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Final Technical Report

OPERATION AND MAINTENANCE OF THE WASATCH FRONT, UTAH, GPS NETWORK (MONITORING, UPGRADES, DATA RECORDING AND PROCESSING)

Report for Period: April 1, 2004 to February 28, 2007

USGS Cooperative Agreement Award Number 04HQAG0023

R.B. Smith and Wu-Lung Chang
Department of Geology and Geophysics
135 South 1460 East, Room 702 WBB
University of Utah
Salt Lake City, UT 84112
Tel: (801) 581-7129, Fax: (801) 585-5585
E-mail: rbsmith@mines.utah.edu
URL: www.mines.utah.edu/~rbsmith/research.html
Data URL: www.unavco.ucar.edu/data_support/data/data.html

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USGS Project Officer: Elizabeth A. Lemersal
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Dr. Robert B. Smith, Principal Investigator
Dr. Wu_Lung Chang, Co Investigator

University of Utah
Department of Geology and Geophysics
135 South 1460 East, Room 705 WBB
Salt Lake City, UT 84112-0111
Tel: (801) 581-6274 Fax: (801) 585-5585
E-mail: rbsmith@mines.utah.edu

ABSTRACT

Under the USGS National Earthquake Hazard Program, the University of Utah conducted research and GPS monitoring with a focus on evaluating earthquake hazards of the populated Wasatch Front, Utah. The GPS network spans the Wasatch fault in an area ~300-km long and ~200-km wide in north and central Utah and consists 8 permanent GPS stations operating continuously beginning 1997 and implementing campaign GPS surveys at 60 benchmarked sites surveyed in 1992, 1993, 1994,1995, 1999, 2001, and 2003. The main objectives of the project included: 1) operation eight GPS station including the installation of 2 new stations, 2) processing of the data from our 8 GPS stations and an additional 12 stations operated by other institutions, 3) uniform re-processing of seven field campaign GPS surveys of 60 stations, 4) studies of time-dependent fault behavior modeled from the GPS data, and 5) developing an integrated earthquake hazard assessment incorporating GPS fault loading rate data Late Quaternary fault slip rates and historical seismicity rates. Our primary observations extend across a 65-km wide area centered on the Wasatch fault and indicate a spatial variation of the strain-rate field concentrated within ~10-20 km across the Wasatch fault and thus marks an abrupt transition in the horizontal deformation between the eastern Basin-Range and the Rocky Mountains. The principal strain rate across the fault was found to be 24±6 nstrain/yr that corresponds to a horizontal displacement rate of 1.6±0.4 mm/yr. Note this deforming zone accommodates ~50% of the crustal deformation across the ~200 km-wide eastern Basin-Range.

We also employed a finite-strain model that accounts for simple-shear deformation of the hanging-wall to compare horizontal extension rates measured by GPS with vertical fault-displacement rates determined by trenching. When compared to geologically determined rates these results are comparable to the average Quaternary fault-slip rate, 1.7±0.5 mm/yr, but the average Holocene strain-release rate is higher than the contemporary strain-loading rate for the

Wasatch fault if the fault dips less than 30ºW, but these two rates are consistent if the fault dips more steeply.

Studies of the validity of viscoelastic fault relaxation models to assess the influence of Utah's historic and paleoearthquakes on the GPS observations were initiated in this project. We employed time-dependent changes in crustal motion determined by GPS and trilateration measurements from 1973 to 2000 following the 18 August 1959 M_s=7.5 Hebgen Lake, MT, earthquake to determine a rheological model for a normal faulting earthquake in a similar tectonic regime as the Wasatch fault. The derived rheological models include a brittle upper crustal layer, a more viscous lower crust than the upper mantle and lower mantle viscosity. Using the derived Hebgen-Lake rheological model we evaluated the post-seismic deformation of the Intermountain region produced by both the Hebgen Lake and the 1983 M_s=7.3 Borah Peak, ID earthquakes. These results suggest that the post-seismic relaxation of these large earthquakes produced horizontal ground motions up to ~2 mm/yr that must be considered when employing intraplate kinematic models. Similarly, a viscosity model based on the above historic fault data and observations of the Late-Quaternary loading and vertical rebound of Lake Bonneville, adjacent to the Wasatch fault, was also used to evaluate post seismic ground motions associated with six most recent, <1.5 ka, Holocene paleoearthquakes and three large, M≥5.6, historic earthquakes of the Wasatch fault zone, UT. These results demonstrate ≤0.1 mm/yr of contemporary horizontal motions induced by these earthquakes, that are negligible compared to the ~2 to 3 mm/yr of E-W extension determined by GPS measurements. This study provides new insights into the widespread effects on regional deformation from post-seismic relaxation of large earthquakes that must be considered in kinematic models and earthquake hazards of intraplate tectonic regions.

In summary the GPS data were then included in a probabilistic seismic hazard modeling that integrated thus integrated geodetic data, historic earthquake rates and geologically determined fault slip rates. These models evaluated how the GPS data could be implemented from equivalent moment rates to conversion to fault slip rates. The results are not definitive or either model as the GPS data are assumed to included seismic and non-seismic loading mechanisms, and it is not yet clear what proportion of the deformation budget contributes to the seismic component.

Other accomplishments during the report period included: 1) publication of a paper in JGR and submission of two additional papers in JGR; 2) presentation of our results at national and regional earthquake meetings, 3) participation with colleagues of the USGS and other universities assisting with the development of the Basin and Range province earthquake working group seismic hazard recommendations to the USGS, 4) routine transmission of our data on a daily basis to the PBO data facility at UNAVCO for all interested users, and 5) assisting local surveyors and other users with use of the Utah permanent GPS station data for their purposes.

