Cascadia Amphibious Facility Planning Group Report

July, 2009

1. Introduction

On June 30 and July 1, a mix of 31 scientists and NSF officials met at Lamont-Doherty Earth Observatory with a brief six weeks forewarning to discuss the Cascadia Facility Enhancement Initiative. This Report summarizes the recommendations of that group.

1a. Brief description of Initiative formulation

As part of the 2009 Stimulus or ARRA (American Recovery and Reinvestment Act) spending, NSF's Earth Sciences (EAR) and Ocean Sciences (OCE) divisions are each receiving $5M in facility-related investment. The funds are targeted toward Facility-related investments to support EarthScope and MARGINS science objectives, with an initial emphasis on onshore/offshore studies of the Cascadia margin. Under current plans, the EAR portion will be spent to enhance data collection from the EarthScope PBO geodetic facility in Cascadia, and to deploy additional USArray Transportable Array seismic equipment in the region, not necessarily only re-occupying previous stations. The OCE portion will go toward a pool of Ocean Bottom Seismographs (OBS's), ultimately part of the OBS Instrument Pool (OBSIP), to be deployed off Cascadia. OBS deployments will be supported by other funds. NSF currently envisions an initial deployment of at least 3 years, with a review to determine future use of this equipment. All of these instruments are to be "open" community facilities providing data to any interested investigator as quickly as possible, in the manner of most current EarthScope stations.

1b. Planning Group Meeting

Upon request from the National Science Foundation, the chairs of the EarthScope and MARGINS Steering Committees convened a 24-person Planning Group to provide guidance on the use and implementation of the facility. The Planning Group was given two charges: (a) to describe the primary scientific opportunities and critical objectives that the new Facility could address, and (b) to devise an initial implementation plan for the Facility. Participants were invited immediately upon announcement of NSF's ARRA opportunities, and were selected from both EarthScope and MARGINS communities, and from a range of institutions (Participant List at end of this document). At the same time, the initial description of the Facility was distributed broadly to the MARGINS and EarthScope bulk email lists, and an open web-based Forum was established to allow for community-wide input to this planning (*cascadia.freeforums.org*). The Planning Group was joined, during portions of the meeting, by seven representatives of NSF and the major facility support groups involved (IRIS/USArray; UNAVCO/PBO; OBSIP Instrument Centers). The resulting Report, drafted immediately after the meeting, summarizes discussion first about scientific opportunities and then about implementation.

2a. Science objectives – seismic and aseismic sources

ETS - Episodic Tremor and Slip

The recently discovered geophysical phenomena of slow aseismic slip, tremor and other low frequency seismic events raise basic science questions (Figure 1) and offer clues to hazard assessment and mitigation for the populations in the Pacific Northwest. Because of their repeated and quasi-periodic occurrence in Cascadia, all these phenomena collectively have been termed ETS. Thus far the seismic sources have been modeled only as point sources of unknown mechanism, and slow slip as shear on the plate interface. The connection between tremor and slow slip has been elusive – so far resolution of slow slip is much more limited than for tremor, and determination of tremor depth fraught with large uncertainties.

The picture of how these sources are distributed and evolve in space and time is beginning to emerge in the onshore regions, albeit with highly variable resolution, and offshore even their existence is largely unknown. However, theoretical models and observations from other subduction zones lead us to anticipate them in offshore Cascadia.

The underlying physical processes, particularly with respect to the seismic phenomena, are unknown although correlations with fluids, elevated pore pressures, and structural features begin to suggest causative mechanisms. ETS appears to delimit the edges of where the plate boundary is locked and seismogenic, and thus if mapped in detail would permit accurate forecasts of the rupture limits of future great earthquakes. The currently understood downdip boundary of the locked zone coincides with the coastal regions of Cascadia, and all that is known about the updip boundary is that it is well offshore; better defining these boundaries necessitates an amphibious integrated deployment of both geodetic and seismic instrumentation.

These processes of slow slip and tremor appear dynamic in time and space. Existing observations indicate significant variability in behavior along the Cascadia coastline – we need to verify that these differences are real and why they exist. Progress requires a broad deployment of GPS receivers and seismic stations augmented by leveraged denser installations and complementary geophysical facilities.

Interplate seismicity

The Cascadia shallow thrust zone, where faulting occurs during great earthquakes, generally shows few thrust earthquakes, and GPS data indicates that the shallow part of the zone is locked. However, several moderate-size (M4-5) low-angle thrust earthquakes have recently been documented on the plate boundary, and earthquakes as large as M=9 have been inferred from the paleoseismic record. The region of moderate-sized earthquakes is primarily located offshore, and the depth and mechanism of earthquakes are not well determined by the current station distribution. Moreover, the temporary presence of USArray in the Pacific Northwest has revealed that many small earthquakes offshore and in the Coast Range have been missed by the current network. New high quality stations near the coast, combined with better knowledge of the crustal velocity structure, are needed to illuminate the pattern of seismic activity offshore on and around the megathrust. Where and what is the nature of the boundary between the locked, earthquake-producing region and the ETS zone? Better definition of the patterns of forearc seismicity is needed to determine whether there are temporal, as well as spatial, correlations between ETS activity on the deeper part of the megathrust and earthquake activity updip, as predicted by theoretical models. Moreover, a fundamental goal of the MARGINS program is to understand the connections between thermal structure, fault-zone composition, metamorphic dehydration, pore pressure, fault strength and fault slip behavior. The variation of these properties both along strike and downdip are likely to have significant influences on the rupture of great earthquakes. The Cascadia initiative will help constrain the spatial variation in both physical properties and the spectrum of deformation events all the way from the deformation front down to the ETS region. These improved constraints are crucial for physical models of the thrust zone and hence for refining estimates of both seismic and tsunami hazard in Cascadia.

