Mineralogy and Petrology of Rare Element Pegmatites in The Eau Claire River Complex, Eau Claire County, WI

Sara E. Hanel, Mentor:Robert Hooper
Department of Geology - University of Wisconsin Eau Claire

Abstract

Pegmatites are economically targeted for mining critical metals (Nb, Ta, Zr, Y, Th, U and REEs). The Eau Claire River pegmatite complex, originally mistaken as potassium-feldspar granite, are highly fractionated, garnet, two-mica, albite, quartz Nb, Y, F (NYF) pegmatite granites significantly enriched in a wide variety of high field strength (HFS) elements. The rare HFS elements occurs in a variety of mineral phases including REE-epidotes, phosphates (LREE-monazite and HREE-xenotime), REE-carbonates (parasite), oxides (uraninite, thorite, columbite group minerals, Zn spinel (gahnite)) and Hf and U-enriched zircon series minerals. The extreme fractionation of the alkalic magma that formed these pegmatites results in Zr/Hf ratios of significantly less than 10. Most of the Penokean age plutonic rocks in the Eau Claire region are tonalites, a product of decompression melting of basalts and gabbros. The Eau Claire River pegmatite complex mineralogy is not compatible with fractionation of Penokean age granitoids. Rare-element pegmatites of the NYF association are always associated with Na-rich anorogenic magmatic complexes. Rare NYF pegmatite occurrences are known in central Wisconsin and have ages consistent with Wolf River magmatism. Based on the NYF mineralogy, the Eau Claire pegmatites are most likely related to 1.4Ga anorogenic magmatism in central Wisconsin.

Why study pegmatites of the Eau Claire River Complex?

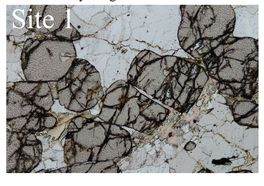
- Garnet and Mica bearing **Albite Granitoid** with pervasive potassic alteration results in the pink appearance. Not all pink granites have abundant primary K-spar!
- These Pegmatites have a distinctive mineralogy associated with Niobium (**N**) Yttrium (**Y**) Fluorine (**F**) a rare-element **(NYF**) class of pegmatites(Cerny et al., 2012). NYF pegmatites are the primary source rocks of some strategic metals such as Nb (Ercit, 2005).
- NYF pegmatites are always associated with highly fractionated Anorogenic (A-type) granitoids (reference) and the closest recognized A-type granites are in NE Wisconsin associated with the Wolf River Batholith.
- NYF pegmatites contain rare, and poorly understood minerals with potential economic value and are especially enriched in Lanthanides (**REE**) and Actinides (U,Th).
- Some of the rare minerals in the EC-River complex may represent new mineral species.

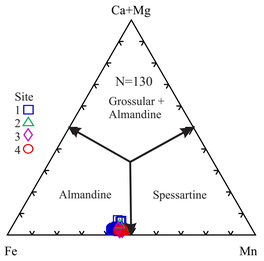
Table 1. Minerals in the EC Complex Pegmatites

Mineral Name	Mineral Formula	Common Impurities
Silicates		
Allanite	$\{Al^{2+}REE^{3+}\}\{M^{3+}_2M^{2+}\}(Si_2O_7)(SiO_4)O(OH)$	Y, Nd, Ca, Cr
Thorite	$Th(SiO_4)$	Al, Fe, Pb, Ca, P, Ti, REE, Y, Mg, H_2O
Uranothorite	$(Th,U)SiO_4$	Al, Fe, Pb, Ca, P, Ti, REE, Y, Mg, H_2O
Zircon	$Zr(SiO_4)$	U, Th, Pb, Hf, Y/REE, P,Sc
Phosphates		
Apatite	$Ca_5(PO_4)_3(Cl/F/OH)$	U, Th
Auerlite	$Th(Si,P)O_4$	U, LREE,
Monazite	$La, Ce(PO_4)$	LREE
Xenotime	$Y(PO_4)$	HREE, Ca, U, Th, Si, F
Oxides		
Columbite	$Fe^{2+}Nb_2O_6$	Mn^{2+}, Ca^{2+}, Ta, REE
Gahnite	$ZnAl_2O_4$	Fe, Mg
Hematite	Fe_2O_3	Ti, Al, Mn, H_2O
Magnetite	$Fe^{2+}Fe^{3+}{}_2O_4$	Mg, Zn, Mn, Ni, Cr, Ti, V, Al
Lepidocrocite	γ-$Fe^{3+}O(OH)$	Mn
Samarskite	$YFe^{3+}Nb_2O_8$	$Y,Fe^{3+},Fe^{2+},U,Th,Ca,$ Ta, REE
Uraninite	UO_2	Th, Zr, Pb, Ra, Ac, Po, Ce, Y, Er, La
Sulfides and Sulfates		
Barite	$BaSO_4$	
Chalcocite	Cu_2S	Fe
Chalcopyrite	$CuFeS_2$	In, Tl, Se, Te
Galena	PbS	Cu, Fe, Bi
Sphalerite	ZnS	Mn, Cd, Hg, In, Tl, Ga, Ge, Sb, Sn, Pb, Co
Pyrite	FeS_2	Ni, Co, As, Cu, Zn, Ag, Au, Tl, Se, V
Carbonates		
Parisite	$Ca(Ce, La, Nd, REE)_2(CO_3)_3F$	
Synchysite	Ca(Ce+REE)CO3(F)	