NON-TECHNICAL SUMMARY

April 1, 2004 to February 28, 2007

Under the USGS National Earthquake Hazard Program, the University of Utah conducted research focused on evaluating earthquake hazards of the populated Wasatch Front, Utah by operating the Wasatch Front GPS (Global Positioning Systems) network to monitor the surface deformation Utah. High resolution GPS data, acquired by 20 continuous stations and seven field campaign surveys of ~ 60 stations, were integrated with other earthquake source data, including paleoearthquake fault-slip rates and historic seismicity, to evaluate the earthquake hazard of the Wasatch fault. Our results suggest that the contemporary horizontal deformation rate across the Wasatch fault, 1.6±0.4 mm/yr, is comparable with the average Quaternary fault-slip rate, 1.7±0.5 mm/yr. Results of our elastic fault modeling from the GPS data, however, indicate a fast, subsurface, loading process of the Wasatch fault with rates ~2-3 times higher than the geological fault-slip rate. These results provide additional information that significantly improves the earthquake hazard assessment from previous estimates. The University of Utah GPS data are automatically transmitted to the University Navigation Consortium (UNAVCO) archive on a daily basis and are accessible to any user over the Internet in near-real time.

TABLE OF CONTENTS

	PAGE
ABSTRACT	**ii**
NON-TECHNICAL SUMMARY	**iv**
TABLE OF CONTENTS	**v**
FINAL REPORT SUMMARY	**1**
RESULTS (FEBRUARY 1, 2004 TO JANUARY 31, 2007)	**4**
MEETINGS AND NHERP PROGRAM PLAN PARTICIPATION	**7**
COLLABORATIVE EFFORTS	**7**
PAPERS PUBLISHED IN NATIONAL JOURNALS (2004-2006)	**8**
ABSTRACTS OF PRESENTATIONS AT NATIONAL MEETINGS (2004-2006)	**8**
AVAILABILITY OF UNIVERSITY OF UTAH GPS DATA AND GROUND DEFORMATION PRODUCTS	**9**
DISTRIBUTION OF FINAL REPORT	**11**
APPENDIX TABLE 1: GPS STATIONS OPERATED BY THE UNIVERSITY OF UTAH AND OTHER INSTITUTES AND PROCESSED BY THE UNIVERSITY OF UTAH	**12**
ATTACHMENTS	**14**

ATTACHMENT A

JGR REPRINT: CONTEMPORARY DEFORMATION OF THE WASATCH FAULT, UTAH, FROM GPS MEASUREMENTS WITH IMPLICATIONS FOR INTER-SEISMIC FAULT BEHAVIOR AND EARTHQUAKE HAZARD: OBSERVATIONS AND KINEMATIC ANALYSIS – (*ATTACHED*).

ATTACHMENT B

JGR PREPRINT: LITHOSPHERIC RHEOLOGY FROM POST-SEISMIC DEFORMATION OF AN M=7.5 NORMAL-FAULTING EARTHQUAKE WITH IMPLICATIONS FOR CONTINENTAL FAULT KINEMATICS. –(*ATTACHED*).

ATTACHMENT C

JGR PREPRINT: INTRAPLATE DEFORMATION AND BLOCK ROTATIONS OF THE WESTERN U.S. INTERIOR–(*ATTACHED*).

FINAL REPORT SUMMARY

Earthquake hazards related to the Wasatch fault are of great concern because 80% of Utah's two-million+ population lives within 50 km of this major seismogenic structure. Geological studies reveal evidence of at least 17 paleoearthquakes, 6.8<M<7.1 on the fault in the past 5,600 years, which implies a high likelihood of large earthquakes in the future.

General Background -- The University of Utah GPS project reported here focused on an evaluation of the earthquake hazard of the Wasatch fault, Utah, by integration of various types of seismic sources contributing to earthquake hazard: paleoearthquake slip rates, historic seismicity and geodetic data. Eight GPS stations and multiple campaign GPS measurements of the Wasatch Front provide precise geodetic data for determination of fault loading rates (Figure 1). In addition we evaluated the time-dependent effects of paleoearthquakes by viscoelastic modeling of fault-specific sources on the Wasatch fault. The project was conducted within the framework of the USGS National Earthquake Hazards Reduction Program.

During the period of the award, efforts were devoted to investigations outlined and described below and in the papers that are attached, as well as in our annual reports and national meeting presentations supported by this grant. The summaries are updated and expanded versions of those submitted for inclusion in the National Earthquake Hazards Reduction Program Summaries of Technical Reports.

Our main field project included operation of eight University of Utah continuous GPS stations and unified reprocessing GPS campaign field surveys of the central and southern Wasatch fault. We continued developing routine data processing of 30 collaborative GPS stations in the Wasatch Front study area (including five from the Harvard/Caltech northern Basin-Range and the PBO arrays). Our GPS data are sent daily to the UNAVCO archive and are web accessible to any user.

In addition we also evaluated the time-dependent effects of interseismic loading by employing viscoelastic models of paleoearthquakes and the larger, M>5, historic earthquakes of the Wasatch Front region.

Wasatch Front Continuous GPS Operation -- The Wasatch Front GPS network has been operating for eight years (1997-present), beginning from a skeletal 3-station network that is now up to an 8-station array. Our eight continuous GPS sites (Figure 1) are designed to operate in high mountainous, cold weather environment that requires specially planned reliable systems that require robust systems and redundant power supplies. Spread spectrum digital radio links to the University of Utah campus transmit the GPS data, which are then recorded on a Sun computer. Data are sampled at a 30-second rate. See Table 1 for a list of GPS stations in the Utah GPS array and ancillary stations of the BARGEN and PBO networks that we collaborate and co-process.

