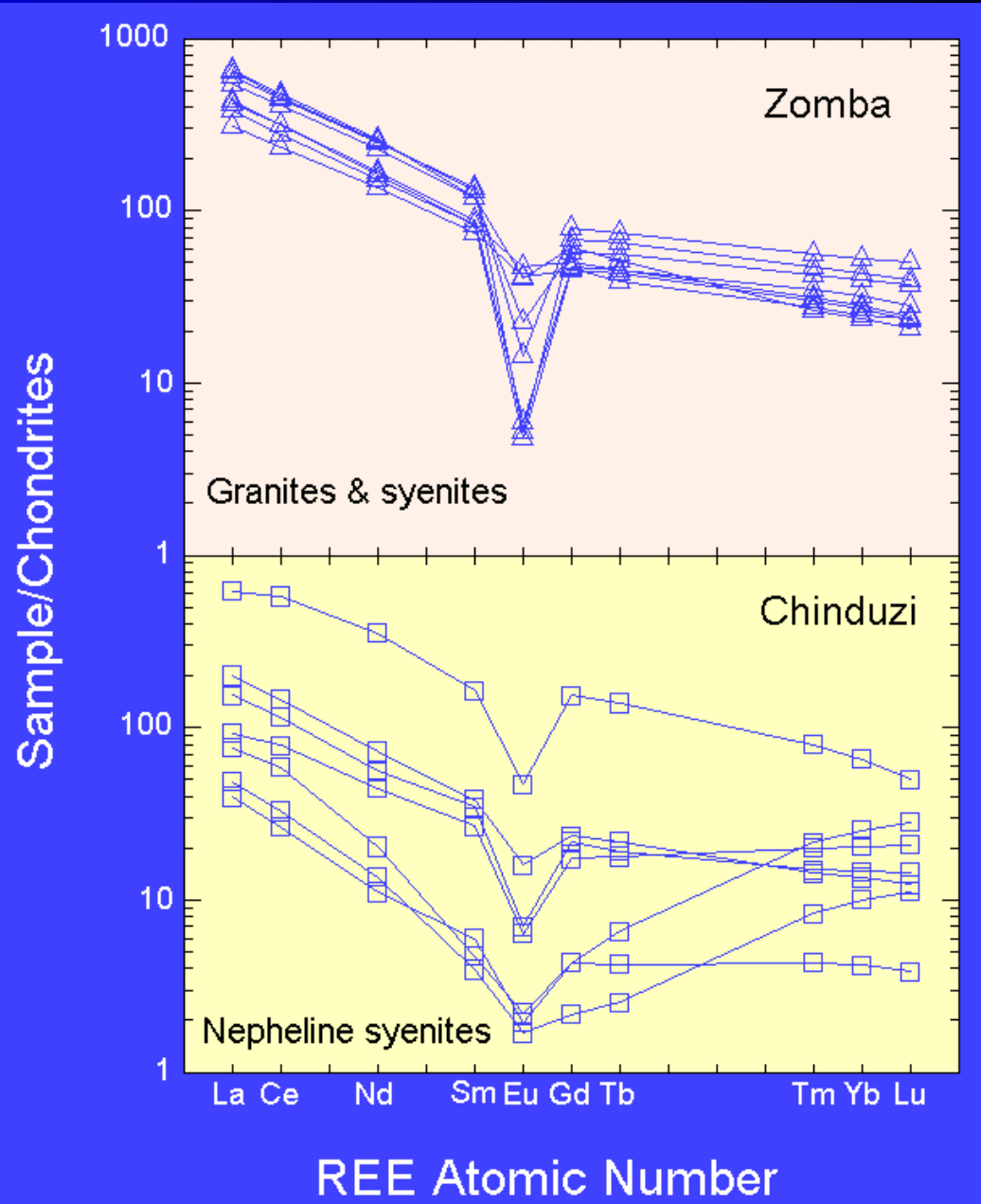
The two phonolite groups are distinguished on the basis of the presence or absence of an Eu anomaly. Note that the REE patterns are broadly similar for both groups. Several Phonolite I samples show small positive Eu anomalies suggesting the presence of cumulus feldspar.

The inference is that the evolution of group I phonolites occurred at high pressures where plagioclase crystallization was suppressed.

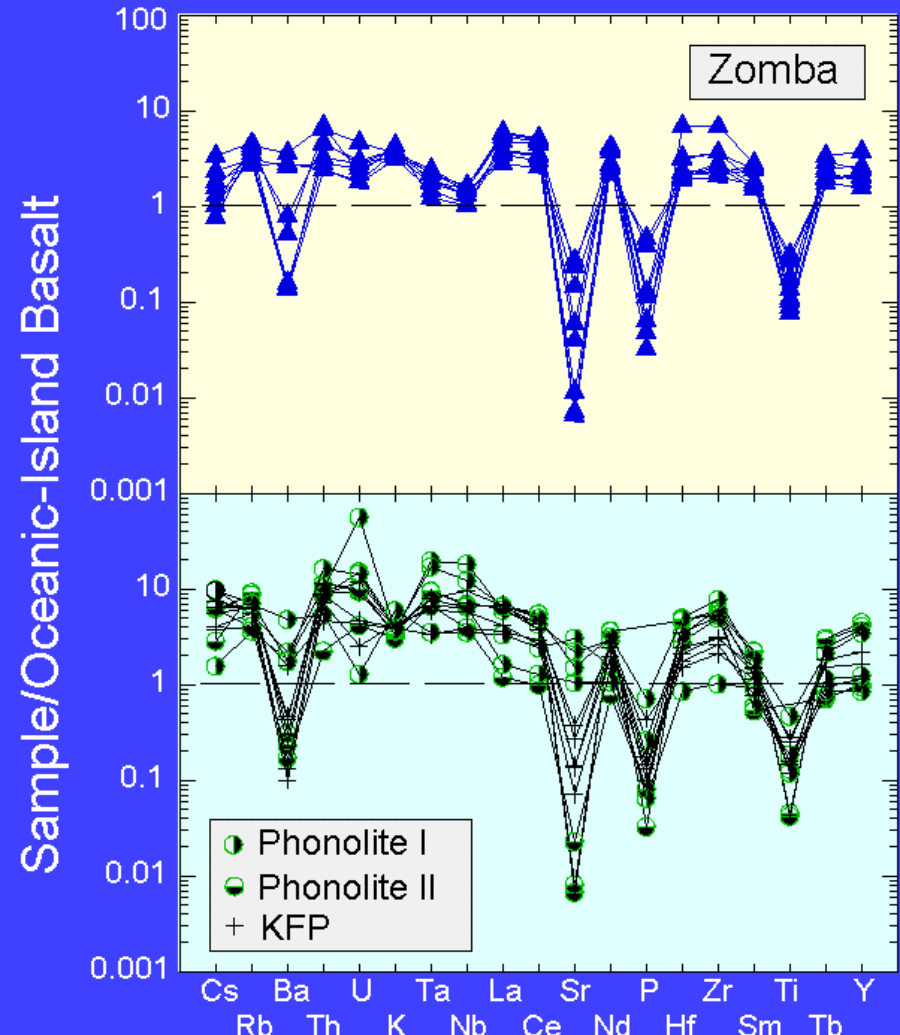
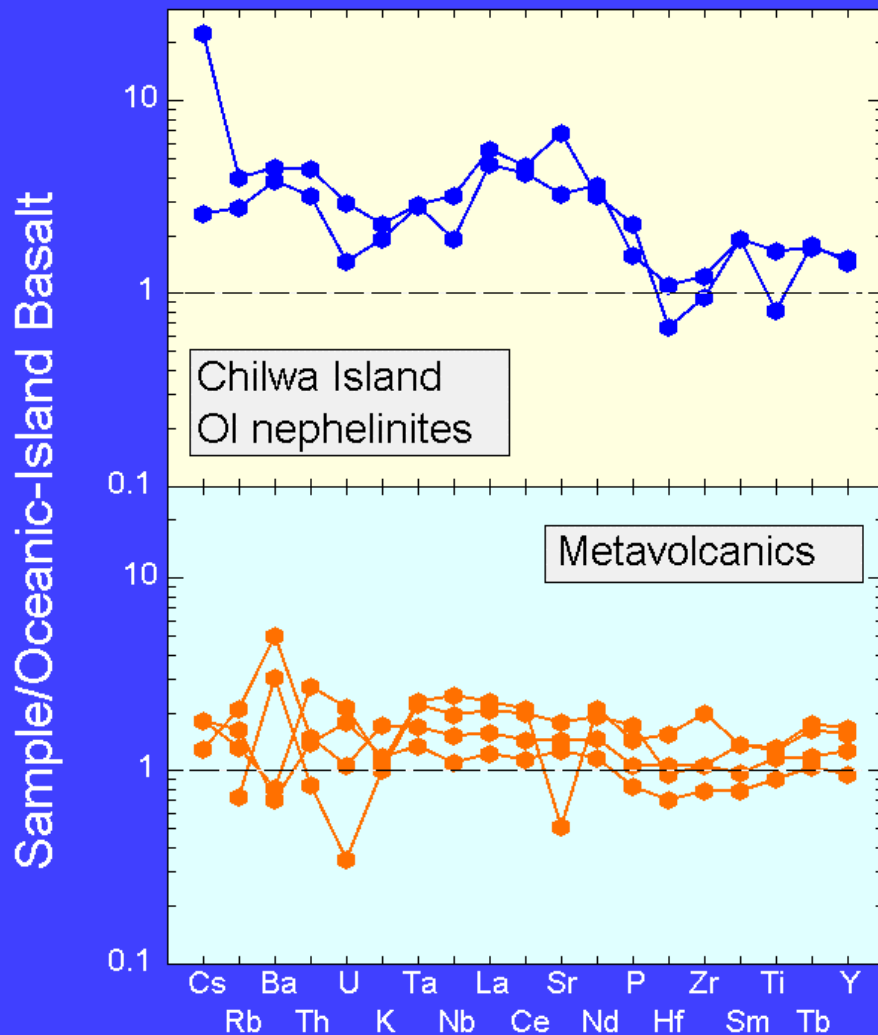


REE patterns for Zomba are subparallel and show increasing negative Eu anomalies with increasing total REEs, typical of a feldspar fractionation trend.

REE patterns for Chinduzi are much more irregular and, in particular, the presence of U-shaped (or V-shaped) patterns suggests that there may have been postmagmatic redistribution of the elements by F- and/or CO₂-rich hydrothermal fluids.



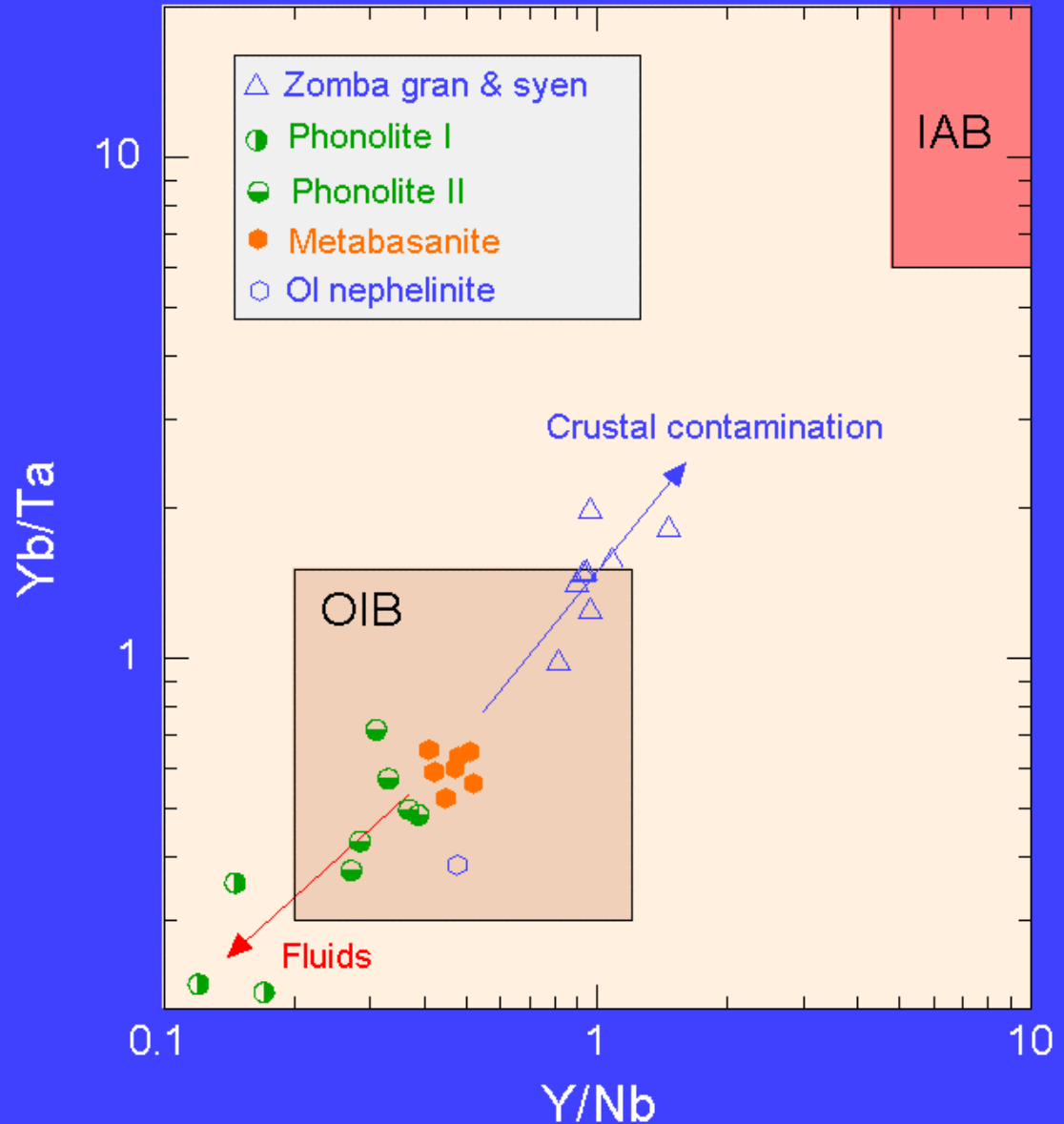
Spider diagrams: Note the similarity to OIBs. Depletion of Ba, Sr, P, and Ti in the more evolved rocks is indicative of feldspar, apatite, and ilmenite/magnetite fractionation.



