shear. Nevertheless, seismic waves do originate at depth, and rapid displacements are a logical necessity for their generation. A mechanism must therefore exist that allows motion to take place under high pressure.

Since friction prevents solid surface on solid surface sliding along a plane of maximum shear, displacement must occur by one or the other of the following means: (1) a translation of separation of the failure surface in the direction of the tensional component of a shear, followed by one in the direction of the compressional component or (2) a sliding motion because of the presence of a shear-strain-induced state of fusion at the surface of failure. The following argument is given in support of the first mechanism of motion.

Consider an element of isotropic solid confined in a less rigid pressurized isotropic environment. Impose an unbalanced stress field. A principal compressive stress will do. Analogous to the Poisson effect, the sample 'feels' tensional stress perpendicular to the direction of the compressive stress and responds accordingly. This effect yields a surface of maximum shear. When the tensional action is sufficient, the sample will fail.

This phenomenon was first described by *Bridgman* [1912]. He called it the 'pinch-off effect.' Geological examples have been recognized [*Ramberg*, 1956]. *Bobrowsky* [1963] described pressure differences generated by pressurized composite structures due to this effect. Such tensional effects in components of composite materials have resulted in the forming of internal openings under environments where all principal stresses are compressive but of sufficiently different magnitude. The phenomenon is now recognized in metallurgy and is variously called chevroning, central burst, and cuppy core [*Kalpakjian*, 1967].

Shear failure of a relatively rigid rock contained in a less rigid pressurized environment can therefore occur by a sequence of translations, the first being one of separation in the direction of the apparent tensional stress and the second being one of closure in the direction of the compressional stress. This mechanism is believed to occur in rock failures under pressure to about 50 kbar (i.e., to depths of about 150 km) because intragranular ruptures are observed to be the predominant microstructural mode of stress relief to this pressure in the torsional tests.

In triaxial tests [*Giardini et al.*, 1968] the copper jacket and surrounding pressurized fluid constitute the less rigid environment. Here a bulk failure of the specimen takes place. This situation is analogous to a cooler more rigid central part of a downmoving crustal slab enclosed by a warmer less rigid earth. In the torsional tests, however, samples are contained in an environment of greater rigidity (tungsten carbide), and a bulk sample failure cannot occur as long as the rock maintains a rigidity adequate to retain elastic strain, as is explained below.

Under dry conditions of torsional test between 1 and 15 kbar, failures were microstructural and mainly extensional ruptures. Displacements were accommodated by original interstitial space. The shear strength of the rock increased smoothly and quietly over this span of pressure. Bulk sample failures did not occur.

Between about 15 and 40 kbar, extensional intragranular ruptures continued as the predominant mechanism of stress relief. They were accompanied by scattered occurrences of intragranular slips. These regions of plasticity adjacent to ruptures are assumed to provide the weaker environment needed for local intragranular ruptures. Bulk failures did not occur in torsional tests to 40 kbar.

Between 40 and 80 kbar the shear strength, and therefore the bulk rigidity (granodiorite), continued to increase with increasing pressure but only slightly because in this range numerous randomly oriented intragranular regions sequentially underwent abrupt but finite plastic strains. Catastrophic sample failure still did not occur.

A rough experimental measure of room temperature relative limiting strengths for regions of elastic and plastic behavior can be gleaned from the torsional shear diagrams wherever abrupt minor stress drops and rapid strength recoveries occur (e.g., Figure 2, between 40 and 80 kbar of pressure). As was previously stated, the steep rise in strength relative to the increasing pressure and strain that preceded each abrupt stress drop is assumed to represent accumulation of elastic strain. Similarly, abrupt stress drops are interpreted as reflecting sudden onsets of localized strain-induced fusions along intragranular planes of high defect concentration (slips). Consequently, slopes of rapid strength increase relative to pressure and elastic strain e, $(\Delta S/\Delta P) \cdot (\Delta S/\Delta e)$, give a differential measure of elastic strength, and the slope of sequential strength maximums s over a range of pressure and cumulative plastic strain x, $(\Delta s/\Delta P) \cdot (\Delta s/\Delta x)$, gives a differential measure of plastic strength.

Measured averaged values of elastic slopes between 40 and 80 kbar of smoothly increased pressure with different rates and degrees of concurrently applied torsional strain from seven granodiorite tests range from about 3 to about 6. The average plastic slope over this range is about 0.3. The relative differential strengths of elastic and plastic states are therefore about 10 : 1 near 40 kbar and about 20 : 1 in the vicinity of 80 kbar. It is the onset of local plasticity therefore that is critical to failure.

The stress, displacement, and nodal patterns for a simple case of failure by extensional and compressional displacements are illustrated in Figure 8. The nodal pattern of seismic waves generated by this mechanism is similar to that associated with the type 2 model of earthquake focal mechanism [*Hodgson and Stevens*, 1964]. In the present case, however, transverse seismic waves would be generated by the translations of disengagement and recombination relative to the rupture surface. The initial compressional wave would be due to the normal component of displacement of the rupture surface.

As is shown, granodiorite remained at least partially elastic in torsional tests up to 80 kbar. Confined in a more rigid closed environment, specimens could not and did not undergo bulk failure. At about 85 kbar of pressure, however, explosivelike sample failure was encountered, and a different condition prevailed. Here an apparent rapid spread of shear-strain-induced fusion within the sample created an 'instantaneous' state of lamellar fluidity between opposing tractive surfaces. This fluid interface (zero rigidity) corresponds to the second mechanism of failure introduced earlier. In principle, it is similar to a rock with a pressurized pore fluid described between 0 and 5 kbar of confining pressure. The sudden existence of liquid lamellas parallel to the direction of shear provides a means for a rapid relief of accumulated elastic bulk strain and therefore a catastrophic failure of the sample. This phenomenon occurred.

The nodal pattern expected for rock failures from 0 to 5 kbar of confining pressure with a pressurized pore fluid, and those failures that occur at high pressure due to shear-induced