Repeating and slow earthquakes

Repeating earthquakes, that is, events that have the same location, magnitude, waveforms and source mechanism, are observed in the region of the Mendocino Triple Junction. Slow earthquakes that lack high-frequency radiation also occur on the same fault planes as regular earthquakes. The repeating events are thought to be the result of asperities on the fault plane and the slow events imply a relatively low stress drop. Both provide information about the nature of the fault plane and raise the question of how these unusual and more regular earthquakes are related. Why do both types of events occur on the same fault plane and why are the unusual events not (so far) observed on more faults? The proposed deployments, both onshore and offshore, will enable more detailed analysis of the source processes and will likely identify new regions where this unusual seismicity occurs.

Crustal seismicity

Intra-plate, crustal seismicity is observed throughout the study area and has been concentrated in several specific regions. The Gorda section of the subducting plate is highly seismic with many moderate-size events that show left-lateral strike-slip motion along a NE-SW striking plane. These events provide information on the stress and strain distribution throughout this micro-plate. All these events have only been studied using onshore instrumentation and better sampling with offshore instrumentation will allow the detection and study of a much larger number of events and provide a more detailed picture of the deformation field. Additionally, crustal seismicity within the North America plate also exhibits variability throughout Cascadia. For example, in the Puget Sound region small and moderate earthquakes are relatively abundant compared to nearly silent Oregon, and almost none of these can be associated with known geologic structures.

Earthquakes within the subducting plate

Most of the damaging historical earthquakes in Cascadia (1949, 1965, 1992, 2001; M=6.5-7.1) occur within the subducting plate, beneath population centers. These “intraslab” earthquakes have only been observed north of south-central Washington and near the Mendocino triple junction, showing similar segmentation as ETS, for reasons not well understood. Breakdown of hydrous minerals within the subducting plate is often argued to provide a critical trigger for intraslab earthquakes, but other factors may be important as well. The Facility should greatly increase our sampling of these earthquakes as well as our understanding of along-strike changes to Juan de Fuca plate structure, both inland and offshore before it subducts.

2b. Science objectives - Structure of the Juan de Fuca plate and Cascadia Subduction zone

The Cascadia region offers a unique opportunity to image structure associated with an entire plate, including a spreading center and subduction zone, within an easily accessible part of the continental and offshore US that has already been targeted for study by several major initiatives, including Earthscope, Canada-Neptune, and the Ocean Observing Initiative. The new Facilities can provide critical observations for several major scientific problems.

Water transport in a young subduction zone.

Subduction zones control the primary flux of water (and other volatiles) from the Earth's surface to deep interior, so their ability to retain water regulates the long-term surface water budget (Figure 2). Cascadia is an end-member subduction zone, containing the warmest slab in the world that is associated with a volcanic arc. Since heat limits the stability field of most hydrous minerals, yet water is abundant in the lavas, it is important to understand how water is transported to depth in Cascadia. One aspect of this question is how water is carried into the subduction zone by the Juan de Fuca plate. Possible hydration of Juan de Fuca mantle through hydrothermal circulation either near the spreading center or at the plate-bending region closer to the trench is particularly important. That is particularly true if water can circulate deep enough to hydrate the upper mantle, a potentially vast reservoir and currently the largest uncertainty in the water input. The output budget during subduction also remains unclear. Previous studies suggest extensive hydrous alteration (serpentinization) of the mantle forearc, indicating much water release at shallow depths, but further work is needed. The rate at which dehydration reactions proceed with depth in the downgoing slab is another important question; thermal models predict shallower dehydration in Cascadia than elsewhere. This shallow fluid release may play in important role for creating conditions in which ETS and other slow slip modes can occur. Hydration has a strong effect on seismic velocities, so seismic imaging has great potential to constrain the effects of water transport at depth. The integrated amphibious facility will allow for the first time the extent of hydration to be imaged systematically on both sides of the trench.

Melt production and the plumbing system of volcanoes.

The magma production system in volcanic arcs is a fundamental earth process that generates crustal material, but is poorly understood. Cascadia magmas are hydrous and show high concentrations of fluid-mobile elements, and water has been directly sampled in melt inclusions of primary magmas, implying that water released by the slab plays a major role. The presence of such volatiles plays a critical role in the explosiveness of arc volcanoes, and so understanding the relevant fluid pathways has implications for hazards as well as fundamental science. However, as described above, the high temperatures expected within the slab are difficult to reconcile with the delivery of volatiles to sub-arc depths. Seismic imaging combined with the results of experimental rock mechanics can place constraints on the geometry of melt and the porosity and permeability of the melt production and transport regions, giving insight into fluid and magma pathways. Other types of signals, such as exotic seismic sources associated with melt transport and transient geodetic signals from volcanoes will provide additional constraints on the shallower part of the system.

Seismic anisotropy and Mantle flow Patterns.

