MENDOCINO TRIPLE JUNCTION REGION PBO MINI PROPOSAL
by the Mendocino Triple Junction PBO Working Group

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INTRODUCTION

The Mendocino Triple Junction (MTJ) is the location of a profound change in plate boundary interactions along the western margin of North America. We propose to deploy ~40 continuous GPS stations to investigate questions concerning the tectonics and seismotectonics of the MTJ region (Fig. 1 and 2). Investigators involved in this proposal include geologists, geophysicists and geodesists who represent a broad spectrum of the interdisciplinary neotectonics community.

The MTJ is a high priority for implementation of continuous GPS receivers for several reasons. First, there are a set of compelling tectonic questions, which we outline below. Second, modeling (Furlong and Govers, 1999) has led to testable hypotheses for the kinematics of triple junction migration and crustal response. Third, previous and ongoing GPS and other neotectonic fieldwork within the MTJ region provide the foundation upon which to effectively site the proposed continuous array. The last decade has seen the execution of several GPS campaigns, as well as the initiation of an ongoing GPS study involving new and reoccupied stations monitored in a campaign mode; and finally, in the last years there has been renewed coring and trenching of active upper plate faults to ascertain slip style and rate in a geologic time frame. Investigators active in each these studies are party to this mini proposal. Each of these justifications for funding are discussed below.

<u>Compelling questions</u>

1. What do real-time vertical and horizontal velocities tell us about the transition from San-Andreas-style strike-slip deformation to oblique contraction, which is characteristic of the Cascadia subduction zone (CSZ)? Specifically, how much of a lateral component to deformation is there in the upper plate of the subduction zone immediately north of the triple junction? How broad is the zone of crustal deformation?

2. How does subduction of the southern Gorda plate differ from subduction further north ? How do M~7 events relate to the larger great earthquakes? Do these smaller events rupture separate small asperities or do they rupture parts of the plate interface "left behind" in a great earthquake?

3. The M_S 7.1 Cape Mendocino earthquake of April 1992 was confined to the extreme southernmost extent of the Cascadia subduction zone (Oppenheimer et al., 1993; Carver et al., 1994; Dengler et al., 1994). What are time-dependent effects of this type of earthquake ?

4. What is the rate of contraction across the upper plate thrust faults just north of the MTJ? How is the strain partitioned between upper plate contraction and strain accumulation on the megathrust?

5. Can we document (observe) the proposed escape of Eastern California Shear Zone (ECSZ) strain out to the plate boundary through the Klamath Mountain region? (Miller et al., submitted)

Ongoing geophysical modeling to be tested by continuous GPS deployment: Furlong and Govers (1999) propose that associated with the migration of the MTJ is a broad region of crustal contraction and crustal thickening followed (in space and time) by a subsequent crustal thinning. This process, termed the Mendocino Conveyor, conveys mantle material welded to the trailing edge of Gorda and underlying NAM plate northward. This results in patterns of contraction, crustal thickening and uplift of the northern California Coast Ranges, that propagate at the speed of

