Kinematics and Earthquake Physics of the Wasatch Fault
(Investigators: Smith, Thatcher, Meertens, Harris, Dieterich, Friedrich, Wernicke, McCalpin, Bruhn, Schwartz, Machette, Wong, Olig, Christensen)

Introduction --The Wasatch fault zone, Utah, is a major part of western U.S. plate boundary that bounds the extensional deforming Basin-Range and the stable North American Plate (Fig. 1a). It is a quintessential normal fault that separates the topographically high Wasatch Range, with up to 2 km of topographic relief, from the stable interior. Also it extends more than 370 km of the 1300-km-long Intermountain Seismic Belt, traversing the populated Wasatch Front where 80% of Utah s 2 million population live. It is an important candidate for a PBO mini-cluster study of earthquake physics and related intraplate driving mechanisms.

Tectonic Setting and Deformation Rates of the Wasatch Fault

The Wasatch fault has been the focus of extensive geologic and geophysical studies beginning with G.K. Gilbert s pioneering work of the on normal faults at the turn of the 20th century. These studies emphasized the significance and scope of the Wasatch fault within the extensional architecture of the Basin-Range.

Late Quaternary Loading Rates -- Recent studies have elucidated Late Cenozoic slip and exhumation rates of the Wasatch Range and accompanying fault slip of ~1 mm/yr. (in the plane of the fault) with up to 11 km of total fault offset (Parry, Bruhn, and Ehlers, Univ. of Utah). New mapping by Harris, BYU, and Friedrich, CalTech, aided by comparisons with Basin-Range seismic reflection profiles of normal faults, has suggested a low-angle geometry of the Wasatch fault, ~ 40°, surprisingly similar to the inverse models of GPS data (below). But they are in contrast to the results from focal mechanism studies of large normal faulting earthquakes across the globe (Jackson, Cambridge; Doser and Smith, Univ. of Utah) that showed an average 55° dip, notably steeper than modeled for the Wasatch fault. These and ancillary seismic and gravity analysis (Smith and Bruhn, Univ. of Utah, Zoback, USGS), as well as seismicity of the Wasatch Front (Arabasz and Smith, Univ. of Utah), provide key background information for this proposed project.

Further, the Wasatch fault is one of the most, if not the most intensively studied normal faults on the globe. It is a quintessential normal fault because of its remarkably long 370-km length, large offset, and seismic activity. Twenty-seven trenches have been excavated on the fault, most accompanied by geomorphic analyses (Schwartz, Machette, USGS; Christensen, Utah Geol. Survey, McCalpin, Olig and Wong, consultants). These studies revealed Holocene slip-rates of 0.5 to 1.5 mm/yr. importantly, these studies lead to the definition of characteristic earthquakes where slip occurs repeatedly with constant offsets.

Recent investigations, integrating paleoseismicity and GPS information (Chang and Smith, Univ. of Utah), have demonstrated 13 (dual-segment) or 17 (single-segment) M7+, scarp-forming earthquakes in the last 5,600 years, with an average return rate of 430 or 350 years, respectively. The last event on any segment was 600+ years ago. However, a mega deep trench excavated in 1999 (McCalpin, consultant) near Salt Lake City accessed strata as old as Lake Bonneville time, 12,000 years ago, and surprisingly did not reveal any slip on the fault to 5,600 years ago, the age of the oldest event. This implies a ~ 6,000 year hiatus and more importantly, suggests contemporary earthquake clustering. Also, Wernicke and colleagues have argued that a significant component of Wasatch fault loading rates may be attributed to viscous strain recovery in response to large prehistoric earthquakes.

Contemporary Deformation Rates — On the other hand, EDM (Savage, USGS) and campaign GPS studies, begun in 1972 and now corroborated by continuous GPS measurements (Smith, Meertens, Martinez, Univ. of Utah; Wernicke, Friedrich, Bennett, CIT; Thatcher, USGS), have revealed horizontal deformation rates that are higher than those implied by the geologic rates. For example, a strain rate of 50 _ 20 nstrain/yr across a 55 km wide network observed, from 1993-1996, by the Univ. of Utah corresponds to horizontal deformation rates up to 2.7 – 1.3 mm/yr spanning the Wasatch fault. These values were corroborated by CGPS measurements that revealed rates increasing south to north of 1.7 to 2.7 mm/yr across the fault zone, averaging ~ 2 mm/yr. These rates are a notable component, 20%, of the total Basin-Range opening rate of ~10 mm/yr. (Fig. 1a and 2a), suggesting that strain rate is concentrated on the Wasatch fault.

