Gravity Modeling of Black Point, a “Surtseyan” style Tuff Cone, near Mono Lake, California

Senior Thesis Project

By

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Abstract

Geologic mapping and a gravity study of the “Black Point” tuff cone located on the NW shore of Mono Lake, near Lee Vining, California ($38^0$02’ latitude, $119^0$06’ longitude) was performed in this study. Black Point is a “Surtseyan”-style tuff cone that erupted approximately 13,300 years ago beneath glacial Lake Russell. The goal from the gravity study was to test models for the subsurface geometry. Specifically, to determine the distribution of consolidated versus unconsolidated tephra observed near the summit of Black Point. These models were developed based on observations of the consolidation of extruded tephra by a process called “palagonitization” following the eruption of the Surtsey tuff cone in Iceland in 1963. Measurements using a Worden gravimeter were captured over a three-day span, covering 185 individual stations. Stations were spaced at 5-20 meter intervals across the principal area of the main vent. Two perpendicular arrays were followed, striking approximately N56E and N34W respectively. Both arrays transect suspected main vent area for Black Point. Rock samples were obtained and analyzed for their densities, which were then used to generate “best-fit” models matching the observed gravity using the “Grav-2D” program. The observations (in mgals) collected using the Worden gravimeter have been corrected for elevation above the geoid, local topography, local mass and density of rock, drift of Earth, and terrain, to provide an anomaly without background noise. Two simple models were generated to demonstrate the idealized two-dimensional subsurface of Black Point in proximity to the suspected main vent. These models imply that palagonitization occurs to significant depths, and, occurs on either side of the suspected main vent at Black Point. Both models assume that surface densities can be extrapolated to a depth of at least 300 meters. Further southeast of the vent, the tuff cone is underlain by a deep-rooted, high-density (~3.0 g/cm^3) body suggesting a mafic dike swarm or feeder dike system. The correlation of the consolidated tephra alongside the vent implies that palagonitization may have occurred in direct response to localized hydrothermal activity near the vent. The models are in direct contrast to work by others who suggest that this phenomenon will only occur after all heat is lost via the interaction of rainwater percolation. Clearly, by the gravity models constructed, this is not so.

Introduction

The Long Valley Caldera formed in the early Pleistocene, beginning with tuff, domes, and flows, approximately 2.2-0.8 Ma. In the Long Valley system, rhyolite followed the tuff with a lake sediment covering. The Mono-Inyo system of post-caldera rhyodacite and rhyolite extends just N of the Long Valley system. The Mono volcanic vents or volcanic craters trend N to S from the Long Valley caldera to N of Mono Lake. Currently, in Mono County, there is still active tectonism, which accounts for local volcanic vents. At the NW side of Mono Lake is Black Point (Fig.1). Black Point is a Surtseyan-style tuff cone or vent. It is defined as a tuff cone following the work by Wohletz and Sheridan (1983). The Black Point tuff cone was formed by a phreatomagmatic eruption approximately 13,610 years old (Benson et al 1998) and centered near 38^{0}02' latitude, 119^{0}06' longitude. There is evidence indicating that there are at least two volcanic vents, with the N vent appearing to have erupted after the S vent. Evidence stems from: (1) the relative sizes of the two vents (with the N vent being much smaller than the S vent), (2) strike and dip measurements, and (3) the elevation of the vents (hypothesized with an erosion factor taken into consideration). The eruption of Black Point occurred beneath glacial Lake Russell during the Tioga Glaciation period and produced basaltic tephra particles incorporated into high-energy wet surge clouds as water interacted with the melt during eruption. At this time, Mono Lake was roughly five times larger than it is today and ten times its current depth at around 2100 meters (Lajoie 1968). Since the eruption occurred underwater (or under a glacier), the top of the tuff cone formed essentially flat, with little to no peak and has been subsequently eroded off. Continuation of extruding material extended the cone, and the eruption ceased. After the eruption, a cooling period began, where tephra began to consolidate and fissures were then developed within consolidated material. These fissures may have formed as a stress relief of its building out process, or more likely, from localized faulting. These fissures most likely had high pressure (due to water depth), and superheated steam that vented through unconsolidated tephra to cause alteration. This is, of course, the modern school of thought, but little evidence exists.

