"The Seismogenic Zone"
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Abstract

The seismogenic zone is where earthquakes occur. Given the impact that earthquakes have on society and their important role in tectonics, the processes and properties that control and limit the seismogenic zone are of fundamental importance.

Earthquakes are dynamic shear failures along fault surfaces. Faults can also creep, thus the focus of both theoretical and observational studies is to define the conditions and variables that produce either fault creep or earthquakes. Since the behavior of the rock volume that surrounds a fault can be modeled as elastic for both fault creep and earthquakes, the key to the seismogenic zone is the macroscopic frictional constitutive law of the fault surface. For an earthquake to occur, fault friction must decrease as slip occurs. In other words, dynamic friction must be less than static friction -- though there are additional considerations. The current view is that earthquakes occur where fault friction exhibits a "velocity weakening" behavior. This fault property is rather obscure and it is easy to imagine that dynamic friction behavior depends on many variables; for example, rock composition, pressure, temperature, stress state, pore fluids, strain rate and history. Another possible complication is that the macroscopic friction behavior might be an emergent property of interactions between small elements with a different microscopic behavior. On the hand, laboratory-scale experiments can produce both velocity weakening and strengthening behavior.

The simplest situation would be that just pressure and temperature determine the macroscopic friction law, and there is some experimental and observational support for this notion. The observed limits of the seismogenic zone in various tectonic settings provide the most direct test of the role of pressure and temperature in controlling seismogenic behavior. Detailed investigation of the seismogenic zone depth range requires accurate hypocentral depths;

this requires either a dense seismographic network or waveform modeling of larger events. A uniform global study must use earthquakes with a magnitude larger than about 6. There is still some question whether the seismogenic depth limit is magnitude dependent.

Just a cursory examination of global seismicity exposes the basic result that earthquake depth distribution is mostly restricted to the outermost part of the Earth. Except for Wadati-Benioff zone earthquakes which can occur down to a depth of 700 km, earthquakes are confined to the shallowmost 40 km in subduction zones, and to less than half that depth in other tectonic settings. Since there is deformation and shear stresses deeper than 40 km in the Earth, these basic observations suggest that some combination of pressure and temperature, either directly or indirectly, controls the seismogenic zone. A detailed survey of the results for different plate boundary settings offers more insight as to the controlling processes.

The seismogenic zone of plate boundaries is connected to the related issues of shear stress and pore fluid pressure levels. One current view is that the seismogenic zone operates at quite low stress levels, while higher stress may be associated with aseismic deformation and intra-plate regions. Hence earthquakes may enhance tectonics by lowering the level of resistive stress. The seismogenic zone plays a key role in tectonics and global dynamics, and the limits, stress level, and evolution of the seismogenic zone will continue to be key topics in future studies.

Outline of "The Seismogenic Zone"

I. What is it?
- Ia. Practical definition of the seismogenic zone
  - Where earthquakes occur
- Ib. Theoretical definition of the seismogenic zone
  - Velocity weakening friction constitutive law
- Ic. What is an earthquake?
  - When does slip become dynamic

II. Determination of the limits to the seismogenic zone

IIa. Techniques:
   accurate hypocenters
   waveform modeling
   tsunami modeling
IIb. Plate boundaries:
   Up-dip & down-dip limits
IIc. What about co-seismic slip that extends beyond the limits?
   More complicated definitions

III. Variability of Seismogenic Zone
  IIIa. strike-slip faults
     slight variations
  IIIb. normal faults: continental and oceanic
     can the entire lithosphere be seismogenic?
  IIIc. intra-plate thrust faults
     the shallow initiation of thrusting
  IIId. subduction zone plate interface
     a "rich" environment for variations
  IIIe. subduction zone intra-plate
     are deep earthquakes fundamentally different?

IV. Experiments
  IVa. Lab experiments
     exposes the basic processes and variability
  IVb. Induced seismicity
     offers valuable insight to seismogenesis

V. Conclusions and Connection to Earth Dynamics
  Va. Rock type and temperature can explain most observations
     and theoretical constraints
  Vb. The role of water is still an open question
  Vc. Several important implications if plate boundary seismogenic
     zones slip at low shear stress levels.

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