Seismic anisotropy in the earth's mantle generally forms through lattice preferred orientation of anisotropic minerals like olivine as a result of shear strain associated with mantle flow. In subduction zones, complex patterns of inferred anisotropy have led to consideration of other effects, such as anisotropy due to melt fabric, to metamorphic fabric within slabs, or to deformation processes associated with high water content. Limited spatial coverage in many subduction zones has made these various effects difficult to separate. Observations of seismic anisotropy thus may provide constraints on mantle flow patterns and on the dynamics of plate spreading, plate motions, and subduction. In particular, the Juan de Fuca region provides a unique opportunity to map the seismic anisotropy of an entire plate system from spreading to subduction. Sampling anisotropic fabric from the creation of new lithosphere to its descent into subduction zones would provide coverage, for the first time, of the entire top half of a convective cell. This complete sampling might help separate anisotropy frozen in subducting lithosphere from that generated by deeper flow, allowing tests of theories that relate mantle convection to plate motions.

The USArray component of EarthScope has revealed many striking seismic velocity anomalies in the upper mantle beneath the western U.S. that appear to be related to convective upwellings and downwellings. Resolution decreases near the coast due to one-sided coverage from lack of off-shore stations, but in some tomographic images, there appears to be a major low-velocity anomaly in the asthenosphere beneath the coast from the Mendocino triple junction north to the middle of Oregon. It is too deep to be directly part of the segmentation of the Juan de Fuca plate, but it may be a dynamic flow feature related to the overlying plate or to the segmentation of the subduction zone. Offshore instrumentation is needed to resolve the extent and tectonic role of this and other sublithospheric anomalies.

Subduction zone segmentation.

The Cascadia subduction zone is clearly segmented in many ways, including geological structure, forearc basin structure, location and recurrence of ETS events, and rupture zones of paleo-earthquakes. There is some evidence that these different modes of segmentation coincide, but it is unclear what fundamental process produces the segmentation. Mantle structure may be the key to understanding this along-strike variability, and segmentation is imaged in the subducting slab from ~100 to ~400 km depth. It has been hypothesized that this segmentation is the product of either N-S variations in the Juan de Fuca plate or of deeper mantle processes. Above ~100 km it has been difficult to image the slab due to its proximity to the edge of seismic deployments imposed by the coastline. Does the deeper segmentation continue to the west, implying that it is due to variations in the structure of the Juan de Fuca plate, or does it stop, implying modification of the subducting plate by a deep source?

3 Implementation

The planning group based its discussion of the implementation of the Cascadia Facility Initiative on guidance from the NSF as well as on documents provided by the PBO/UNAVCO, USArray/IRIS and OBSIP facilities, and on presentations given by representatives from these facilities.

The group recognized that the integrated nature of the proposed onshore-offshore facility offers a great opportunity to address a wide range of fundamental science questions, and that immediate open access to onshore and offshore data from both seismic and geodetic instrumentation will facilitate integrated research by many members of the community.

The group further recognized that the proposed new facility, which is aimed specifically at augmenting seismic and geodetic capabilities will meet only a subset of identified instrumentation needs, and that additional facilities and experiments are required to address several of the scientific objectives discussed at the meeting.

With regard to the onshore portion of the new facility (PBO and USArray), the planning group recommends that the initial instrument deployment in Cascadia take place essentially in the form proposed by the facility groups. The uniform distribution of GPS and broadband seismic stations should extend along the length of Cascadia from the Canadian border to south of the Mendocino Triple Junction and from the coast to east of the High Cascades. It is desirable that the backbone onshore deployment GPS and broadband seismic stations described here be complemented by additional instrumentation and dense deployments of the USArray Flexible Array, particularly to complement dense offshore OBS deployments.

The strategy for deployment of the offshore component was identified as more complex on account of limited prior data and experience, the variety of science goals and targets, and the differences in the instrumentation needed for the different targets. Within the timeframe available for the Cascadia experiments, three phases of OBS deployments prior to 2014 appear possible (Figure 3): (1) Plate-crossing deployments to sample all, or sections of, the entire Juan de Fuca plate as far west as the ridge, (2) Synoptic trench deployments to extend the onshore observations of tremor, seismicity and structure offshore to the trench along the length of Cascadia, and (3) Focused deployment(s) with station spacing of 10-30 km to support high-resolution studies of the physical properties and seismic activity in the seismogenic zone and accretionary wedge. All three were found to have strong scientific merit but a prioritization emerged from the discussion. A focused thrust-zone deployment(s) was identified as a priority, however it was recommended that the location(s), deployment plan and scientific target be identified at a later workshop that follows initial analysis of data from the amphibious facility. Some degree of coverage across the entire plate can be achieved during one or more of the deployment phases, with less dense station spacing in the western part of the study region near the spreading center. Coverage of the northern end of the Juan de Fuca plate will also be enhanced by the broadband instruments installed by the Neptune Canada array and by the Ocean Observatory Initiative.

The planning group identified and discussed the opportunities for future deployments of the OBSIP and USArray components of the new facility to other areas, in particular in conjunction with the future deployments of the USArray TA, and the appropriate duration of the initial deployment in Cascadia considering competing scientific objectives. The group recommends that the onshore/offshore facility be operated in Cascadia until mid 2014, allowing for three OBS deployment phases, and subsequently for it to be available for deployments in other locations.

3a. PBO Upgrade

The upgrade of Cascadia PBO stations to high-rate sampling and real-time telemetry (Figure 4) will enable a host of new analyses that are not currently possible with existing Cascadia PBO infrastructure. GPS is not limited to daily positioning of steady-state deformation, but can resolve dynamic ground motions at amplitudes down to roughly a centimeter and frequencies up to a few Hz. Seminal examples include GPS-based estimates of near-field, extreme strong ground motion during the 2002 Mw 7.9 Denali earthquake and the passage of its teleseismic surface waves through Southern California, 3900 km from the source. In this example, the analysis of 1 Hz GPS data faithfully resolved teleseismic amplitudes between 2 mm and 3 cm, as confirmed by comparison with nearby broadband seismometers.

