Zonation of Titanite from the Notch Peak (Jurassic) and Little Cottonwood (Oligocene) Granites, Utah, Provides Clues to Magmatic and Hydrothermal Histories

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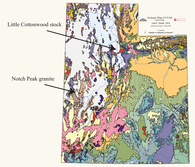
Introduction

Titanite is an accessory mineral in many granites. Due to its incorporation of a wide variety of trace elements, low elemental diffusion rates, and relative abundance, titanite is useful in the study of petrogenetic processes. In addition, titanite also retains clear growth zoning from past events. We sampled titanite from two localities, the Notch Peak Granite located in Western Utah, and the Little Cottonwood stock located near Salt Lake City, Utah in order to evaluate titanite usefullness in interpreting magmatic and hydrothermal histories.

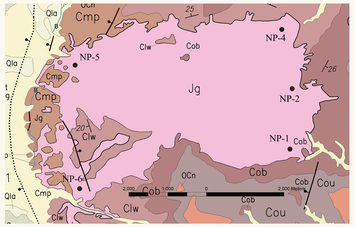
The Notch Peak granite formed in the mid Jurassic (~167 Ma) from a single pluton. It is more chemically evolved than the Little Cottonwood stock. Titanite grains from Notch Peak tend to form simple, euhedral grains with prominent sector and oscillatory zoning (Fig. 2). Some grains exhibit prominent dark zones that contain distinct irregular zonation from a replacement event (Fig. 4). Finally, some titanite grains have been completely replaced by fine grained quartz, ilmenite, magnetite, and rutile (Fig. 8).

The Little Cottonwood granite formed in the early Oligocene (~31 Ma) and is more mafic than Notch Peak. Its titanite grains also display a more complex texture than Notch Peak's. Titanite grains from Little Cottonwood tend to have primary patchy interior zoning with abundant inclusions of apatite and rounded ilmenite, mantled by sector and oscillatory zones (Fig. 3). Anhedral interstitial growth occurs as a secondary process and accompanies dissolution surfaces (Fig. 7). Titanite grains from mafic enclaves found in the Little Cottonwood stock and have unique texture and zonation.

Sample Sites



Notch Peak Granite



Little Cottonwood Stock

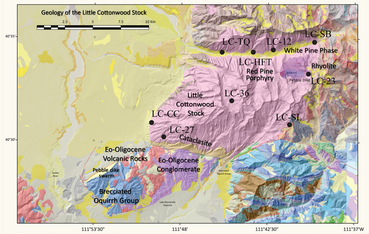


Figure 1. Maps of Notch Peak granite and Little Cottonwood stock. Sample locations are included on map.

Backscattered Electron Titanite Images

Notch Peak

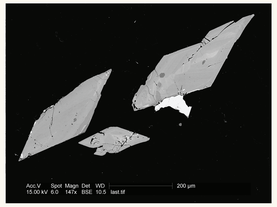


Figure 2. Notch Peak sample Np-1-4. Titanite forms in euhedral wedge-shaped grains which include sector and oscillatory zones. Titanites often have inclusions such as apatite, zircon, and ilmenite.

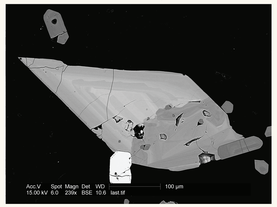


Figure 4. Notch Peak sample Np-6-4. In the Notch Peak, some grains are replaced with less REE rich titanite with its own distinct but less complex zoning pattern.

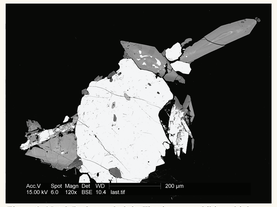


Figure 6. Notch Peak sample 3-2. Titanite may exhibit multiple textures and inclusions. Shown here are rounded ilmenite, oxidized titanite, and magnetite.

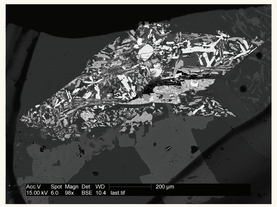


Figure 8. Notch Peak sample 5-6. After crystallization, titanite may be completely replaced by ilmenite, rutile, and magnetite by hydrothermal oxidizing fluid. There is no titanite in this grain.

Little Cottonwood

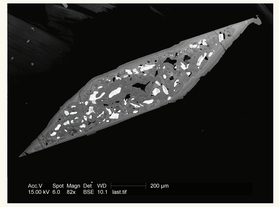


Figure 3. Little Cottonwood sample LC-HFT-1. Little Cottonwood samples often include patchy interiors with rounded ilmenites. Oscillatory zoning often follows with late stage interstitial growth.

