SEIZE Vision Statement – Consensus views from the 2008 SEIZE workshop on the next decade of the Seismogenic Zone Experiment

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Introduction

During the past decade, the MARGINS SEIZE program has led a campaign of focused field studies in Nankai and Central America with complementary laboratory and theoretical work to address fundamental questions about slip behavior during major subduction zone earthquakes. These questions included: What controls energy release in great subduction earthquakes?; where does slip occur, and what controls the spatial limits of coseismic slip and interseismic locking?; and how do stress, fluid pressure and strain vary throughout the seismic cycle? SEIZE has greatly facilitated long-term integrated studies of seismicity, seafloor bathymetry, geodesy, and fluxes of heat and fluids at these focus sites that would not be possible without a dedicated program at NSF. A workshop held on September 23-26, 2008, gathered 80 scientists from around the world at Timberline Lodge on Mt. Hood, OR to summarize progress and discuss future directions for the SEIZE initiative. A report on the outcome of the workshop is available at: http://www.nsf-margins.org/SEIZE/2008/index.html. The 3 day workshop: assessed the progress made in the last decade on major SEIZE science objectives, defined critical gaps or unanswered questions, and identified new fundamental questions about subduction zone behavior, many of which have emerged from MARGINS and related studies over the past decade. In addition, we discussed the need for new facilities and technological developments to address the core science questions, the relative merits of focus sites vs. a thematic-based initiative, and the need for a dedicated program at NSF to adequately address key SEIZE science objectives.

The upcoming MARGINS Successor Planning Workshop in San Antonio, TX in February 2010 will serve to refine the SEIZE workshop outcomes and integrate them with those of the other MARGINS initiatives to formulate a new program. Here we review the consensus opinions at the Mt. Hood workshop to lay groundwork for discussions in San Antonio.

New and Emerging SEIZE questions

One key outcome of the workshop was the definition of a new generation of core science questions that have emerged from new discoveries during the last decade of SEIZE-related research. These new questions are largely motivated by new datasets and theoretical studies that have documented a wide spectrum of fault slip behaviors in both space and time, ranging from "normal" earthquakes, to episodic tremor and slip (ETS), to tsunami earthquakes and slow slip events (Figure 1). Detailed observations in a variety of major plate boundary fault zones, but in particular, subduction zones, show that fault slip occurs over time scales from seconds (earthquakes) to months (silent earthquakes, ETS, low and very low frequency (VLF) earthquakes). It is unclear what controls the broad range in slip behavior and particularly how these slower time constant events relate to strain accumulation and release on subduction megathrusts, or what processes or rock properties facilitate them (e.g., rock composition, stress state, and pore fluid pressure).

