Determining the long-term behavior of monogenetic volcanic fields:

An integrated study of physical volcanology, tectonics and hazard assessment at the Lunar Crater and Reveille Range Volcanic Fields, Nevada (USA)

A proposal submitted to the committee of

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Abstract

The Lunar Crater and Reveille Range volcanic fields (Nevada) will be used to initiate an investigation into the widespread, global nature of monogenetic volcanic fields. These fields will be examined in terms of their physical volcanology, relationship to local structure, internal plumbing and potential future eruptions. This work proposes to determine the long-term eruptive behavior of these fields and to project comparable behaviors onto other volcanic fields with similar physical characteristics.

I. Introduction and Background

There are at least 150 monogenetic volcanic fields around the world (it is currently unknown how many are considered 'active'), some on the sea floor, but the overwhelming majority occur on the continental crust (Connor and Conway, 2000). Some fields have been studied extensively (e.g. the Southwest Nevada Volcanic Field (SNVF) in Nevada), but many are fundamentally unstudied, and even unnamed. The SNVF is likely the most studied volcanic field in the world due to its proximity to the proposed Yucca Mountain Nuclear Waste Repository. Like many of the volcanic fields in the United States, specifically those in the Southwest, the SNVF is considered remote and a future monogenetic eruption is not likely to seriously impact a large population (SNVF is ~150 km from Las Vegas, Nevada) in the next 10^{-8} years (Coppersmith et al., 2005). However, this is not the case for many other volcanic fields whose potential hazards may have a significant impact on populated areas (e.g. the San Francisco (near Flagstaff, Arizona) and Zuni-Bandera (near Albuquerque, New Mexico) volcanic fields in the United States or the Auckland (beneath Auckland metropolitan area, North Island) volcanic field in New Zealand). It is therefore necessary that volcanic fields be further examined in terms of their overall eruptive potential, which includes unraveling eruptive histories and magnitudes.

Volcanic fields occur throughout the world in every tectonic environment and have also been observed on other celestial bodies in our solar system (Head et al., 1992; Tanaka et al., 2009; Wood, 1979). They range in size from several to hundreds of square kilometers, and typically consist of monogenetic eruptive features such as; scoria cones, tuff cones and rings, maars, domes, and small shields. Some fields also contain polygenetic eruptive features like stratovolcanoes, calderas and somma volcanoes. While mafic compositions largely prevail in most volcanic fields, some are bimodal, especially those containing polygenetic eruptive centers.

The wide range of volcanic field sizes, number of vents, time-scales, explosive magnitudes, types of deposits and erupted volumes observed on fields around the world result from the complex relationships between variations in rising magma compositions, regional structure, environmental heterogeneities and many other factors encountered from source to eruption and deposition. While many researchers have focused largely on their geochemical evolution and modeling of a mantle source (Bergman et al., 1981; Dickson, 1997; Foland and Bergman, 1992; Stickney, 2004; Yogodzinski et al., 1996) there is little work in the literature regarding the wide spread characterization of volcanic fields. A small number of studies conducted at the scale of individual monogenetic volcanoes have expanded our knowledge individual eruptions over the lifetime of that volcano (e.g., Di Traglia et al., 2009; Kienle et al., 1980; Luhr, 1993; Riggs and Duffield, 2008; Valentine et al., 2005). However, few studies, if any, have explored the idea that systematic similarities may exist from field to field.

The aim of this project is to document in detail the physical volcanology, eruptive styles, behaviors and structural characteristics of two volcanic fields, the Lunar Crater and Reveille Range volcanic fields (LCVF and RRVF, Nevada), and to identify representative physical characteristics that will aid in the development of a general model of long-term eruptive behavior for all volcanic fields. I hypothesize that the long-term behavior of these two fields can be characterized based on physical parameters such as erupted volumes of melt, eruptive style (i.e. Hawaiian, Strombolian, violent Strombolian, phreatic etc…), and tectonic influence. I expect to then use these characteristics as a proxy to ascertain the long-term behavior of other volcanic fields, with the intention of developing a theory that most, if not all, volcanic fields around the world are fundamentally controlled by the relationship between the above mentioned physical parameters. This will ultimately result in presenting the scientific community with quantitive thresholds for those parameters.

The LCVF (Fig. 1) is an intermediate sized (80 km^2) alkali basalt volcanic field located in the and around the southern portion of the Pancake range in Nye county, Nevada. The volcanism here is superimposed on as many as 12 nested calderas known as the Central Nevada Caldera Complex (Best et al., 1989). Caldera-forming volcanism dominated the area from the Late Oligocene through Early Miocene (Best et al., 1993). These large ignimbrite deposits make up much of the underlying strata on which the later Tertiary and Quaternary basaltic volcanism is deposited (Rash, 1995; Sweetkind and du Bray, 2008). The field has been actively producing small-volume (< 0.5 km^3) scoria cones, maars and lava flows for the past ~4 Ma (Foland and Bergman, 1992; Yogodzinski et al., 1996), with the most recent eruption estimated between 38-20 Ka (Dickson, 1997;

Shepard et al., 1995). During this time the field produced at least 75 scoria cones, 3-4 maars and numerous lavas and produced an estimated total of 100 km^3 of volcanic deposits (Bergman, 1982; Foland and Bergman, 1992). The RRVF (Fig. 1) is a smaller bimodal volcanic field immediately south of the LCVF that has produced roughly 20 km^3 of basaltic, basaltic-andesite, and rhyolitic lava flows, scoria cones and domes for the past ~6.5 Ma (Naumann et al., 1991).

