Daniel Walsh

Research Paper

Relative Dating of Volcanic Flows on a Back-Arc Stratovolcano

Abstract: The accurate dating of lava flows is important if we are to understand the eruptive nature of volcanoes. Of particular use to geologists in the field of hazard management is the ability to collect a large amount of data in a short time. This has become possible recently with the advent of remote sensing techniques such as aerial photography, which can collect data over a large region at one time using a wide range of wavelengths. Here I apply visible spectrum photographs to the problem of dating lava flows. I analyze images for trends in average reflectance and color that are caused by a variety of factors including erosion of glassy rinds, the oxidation of iron, and the development of vegetation upon the flows. There is a clear trend visible when the known relative ages of flows are plotted against measurements of color levels and reflectivity. This trend allows for the dating of flows for which relative ages can not be determined by traditional field techniques. This study shows that the use of visual imagery that is available without requiring of specialized equipment is an economic and feasible way to conduct preliminary surveys of eruption histories.

Introduction:

Remote sensing technology continues to revolutionize the ways in which Earth scientists learn about our planet. Abrams et al. (1990) conducted research on the use of visible as well as reflected and thermal infrared light in the dating and mapping of Hawaiian lava flows. These flows spanned a wide variety of climate zones as well as ages. A few key indicators of flow age which transcended climate zones were noted in the study. Of particular importance are the following:

1. The oxidation of iron (rust formation) makes older flows highly distinguishable from younger flows (Lockwood and Lipman, 1987). It was found that the oxidation in a flow was

in general correlated with radiocarbon ages of organic debris buried under flows.

2. The development of “rinds” on the flows through time leads to changes in the reflectance of light. These rinds are silica rich and may be accreted from windborne soil. They can range in thickness from 1-400 micrometers. This accretion occurs when rocks are coated with windblown debris and then wetted by dew or light rain. This causes soluble constituents of the soil to go into solution and precipitate on the flow surface (Curtis et al.,1985) , (Farr and Adams, 1984).
3. The devitrification of the thin veneer of volcanic glass that forms on pahoehoe flows as they cool rapidly in contact with the air. This effect occurs primarily on effusive mafic volcanoes where these types of flows are most common (Fair and Adams, 1984) .
4. Soil development and the accompanying vegetation cover has a strong effect on how a flow appears in an aerial image. Thus, revegetation levels of volcanic flows can tell us something about their age. Clarkson (1990) conducted a study of vegetation development following recent (<450 years) flows on the North Island of New Zealand.

In this study I focus on the relative dating of lava flows on Ngauruhoe, a back-arc stratovolcano on the North Island of New Zealand. Flows on Ngauruhoe are primarily effusive with mafic to andesitic composition. Using digital images of the mountain, I attempt to correlate spectral RGB data to the relative ages of flows as determined during field work in February 2010.

RGB Data: An Overview

RGB data is instrumental to this study. When images are captured and converted to a digital form, they are separated into three channels, the red, green and blue channels represented by the acronym. This is done through the use of sensors which are sensative to different wavelengths of light within a CCD, a light-sensative microchip present in the digital camera or scanner. Each pixel in an image (located by the use of XY coordinates) has three values associated with it: one brightness value for each color. By combining the brightnesses of all three colors on a display screen the image is restored to the way it appeared when captured.

Here RGB data is analysed with the use of histograms. For a certain area of an image, the number of pixels that fit into each brightness level for each color are counted. It is important to note that two pixels with the same red value, for example, might display differently because of different levels of the blue or green values associated with that cell in the raster image. Although the use of RBG data is limited in it's spectral range, it is easily accessible and contains many highly recognisable patterns.

Methodology

Flows were mapped on Ngauruhoe during February 2010 (Figure 1). Relative ages were determined using known stratigraphic indicators. These ages can be used in determining the accuracy of optical chronology methods. I analyzed rectified satellite images of Ngauruhoe obtained from Google Earth using a simple java program which tallies brightness values for red, blue, and green components of the images for a region 20 pixels to a side (400 pixels per color). Data were collected using the following procedures:

1. A random point on the image is repeatedly chosen by a computer until the point is within one of the flows. At this point a selection is be made by the operator in the center of the flow along a line perpendicular to the direction of flow from the point. A square of pixels reaching 10 pixels in each direction from the selection point is analyzed and the data saved to an output file. Data is in the form of a histogram of brightness values in the red, blue, and green color layers and output is generated in the form of a table listing the number of pixels in each 8 bit brightness category (256 discrete levels). Thus at each sampling location on a flow there are 768 bins for 1200 pixels (400 for each color).
2. The following areas were excluded from analysis due to factors that make them unsuitable:
    a) areas where the flow is covered with ash flow deposits since these are not related to age of flow
    b) areas where artificial structures exist on the flows
    c) areas of obvious shadows. These areas include steep slopes on the sides of flows and

fluvial channals.

d) areas which could not be assigned to a particular flow in the field.

e) Areas where the flow is less than 20 pixels across on the image.

The results of five pixel counts for each respective flow were averaged together, creating a histogram for that flow representing five sampling locations. The histogram data itself was plotted for visual comparison. I then took a moving average of five brightness values to smooth the curves for further analysis. The most common brightness value of each color for each flow was recorded along with the number of pixels in that particular bin. Graphing these data in particular revealed several important trends which open the path for future research.

Results/Discussion:

The data show several clear general trends (Figure 2). First, it is notable that pixels in older flows tend to be brighter in general – they peak at higher brightness values than the historic flows. A general trend is visible in the data, although it is difficult to quantify since the time durations between flows are only vaguely known. This trend is congruent with what is visible in the aerial photographs – the newer flows appear flat in texture and dark in color, while the older flows tend to be lighter and more multicolored, especially when vegetation is present.

The newer a flow is, the closer together are its blue and green peaks. Flows 1-3 show the peaks as relatively far apart. In flow 4 the blue and green segments have two peaks, which each overlap. The rest of the flows have (single) similar brightness peaks for the blue and green layers. This may imply that young flows originally have a color reflectance spectrum involving matched peaks of blue and green. Flow 4 may represent an intermediate stage. The older flows show a divergence of blue and green peaks – this may be due to the development of vegetation on the flows, which would boost blue and green values in particular. Since the older flows are brighter, the merging of the two peaks may reflect an increase in the brightness of the green peak rather than a decrease in the value of the blue peak.

Flows were placed into several groups by Hobden et al. (2002), who studied the evolution of the volcanic system. The data analyzed here is from flows in three of the groups: 1, 2, and 5, from oldest to youngest. Figure 2 shows the trends in peak brightness modes and values – group 1 contains the two oldest flows, group 5 contains the three historic flows, and group 2 contains the rest of the flows. Group 1 represents flows older than ~1.8 ka, group 2 contains flows that occurred between 1.8ka and 1800 C.E., and group 5 contains the historic flows that have occurred since 1870 C.E.. Unfortunately, without more isotope dating of the flows it is difficult to know how much time passed between different flows, limiting the usefulness of quantitative methods of modeling age using optical data.

The different age-groups appear to act differently insofar as weathering affects the RGB spectrum through time. Group 5, the historic flows, displays the most interesting pattern. All of the spectral channels evolve in the same manner as the flows become older, becoming darker and less monotonous (Figure 3). This stands in contrast with the long term pattern of flow lightening. However, the pattern is consistent with the work of Fair and Adams (1984), who show that the devitrification of glassy rinds on the surfaces of flows decrease reflectance and thus make flows darker. It is likely that it is only in the historic flows that this effect is observable – beyond the age of these flows the effects of vegetation and erosion may become dominant.

Abrams et al (1990) note that on Hawaiian effusive flows, blue begins as the dominant color to be supplemented in the oldest flows by green. On Ngauruhoe the flows do not follow this pattern. The blue coloration becomes slightly more dominant in the older flows, changing from controlling the same number of brightness-pixels as green to controlling 1.03 times as many. This is a surprising finding, given the fact that blue coloration seems to shift drastically under visual inspection of the graphs. This might be attributable to in increase in the range of the green coloration which partially cancels out the relative decrease in the brightness peak.

Flow 4 is a major outlier in the brightness levels. It consistently scores as brighter than any of the other flows from the same era. This appears to be due to the relatively smooth texture of the flow. Flows 1 and 2 were contained to a valley while flowing, leading to the creation of dark ogives upon the ridges of which sediment does not collect. These can be seen in the satellite imagery as dark bands running roughly north-south. Flow 4 is bulbous and was probably quite viscous on eruption, and thus lacks these ogives. This has allowed the relatively smooth top surface to accumulate a layer of light colored ash debris.

