METASOMATIC MICROTEXTURES AND THE PETROGENESIS OF AMPHIBOLE ASBESTOS

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1. Introduction

Amphiboles exhibit a variety of habits including non-fibrous (e.g. massive, prismatic, acicular) fibrous (asbestiform) morpholoies. Fibrous amphibole is a known health hazard and is classified as asbestos. An understanding of the processes forming, and geologic settings hosting, amphibole asbestos (AA) is necessary to mitigate non-occupational exposure to AA.

It has been understood that prismatic fragments are common, but formation of amphibole asbestos are rare. It has also been discussed that necessity of metamorphic fluids and open space for asbestos minerals to form (Bailey et al., 2004). We interpret AA in fracture-fill veins as the result of primary growth of fibrous amphibole by direct precipitation from hydrothermal fluids, and replacement AA as secondary growth via a grain-scale dissolution-reprecipitation process.

2. Previous Work

Fibrous amphibole (amphibole asbestos) has recently been reported (Buck et al., 2013; Metcalf and Buck, 2015) in two Miocene age plutons along the Nevada-Arizona border near Hoover Dam (Figs. 1-3).

Actinolite asbestos was found in the 13.9 Ma Boulder City pluton (Nevada) and nearby satellite plutons (Figs. 1, 2). Fibrous actinolite is federally regulated asbestos.

Fibrous $NaFe^{3+}$-amphiboles (winchite and magnesio-riebeckite; Figs. 1, 2) are found in the 13.7 Ma Wilson Ridge pluton, Arizona. Fibrous winchite falls outside the regulatory definition of amphibole asbestos but similar in composition and morphology to amphibole asbestos linked to disease at the Libby, Montana EPA Superfund site (Meeker et al., 2003).

Amphibole asbestos in both plutons formed within 2 million years of pluton crystallization by hydrothermal/metasomatic processes active during Basin and Range faulting and uplift.

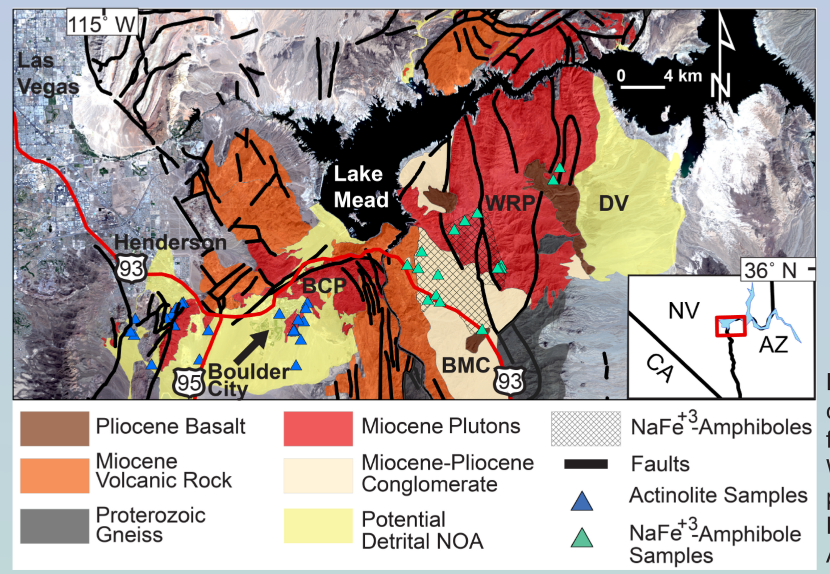


Figure 1: Map that includes location of Boulder City pluton, Wilson Ridge pluton, and found fibrous amphiboles (Buck et al., 2013) WPR- Wilson River pluton; BCP-Boulder City pluton; BMC-Black Mountain conglomerate; DV-Detrital Valley; NV-Nevada; CA-California; AZ-Arizona

Mineral assemblages in actinolite-bearing rocks (quartz, epidote, chlorite, K-feldspar, calcite) are the same as those associated with actinolite asbestos recovered from core in the active Salton Sea geothermal system (Yau et al., 1986), suggesting Na-Ca brines similar to Salton Sea.