In the past ~6.5 Ma the focus of volcanic activity has gradually trended northward from the RRVF to the LCVF (Yogodzinski et al., 1996). The older volcanoes of the RRVF are more heavily eroded compared to the relatively pristine condition of the LCVF volcanoes and are hypothesized to be representative analogs of each other in terms of physical volcanological processes. Rarely is the shallow plumbing of subaerially preserved volcano able to be directly observed, and few studies have focused on using this type of exposure to constrain eruption controls (Valentine and Keating, 2007; Valentine and Krogh, 2006; Valentine and Perry, 2006). This exposure is expected to increase our insight into small-volume volcanic plumbing systems.

II. Approach and Methods

There have been many age determinations made in the LCVF and RRV. (Dickson, 1997; Dohrenwend et al., 1987; Kargel, 1987; Naumann et al., 1991; Scott et al., 1971; Shepard et al., 1995). However, many of these sources are found in the grey literature and meeting abstracts only and do not provide complete information as to their methods and/or sample locations (Bergman et al., 1981; Connor and Hill, 1994; Dohrenwend et al., 1987; Foland and Bergman, 1992). Of the approximately ~80 eruptive centers, there are only 20-25 useable age dates. Part of the proposed fieldwork will collect samples from volcanoes that are otherwise undatable through relative means to have new radiometric analyses performed.

The work proposed here will detail physical volcanological deposits (i.e. processes and behaviors) from several specific volcanoes in the LCVF and RRVF. Four sites were previously identified based on known characteristics and/or map and aerial photographs. Two volcanoes, the Easy Chair (Fig. 2) and Marcath (Fig. 3), appear to represent a complex form of monogenetic volcanism where the mapped deposits appear to show evidence of Hawaiian fire-fountaining and Strombolian-type explosions. The Easy Chair volcano, in particular, also has a phreatomagmatic component that effectively acts as a ‘quarry’ for exposing many eruptive sequences. This raises the question, with so many eruptive sequences, is Easy Chair monogenetic? The Lunar Crater maar (Fig. 4), the volcanic field’s namesake, is interesting in its own right. It too has acted like a quarry and exposed many previously buried eruptive sequences. One of the most interesting features, however, is a cross-section through the northeastern section of the maar where a fissure eruption and its lava flow have been preserved (Fig. 5). This cross-section is thought to represent the very last magma that moved through this system and will be petrographically and geochemically analyzed to determine any crystallographic textures or geochemical compositions that may be useful in determining the end of an eruption.

Field studies in the RRVF (Fig. 1) show that many of the scoria cones have eroded to expose their intra-cone plumbing systems by way of complex dike systems. These dikes were documented, measured and mapped in terms of their physical dimensions, vesicularity, crystalline and orientations on the remnants of one scoria cone in detail, tentatively named the No Name Reveille cone (Fig. 6). Insights from this work will be used as analogs for the proposed intra-cone plumbing systems of the younger LCVF scoria cones. Petrographic textural analysis to be performed on several samples collected from distal and proximal dike outcrops may be able to ascertain information about magma residence times, mixing and mingling events, and near eruptive conditions of the magma in the last stages of the eruption (Marsh, 1988, 1998; Morgan and Jerram, 2006).

During a volcanic eruption, information about the eruption dynamics and style are recorded in the clasts they eject. This information is in the form of clast shapes and sizes, textures from crystallinity and vesicularity, and lithic content. Understanding the link between the petrology of pyroclasts and the eruptive processes they record may help deduce similarities among many types of volcanoes and may well help constrain volcanic hazards for future eruptions.

Petrographic studies at individual volcanoes such as Paricutin (Pioli et al., 2008), Jorullo (Johnson et al., 2008), Stromboli (Lautze and Houghton, 2007), Mount Etna (Polacci et al., 2006; Taddeucci et al., 2004) and Lathrop Wells, Nevada (Genareau et al., in prep) reveal information about the magmatic processes controlling their respective eruptions. These studies include the textural analysis of clasts that is comprised of crystal size distributions (CSD), vesicle size distributions (VSD), clast sizes and shapes, crystal textures, and microtextures. Petrographic analyses on the volcanic rocks of the LCVF and RRVF may provide key insights into deciphering magmatic processes during eruptions.