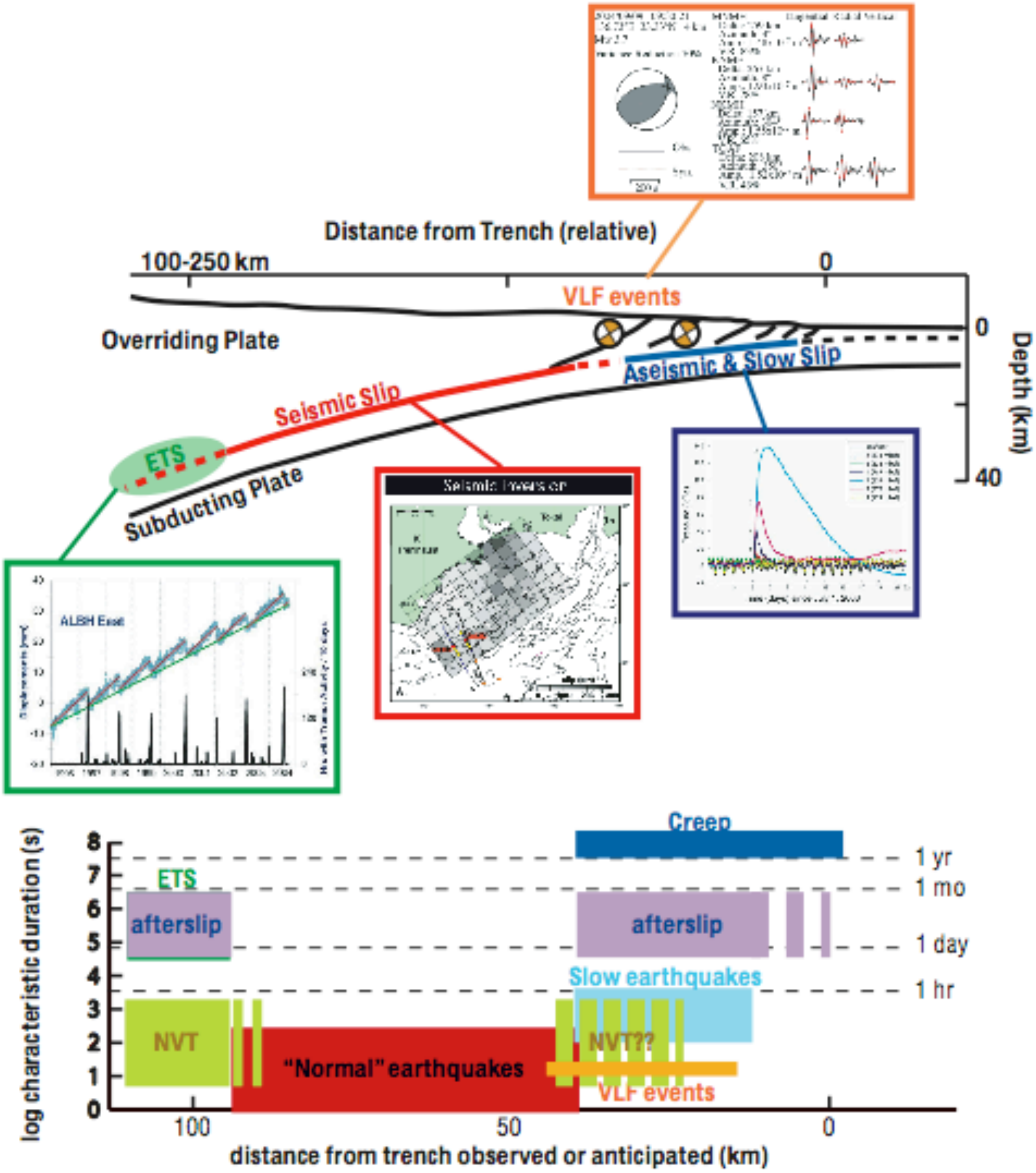

Figure 1. Recent observations over many different time and length scales demonstrate a wide range of slip behaviors on active fault zones, particularly near the updip and downdip limits of normal earthquakes.

Specifically:

1. *What is the role of fluids in controlling fault rheology?*

It has been hypothesized that metamorphic dehydration, pore pressure, and their distribution affect slip behavior (specifically the locations of ETS, VLF, and the updip limit of interseismic locking) and fault strength. Fluid release and pore pressure evolution, possibly mediated by sediment composition and thickness, basement topography, or thermal structure, may play defining roles in controlling fault rheology. New observations, theoretical studies, and experimental efforts are needed to test these ideas.

2. What governs along-strike variations in moment release in great earthquakes, and similar variations in interseismic locking?

Variations in seismicity and interseismic deformation along- and across-strike have been correlated with subducting plate roughness and age, upper plate structure and lithology, and contrasting properties and processes within the fault zone. Are these correlations universal or local? Are there other factors (e.g., pore pressure distributions or thermal state) that strongly influence or control these variations, and if so, how?

3. What causes the observed temporal variations in seismogenic zone behavior and plate boundary deformation in interseismic, coseismic, and post-seismic periods?

Integrated onshore-offshore surveys at Nicoya, Nankai, Cascadia, and elsewhere demonstrate distinct fault behaviors and surface deformation in each setting, often varying along strike. These regions are all at different points within the seismic cycle. How do the observed variations relate to the time since the last earthquake, and what controls this temporal variation? Comparative studies along several margins at different stages within the seismic cycle can help to establish a unified understanding of evolving processes at subduction margins.

4. What are the state of stress and absolute strength of subduction faults and wall rock?

New results suggest strong spatial variations in stress at the Nankai margin from borehole breakouts, extremely low apparent stress drops (< 0.1 MPa) for VLF events, and dynamic triggering of tremor at Cascadia suggestive of low effective stresses. How are these observations related to overall fault strength, fault composition and subduction inputs, and fluid pressure?

5. What is the geology of the seismogenic zone and its transitions?

In particular, what is the character of the upper plate, and the composition, fabric, architecture, and physical properties of fault rock, and how does it influence fault mechanics and rheology, and strain accumulation and release? Is strain accumulated in an extremely localized zone, as observed in some continental fault systems?

