Yellowstone Hotspot Component of the Plate Boundary Observatory

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Introduction The Yellowstone hotspot is the preeminent and most accessible hotspot on the globe. Its volcanic and tectonic activity has affected five states, fully 25% of the western U.S. interior, in the last 16 Ma years (Fig. 1a.). The hotspot is currently active at Yellowstone and it has left a trail of volcanic centers on the Snake River Plain (YSRP). It is located within the extending Basin-Range intraplate regime and occupies a prominent part of the eastern edge of the deforming western U.S. Cordillera. Further, Yellowstone s active tectonic and volcanic history has been studied in a wide range of geologic and geophysical investigations, beginning with the famous Hayden 1872 surveys. Pertinent to this proposal is that it has included unprecedented crustal deformation of the Yellowstone caldera and the adjacent Hebgen Lake fault measured by leveling, GPS, and InSAR. This information offers an important basis for a Yellowstone geodetic PBO mini-project.

We specifically note that the YSRP is more than just a volcanic province. It is a profoundly active tectonic feature dominated by Basin-Range extension and normal faulting including the largest earthquake in the province, the M 7.5 1959 Hebgen Lake earthquake, as well as a M 7.3 event in 1983. Its seismotectonic processes are driven by a combination of intraplate tectonic and magmatic mechanisms that interact and are fundamental to plate boundary deformation.

The mini-cluster proposal defined here is designed to assess the kinematics and dynamics of the Yellowstone hotspot and its interaction with the continental lithosphere by densifying the existing CGPS array. This will be done by adding 37 new continuous CGPS stations, 5 strainmeters, and conducting campaign GPS surveys on specific targets. The new geodetic network will address key geodynamics questions such as how the hotspot processes affects active tectonism and volcanism including transient deformation associated with the Yellowstone caldera, the influence of Basin-Range extension, and how intraplate deformation is driven.

Our plan builds upon the infrastructure developed in the Universities of Utah and Oregon 1998-2002 NSF Geodynamics of the Yellowstone hotspot study and a USGS Volcano Hazards project that covers the Yellowstone volcanic field. The current YSRP projects have a combined 13-station skeletal CGPS network, but this array only begins to provide station density needed a full-scale crustal motion investigation.

We suggest the Yellowstone hotspot for study because: 1) It is the world s largest continental hotspot and it is accessible, which is essential for operation of reliable and efficient GPS facilities. 2) The Yellowstone hotspot has interacted profoundly with the continental lithosphere during its 16 Ma history, including development of giant volcanic centers and affecting normal faulting on its perimeter, 3) It has experienced high rates of crustal deformation. 4) It is the most seismically and tectonically active area of the eastern Basin-Range. And 5) it occupies a significant part of the U. S. plate boundary.

Tectonic and Volcanic Setting -- Underlying our proposed study, the YSRP is an 800 km-long 16-Ma track of explosive silicic volcanism with more than 150 caldera-forming eruptions. It is surrounded by a zone of earthquakes and active normal faults, and is most volcanically active at Yellowstone (Fig. 1a). The hotspot has caused modification (re-melting, igneous intrusion, etc.) of the crust and mantle and has reformed large-scale topography by faulting and extension, all processes that remain active today.

Moreover, the smaller but more volcanically active Yellowstone area includes a silicic caldera-forming volcanic system fed by a shallow crustal magma source and includes three giant calderas 2.0, 1.2 and 0.63 Ma years old as well as 30 post-caldera flows and active faults. The youngest caldera, the Yellowstone caldera, 50 km x 40 km, has experienced unprecedented historic crustal uplift measured by leveling and campaign GPS of ~1 m (1923-1985), followed by subsidence and caldera contraction at rates of 1 to 2 cm/yr (1985-1995). These processes have occurred within a 5 mm/yr. NE extensional field (Fig. 1b) and demonstrates the influence of regional Basin-Range tectonism. Most recently InSAR and GPS studies suggest that the caldera is experiencing yet another change in deformation to uplift — it is indeed a living, breathing caldera .

Background investigations of Yellowstone, the Snake River Plain volcanic field and the surrounding tectonic parabola include: 1) volcano and tectonic studies by the USGS, Christiansen and Morgan; R.P. Smith, INEEL; Anders, Columbia Univ. and Perkins and R.B. Smith, Univ. of Utah; 2) tectonic framework, active tectonic and trenching studies by University, USGS and consultants, including Janecke, Lageson, McCalpin, Schwartz, Olig and Machette; 3) seismic network and tomographic imaging of by the Universities of Utah and Oregon, Smith, Humphreys and Duekers, as well as the availability of earthquake information from the Montana, Yellowstone and INEEL seismic networks; Stickney, Smith and Payne; and 4) crustal deformation measurement of by leveling, GPS and InSAR, by Universities and the USGS Smith and Meertens, Dzurisin and Thatcher

Scientific Goals-- The scientific goals of our proposal are to develop an intraplate deformation model of the YSRP and its effect on the overall North American plate motion dynamics. This will include elucidating horizontal and vertical strain partitioning on faults and volcanic features, asthenosphere-lithosphere interaction, and assessing short term transients of tectonic and volcanic activity of the Yellowstone volcanic field.

