The magnitude of crustal shortening/thickening in the Sevier hinterland is inconsistent with the back-arc origin.

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1 Introduction

As presented by Hildebrand in his 2013 and 2009 works, a key argument against the conventional "back-arc" model relies on the geodynamic constraints on the development of the Sevier hinterland [8] [9]. Generally, there are two models of interest (the traditional "back-arc" model [4] and Hildebrand's "Rubia" model [8]) regarding the Sevier hinterland and how its development relates to the Cordilleran orogeny. Regardless of differences in the two models, they both in some way hang a hat on the timing and the quantity of crustal thickening and shortening as evidence for their respective orogenic processes. Observational constraints on Late Cretaceous and early Tertiary thickness of the Sevier hinterland will be pivotal when attempting to argue for or against either model. In this paper we attempt to assess the magnitude of crustal shortening and thickening in the Sevier hinterland.

The Sevier hinterland is widely regarded as a high-elevation, low-relief orogenic plateau that formed in the Late Cretaceous to Paleogene [7] [12]. It is commonly split into the western, central, and eastern regions which have distinct lithologic compositions and deformational histories [2] [6]. The western region of the Sevier hinterland is comprised of extensive metasedimentary units and deformed Precambrian basement rocks [4]. The central region consists dominantly of the Willard thrust sheet and the eastern region is mainly metamorphosed, imbricated thrust sheets.

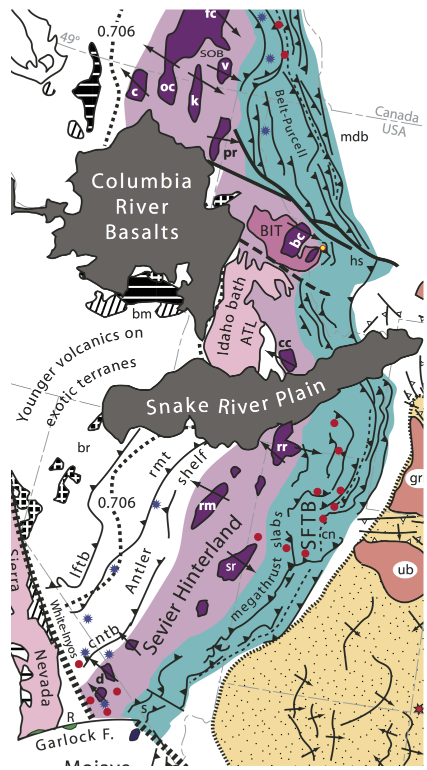

Figure 1: Location of Sevier hinterland from Hildebrand 2009 [8].

2 Origin and Robustness of 30km of Thickening

Within the western region of the Sevier hinterland, workers have estimated that there was at least 30 km of crustal thickening and 70 km of shortening along the inferred "Windermere thrust" [2] by the end of the Late Cretaceous. This 30 km of crustal thickening reported in Camilleri and Chamberlain (1997) is the specific value Hildebrand cites in his 2009 paper so it's worth examining the study in more detail [8].

Camilleri and Chamberlain (1997) base their thickening estimates largely on detailed geologic and metamorphic mapping and thin section analysis in the Woods Hills and Pequop Mountains. By integrating their data with previous studies of the nearby Ruby Mountains they were able to create a series of detailed structural (Figure 2) and metamorphic reconstructed cross sections in northeast Nevada. By observing repetitions in stratigraphic sections as well as extensive unexplained metamorphism, they inferred the existence of the Windermere thrust fault.

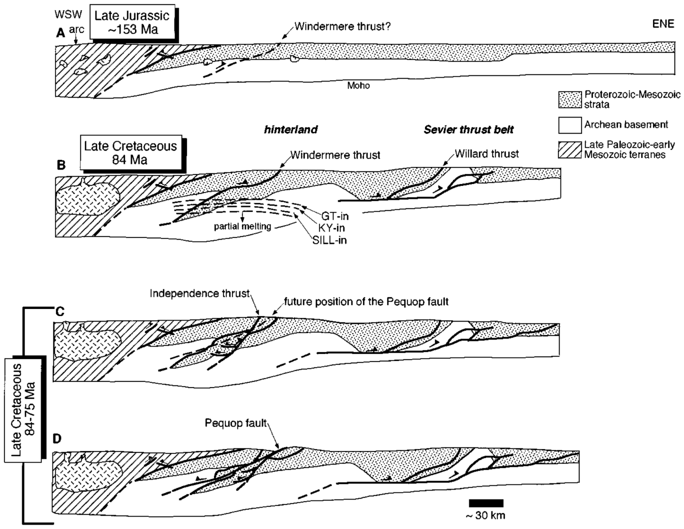

Figure 2: Schematic reconstruction of Sevier orogen from Camilleri and Chamberlain 1997 [2].

A major aspect of their analysis was determining the pressure-temperature (P-T) paths by examining the metamorphic facies in over 200 thin sections from the inferred footwall of the Windermere fault. These P-T paths showed regional trends in metamorphic grades (an increase in metamorphic grade to the north-west) and when combined with structural evidence, were inferred to be clockwise paths (increasing pressure dominating metamorphic onset). These paths, in conjunction with U-Pb thermal histories, indicate contraction and burial culminating until peak metamorphic conditions were reached at 84 Ma. The peak pressure conditions are converted to paleo burial depths to determine an estimate of 30km of crustal thickening. After peak metamorphism, the thermal histories indicate moderate cooling rates and contractional deformation ending completely by 75 Ma.