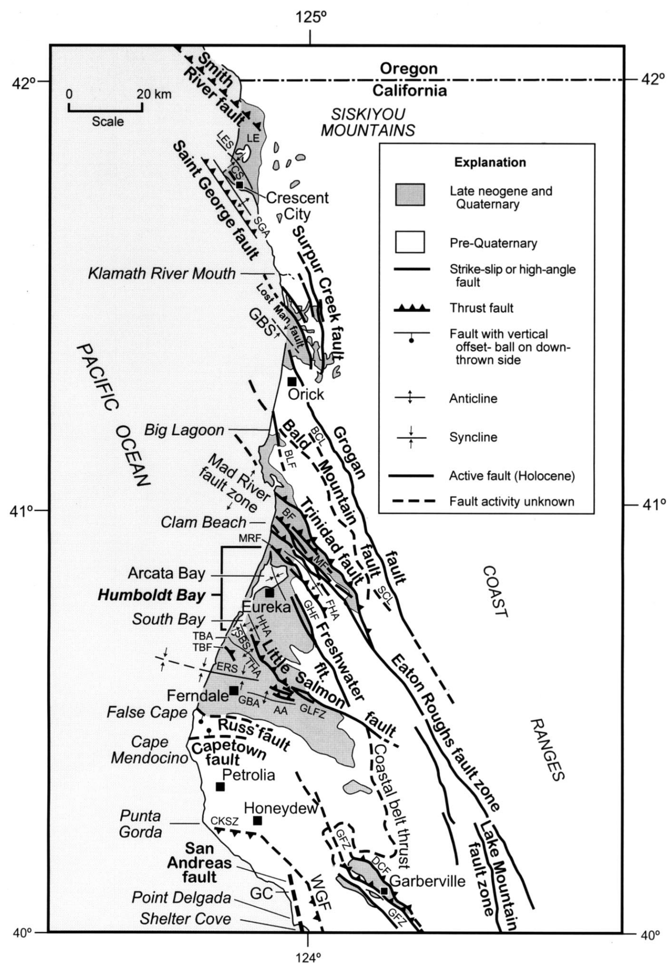

Figure 1. Tectonic map of Northern California (Major Faults and Folds;Kelsey, 2000).

LES, Lake Earl syncline; SGA, Saint George anticline; CS, Cemetery scarp; LE, Lake Earl; GBS, Gold Bluffs syncline; BCL, Bridge Creek lineament; SCL, Snow Camp lineament; BLF, Big Lagoon fault; BF, Blue Lake fault; MF, McKinleyville fault; MRF, Mad River fault; FHA, Fickle Hill anticline; FHF, Fickle Hill fault; GHF, Greenwood Heights fault; FS, Freshwater syncline; HHA, Humboldt Hill anticline; SBS, South Bay syncline; TBA, Table Bluffs anticline; THA, Tompkins Hill anticline; ERS, Eel River syncline; GLFZ, Goose Lake fault zone; AA, Alton anticline; GBA, Grizzly Bluffs anticline; CKSZ, Cooksie shear zone; WGF, Whale Gulch fault; GC, Gitchell Creek; GFZ, Garberville fault zone; DCF, Dean Creek fault.