Garnets

Glomercrystic garnet

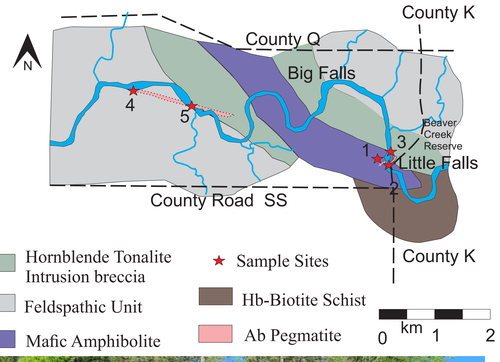




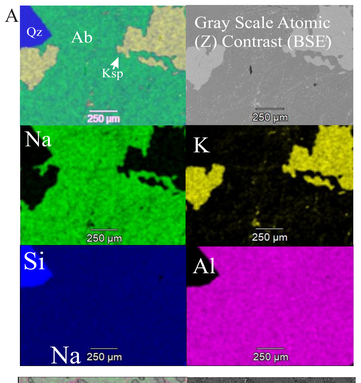
Conspicuous garnet clusters could be interpreted as either xenocrystic (inherited) or primary (magmatic). The tight chemical grouping near the almandine-spessartine boundary is typical of garnets that have been interpreted in other NYF pegmatites as being primary igneous garnets. Metamorphic garnets would typically show a much broader range of chemistry.

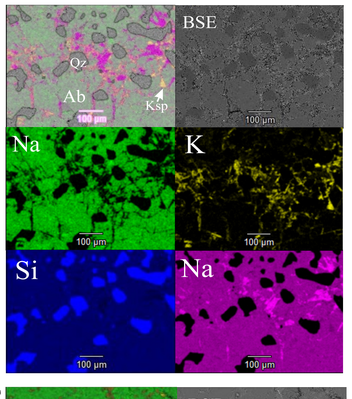
Regional Geology

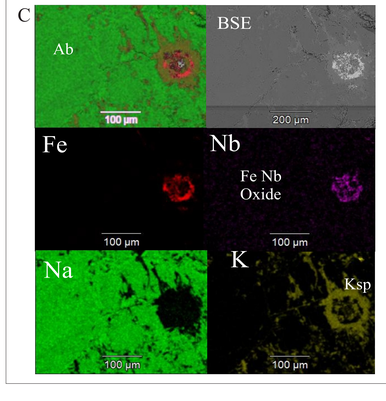
Eau Claire River Complex(Cummings, 1984)