<u>Fault Slip vs. Geodetic slip</u> -- The project will provide key information on the differences between Holocene and geodetically determined fault slip rates. The SRP itself has no mapped faults but includes several Late Quaternary volcanic rifts and associated dikes. This raises the question if GPS determined displacement rates, currently only measured using campaign surveys across the SRP volcanic field, are comparable to extension of the surrounding fault zones. This balance would be necessary to maintain the deformation pattern. In addition, what is the driving mechanism of the aseismic deformation of the SRP. These examples demonstrate the importance of the understanding the interaction of magmatism and tectonism and are key elements of the distribution of strain across the intraplate boundary.

<u>Tectono-Volcano Transients</u> — We will focus a part of the on densification of a CGPS network (building upon 7 existing CGPS stations from current NSF and USGS studies) and adding five borehole strain meters across the Yellowstone caldera to asses transient deformation. Ephemeral motions of the caldera as demonstrated by the unprecedented changes from uplift to subsidence and now to uplift in just 15 years plus concomitant earthquake changes that suggest important short-term interactions.

<u>Long Term, Regional Deformation Field</u> — We note that as much as 6 to 7 mm/yr NE extension occurs across the entire YSRP system (Fig. 1c). This is about 75% of the total Basin-Range opening rate. Therefore a broader goal is to investigate how the deformation field of the YSRP fits into the western U.S. The data gained in this PBO mini-project will

provide a key constraint on models of the intraplate boundary process and the balance of plate motion. This task also addresses the question of continuous deformation vs. discrete fault-boundary deformation to accommodate the overall motion field (Fig. 2a).

<u>Continental Hotspot Deformation and Superposed Extension</u> --The continuous GPS measurements and kinematic modeling will also help resolve how the Yellowstone hotspot deformation field ties into a western U.S. extensional framework.

Therefore a more complete goal is to develop a unified dynamic model (Fig. 2a) constrained by observed geologic (fault slip rates), dike models (extension rates), and GPS determined rates within a framework of intraplate deformation. New images from seismic tomography will constrain the structural geometry of the crust and mantle and will be supplemented by densified USArray seismic deployments.

The larger scale geodynamics goals are thus to determine the geometry and dynamics of plume flattening and small-scale convection within the asthenosphere and lithospheric deformation driven by tectonic and magmatic processes. These models will include intraplate boundary forces, vertical and horizontal strain and density partitioning, effects of weaker or stronger inclusions such as a strong core of the SRP, a weak and hot Yellowstone crust, and the effects of dynamic topography and thermal buoyancy forces on faulting and topography. And of course the influence of variable rheology due to thermal sources will be a key feature of the models.

Infrastructure — The proposed Yellowstone hotspot PBO network will benefit by the existing facilities developed for the NSF Yellowstone hotspot project and USGS Volcano Hazard programs. These include established recording and processing facilities and the development of cost-effective monument installation. It also involves extensive experience and installation of microwave, satellite and spread-spectrum telemetry links and repeaters that tie to Internet access sites, as well as related efforts by UNAVCO and University engineers to develop telemetry-Internet connectivity software. Telemetered GPS data are currently archived at the UNAVCO facility and are transmitted to the University of Utah for processing using the Bernese Processing engine.