Wilson Ridge plutonic rocks associated with $NaFe^{3+}$-amphiboles (+ hematite) exhibit elevated Na2O contents and have undergone significant albitization of plagioclase and quartz. Fibrous $NaFe^{3+}$-amphiboles at Wilson Ridge formed from hypersodic, high-fO_2 hydrothermal fluids (Metcalf and Buck, 2015).

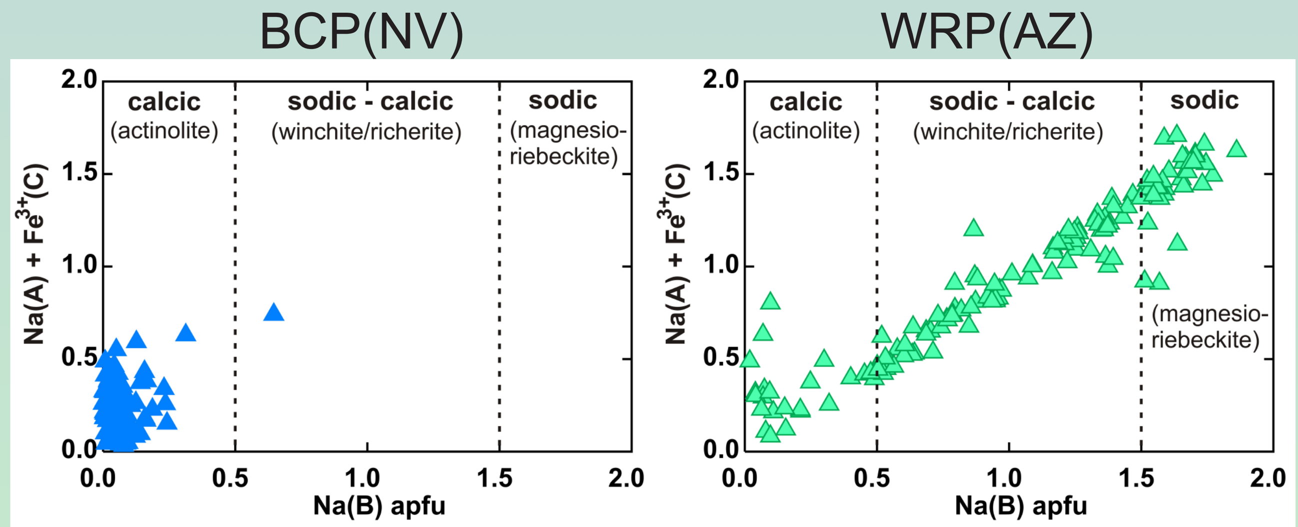


Figure 2: EMPA analysis of asbestos fibers from BCP (left) and WRP (right).

