Bulletin: *Apples to Oranges --A study of the distribution contours of age- and timing-unrelated volcanics throughout the world, a useful comparative technique*

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<u>Abstract:</u> Volcanic centers are subject to many rate-driving factors controlled by large scale regional processes that regulate the frequency distribution and total volumes of eruptions. This leads to widespread disparities from center to center among similar chemical species. In order to simultaneously compare volcanoes throughout the world, this study seeks to normalize functional space such that physical and chemical properties of differing lavas can be assessed. This is easily and quickly achieved by rationalizing the total lifespan of individual vents to a common unit by equating the most recent eruption to time=1 and least recent eruption in consideration to time=0, and then plotting the relationships between any desired quantifiable variable in the system against it. This case study optimizes K2O, Nd and Sr concentrations of the respective deposits in 4 world-wide localities to their positions in the scalar time space. The high fluid-mobility of potassium allows K2O concentrations to serve as proxy for the relative degree of fluid influx into the magmatic reservoir; similarly, Nd is fluid-immobile and can indicate degrees of crustal assimilation, while the input of enriched mantle material can be tracked with variation in Sr concentrations. Case studies containing legacy data and data obtained by the team at U. Canterbury in 2010 provide the sample space, from which we examine: Barren Crater, Adaman Sea, Nevado Solimana, Peru, Ngauruhoe, New Zealand (from original field work) and the Kusdach volcanic massif in Kamchatka. This study broadens volcanic knowledge by offering correlatives among similar individuals and may aid hazards considerations by highlighting eruptive timing with physiochemical processes. With considerable fine-tuning the method described herein may offer future insight into the intervals of eruption expected at volcanoes, leading to predictive capabilities.

Introduction

Given the widely disparate nature in timing, extent and longevity of volcanic episodes and vents, it makes little sense to make direct comparisons from example to example around the world because the periodic contour of each becomes distorted. Instead, the physical processes have come to serve as the discriminating characteristics for classification, such as eruptive vigor and subaerial emplacement modalities. However, as much as volcanoes of similar chemical fingerprints differ from one to the next as a function of factors like the shape and extent of the magmatic chamber, overlying lithology, and rate of magmatic inflow, many of the aspects in the system remain congruent from one example to the next, and so may be compared despite periodicity discrepancies. Certain variables within the volcanic model are driven more by physical law than are subject to regionally-related variation, such as *d*viscosity and *d*temperature. The result is that many of the rates, the relationships between physical parameters such as shear modulus and elasticity to time, are similar enough in temporally-differentiated but chemically related magmas that natural constraints (overburden, country rock lithology, crustal temperature, etc.) proportionately relate to one another. Some of the strongest correlations among basaltic centers relate simply to nearly ubiquitous mid-depth seismicity (Dickinson et al, 1967) and so the significance of many measureable aspects in deposits decreases with respect to the whole system.

Five volcanic individuals are compared herein. Wide geologic overview will prepare the examination.

Barren Island consists of a horse-shoe crater in the Adaman Sea formed by sector collapse of the main crater structure with an internal cinder cone built of historic basaltic-andesite volcanism. The cone itself is the result of a narrow spectrum of basaltic-andesite effusive volcanic activities and related scoria and tuff fall deposits, though the latter to a much lesser extent (Chandrasekharam et al, 2009). The majority of the exposed volume of the island has formed within modern times, and so its interval begins in 1803 and ends with the last eruption in 2005.

Nevado Solimana experienced early andesite / desite magmatics, though moved into basaltic-andesite composition early in its eruptive history (Vatin-Pérignon et al, 1991). Dating of flow events, with disregard to ignimbrites, was attained through K-Ar dating of plagioclase phenocrysts and places this vent's activity between 10.6+/-1.2 Ma and 3.5+/-0.78 Ma. The region has since been weathered and is beginning to display prominent regional diking emanating from the vent structure.

