A LONG VALLEY CALDERA – WHITE MOUNTAINS PBO CLUSTER

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INTRODUCTION

Background

Long Valley caldera lies in a left-stepping offset along the eastern escarpment of the Sierra Nevada at the northern end of the Owens Valley and the western margin of the Basin and Range province. The Long Valley caldera-Inyo-Mono Craters (LVCIMC) volcanic system has produced multiple volcanic eruptions in the last 1 Ma including the caldera-forming eruption 760,000 ybp and the recent Inyo-Mono Craters eruptions 500-660 ybp and 250 ybp. This volcanic system is within the White Mountains "seismic gap" [*Wallace*, 1981] between the northern end of the M~7.6 1872 Owens Valley earthquake and the sequence of M>7 earthquakes in the central Nevada seismic belt. Over the past two decades, Long Valley caldera has shown persistent unrest with recurring earthquake swarms, tumescence of the resurgent dome by over 80 cm, the onset of diffuse magmatic carbon dioxide emissions around the flanks of Mammoth Mountain on the southwest margin of the caldera, and other indicators of the invasion of magma to shallow depths beneath the caldera. Seismic activity within the White Mountains seismic gap during this period has included some seven M≥5 earthquakes east of Mono Lake, the M=6.0 Round Valley earthquake of 1984 and the M=6.4 Chalfant Valley earthquake of 1986. In response to onset of caldera unrest, the USGS established a suite of geophysical, geochemical, and hydrological monitoring networks within and adjacent to the caldera to track the unrest and to provide reliable, up-to-date information to local authorities on the nature of the hazard posed by this volcanic unrest. This effort is consolidated under the Long Valley Observatory (LVO), one of four volcano observatories operated by the USGS Volcano Hazards program.

We propose establishing a cluster within the PBO array spanning the Long Valley-Inyo-Mono Craters volcanic system, the northern end of the Owens Valley, and the White Mountains seismic gap. The proposed cluster will serve to expand the aperture of the existing monitoring networks focused on the LVIMC volcanic system to form a regional tie to the broader PBO array. This proposed cluster would provide invaluable leverage for advancing our understanding of the magmatic plumbing system for the LVIMC volcanic system and tectonic and magmatic interactions in the transtensional continental regime of eastern California and western Nevada.

Existing monitoring networks.

The following networks were installed within and adjacent to Long Valley caldera beginning in mid-1982 with upgrades continuing through the present. These networks comprise the current LVO monitoring effort.

**Seismic (~20 stations: a dense node within NCSN plus a TERRAScope station operated by Caltech and a CMG3-ESP station operated by UNR)*

*Borehole dilatometers (4 stations; one with a compromised response)

*GPS: continuous mode (12 stations with 4 baselines operated in real-time mode: 4 additional stations planned for 2001 bringing the total to 16)
**GPS: campaign mode (~45 stations)*
*Tiltmeters (7 borehole stations, 1 long-base with two 0.5-km orthogonal legs)
*2-color EDM (8 frequently measured baseline plus ~ 30 measured annually)
*Magnetic field (8 differential magnetic stations; 2 magnetotelluric arrays)
*Carbon dioxide soil gas concentrations (7 permanent stations, 1 continuous flux station –summer months only, plus periodic campaign and airborne measurements)
*Water wells (6 with continuous data, plus~ 30 measured monthly or triannually)
*The 3-km-deep Long Valley Exploratory Well (LVEW) located at the inflation center on the resurgent dome, which will be instrumented with borehole seismometers, a borehole strainmeter, and pressure transducers over the coming year to serve as a borehole observatory.

SCIENTIFIC PROBLEMS

The unifying scientific theme for the Long Valley caldera-White Mountains PBO cluster is: **Tectonic-Magmatic interactions and dynamics of the magmatic plumbing system.** Scientific issues central to this theme include:
1) Regional tectonic strain. What are the spatial-temporal variations in the strain field in the vicinity of LVC and the White Mountains where eastern California shear zone bifurcates to the Walker Lane and central Nevada seismic belts? Can we resolve temporal variations in strain at the regional scale, and if so, how do they relate to more local variations driven by magmatic processes within and adjacent to the caldera?
2) Magma transport and plumbing systems. Understanding the significance of unrest in the complex LVIMC volcanic field requires that we understand the underlying plumbing system and how it works. Key questions include: How does magma migrate from the lower crust or uppermost mantle to the multiple reservoirs in the upper crust? Are the crustal magma reservoirs beneath the resurgent dome, Mammoth Mountain, and the Inyo-Mono volcanic chain related, and, if yes, how? What can we learn about magma composition and the geometry of the plumbing system (including magma chamber size and shape) by tracking magma transport using a combination of seismic, deformation, and gravity data?
3) Strain partitioning. What governs the partitioning between normal faulting and dike intrusion in accommodating extensional deformation [a la *Sieh and Bursik*, 1986] within the White Mountains seismic gap? What governs the strain partitioning between the recent, dominantly strike-slip faulting in the Sierra Nevada south of the caldera and post-glacial dip-slip faulting on the Hilton Creek and other range front normal faults? What can we learn about variations in strain partitioning with time?
4) Remote (dynamic) triggering. Long Valley caldera has responded to the dynamic wave field from both the Landers and Hector Mine earthquakes with deformation transients and local seismicity. The triggered seismicity appears to be secondary to the local deformation transients. Although a number of intriguing models have been proposed, most of which involve the response of magmatic and/or hydrothermal fluid to seismic waves, limited spatial resolution of the deformation transients precludes a more complete understand the triggering process and its significance.

