The ∼120-80 Ma magmatism along the Mesozoic arc is far more voluminous than would be expected for a typical arc.

Are these volumes higher than earlier in the Mesozoic?

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1 Introduction

The apparent increase in average magmatic flux (AMF) in western North America during the Late Cretaceous is not only an important line of evidence for Hildebrand's collision hypothesis of the North American Cordillera [7], it is also a phenomenon that has been observed and interpreted in other workers' models of tectonic plate behavior and Cordilleran orogenic processes [3]. While plots of AMF (or similar quantities) such as those shown in Figure 1 display evidence for both an increase in magma volume in the Late Cretaceous as well as a cyclic pattern of magma production and lulls, important consideration should be given to the origins of these types of plots. Not only are there substantial assumptions made to calculate these figures [6], but there is also an inherent underrepresentation of the volumes of older plutons. This is due to possible erosion of plutonic bodies as well as interactions between new magma pulses with pre-existing crustal material [11]. These and other factors may have profound effects on the strength of APF calculations as evidence for Hildebrand's collisional theory as well as other orogenesis models.

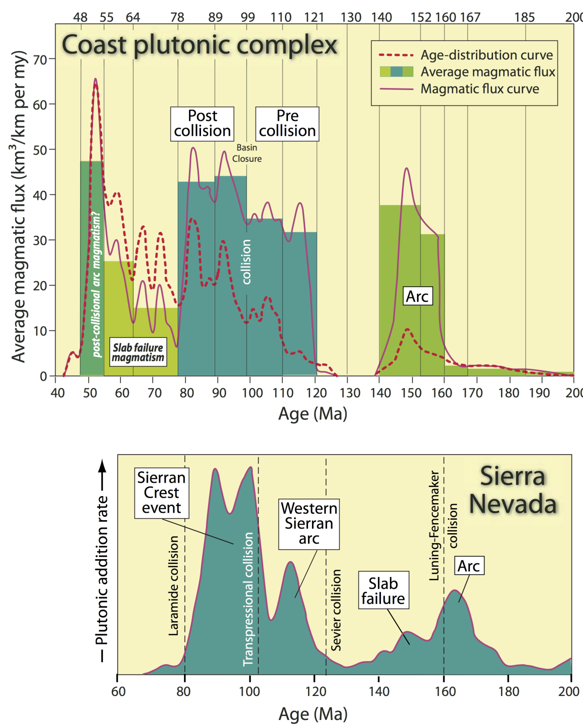

Figure 1: Average magmatic flux of the Coast plutonic complex and average plutonic addition rate for the Sierra Nevada batholith plotted against age. Figure used in Hildebrand 2013 [8].

2 Calculation Methods

Like many geologic statistics, there is some inconsistency in methods of calculation as well as terminology used to describe magmatic flux. The estimated volume of new plutonic rocks (based on areal distributions and inferred thicknesses) that have been created in the crust over a given duration of time, normalized to the inferred strike length of the magmatic arc, is typically referred to as "average" or "apparent" magmatic flux (AMF) [3] [6] or apparent intrusive rate, terms which will be considered equivalent in this paper. Some workers have defined related terms such as magma addition rate (MAR) [11] which is essentially the same quantity as AMF without being normalized to strike length. Magma production rate (MPR) has also been defined in the literature [11] and accounts for the total amount of magma produced in an area during a given time period. MPR includes magmatic material that is no longer present in the crust and both volcanic and plutonic magma products. In general, each of these quantities requires a method to estimate the volume of magma produced in a given area during a specified period of time.