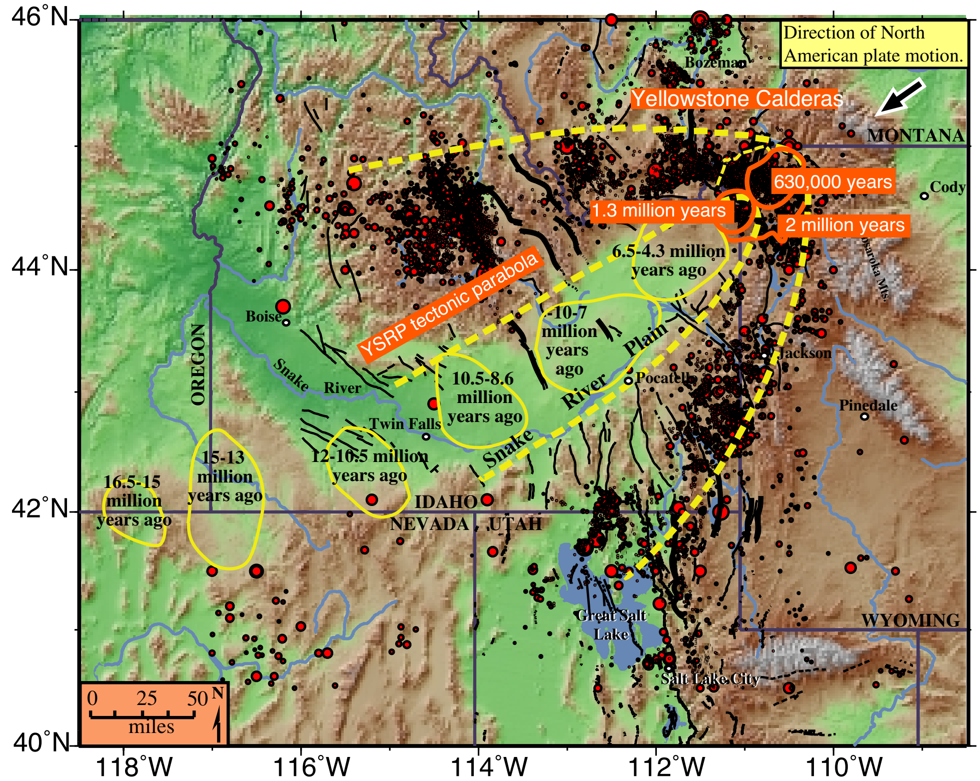
We specifically note that the PBO CGPS mini cluster for Yellowstone will be coordinated with the USGS and National Park Service needs for monitoring, interpretation and educational outreach.

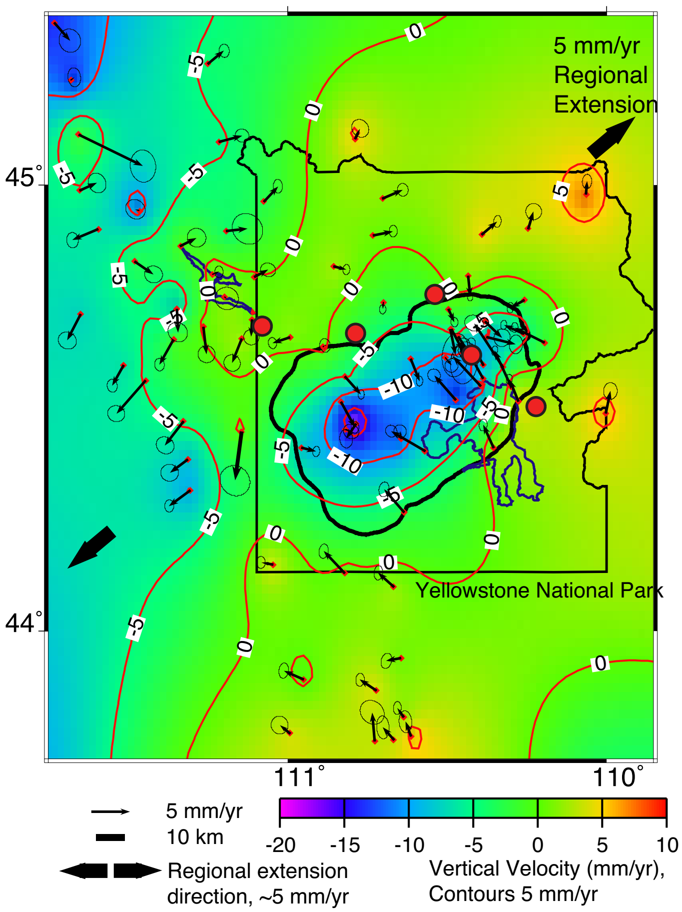
Network Design and Accessibility — To address the science goals of this experiment, we propose an expansion of the existing Yellowstone hotspot CGPS networks (consisting of 13 sites) to a total array of 37 stations (Fig. 2b) with densified networks across the Hebgen Lake and Lost River faults (locations of the two large M7+ historic earthquakes). Station density is predicated on the need to record unaliased horizontal motions of the volcanic and tectonic features while the areal pattern is designed to cover the breath of active tectonic and volcanic features (Fig. 1a)

Campaign GPS surveys will compliment the CGPS surveys in areas of short wavelength deformation such as across specific faults and volcanic features.