5) Static stress triggering. How do changes in the static stress fields associated with regional M>5 earthquakes and the inflating Long Valley magma chamber influence one another? Are “static” stress changes from regional earthquakes truly step-like or do they include a significant transient component similar to those associated with the remote triggering episodes? What can we learn about local tectonic-magmatic interactions?

INSTRUMENT DEPLOYMENT AND LOGISTICAL ISSUES

To address the above scientific problems, we propose a Long Valley Caldera-White Mountains PBO cluster spanning an area 80 to 100 km in diameter populated with ~45 continuous GPS stations and ~24 borehole strainmeters (including the existing LVO sites) as illustrated in Figure 1. The bulk of the installations (18 borehole strainmeters and 24 GPS sites) are within 10 km of the LVCIMC volcanic system with a station spacing of 8-10 km. Such a distribution is necessary to begin to effectively deal with the many degrees of freedom associated with multiple seismic and magmatic deformation sources active over a common time interval in a spatially distributed volcanic system as is typical of caldera unrest. The remaining installations (4 borehole strainmeters and 16 GPS sites) span the White Mountains “seismic gap” with a spacing of 20-25 km. We include the seismically active Sierra Nevada block south of the caldera, which has acted in concert with the caldera unrest since 1978-79. The aperture of this proposed cluster is roughly twice the local crustal thickness (approximately 40 km in this part of the world), which is necessary for resolving deformation patterns associated with magma transport into the base of the plumbing system from sources in the lower crust or uppermost mantle and for resolving the spatial extent of deformation transients associated with remote triggering and stress transfer with future regional M> 6 earthquakes. We believe it is important to integrate the continuous, but spatially aliased, deformation data from this cluster with periodic campaign-mode GPS surveys occupying more closely spaced benchmarks together with periodic InSAR images of the area to maintain a spatially continuous perspective of developing deformation patterns.

We propose that the borehole strainmeters in this cluster be 3-component instruments with co-located borehole tiltmeters and seismometer packages. In this volcanic environment, it will be important to record the seismic band (200 sec to 10 Hz) from the borehole strainmeters. We have, for example, recorded three very-long-period (VLP) volcanic earthquakes (dominant periods of 10’s of seconds to two minutes) on the seismic band of the POPA borehole dilatometer located 5 km west of Mammoth Mountain. These VLP events resemble those detected beneath Kilauea volcano (Hawaii), which *Chouet et al*. [1998] interpret as representing slugs of magma moving through cracks. Where feasible, we propose instrumenting a water well adjacent to the borehole strainmeter installations to track variations in the water table, which can induce local dilatational strain signals.

We propose incorporating the U.C. San Diego absolute gravity network, which will include a continuously monitoring tidal gravimeter to be installed in the spring of 2001, within the instrument cluster together with periodic surveys of microgravity stations in the area. Temporal variations in the gravity field provide unique information on mass transport in areas of active deformation. When combined with reliable information on elevation changes and variations in depth to water table, temporal variations in the gravity field can be used to distinguish between deformation resulting from phase changes (volume increases associated with a crystallizing magma chamber as suggested by *Fournier* [1999]) and local mass increases associated with magma intrusion [*Battaglia et al.*, 1999]. This is a crucial issue for understanding the processes driving the uplift and subsidence in restless calderas.

The high elevation (and associated severe winter weather) together with the rugged topography that characterizes much of the Long Valley caldera-White Mountains area poses challenging logistic problems for the installation and maintenance of instrument arrays that record continuously and transmit data in real time. The proposed distribution of stations illustrated in Figure 1 includes a general recognition these problems. The proposed distribution also reflects the logistical advantage of co-locating GPS and borehole strainmeter sites to take advantage of common telemetry paths and permitting issues. The final configuration, of course, will require a considerable investment in permitting and site evaluation and will differ in detail from the configuration in Figure 1.