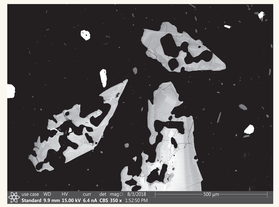


Figure 5. Little Cottonwood mafic enclave sample HFT-18-6-002. The spongy texture suggests that late titanite grew surrounding earlier formed feldspar grains.

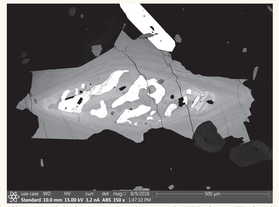


Figure 7. Little Cottonwood enclave sample HFT-18-1-1. The interior of the grain is typical of Little Cottonwood granite. Surrounding the oscillatory growth are late stage overgrowths and interstitial titanite.

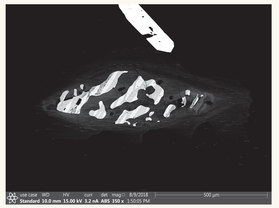


Figure 9. The same grain as figure 7, more contrast is added in electron backscatter imaging to show exsolved ilmenite.

Titanite Compositions

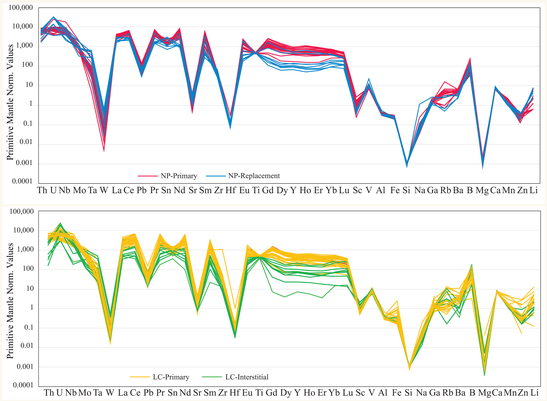


Figure 10. Notch Peak and Little Cottonwood element pattern graphs that include most trace elements and some major elements. Primary titanite tends to have higher concentrations of trace elements with the exception of W, V and U. U contains a strong positive anomaly with a low Th and Nd. A rare earth element pattern diagram can be found in figure 13. Elements are standarized to primitive mantle values.

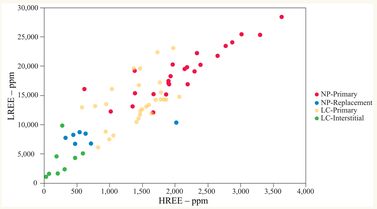


Figure 11. A compositional graph of light rare earths versus heavy rare earths. Primary titanites of both granites have higher rare earths, while secondary crystallization patterns have less. Notch Peak seems to be more differentiated and has more REE's.

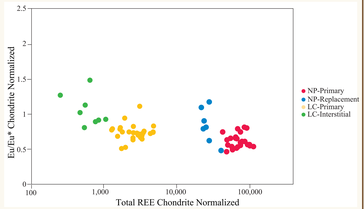


Figure 12. The Eu anomaly compared to Total REE condrite normalized. Secondary crystallization for either granites have either a neutral or positive Eu anomaly. This might be due to post hydrothermal recrystallization. See Figure 13. for REE pattern.

REE patterns

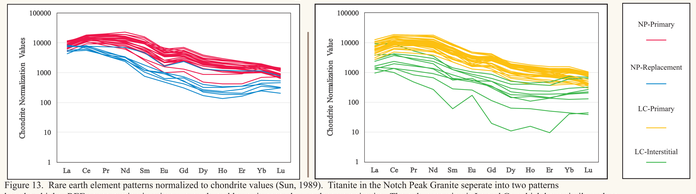


Figure 13. Rare earth element patterns normalized to chondrite values (Sun, 1989). Titanite in the Notch Peak Granite seperate into two patterns based on higher REE concentration in primary growth, and lower in secondary replacement titanite. The only exception is La and Ce, which have similar values. Titanite in Little Cottonwood stock also shows the same separation of REE patterns with late overgrowths and interstitial titanite having lower REE concentrations. Positive Eu anomalies occur in the late overgrowth and interstitial titanite in the secondary titanite in both plutons, which may have come from post magmatic hydrothermal alteration (Fig. 12.) Eu^{+2} may be more soluble than other REE in these hydrothermal fluids, or Eu may have been oxidized to Eu^{+3} making it more compatible.