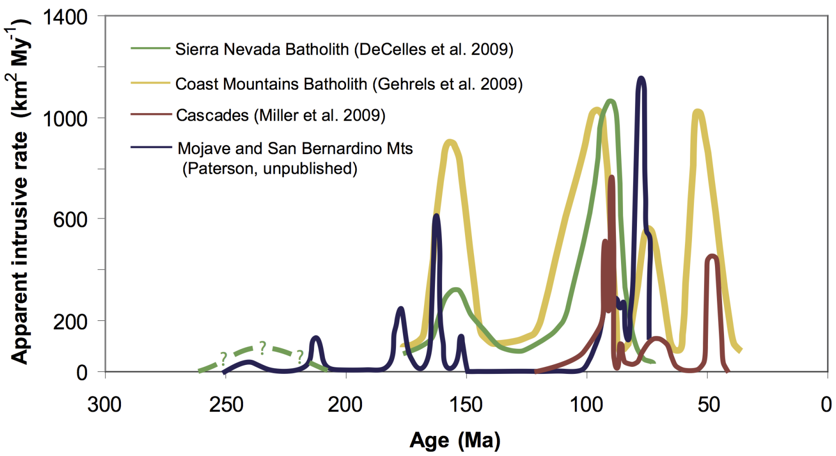

Figure 2: Apparent intrusive rates (AMF) for several North American Cordillera plutonic bodies plotted against age. Displays AMFs calculated from the same raw data that was used to create the plots in Figure 1. Figure from Ducea 2015 [5].

Determining the volume of plutonic rocks in an area requires two key assumptions. First, that the areal distribution of plutonic rocks on the surface can be used to accurately determine the cross sectional areas of plutons, and second, that the thickness of the plutons can be reasonably determined. Areal distributions are largely determined by geologic mapping [11], whereas plutonic thickness maybe determined by a variety of methods. In locations where the plutonic bodies have been significantly exhumed, plutonic geometry and shape can be constrained by surface topography [10]. In other areas, seismic data is used to estimate thickness [4]. Often published plutonic thicknesses for one batholith are used in other analogous studies [6].

Reliable and well sampled radiometric dates are needed to reasonably constrain the ages and durations of magmatic activity in AMF calculations. Radiometric crystallization ages for a large, well sampled selection of plutonic rocks are used to create an age distribution profile for a given area. The plutonic volume estimate is then proportionately associated with the age distribution profile [6]. Mineralogy, compositional analysis, and thorough sampling techniques can be used to correlate contemporaneously crystallizing plutons, however there is a large degree of uncertainty in the assumption that the dated samples accurately represent the age distribution for the entire pluton.

3 Are 120-80 Ma magmatic volumes higher than earlier in the Mesozoic?

Figure 2 shows the AMF for several batholiths in the North American Cordillera. The APF of the Coast and Sierra Nevada are calculated from the same data as the plots in Figure 1. At first glance, there does seem to be a general increase in AMF for several regions in the Cordillera, as claimed by Hildebrand.

However, the aforementioned methods for calculating AMF introduce uncertainty in AMF values which should be considered when using these statistics as supporting evidence for any hypothesis. Some workers have asserted that plots such as those in Figures 1 and 2 should only be interpreted for the timing of magma pulses rather than absolute, or even relative magnitude of volume [6].

In particular, there is a significant limitation in determining the AMF magnitudes of older plutonic bodies. This limitation is particularly relevant to Hildebrand's interpretation. First, it is reasonable to assume that as time passes, the likelihood of a pluton being eroded, deformed or otherwise reduced in volume increases. Second, there has been a fair amount of geochemical evidence that indicate younger magmatic intrusions will incorporate older crustal material, potentially absorbing older plutons and destroying the spatial evidence of their volumes at inception [12]. While some workers have attempted to address degradation of plutonic volumes producing calculations of MPR rather than AMF [9], these types of in depth studies are geographically limited and often focus on younger, better preserved plutonic bodies. The data presented and cited by Hildebrand are all plots of APF which, all else considered equal, are almost guaranteed to illustrate an increase of AMF over time.

In general, the literature on AMF in the North American Cordillera would benefit from some additional data sets and more modern calculations before magnitudes of AMF should be considered strong evidence in any hypothesis. Many studies, particularly in the Sierra Nevada are citing and re-citing values derived from rather old collections of volume estimates and radiometric dates [1] [2].

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