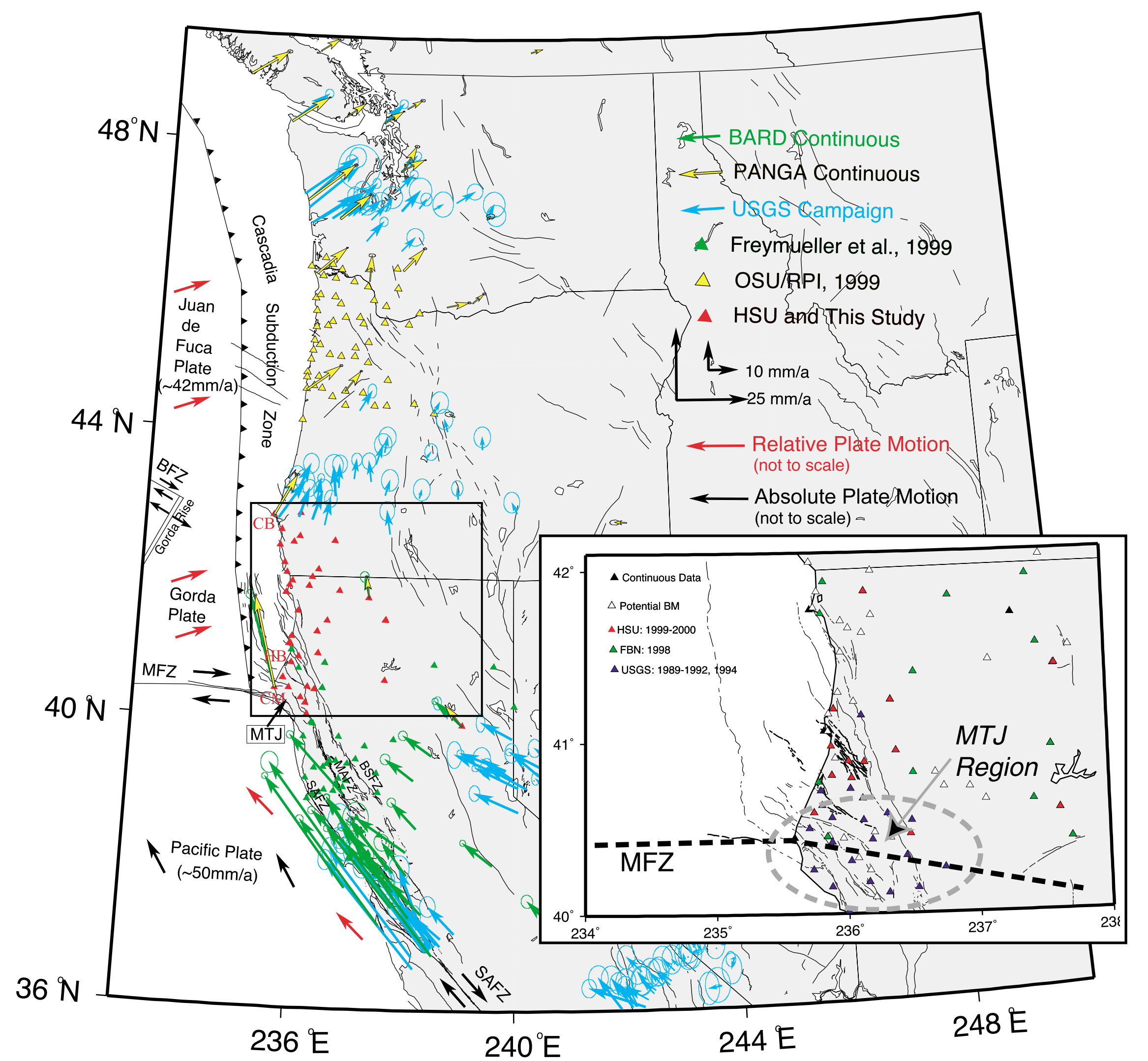

Figure 2. Regional Velocities, Western Cordillera of North America.

Compilation map of published GPS data from continuously operating sites and campaign mode data collection. All velocity vectors shown are residual to a fixed North American plate,error ellipses depict 95% confidence interval. Scale applies to observed GPS velocities only, (not schematic plate motions). Inset map shows details of GPS sites in MTJ region; CGPS receivers will be sited according to priorities identified in the proposal. Inferred location of the Sothern Edge of the Gorda slab is shown as the on-land extension of the Mendocino Fracture Zone (MFZ). Note that the MTJ is a broad region of transition from San Andreas to Cascadia dominated tectonics.

Abbreviations: BFZ = Blanco fracture zone; BSFZ = Bartlett Springs fault zone; CM = Cape Mendocino; CB = Cape Blanco; HB = Humboldt Bay; MAFZ = Ma'acama fault zone; MFZ = Mendocino fracture zone; MTJ = Mendocino Triple Junction; SAFZ = San Andreas fault zone.

migration of MTJ, followed by subsidence as the conveyor passes through the region. Continuous GPS in the MTJ region will provide first-ever vertical velocities for the area, which will test for high uplift rates in the area, uplift rates that are unattainable by other methods.