Kursdach massif in Kamchatka is marked by distinct carbon-rich layers within the deposit stratigraphy. Dates of events are attained with radiocarbon dating of these organic-rich marker beds within the stratigraphy of the massif providing a rougher indication of the dates of the related basaltic-andesite flows (Volynets et al, 1999). However, the accuracy of this chronology will still prove largely effective in communicating similarities among the volcanoes used here. The massif itself consists of 2-pyroxene basaltic-andesite to rhyodacite lavas with related tuff and was constructed by caldera-forming eruptions throughout the Holocene until 240 AD. The eldest organic C14 marker beds date to an average 6,300 years old and rests on top of the basal deposit, and so that deposit was placed arbitrarily at 10,000 years old. The most recent deposit was dated by K/Ar ratios at 240 AD (Volynets et al., 1999).

Figure 1.) Ngauruhoe (www.accomodation.co.nz

Ngauruhoe is a steep-sided cone formed of calc-alkaline basaltic deposits representing more than 70 discrete events over at least 2.5 ka (Williams, 1994). This study is particularly pertinent to Ngauruhoe, as it host the famous and frequented Tongagiro Crossing, a popular tourist activity, and so further understanding of basaltic-andesite magmatics will improve the mitigation efforts related to volcanic disasters. XRF data obtained by the research team at the University of Canterbury in 2010 of historic flows from 1870 to 1975 provide basis for this vent's comparison.

Methods

This method is extremely user friendly and easily approached.

In order to achieve a "normalized" time space, we first have to establish a total 'age' for each volcano, how many years it has seen from the first eruption to the most recent event. If we then count up from the first eruption, t=0, we can divide the age of each deposit we reach after 0 by the total age of the vent to give it a ratio representing its place respective to the whole period of time in which volcanic activity occurred. The eruptive time line of each vent then equates to the same number line stretching from 0 to 1, and variability comparisons may be made. Most of the other variables that one might consider with this technique do not require scaling, such as all the variables used in this report, though the operators may certainly scale any property they wish to consider to make it more easily compared to other sites.

Results

Plotted relationships reveal strong correlations amongst the subject volcanoes. Of particular interest are the relationships of potassium over time from volcano to volcano, which shows strong correlations and two distinct patterns. All

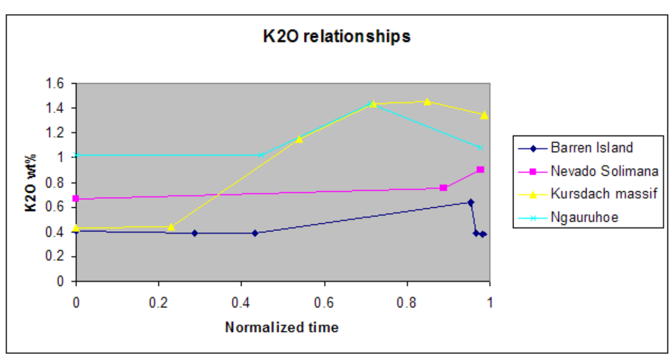

Figure 2.) Wt% K_2O concentrations per time

K2O concentrations, and in the case of the Kursdach massif the concentration rises by more than a factor of three throughout its eruptive history. Interestingly the two extant volcanoes that represent modern basaltic-andesite production, which are therefore of particular interest to the considerations of hazard mitigation, display more recent and relatively sudden depletion in K2O. This contrasts with the more gradual decline in K2O abundance displayed by the Kursdach massif and the final increase displayed by Nevado Solimana volcanics. K2O concentrations are indicative of fluid interactions within the magmatic system, and as fluid-rich portions of fractionated magma chambers are highest in volatile content and the most likely to erupt, it makes good logical sense that this portion of magmatic systems would deplete toward the end of a volcano's life. This presents an interesting point when considering the final signature of the Nevado Solimana: as the deposits here do not conclude compositionally in a decreased K2O signature, it seems likely that the fluid-mobile portion of the magma that would have formed a final eruption event with a decreased K2O concentration has been removed from the system via a non-eruptive emplacement such as diking. Indeed, extensive diking is observed in the regional geology (Vatin-Pérignon et al, 1991) as weathering unroofs the magmatic chamber and its surroundings.