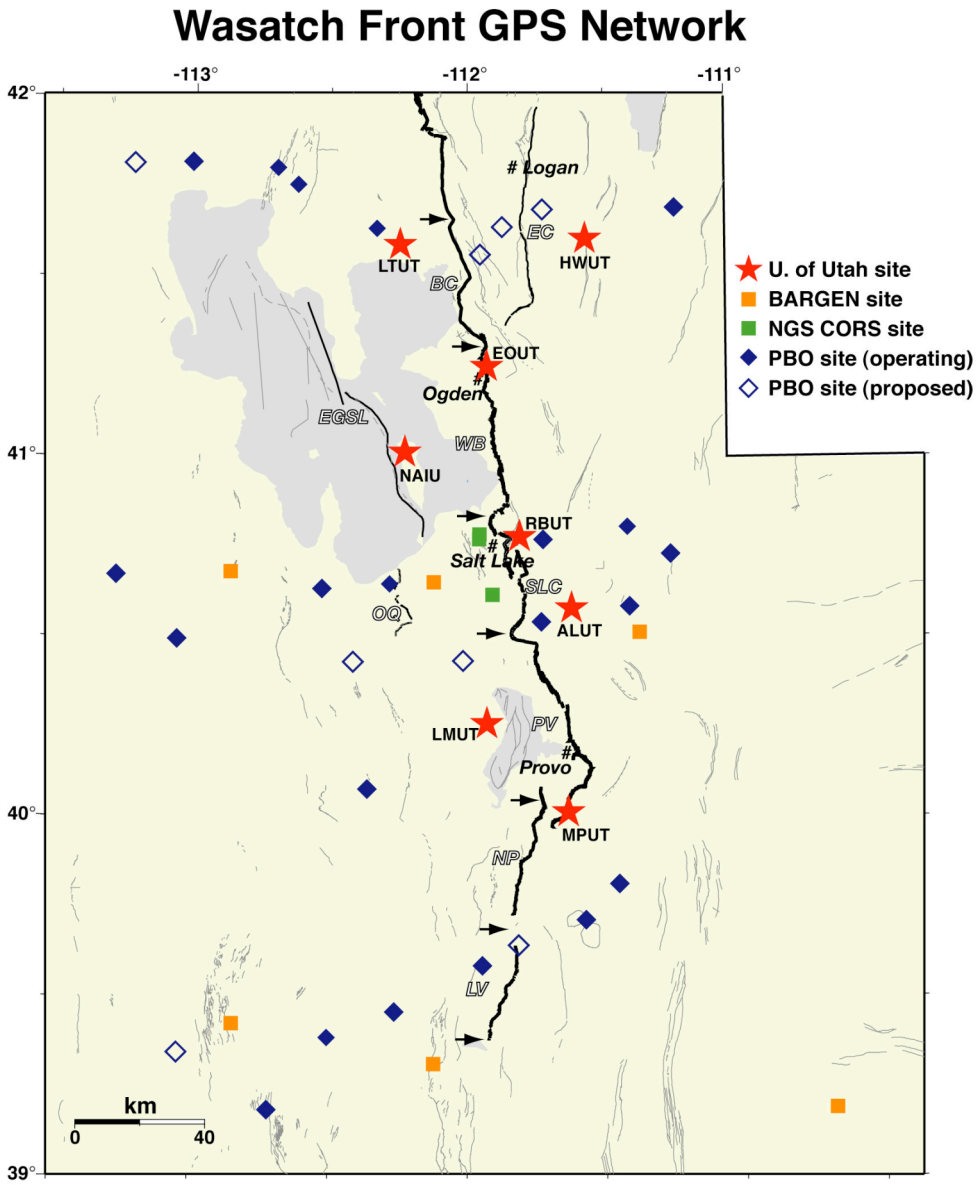

Fig. 1. Continuous GPS network of the Wasatch Front area. The Wasatch fault is highlighted by a thick black line, and arrows represent boundaries of the fault segments including the Brigham City (BC), Weber (WB), Salt Lake City (SLC), Provo (PV), Nephi (NP), and Levan (LV) segments. Thin black lines indiate other Holocene-active faults include East Cache (EC), East Great Salt Lake (EGSL), and Oquirrh (OQ) faults.

The technical details of our GPS instrumentation are provided in an online document that describes the engineering and operating parameters of our stations. This information is accessible in two forms from: 1) http://www.mines.utah.edu/~rbsmith/RESEARCH/UUGPS.html; 2) http://www.mines.utah.edu/~rbsmith/RESEARCH/CGPS_summary.html. A summary table of all the GPS stations of the Wasatch Front that we process is in the attachments.

Our automatic GPS processing scheme employs the Bernese Processing Engine, Bernese 4.2 software. The precise (final) GPS orbit data are acquired from International GNSS Service (IGS), that are available with a 10-day latency. With this scheme the Wasatch fault GPS time-

series are updated weekly using the past two weeks precise orbit data and are posted on our website at: http://www.mines.utah.edu/~ggcmpsem/UUSATRG/GPS/time_series.html. Coordinate solutions are saved in SINEX-formatted files that can rigorously be combined with solutions determined by other institutions using different processing software.

For redundancy of different methods, the EarthScope PBO GPS system processes four of our eight stations including those of the Basin-Range PBO Extensional network and that of the BARGEN network. This multiplicity of different processing schemes needed to assure data quality and reliable solutions.

Our specific efforts included:

- Operating and maintaining eight permanent GPS stations, including the installation of two new stations in the Wasatch fault footwall at the Hardware Ranch (HWUT, summer of 2004) and Alta, Utah (ALUT, summer of 2005).

  The station ALUT is in the immediate vicinity of the Wasatch fault footwall-block near Salt Lake City and assists with monitoring ground motions along this most populated part of the Wasatch Front. This site was installed on a 20' steel tower erected on bedrock, and have solar power and transmit data in real-time to a University of Utah seismic station at the Alta town office. Importantly this site was a cooperative project between the University of Utah and the Alta Ski Lift Corp who allowed and assisted us with installation on one of their large steel towers.