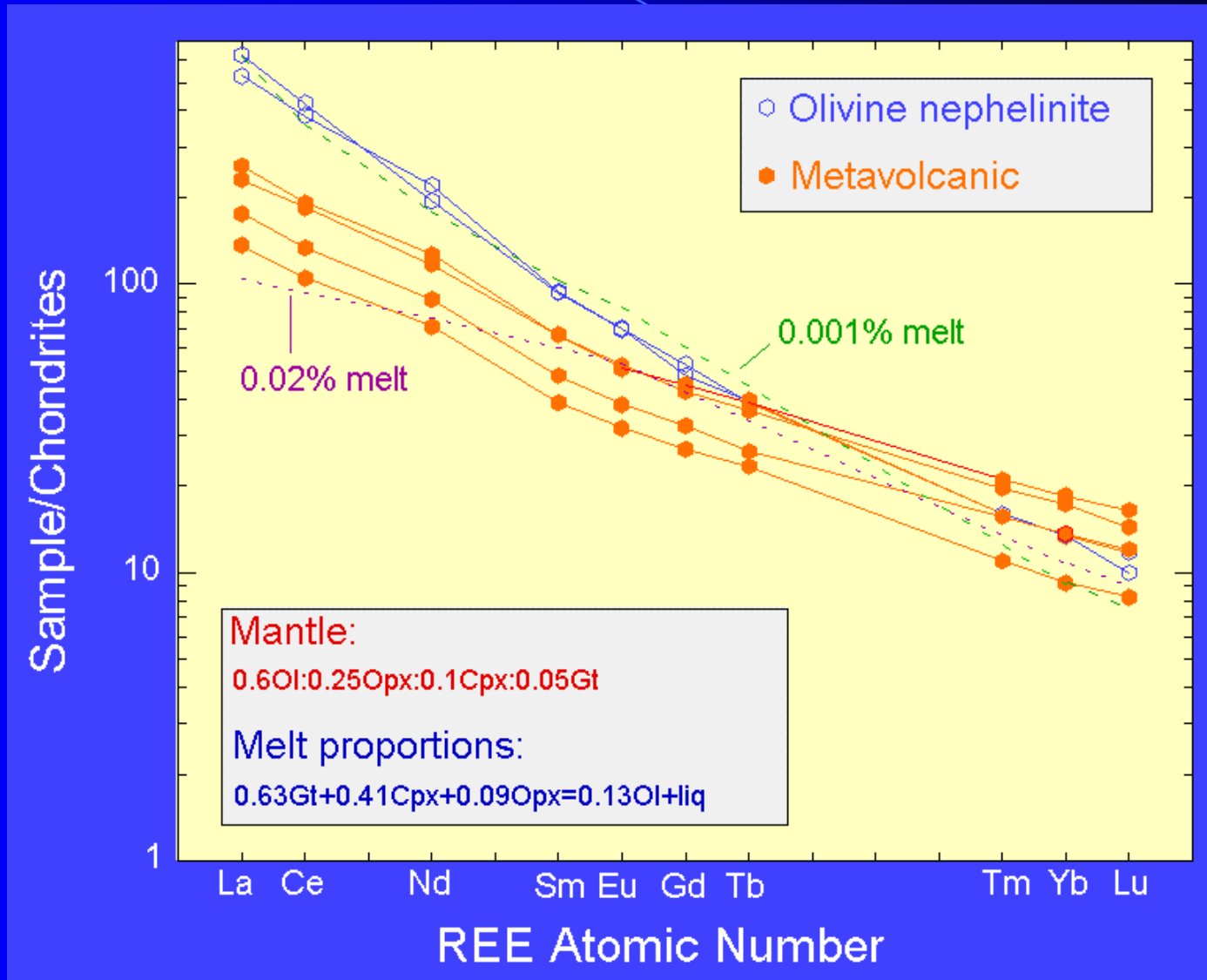
Y/Nb vs Yb/Ta diagram: The metabasandites and olivine nephelinites plot in the OIB field.

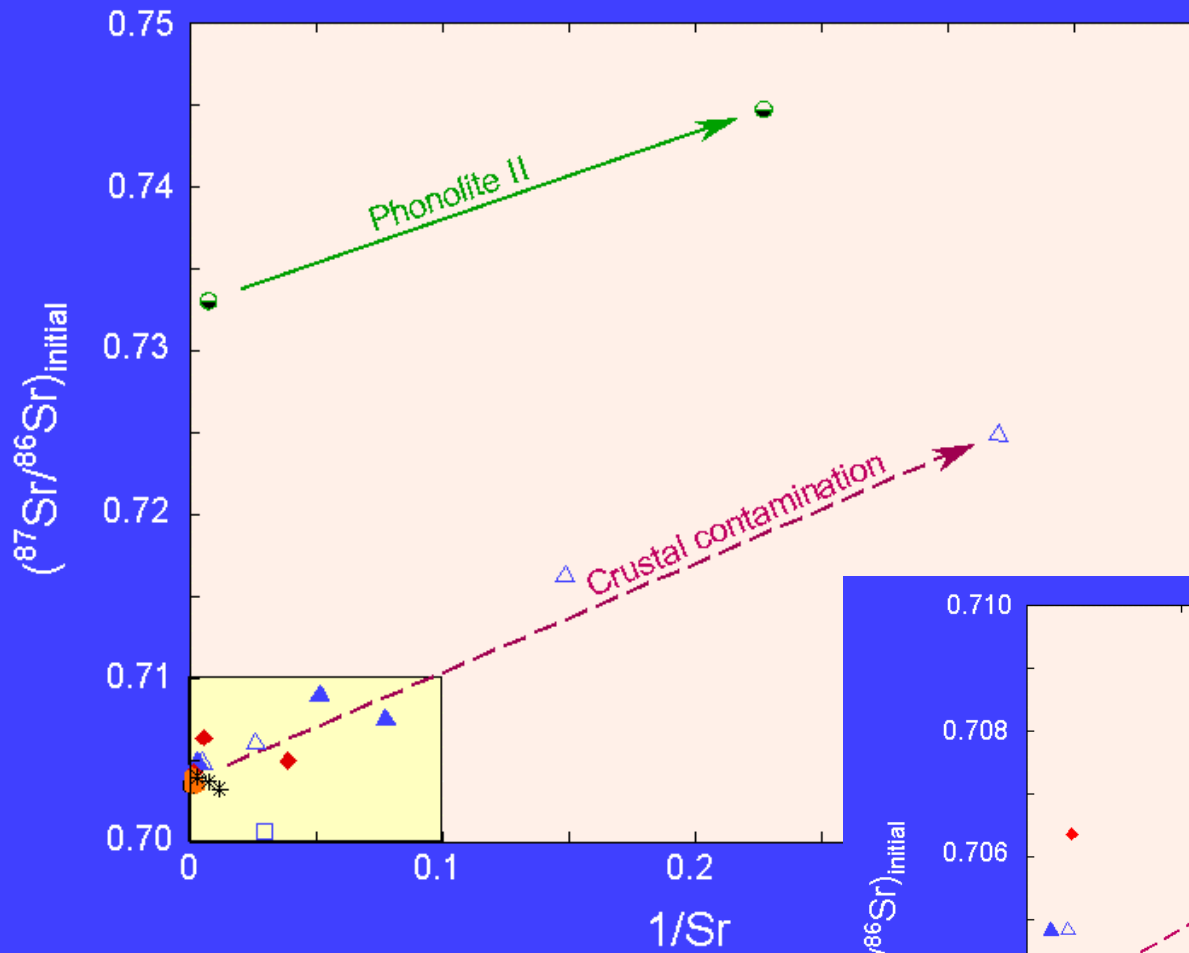
The blue vector indicates the effect that crustal contamination would have on these ratios.

The red vector indicates the effect that F- and/or CO₃-rich fluids would have on these ratios.



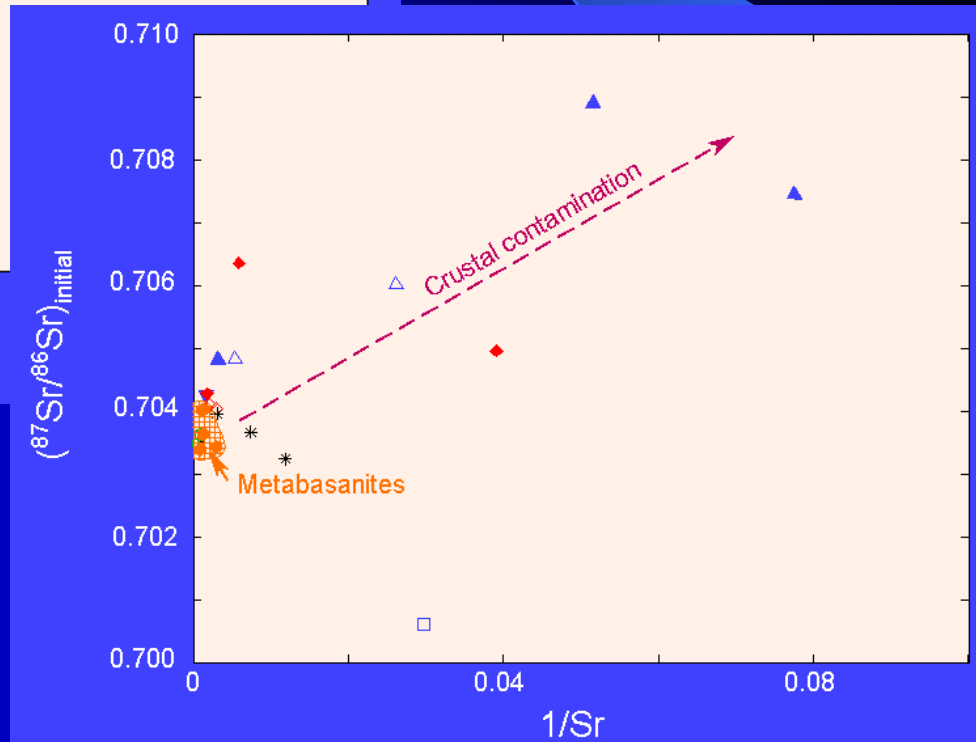
Melting model for the generation of the olivine nephelinites and basanites (metavolcanics) from a garnet lherzolite, chondritic mantle.