Further, the GPS studies are supported by a preliminary InSAR analysis of Wasatch fault deformation (Sabatier and Feigl) that demonstrated a complex pattern of valley-wide uplift and subsidence from 1992 to 1998. However the data lacked coherency in the footwall block for a complete analysis. None the less, they point out the need to investigate in more detail the relationship between foot- and hanging-wall deformation and how it varies along the entire fault zone. (See Fig. 1b for a summary of various geologic, geodetic and seismic source contributions to earthquake recurrence of the Wasatch fault).

Inverse Modeling of GPS Data -- While the geometry of the Wasatch fault is not known GPS deformation measurements have been helpful to evaluate this property. Recently, Chang and Smith, applied Cerevilli s self-annealing inversion code to the campaign and CGPS data as well as the EDM measurements on the Wasatch fault at Ogden, Salt Lake, Provo and at its southern end (Fig. 2a). The inverse models suggest slip-rates of 5 to 7 mm/yr. on a single, 35¡ to 50° west dipping normal faults with locking depths of ~15 to 17 km. These rates are notably in excess of the loading rates deduced from the Holocene slip estimated from the trenching measurements. This emphasizes the question of how slip determined on near-vertical fault exposures in alluvium reflects the tectonic loading at seismogenic depths loading inferred by the GPS models.

These findings raise important questions that can be answered by a focused PBO study regarding the physics and magnitude of strain on the Wasatch fault and its overall contribution to the plate boundary process.

Scientific Goals and Key Questions

The principal objectives of a Wasatch fault PBO study are thus to investigate the physics of normal faulting earthquakes and how this specific fault fits into plate boundary dynamics. The project involves the integration of the extensive geologic information, noted above, into analytic simulations of fault nucleation including models of co-, post- and perhaps pre-seismic deformation. It will include: 1) how state-dependent fault properties (Dieterich, 1994), that effect aftershock duration, are a function of stressing rate and strain rate on mainshock recurrence time, as well as 2) how these rate-state models apply to nucleation of normal faults. Further we need to understand fault geometry and how it relates to rheology and loading rate. The models will be inherently complex taking into account viscoelastic loading for long-term deformation including variable low- to high-angle slip in the elastic layer overlying a lower crustal creeping layer. And on a dynamics scale, interrelationships between plate driving forces applied at the boundaries of the fault blocks, internal forces due to lateral and depth-dependent density contrasts, and how Basin-Range driving forces counterbalance with plate boundary forces are key elements of the plate boundary story that can be addressed by the proposed PBO study.

Our objectives are thus to assess the kinematics of plate boundary process and to provide important information on the physics of normal faults. We will address such topics as: 1) the differences between geologic and geodetic stain rates, 2) determining the regional kinematic field, 3) fault-stress interaction, 4) the effect of low stressing rates on fault loading, 5) long-term visco-elastic response , 6) providing key input into normal fault dynamics and plate driving models, and 7) contributing important information for earthquake hazard assessment.