- Reconnaissance for an additional GPS sites on the hanging-wall and footwall blocks of the Wasatch fault was done. These stations are needed to provide deformation information on the lateral E-W extension of the Nephi segment of the fault and providing east-west continuity across the northern Wasatch fault. The new sites will employ separate telemetry repeaters to link to our installed transmission system. Site reconnaissance and permitting of this site was begun summer 2005.

- Automatic GPS data processing of total 41 stations is done encompassing the Wasatch fault (Figure 1), including eight from the University of Utah, six from the BARGEN CGPS array, 23 from the EarthScope PBO network, and four from other cooperative CORS stations. Updated time series of these stations are posted on our website: http://www.mines.utah.edu/~ggcmpsem/UUSATRG/GPS/time_series.html.

- Our level 1 raw GPS data are transmitted daily to the UNAVCO archive center and are web accessible to any user in near-real time (http://archive.unavco.org/query/pss).

- Modeling our GPS data was done using linear and non-linear inverse methods to evaluate the geometry and rates of causative faults especially incorporating a 3D geometric model of the Wasatch fault.

- Completed a paper on Wasatch GPS observation paper titled "Contemporary deformation of the Wasatch Fault, Utah, from GPS measurements with implications for inter-seismic fault behavior and earthquake hazard: Observations and kinematic analysis" that was published by the Journal of Geophysical Research in 2006 [*Chang et al.*, 2006].

- Completed a paper on the viscoelastic modeling of lithospheric rheology of normal faults and evaluating post seismic deformation of the Wasatch Front, Utah. This paper was submitted to the Journal of Geophysical Research and is under review.

- Presented invited and contributed papers on our research at the following scientific meetings: 1) the 2004 fall meetings of the American Geophysical Union; 2) the 2005 EarthScope meeting; 3) the 2005 annual meeting of the Geological Society of American; 4) the 2006 Utah Quaternary Fault Parameters and Ground Shaking Workshop; 5) the 2006 Basin-Range Province Earthquake Working Group, and 6) the 2006 EarthScope meeting.

- Organized and assisted the efforts to include the northern Basin-Range, including the Wasatch fault, as a major element of the Plate Boundary Observatory. The research objective is to focus on the physics of earthquakes as well as an example of GPS monitoring of an active fault with major societal impact. The University of Utah has assisted PBO engineers with sitting and permitting issues for their sites in northern Utah. New PBO sites are included in the Figure 2.

- Participated as a major research and monitoring group in the 2006 Basin-Range USGS National Hazard maps

Problems Encountered -- We did not encounter any major logistical problems during the report period except the extended negotiations of permitting the Alta site due to strict environmental requirements and engineering specifications required. Permitting delays of the two new sites, described above, limited our progress on their installation.

Campaign GPS Observations -- We reprocessed the data from seven GPS campaign field surveys (49 stations) along the Wasatch fault for the years: 1992-1995, 1998, 2000, and 2003 to update the contemporary velocity and strain field of the Wasatch fault. Our latest results indicate that the Wasatch fault and subsidiary faults has notably higher ground deformation rates than expected from Holocene geologic data that increases the earthquake hazard from previous estimates.

RESULTS (APRIL 1, 2004 TO FEBRUARY 28, 2007)

Contemporary Loading Rates of Wasatch Fault from GPS Data -- We used the resulting GPS data from the Wasatch Front, UT, to determine the contemporary crustal loading rates based on the derived horizontal velocity field (Figure 2 and Attachment B). We then employed an elastic dual-dislocation fault simulation to estimate the fault-loading rates and related elastic parameters. This model assumes loading of the fault is taking place beneath the locked-upper crust containing the elastic controlled Wasatch fault, or at depths beneath the seismic locking depth of ~10 km. Our results show that the loading rates are 5-6 mm/yr on a west-dipping, ~30°, creeping zone that is about a factor of 2 to 3 higher than the geological fault-slip rate of the Wasatch at the surface. The high loading rate of this system, if assuming all of the stress is concentrated on the seismogenic fault, implies a higher earthquake ground-shaking hazard from the fault compared with that calculated only by historic seismicity and paleoearthquake data.

