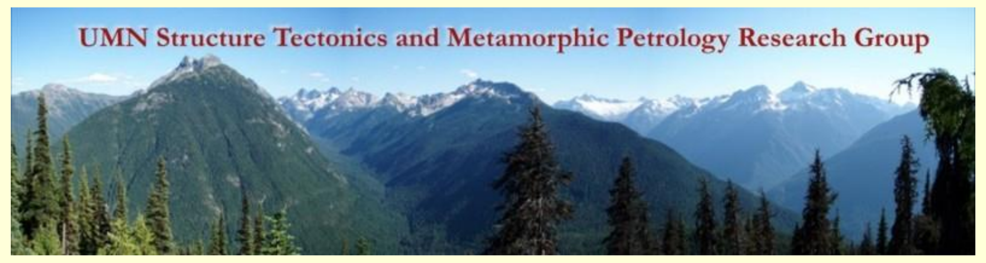
Relations between Subduction Parameters and Magmatism



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Abstract

One of the main effects of plate tectonics is volcanism. When two lithospheric plates converge, one must be subducted, usually beneath the younger and less dense plate; this subduction leads to arc volcanoes observed behind the subduction front. This research seeks to test the correlation of various subduction parameters (ie. convergence rate, dip angle, etc.) against the frequency of volcanoes in an arc, or more generally, to find how variation in slab dynamics affects the presence and density of volcanoes at the surface. Previous work published in *Jarrard (1986)* focuses on the relationships between 26 subduction parameters for 39 modern subduction zones. This work focuses on taking those measured parameters along with other acquired data, and relating them to known volcanic activity. First tested was the reliability of the generally held belief that arc gap is determined by the angle of subduction. Using data from *Jarrard (1986)*, along with data collected from Google Earth, the relation between was found to be good ($R^2 = 0.77$). However, the variability that *is* present in the data supports the work done previously in *England (2003)* suggesting that there is greater variation in partial melting depth for each arc than previously thought; 65-130 km. For 35 of the 39 volcanic arcs, volcano count and length of the subduction zone were obtained using Google Earth interactive maps, yielding essentially a volcano concentration for each arc. There is a great degree of variability observed in the volcano concentration, from zero Holocene (recently active) volcanoes observed in the Central Chile subduction zone, to 73 in the Kamchatka arc. As length of subduction increases, a greater number of volcanoes would be expected, however, this accounts for only 19% of the variability of the volcano frequency; there must be other contributing factors (figure 2). Strain class, convergence rate, and maximum earthquake moment were shown to be weakly correlated to the observed volcanism, while slab dip, age, and many other variables appear to have no effect on volcano concentration at the surface. Maximum earthquake moment was the largest contributing factor (R^2=0.19), suggesting that no one factor can be attributed to observed volcanism, but likely many factors have an impact.

Introduction

The earth is broken into layers according to their physical properties. The outermost layer is known as the lithosphere, and is approximately 100 km thick. This relatively thin layer is the brittle shell to the earth that overlies the more ductile asthenosphere, and is the layer that makes up the tectonic plates studied further in this research.

When two pieces lithospheric plates converge, the older and denser plate typically is subducted; the subducting lithosphere is called a subducted slab, or 'slab' for brevity. As the slab continues to subduct, increasing pressure and temperature dehydrate the slab, which lowers the melting point of the overlying mantle wedge and causes partial melting to occur. Melting generates magma that rises to form a chain of volcanoes along the front of the converging plates; this chain of volcanoes is called a volcanic arc. The location of the volcanic arc, or 'arc' for brevity, depends on the angle that the slab subducts. Figure 1 is an idealized representation of a subduction zone.