The scientific, monitoring, and hazards mitigation potential for the proposed Cascadia PBO upgrades is high. High-rate GPS position measurements complement strong ground motion seismometers by not clipping, and indeed the signal to noise ratio of position resolution increases as motion amplitude increases towards arbitrarily large values. Moreover, its complementary nature also includes the fidelity with which GPS measures long-period deformation. Force-balance and strong ground motion seismometers both suffer an intrinsic physical ambiguity between resolving tilt and acceleration, and at long periods both contribute significantly to what seismometers record as acceleration or velocity. With GPS, by contrast, displacement is estimated directly, eliminating this bias. The ability to stay on scale and measure accurately near-field dynamic velocities upwards of meters per second without clipping or aliasing has no other instrumental analog and is unique to GPS.

The proposed upgrades to Cascadia PBO communications will enable several new research avenues and assist in mitigating damage from natural hazards. Currently, high-rate data recorded at Cascadia PBO stations is not downloaded but rather is stored on the GPS receiver for two weeks. In exceptional circumstances, for example following large earthquakes, these data can be made available by manual download initiated by specific requests made by community PIs to the UNAVCO facility. Continuous downloading will enable new routine analyses for strong ground motion monitoring, earthquake hazards mitigation, and the like to be developed, tested and deployed in the interest of hazards mitigation. It should be noted that while the geodetic signature of ETS, approximately 5mm, currently lies at the resolution limit of real-time GPS positioning, ongoing improvements in the resolution of real-time GPS will likely allow future events to be imaged in real-time. This will guide the deployment of temporary instrumentation to record these events better.

The planning group recommends that the community develops and implements a plan for support of the routine analysis of the real-time, high-rate data in such a way as to make the data products available in real time. Without the routine generation of displacement time series and auxiliary metadata, the number of users of these data streams will be limited, given that few users have the facilities in place to derive position estimates from the raw real-time GPS phase observations that will be streamed to the UNAVCO facility.

It was noted that at the current time there is a high degree of integration between PBO stations and the approximately 130 non-PBO, real-time Cascadia GPS stations that comprise the Pacific Northwest Geodetic Array (PANGA, supported by the USGS NEHRP program). Care was taken during site selection of PBO sites to maximize spatial coverage and avoid redundant installations, so the combination of the PBO, PANGA and WCDA networks provides over 350 GPS stations throughout the Cascadia subduction zone. In addition, it was noted that ongoing analysis of real-time PANGA data is well integrated with other real-time GPS efforts such as NASA's global tsunami detection program (GREAT); incorporation of real-time data from upgraded PBO stations in such hazard mitigation efforts should be facilitated. Real-time upgrades to Cascadia PBO stations will improve the efficiency of routine operations and maintenance of PBO Cascadia stations, at little extra cost. The current telemetry billing structure for PBO operations includes fixed costs based on total quantities of data downloaded, and changes little whether the download is continuous or daily. By enabling continuous downloading, the proposed upgrades will allow continuous monitoring of PBO network health.

3b. USArray Seismometer Deployment

The recommended style of initial instrument deployment for the onshore seismic component in Cascadia is as an element of the USArray Transportable Array (TA), in a static configuration for the duration of the deployment and with continuous data transmission and integration with other TA data streams.

A geometry of regularly distributed stations across Cascadia is preferred over more locally concentrated geometries. Breadth of coverage allows many topics to be addressed, including comprehensive tracking of tremor and other seismicity along the entire length of the subduction zone. Focused studies may be added as PI-driven EarthScope flexible arrays or other experiments, and generally could be shorter in duration, less broadband in frequency response, and would probably make use of a larger number of instruments than the backbone network.

While some offshore experiments discussed would benefit from a complementary seismometer distribution onshore, the multi-stage OBS strategy and the adaptive nature of OBS planning make logistically impractical perturbations to the onshore seismometer configuration. Onshore complements to focused OBS deployments would be better accomplished with deployments of the USArray Flexible Array, or similar equipment.

A trade-off exists between the number of instruments that can be procured for the facility and the duration of the initial Cascadia deployment. A longer duration (longer than 3 years) of deployment increases operational costs, but the benefits are substantial. Most importantly, we expect the science benefits from this deployment to grow with time, and initially the sensors will complement a variety of offshore experiments. Many cycles of

ETS need to be recorded to capture the variability or lack thereof in ETS cycles, and have the time to focus experiments on critical times and places. In addition, a longer initial deployment will allow additional time to secure the resources necessary to convert most or all of the new sites to permanent monitoring stations. Both the CISN and the PNSN recognize the merit of keeping these stations and NSF recognizes the scientific benefit of such an adoption. Adoption in this case refers to purchase of replacement equipment by other groups from USArray. In any case, at some point in 2014 the full onland seismic component of the facility will become available for onshore/offshore deployments in other areas.

Strong motion sensors and the enabling 6-component dataloggers are included in the station deployments for three reasons: 1) The broadband sensors saturate easily, even on moderate earthquakes, so strong motion instruments are necessary to record close in moderate earthquakes; 2) large magnitude earthquakes, even though rare, are poorly represented in global recordings, and so there is great value in recording a potential M7.5 or greater earthquake nearby; 3) inclusion of such sensors, which are standard for broadband installations in both PNSN and CISN, would make the desired permanent adoption of these stations by the regional seismic networks more straightforward.