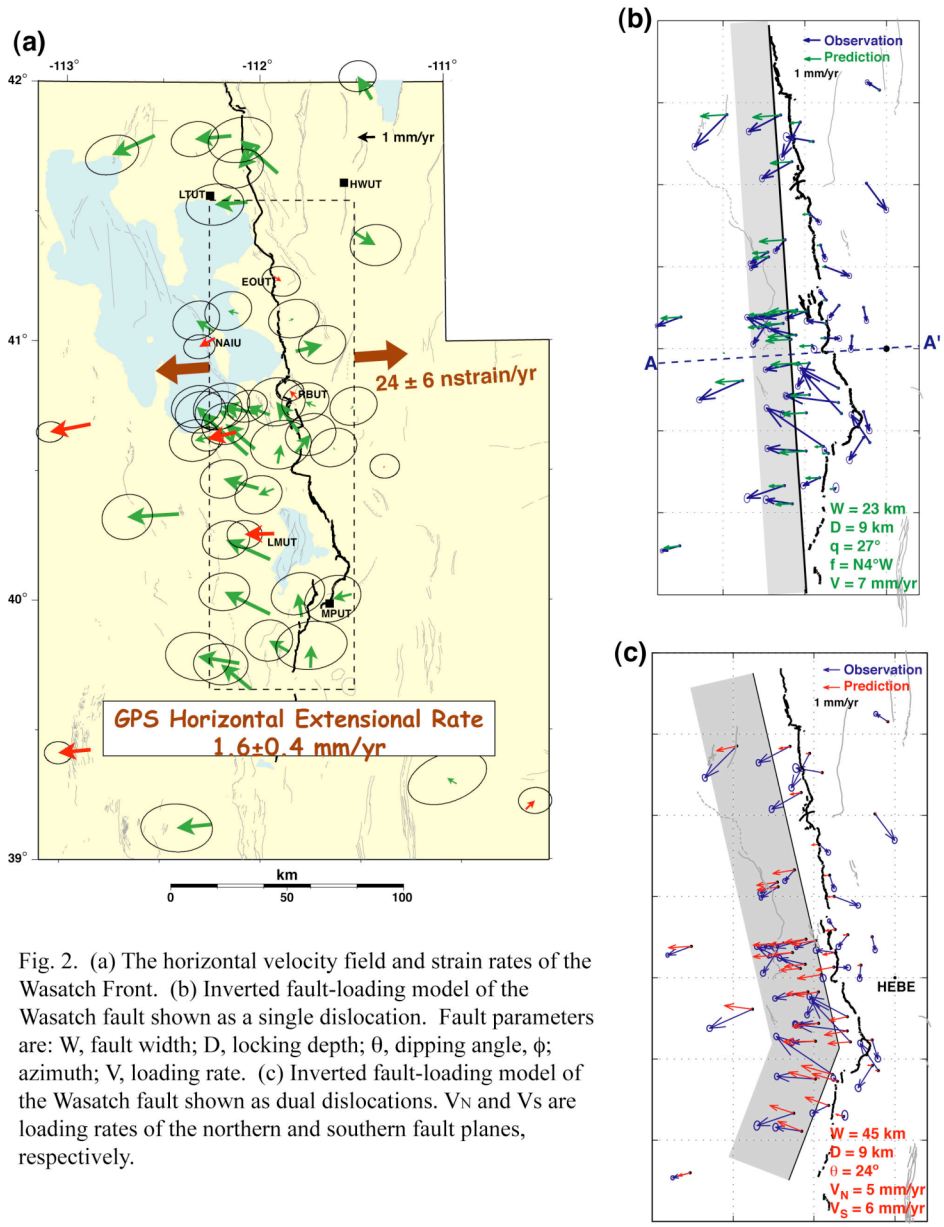

Fig. 2. (a) The horizontal velocity field and strain rates of the Wasatch Front. (b) Inverted fault-loading model of the Wasatch fault shown as a single dislocation. Fault parameters are: W, fault width; D, locking depth; θ, dipping angle, ϕ; azimuth; V, loading rate. (c) Inverted fault-loading model of the Wasatch fault shown as dual dislocations. V_N and Vs are loading rates of the northern and southern fault planes, respectively.

Post-Seismic Deformation of the Wasatch Front -- Viscoelastic relaxation of prehistoric (M>7) and historic (M>5.6) earthquakes were evaluated to examine time-dependent effects of past earthquakes on the contemporary strain field (Figure 3 and Attachment 3). We first examined the post-seismic deformation caused by the 1959 M=7.5 Hebgen Lake, MT, earthquake, a large, scarp-forming rupture that is the only historic normal-faulting event in the world with the recorded post-seismic relaxation history recorded by a variety of geodetic and seismic methods.

Because this earthquake is the only large normal-faulting event in the Basin-Range with time-dependent crustal deformation data, we used it as a proxy for time-dependent behavior that would be expected on the Wasatch fault. Geodetic data for the Hebgen Lake earthquake include GPS, precise leveling and EDM acquired over the ~45 year post seismic period. This event thus provides a unique source of information on the viscoelastic behavior and rheology that is crucial to inter-seismic modeling of similar faults such as the Wasatch fault. Our

viscoelastic modeling results of the Wasatch fault using a modified rheology model from the Hebgen Lake earthquake demonstrate that there is ≤0.1 mm/yr of horizontal motions from the are negligible compared to the 1-3 mm/yr of E-W extension measured by GPS in the Wasatch Front area.