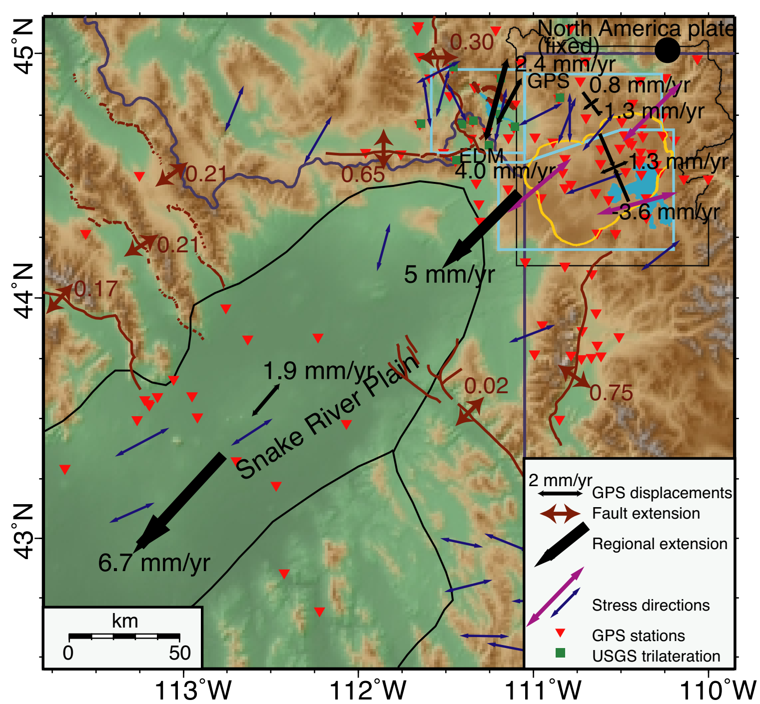
A five station borehole strain meter array (Fig. 1b) will be placed strategically within and around the Yellowstone caldera near. These will be near the areas of maximum observed deformation gradients and near the areas of hydrothermal/ magmatic fluids systems accommodating the unprecedented deformation changes. These data can be correlated with observations of temporal changes in seismicity and concomitant changes in hydrothermal activity.

1a. Topography, volcanic centers, faults and earthquakes of the Yellowstone Hotspot (Yellowstone-Snake River Plain)