New technologies, methods, and scientific strategies

The new science questions listed above will guide future program development; however, new methods, technologies and strategies with respect to program structure and focus sites will be critical to assure future success. A future program will implement a broad application of existing scientific techniques and emerging new ones. Recent studies at the Costa Rica SEIZE focus site have made direct connections between fluid flow and seismic activity from a campaign deploying new instrumentation to measure fluid flow and seismicity simultaneously. Similarly, paleoseismological studies have delineated rupture history and segmentation in great detail along the Cascadia margin, which will be key to unraveling long-term rupture patterns at a variety of margins. Both of these and other recently developed, promising techniques will need to be broadly employed. Coordination and collaboration of facilities and technologies between ongoing, complementary programs, such as long-term observatory efforts with OOI, SAFOD and others, will be a key component of future efforts to span the shoreline and expand the range of observations.

In addition, several emerging technologies have the potential for transformative breakthroughs to address the new SEIZE-related science questions. For example, continuous GPS-Acoustic buoy/seafloor transponder systems for continuous monitoring of seafloor vertical and horizontal motions with cm-scale resolution is in development and could provide a critical complement to onshore stations that have been instrumental in unraveling strain accumulation during the seismic cycle. Offshore geodetic measurements combined with continuous monitoring of strain, pore pressure, and seismicity in boreholes provide a powerful suite of tools for characterizing strain over a range of magnitudes, and spatial and temporal scales. For example, fluid pressure can now be measured in borehole observatories to +/- 0.5 Pa and at frequencies up to 1 Hz. These offer promising new ways to measure strain within hydrologically isolated formations, especially where they can be tied to cabled networks and monitored in real time. Ultimately, buoy systems will complement permanent cabled network systems that will provide similar data for both early warning systems and long-term focused studies, such as the DONET system scheduled to come on line in 2010 in the NanTroSEIZE study area and the OOI/NEPTUNE-Canada system offshore Cascadia.

Programmatic strategies

In order to adequately address the next generation of SEIZE questions enumerated above, a future SEIZE program (1) will require branching out to new locations beyond the current focus sites; and (2) incorporate a continued role for co-located cross-disciplinary and complementary studies at the current focus sites. Understanding the fundamental controls on the observed spectrum of fault slip behaviors requires efforts along several subduction margins, because no single site exhibits all of these behaviors. Similarly, addressing the causes of observed temporal variations in seismogenic zone behavior can be achieved only through studying multiple systems at various stages in the seismic cycle, and by examining along-strike variations at individual margins. Notably, many important and relevant datasets have come from studies outside of the current focus sites, such as Cascadia, Alaska, and Sumatra, and from laboratory and theoretical studies.

A continued presence at existing focus sites will take advantage of valuable infrastructure developed during the past decade, and generate time series data critical for events during the seismic cycle.

The MARGINS program, including the SEIZE Initiative, require a separate program outside of the NSF Core program for several reasons. In particular, studies focused on subduction zone seismogenesis require integrated studies that span the shoreline, a mechanism for long term data collection over multiple co-located field campaigns, complementary laboratory and theoretical studies, and a mechanism to foster broad collaboration and data synthesis between programs. As an example, the CRSEIZE Program along Costa Rica defined and compared the pattern of strain accumulation to the distribution of seismicity, while the collocated TicoFlux Program identified along-strike thermal transitions and constrained the subducting sediment composition and distribution. Results from TicoFlux and CRSEIZE were combined to test the hypothesis that transitions between stable sliding to stick-slip behavior are thermally controlled. At the up dip limit, they concluded that the transition, including along strike variations, coincides with declining fluid pressure related to thermally controlled diagenetic fluid sources. At the down dip limit the deepest microseismicity corresponds with the estimated location of the 350^{o}C isotherm. Integrated studies and broad syntheses are critical for future SEIZE progress. Development of a programmatic structure for SEIZE that fosters integration and synergy with other emerging MARGINS programs, such as SUBFAC, will add value to SEIZE and strengthen both programs.

Concluding Remarks

The discussions at the Mt. Hood workshop laid out the foundation for the future SEIZE scientific goals and addressed the critical issues for achieving those goals within the MARGINS program. The MARGINS Successor Planning Workshop in San Antonio, TX in February 2010 will enable us to further refine the SEIZE program and develop a strategy to achieve our scientific goals. We encourage the SEIZE community to shape the future of SEIZE by submitting white papers to the workshop to guide discussions and by attending in San Antonio.