Ancient records of mountain building in the New England 'Big Garnet' Schist

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Over 260 million years ago, Africa, part of the continent Gondwana, collided with North America and Europe, creating the supercontinent known as Pangaea. This mountain building event, or orogeny, formed what is known as the Appalachian Mountains. This mountain chain has since been eroded down to its deep crustal levels, allowing us an insight into the processes that occurred at depth, such as ductile deformation and metamorphic mineral growth.

In the forests of western Massachusetts, sparse outcrops of rocks record the compression and burial of ancient mudstone to depths of around 25-30km (7-8kbar). This unit, known as the Hoosac formation extends from Vermont, in the north, down to Connecticut in the south. The mudstone was deposited around 500 million years ago and has since been subject to two deformation events within the Appalachian orogeny.

These rocks contain the metamorphic mineral garnet, which grew in response to increasing temperatures and pressures. Garnets are excellent recorders of the geological histories of rocks because they can trap small crystals of other minerals as they grow, preserving the combination of minerals present at different points during the crystallisation of the rock. Garnets change composition as they grow, reflecting the temperature and pressure of their surroundings. These changes are recorded as concentric zones seen within the mineral. It is for these reasons that garnets are a useful tool for interpreting the geological history of a deformed region.

The garnets of the Hoosac Schist are particularly interesting because they show distinct core and rim compositions, indicating that a change in conditions occurred during garnet growth. It has been hypothesised that the core and the rims of the garnets grew in response to two different metamorphic events, separated in time by millions of years. It is this hypothesis that I aim to refute, by determining if I can describe the growth of the garnet by one pressure-temperature path created by a single tectonic collision.

In order to extract information from these rocks, I made thin sections and studied them under the optical microscope. This allowed me to identify the minerals present in the samples, and determine which order they grew in and when they grew relative to the deformation of the rock. I measured the mineral chemistry using a Scanning Electron Microscope, to look at the change in major elements such as iron, magnesium, calcium and manganese across the core-rim boundary within the garnet. The core-rim boundary and the major element profiles are illustrated in figure 1 from low temperature (garnet zone) to high temperature (kyanite zone).

I found that the mineral inclusions present in the garnet cores, are very different from those found in the garnet rims, indicating a change in conditions during growth. This change occurred over what seems to be a very sharp boundary, where the pattern of minerals in the core is very different to the pattern in the rim. But, by looking at the presence of chemical elements in the garnets, although there is a change in composition from the core to the rim, it is a gradual one. This would suggest that the garnet was not formed in two separate events but instead, in a singular, continuous one.