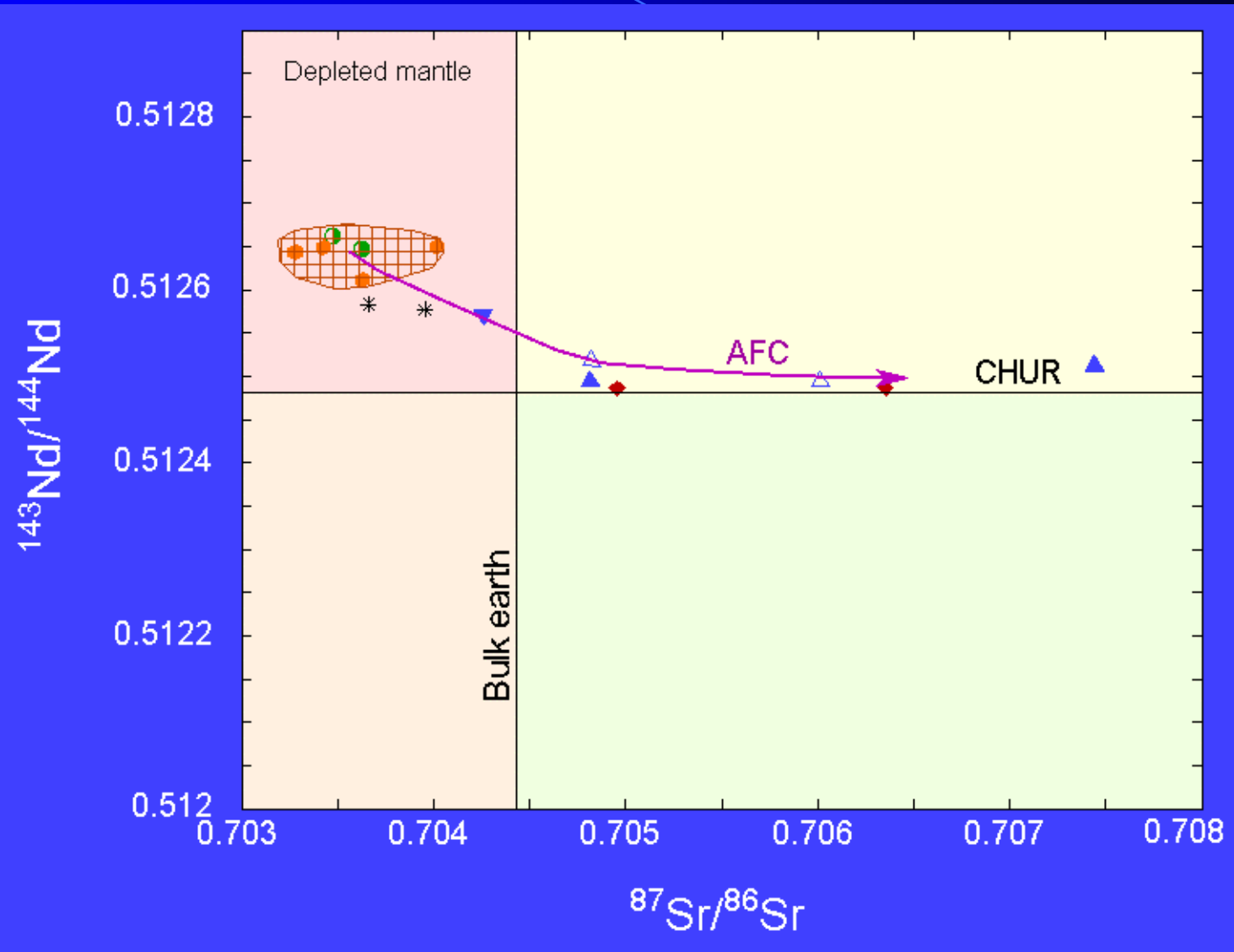


1/Sr vs initial $^{87}\text{Sr}/^{86}\text{Sr}$ for the various lithologies

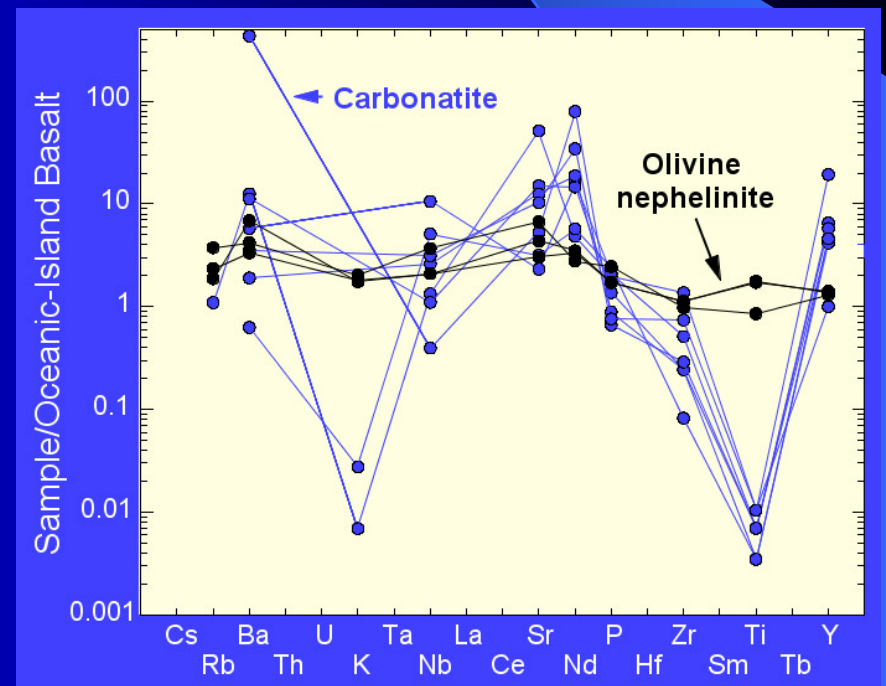
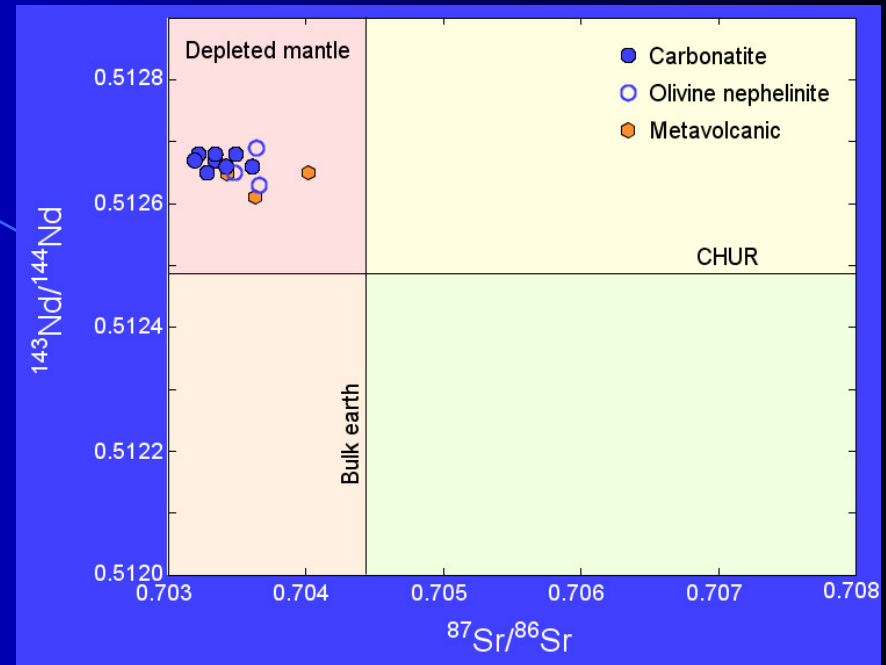
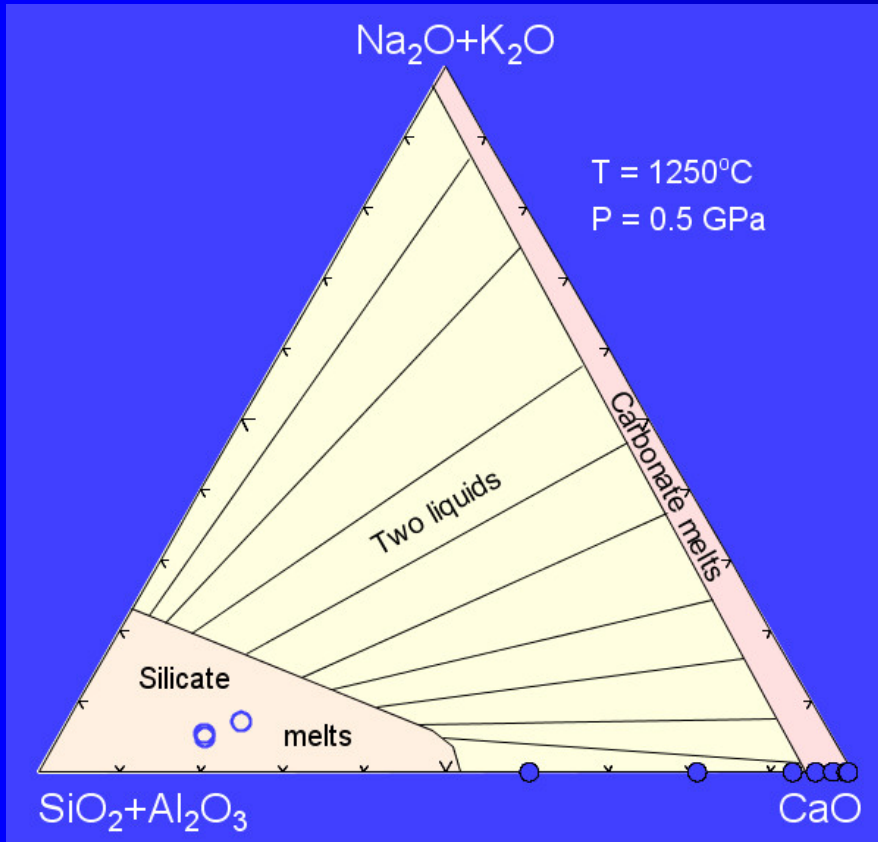
Note that the phonolites also form two isotopically distinct groups. Vector indicates effect of crustal contamination on isotopic compositions.



The majority of the CAP samples fall in the depleted mantle field. Samples that plot outside this field lie along a possible AFC curve.



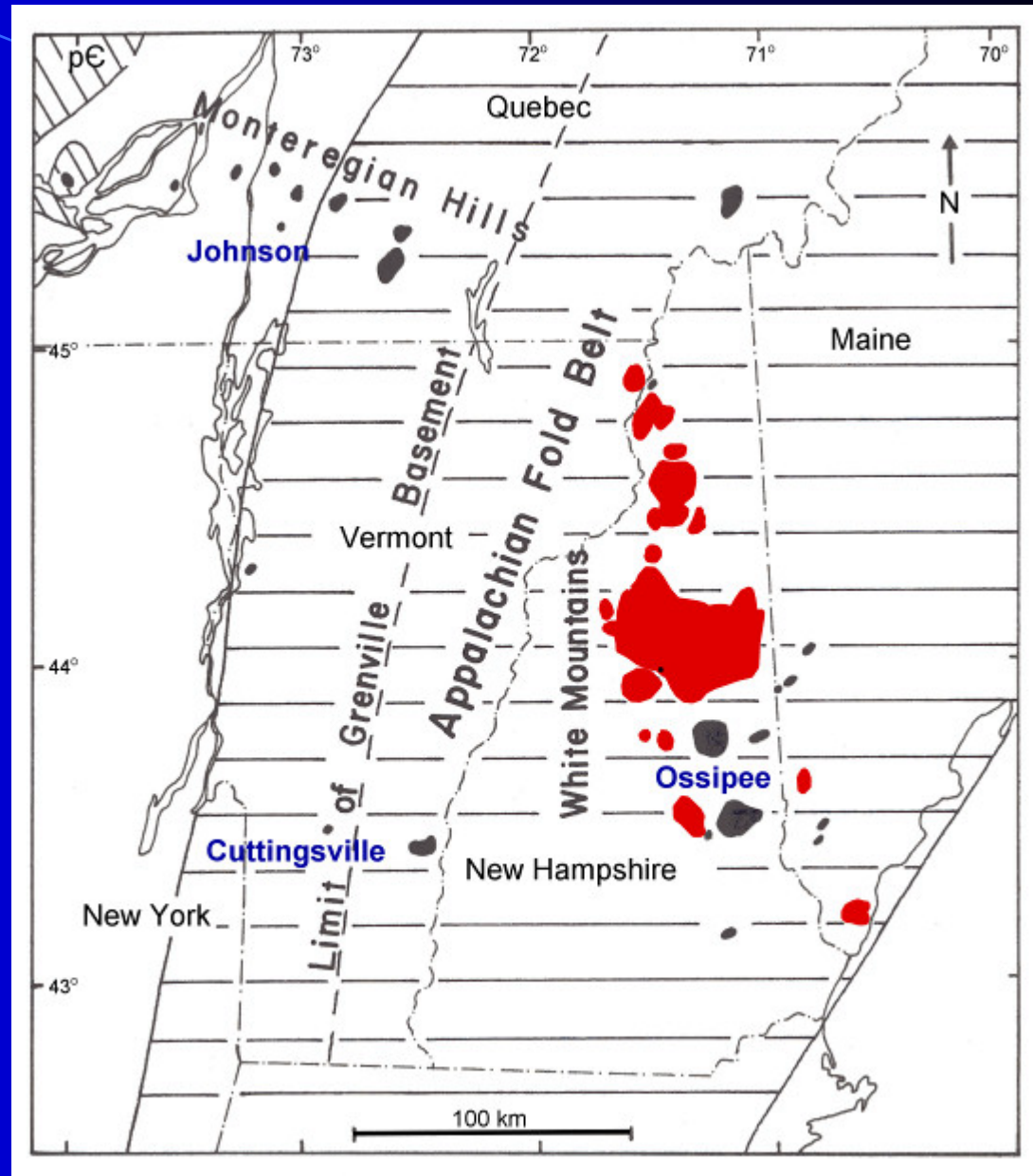
Relationships between mafic silicate volcanics and carbonatites at Chilwa Island



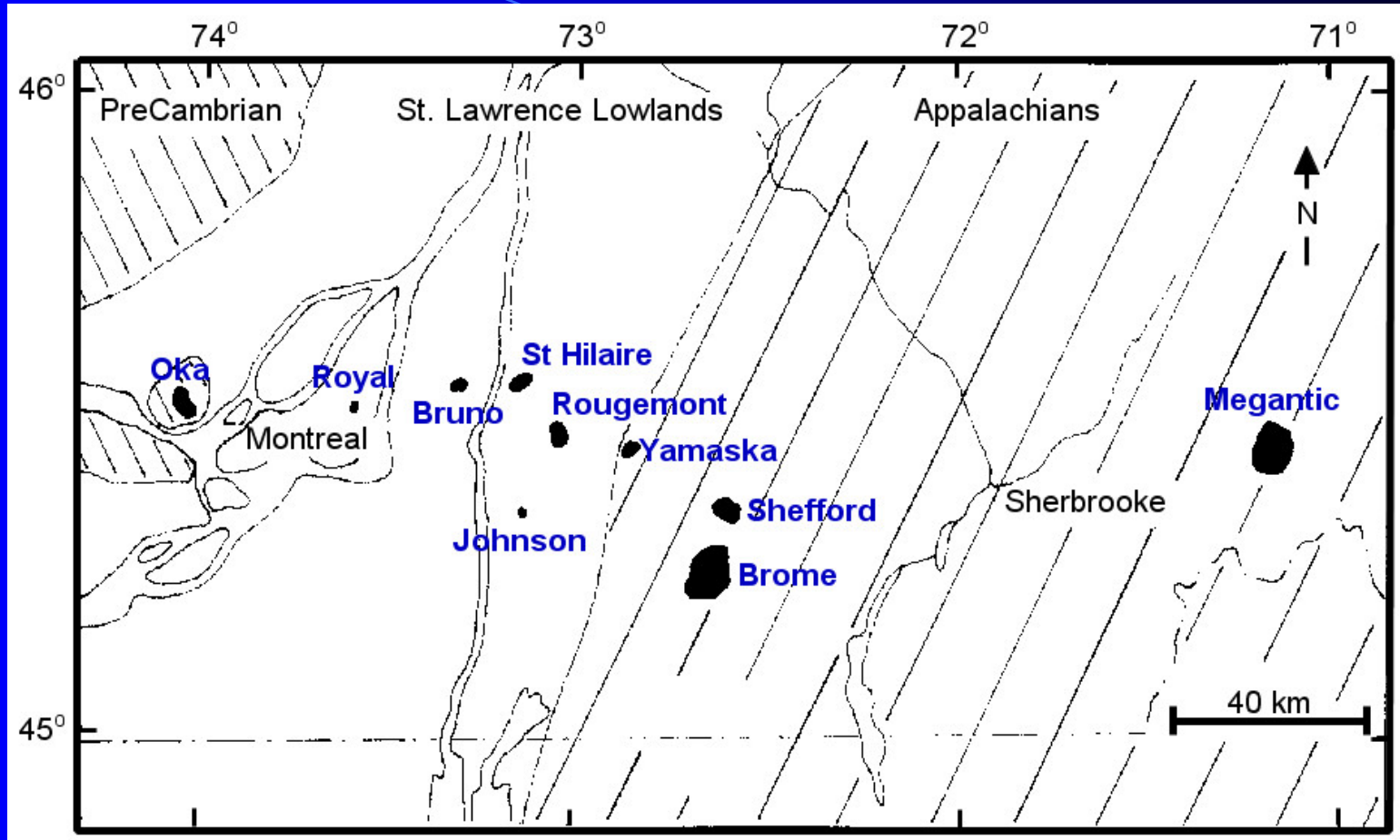
Conclusions:

- **The CAP magmas were drawn from a depleted mantle source**
- **This source does not need to be enriched, small volume melts can generate the observed REE patterns for the olivine nephelinites and basanites**
- **All the lithologies show a strong OIB-like source imprint and can be related by fractional crystallization + some crustal contamination (AFC)**
- **With time, the magmas became relatively enriched in silica presumably due to crust-magma interactions at depth**
- **Late-stage fluid interactions played an important role in redistributing HFSE**

Location of Monteregeian Hills and younger White Mountain plutons (~124 Ma) (black filled areas). Older White Mountain plutons (200- 160 Ma) are shown in red. Mafic silicate rocks are rare in the older White Mountain intrusions.

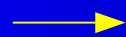


Monteregian Hills



Ultramafic → Mafic → Mafic-felsic → Felsic

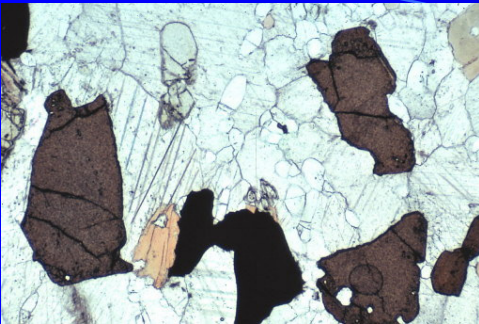
Silica
undersaturated



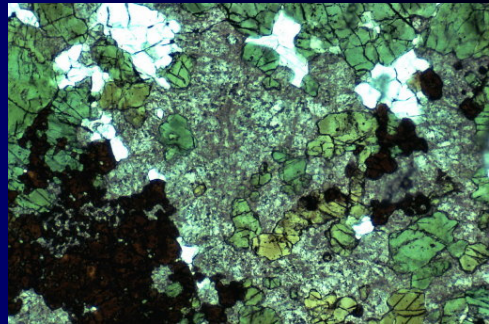
Silica undersaturated to
silica saturated



Silica
saturated

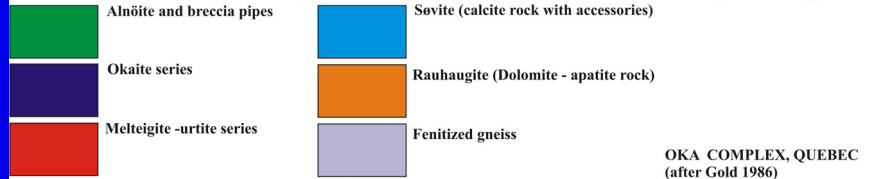
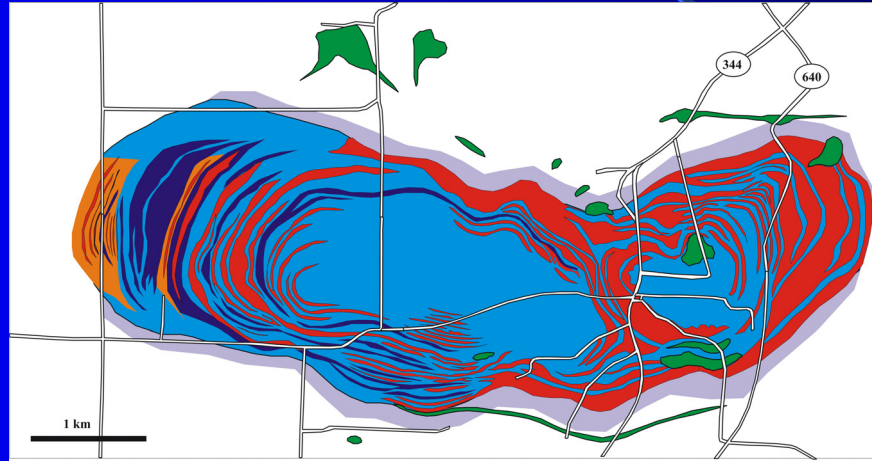
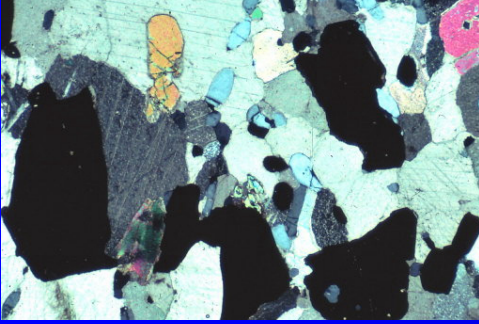