One of the major challenges of this project will be to properly characterize the pre-volcanic basement in terms of its structure and how it has affected the recent volcanism. It is necessary to understand how the local structure and topography affect the eruptive behavior of individual eruptions as well as the volcanic field as a whole. This will be undertaken by identifying structural relationships in the field area such as; detailed mapping of fault and volcanic vent locations, identifying fissure sequences, vent lineations and mapping of exposed dikes. The better these features can be observed, mapped, measured and overall constrained, the more accurate the volume calculations can be.

The above-discussed physical volcanological and petrographic analyses will provide key insight into the individual nature of some of the volcanoes in the LCVF and RRVF, but the overall eruptive history and therefore field-wide, long-term behavior will be examined using statistical methods. Valentine and Perry (2007) have proposed that the long-term time-volume behavior of a volcanic field can be used as a deterministic empirical approach to predicting a volcanic field's future behavior. They argued that characteristics such as; erupted volume flux, repose intervals, pre-existing structure and topography reflect the relationship between tectonic strain, incipient melt and ascent through the lithosphere. A volcanic field with a high magmatic flux, such as the Eastern Snake River Plain (ESRP, Idaho), can repeatedly inject magma into the lithosphere, relieving the buildup of local stresses, overwhelming the regional tectonics of the area by changing the orientation of the least principle stress and suppressing faulting and seismicity (Parsons and Thompson, 1991). This magmatically controlled end member (i.e. volume-predictable) would exhibit a long-term linear relationship between the cumulative volume of a eruptive episode plus earlier episodes that could be regressed to estimate the repose time to the next eruption (Kuntz et al., 1986; Valentine and Perry, 2007). However, a volcanic field with a very low magmatic flux, such as the SNVF, has such low volumes of melt and therefore melt pressure, that it can only achieve an eruption once sufficient pressure is available to propagate dikes and erupt. This tectonically controlled end member (i.e. time-predictable) exhibits a long-term linear relationship with the repose interval and cumulative volume of earlier eruptions only (Bacon, 1982; Valentine and Perry, 2007). The LCVF was estimated by Bergman (1982) to have ~100 km^3 of erupted material, though this is a likely overestimate, the volume of the LCVF is substantially larger than that of the SNFV and substantially smaller than that of the ESRP and likely represents a transitional volcanic field between the two end members.

To assess the time-volume behavior of the LCVF, accurate volume calculations of individual volcanoes are needed. Determination of the long-term volume flux, along with the temporal distribution of eruptions in the field will be dependent on the observations made in the field and the development of a quantitative geometric model to compute the volumes. Field based work will be used to separate units and characterize the basement and other structures (e.g. faults, burial by later eruptions and/or sediments, erosion etc.) that may interfere with the integrity of the calculations. I propose to devise a model in either a GIS or CAD-based software platform to account for some of these uncertainties.

Traditionally, the ability to provide hazard analyses for monogenetic fields has been hampered by the additional complexity of not only predicting when the likelihood of a future eruption might occur, but where (Connor and Hill, 1995; Hintz, 2008; Jaquet et al., 2008). While this approach to predicting volcanic activity cannot solely be used to assess the likelihood of a future eruption, it does provide a systematic approach to correlating eruptive products and interactions with eruptive behaviors and processes so that we may apply it to other fields and make advances in our understanding of how monogenetic fields operate.

Some of the major tasks associated with this project are;

- Add new field data to existing maps and refine them to this project's needs.
- Construct technical illustrations of the dikes and fissure eruption from field observations.
- Calculate the erupted volumes of the LCVF and RRVF.
- Perform Crystal Size Distribution and Vesicle Size Distribution analysis on selected rock samples.
- Perform Monte Carlo Simulations on volume and age data sets.
- Perform time-volume behavior analysis.
- Perform spatio-temporal statistical analysis.

III. Expected Results

It is expected that through this work fundamental knowledge about the inner workings of several volcanic fields will be gained in hopes of applying it to more volcanic fields around the world. Aside from addressing the overall behavior of these volcanic fields, several papers are planned to address several features observed during the recent field work. One paper will focus on the intra-edifice plumbing observed on the No Name Reveille volcano and its role in aiding our understanding of monogenetic plumbing. At least one paper will likely focus on the complexity of the Easy Chair and Marcath eruptions. Another potential paper may focus on characterizing the end of eruptions in monogenetic volcanoes based on textural and geochemical analysis from the preserved dikes and fissures in the No Name Reveille and Lunar Crater volcanoes.

At present, what is known about volcanic fields has largely been focused on several fields in the western United States, Canada and New Zealand. There is a need for a global perspective, and therefore resource on volcanic fields. During the course of this study, I plan to compile information about various volcanic fields as I come across them in the literature. This will be the beginning of a comprehensive monogenetic field database that will be hosted online and provide references to peer-reviewed sources for the volcanological community. This database will serve a global resource for scientists studying intraplate or monogenetic fields. This work aims to better our fundamental understanding of these volcanic fields, which in turn will aid the abilities of future workers to assess volcanic risk.

