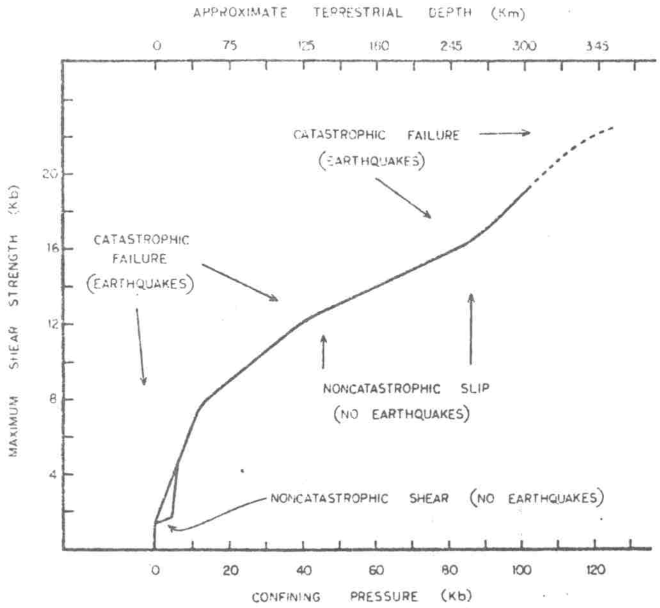

Fig. 7. A revised room temperature failure model for unaltered plutonic igneous rock based mainly on the observed triaxial and torsional shear strengths of granodiorite to 85 kbar and dunite to 95 kbar. The parenthetical designation of earthquake occurrence relative to the mode of rock failure with increasing depth applies to a hypothetical case of zero geothermal gradient.

Measured values of the derivative are:

	$(\Delta S/\Delta P)_{20^\circ C}$
Figure 2 (top)	0.13
Figure 2 (bottom)	0.11
Figure 3	0.12
Average	0.12

The value of strength thus obtained for a confining pressure of 125 kbar is

$$S_{125\text{kbar}} = S_{40\text{kbar}} + \Delta S_{125-40\text{kbar}} = 12.2 + 0.12(85) = 22.4 \text{ kbar}$$

Comments concerning earthquakes in this section are based on a tentative assumption that elevated temperature will not significantly alter the general nature of the failure model. The influence of temperature will be considered in a later section.

The following interpretation is given to the failure diagram. Under conditions of initial increasing pressure, rocks that contain a pore fluid (or a very low shear strength solid phase) will experience only a low to modest initial increase in strength with increasing pressure. The rate of increase will depend on the nature of the interstitial network and the type, amount, and pressure of material contained therein. A minimum rate of strength increase will occur when the pore network is extensive, well interconnected, and filled with a fluid pressurized to the confining pressure.

Under such conditions rock will fail by a noncatastrophic (nonbrittle) shear. (Through intergranular contacts the mineral constituents of the microstructure absorb elastic strain and undergo brittle failures. The viscous pore fluid acts against the compressive components of stress and also dissipates shear. The results are a weakened rock and a dampened shear displacement after failure.) Shear displacement at the rupture will take place by frictional sliding because of the effect of the pressurized pore fluid. The minimum initial rate of strength increase holds to a confining pressure of 3–5 kbar. Termination of the region of noncatastrophic failure is caused by disruption and collapse of the pore network as a result of microstructural consolidation. This collapse occurs through point-contact-induced intragranular ruptures. High-magnitude earthquakes are not considered likely to occur under conditions of noncatastrophic failure, but significant fault displacments could occur.

Termination of the pore network as an independent hydrostatic entity takes place over a brief transitional span of pressure (1–2 kbar). Beyond the transition, failure takes place by catastrophic (brittle) shear.

Rock that does not contain a pressurized pore fluid (or a mechanically weak interstitial phase) will undergo an initial smooth sharp rise in maximum shear strength with increasing confining pressure. This behavior will continue to a pressure of 10–20 kbar. The mode of bulk failure over this range will be a catastrophic shear. Earthquakes of high magnitude are expected where catastrophic failure can occur.

After the elimination of interstitial space the grains experience total crystalline confinement, and strain by plastic (slip) deformation begins to occur. This transition initiates at 10–20 kbar, depending on the physical characteristics of the minerals in the rock. It is reflected by a reduced rate of shear strength increase. This type of behavior extends to a pressure of 35–50 kbar.

Over the span 10–50 kbar, extensional intragranular ruptures are the predominant means of strain relief, although to a diminishing extent as strain becomes progressively more plastic as the pressure approaches 50 kbar. Catastrophic shear remains a mode of bulk failure to 35–50 kbar, and earthquakes are expected phenomena to about 50 kbar.

From 35 to 50 kbar on, slip mechanisms become the predominant mode of strain. Ruptures that do occur are isolated by regions that undergo plastic deformations. Consequently, a bulk catastrophic failure cannot take place. This transition to a predominantly plastic strain is reflected by a further reduction in the rate of shear strength increase with increasing pressure. The new rate holds to a confining pressure of 75–100 kbar, depending on the refractoriness of the minerals involved. Between 35–50 and 75–100 kbar the mode of bulk response to shear is noncatastrophic deformation. Earthquakes are not expected over this range of pressure.

Between 75 and 100 kbar the microstructures appear to lose their ability to undergo further intragranular plastic strain. Stress no longer can be relieved by dispersed local mechanisms, and rocks regain an ability to accumulate bulk elastic strain. This transition is reflected by a sharp upturn in shear strength.

Between 85 and 125 kbar a catastrophic mode of bulk failure occurs. Microstructural observations suggest that this behavior may be due to a rapid and extensive shear-strain-induced lamellar fusion within the rock. Earthquakes are expected over this region of the failure diagram.

MECHANISMS FOR SHEAR FAILURE UNDER HIGH CONFINING PRESSURE

As was discussed earlier, shear displacement along ruptures is adequate to explain nodal models of longitudinal and transverse seismic waves. However, beyond a depth of more than a fraction of a kilometer in the absence of a pressurized pore fluid, or about 20 km with such a fluid, friction prevents sliding movements parallel to the direction of maximum