Pyrochlore sovite

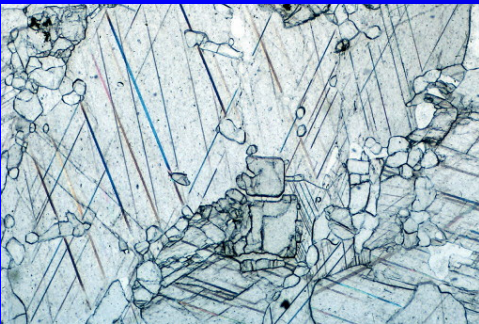
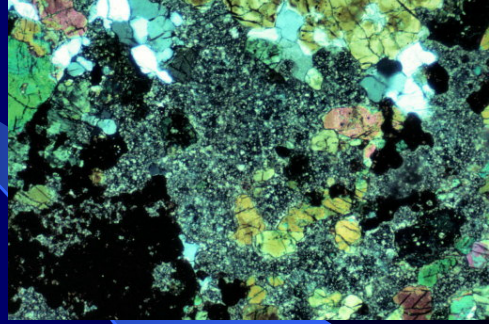


Melanite ijolite

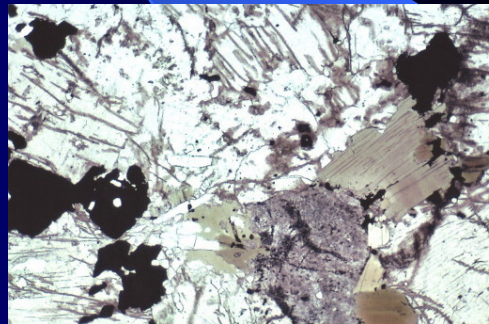
Oka



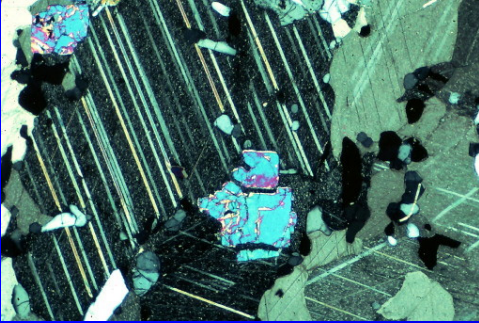
OKA COMPLEX, QUEBEC (after Gold 1986)



Niocalite sovite



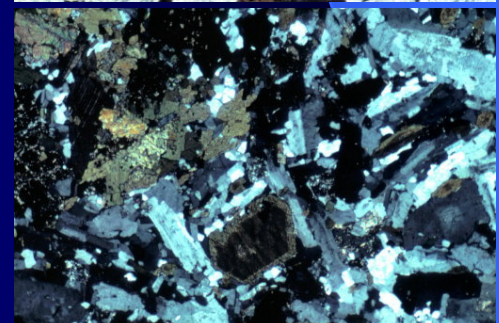
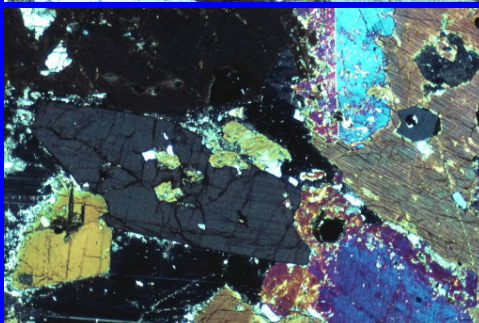
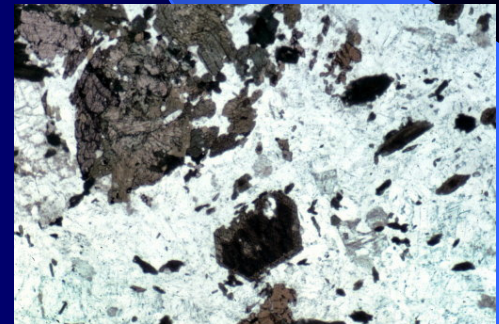
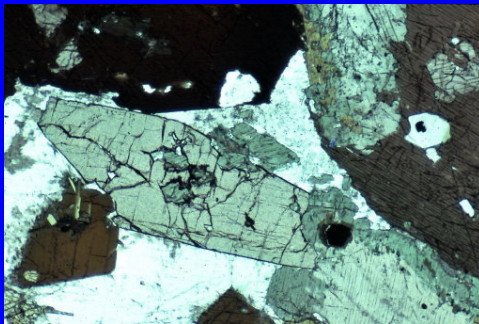
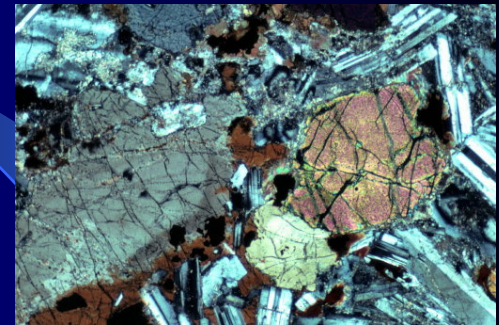
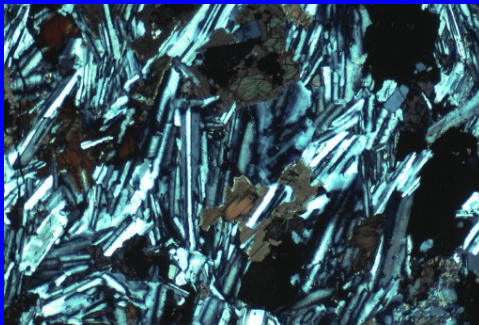
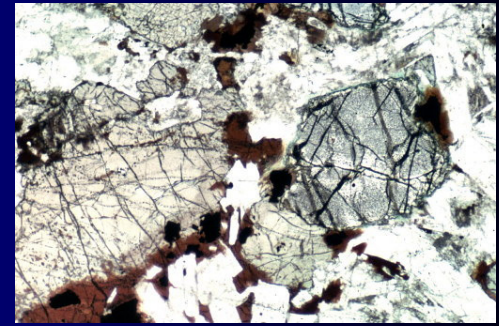
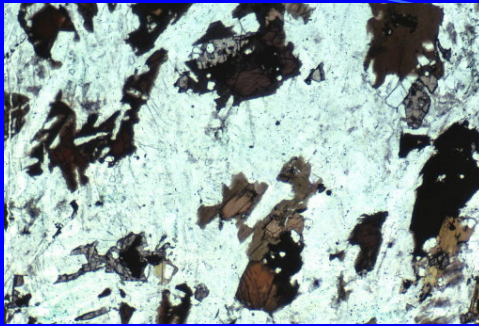
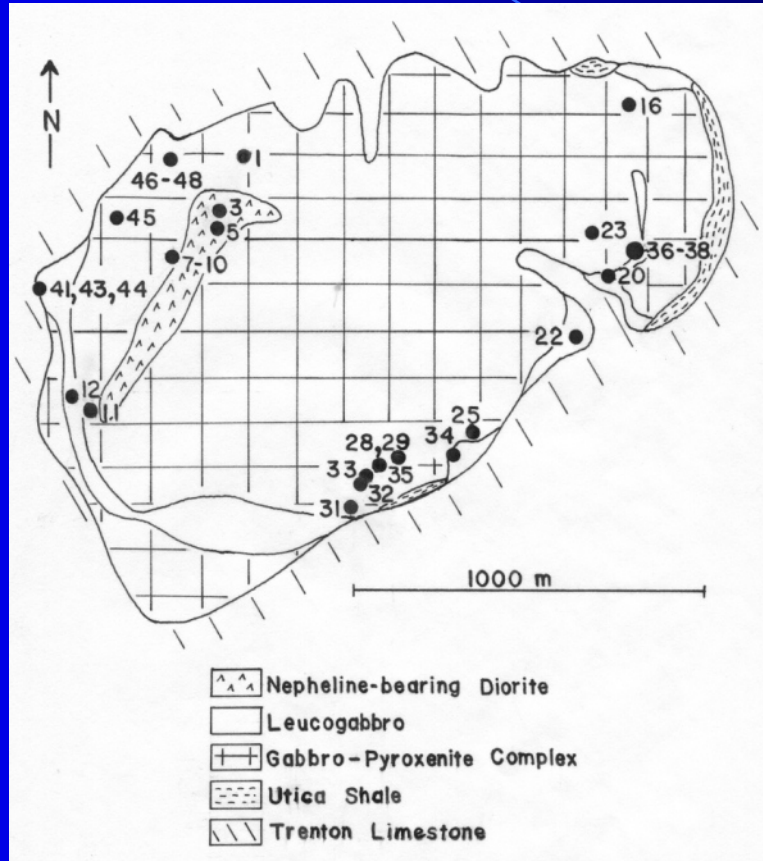
Okaite



Nepheline diorite

Leucogabbro

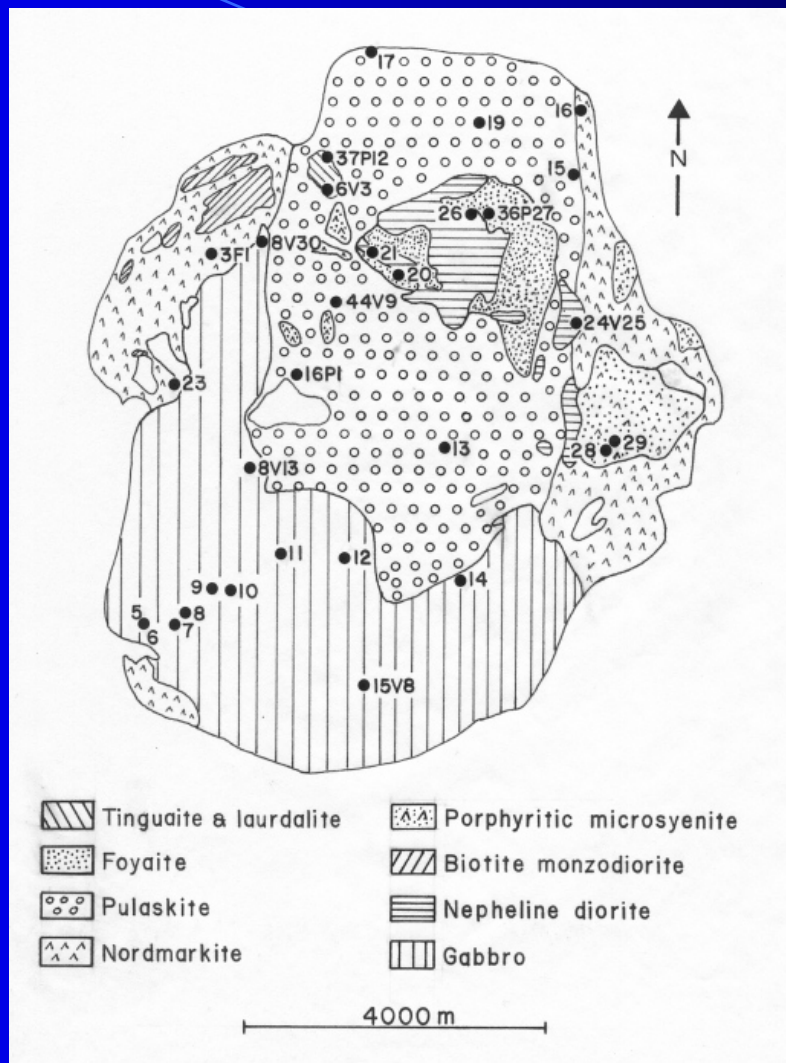
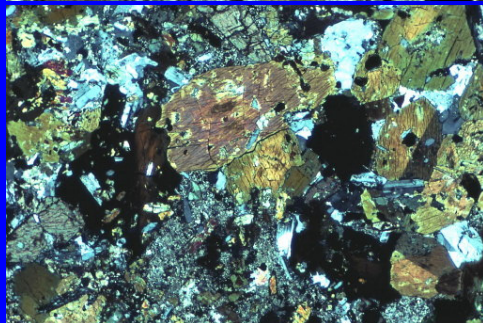
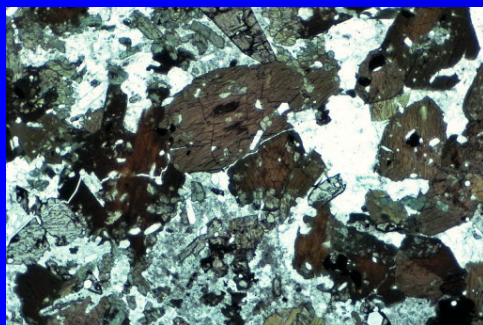
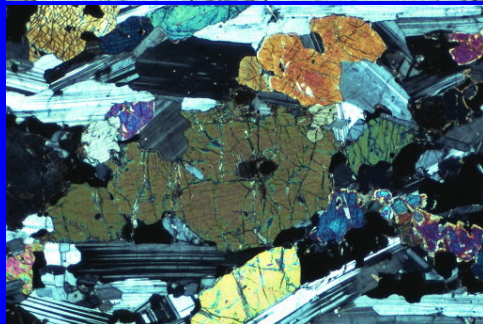
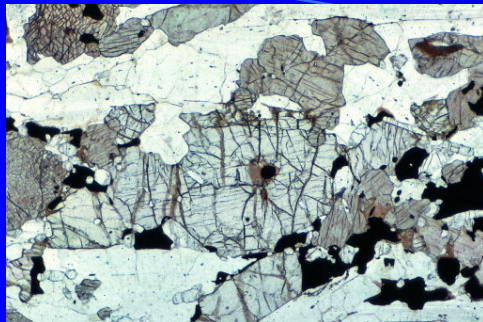
Mont Royal



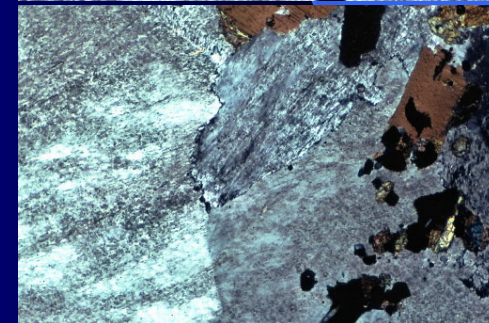
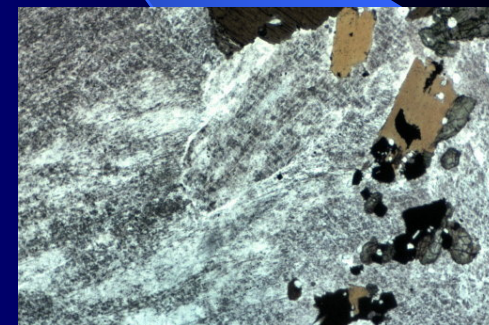
Foidal syenite