Recent and Ongoing GPS campaigns compatible with continuous GPS deployment A solid base of campaign style GPS measurements will be used to guide the continuous GPS deployment. Campaign GPS has been executed and analyzed by Mark Murray. More recently, Williams and Kelsey of HSU have initiated a new set of measurements, using existing and newly established stations. The HSU project is aimed at characterizing deformation on the north side of the MTJ to understand the transition from strike-slip to subduction tectonics. Williams will have 12 to 24 months of velocity data by Jan. 2001; a time frame when deployment decisions will be made.

Companion studies of upper plate faults to supplement real time strain measurement In the last twelve months, there has been renewed coring and trenching along the Little Salmon fault (R. Witter, G. Carver, H. Kelsey and HSU graduate students) to further refine estimates of fault style and slip rate. These studies, when joined with the previous studies of active upper plate faults by Carver and colleagues (Carver and Burke, 1988; Carver and McCalpin, 1996; Clarke and Carver, 1992), provide a better estimate of deformation rate and style in geologic time.

BACKGROUND TECTONIC AND GEOLOGIC SETTING

The southernmost 150 km of the 1,200-km-long Cascadia subduction zone (CSZ) is offshore of northern California. In January, 1700, a $M_w \sim 9$ subduction zone earthquake ruptured the entire length of the subduction zone from northern California to south coastal British Columbia (Satake et al., 1996; Jacoby et al., 1997; Yamaguchi et al., 1997). While the AD 1700 event represents the maximum magnitude for a CSZ earthquake, other modes of rupture are observed. The M_S 7.1 Cape Mendocino earthquake of April 1992 was confined to the extreme southernmost extent of the Cascadia subduction zone (Oppenheimer et al., 1993; Carver et al., 1994; Dengler et al., 1994).

The southern CSZ and Mendocino triple junction are overlapping geologic regimes where deformation at the fault-fault-trench triple junction has been migrating north since the inception of the San Andreas fault in the Oligocene (Atwater, 1970). The deformation front of the Cascadia subduction zone is submarine and offshore of the North American coast from the north tip of Vancouver Island, B.C., south to northern California at latitude ~41.5°. In the MTJ-GPS deployment area, the fold and thrust belt of the CSZ is uniquely distinguished in that active upper plate thrust faults occur on land; exposed subaerially as NW trending anticlines and synclines, with anticlines in the hanging walls of associated northeast dipping thrust faults (Clarke and Carver, 1992). These thrust faults and folds trend approximately normal to the Gorda Plate convergence direction and are evidence of late Quaternary contraction of the North American margin (Clarke, 1992). Trending N-NW into the fold and thrust belt from the south are strike-slip faults associated with the northern end of the San Andreas transform (Kelsey and Carver, 1988; Fig. 1). Freymueller at al. (1999) analyzed strain on these strike slip faults using GPS data. Recently analyzed marine seismic reflection transects suggest a component of Pacific-North American-related strike-slip motion continues offshore (Gulick et al., submitted), consistent with the Mendocino conveyor model.

These faults within the North American plate (Figure 1) are sources of seismicity and of strain; accommodating contraction in the upper plate (Carver, 1987; Clarke and Carver, 1992). This implies that the subduction zone is in part coupled and a portion of the plate convergence is accommodated by upper-plate shortening, with the rest by slip on the subduction zone. Trenching studies indicate that upper-plate thrust faults in the Humboldt Bay region have slip-event recurrence intervals that range from hundreds of years for the Little Salmon fault (~ 400 yr.; Clarke and Carver, 1992) to thousands of years for the Mad River fault zone (3,000-4,500 yr.; Carver and Burke, 1988). The geologic evidence provides support that the southern CSZ is currently building up strain preparatory to the next subduction zone earthquake, and that this earthquake may involve synchronous rupture of associated upper-plate thrust faults. Although we know the geologic slip rates for of some of these faults, present-day, real time slip rates will provide critical data to address the kinematic and seismotectonic questions posed above.