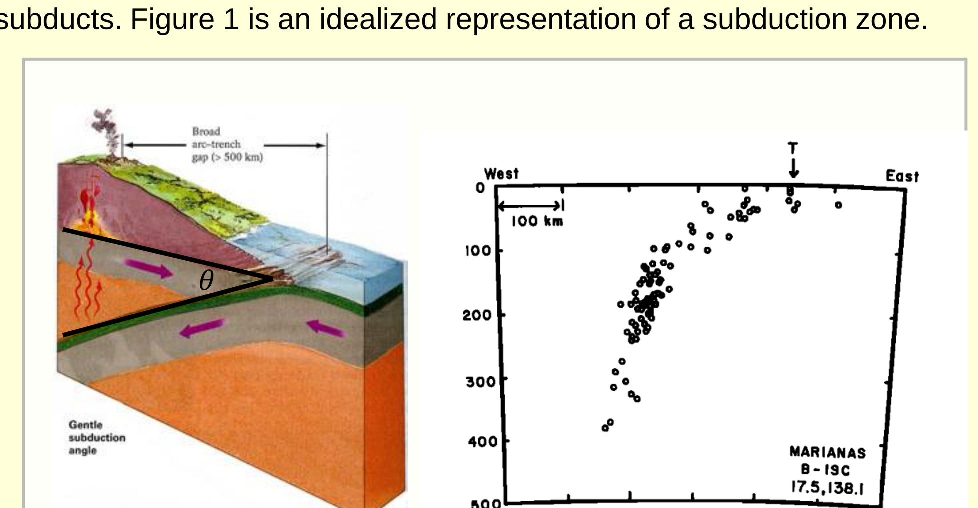


Figure 1. Graphic representation of a subduction zone. Through simple geometric relationships, the location of the volcanic arc is determined by the angle that the slab subducts; a steeper dipping slab results in a smaller arc-gap. The slab surface is found through the location of earthquakes at the interface between the slab surface and the overriding plate; the alignment of seismic events (figure on right) is called the Benioff zone. [1][3]

Methods

The ***observed*** arc-trench gap data *(Jarrard 1986)* are plotted against the ***expected*** arc-trench gap in graph 1. Expected arc-trench gap assumes that partial melting occurs at 100 km depth (Tatsumi, Y. 2005) and that intermediate slab dip (dip angle from 60-100 km) best represents the angle of subduction. The expected arc-trench gap is calculated using $ArcGap = \frac{100}{Tan(\theta)}$. This relationship can be seen in Figure 1.

Using Google Earth mapping software, the spacing of volcanoes over the length of arcs was found for 35 out of the 39 modern subduction zones. Sulawesi, New Britain, Palau, and Yap arcs were omitted owing to lack of reliable data and complicated plate geometry. Figure 2 represents a typical subduction zone with labeled volcanoes, and the length of the subducting plate was obtained by tracing the clearly defined trench. Google Earth labels only volcanoes with a known or inferred volcanic history in the past 10,000 years [5].

Volcano concentration was found by taking the number of volcanos divided by the length of the subduction zone obtained. This was added to a table of all the parameters discovered in *Jarrard (1986)* so as to test the correlation of each parameter to the observed volcanic concentration. Strain class, maximum earthquake moment, and convergence rate were shown to have a very weak correlation, while slab dip ($R^2 < 0.01$), age ($R^2 < 0.01$), and radius of curvature ($R^2 < 0.01$)