Pyroxenite

Gabbro



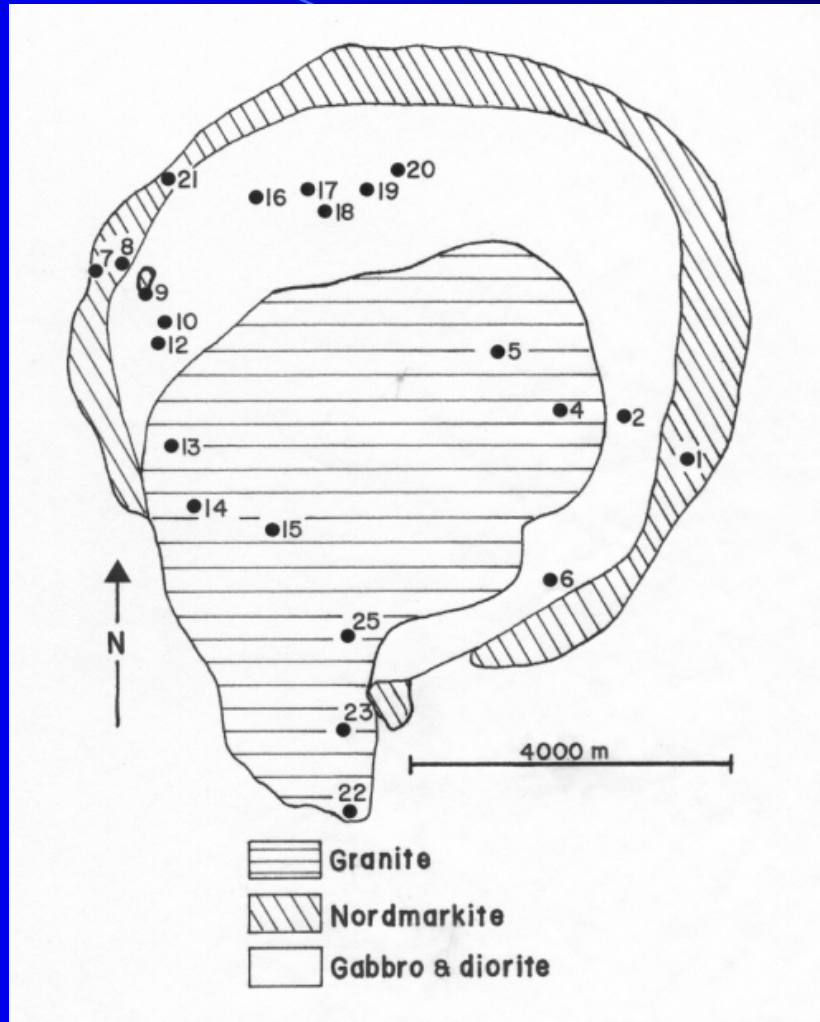
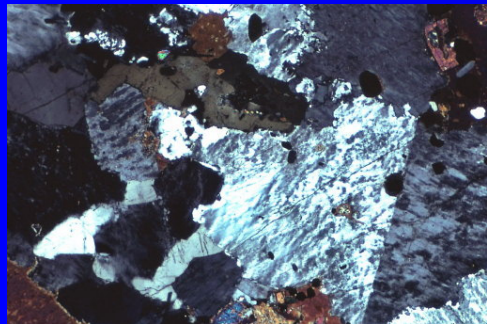
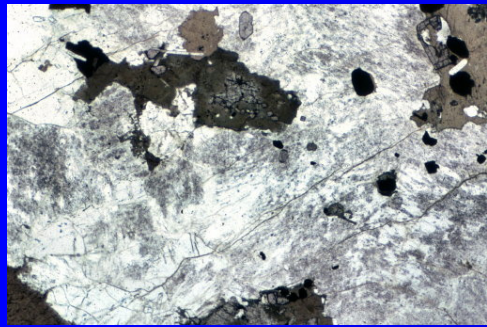
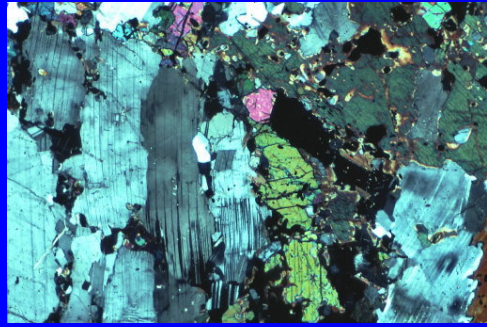
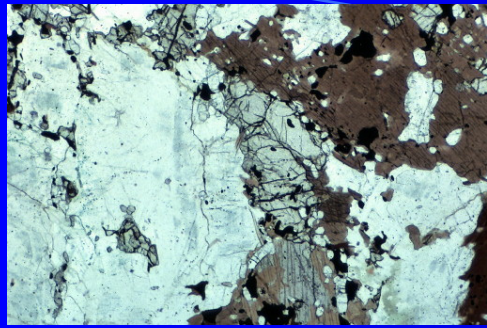
Mont Brome



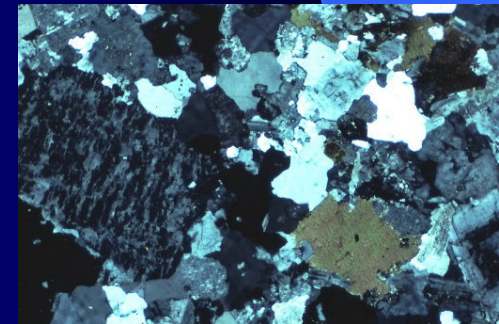
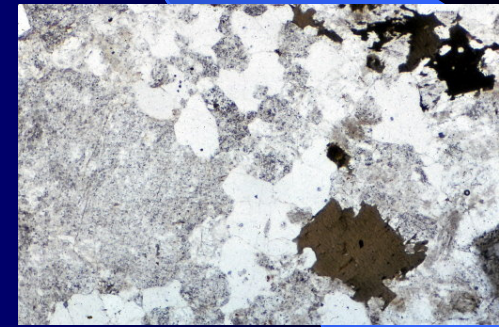
Nepheline diorite