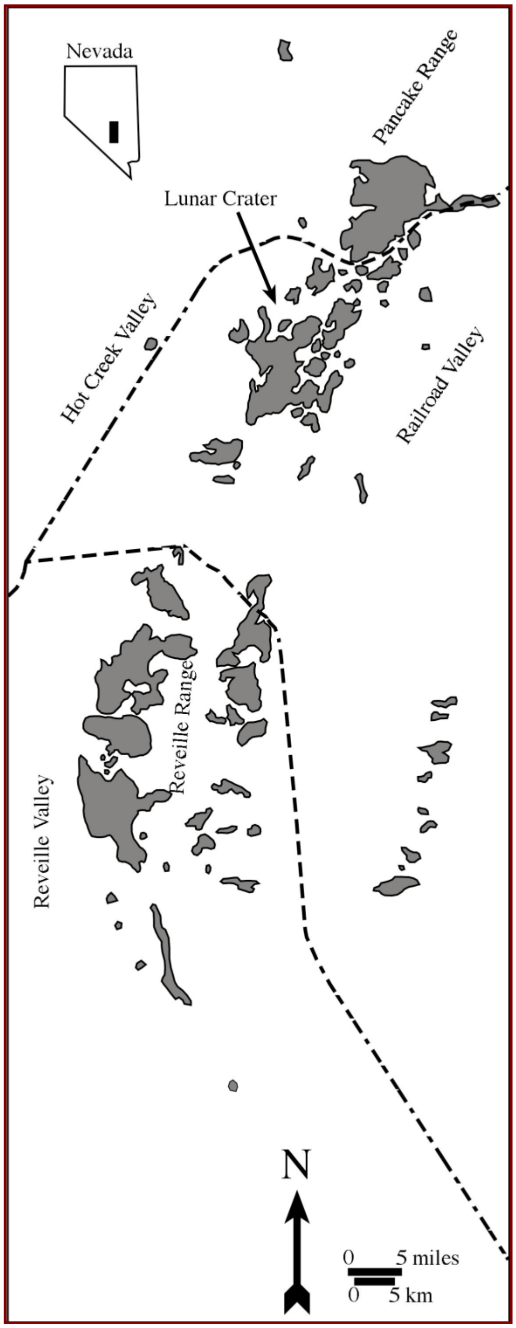

Fig.1. Simplified location map of the LCVF and RRV. Volcanic deposits are shown in grey. Dashed lines represent major roads. Modified after Foland and Bergman (1992).