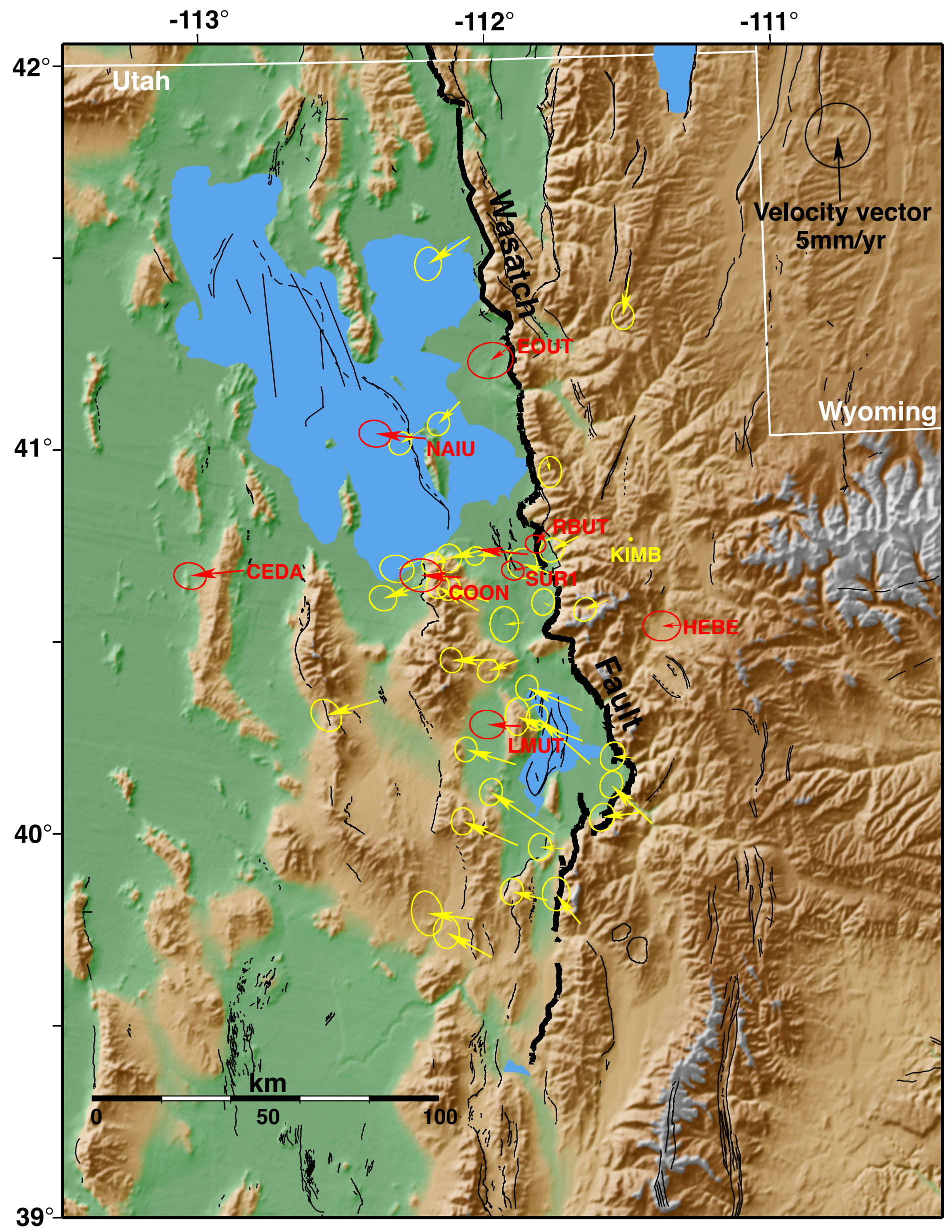
Proposal -- We thus propose a Wasatch fault mini-cluster network that will augment the existing geodetic infrastructure of 4 University of Utah and 3 BARGEN CGPS stations with the addition of 50 new CGPS stations. The plan involves densifying the Wasatch network by adding five east-west profiles CGPS stations necessary to accurately cover the footwall and hangingwall components of normal fault loading and with additional stations between profiles that will tie them together, making up a 57-station network (Fig. 2b). The profiles will traverse (with ~2 to 3 km spacing) five key areas of the Wasatch fault that will be tied to regional sites further away from fault related deformation. Note that the proposed sites were chosen to be in bedrock where possible, including across the bedrock salients of the fault.

Infrastructure -- The proposed network will take advantage of technology and infrastructure developed in earlier GPS studies done under the auspices of the USGS National Earthquake Hazards Program, NEHRP (Univ. of Utah) and the NSF for the BARGEN array. It will benefit by the use of well-developed telemetry links, recording and processing facilities, and cost-effective monumentation. It will also build upon our experience of installing and operating microwave and spread-spectrum telemetry to local Internet access sites and take advantage of telemetry technology developed by UNAVCO engineers. The CGPS data can then processed by the respective users connected to data archives via the Internet. We specifically note that the PBO Wasatch CGPS network will be coordinated with USGS NEHRP projects that support research on the earthquake hazards of the area.