Pulaskite

Gabbro



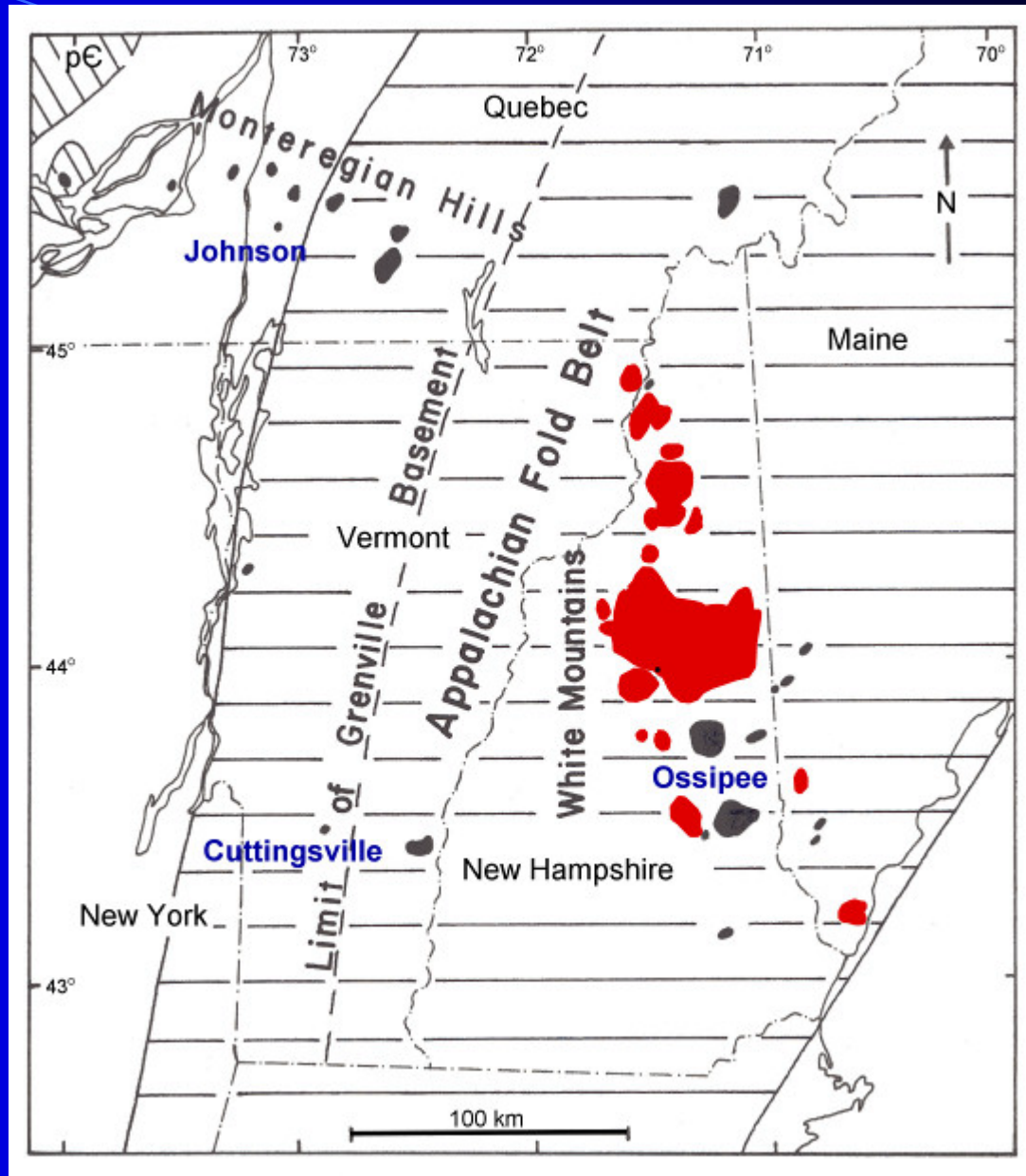
Mount Megantic



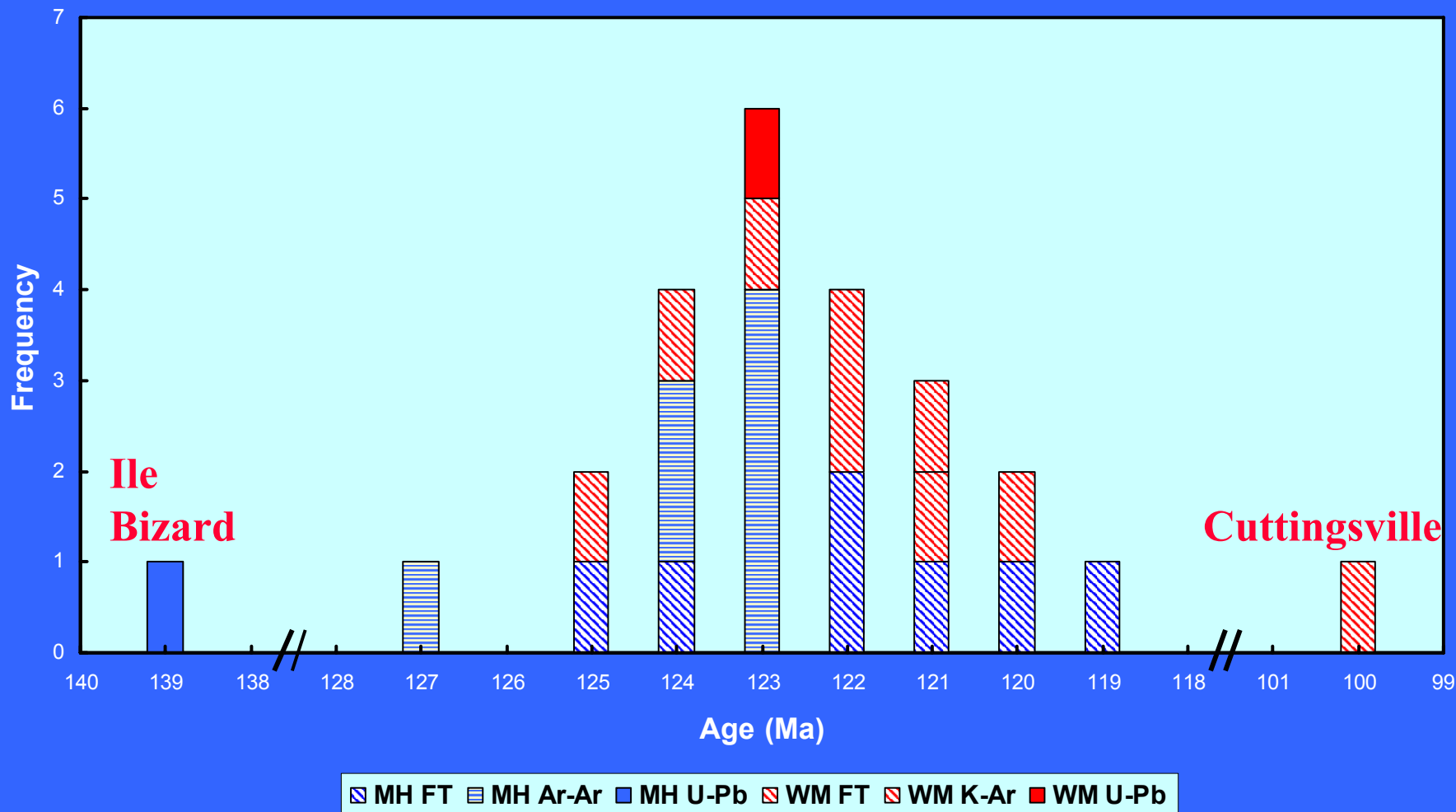
Nordmarkite

Granite

Age relations for the Monteregian Hills and Younger White Mountains

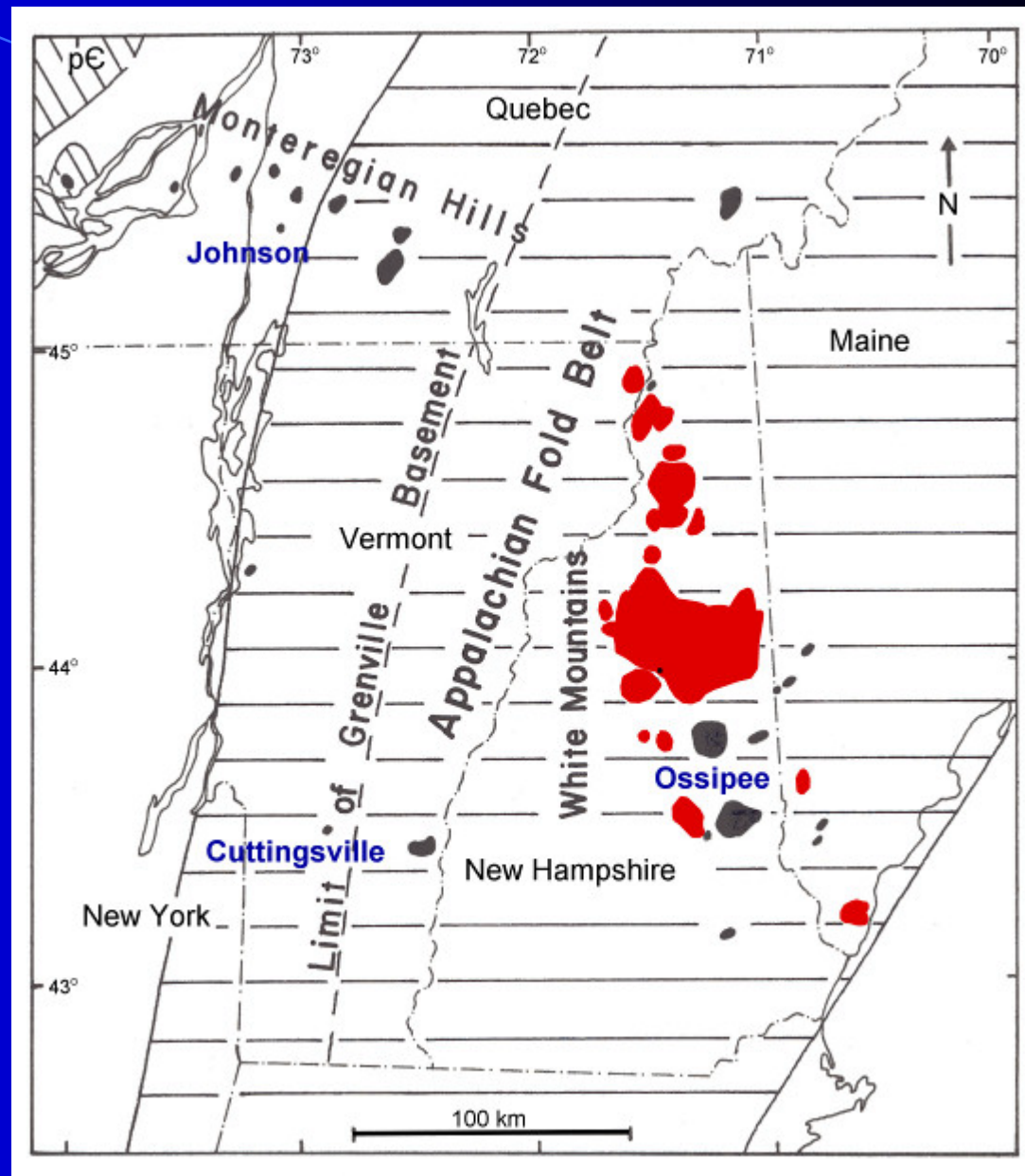


Age relations for Monteregeian Hills and Younger White Mountains



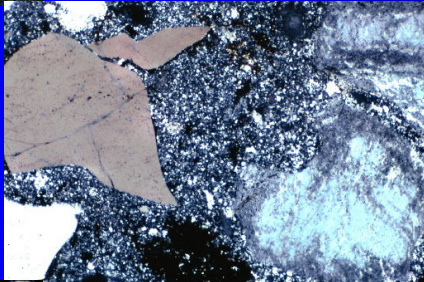
With the exception of Ile Bizard and Cuttingsville, there is essentially a complete overlap in ages for the two provinces.

Johnson, Cuttingsville, and Ossipee all contain mafic silicate rocks that may approximate magmatic compositions. We will use the chemistry of these rocks to make inferences about the sources and melting processes.

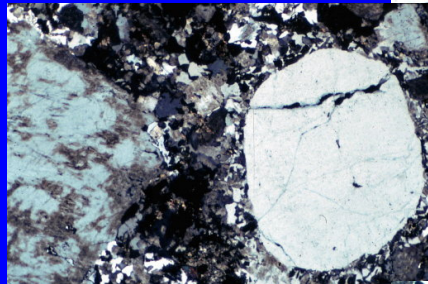




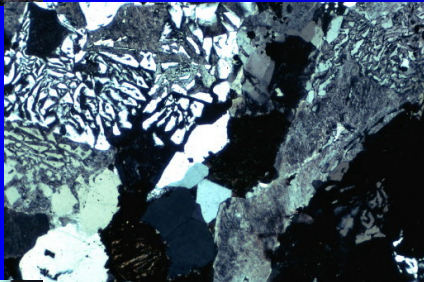
Basalt



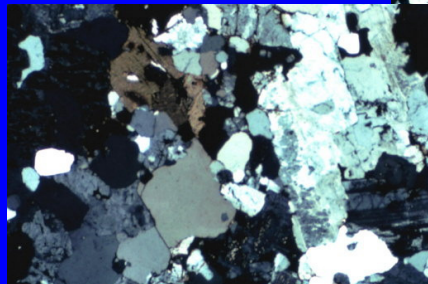
Rhyolite



Porphyritic quartz syenite

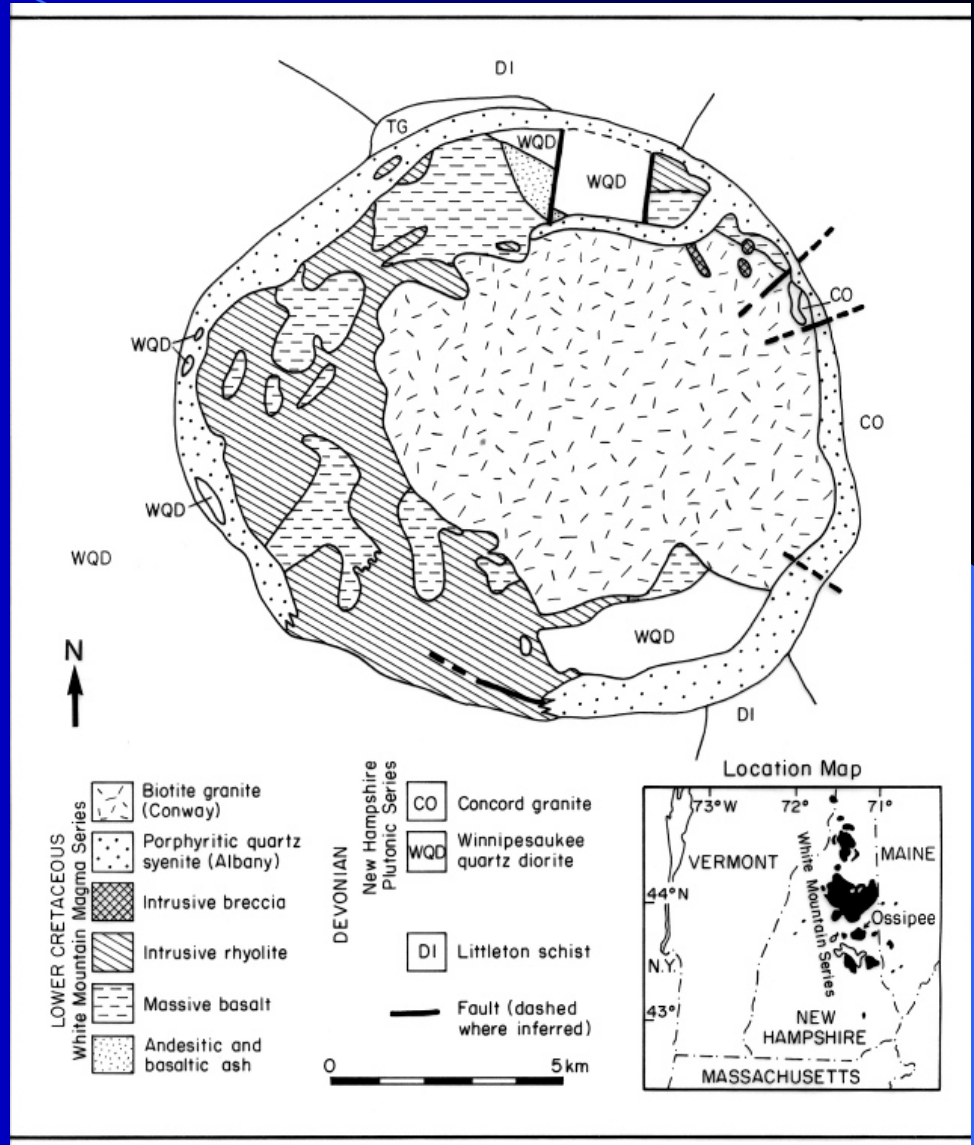


Microgranite

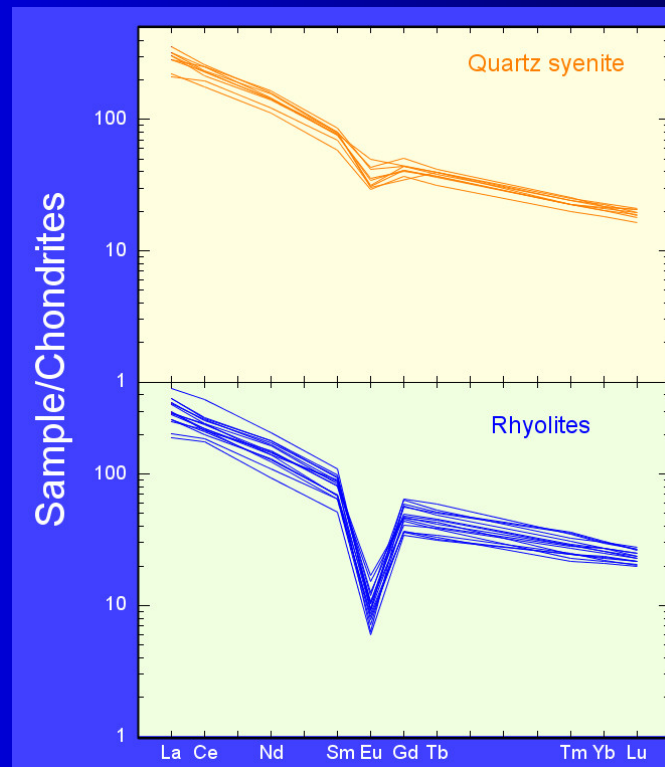
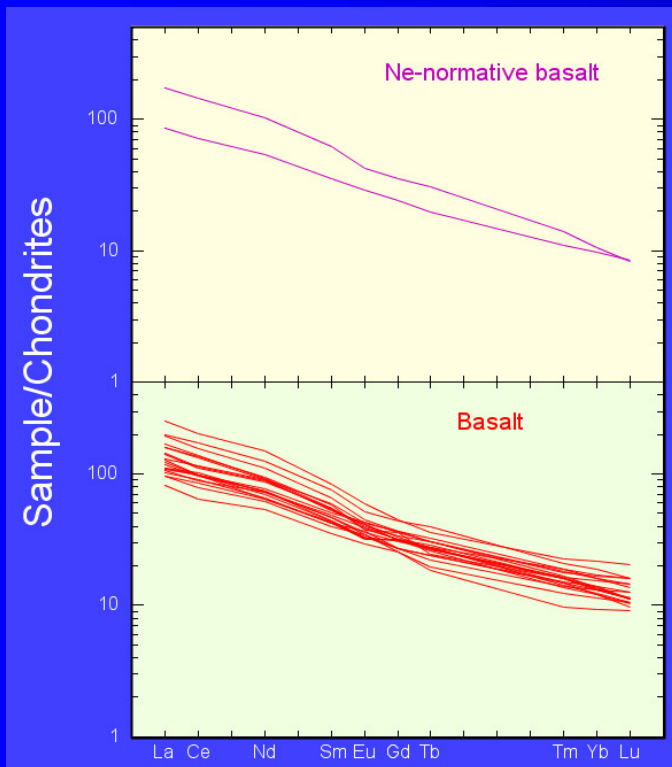
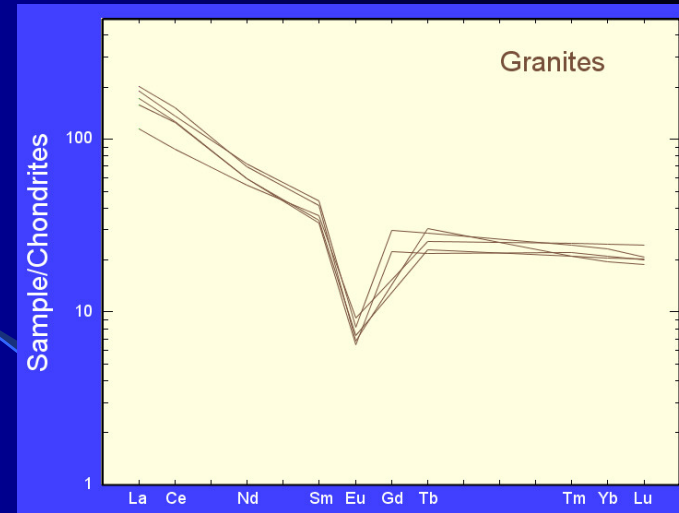