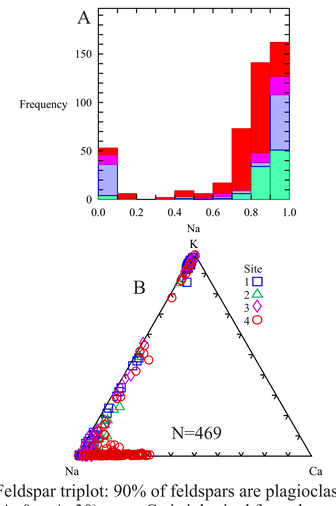


Feldspars

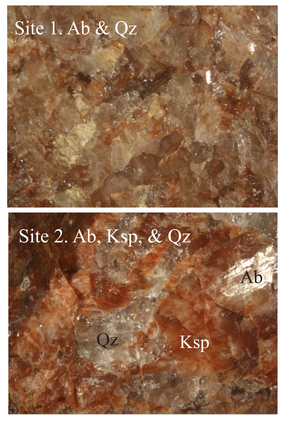






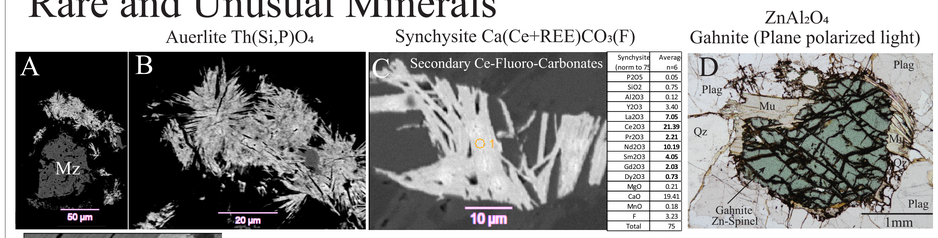


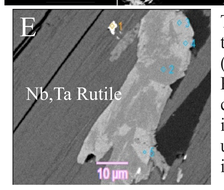
Feldspar triplot: 90% of feldspars are plagioclase (An0 to An30) some Ca is inherited from the wall rock. Kspar is rare and usually associated with late stage K-metasomatism.



Feldspar EDS quantitative maps of Albite (Ab) and Quartz (Qz) matrix with (A) K-Feldspar (Ksp) grains (B) K-feldspar metasomatism along grain boundaries (Sample site 4 - N edge) (C) Subsolidus mixed Fe-Nb oxide surrounded by K-feldspar (Ksp) sample site 4 N.edge

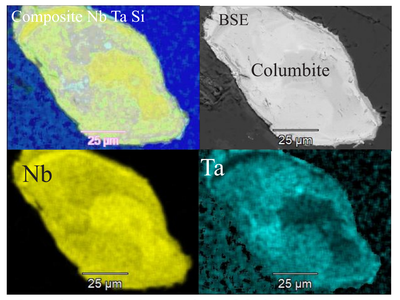
Rare and Unusual Minerals

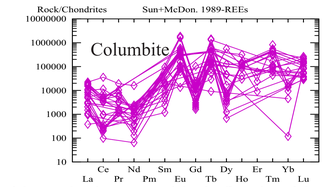




These pegmatites contain minerals that are both very rare and also minerals with chemistries that represent extreme substitutions. A-B represent subsolidus reaction rims around Monazite (Mz) that has been altered to Aurelite $Th(Si,P)O_4$, the second record of Aurelite in the USA. REE carbonates such as Parisite and Synchysite(C) are secondary minerals filling veins. The REE content is shown in the table to the right of figure C. Ghanite(D), a rare zinc spniel, is quite common in the pegmatites. Rutile (E) from the pegmatites contains unusual concentrations of Nb and Ta with up to 15wt% combined substitution for Ti. Nb rich areas are shown as brighter areas in the BSE image in E.

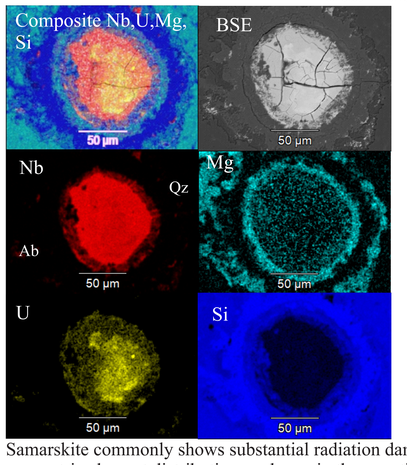
Niobates

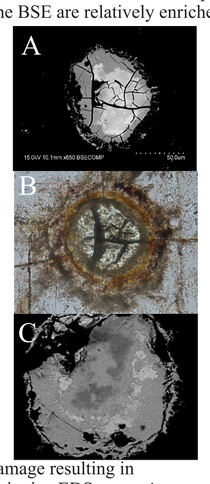


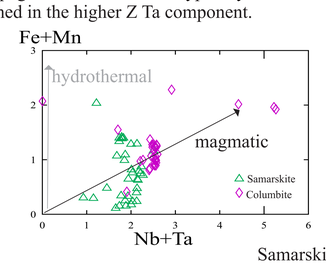


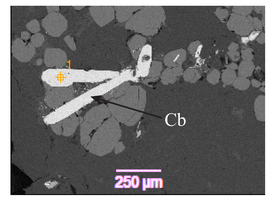
Columbite grains have a realtively flat chondrite normalized REE pattern. The columbite grains are one of the few REE-rich minerals with substantial Eu, probably substituting for Ca^{2+} in the columbite structure.