Temperature need not be superheated to form these alterations, but we could expect high temperatures as the tuff cone was in a cooling off process, and was not cold. With a cold outer crust formed, the inside temperature would easily rise due to the insulation the outer crust would provide. This alteration changed unconsolidated tephra into a consolidated material within a very short time, perhaps 5-10 years (based on the observations of the Surtsey volcano, Iceland). During the consolidation of the tephra, palagonitization of the rock also was occurring. This process alters basaltic hyaloclastite to a palagonite. A palagonite is a volcanic rock consisting of hydrated and chemically altered basaltic hyaloclastite. This process can occur at any temperature, but must be in the presence of seawater or as is the case for Black Point, meteoric water. After the tephra had become palagonitized, then carbonate rich water, leached from the local groundwater, intruded these fissures and began to form tufa veins and mounds. The tufa formed as a thin coating around palagonitized clasts, proving that palagonitization must have occurred prior to lake level rise and tufa deposition. Tufa formations are mainly tower structures but there are also horizontal lying formations in smaller abundance. The long flat tufa veins may have been in a horizontal fissure that had little flow but high carbonate concentration. Along with the formation of the tufas, Mono Lake began to rapidly rise to a highstand of 2155 meters (Benson et al 1998) within a couple hundred years of the Black Point eruption. This rapid rise in water level aided in the fast growth of the tufas (tufas only form underwater) by circulating carbonate rich water from a local network of underground sources. Tufas can be seen on the peak of Black Point today, which indicates that the summit of Black Point was indeed underwater. Black Point may have also been much higher than its present height. Shortly after the massive formations of tufa, Mono Lake began to fall very rapidly. Within 500 years the eruption of Black Point occurred, Mono Lake rose to a 2155-meter highstand, tufa veins and mounds abundantly formed, and then Mono Lake plummeted approximately 65 meters. As the water level quickly dropped, large mass wasting and erosion occurred. In the last 13,000 odd years, Black Point has been severely eroded by glacial retreat and water evaporation forming the wave cut terraces to the NNW and its present topography. Sediment transport from calving glaciers was immense and helped to create the broad beach landscape. Today, unconsolidated tephra deposits, aeolian sand deposits, granite clasts, volcanic bombs, carbonates, consolidated clasts of lapilli stone and tuff, and lake terraces are the flanking landscape near the summit of Black Point. Palagonitized tuffs are exposed only on or near the summit at Black Point. The purpose of this study was to use gravity observations to investigate the density of material beneath Black Point summit. Interpreting the subsurface geometry via gravity observations and simplistic models will help better identify the constraints in predicting when the palagonitization occurred and to what extent at Black Point Tuff Cone. This research project was undertook to test the hypothesis that palagonitization occurs at depth, specifically whether a palagonitized "root" exits at Black Point.

Theory

Gravity

Gravity (known as just "g"), is the acceleration experienced by an object under the influence of the Earth's mass according the Sir Isaac Newton's law of gravitation. Newton concluded that not only does the Earth attract the Moon, but it also attracts an apple in much the same way. Every body in the universe attracts every other body. This phenomenon of bodies moving towards other bodies is called gravitation (Halliday 1997). Newton's law of gravitation is actually a force law that is described by:

$$F = G \frac{Mm}{r^2}$$

where, the universal gravitational constant is $G = 6.67 \times 10^{-11}\ N*m^2/kg^2$, M = mass #1, m = mass #2, r = separation between the masses from center to center. This is the ideal case with Earth viewed as a non-rotating uniform sphere of mass M. If a particle is released under these conditions it will fall according to Newton's force law with an acceleration called gravitational acceleration (a_g). Newton's force law:

$$F = G\frac{Mm}{r^2} \qquad \text{equals} \qquad F = m\,a_g$$

which can be rearranged to read $a_g = F/m$. Thus,

$$a_g = F/m = GM/r^2 = \text{gravitational field strength} = g$$

Now, since Mass = density * volume or ($M = \rho * V$) , then

$$g = \frac{G\rho\, dV}{r^2}$$

Since 1) the Earth is not uniform, 2) is not a sphere but a spheroid, and 3) is rotating, gravitational acceleration *g* will not be the same as free-fall acceleration *g*. Gravitational forces obey the "principle of superposition", which explains that the total force F_1 on particle 1 is the sum of the forces exerted on it by surrounding particles. Shown as

$$F_1 = \sum_{i=2}^{n} F_{1i} \quad \textbf{or} \quad g_{\text{total}} = \left\{ \sum^{\infty} \frac{\rho_i}{r^2} \right\} G\,dV$$

The sum is a vector sum of the forces exerted on particle 1 from other particles labeled 2, 3, …, *n*. The gravitational force F_1 exerted on a particle by a real object is found by dividing up the mass into differential units of *dm* with each dm units exerting a differential force *d*F on the particle. The vector sum (see above) becomes the integral

$$F_1 = \quad dF \quad \textbf{or} \quad g = G \frac{\rho}{r^2}dV$$

Only if the object is a uniform sphere or shell can we use Newton's law of gravitation.

Since the Earth is not a perfect sphere or spheroid for that matter, a reference surface must be established so that the observations made can be corrected to it. The oceans are approximately an equipotential surface and therefore become the reference surface called the *geoid* (Fowler, 1994). All gravity observations in this study will be corrected to the geoid. An oblate spheroid most closely represents the Earth's geoid, and the international reference gravity formula gives the value of *g* on this spheroid. Corrections to the observations made using this formula will make allowance for this fact. The reference gravity formula is calculated by the International Association of Geodesy about every ten years and is represented as:

$$g(\lambda) = g_e\,(1 + \alpha \sin^2 \lambda + \beta \sin^4 \lambda) \qquad \text{where,}$$

λ = latitude of site location, or "colatitude"; α and β are constants. The values below were used for this study.

$$\alpha = 5.278895 \text{ X } 10^{-3} \quad \beta = 2.3462 \text{ X } 10^{-5} \qquad g_e = 9.7803185 \text{ ms}^{-2}$$

All gravity observations in this and any study are expressed as deviations of this formula.

*Note: The GRACE satellite mission in 2001 will map the Earth's gravity field with a resolution of a few hundred kilometers which will define a more accurate geoid surface (Swenson and others, 2000) for future studies.

Methods

Gravimeter

Measuring the relative gravitational field strength can be easily done with the use of a gravimeter. The Worden gravimeter (there are many) used for this study was the *Master Worden Gravimeter* No. 1313 Model III (herein just called gravimeter) made by Texas Instruments, owned by University of California Davis Geology Department (Fig. 2 no. 3). In its most basic essence, it is a tiny mass hanging from a machined quartz spring held inside a vacuum container.

It is a sensitive instrument, capable of detecting very minute changes in gravitational acceleration as the spring is stretched and/or recoiled. The field accuracy for this gravimeter is approximately 0.1 mgals. Changes in spring length will provide an observational reading in units of divisions. Conversion of divisions to mgals (milli-gals) is easily done by multiplying number of divisions times the dial constant for the gravimeter (in this case, it was 0.0842). Milli-gals stems from the unit “gals” which is a gravitational unit named after Galileo (1 gal = 10^{-2} m s^{-2}). The gravitational acceleration of the Earth at the surface is approximately 980 mgals. The gravimeter needs calibration (performed by Texas Instruments, Inc.) only when it has been dropped or severely jarred. Calibration for this gravimeter was checked and deemed satisfactory during this entire project.