3c. OBS Facility Implementation

The Cascadia initiative presents a great opportunity to develop a new generation of ocean bottom seismometers (OBSs) that utilize improved technology over the present OBSIP equipment. Both the Cascadia Initiative and future onshore/offshore experiments elsewhere will require a mixture of instrument types. To achieve a high rate of return of quality broadband seismic data, instruments deployed in water depths shallower than about 1000 meters will require a combination of shielding from currents, burial, and trawl resistance that is not currently available. The general consensus of the planning group was that approximately one third of the instruments built with stimulus funding should be suitable for shallow water conditions. These instruments might require deployment and/or recovery by Remotely Operated Vehicles (ROVs). The intermediate water depth (1000-5500m) instruments would be similar to current OBSIP instruments deployed by freefall, hopefully with burial and/or shielding technology. They would carry either a Trillium Compact or other broadband seismometer.

The planning group also strongly supported the integration of Absolute Pressure Gauges (APG), particularly at sites where deformation from slip events, earthquakes, or submarine slides are possible. These instruments have much more accurate absolute calibration than Differential Pressure Gauges (DPG) and very high dynamic range. They provide back-up for the vertical seismometer, allow removal of much ocean-generated, long-period noise from vertical-component seismographs, and do not require the ad hoc, pressure-dependent amplitude corrections needed for DPGs. They have potential to record much longer period deformation and precise measures of depth changes and thus may provide critical geodetic information during and after a large nearby slip event. For deep water, mid-plate sites either an APG or a DPG could be used, but at least one is required. At sites where strong motions from large earthquakes are possible, an accelerometer is recommended.

Due to the time lag in constructing OBSs and the limited weather window in the Northeast Pacific, the Cascadia deployment of the OBSs is likely to occur in several phases. Because of uncertainties in the construction schedule of OBSs and other operational considerations (e.g., weather window, ship schedules), a specific deployment plan was not recommended at the meeting. Following is a notional plan that provides one example of a plausible deployment/recovery schedule. On the basis of the timelines for construction discussed at the meeting, the planning group envisions that roughly half of the OBSs could be built during the winter/spring of 2010, and the first stage would deploy them from summer of 2010 to spring/summer of 2011 (10-12 months). A second stage could involve a deployment of the full facility from summer of 2011 to fall of 2012 (14-15 months). The instruments would then be refurbished during the 2012-2013 winter. A third stage would be a deployment of the full facility from summer of 2013-summer of 2014 (12-15 months). The new OBS facility would then be available for deployment elsewhere after recovery and necessary refurbishment. The planning group recommends that the development of a deployment plan be the responsibility of a community planning group or committee, to be constituted.

The planning group identified the integration of the OBS data with other onshore seismic data as a high priority. This is unlikely to happen without a specific and focused effort. To accelerate the scientific investigations and maximize the utilization of the data, a complete and uniform earthquake catalog should be created. Several models for the generation of such a catalog were discussed including, for Cascadia, by the PNSN and/or the CISN or through individual experiment PIs.

4. Management

The Cascadia Facility Initiative is an audacious undertaking that requires proper management to achieve desired integrative science outcomes. Numerous decisions regarding scientific targets, experiment design, and deployment logistics will be required during the period of initial deployments in the Cascadia region. In addition, the envisioned community mode of operation, with open data access and, as recommended by this group, integration of onshore and offshore data sources, will require planning, organization, and implementation. The planning group recommends that NSF set up an appropriate small steering committee to provide guidance to the facilities in their implementation of the technical aspects of the initiative. In addition, this committee (potentially together with or with representation from existing community committees, such as the MARGINS and EarthScope Steering Committees) should be charged with the development of a plan for how the scientific value of the new facility can be optimized. An important component of this is the encouragement of broad community involvement in the initial Cascadia deployment, and utilization of the data that will result. A second component is the development of a community planning process for future deployments of this onshore/offshore facility in a mode of community experiments.

4. Conclusions

The Cascadia Facility Initiative will provide an unprecedented amount of new data on the Cascadia region that will lead to new discoveries and insights. It will also create an opportunity to leverage these advances with additional instrumentation and studies not funded with ARRA funds. In particular, both onshore-offshore MT experiments and focused dense deployments of on-land seismographs were seen as high priorities by the planning meeting participants.

Many of the vigorous discussions at the meeting indicated a clear scientific need for coordinated data gathering and experiments that cross the shoreline. The Cascadia Facility Initiative represents both a scientific and structural opportunity to accelerate this integration.