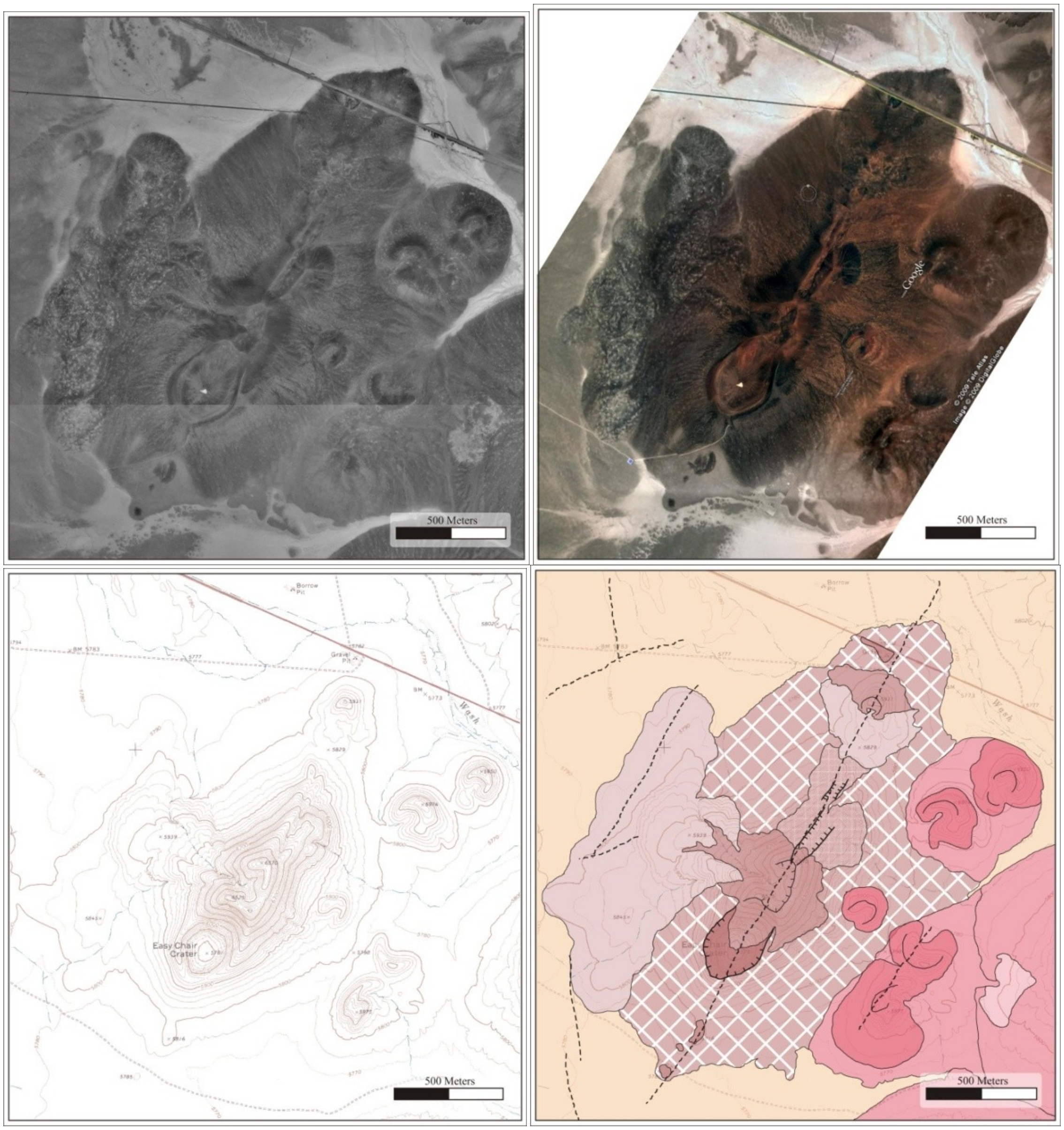

Fig. 2. Easy Chair volcanic cluster. (A) Aerial photograph of the Easy Chair area compiled from 3.5" USGS Digital Ortho Quads. (B) Satellite image compiled from Google Earth satellite imagery. (C) Topographic map of the Easy Chair area compiled from the Lunar Crater and Moores Station 7.5" USGS topographic quadrangles. (D) Preliminary geologic map compiled from (A), (B), (C), Snyder et al. (1972) and Dickson (1997). Geologic map does not reflect new data recently acquired from fieldwork. Geologic map from Stickney (2004) was not included in the preliminary map due to major differences from previously published maps, though this map deviates from previously published maps as well. Quaternary volcanic deposits shown as shades of red. Easy Chair deposits are variants of dull red, other deposits in bright red. Lava flows of Easy Chair shown as solid, pale, dull red and feeder cones shown darker with maar crater shown as darkest red; fissure deposits shown as stippled; ejecta apron shown with diamond pattern; scoria cone rims shown as solid black lines; alluvium and colluvium shown as tan; faults are shown as heavy dashed lines.