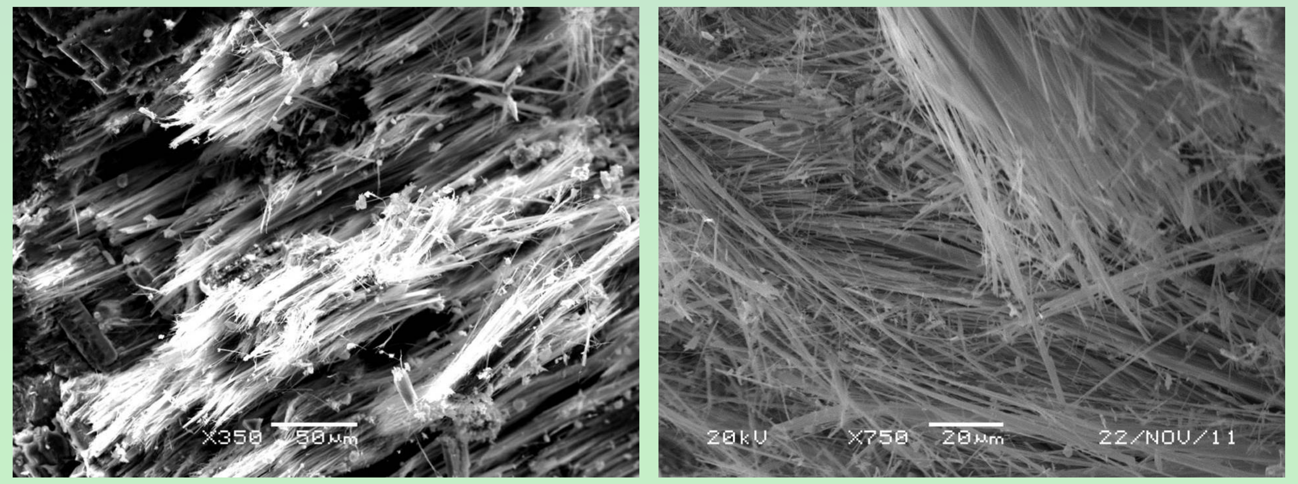


Figure 3: Photomicrograph of analized asbestos fibers from BCP (left) and WRP (right) by SEM.

3. Result

Boulder City Pluton (NV)

pp-plane polarized
cp-ross polarized

Figures 4A-pp, 4B-cp:
Fibrous actinolite (arrows) in monomineralic fracture fill vein cutting altered granitic rock; sample MR2a, McCullough Range, NV.

1) Mats of fibers in monomineralic fracture fill veins

Figures 4B-pp, 4B-cp:
Fibrous actinolite (arrows) in monomineralic fracture fill vein cutting altered granitic rock; sample MR415-1, McCullough Range, NV.

Figures 5A-pp, 5A-cp:
Vein cutting altered granitic rock (plg = altered plagioclase) with intergrown epidote (epd) and fibrous actinolite (arrows), sample Adams2, Boulder City, NV.

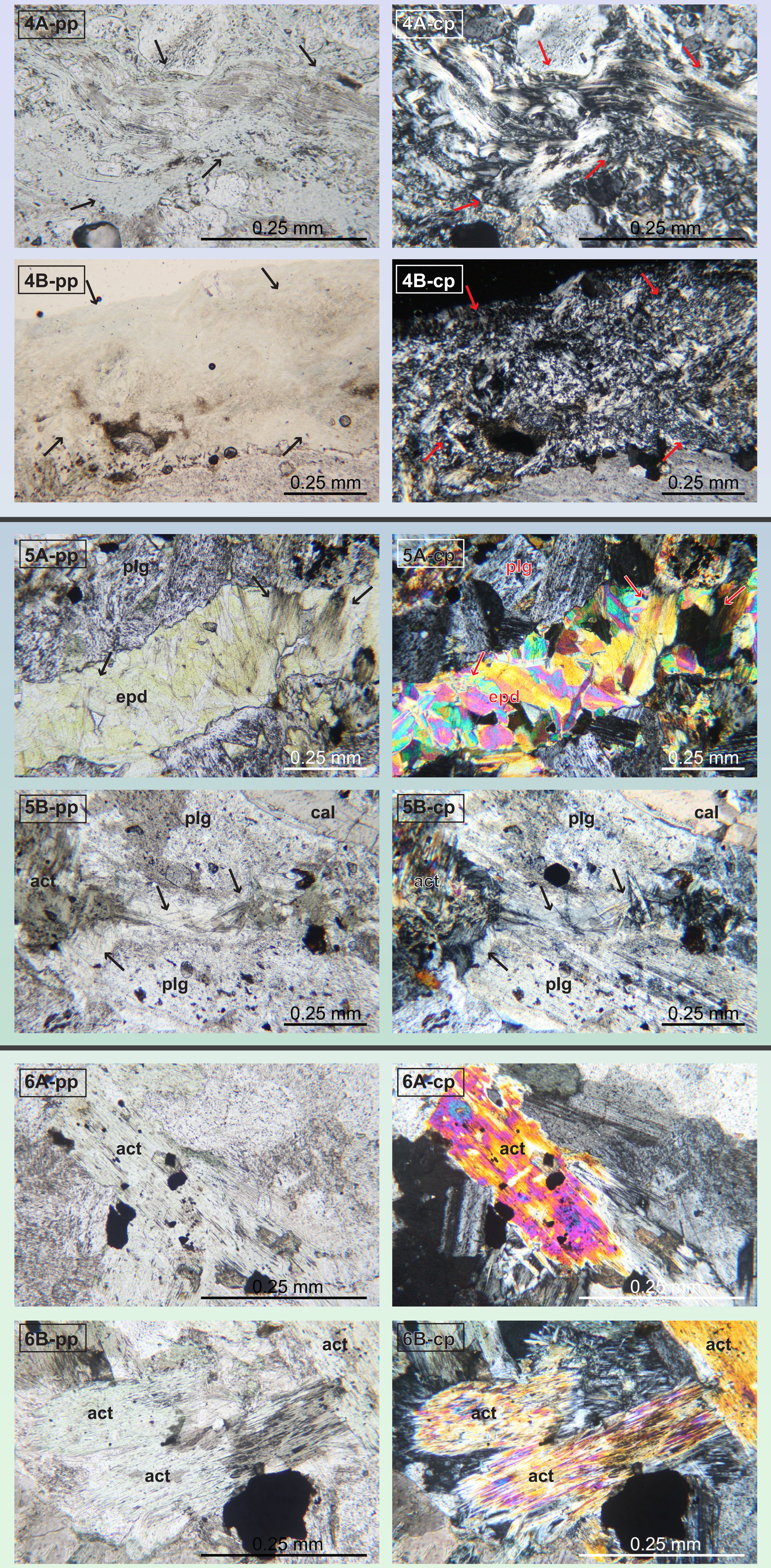
2) Splayed bundles and cross-fibers intergrown with other minerals in -polymineralic fracture-fill veins