Table 1. List of Planning Group Meeting Participants, June 30 – July 1, 2009

N	Name	Institution	State	Note
1	Abers, Geoff	LDEO	NY	MARGINS S.C. Chair
2	Allen, Richard	U.C. Berkeley	CA	
3	Brodsky, Emily	U.C. Santa Cruz	CA	
4	Brudzinski, Mike	Miami Univ. (Ohio)	OH	
5	Carbotte, Suzanne	LDEO	NY	
6	Davis, Jim	Harvard-Smithsonian	MA	
7	Ekström, Göran	LDEO	NY	EarthScope S.C. Chair
8	Evans, Rob	WHOI	MA	
9	Forsyth, Don	Brown	RI	
10	Gomberg, Joan	USGS-Seattle	WA	
11	Laske, Gabi	U.C. San Diego/SIO	CA	
12	McGuire, Jeff	WHOI	MA	
13	Melbourne, Tim	Ctrl. Washington Univ.	WA	
14	Obana, Koichiro	JAMSTEC	Japan	
15	Rubin, Allan	Princeton	NJ	
16	Schultz, Adam	Oregon State Univ.	OR	
17	Schwartz, Susan	U.C. Santa Cruz	CA	
18	Tobin, Harold	U. Wisconsin	WI	
19	Toomey, Doug	U. Oregon	OR	OBSIP-Adv. Com. Chair
20	Trehu, Anne	Oregon State Univ.	OR	EarthScope Nat. Ofc.
21	Vidale, John	U. Washington	WA	
22	Wang, Kelin	PGC-Canada	B.C.	
23	Weeraratne, Dayanthie	C.S.U. Northridge	CA	
24	Wiens, Doug	Washington Univ (St Louis)	MO	
	NSF and Facility Representatives			
25	Anderson, Greg	NSF	VA	NSF-EarthScope
26	Batiza, Rodey	NSF	VA	NSF-OCE
27	Busby, Bob	IRIS (USArray)	MA	FACILITIES(USArray)
28	Carlson, Rick	NSF	VA	NSF-OBSIP
29	Gaherty, Jim	LDEO (OBS Inst. Ctr.)	NY	FACILITIES(OBS)
30	Haq, Bilal	NSF	VA	NSF-MARGINS
31	Jackson, Mike	UNAVCO (PBO)	CO	FACILITIES(PBO)

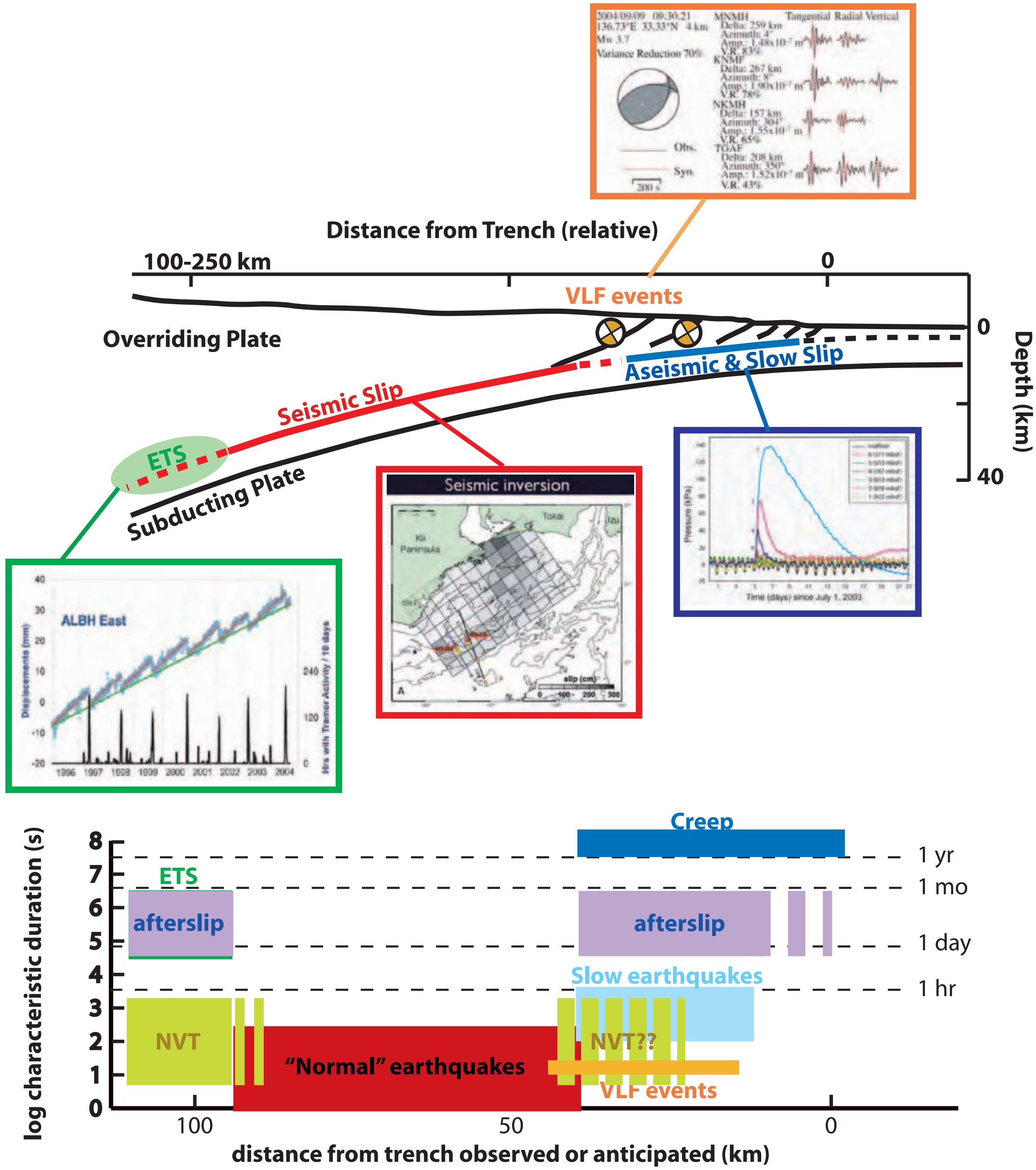

Figure 1. Spectrum of slip anticipated or observed for a generic subduction zone. A wide variety of transient phenomena have been observed, at time scales from 10^0 to $>10^8$ seconds, at different depths along the plate boundary. From MARGINS Decadal Review Report.