The Long Valley Caldera-White Mountains PBO cluster and volcanic hazards. The USGS carries statutory responsibility through the Long Valley Observatory (LVO) for monitoring the volcanic unrest in the Long Valley caldera-Inyo Mono Craters volcanic system and communicating the implications in terms of volcanic hazards to civil authorities. Two issues deserve special emphasis in this regard: 1) Data bearing on an evolving seismic or volcanic crisis must be available to LVO in near-real time; and 2) the scientific community must coordinate any statements on volcanic hazards through the Scientist-in-Charge of LVO. It is essential, particularly during a crisis, that we (the scientific community) present legitimate differences in scientific viewpoints to civil authorities in a coordinated manner that honestly reflects uncertainties in our understanding of the evolving crisis and its likely outcome.

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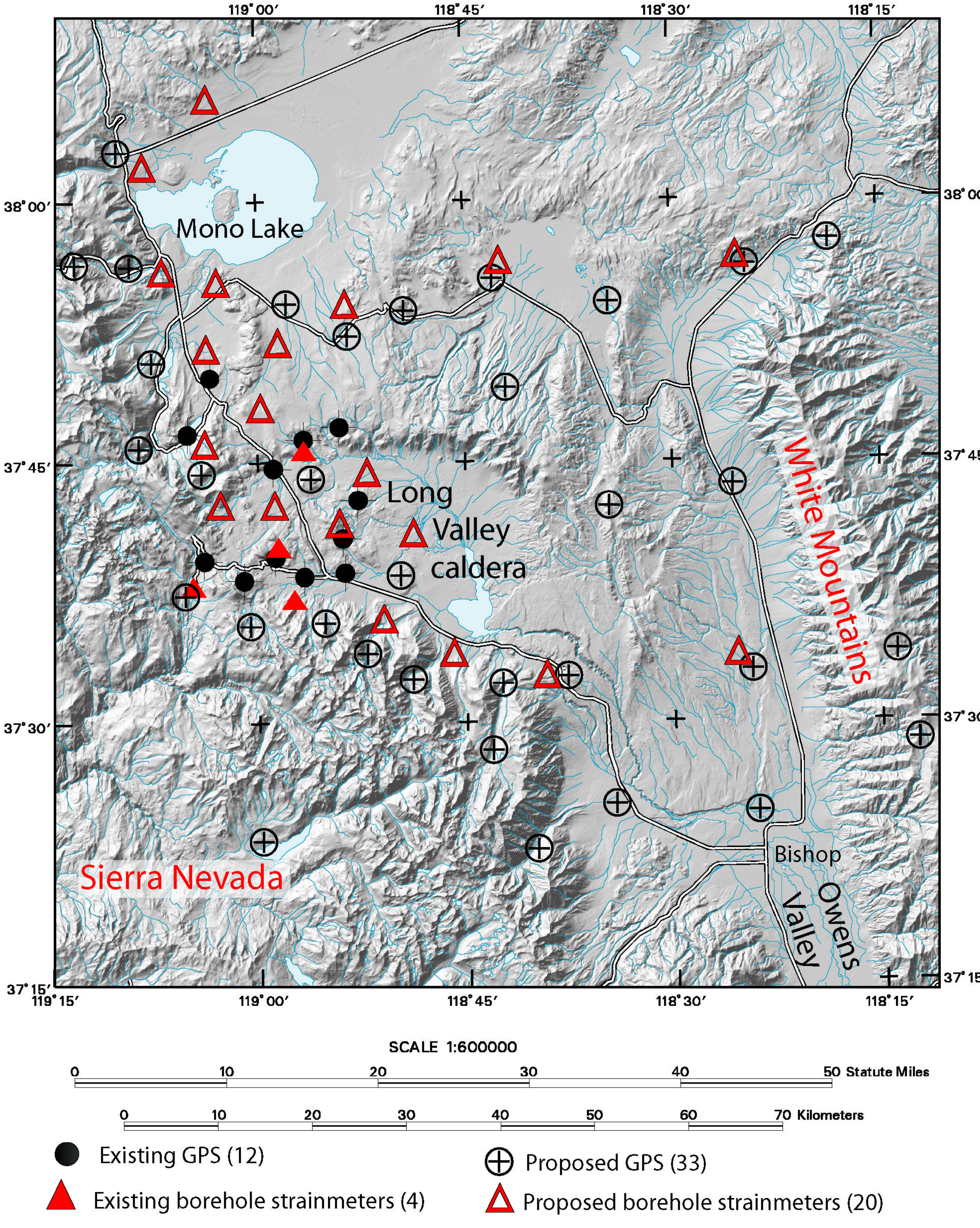

FIGURE 1. Existing and proposed locations for strainmeter and GPS sites in the Long Valley caldera-White Mountains area