When using the gravimeter some general guidelines are to be followed before any reading is observed and recorded.

1) The gravimeter must be cooled (or warmed) to its local environment for approximately one hour outside of its white protective case. This will ensure that the temperature inside the vacuum is the same as the outside environment, thus ensuring an accurate reading.

2) New “AA” batteries were installed every day. The batteries insert under a small cover plate on the top of the gravimeter. They are needed to illuminate the “background” scale against the observed reading beam of light.

3) The gravimeter will always rest on the Aluminum base plate and leveled before each observation, or for calibration of coarse adjustment.

4) A “coarse” adjustment must be made for the local gravitational field or all readings will be “off-scale”. This coarse adjustment is performed by removing a small, plastic cover piece on top of the gravimeter and inserting the provided screwdriver. Set the “fine” adjustment dial to 1000 divisions and turn the power “on”. While looking through eyepiece, slowly turn the screw so that the beam of light centers in the crosshairs, parallel to long lines. If the beam does not seem parallel, perhaps the eyepiece may need to be shifted slightly. Rotate the eyepiece so that the beam and long lines line up parallel.

5) The gravimeter must remain upright at all times. Calibration may be lost if it is tilted, or laid on its side for any length of time.

Field mapping

Black Point Tuff Cone extends approximately 2000 meters square (Fig. 2 no.1). Detailed field mapping was done over three different visits (3-4 days each) covering the entire area with emphasis on any outcrops observed. Over 50 strike and dip measurements were obtained by use of Brunton compass within the consolidated tephras confirming only that Black Point has very shallow dipping beds of less than ten degrees. Rock samples were collected at fifteen consolidated tephra locations to insure a generalized density for each unit. Four Pleistocene units were identified as **tu** (tephra, unconsolidated), **ltu** (lake terrace deposits, consolidated), **tcg** (tephra, consolidated, grey color, palagonitized), and **tco** (tephra, consolidated, orange color, palagonitized). The vast majority of outcrops are tco. The concentration of tco above 6800 feet elevation correlates with findings of Lajoie (1968), but there are many smaller outcrops of tco and tcg to elevations just below 6600 feet contradicting his reasoning of no palagonitized tephra below 6800 feet elevation. Two Holocene units were identified as **Qal** (alluvium, undifferentiated), and **ltc** (lake terrace deposits, consolidated). Small outcrops of ltc are found along the southern perimeter of Black Point increasing in size to the W. The Qal covers the vast majority of Black Point as expected due to erosion and aeolian deposition of nearby sediments. The "open pit mine" area is the only exposed area of unconsolidated material as seen in Figure 2 no. 6. This material is very black in color and is mined for local roadway use during winter months. Presence of tufa was found within the consolidated tephras, but no vertical tower structures are present on Black Point. The ltu unit covers the entire S side of Black Point from Mono Lake and extends to an approximate elevation of 6660 feet, continuing to wrap around Black Point to the NE. Many different types of grasses, shrubs, and plants litter the alluvial deposits along Black Point as illustrate in Fig. 2 no. 3 & 5.

Data Collection

Where

As shown in Figure 2 no.1, the arrays were cast perpendicular across the suspected main vent area. The modeling will work best if arrays are perpendicular to strike, but in this survey, the object to model was a round structure with rotating strike orientations, so perpendicularity was difficult to approximate. Array A-A' extends to 1600 meters and array B-B' extends to just over 500 meters. The upper base station is at the intersection of these two arrays.

When

The observations were obtained from November 2, 2000 through November 5, 2000. Readings began at approximately sunrise and ended at sunset daily during this period. Additional field mapping and sample collection took place March 15, 2001 through March 20, 2001.

Why

These observations provided the necessary data to model the volcano.

What

One hundred eighty five gravity observations were gathered along both arrays (combined observations).