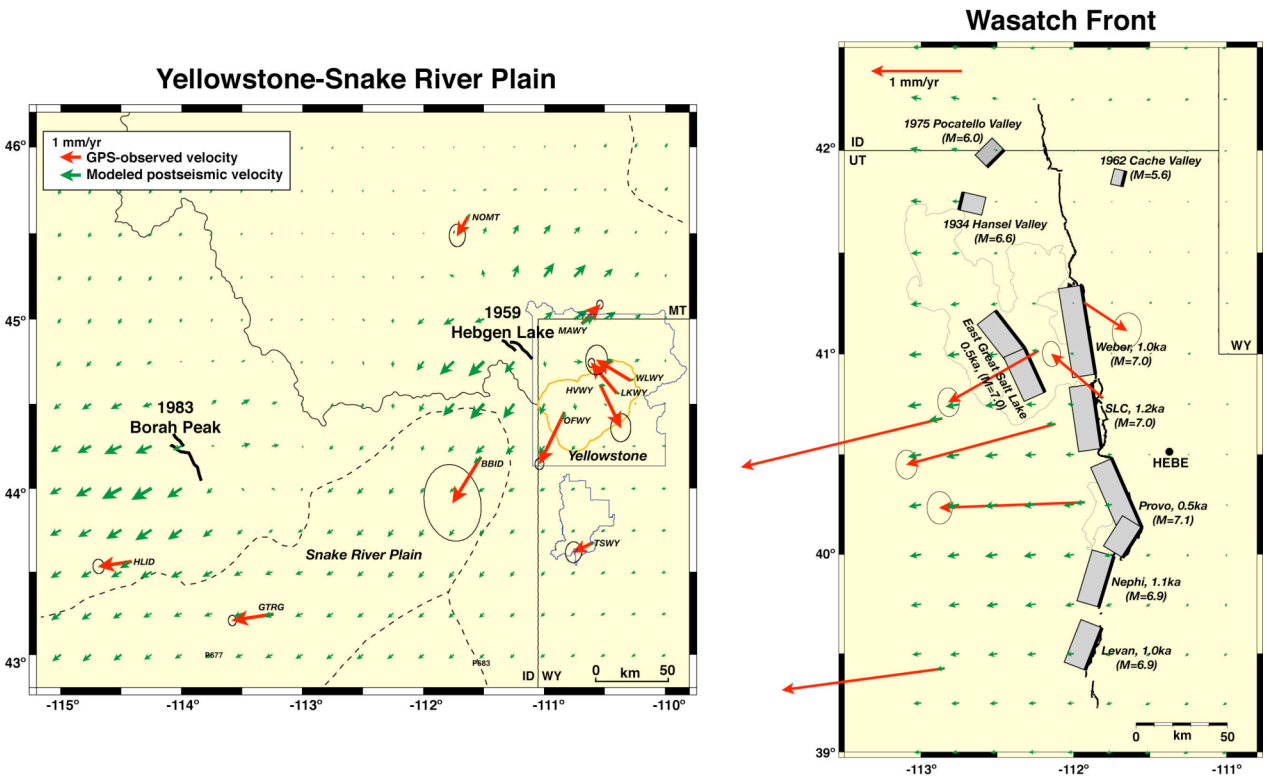

Fig. 3. Modeled post-seismic deformation (red arrows) and its comparison with GPS-measured horizontal ground motion (green arrows) for the Yellowstone-Snake River Plain and Wasatch Front areas.

Integrated Earthquake Hazard Assessment -- Various earthquake sources and recurrence models contribute differently to the probabilistic earthquake hazard estimations (Figure 4). The Wasatch Front seismic, geologic, paleoearthquake, and GPS data were included in a study to evaluate the integration of the data on probabilistic ground-shaking hazard for a specific location in Salt Lake Valley. Results demonstrate the usefulness of integrating all available data for a more complete estimate of earthquake hazard for the entire region area. The ground-shaking curve was constructed for a site near the intersection of I-15 and I-80 in Salt Lake Valley.

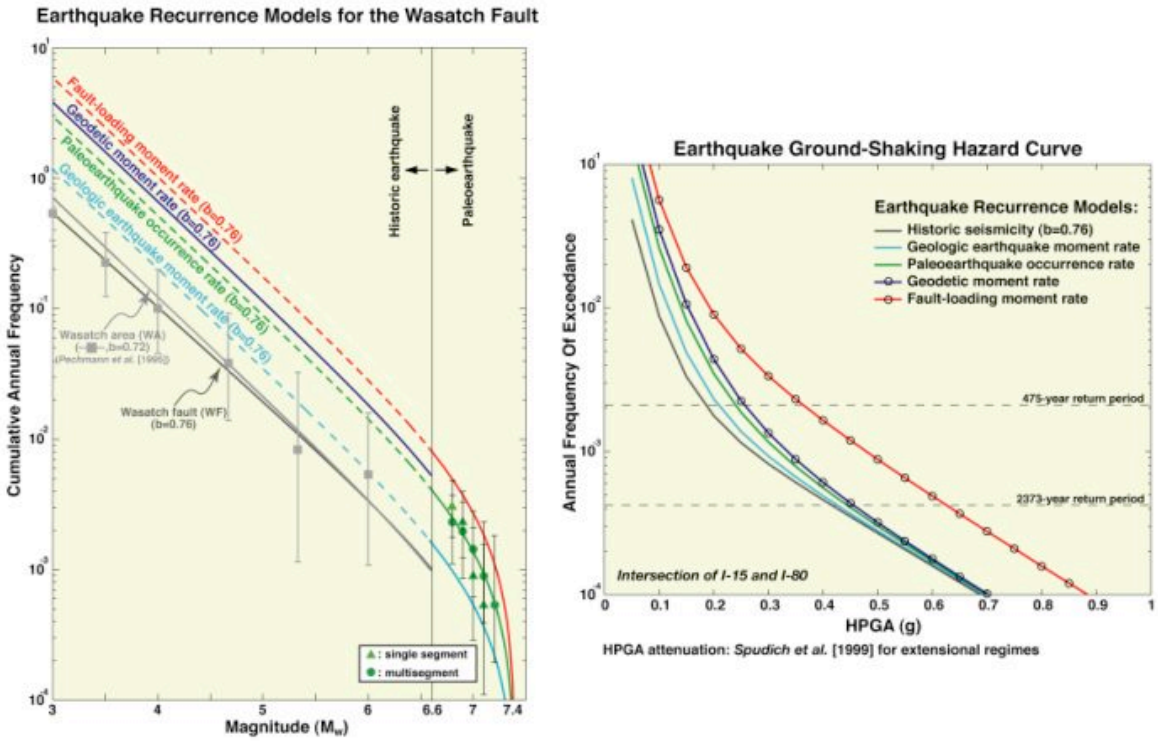

Fig. 4. Earthquake recurrence and ground-shaking hazard curves for the Wasatch Front

MEETINGS AND NHERP PROGRAM PLAN PARTICIPATION

We presented invited and contributed papers on our research at the: 1) the 2004 Fall Meetings of the American Geophysical Union, 2) the 2005 EarthScope meeting, 3) the 2005 annual meeting of the Geological Society of American, 4) the 2006 Utah Quaternary Fault Parameters and Ground Shaking Workshop, and 5) the 2006 Basin-Range Province Earthquake Working Group.

Note that our Wasatch Front GPS observations provided key information on the role and use of GPS data for the new USGS next generation (2007) National Hazard maps, as well as their use a proxy for fault slip rates in seismic hazards models recognized by the Basin and Range Province Earthquake Working Group meetings, Salt Lake City, Utah, and in the Intermountain West National Seismic Hazard Mapping Program Regional Meeting in Reno on May 31-June 1, 2006.