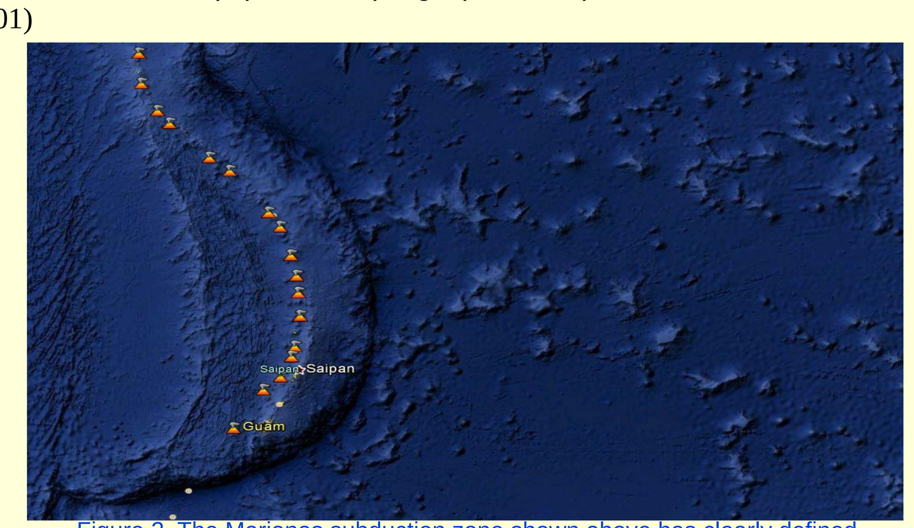
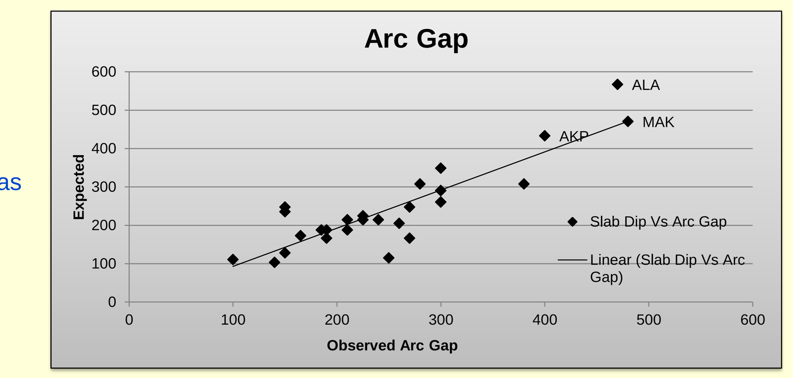
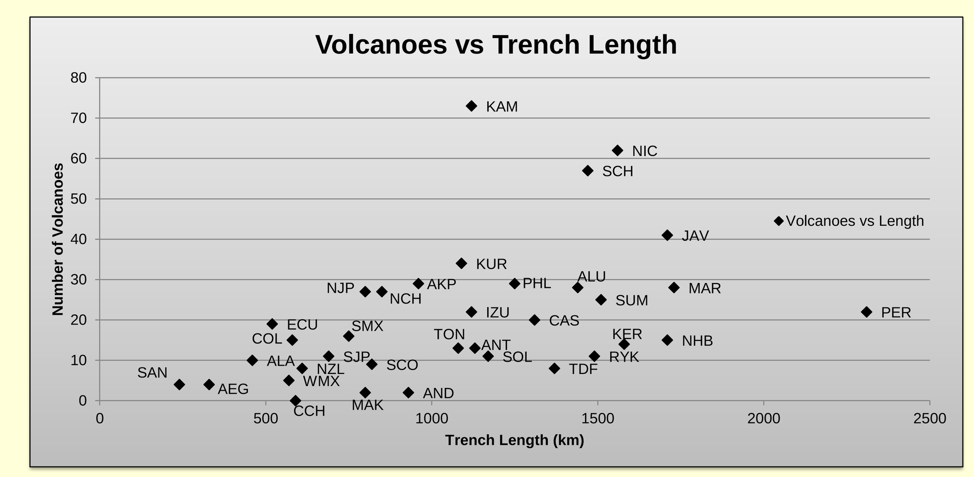


Figure 2. The Marianas subduction zone shown above has clearly defined plate boundaries, and fairly constant arc-trench gap.

Results

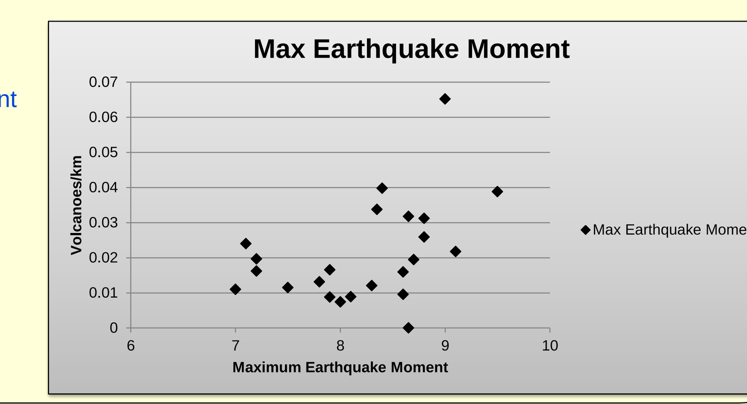
Graph 1 (to the right) depicts the variance in the observed versus expected arc-gap. Though a good correlation is found (R^2 = 0.77), the variance that is present is interpreted as support for a greater range of partial melting depth for different slabs.