JUSTIFICATION FOR CONTINUOUS GPS MONITORING

Although significant geodetic work has now been undertaken in Oregon and Washington, the southernmost part of the Cascadia margin remains poorly-studied geodetically (Figure 2). Today there are precise GPS velocities available for only a few permanent sites between central Oregon and Cape Mendocino (Cape Blanco, Crescent City, Trinidad, and continuous site CME1 at Cape Mendocino). Valuable preexisting data bases include surveys over the last decade of the California High Precision Geodetic Network (HPGN), supplemented by surveys by Mark Murray and colleagues and more recently (1999 and 2000) by Humboldt State University. A compilation of the existing GPS velocities, relative to North America, from Cascadia and adjacent parts of western North America is shown in Figure 2. Data from the regional BARD (Bay Area Regional Deformation) and PANGA (Pacific Northwest Geodetic Array) permanent networks are shown along with a compilation of campaign data from the USGS. Each velocity solution used a slightly different realization of a North American reference frame, so small inconsistencies between the data sets at common sites are expected. The general deformation patterns are clear in this compilation. The northward component of velocities along the coast decrease from Cape Mendocino to Vancouver Island. The continuous site CME1 at Cape Mendocino moves to the NNW at approximately 30 mm/year, a direction roughly orthogonal to the Gorda-North America (G-NA) relative motion. CME1 shows clear effects of a combination of Pacific-North America and G-NA relative motion. The site at Cape Blanco and the USGS sites inland of it show a combination of northward translation due clockwise rotation of the forearc block about a nearby pole (Savage et al., 2000; McCaffrey et al., 2000) and strain in the direction of G-NA relative motion. Further north, velocities agree more closely with Juan de Fuca-North America relative motion. Through continuous GPS observations, the northern limits of Pacific-North American relative plate motion in northern California can be analyzed

PROPOSED DEPLOYMENT OF CONTINUOUS GPS SITES

We propose the installation of 40 permanent sites in northern California within the MTJ region. This area is the last major gap in our first-order knowledge about crustal deformation, compared to better understood first-order tectonics of the CSZ to the north and SAF to the south. Fig. 2 shows potential sites for installation of continuous GPS.. The selection of particular sites is yet to be made, and will be dictated by the following goals:

<u>Deployment Goal # 1</u>: Define the transition from strike-slip to subduction as the San Andreas, Garberville/Maacama and Bartlett Springs/Lake Mountain fault zones interact with the CSZ.

<u>Deployment Goal # 2</u>: Estimate rate of contraction across the most active upper plate faults, the Little Salmon fault and the Mad River fault zone, and the contraction in the upper plate region away from these faults.

<u>Deployment Goal # 3</u>: Document long-term and post-seismic effects of the 1992 Cape Mendocino and similar earthquakes; ("typical" earthquake for the south-most part of the CSZ near the MTJ?).

<u>Deployment Goal # 4:</u> Strategically place continuous recorders to test the model of escape of the ECSZ through the Klamath Mountains to the coast at the latitude of northern-most California

COORDINATION WITH PANGA MINI PROPOSAL AND OTHER INVESTIGATORS

We have coordinated our mini proposal, in terms of geographic scope (i.e. non-overlapping) with a mini proposal to be submitted by the Pacific Northwest Geodetic Array (PANGA), which focuses on east-west study transects from the CSZ to the arc. Additionally, our region is a western extension of the Shasta-Medicine lake transect for volcano monitoring, conducted by the Cascade Volcano Observatory (CVO); leading to a transect of GPS across northern California.

REFERENCES

Atwater, T., 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America; Geological Society of America Bulletin, 81, 3513-3536.

Carver, G. A., 1987, Late Cenozoic tectonics of the Eel River basin region, coastal northern California. In H. Schymiczek and R, Suchland, eds., Tectonics, sedimentation, and evolution of the Eel River and other coastal basins of northern California: San Joaquin Geological Society Misc. Publication 37, p. 61-72.