How

The observations are gathered by a series of steps (repeatable for every observation). The assumption here is that acclimation of the gravimeter has already taken place. The gravimeter carrying case is opened and base plate is removed and put on ground where the reading is to be taken. Proper seating and leveling of the base plate must occur first, or the reading will be tainted. The base plate is leveled using a portable center bubble level. Once this is achieved, the gravimeter is placed on it and leveled by adjusting the three swivel legs on its bottom side. Two indicator bubble levels are on the top of the gravimeter and obvious. After leveling, the gravimeter is ready. Turn the power “on”, look down the eyepiece, and obtain the reading. The reading is taken by lining up the bright yellow beam in the center of the eyepiece cross hairs by rotating the division dial on the top of the gravimeter. As long as the “coarse” adjustment was made prior to start, it should take just a few turns to line up the yellow line. The observation “reading” is in 1000ths, 100ths, 10ths, and single divisions. When the observation is recorded, the local time must be recorded, and the position must be plotted on a topographical map (of useful scale). This is for corrections to the data before modeling. Local geology and structures surrounding the observation must also be noted, for they will factor into the corrections of the data also. Sampling of surface rock was done at this time.

The rocks were later analyzed for density by the “Liquid Saran” method (Schiffman and Mayfield, 1998). These gravity readings were obtained by following the two arrays (by use of a Brunton compass) and using a 200-meter measuring tape. I strung out the tape along the arrays and paced off 5-meter intervals to acquire the observations (Fig. 5). In places where the gravity observations changed little, the gap was widened to 20 and 40-meter intervals. No adverse affects in the modeling occurred by increasing the distance. The 5-meter interval was done for accuracy of the modeling. Base station readings were taken before starting each day, every hour during the survey, and at the end of the day.

*Note: Actual data is listed in Appendix I – transcribed from field notes.

Results

Results stem from corrections to measurements that must be done in order to eliminate all background interference to isolate the anomaly we seek. Results are in the form of the “Complete Bouguer Anomaly” after all corrections have been summed to the observation point. The corrections made to this data are described below.

*Note: The actual numerical results are found in Appendix II

The first correction is the Reference Gravity Formula, which accounts for Earth not being a perfect sphere and rotating, and which expresses gravity as a function of latitude. The latitude used for this survey was $\lambda = 38^0 02'$.

The next correction made is the “Free-Air” correction. This correction is used to compensate for the height (in meters) above (or below) sea level (the supposed geoid) where the observation was taken. The correction assumes no material is between the observation point and sea level, just air. The Free-Air correction can also be corrected to the base station instead of sea level, as it is a relative measurement only. In this study, the Free-Air correction was corrected at the upper base station.

The next correction accounts for the gravitational attraction of the rock material between the geoid and the observation point. It is called the “Bouguer Correction”. The rock is assumed as an infinite horizontal slab of rock, as thick as the elevation difference between the observation point and the geoid.

Next, is the “Terrain correction” which accounts for attraction of topographical features near the observation point. This is obtained by placing a “bulls-eye” template over each observation point on the topographical map and calculating the elevation difference for each box on the template. The differences are summed, and then correlated to mgal values listed in the B, C, D, E, and F terrain correction reference register. For this survey, corrections were grouped together because of the proximity of observation points relative to other each other. As an example, observation points a – d were corrected to the same value. The terrain corrections can be found in Appendix III.

The last correction can be made at any time. It is the “Drift” or “Tidal” correction. This will eliminate any tidal or moon influence from the observation stations throughout the day. The first reading of the day is the base station reading. Then, observations were taken at the base station throughout the day, every hour, to limit the percent error in this correction. Base station observations (*g* in mgals) were plotted against time (minuets), and a linear relationship between base stations was established. Every correction value is obtained by calculating the difference between the observation point and the first base station reading of the day on the graphs. Correlation between the upper and lower base stations was established by obtaining an observation value at the lower base station first thing everyday and lastly every night. Drift corrections can be found in Appendix IV.