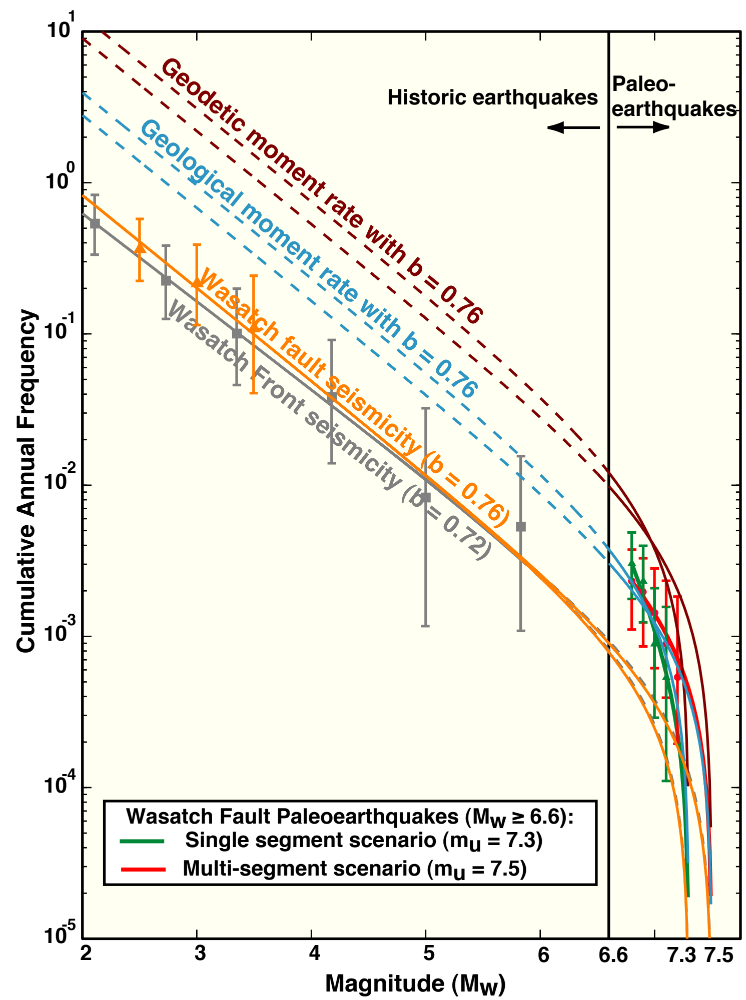
Network Design and Accessibility -- Station density is predicated on the need to record unaliased horizontal and vertical motions associated with normal faulting as well as providing long-term baselines across key segments of the fault. All sites, even in the mountainous areas, are accessible. Telemetry links are accessible and reliable because of the location of centrally located repeaters that are already operating at high topography sites with reliable AC power.

Campaign GPS surveys will compliment the CGPS surveys on focused targets that require higher station density and that compliment the CGPS measurements (Fig 2b), especially in areas outside the arrays and across adjacent faults.

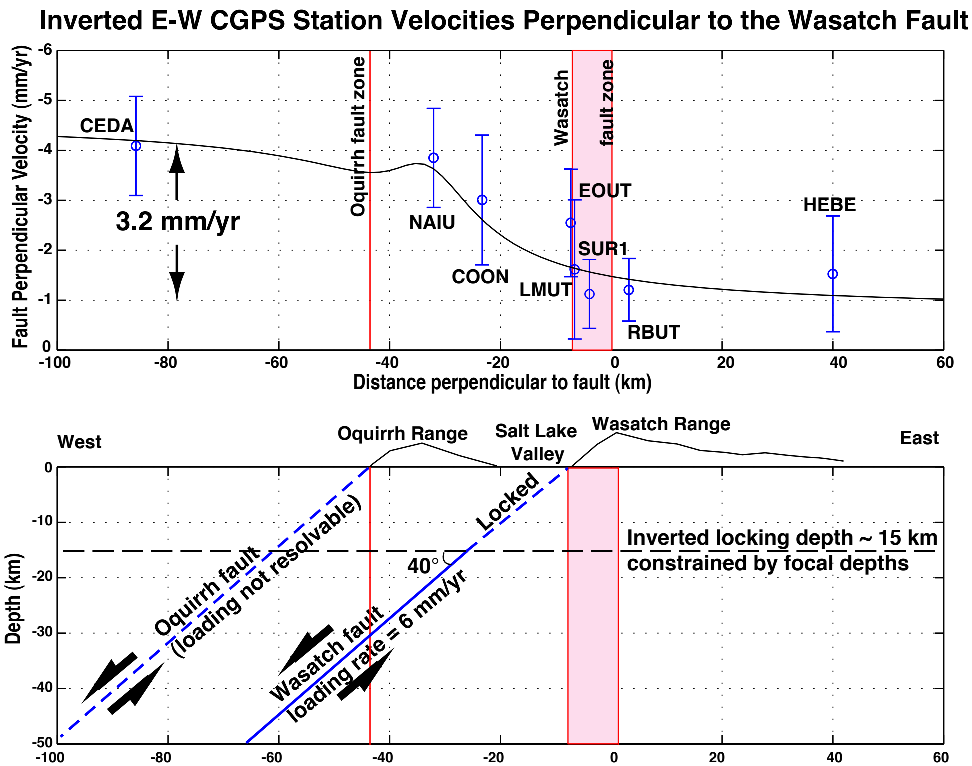
We also note that the Wasatch fault will be targeted for a densified USArray deployment that will supplement information on crustal and lithospheric seismic velocity structure from tomography.