Carver, G.A., and Burke, R.M., 1988, Trenching investigations of northwestern California faults, Humboldt Bay region: U.S. Geological Survey, NEHRP Final Technical Report, 53 p.

Carver, G.A., Jayko, A.S., Valentine, D.W., and Li, W.H. 1994, Coastal uplift associated with the 1992 Cape Mendocino earthquake, northern California: Geology, v. 22, p. 195-198.

Carver, G.A., and McCalpin, J.P., 1996, Paleoseismology of compressional tectonic environments: *in* J. P. McCalpin, ed., Paleoseismology, Academic Press, New York, 183-270.

Clarke, S.H., Jr., and G. A. Carver, 1992, Late Holocene tectonics and paleoseismicity, southern Cascadia subduction zone: Science, v. 255, p. 188-192.

Dengler, L., Moley, K., McPherson, R., Pasyanos, M., Dewey, J. W., Murray, M. H., 1995, The September 1, 1994 Mendocino fault earthquake. California Geology, v. 48, n. 2, p.43-53.

Freymueller, J. T., Murray, M. H., Segall, P., Castillo, D., 1999, Kinematics of the Pacific-North America plate boundary zone, northern California. Journal of Geophysical Research, v.104, no. B4, p. 7419-7441.

Furlong, K. P. and Govers, R., 1999, Ephemeral crustal thickening at a triple junction: the Mendocino crustal conveyor, Geology, 27, 127-130.

Jacoby, G.C., Bunker, D.E., and Benson, B.E., 1997, Tree-ring evidence for an A. D. 1700 Cascadia earthquake in Washington and northern Oregon: Geology, v. 25, p. 999-1002.

Kelsey, H.M., 2000, Active faulting associated with the southern Cascadia subduction zone in northern California, *in* Engineering Geology Practice in Northern California, H. Ferriz, ed., Association of Engineering Geologists and California Division of Mines and Geology, submitted, 22p.

Kelsey, H. M., and Carver, G. A., 1988, Late Neogene and Quaternary tectonics associated with the northward growth of the San Andreas Transform fault, northern California. Journal of Geophysical Research, v. 93, no. B5, p. 4797-4819.

McCaffrey R., M. D. Long, C. Goldfinger, P. C. Zwick, J. L. Nabelek, C. K. Johnson, and C, Smith, Rotation and plate locking at the southern Cascadia subduction zone, Geophysical Research Letters, v 27, p. 3117-3120, 2000.

M. M. Miller, D. J. Johnson, C. M. Rubin, H Dragert, K. Wang, A. Qamar, andC. Goldfinger, GPS-determination of along-strike variation in Cascadia margin kinematics: Implications for relative plate motion, subduction zonecoupling, and permanent deformation. Tectonics. Submitted April, 2000.

Oppenheimer, D., Beroza, G., Carver, G., Dengler, L., Eaton, J., Gee, L., Gonzalez, F., Jayko, A., Li, W.H., Lisowski, M., Magee, M., Marshall, G., Murray, M., McPherson, R., Romanowicz, B., Satake, K., Simpson, R., Somerville, P., Stein, R., and Valentine, D., 1993, The Cape Mendocino, California, earthquakes of April 1992: Subduction at the triple junction: Science, v. 261, p. 433-438.

Savage, J. C., J. L. Svarc, W. H. Prescott, and M. H. Murray, (2000), Deformation across the forearc of the Cascadia subduction zone at Cape Blanco, Oregon, *J. Geophys. Res.*, 105 3095-3102.

Satake, K., Shimazaki, K., Tsuji, Y., and Ueda, K., 1996, Time and size of a giant earthquake in Cascadia inferred from Japanese tsunami records of January 1700: Nature, v. 379, p. 246-249.

Yamaguchi, D.K., Atwater, B.F., Bunker, D.E., Benson, B.E., and Reid, M.S., 1997, Tree-ring dating the 1700 Cascadia earthquake: Nature, v. 389, p. 922-923.