White Paper for the Rationale to Include Northern Baja California in SCEC

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The SCEC Model for Addressing the Earthquake Problem states: "Combine the monitoring and characterization of natural fault systems to understand the processes of faulting well enough to make meaningful predictions of large earthquake events." The multidisciplinary approach applied by SCEC can be thought of in terms of the effort to characterize the activity, geometry and kinematics of major faults in the natural laboratory on three different time scales: decadal, millennial, and million-year time frames. This provides critical observations for characterizing important mechanical parameters of faulting including: fault growth and finite displacement; spatial and temporal variation in slip rates and earthquake activity; evolution in fault geometry and mechanical interactions between faults; and, ultimately, better understanding the state of stress on faults relevant to earthquake physics. The expression of plate-boundary shearing reflects the rheologic evolution of the lithosphere as well as interactions with pre-existing lithospheric structure and its evolving configuration. The understanding gained from such an integrated approach is key to evaluating seismic risk and improving physics-based earthquake forecasting.

We propose to expand the limits of the natural laboratory southward, into northern Mexico, to encompass important interactions at a major structural boundary of the plate boundary fault system. The transition from a predominantly strike-slip plate boundary hosted within the continent to rifting and continental rupture presents a fundamental change in the rheology of the lithosphere and the processes that drive tectonic loading. Currently, SCEC uses southern California as the designated laboratory for fundamental earthquake research, in part because: 1) the southern California fault network is complex, yet compact, resulting in an excellent laboratory to study earthquake recurrence patterns, fault interaction, etc.; 2) southern California has the highest earthquake hazard in the US; and 3) the southern San Andreas system is delineated from the northern San Andreas system by a creeping section, starting at latitude 36°, that does not store elastic strain, making the southern San Andreas fault system a discrete region to study earthquakes. However, the plate boundary system extends into northern Baja California with no such delineations other than the international border near latitude 32°. Several important fault zones cross the international border and assume Mexican names, but their earthquake histories, continuity of structures, and the fundamental observation that they are primary players in the plate boundary deformation all argue that northern Baja California faults should be included in the research scope of the next earthquake center. Furthermore, the trans-peninsular Agua Blanca fault represents the southern boundary of the Big Bend domain of the southern San Andreas fault, and all faults to the north have continuity across the border.

The complex Pacific-North America plate boundary begins in the northern Gulf of California. South of latitude 30°, the continental lithosphere has ruptured to produce a well-organized ridge-transform system that accommodates >90% of transtensional shearing between the Pacific and North American plates. However, at the northern limit of the Canal de Ballenas transform, shearing becomes redistributed and partitioned into a complex regime of multiple structural domains that expand northward into southern California. They include: the southern San Andreas fault system (San Andreas, San Jacinto, Elsinore faults), the Coastal California shear zone including offshore faults, the Eastern California shear zone (ECSZ), and the Transverse Ranges fold and thrust belt. In the broad sense, plate boundary shear is also accommodated by the Walker Lane and oblique extension in the Basin and Range, and even as far east as the Rio Grande Rift. None of these domains accommodate shearing with the same slip direction as the relative motion of the lithospheric plates and thus the sense of shear across individual domains must also be strongly affected by topographic potential energy gradients, mechanical interactions among domains, and boundary conditions at the plate margin. For example, the extensional component of relative plate motion is partitioned into topographically elevated regions along the Wasatch front and Rio Grande Rift. Here the rate of extension driven by gravitational collapse greatly exceeds the westward drift of the Pacific plate. The residual is accommodated by crustal thickening and transpression in the Coastal California shear zone.

Another series of important structural transitions in plate margin shearing occur at the boundaries between the southern San Andreas system and the ECSZ northward into the Walker lane. Despite the fact that all have the same orientation and are linked along the same NNW striking trajectory, they define abrupt transitions in slip directions. The ECSZ, which is dominated by dextral wrenching, is bounded to the south by strongly transpressive shearing along the southern San Andreas fault and Transverse Ranges, and to the north by the Garlock fault, where shearing abruptly changes to transtension in the Walker Lane belt. The direction of relative shearing between large lithospheric plates, such as the North American and Pacific plates, undergoes subtle and gradual changes that only become significant over large distances. Therefore, abrupt variations in the character of shearing in adjacent domains must reflect other important parameters such as the distribution of topographic gradients, lithospheric strength heterogeneities, evolving fault geometry (e.g. bending of the San Andreas fault through the Transverse Ranges) and mechanical interactions between domains.