All these corrections add up to one result for each station point taken. These results were used as the input data for the Grav 2-D program. A detailed explanation of the program is located in Appendix V. A few data points were deleted during the modeling of the data due to extraneous values. Gross removal of data will significantly alter the data.

Discussion

Black Point is but a small feature in the Mono Basin. To learn why Mono Basin is present today, we must look in the past. After the subsidence of the Antler and Sonoma orogenies, California was built. Pangea began to break up and North America (as we know it today) began to over-ride the Farallon Plate. This brought about volcanism and the Sierran Arc via the Nevadan and Sierran orogenies. Continued rifting away from Europe reduced the angle of subduction and volcanism began to slow. When the Farallon Plate was almost completely under North America (sometime during the Oligocene epoch), it caused the Pacific Plate to encounter the North American Plate. When this occurred, a quadruple junction formed quickly changing into two triple junctions with the transform fault left in-between (Twiss and Moores, 1995). The San Andreas transform fault began, and this created a space in the middle of the remaining Farallon Plate where the crust was no longer thickened by a down going slab. This scenario caused the mantle to become closer to the continental crust than ever before and began to heat it up. The heat caused stretching and thinning of the North American Plate along the Pacific Plate boundary and has produced the Basin and Range Province. This province extends to the eastern side of the Sierran Arc, where an escarpment occurs. This escarpment was created by the uplift of the Sierras and the down-drop of the basin to the East. Mono Basin formed, and is part of the Basin and Range Formation that extends into California. Within Mono Basin, recent volcanism has taken place forming Black Point and surrounding Mono Craters. During the Tioga Glaciation, between 11 – 21 thousand years ago, Black Point erupted under glacial Lake Russell. Retreat of the glacier, and subsequent erosion leaves Black Point where it is today.

Two "best-fit" models were created using the Grav 2-D program (Fig. 3 & 4). By inputting the corrected gravity observations along a horizontal profile distance, and using densities of materials collected at observation sites, two models were generated. Density calculations can be found in Appendix VI. These models approximate the subsurface geology at Black Point. Constraining the model to a “best-fit” was accomplished by 1) keeping the data collection error to a minimum, 2) performing density measurements cautiously yet accurately, 3) corrections to calculations were error free, and 4) the models fit geologic constraints. The models correlate well, in that, densities of polygons, and placement of polygons match the given profiles and the intersection point between the two. An approximate depth of 300 – 500 meters for the base of these rocks was reasoned by using the bottom lake level of Mono Lake. Creating these polygons into their shapes achieved the best possible "fit" of the anomaly curve with the gravity profile curve. Spikes and sharp edges of the gravity anomaly cannot be closely matched due to the relatively small scale of this survey. The suspected main vent area only has approximately one-forth if its original cone present due to massive erosion over the last 13,000 years. On the array A-A', beginning from "A", the models show low-density (~1.43 g/cm^3) material that extends to the east until it reaches the palagonitized tephra (2.34 g/cm^3). Densities drastically change at this point and range from 2.34 g/cm^3 to 2.55 g/cm^3. Past this area continuing east, the density reverts to low density material of about 1.2 g/cm^3. A general trend of E-W dipping beds can be inferred from the models. This is the area of the suspected main vent. How can this be? Perhaps the vent has been filled in with 13,000 years of sediment and eroded products (?). Since it erupted underwater, it may have trapped water within it as Lake Russell rapidly receded. Aeolian deposits, slump structures, and erosion of the cone itself may have filled the vent. Further east on the A-A' profile, density measurements climb to 3.0 g/cm^3. This is very dense material for this area and requires regional thinking to explain its presence. This density is very suggestive of a basaltic magma. Where did it come from? The Sierran Batholith (made up of mostly granite; density ~2.7g/cm^3) lies to the west of Black Point. Mono Craters are of a granitic composition and are just south of Mono Lake, whilst Black Point is a palagonitized basaltic tephra with no indications of it being granitic in nature at all. With all this granite, where did basalt come from? The answer lies in past and present regional volcanism. The Cowtrack Mountains to the east of Mono Lake are mostly basalt in composition and erupted about 3 million years ago (Tierney, 1997). This provided a network of fissures and feeder dikes to the area. Perhaps the high-density material seen at depth in the profile is the lower or outer remnants of the Cowtrack Mountain formation (?). Black Point is perhaps a recharge event into a smaller fissure network that bypassed the Mono Craters magma chamber and the Long Valley magma chamber. Long Valley caldera has had notable geologic unrest since the eruption of Mt. St. Helens, with six earthquakes of magnitude 6 or higher. The resurgent dome has also had cumulative uplift of nearly 0.6 meters in the center of the caldera (Thatcher, 1997). Thatcher also suggests that there is magmatic activity just southwest of the caldera, which, on a regional scale, is very close to Black Point.