Figures 5B-pp, 5B-cp:
Vein of secondary plagioclase (albite) intergrown with fibrous actinolite (arrows) cutting altered (turbid) plagioclase; sample MR2c, McCullough Range, NV.
(act = actinolite, cal = calcite, plg = altered plagioclase)

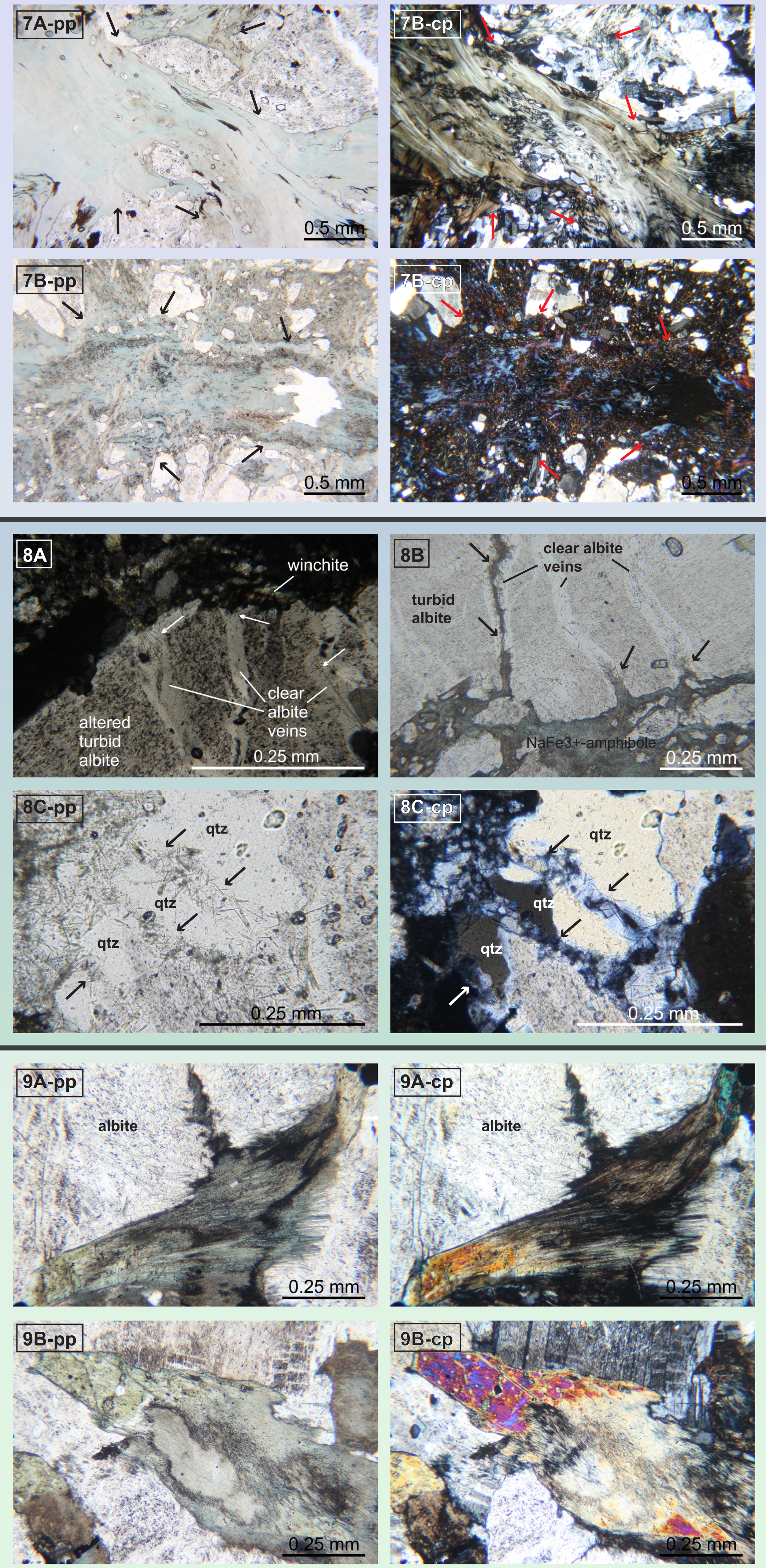
Figures 6A-pp, 6A-cp:
Fibrous actinolite pseudomorph (replacement) after primary magmatic magnesio-hornblende within altered granitic rock; sample MR2a, McCullough Range, NV.
(act = actinolite)

3) Secondary replacement of magmatic amphibole

Figures 6B-pp, 6B-cp:
Fibrous actinolite pseudomorph (replacement) after primary magmatic magnesio-hornblende within altered granitic rock; sample MR2c, McCullough Range, NV.
(act = actinolite)



Wilson Ridge Pluton (AZ)



pp-plane polarized
cp-ross polarized

Figures 7A-pp, 7A-cp:
Fibrous NaFe3+-amphibole (arrows) in monomineralic fracture fill veins cutting altered granitic rock, sample DP-1, Horsethief Canyon, AZ.

1) Mats of fibers in monomineralic fracture fill veins

Figures 7B-pp, 7B-cp:
Fibrous NaFe3+-amphibole (arrows) in monomineralic fracture fill veins cutting altered granitic rock, sample KW4-24-5a, Kingman wash, AZ.

Figure 8A:
Clear albite veins intergrown with winchite fibers (arrows) cutting altered plagioclase (turbid albite) in altered granitic rock, plane polarized, sample HT794-4a, Horsethief Canyon, AZ.

Figure 8B:
Clear albite veins intergrown with winchite fibers (arrows) cutting altered plagioclase (turbide albite) adjacent to fracture fill vein of NaFe3+-amphibole, plane polarized, sample HT794-4a, Horsethief Canyon, AZ.

Figures 8C-pp, 8C-cp:
NaFe3+-amphibole fibers (arrows) intergrown with albite grains in a vein cutting through quartz (qtz); sample KW3-18/5B, Kingman Wash, AZ.

Figures 9A-pp, 9A-cp:
Fibrous NaFe3+-amphibole partially pseudomorphing primary magmatic magnesio-hornblende surrounded by altered plagioclase (albite). Fibrous amphibole is intergrown with albite at the right edge of the amphibole pseudomorph, sample WR-1A, White Rock Canyon, AZ.