The juxtaposition of contrasting domains of shearing provide important insight into the nature of stress build up and represent an opportunity to understand the factors that control the limits of lithospheric stress prior to its release in large earthquake events. Northern Baja California provides one of the most outstanding and fundamental transitions between domains, where dextral wrenching transitions to the transtentional rifting and, ultimately, complete rupture of the continental crust. The 2010 El Mayor-Cucapah Earthquake provides a clear demonstration of the understanding gained from close examination of these transitions. This earthquake showed, through both its surface rupture and aftershock activity, how the seismogenic crust is composed of mechanical discontinuities of diverse orientations, which gives rise to the existence of interlocking networks of faults and complex cross cutting relationships. Large-magnitude multi-fault earthquakes, such as occurred in 2010, represent a collapse of the interlocking network, and the extreme geometric diversity of faults activated in single earthquake events suggests that all faults, regardless of orientation, are close to failure prior to such events. This raises fundamental questions concerning the factors that control the stability of complex interlocking fault networks, a controversy that lies at the heart of addressing the earthquake problem. The current paradigm of fault stability assumes that the limit of lithospheric stress is controlled by optimally oriented faults, which are those that form at angles of ~30° to the maximum compressive stress[1]. However, many multi-fault earthquakes initiate on mis-oriented faults, which are oriented at angles nearly orthogonal to the maximum compressive stress, and have a frictional strength two to three times greater than optimally oriented faults. Additionally, the seismic release of nearly all multi-fault earthquakes is dominated by slip on mis-oriented faults. The keystone fault hypothesis, developed from the 2010 example, challenges the current paradigm and proposes instead that mis-oriented faults control network stability and lithospheric stress[2]. It is likely that all complex fault networks share some set of fundamental structural characteristics dictated by relative slip tendency and cross-cutting relationships of the constituent faults. By studying the geometry and mechanical behavior of such fault systems in shear domains with distinct slip directions and applied stress, we may begin to identify the fundamental structural characteristics that control the limits of network stability.

In summary, individual domains of shearing display significant differences in all key parameters that control lithospheric shearing including: the sense, rate and long-term history of relative shear; the configurations of fault networks that accommodate relative shear and mechanical interactions between individual faults, the location relative to internal and external topographic gradients, the distance from the margin of the two lithospheric plates, heat flow and compositionally controlled rheology of the lithosphere. The style, rate and sense of shearing in any domain is the product of the integrated effects of all these parameters as well as the interactions between domains, and thus it is difficult to understand the contribution of any individual parameter by studying a single shear domain in isolation. Nor can this be accomplished by studying only parts of multiple domains, but none in their entirety, as is the case of the current limits of the SCEC natural laboratory. From this perspective, it is critical to include northern Baja California, and potentially the other domains to the northeast, in the next earthquake center so that the fundamental questions examined so far by SCEC can be truly addressed at the systems level.

Expanding the Earthquake Center to the South

Several important spatially-distinct fault systems traverse the international border and accommodate the transfer of slip from the northern Gulf of California to multiple domains of shearing in California. The topographic depression formed by the northern Gulf of California and Salton Trough carries the majority of plate motion along penetrative networks of high- and low angle faults that have accommodated crustal thinning and dextral wrenching since the onset of rifting in late Miocene time. Releasing step-overs between major transforms are sites of extreme crustal thinning and, locally, complete crustal rupture and formation of transitional crust comprised of mantle-derived melts and sediments. For example, 30-40 km of new transitional crust has formed in the northernmost Gulf of California in the past 2-3 Ma[3], and a similar amount is proposed to underlie the axis of the Salton Trough. The western margin of the Gulf of California-Salton Trough is defined by a segmented series of three fault-controlled topographic escarpments where a regional pre-rift disconformity, formed on the roots of the Cretaceous batholith, rises above the valley floor with as much as 2.5 km of relief. The faults controlling the escarpments show reversals in tectonic transport along strike. The northern and southern segments are controlled by the east-directed West Salton and San Pedro Martir-San Felipe detachment fault systems, respectively[4]. These detachment faults root toward the axis of rifting and are imaged in seismic profiles extending all the way to the ruptured edge of continental crust. In contrast, the middle segment of the main gulf escarpment roots underneath the Peninsular Ranges, unroofing the mid-crustal rocks in Sierras El Mayor and Cucapah. Here, the interaction of dextral wrenching with strike-slip faulting is exposed and revealed by major earthquakes in 1892, 1934, and 2010. The dextral Laguna Salada fault intersects and separates the west-directed Cañada David detachment to the south from a complex network of strike-slip and detachment faults in the Sierra Cucapah to the north. Located close to the axis of shearing and containing faults with a diverse range of structural characteristics, the Sierra El Mayor and Sierra Cucapah is perhaps the best place to perform detailed structural and paleoseismic studies to understand the mechanics of transtensional plate margin shearing. In addition to faults within the greater Gulf of California province, a fraction of plate-boundary shear shifts westward across the Peninsular Ranges. Faults that cut across the Peninsular ranges batholith include the Agua Blanca and San Miguel-Vallecitos fault zones, the latter of which sustained seven M>6 earthquakes in the past century culminating in the 1956 M6.8 San Miguel earthquake that produced over a meter of offset at the surface[5]. This fault zone, which is less than 2-3 Ma in age, feeds slip directly into San Diego, the 7th largest city in the US.

Broader Impacts – The southern San Andreas fault system represents significant seismic risk to major metropolitan areas throughout California and northwest Mexico. Expanding the natural laboratory to include northern Baja California recognizes that both the hazard, and the processes that drive it, do not stop at the international border. An expanded natural laboratory provides a larger tent for increasing international collaboration required to address the earthquake problem.

Intellectual Merit – The Gulf Extensional Province is a natural tectonic boundary for the San Andreas transform plate margin. The southern San Andreas system doesn't stop at the border and several major faults span the border. To fully understand local and regional fault interaction as it relates to the goals of the next earthquake center, northern Baja California should be included.

References Cited

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