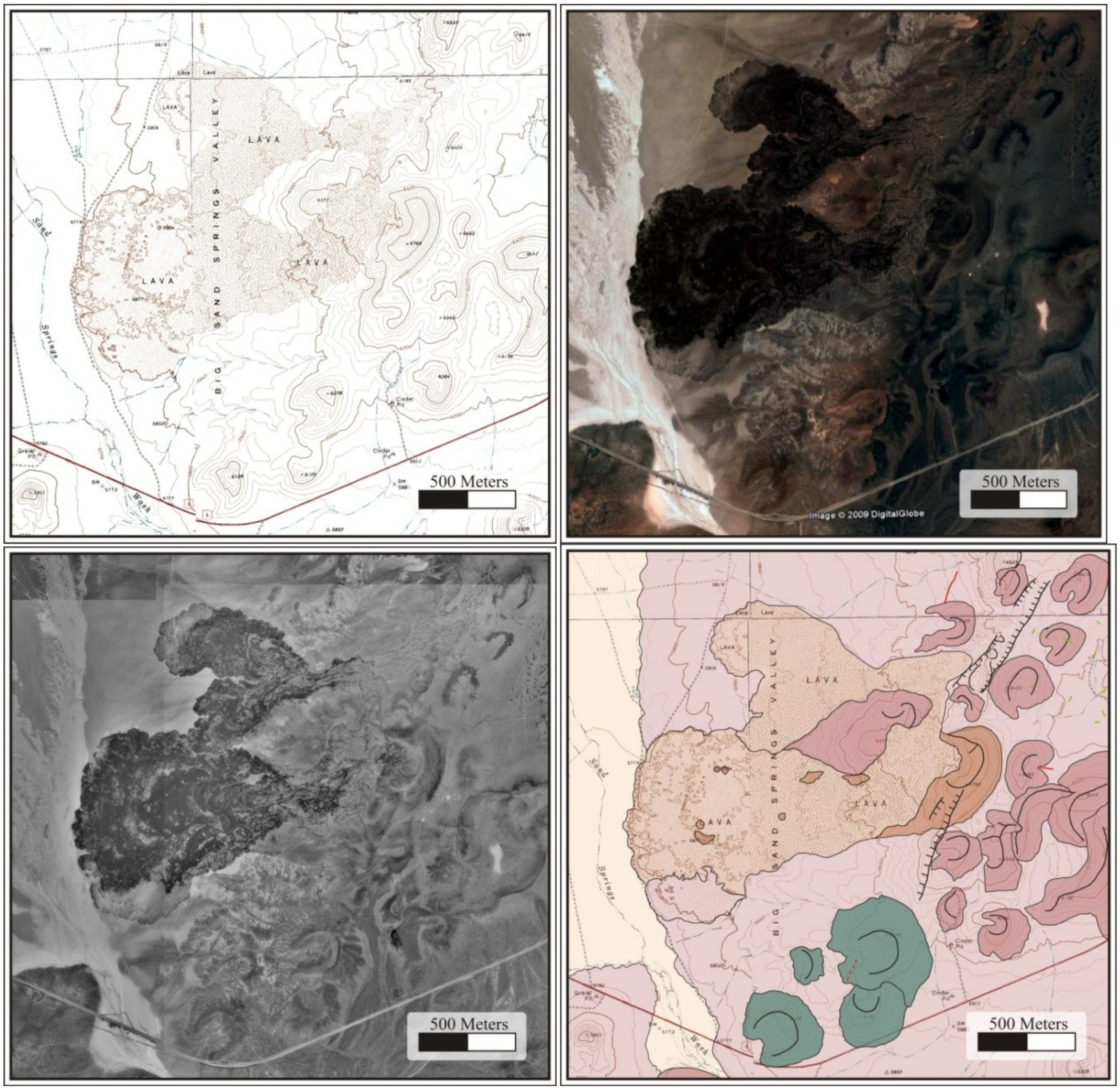

Fig. 3. Marcath volcano and related volcanics. (A) Aerial photograph of the Marcath area compiled from USGS Digital Ortho Quads. (B) Satellite image of the Marcath area compiled from Google Earth satellite imagery. (C) Topographic map of the Marcath area compiled from the Lunar Crater, The Wall, Black Rock Summit and Moores Station SE 7.5" USGS Topographic maps. (D) Preliminary geologic map of the Marcath area compiled from (A), (B), (C), and Stickney (2004). Tertiary volcanic deposits are shown as green; Quaternary volcanic deposits red; the Marcath cone and associated lava flows shades of orange; alluvium and colluvium as tan. Scoria cone rims are shown as solid black lines, dikes as dashed or solid red lines, suspected excavation pits as solid green lines, and suspected fissures as solid black lines with hachure marks.