COLLABORATIVE EFFORTS

We continue to work with other scientists, such as Gerald Bawden, USGS, and his studies of Wasatch Front ground deformation from InSAR imaging. We also have worked with Fred Pollitz, USGS, to conduct viscoelastic modeling effects. We also collaborated with Wayne Thatcher, USGS, and Bill Hammond, Univ. of Nevada on understanding the contemporary

deformation of the entire Basin and Range province by combining the University of Utah, USGS and PBO data. We also worked with Peter Cervelli, USGS, on elastic modeling of the Wasatch fault.

We also work with Professor Ron Harris of Brigham Young University, Provo Utah for campaign GPS measurements. Mr. Harris has four Trimble GPS receivers that he loans to us when needed. Moreover, he supervises a team of undergraduate students that conduct campaign GPS surveys of the Wasatch fault in 2003 to our specifications costing us only their salaries and travel. This cooperative effort has materially contributed to this project.

PAPERS PUBLISHED IN NATIONAL JOURNALS (2004-2006)[1]

Chang, W.L., R.B. Smith, C.M. Meertens and R. Harris, 2006, Contemporary deformation of the Wasatch fault zone, Utah, from GPS measurements with implications for interseismic fault behavior and earthquake hazard: *J. Geophys. Res.*, *111*, B11405, doi:10.1029/2006JB004326.

Chang, W. L., and R. B. Smith, 2006, Rheological properties of extensional lithosphere from post seismic relaxation of the 1959 M=7.5 Hebgen Lake Montana earthquake, J. Geophys. Res, (in revision).

Puskas, C., R. B. Smith, and R. McCaffrey, 2007, Intraplate Deformation and Block Rotations of the Western U.S. Interior, J. Geophys. Res. (submitted).

Chang, W., and R. B. Smith, 2007, Elastic and viscoelastic models of crustal motion across the Wasatch fault, II. Models, , J. Geophys. Res. (in preparation).

Lund, W. editor, 2006, Basin and Range Province Earthquake Working Group Seismic Hazard Recommendations to the U.S. Geological Survey National Seismic Hazard Mapping Program, Prepared by the Basin and Range Province Earthquake Working Group in cooperation with the Basin and Range Province Committee of the Western States Seismic Policy Council, Utah Geological Survey, Open File report 477. Contributions by R.B. Smith and many others.

ABSTRACTS OF PRESENTATIONS AT NATIONAL MEETINGS (2004-2006)[2]

Bawden, G. W., B.J. Stolp, W. Chang, R. B. Smith and JT Brandt, 2004, Subsidence induced by ground-water withdrawals across the Wasatch Front, Salt Lake Valley, Utah, in 2004, Eos, Transactions Amer. Geoph. Un., 2004 Fall Meeting, Suppl. Abst. G51B-0083.

Chang, W. L. and R. B. Smith, 2004. Integrated earthquake hazard of the Wasatch Front from GPS measurements ad elastic-viscoelastic fault modeling, *Programs and Abstracts, Basin and Range Province Seismic Hazards Summit II, Western States Seismic Policy Council*, 73-76.

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[1] *We have not included reports or informal presentations at workshops or meetings that do not publish their proceedings.*

[2] *We have not included reports or informal presentations at workshops or meetings that do not publish abstracts of which there are several.*

Chang, W., and R.B. Smith, 2004, Post seismic and Interseismic Deformation of Large Normal-Faulting Earthquakes in the Basin-Range, in 2004, Eos, Transactions Amer. Geoph. Un., 2003 Fall Meeting, Suppl. Abst. G13A-0797.

Chang, W. L. and R. B. Smith, 2004. Post seismic and interseismic deformation of large normal-faulting earthquakes in the Basin-Range, *Eos. Trans. AGU* 85, F537.

Chang, W. L. and R. B. Smith, 2005. Lithospheric rheology from post seismic deformation of a M=7.5 normal-faulting earthquake with implications for continental kinematics, *Abstracts with Programs, 111th Ann. Meeting and Exposition, Geol. Soc. Am.*, 37, 497.

Chang, W. L., R. B. Smith, and R. Harris, 2005, Elastic and viscoelastic strain loading models of the Wasatch fault, Utah, from GPS measurements and comparisons with geological observations, *Eos Trans. AGU, 86(52)*, Fall Meet. Suppl., Abstract G53A-0875.

Smith, R. B., 2004, Earthquake Hazards of the Eastern Basin-Range Province, presented at the September 2004 SESAC (Scientific Earthquake Studies Advisory Committee of the USGS) meetings, Jackson, Wyoming.

Smith, R. B., 2005, Kinematic and Dynamic Models of Western U.S. Plate Boundary Deformation, Hamilton Visiting Scholar Lecture, Southern Methodist University, Printed Scholar Schedule, Feb. 22. 2005.

AVAILABILITY OF UNIVERSITY OF UTAH GPS DATA AND GROUND DEFORMATION PRODUCTS

The University of Utah is an earthquake information, data and educational center for Utah and the Intermountain region. Results from our GPS projects are disseminated to public officials, technical users of earthquake hazard information, and the general public in numerous ways—including reports and scientific journal articles and on the Internet,

All University of Utah continuous GPS observed data are made available to the interested user and public in near real-time via the Internet. The data are downloaded daily and archived in Rinex format the UNAVCO (University NAVSTAR consortium) data management center, Boulder, Colorado at http://www.unavco.org/query/pss.

University of Utah processed GPS data are also posted on our own website at http://www.mines.utah.edu/~ggcmpsem/UUSATRG/GPS/time_series.html

Interpretative-level research products including ground motion vectors, error analyses, etc. are available on our website http://www.mines.utah.edu/~rbsmith/RESEARCH/UUGPS.html

An important local user component of our GPS monitoring provides the surveying community with our data for base station referencing via access to our data at the UNAVCO data web site.

In addition, hourly GPS data from the RBUT station are provided to the National Geodetic Survey and contribute to the NGS CORS on-line network that are accessible by ftp at ftp://cors.ngs.noaa.gov/coord.