TOP: Examples include Episodic Tremor and Slip (ETS) near the downdip edge of the seismogenic zone at Cascadia (inset after Rogers and Dragert, 2003); coesiemic earthquake slip (red) and example of the 1944 great Nankai earthquake (inset, after Ichinose et al., 2003); very low frequency (VLF) events within the accretionary wedge at Nankai (orange) (inset after Ito and Obara, 2006); and region of slow slip, afterslip, and/or aseismic creep sometimes infered responsible for hydrologic transients such as in Nankai (e.g., Davis et al., 2006). Diagram not to scale.

BOTTOM: Schematic showing the observed or suspected locations, and characteristic duration of a range of slip behaviors to date.

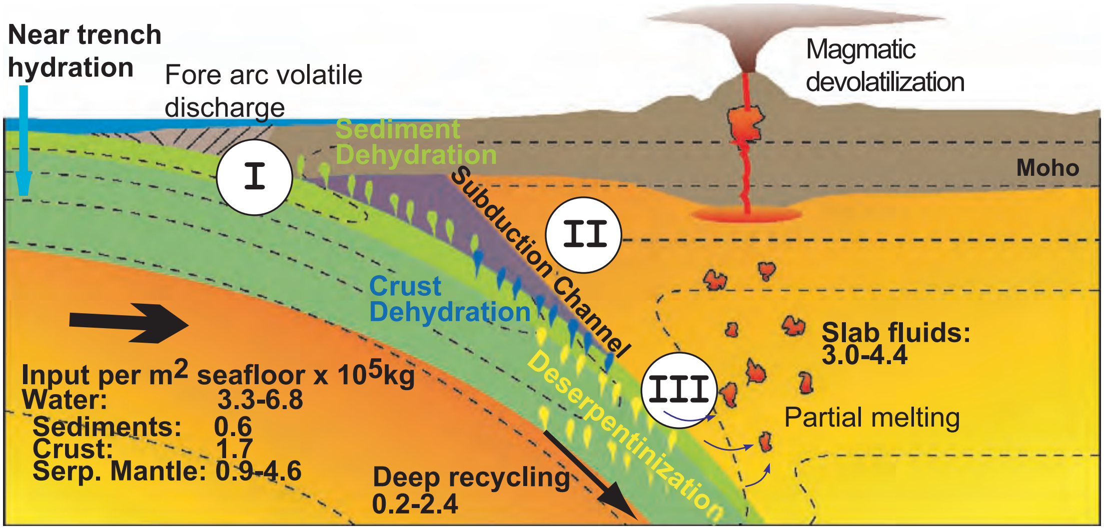

Figure 2. The subduction zone water cycle, from Rüpke et al. (2004, EPSL). Fluids enter the subducting plate near the ridge, at fracture zones, and near the trench. Large uncertainties in input budgets are associated with unknown extent of serpentinized mantle at most subduction zones. Some fraction of the fluids are released, through low-temperature discharge in the forearc (I), as input to an intermediate-temperature serpentinized forearc (II) or in the arc source region (III). Some water may remain to supply the deep earth.