Titanite Growth Patterns

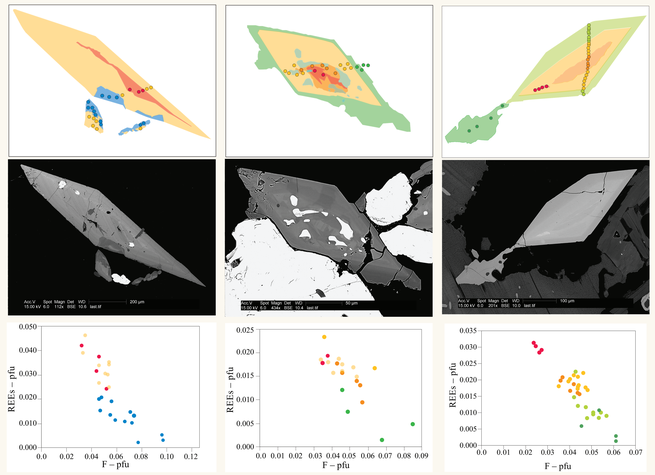


Figure 14. Titanites have been shaded according to proposed growth models, ranging from bright (red) zones in BSE to replaced and interstitial titanite (blue and green). Yellow and orange marks indicate primary titanite that mantles the core. Microprobe analysis are marked in the shaded pictures and F versus REE's have been plotted. Primary titanite located at the core have higher REE's (0.02-0.05 apfu) and lower F (0.02-.05 apfu), while Secondary and replaced titanite have lower REE's (0.01-0.02 apfu) and high F (0.04-0.1 apfu).

Crystallization Paths

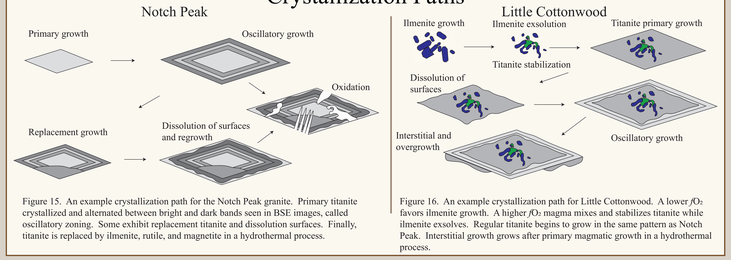


Figure 15. An example crystallization path for the Notch Peak granite. Primary titanite crystallized and alternated between bright and dark bands seen in BSE images, called oscillatory zoning. Some exhibit replacement titanite and dissolution surfaces. Finally, titanite is replaced by ilmenite, rutile, and magnetite in a hydrothermal process.

Figure 16. An example crystallization path for Little Cottonwood. A lower fO_2 favors ilmenite growth. A higher fO_2 magma mixes and stabilizes titanite while ilmenite exsolves. Regular titanite begins to grow in the same pattern as Notch Peak. Interstitial growth grows after primary magmatic growth in a hydrothermal process.

Titanite $^{238}U/^{206}Pb$ Age Probablility Plots

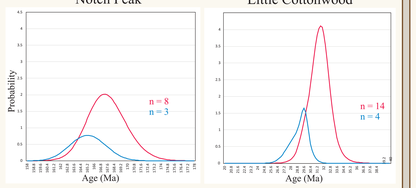


Figure 17. Age probability graphs from $^{238}U/^{206}Pb$ ages in titanite grains from Notch Peak and Little Cottonwood granites. More ages are in process, but this preliminary data set suggests that the secondary titanite in Notch Peak granite and Little Cottonwood stock are about 2-3 Ma younger than primary titanite.

Conclusions

General:

- Primary titanite contains dark and bright sector, oscillatory, and patchy zoning in BSE imaging, with high REE's (0.02-0.05 apfu) and low F (0.02-0.05 apfu)
- Replaced titanite retains its own zonation, has lower REE's (0.01-0.02 apfu) and higher F (0.04-0.1 apfu)
- Replaced and interstitial titanite has a more positive Eu* (0.8-2.0) than primary titanite (0.5-1.1), most likely due to a hydrothermal fluid involvement.

Notch Peak Granite:

- Notch Peak initially crystalized around 167 Ma with a recrystalization event around 165 Ma
- Some samples have been completely replaced by fine-grained quartz, ilmenite, magnetite, and rutile, most likely by a hydrothermal oxidation event.
- Notch Peak's primary and replacement REE patterns are similar, but tend to drop in heavier REE's.

Little Cottonwood Stock:

- Little Cottonwood initially crystallized around 32 Ma in addition to a secondary interstitial event around 29 Ma.
- Resorbed ilmenite indicates a lower fO_2 magma mixed with a higher fO_2 magma causing the dissolution of ilmenite and stabilization of titanite.
- Additional crystallization events may have occured creating resorption surfaces and interstitial growth, similar to Notch Peak.