Biotite granite

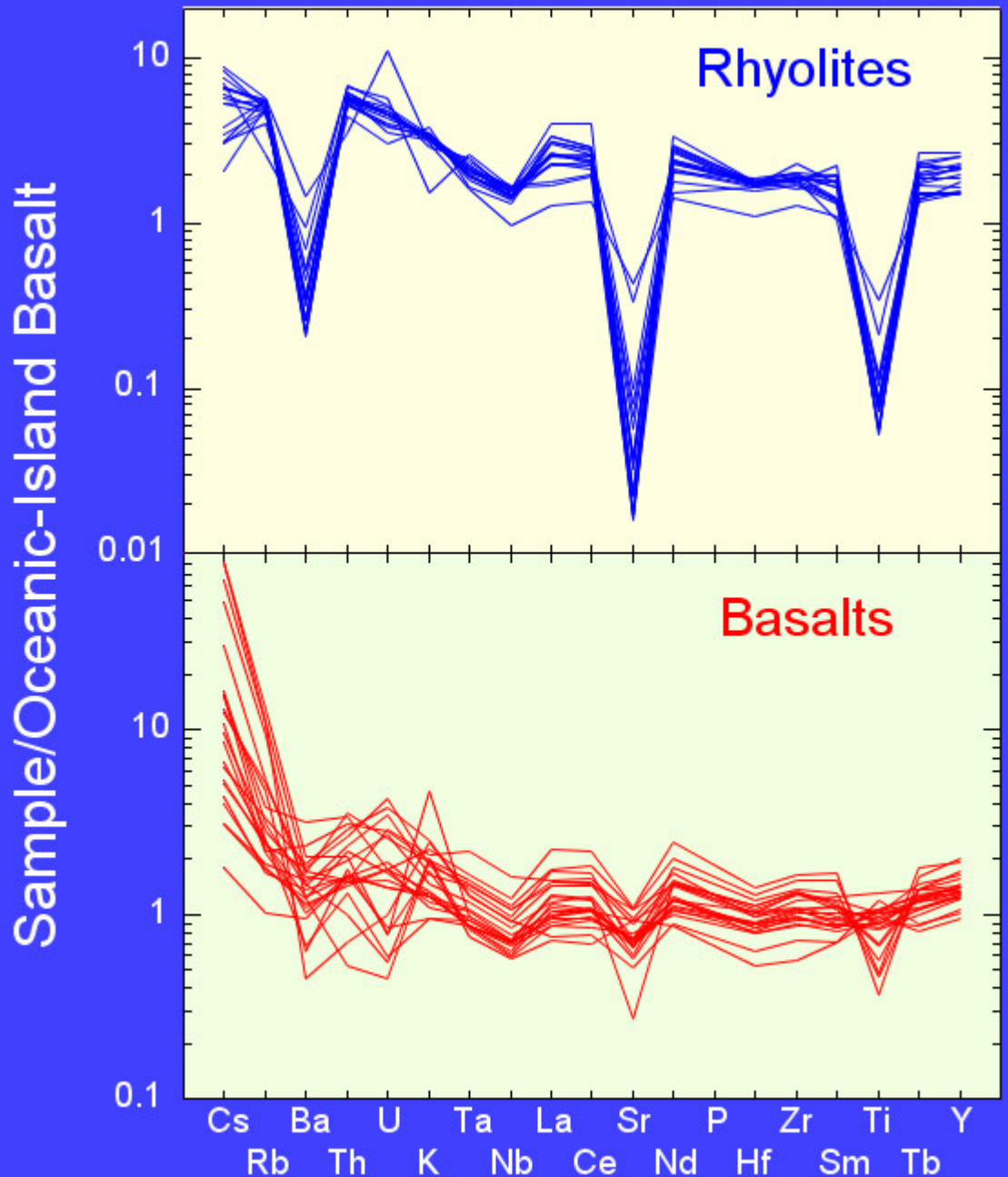
Ossipee ring complex



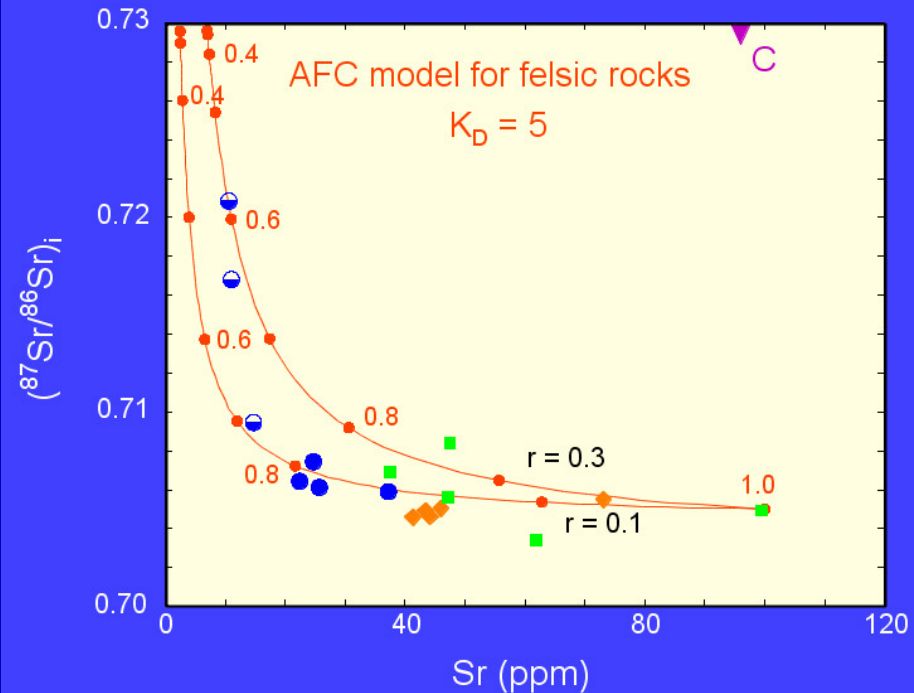
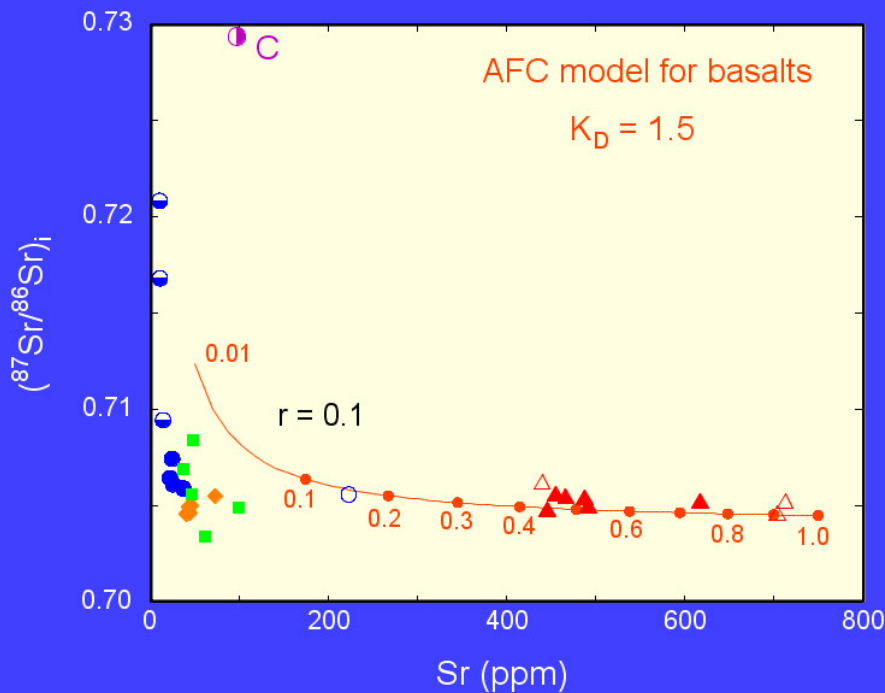
Chondrite normalized REE plots for the various lithologies of the Ossipee ring complex. Note the similar slopes of the REE patterns for all lithologies with the exception of the granite which shows a flattening at the HREE end.



OIB normalized spider diagrams for Ossipee rhyolites and basalts. Note the similarity of both lithologies to OIB. Variations can be explained by the fractionation of alkali feldspar and opaque oxide minerals. Cs enrichment in basalts is due to late-stage hydrothermal alteration as evidence by the partial replacement of plagioclase by epidote.



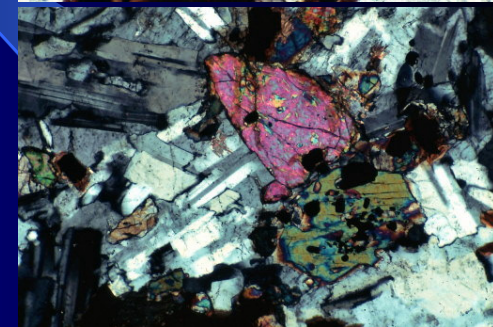
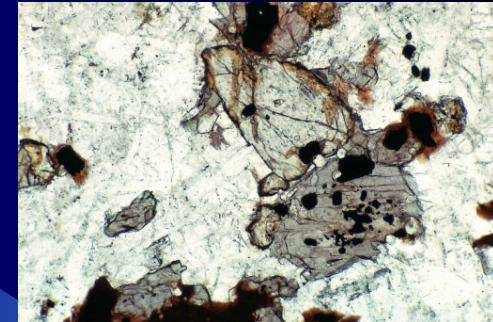
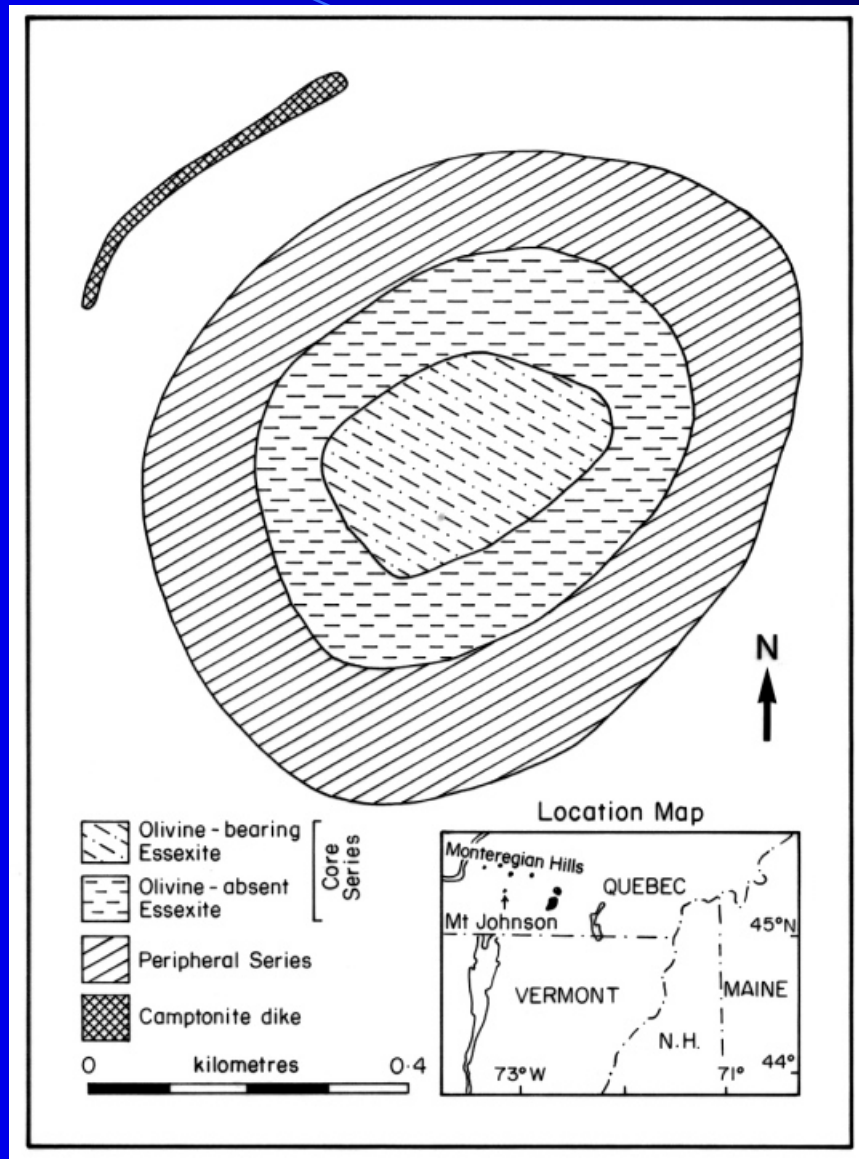
AFC models for basalts and felsic rocks. The isotopic variations require only minor contamination of the melts by country rock.



Mont Johnson

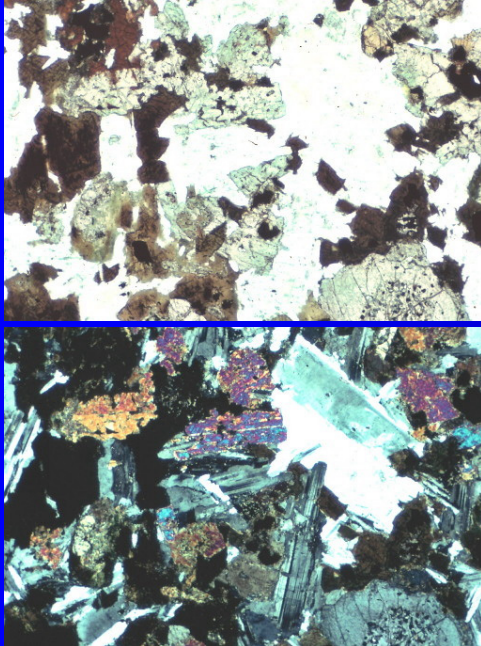


Core series
essexite from
center of pluton.

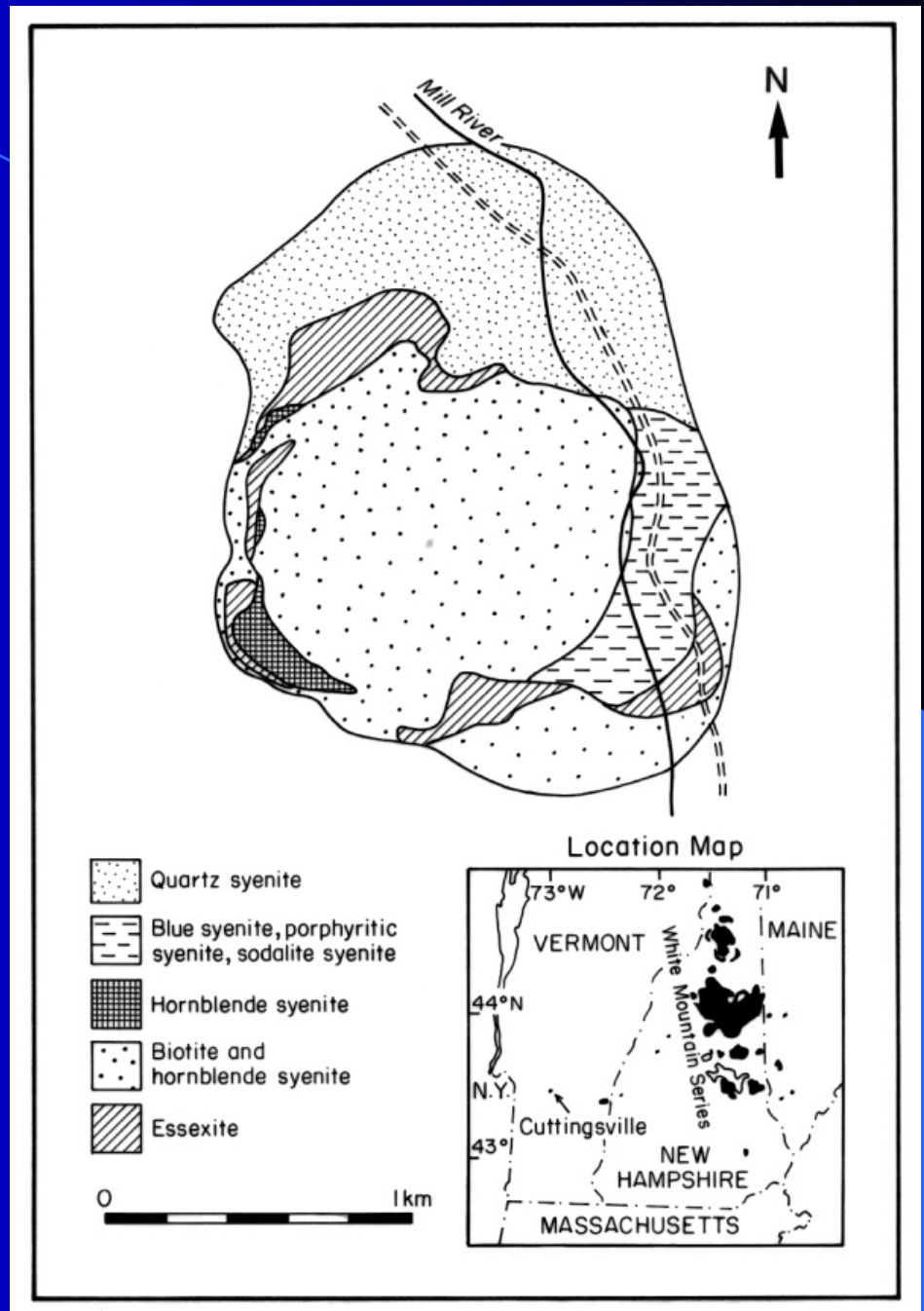


Core series
essexite. Width of
field of view,
2mm.