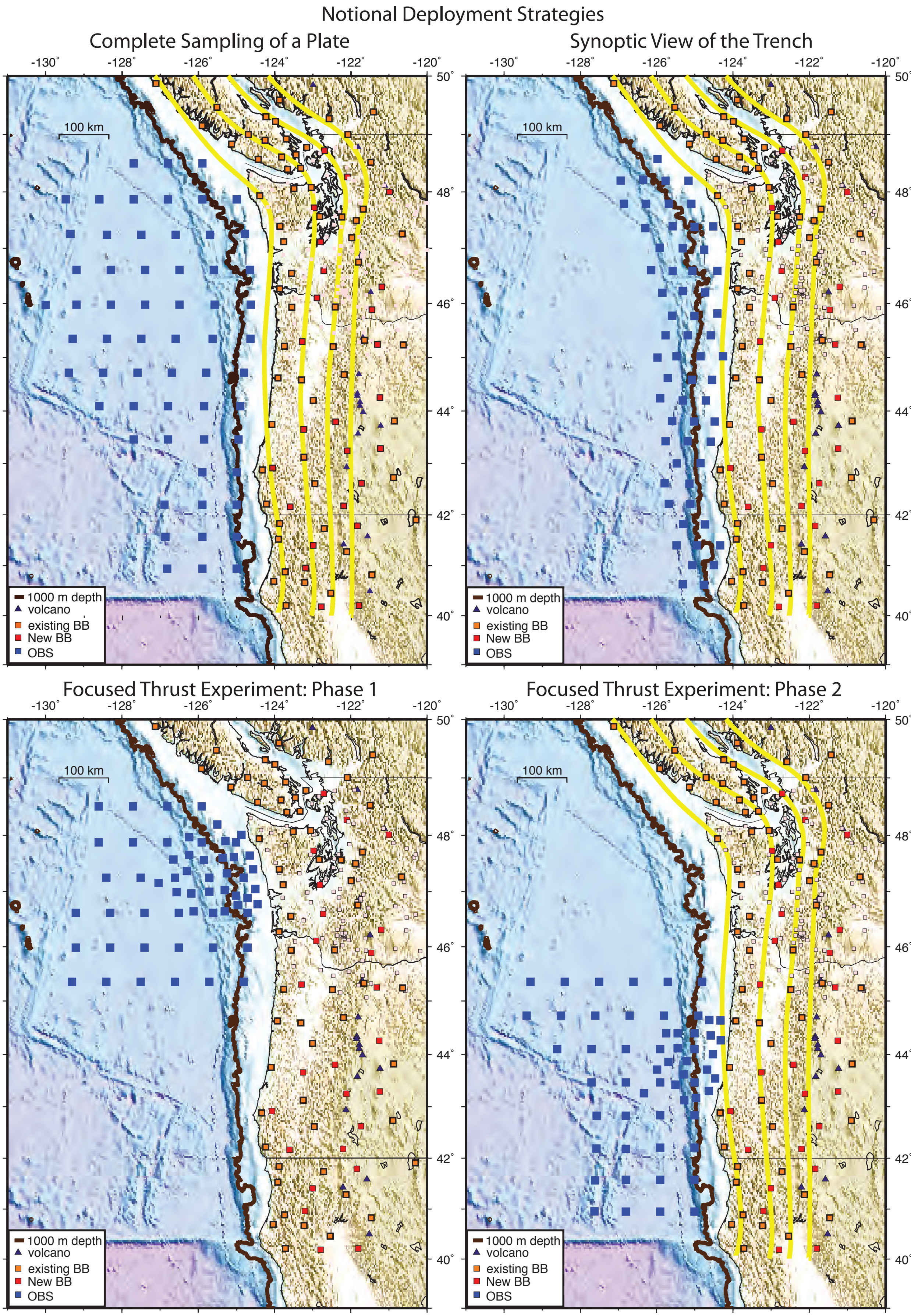

Figure 3. Maps showing planned seismic deployments, for four notional configurations discussed in the meeting. Some combination of these will likely take place over the three projected phases of OBS deployment. Orange squares: existing broadband stations; red squares: propose new stations; blue squares: proposed OBS sites; small white squares: PNSN short period seismometers. Thick dark line shows 1000 m water depth, the approximate limit between shallow and deep-water OBS deployment. Yellow lines show slab depths at 20 km intervals.

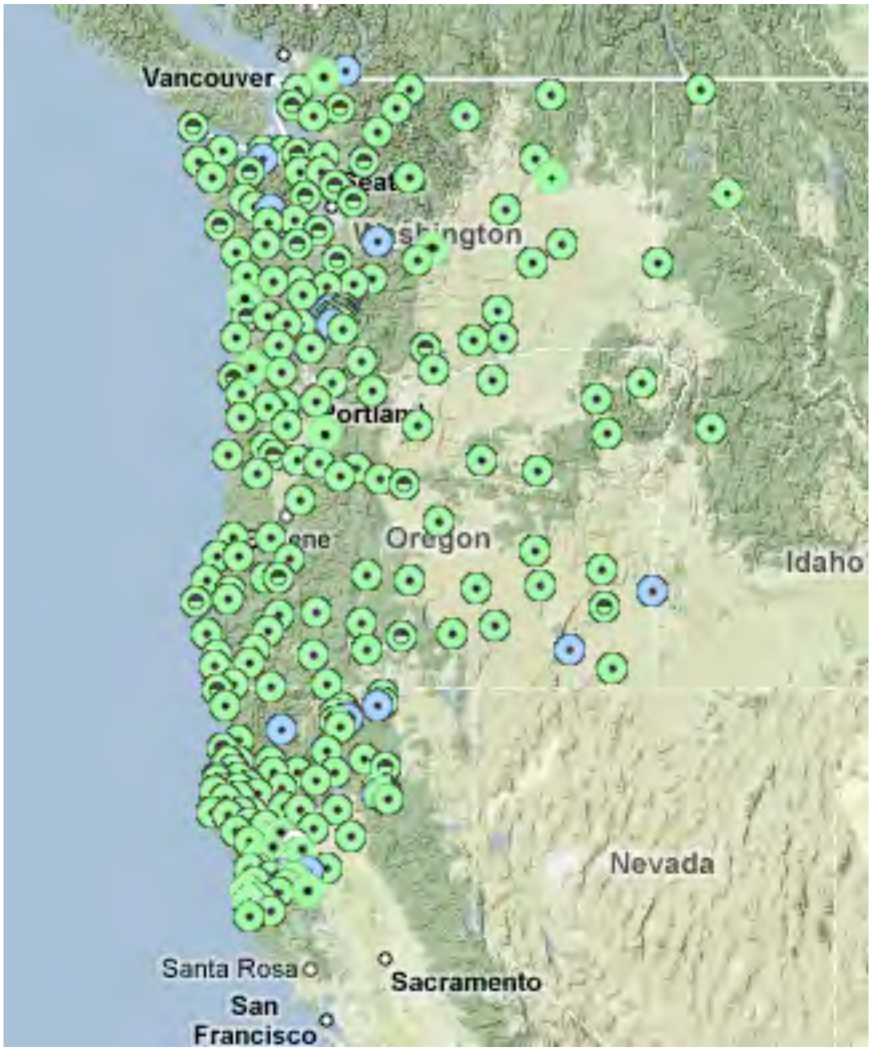

Figure 4. Map showing the locations of 232 GPS stations to be upgraded to realtime, high-rate recording, as part of the Cascadia Facility Initiative. Courtesy M. Jackson, PBO/UNAVCO.