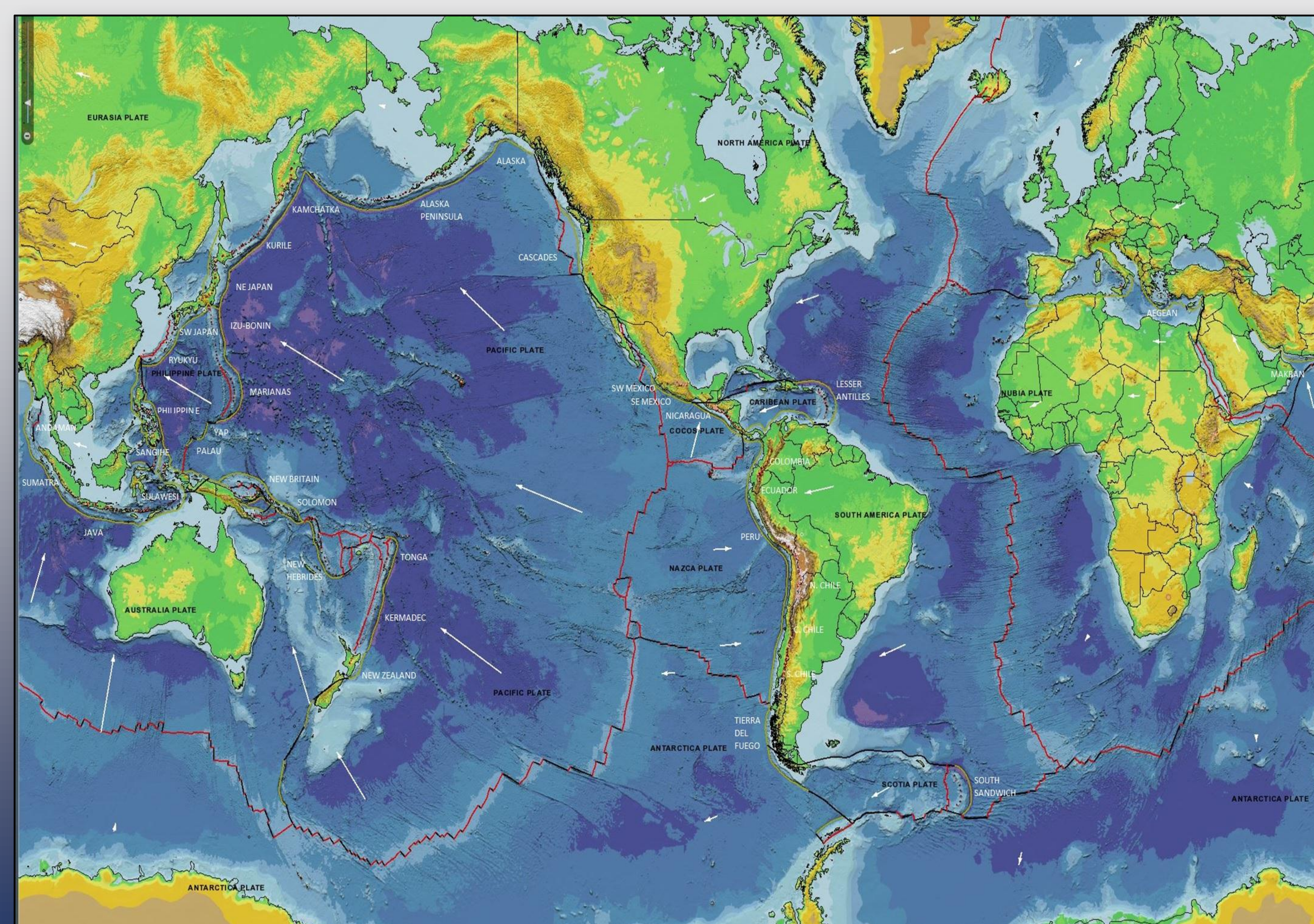




Graph 2 (below) illustrates the large discrepancy between volcano number and trench length. Though the general trend is increasing with trench length, this accounts for only 19 percent of the variance; other variables must play a key role in determining volcano concentration.

Graph 3. Maximum earthquake moment was the variable with the largest correlation to the observed volcanism (R^2 = 0.19), suggesting that one variable alone cannot account for the large variance, but likely many factors have an influence.