DISTRIBUTION OF FINAL REPORT

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APPENDIX

Table 1: GPS stations operated by the University of Utah and other institutions and processed by the University of Utah.

	Site ID	Station Name	Lat.	Lon.	Elev. (m)	Site Location	Data Started
University of Utah	**ALUT**	Alta	40.58º	-111.62º	2826	Alta, UT	2005-06-27
	EOUT	East Ogden	41.25º	-111.93º	1678	Ogden, UT	1998-06-01
	HWUT	Hardware Ranch	41.61º	-111.57º	1715	Hyrum, UT	2004-10-07
	LTUT	Little Mountain	41.59º	-112.25º	1565	Brigham City, UT	2002-09-27
	LUMT	Lake Mountain	40.26º	-111.93º	2312	Provo, UT	1997-11-10
	MPUT	Maple Canyon	40.02º	-111.63º	1829	Payson, UT	2003-04-01
	NAIU	North Antelope Island	41.02º	-112.23º	1456	Syracuse, UT	1997-10-14
	RBUT	Red Butte	40.78º	-111.81º	1668	Salt Lake City, UT	1996-10-01
PBO	**P111**	WildcatHlsUT2006	41.82º	-113.00º	1366	Snowville, UT	2006-06-13
	P121	HnslVally_UT2004	41.80º	-112.70º	1452	Snowville, UT	2004-06-20
	P057	Hill72____UT2004	41.75º	-112.62º	1382	Snowville, UT	2004-08-27
	P122	CnrSPrings_UT2004	41.63º	-112.33º	1293	Penrose, UT	2004-06-27
	P101	RandolphLLUT2005	41.68º	-111.23º	2016	Randolph, UT	2005-09-02
	P089	Wanship___UT2004	40.80º	-111.42º	1816	Wanship, UT	2004-08-27
	P119	MahoganyHRUT2005	40.73º	-111.25º	2045	Oakley, UT	2005-05-04
	P118	KamasLloydUT2005	40.63º	-111.35º	2083	Kamas, UT	2005-11-20
	P088	LittleMtStUT2006	40.77º	-111.72º	1921	Salt Lake City, UT	2006-09-01
	P117	AmericanFCUT2006	40.43º	-111.75º	1629	Highland, UT	2006-05-04
	P086	Kennecott1UT2005	40.48º	-112.28º	1342	Stansbury Park	2005-01-04
	P114	BurgessRchUT2005	40.63º	-112.52º	1352	Grantsville, UT	2005-07-30
	P084	CedarMountUT2006	40.48º	-113.05º	1433	Tooele, UT	2006-05-17
	P113	KnollsWestUT2006	40.67º	-113.27º	1318	Tooele, UT	2006-04-16
	P016	VernonHillUT2006	40.07	-112.35º	1731	Vernon, UT	2006-04-14
	P112	Indianola_UT2005	39.82º	-111.22º	1930	Indianola, UT	2005-11-22
	P110	SanPeteValUT2005	39.72º	-111.57º	2266	Fountain Green	2005-11-01
	P108	SageValleyUT2005	39.58º	-111.93º	1683	Levan, UT	2005-10-31
	P106	FoolCreek_UT2006	39.45º	-112.25º	1560	Leamington, UT	2006-04-11

	P105	DeltaMuni_UT2004	39.38º	-112.50º	1431	Delta, UT	2004-09-22
	P104	BlackRock_UT2006	39.18º	-112.72º	1398	Hinckley, UT	2006-04-12
	P082	TuleValleyUT2006	39.27º	-113.50º	1382	Delta, UT	2006-05-09
	P081	Buckskins_UT2006	39.07º	-113.87º	1588	Garrison, UT	2006-04-13

BARGEN	**CAST**	Castle	39.19º	-110.68º	2245	Cleveland, UT	1997-03-26
	CEDA	Cedar	40.68º	-112.86º	1472	Delle, UT	1996-07-14
	COON	Coon	40.65º	-112.12º	1610	Magma, UT	1996-07-13
	HEBE	Heber	40.51º	-111.37º	1806	Heber City, UT	1996-07-12
	SMEL	Smelter	39.43º	-112.84º	1422	Woodrow, UT	1997-03-26
	SPIC	Scipio	39.31º	-112.13º	1670	Scipio, UT	2003-01-01
	CAST	Castle	39.19º	-110.68º	2245	Cleveland, UT	1997-03-26
	CEDA	Cedar	40.68º	-112.86º	1472	Delle, UT	1996-07-14

NGS	**SLCU**	Salt Lake City	40.77º	-111.95º	1278	Salt Lake City, UT	2001-10-18
	ZLC1	Salt Lake WASS 1	40.79º	-111.95º	1287	Salt Lake City, UT	2003-02-01
	MIDV	Midvale	40.62º	-111.91º	1312	Midvale, UT	2002-01-01
	MYT1	Myton 1	40.10º	-111.05º	1610	Myton, UT	2002-01-22

ATTACHMENT A

CONTEMPORARY DEFORMATION OF THE WASATCH FAULT, UTAH, FROM GPS MEASUREMENTS WITH IMPLICATIONS FOR INTER-SEISMIC FAULT BEHAVIOR AND EARTHQUAKE HAZARD: OBSERVATIONS AND KINEMATIC ANALYSIS (*ATTACHED REPRINT*)

ATTACHMENT B

LITHOSPHERIC RHEOLOGY FROM POST-SEISMIC DEFORMATION OF A M=7.5 NORMAL-FAULTING EARTHQUAKE WITH IMPLICATIONS FOR CONTINENTAL KINEMATICS (*ATTACHED PREPRINT*)

ATTACHMENT C

INTRAPLATE DEFORMATION AND BLOCK ROTATIONS OF THE WESTERN U.S. INTERIOR (*ATTACHED PREPRINT*)