R.A. Bailey (1981) suggests that Black Point and other Mono Lake complexes are a continuation of the Long Valley complexes that have not finished evolving through the "Long Valley 5 stages of evolution". The stages entail (1) the eruption of basalt followed by (2) a pre-caldera ring-fracture extrusion, (3) ash-flow eruption and caldera collapse, (4) magmatic resurgence, and (5) final extrusion of intracaldera rhyolite and quartz latite. This would mean that Black Point is only in stage 1 of this evolution, except Black Point is too young.

It seems reasonable to assume that a vent or fissure could extend directly from a basaltic magma chamber deep in the mantle, up into a weak faulted zone (horst?) beneath existing Black Point. Black Point lies along a similar path as that of Mono Craters and stretching further south to Obsidian dome and into the Long Valley Caldera. Is there some deep underlying fault covering this entire region? Is this fault responsible for all the recent volcanic activity? Under the resurgent dome of the Long Valley caldera, a horst structure has been identified trending NW to SE (Hermance and others, 1988). This buried resistive ridge could possibly continue the necessary 40 kilometers to reach Black Point, and may have contributed to its eruption.

The B-B' array has similar implications to A-A' array. There is a shallow N to S dip in the polygon models, which may indicate that it outlines a possible cone shaped polygon in 3-D when correlated with the A-A' array. This dip is somewhat arbitrary in that it is interpreted from the data. This, along with strike orientations, provides convincing evidence that this is a vent structure. Mapping the area suggests that this was the vent responsible for most, if not all, of the Black Point tephra deposits, hence, is the main vent area. Beginning on the north side of the array, density is ~1.2 g/cm^3 until it abruptly changes to ~2.55 g/cm^3 where the palagonitized tephra lies. This location accurately meets the intersection of both arrays. Moving to the south end of this array, the same high-density material is found as in the array A-A'. Surficial mapping indicates nothing but low density, unconsolidated deposits of mixed composition and nature for this area. In the matter of the palagonitized material surrounding the vent, it is inferred from the models and sampling, that this vent must have been basaltic in nature, and was most likely very hot. The heat source from this upwelling magma along with the water beneath Lake Russell altered the extrusive tephra to a palagonite within a relatively short time (based on similar findings of the Surtsey volcano, Iceland). Three distinct palagonite types make up Black Point, varying in clast size and vesicle size. Zeolites infill the majority of vesicles in all types, indicating low-grade metamorphism may have occurred. The most highly palagonitized material (tco unit in Fig.2 no.1 & no. 3) was shown to be surrounding the ring of the vent, not on the inside of the vent (Briggs, 1998). The dark grey palagonite (tcg unit in Fig.2 no.1) is found on the outskirts of the tuff cone. These facts suggest that palagonite changes composition from vent to outer areas. Taking these facts into consideration, suggests (1) palagonitization is lower inside the vent area; this may be due to a vastly higher water content throughout the alteration process, hence lower temperatures, (2) palagonitization is highest on the outer flanks of the vent; where temperature was increased as water was trapped and could no longer freely flow within the surge deposits, and (3) the composition of the palagonite changes as distance increases from the vent; euhedral plagioclase and olivine phenocrysts increase in size an modal percent as distance is increased from the vent area indicating this change.