3) Secondary replacement of magmatic amphibole

Figures 9B-pp, 9B-cp:
Fibrous NaFe3+-amphibole partially pseudomorphing primary magmatic magnesio-hornblende within altered granitic rock, sample WR-1A, White Rock Canyon, AZ.

4. Discussion

We interpret AA in fracture-fill veins (both mono- and poly-mineralic) as the result of primary growth of fibrous amphibole by direct precipitation from ions in the hydrothermal fluids. Such open fracture primary growth is thought to be required to produce fibrous morphology in amphibole, and has been used to argue that amphibole asbestos is rare in the geologic record.

In contrast, amphibole asbestos pseudomorphs of original magmatic hornblende result from metasomatic processes of grain-scale dissolution-reprecipitation. We used EPMA data collected from partially replaced magmatic Mg-hornblende to evaluate the ionic composition of hydrothermal fluids attending the growth of the secondary magnesio-riebeckite at Wilson Ridge. The results (Fig 10) demonstrate that secondary reactions consumed Si^{4+}, Fe^{3+}, and Na^{1+} from the fluid, and released Ca^{2+}, Mg^{2+}, Fe^{2+}, Al^{3+}, and Ti^{4+} to the fluid. This process drove the fluid to super-saturation with respect magnesio-riebeckite resulting in fluids capable of direct precipitation of fibrous magnesio-riebeckite in fracture fill veins.

magnesiohornblende → magnesioriebeckite (WR-1A-a2-1 → 2)

$$(K_{0.1}Na_{0.3})(Na_{0.16}Ca_{1.7}Fe^{2+}_{0.09}Mn_{0.07})(Mg_{3.02}Fe^{2+}_{1.4}Fe^{3+}_{0.39}Ti_{0.12}Al_{0.07})(Al_{0.98}Si_{7.02})O_{22}(OH)_2 + 0.94\cdot Si^{4+}_{aq} + 0.64\cdot Fe^{3+}_{aq} + 1.6\cdot Na^{+}_{aq}$$
$$\rightarrow$$
$$(K_{0.01}Na_{0.46})(Na_{1.55}Ca_{0.25}Fe^{2+}_{0.21})(Mg_{2.82}Fe^{2+}_{1.09}Fe^{3+}_{1.03}Ti_{0.03}Al_{0.04})(Al_{0.04}Si_{7.96})O_{22}(OH)_2 + 0.97\cdot Al^{3+}_{aq} + 0.09\cdot Ti^{4+}_{aq} + 0.21\cdot Mg^{2+}_{aq} + 0.19\cdot Fe^{2+}_{aq} + 0.07\cdot Mn^{2+}_{aq} + 1.44\cdot Ca^{2+}_{aq} + 0.1\cdot K^{+}_{aq}$$