Conclusions:

It is clear that there are many technical details to be worked out in terms of coming up with a way to date flows absolutely using satellite techniques. However, there are definite trends in the data as the flows age. Analysis by pixel counting of random areas provides data which suggest that flows brighten and become more "mottled" as they age. Within the first few hundred years devitrification of glassy rinds is likely to lead to a darkening of the flows. After this other effects seem to become dominant. Much research remains to be done on Ngauruhoe. Analysis of the rind textures on the historic flows would provide some data to support the hypothesis here proposed about the darkening of new flows. Also needed is an analysis that uses flows of known age to calibrate the patterns here observed. This research has laid the foundations for these and many other projects.

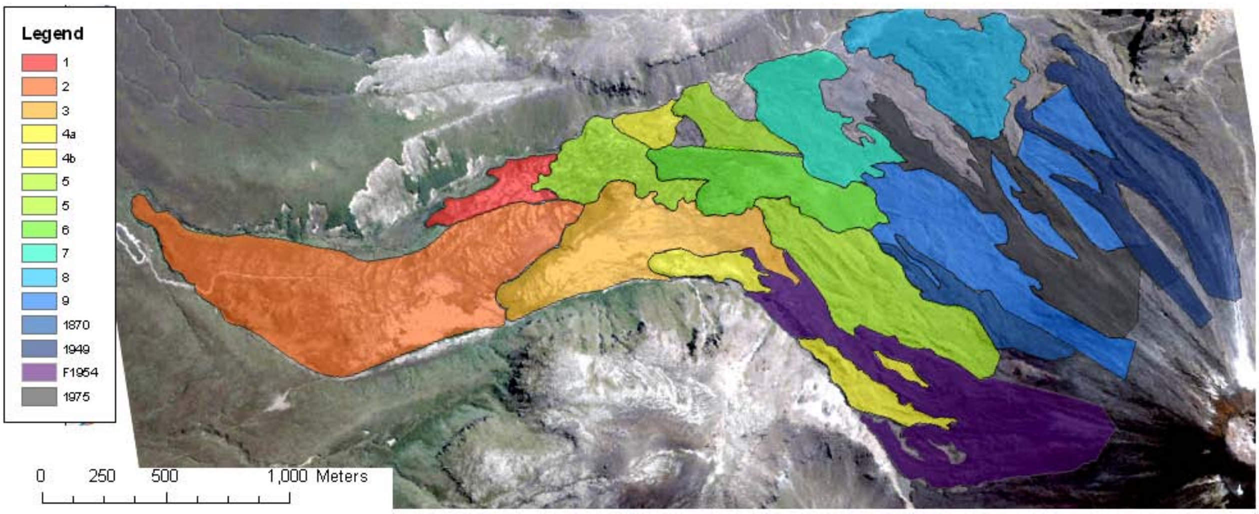

Figure 1: Map of Flows – Flows 4a and 4b were treated as the same flow in this study.