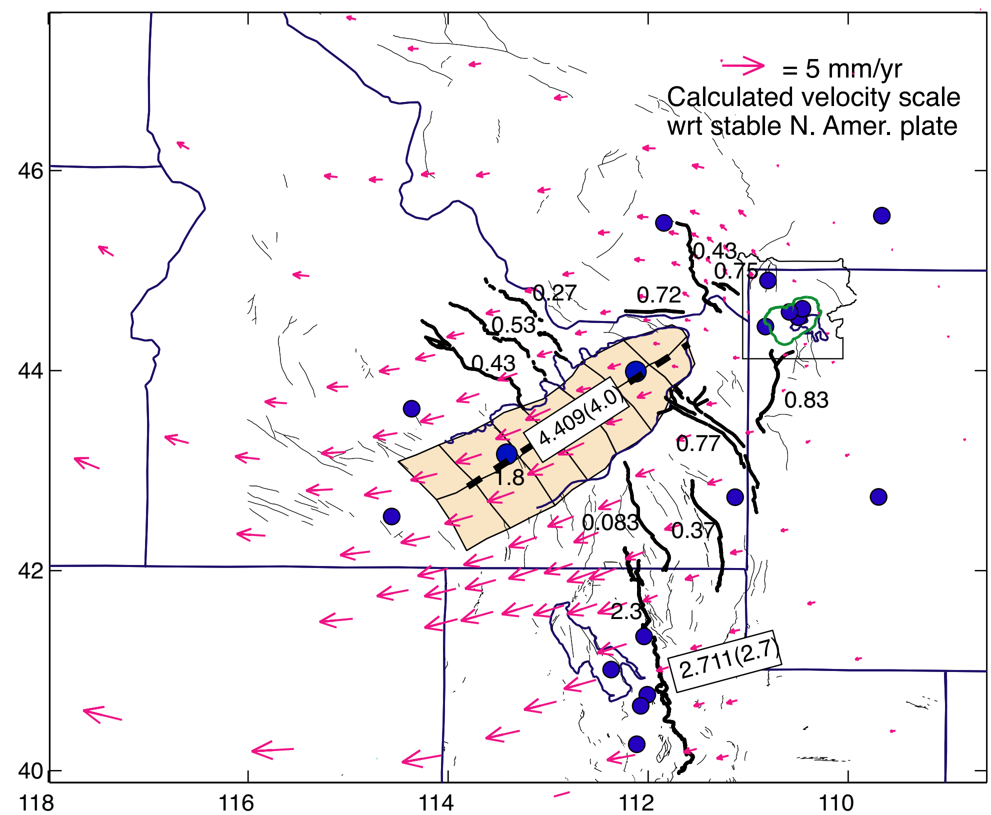


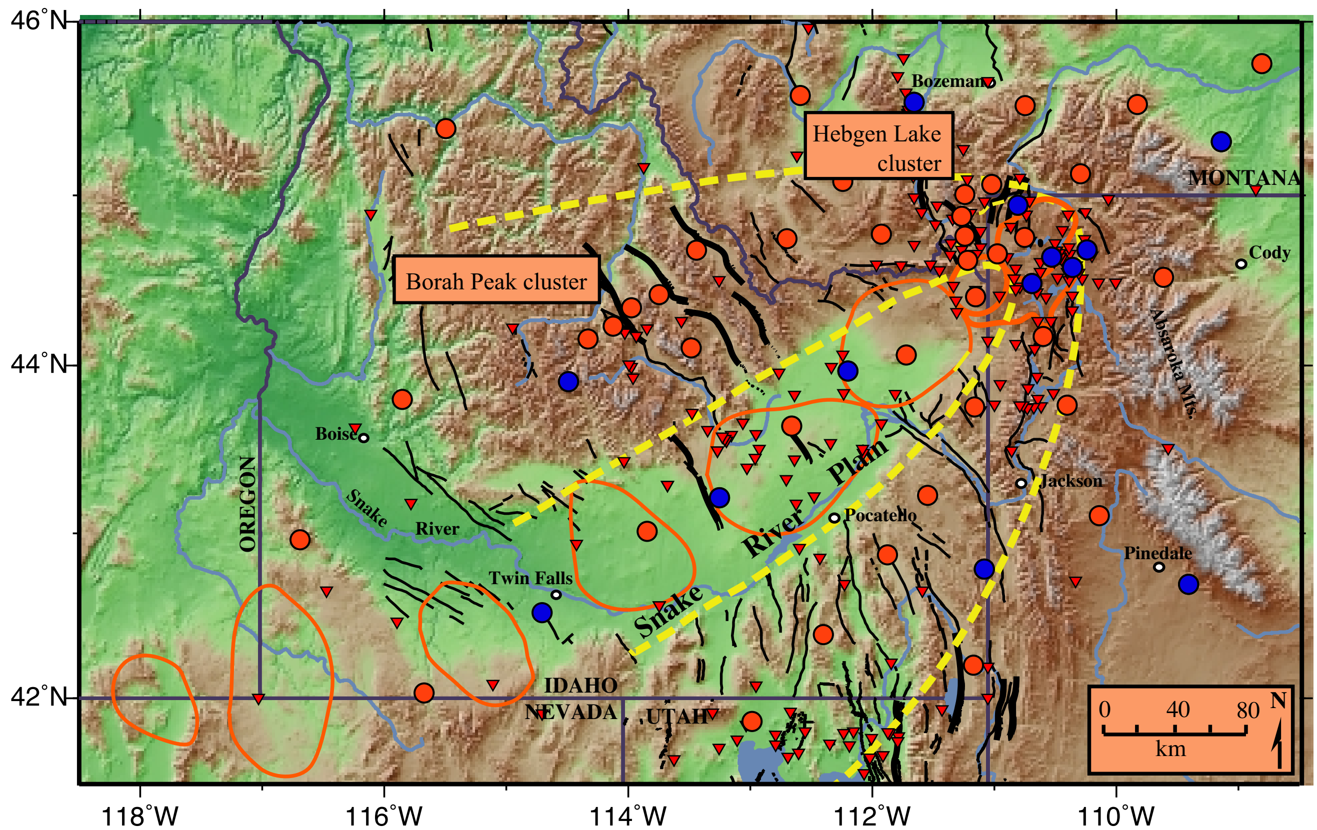
1b. 3-D velocity field of the Yellowstone caldera from campaign GPS measurements, 1987-1995. Proposed borehole sites (●)



1c. YSRP velocity vectors from campaign GPS (1987-1995) measurements. Cumulative velocity vectors shown by large arrows.

2a. Finite-element calculated velocity field constrained by Holocene fault slip rates (mm/yr) and GPS vectors (mm/yr, in boxes). Existing Yellowstone hotspot CGPS sites are noted as (●).





2b. Locations of existing (●) and proposed (●) CGPS sites for Yellowstone hotspot PBO mini-cluster. Campaign GPS sites are noted as (▼)