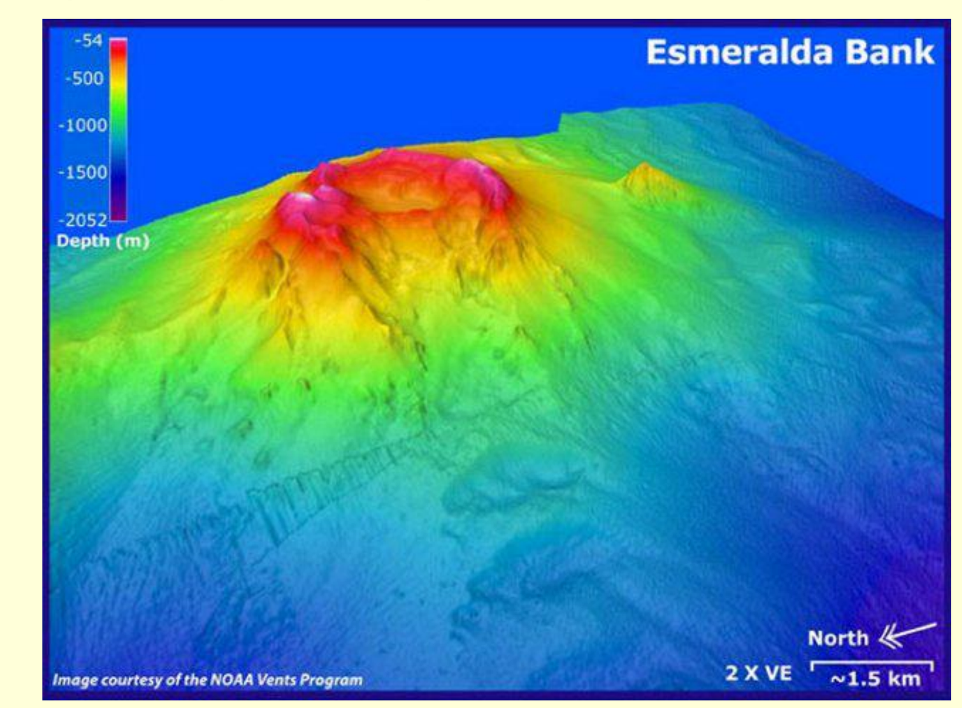


Abbreviations:

Aegean – AEG
Alaska – ALA
Alaska Peninsula – AKP
Andaman – AND
Cascades – CAS
Central Aleutians – ALU
Central Chile – CCH
Colombia – COL
Ecuador – ECU
Izu-Bonin – IZU
Java – JAV
Kamchatka – KAM
Kermadec – KER
Kurile – KUR
Lesser Antilles – ANT
Makran – MAK
Marianas – MAR
NE Japan – NJP
New Britain – NBR
New Hebrides – NHB
New Zealand – NZL
Nicaragua – NIC
North Chile – NCH
North Sulawesi – SUL
Palau – PAL
Peru – PER
Philippine – PHL
Ryukyu – RYK
Sangihe – SAN
Solomon – SOL
South Chile – SCH
South Sandwich – SCO
Sumatra – SUM
SW Japan – SJP
SW Mexico – SMX
SW Mexico – WMX
Tierra del Fuego – TDF
Tonga – TON
Yap - YAP

Discussion

- The observed arc-trench gap was compared with the expected using a simple geometric relationship. Though the relationship is somewhat in error by assuming a constant dip angle, the variance is large enough to support the somewhat contrary hypothesis expressed in *England (2003)*: Partial melting occurs at a range of depths beneath volcanic arcs.
- The density of volcanoes (spacing of volcanoes) as a function of trench length (graph 2) shows a lack of correlation. No one factor was found to explain the variance in the data; however, maximum earthquake moment shows a weak positive correlation. This is taken as evidence that many variables determine the observed volcanism, since the moment magnitude scale is based on length of fault rupture, focus depth, displacement, and rock strength.
- Perhaps a more ideal variable that would explain the concentration of volcanoes is the frequency of earthquakes: an increased number of earthquakes would provide a greater number of volcanic conduits feeding volcanoes. Determining a time-series for seismic events is impossible owing to the very limited range of records; earthquake history goes back no more than 50 years with any reliability. Researchers at the University of Munster, while looking to determine the rate and method with which the magma travels upward, speculate that magma flow is facilitated by earthquakes, or even propelled "like a jet"; research is still needed regarding this mechanism [6].
- Future research is needed to better understand plate dynamics, the process of subduction, and magmatism. While this research uses very general physical observations to speculate about Earth's processes, geochemical evidence gained through detailed field work can lend further insight into the processes that generate active volcanoes.



Submarine volcano from the Marianas arc. Image courtesy of Susan Merle (Oregon State University/NOAA Vents Program)

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