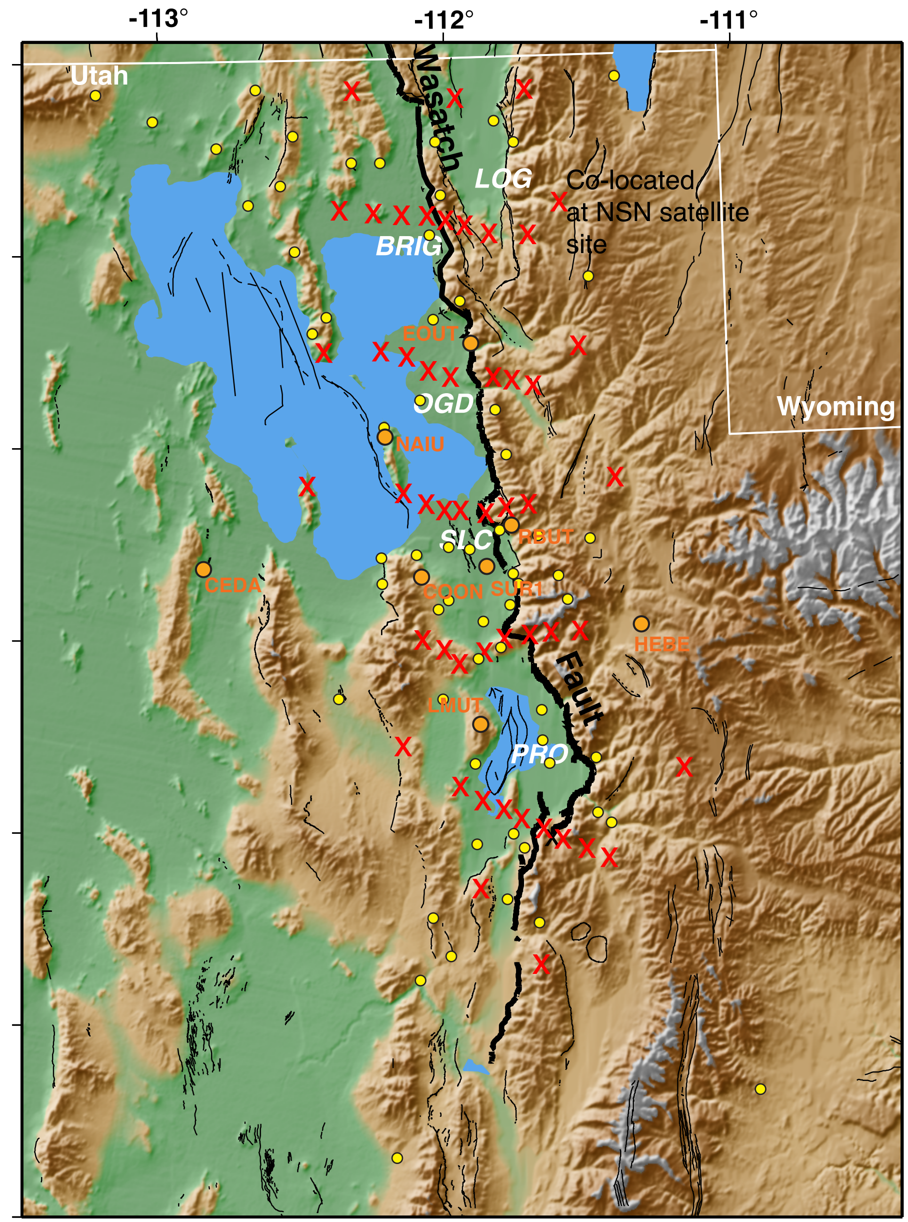
1a. Velocity vectors (with 2σ errors) determined from continuous ( ), 1996-2000 and campaign ( ), 1995-1999, GPS sites in an ITRF framework. CGPS sites operated by the Univ. of Utah and BARGEN (CalTech and Harvard) and processed collaboratively.



1b. Frequency of occurrence curves for the Wasatch fault zone from estimates of historical seismicity, paleoseismicity and campaign GPS results.



2a. Preliminary inversion results showing that the data are best fit by a single north-south striking infinite-edge dislocation. It corresponds to a west dipping ~ 40° normal fault extending eastward toward the surface expression of the Wasatch fault, with a locking depth of 15 km and a creeping segment slip rate of ~ 6 mm per year.



2b. Proposed PBO mini-cluster permanent GPS sites (x) on five profiles that span the Wasatch fault and adjacent structrures. Existing continuous GPS (●) and campaign sites (○) are also noted. Off end locations provide are regional base sites.