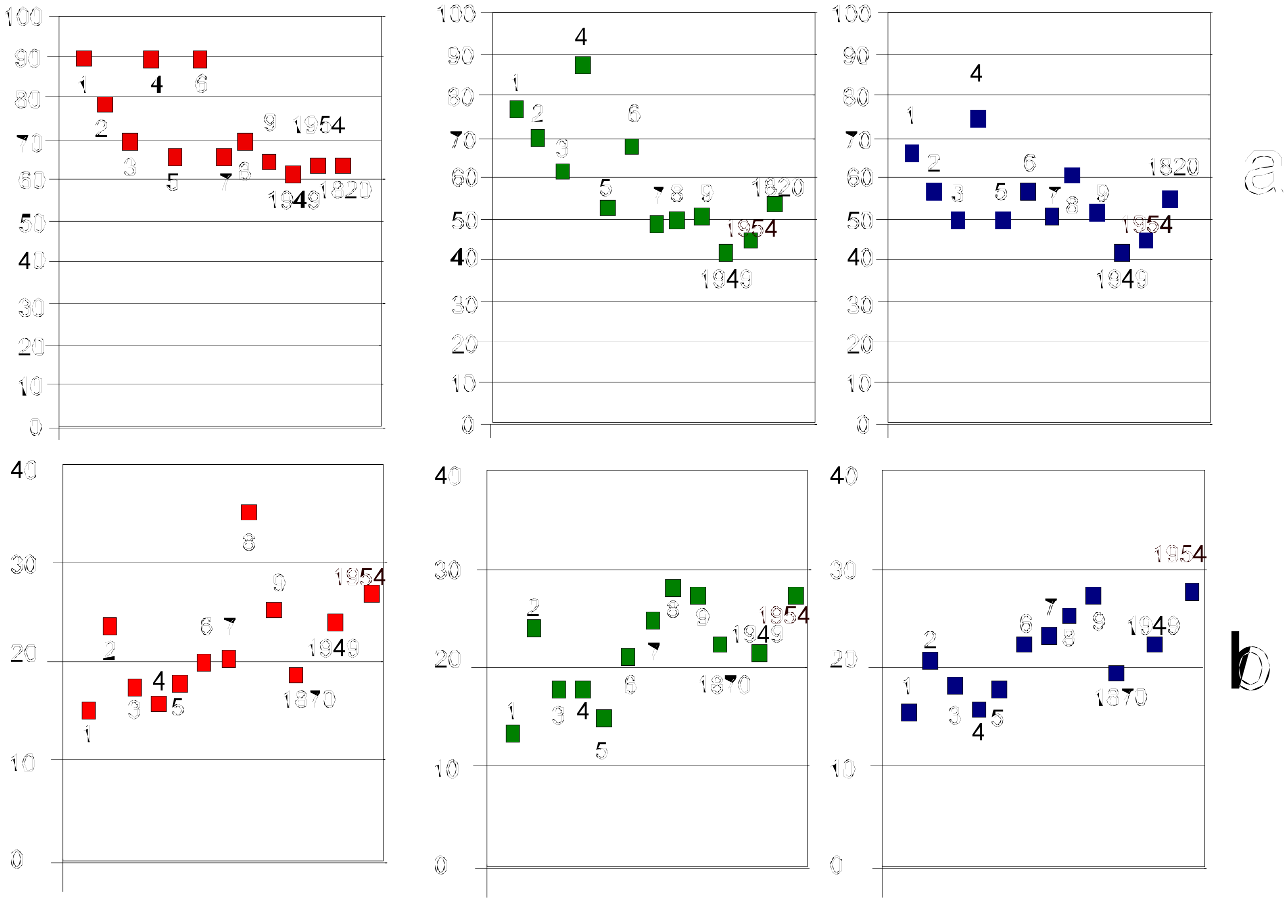

Figure 2: (a) Brightness modes for flows as denoted in Figure 1. Colors denote RGB bands. (b) Pixel counts of the color peaks in (a).

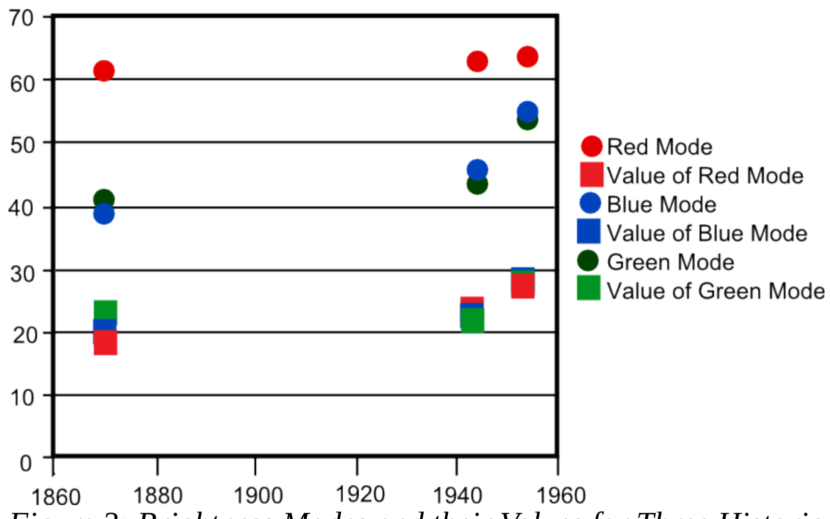

Figure 3: Brightness Modes and their Values for Three Historic Flows on Ngauruhoe (1870, 1949, 1954)

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