U-Pb dating was also used to place an upper limit on the age of metamorphism. By determining the crystallization age of a deformed igneous intrusion, Camilleri and Chamberlain (1997) determined that the Windermere fault did not form prior to 154 Ma. The authors of this paper emphasize that although it's likely that that the onset of shortening and crustal thickening occurred shortly before the time of peak metamorphism, the onset timing is poorly constrained in the region and may have started as early as the Late Jurassic. The phrasing in Hildebrand's 2009 paper slightly mis-represents the timing of crustal thickening reported in this paper by referring to it as a "Late Cretaceous...contractional pulse." This is worth noting because Hildebrand's collisional hypothesis is largely dependent on timing correlations of various tectonic events. In his model, the "pulse" of deformation in the hinterland coincides with the collision of Rubia and North America as seen in Figure 3. However, the Camilleri and Chamberlain (1997) study as well as others [1] [5] present evidence of Late Jurassic contractional deformation. DeCelles (2004) has suggested a 100 Ma period of contraction beginning in the Late Jurassic as seen in Figure 4. While poorly constrained dates do not support any hypothesis, both Hildebrand's and DeCelles' models are contingent on a specific start time to contractional deformation in the hinterland.

Timing issues aside, the 30 km of Late Cretaceous crustal thickening in the Sevier hinterland concluded by Camilleri and Chamberlain (1997) is a convincing figure. The authors utilize sizable data sets, employ rigorous methods, avoid over interpreting the data, and compare their results with thickness estimates obtained by a variety of methods.

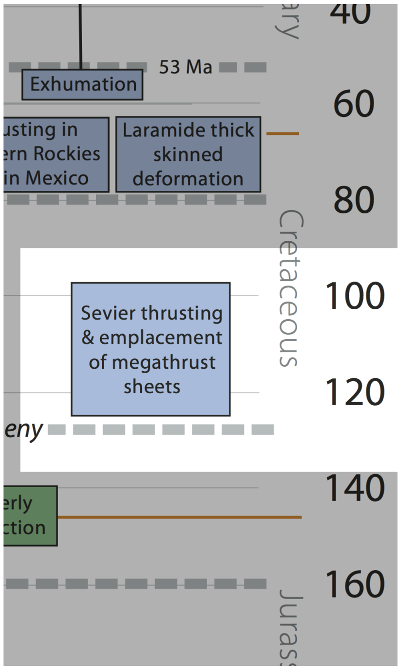

Figure 3: Adapted from Hildebrand (2013), timeline displaying important events in Hildebrand's collisional model, highlighted to show onset of hinterland deformation. [9]

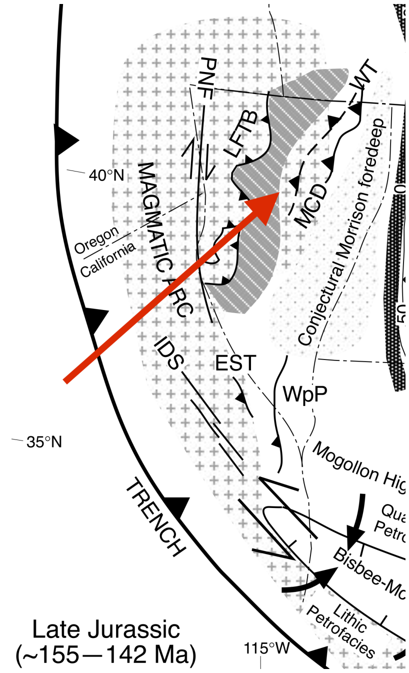

Figure 4: Adapted from DeCelles (2004), hypothesized palinspastic Late Jurassic reconstruction, arrow points to location of Windermere fault, which may not be active until later time. [4]

3 Additional Constraints on Early Tertiary thickness

The declaration of a definitive estimate for the crustal thickness during the early Tertiary is hindered by the complexity and variability of the Sevier hinterland and, therefore, it is still a subject of considerable interest. Numerous workers have attempted to approximate crustal thickness using a wide range of techniques such as structural reconstructions [5], peak Barrovian metamorphism estimates [2] [10] [14] [16], and Sr/Y analysis [3]. From these various approaches, reasonable upper and lower limits have been developed, which will help to better constrain the total crustal thickening.

An over-estimated high end-member crustal thickness can be determined by the apparent lack of garnet in eastern Mojavian xenoliths. Garnet-rich xenoliths have been found in other regions further east, such as in the Colorado Plateau, but the lack of garnets in the Pliocene basalts in the Sevier hinterland indicates crustal thicknesses of less than 90km [11] [15]. Chapman et al. (2015) report crustal thickness estimates for middle Cretaceous to mid-Eocene of 55-65 km by using Sr/Y from intermediate continental arc magmas compared to global compilation data sets [3]. Sr/Y is a common proxy for crustal pressure, which is indicative of depth, because Sr/Y ratios show a strong linear relationship with increased pressure [3]. These crustal thickness and timing estimates generally agree with other estimations based on peak Barrovian metamorphism [2] [14] [15] structural reconstructions [5], and paleoaltimetry estimates [13].

The Late Cretaceous to early Tertiary crustal thickness has been estimated to be 50-60 km by a variety of methods, as cited by Hildebrand (2009, 2013). However, the second part of his claim, that this is too thick for a back-arc model, would require additional investigation. It would be interesting to examine the literature for back-arc analogs to compare crustal thicknesses to those estimated for the Late Cretaceous in the Sevier hinterland.

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