Quantitative EDS mapping of Columbite grain in quartz(qz)/albite matrix showing the complex zoning of Ta-Nb distribution. In these NYF pegmatites the Nb:Ta is typically 15:1 but varies as a irregular patchwork. Lighter areas in the BSE are relatively enriched in the higher Z Ta component.



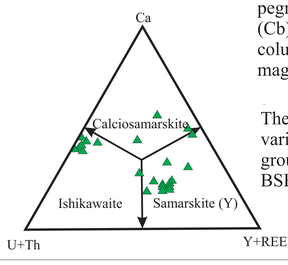






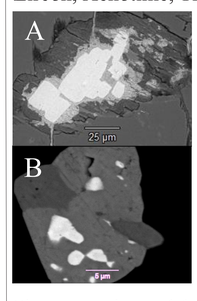
Samarskite commonly shows substantial radiation damage resulting in concentric element distribution as shown in the quantitative EDS maps. A shows a high contrast BSE image, B is the same area in PPL and C shows the same area without fracturing from the thin section processing.

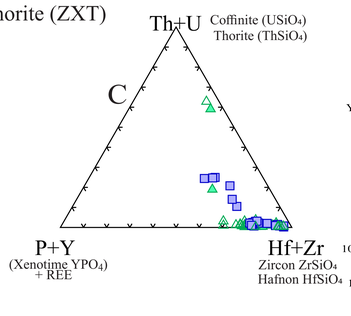
Samarskite and columbite in pegmatites are often late stage or subsolidus phases but in these NYF pegmatites both the samarskite and columbite (Cb) have magmatic signatures and the euhedral columbite in the garnet clusters suggests an early magmatic crystallization history.

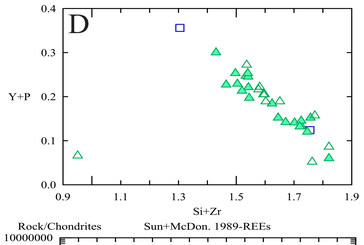


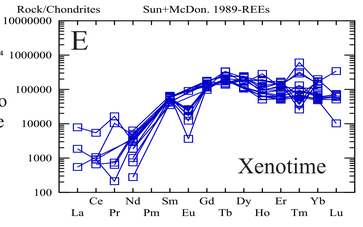
The triplot shows the spectacular chemical variations common in the samarskite group minerals which also shows up in BSE images (A and C).

Zircon, Xenotime, Thorite (ZXT)

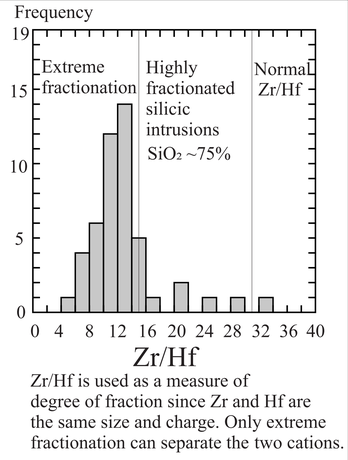








Zircon, xenotime and thorite show complex solid solutions(A) and also complex intergrowths(B). All of the zircons show substantial xenotime substitutions(C and D) as well as solid solution with coffinite and thorite(C). All of the ZXT solid solutions show similar HREE enrichment patterns with pronounced negative Eu anomalies(E).



Zr/Hf is used as a measure of degree of fraction since Zr and Hf are the same size and charge. Only extreme fractionation can separate the two cations.

Conclusions:

1. EC Complex pegmatites belong to the rare NYF classification.
2. Pegmatite mineralogy includes rare minerals and also minerals with novel compositions.
3. Fully understanding the HFS element behaviors will require additional work with an electron microprobe and/or HRTEM

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