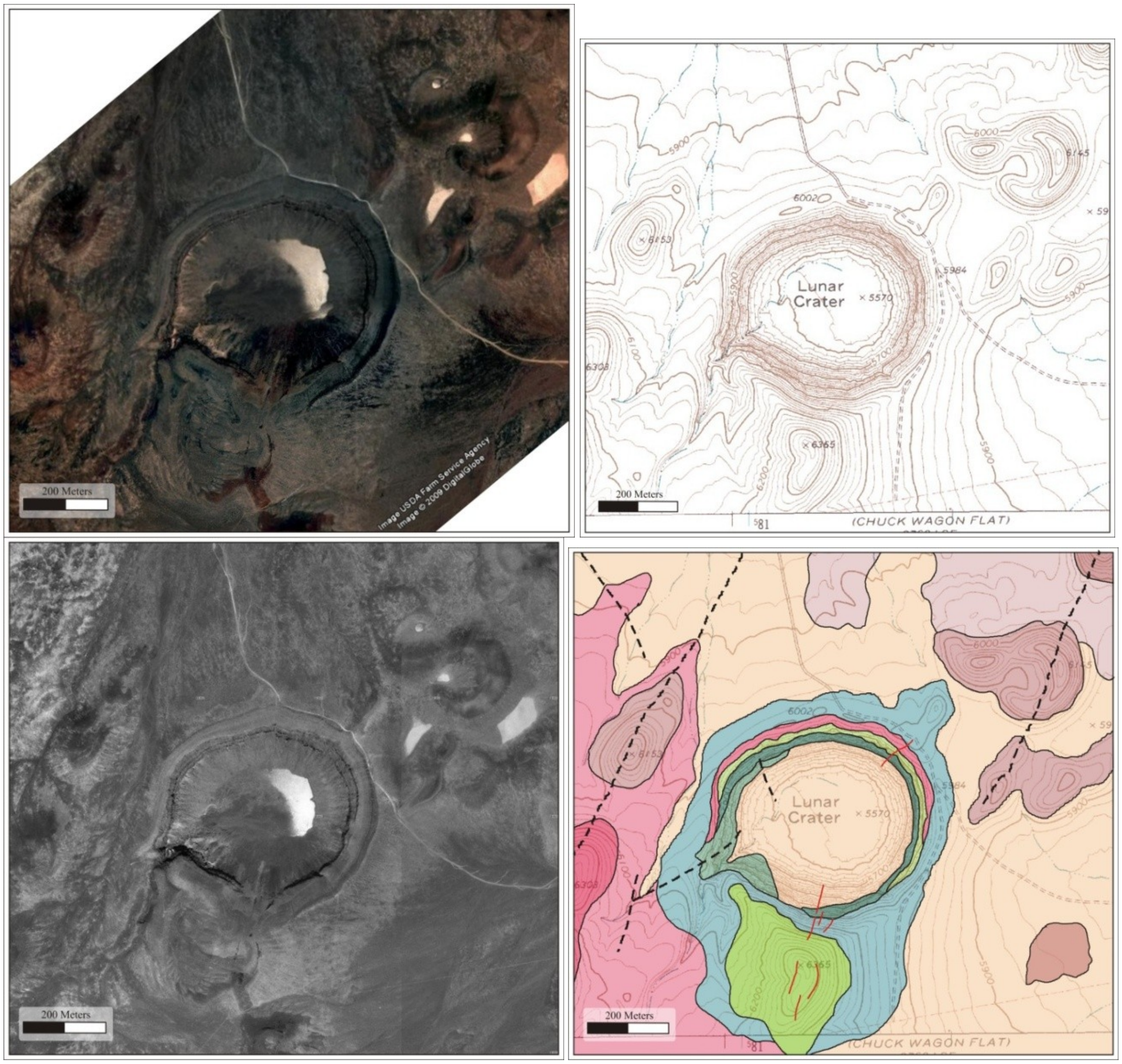

Fig. 4. The Lunar Crater maar and nearby volcanic deposits. (A)Aerial photograph of the Lunar Crater area compiled from 3.5" USGS Digital Ortho Quads. (B) Satellite image of the Lunar Crater area compiled from Google Earth satellite imagery. (C) Topographic map of the Lunar Crater area based on the Lunar Crater 7.5" USGS topographic quadrangle. (D) Preliminary geologic map compiled from (A), (B), (C), Scott and Trask (1969), Snyder et al. (1973), and Dickson (1997). Tertiary volcanic deposits are shades of green; Quaternary deposits shades of red and purple; maar deposits blue. Alluvium and colluvium shown as tan. Faults are shown as heavy dashed lines; dikes as red solid lines.

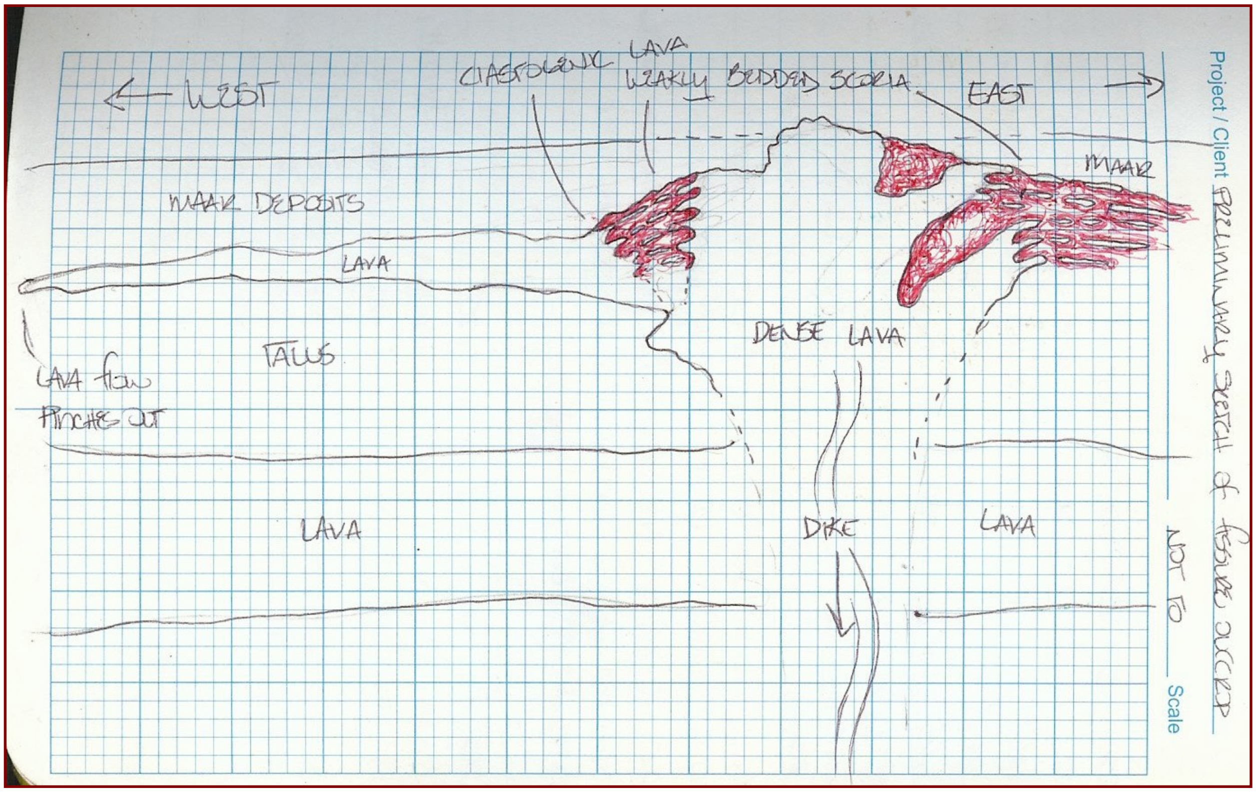

Fig. 5. Rough sketch from fieldbook of the preserved fissure eruption in the Lunar Crater maar. Not to scale.