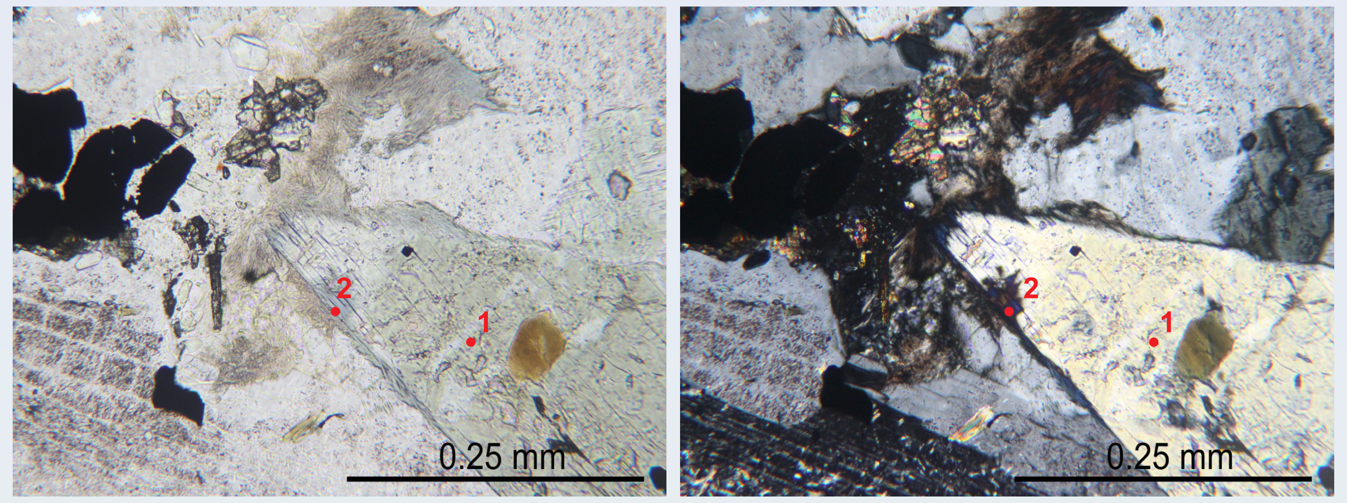


Figure 10: Balanced chemical formula from one amphibole grain based on microprobe analysis (Left) plane polarized (right) cross polarized.

In a companion study (Metcalf et al, 2016), micro-sampling and SEM imaging of Wilson Ridge winchite/ magnesio-riebeckite was used to the compare the fiber morphology of primary and secondary AA (Figure 11). Morphology in terms of length (L), width (W), and aspect ratio (AR) of primary (L = 17.5 microns, W = 0.7 microns, AR = 22.4) and secondary (L = 13 microns, W = 0.8 microns, AR = 15.1) are comparable.

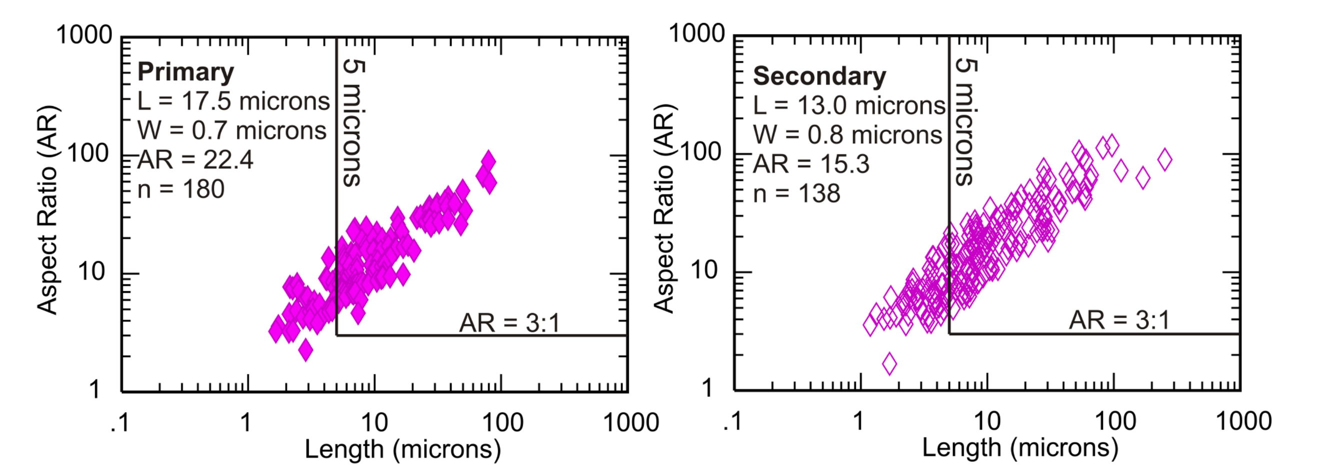


Figure 11: Morphology comparison of primary (left) and secondary (right) AA sampled from Wilson Ridge Pluton, AZ.

5. Conclusion

These results suggest that
(1) Both primary and secondary growth processes can produce AA.

(2) Fibrous habit in amphibole is largely independent of amphibole composition.

(3) Any hydrothermally altered amphibole-bearing igneous rock may be a source of amphibole asbestos.

6. References

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