Even uni-variant trends can offer insight into the complexities of volcanic flux. A distinct lack of variation in amounts of total Sr in each example is in fact quite telling. Partial melting of enriched mantle is typically invoked to explain Sr variation petrologically (Wood, 1980), and the absence of any such variance speaks to an important disconnect between the mantle and these basaltic-andesite systems. As basaltic-andesite is found almost exclusively at regions of low-angle subduction, about 15 to 17 degrees, with prominent mid-depth seismicity in arc magmatic settings (Dickinson, 1967) it is generally agreed that melts are produced in the accretionary prism off of the subducting slab (Luhr et al, 2006, Chandrasekharam et al, 2009) and therefore have little to no mantle interaction, and this relationship is observed in the data.

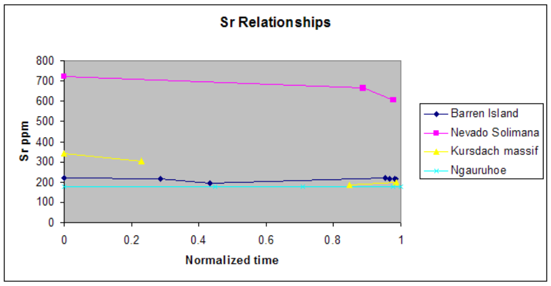

Figure 3.)
Wt % Sr relationships throughout time. Data from Ngauruhoe includes only one value for Sr, which is used to represent all deposits.

Deep crustal and intracrustal material is under nearly continual metasomatic flux and as such the rocks in these regions displays distinct Nd enrichment that is linked to the fluid-mobility of Nd. As Nd remains quite mobile after it incorporated into host rock by metasomatism, it is also re-melted easily and can readily join intrusive bodies during their ascent. As such, Nd flux has long been tied to assimilation of crustal material within igneous provinces. The data here shows no correlation on which the author is willing to posit.

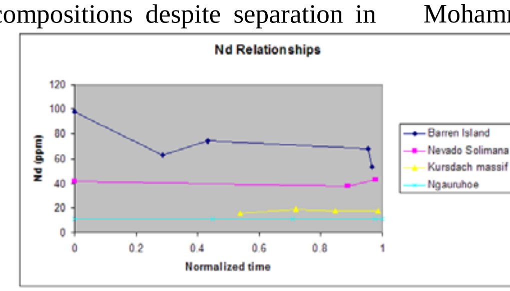

Figure 4.)
Wt % Nd relationships throughout time. Data from Ngauruhoe includes only one value for Nd, which is used to represent all deposits.

Discussion

The relationships described in this report prove interesting as a case study of the regions they represent, relating changes in the total composition of the chemical system over time as represented by variability of individual chemical components. The tendency of K2O to deplete near the end of a volcano's life time seems to indicate that loss of the potassium-rich portions of the melt somehow relates to arrest of the magmatic body and death of the volcanic system. The primary importance of these findings may be related to mitigation of volcanic hazards and risk reduction of disasters, particularly with regard to the modern centers at Ngauruhoe and Barren Island. As relative K2O depletion seems to indicate the final moments of basaltic-andesite volcanic lifespan, it may be that both Ngauruhoe and Barren Island are nearing the moment of extinction; each seems to be depleted in the most recent eruption. Moreover, these findings demonstrate that the normalization technique used herein is an effective means of comparing disparate volcanic centers of similar chemical compositions despite separation in time and timing of. With further and investigation of more widespread volcanic characteristics such as gravity flux and seismicity, this method may allow for predictive capabilites within volcano monitoring in the future.

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