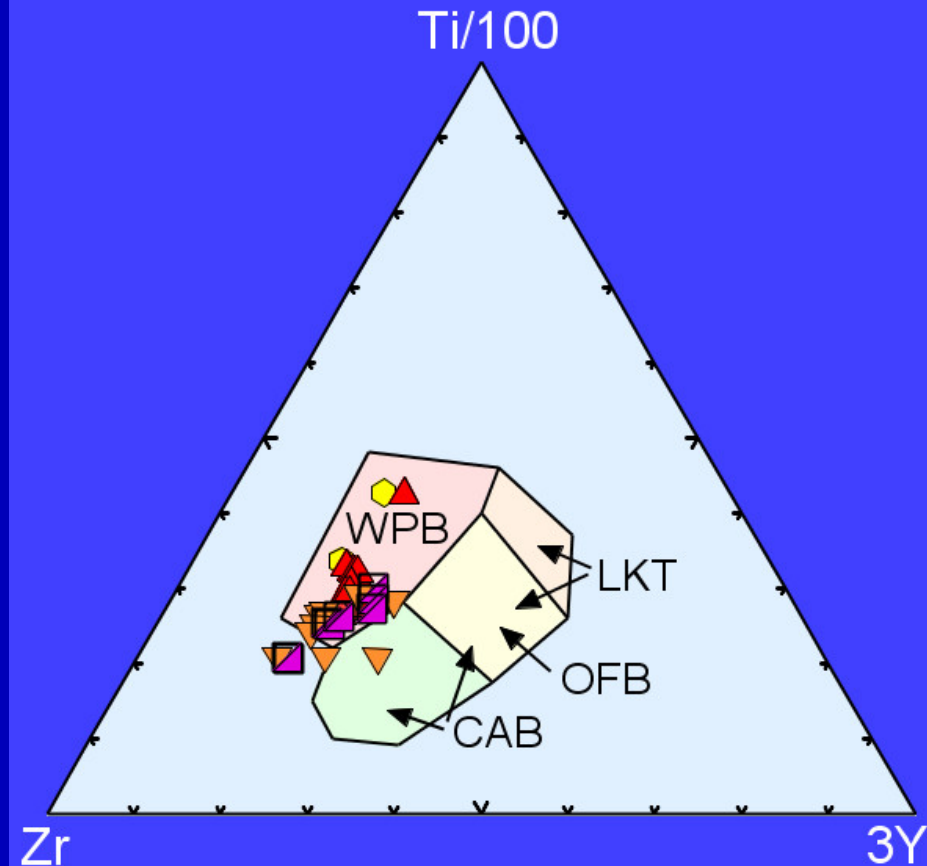
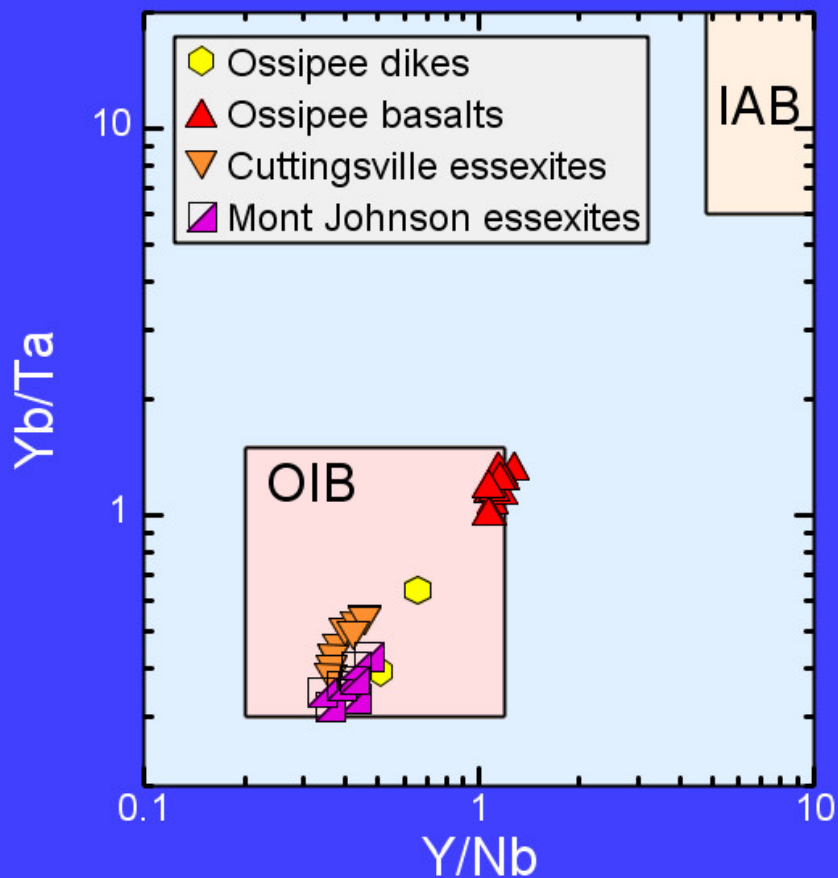
Cuttingsville



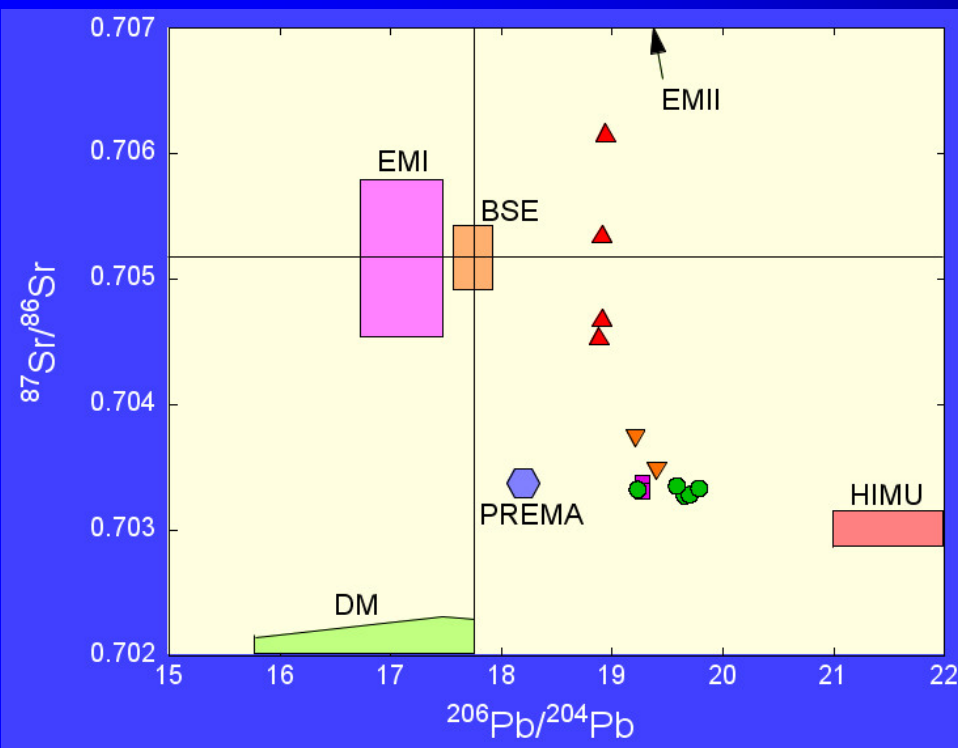
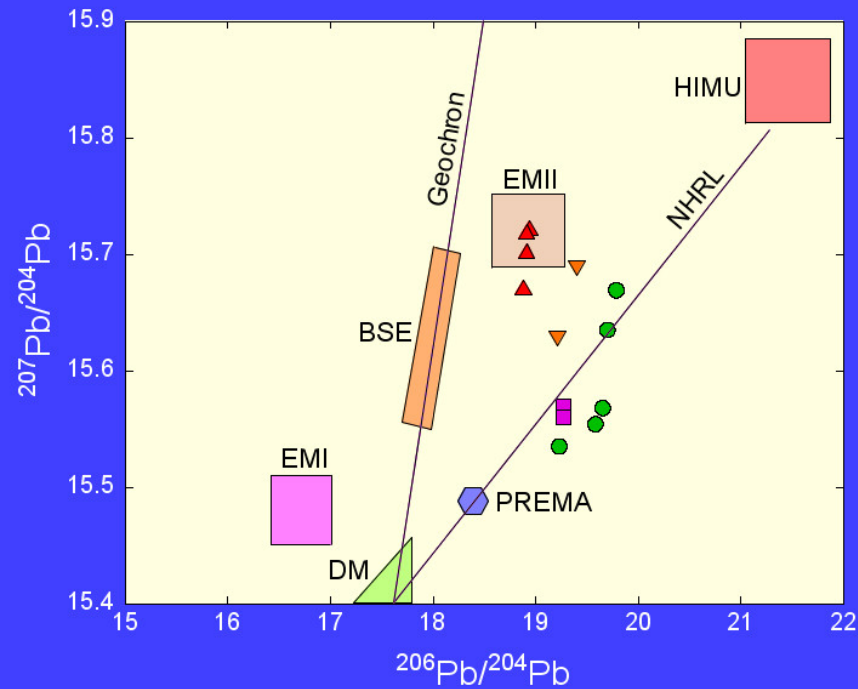
Essexite



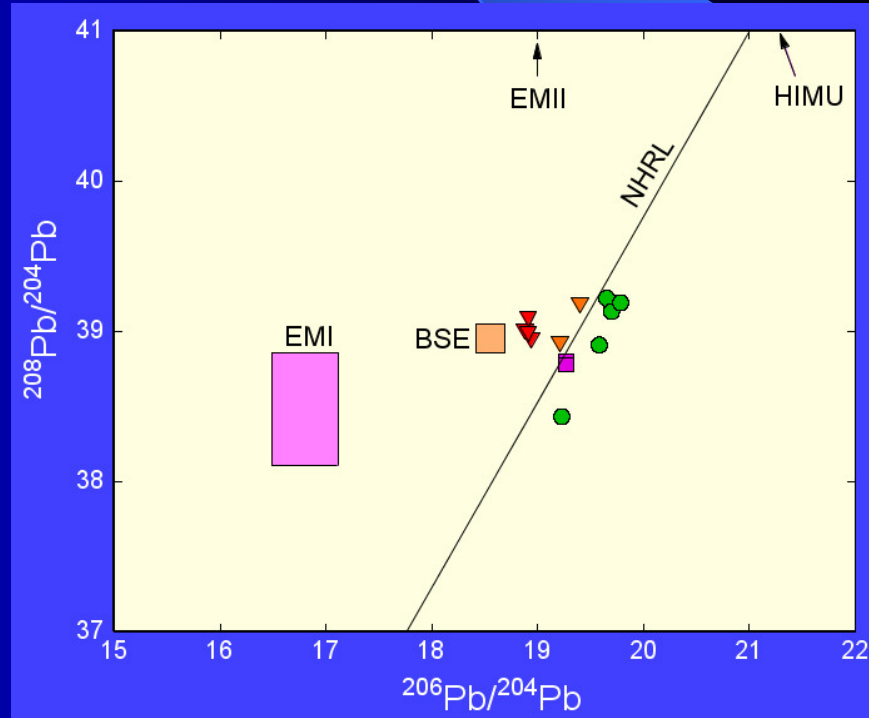
The mafic rocks plot in the OIB and WPB fields on various discrimination diagrams. In the Y/Nb vs Yb/Ta diagram the Ossipee basalts plot towards the IAB field (but still within the OIB field), an indication of minor crustal contamination



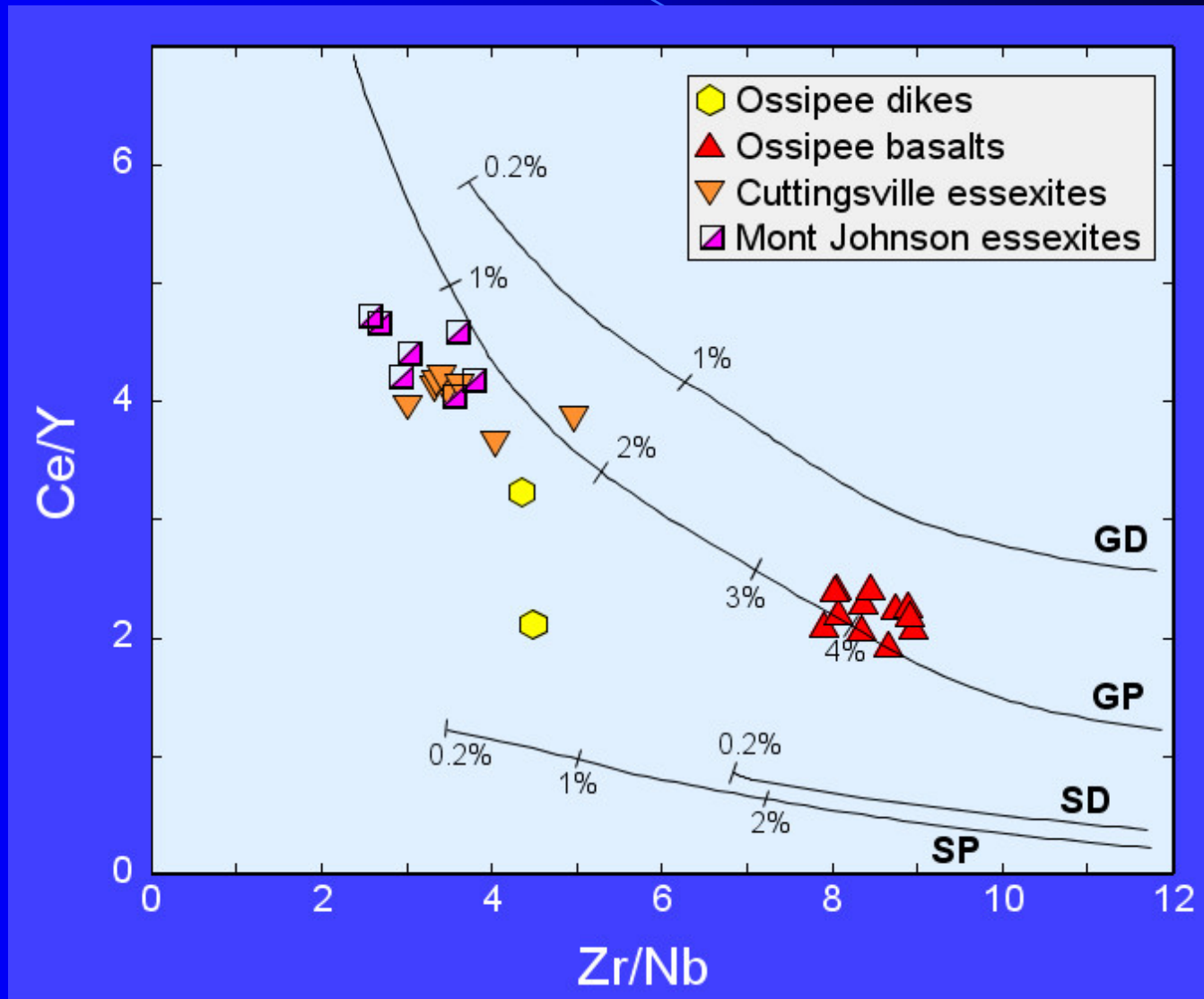
Sr and Pb isotopic relationships for the mafic silicate rocks and the Oka sovites.



- Oka
- ▼ Cuttingsville
- Mont Johnson
- ▲ Ossipee



Melting models for various mantle sources. Note that the MHWM mafic rocks fall along the Garnet Peridotite curve and are apparently related by variable degrees of melting of the source.



Conclusions

- **MHWM magmatism occurred ca 123 Ma.**
- **Lithologic variations are geographically defined. The type of crust played a key role in determining the character of the magmas.**
- **The silicate rocks show a strong OIB-source signature.**
- **The parental magmas were derived by various degrees of partial melting of garnet peridotite mantle.**
- **Interaction of the parental melts with the deep crust played an important role in determining the degree of silica saturation of the parental magmas.**