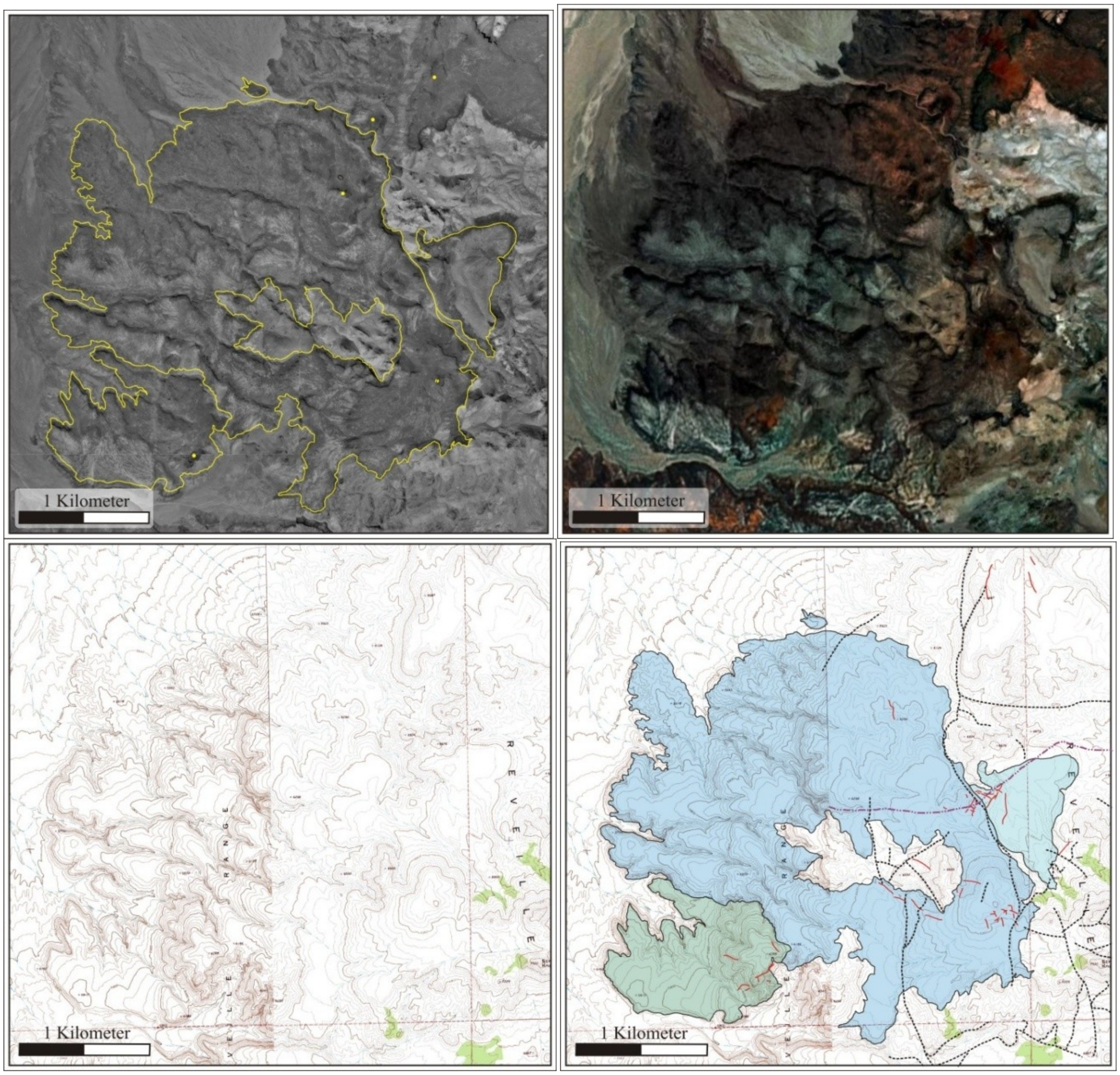

Fig 6. The No Name Reveille volcano. (A) Aerial photograph map showing outlines of proposed study area(s). Probable vent locations are yellow dots. Compiled from 3.5” USGS Digital Ortho Quads. (B) Satellite image compiled from Google Earth. (C) Topographic map compiled after USGS 7.5” Reveille and Warm Springs Quadrangles. (D) Preliminary geologic map compiled from (A), (B), (C), Ekren et al. (1973) and Martin and Naumann (1995). Tertiary volcanic deposits shown in shades of blue and green. Other volcanic deposits were omitted for simplicity. Faults are shown as heavy dashed lines; dikes as red solid lines.

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