Comparisons for Palagonitization

Palagonitized Cap ?

The models made in this study are in direct conflict with the findings of Lajoie (1963). Lajoie reasoned that palagonitization will occur via groundwater percolation and weathering only after the heat source has been lost. Clearly, this cannot be so. The models indicate that palagonite occurs to some considerable depth (300-500 meters) where percolation of gravity fed rainwater could not penetrate, nor was weathering a factor. In addition, tco units are found close to 6500 feet elevation whereas Lajoie infers that the palagonite zone exists only above 6800 feet. I propose that weathering was not a factor in the palagonitization that occurred at Black Point.

Is Black Point just a Pseudocrater ?

The possibility of the Black Point structure being a pseudocrater, or littoral cone has been eliminated due to several facts. The models of Black Point infer that this structure has a root. Pseudocraters are small rootless volcanic constructs (Greeley and Fagents, 2000) that erupt when lava interacts with groundwater.

Is Black Point a Replica of Surtsey Island, Iceland ?

What can be inferred from the formation of Surtsey Island, Iceland?

Summation of Surtsey results by Jakobsson (1978):

1) It is suggested that palagonitization occurs at temperatures ranging from ~ 45-100^{0}C, with abundant water vapor with a pH of 7.7-8.2, and a pressure of 1 atm.
2) The heat source for these alterations is lava craters and their feeders.
3) The process of palagonitization is isovolumetric.
4) Palagonite obtains a distinct color at 10-15 microns.
5) The greater the porosity, the greater the steamflux. The greater the steamflux, the more extensive palagonitization is.
6) Under submarine conditions, palagonitization proceeds evenly.

Summation of Surtsey gravity model studies by Porsteinsson and Gudmundsson, (1999):

1) Anomalous bodies are not present under Surtsey, indicating no pillow lavas present beneath Surtsey Island.
2) Density variations within the tephra must be considered for an accurate gravity survey.

Together, these studies depict the guidelines for the orogeny of the Surtsey volcano. Is this comparable to the orogeny of Black Point?

(1) We know that both erupted in an underwater setting. Surtsey and Black Point also have (at least) two eruptive centers. After the main eruptive site chokes itself off, another branch opens and surges continue until the magma chamber empties. The second eruptive site (near Surtsey), known as little Surtsey, was quickly eroded by wave action shortly after eruption. Black Point has two apparent vents, with the second one NNE of the main vent. Since there was no wave action of oceanic proportions, the second vent at Black Point remains as a remnant structure. It is possible that this vent was the main eruptive center, but not likely as evidenced by field mapping.

(2) Formation of zeolites at Black Point within vesicles indicates a low pressure, low temperature regime consistent with Surtsey and everywhere else palagonite is formed.

(3) The pH of the water during the eruption of Black Point must have been greater than 7.0, but certainly less than 8.0Pure water has a pH = 7.0 (Zumdahl, 1993). Lake Russell was not brackish at the time of eruption, presuming that fresh water predated Mono Lake due to fossils examined in nearby basalt intermixed with stream and lake sediments (Tierney 1997). This pH range is also consistent with formation of palagonite at Surtsey, which Jakobsson (1978) suggests a probable range of pH = 7.7 – 8.2

(4) There is a conflict with Black Point being a volumetric palagonite. Because three types of palagonite were characterized at Black Point by Briggs (1998), it is not prudent to assume that the palagonite on Black Point evolved in the same manner, or time frame, as a “voluminous” palagonite found at Surtsey.

Conclusions

This gravity study has succeeded in producing a geologically constrained model, which depicts the subsurface structure of Black Point. It may not be clear as to where the basement faulting occurs to feed the basaltic magma, but it is clear that Black Point is underlain by a high-density body to the E SE. The models suggest that palagonitized tuffs occur at depth, with the presence of water vapor and a heat source.

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