Subject offered for a contract starting in September 2012

SUBJECT TITLE: Development of an efficient numerical method to study earthquake rupture through complex fault geometries

Advisor: **VILOTTE Jean-Pierre, PR, vilotte@ipgp.fr**
Second Advisor/ Supervisor: **KLINGER Yann, DR, klinger@ipgp.fr & BHAT Harsha, DR, bhat@ipgp.fr**

Host lab/ Team: **IPGP- Team Tectonics/Seismology – UMR7154**

Financing: **Doctoral contract with or without assignment**

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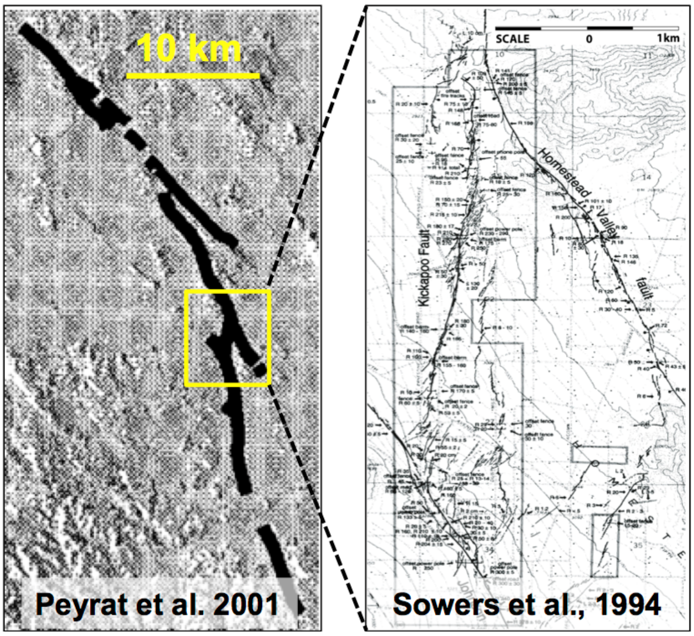
Presentation of the subject (1 or 2 pages)



Multi-Scale geometric complexities associated with fault zones. Example from the surface trace of the 1992 Landers Event in California.

Earthquakes occur generally on discontinuous fault traces that are composed of segments that are separated by discontinuities like branches, bends and step-overs. Dynamic and static stress concentrations resulting from past slip at such discontinuities may slow and stop rupture propagation, or accelerate it; hence they play a controlling role in determining the ultimate length of earthquake rupture. The 2001 M_w 7.8 Kunlunshan event in Tibet is an excellent candidate for this type of analysis. The surface rupture extended 426 km (as expected for large M_w earthquakes) making it one of the longest surface ruptures to date. A field team of geologists from IPG, Paris and the China Earthquake Administration conducted a detailed survey of the surface rupture. Their field observations were supplemented by high-resolution satellite imagery (Ikonos satellite, 1m resolution). The final result is the detailed surface rupture map. In addition the team has also mapped the detailed surface slip-distribution along the fault *(Lasserre et al., 2005; Van der Woerd et al., 2002)*.

Observations like these provide us with a unique opportunity to numerically model rupture through known complex fault geometry and thus calling urgently for an efficient computational modeling framework. In addition to this the question of the origin this complexity is also not well understood. Modeling such complexities really calls for proper constitutive description of the material hosting such faults and there is a real lack of such models in this community right now.

A big technical challenge lies in delineating the right mechanical and numerical framework to address questions associated with earthquakes. Traditionally modelers use Finite Difference, Finite Element, Boundary Element or Spectral Element Methods to model earthquake dynamics. More recently some groups have started using Finite Volume and or Discontinuous Galerkin Methods. Any numerical algorithm that is tailored to earthquake related problems have to fulfill the following requirements. (a) It should be able to model complicated non-planar fault geometries (in 2D as well as in 3D) (b) It should be accurate enough to deal with the multi-scale spatio-temporal complexities associated with the rupture process that in turn is controlled by the details of the fault mechanical behavior (c) It should have the ability to incorporate anelastic constitutive models for the medium hosting the faults (d) It should have the ability to model the dynamic earthquake process (short time scale phenomenon) as well as the interseismic period (longer time scale phenomenon) within a unified framework. All the available computational methods satisfy one or more of the above requirements but not all of them. There is a real need to explore newer numerical tools that would satisfy all of the above requirements and hence allow for a more deterministic modeling of earthquake processes. An additional note of interest here is that the ideas developed along the lines above has implications in other brittle failure processes like hypervelocity impact of a micro-meteorite on satellites, failure of ceramic body armors, meteorite impact on earth's surface etc.

Keeping these two thoughts in mind, the thesis topic here is to develop a homegrown version of a new numerical method based on the Spectral Element Method developed for seismological applications [see *Komatitsch and Vilotte (1998), Festa and Nielsen (2003), Festa and Vilotte (2006), Kaneko et al. (2008)*]. The research focus will be numerical development along three fronts 1) Incorporating Discontinuous Galerkin like formulation, using flux terms at element boundaries, into the Spectral Element Framework to deal with the numerical noise associated with imposing contact conditions at the fault interface, for example through a friction constitutive model 2) Enrichment of the Spectral Element to allow for discontinuities within the element using the framework of Extended Finite Element Methods or Phase field Models / Level Set techniques. This would allow for description of a complex fault geometry, for example, in a simple non-conforming mesh and 3) Incorporation of a two scale adaptive time stepping procedure that allow the modeling of interseismic period (~100's of years) and the seismic period (~1 minute). This would allow for simulation of multi-cycle earthquake dynamics. In addition to these anelastic constitutive response in the bulk medium will also be incorporated to look at the effect of off-fault fracture damage, in the short time scale, and the evolution of fault zone geometry in the long time scale.

All or some of the basic requirements/background are in the area of numerical methods (special emphasis given to past experience in Finite Element/Spectral Element modeling), Solid Mechanics (special emphasis on Fracture Mechanics, Elasto-Plastic constitutive modeling) and a strong interest (no background required) in geophysical problems (earthquake source processes, earthquake cycles).