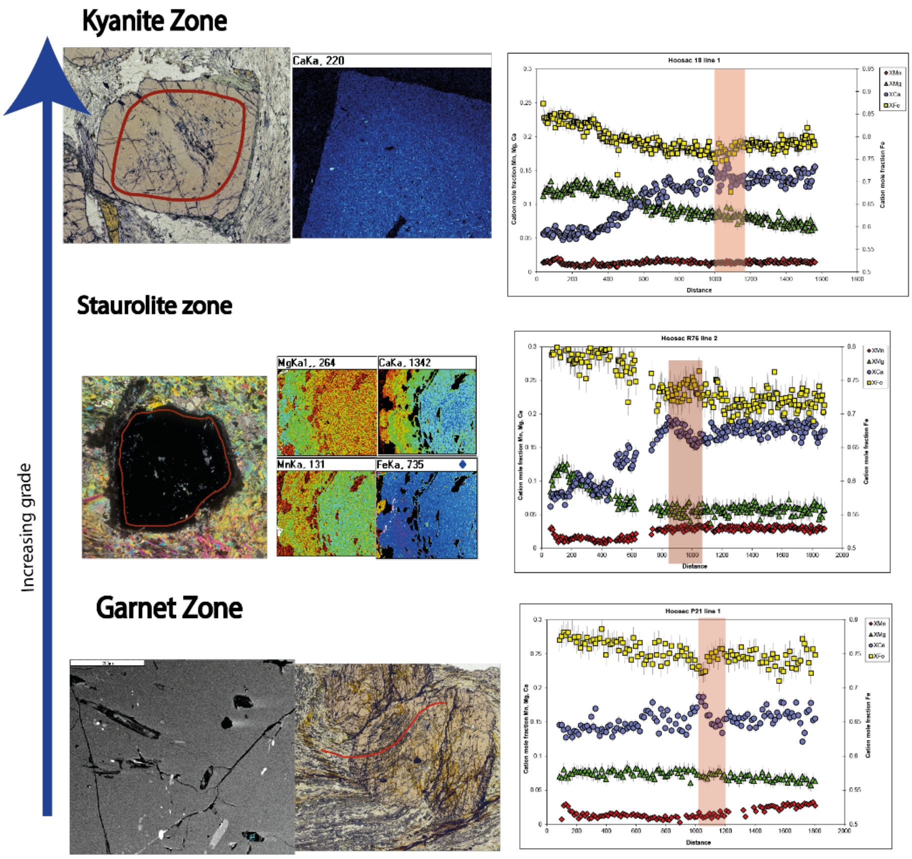

Figure 1 Photos of rock thin sections showing a large garnet in 3 samples of increasing pressure and temperatures (garnet zone to kyanite zone). The core to rim boundary is marked by a red line on the garnets, with major element maps showing the change in garnet compositions from core to rim. The major element profile is taken from core (right) to rim (left) and shows the chemical change becoming more pronounced with increasing pressure and temperature.

By studying these garnets, I have been able to describe the characteristics of their growth and estimate the maximum depth and temperature that the rocks were taken to. I attempted to model the evolutionary history of these rocks by mapping out the expected combinations of minerals which would be present during the deformation of a mudstone at different pressure and temperature conditions. This allowed me to identify the conditions of garnet core growth and garnet rim growth, describing a growth history over which different mineral reactions took place. My results showed me that the measured garnet compositions in the core and the rim, would have grown during the period of accelerated garnet growth (highlighted in figure 2), where a large proportion of the garnet grew over a small temperature range. This growth occurred at around 4-6kbar (14-21km) and 530-570°C.

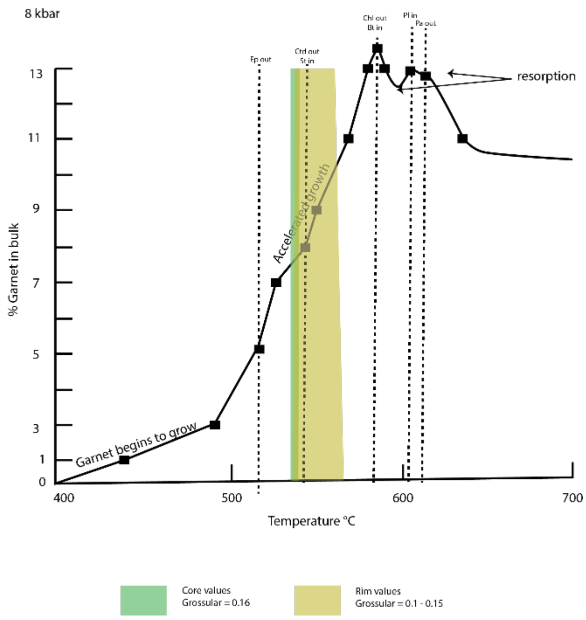

Figure 2 Profile of garnet growth with increasing temperature. Coloured bands show garnet core and rim growth which both occur during accelerated garnet growth.

Combining the results of the observations of the rocks and the predicted models, allows us to draw interpretations as to how these garnets grew and the geological history of the rock. The gradual change in garnet compositions and the fact that they correspond to a period of predicted, accelerated garnet growth, suggests that the garnets formed during a single continuous mountain-building event rather than two separate collisions.

Using this information furthers our understanding of the evolution of the crust, plate tectonics and processes occurring deep in the crust during mountain building. This may provide us with an analogue as to what is happening beneath active mountain belts, such as the Himalayas, today.