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THE HEART MOUNTAIN FAULT: IMPLICATIONS FOR THE DYNAMICS OF DECOLLEMENT;

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The Heart Mountain decollement in Northwestern Wyoming, U.S.A. originally comprised a plate of rock up to 750m thick and 1300km^2 in area. This plate moved rapidly down a slope no steeper than 2° during Early Eocene time, transporting some blocks at least 50km from their original positions. Sliding occurred just before a volcanic erruption and was probably accompanied by seismic events. The initial movement was along a bedding plane fault in the Bighorn Dolomite, 2 to 3 meters above its contact with the Grove Creek member of the Snowy Range formation (see Fig. 1 for a stratigraphic section). The major pecularity of this fault is that it lies in the strong, cliff-forming Bighorn Dolomite, rather than in the weaker underlying shales (Pierce, 1973).

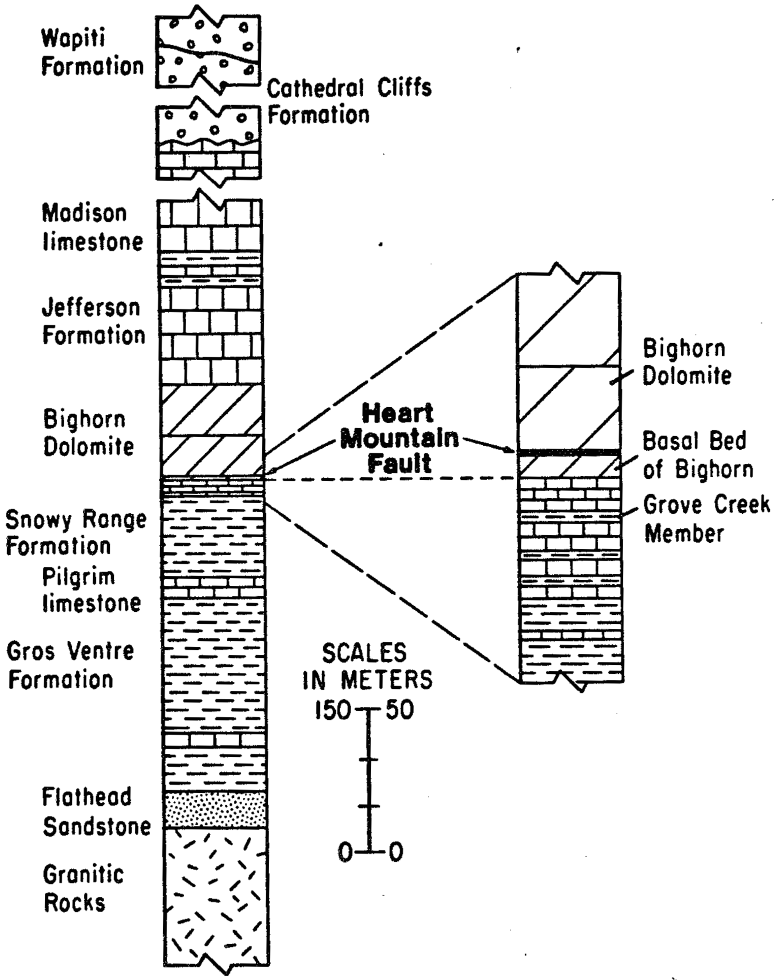

Figure 1. Simplified stratigraphic section showing the formations associated with the Heart Mountain fault. Inset shows a detailed section near the plane of the bedding fault. After Pierce (1973).

The Heart Mountain fault shares this pecularity with other, deeper seated, decollement such as the Keystone and Mormon Mountain systems in Southern Nevada, U.S.A. (Burchfiel et al., 1982). In these latter decollements the detachment horizon lies in strong platformal dolostones several hundred meters above a contact with weak underlying shales, siltstones and limestones. All of these decollements developed at shallow crustal levels (less than 5km depth). None of them show any evidence of having been lubricated by high pressure pore fluids (Guth et al., 1982).

The paradoxical localization of faulting in the strong geologic units in the Heart Mountain and the other decollements provides a strong constraint on the dynamics of the process that produces detachment. It is also clear that this process lubricates the fault plane to an extraordinary degree -- the Heart Mountain decollement slid freely down a slope of less than 2°, and the classic discussions of the mechanics of overthrust faulting (Smoluchowski, 1909; Hubbert and Rubey, 1959) imply a similar degree of lubrication for the Keystone and Mormon Mountain systems. Although many mechanisms have been suggested to account for this reduction of friction, none so far explains the offset of the fault plane into the strongest of the adjacent rock units.

In previous work (Melosh, 1979; 1983) I attributed the fluidization of rock debris in impact crater collapse and large catastrophic landslides to the presence of a strong random acoustic field. A small fraction of the available potential energy is converted into sound waves that are sufficiently strong to briefly relieve the overburden pressure in a portion of the rock mass, there allowing sliding to occur under low net differential stress and, incidentally, also regenerating the sound energy.

A version of this theory also applies to the Heart Mountain fault (Melosh, 1985). The structure of a high-sound-velocity layer (e.g., dolomite) lying next to a low-velocity layer (e.g., shale), Figure 2, approximates an acoustic resonator, capable of partially trapping sound waves. Although fully trapped (Stoneley) waves cannot form under plausible conditions in sedimentary rock sequences, leaky wave modes are possible. Figure 3 shows one such mode and indicates that the maximum wave amplitudes occur in the high-velocity unit (e.g., the dolomite), almost exactly one-quarter wavelength above the lithologic boundary.

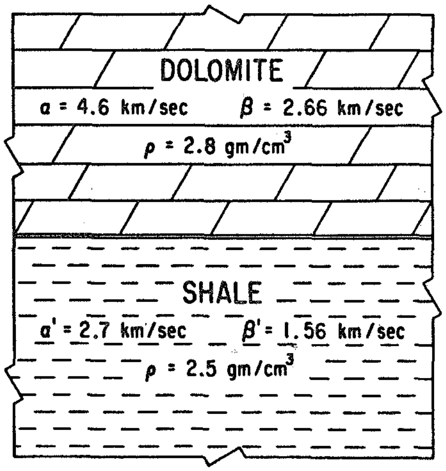

Figure 2. Idealized mathematical model of the rock units near the bedding fault shown in Figure 1. The mechanical properties used to compute the stresses shown in Figure 3 are shown here. The Grove Creek member of the Snowy Range Formation is mechanically grouped with the Bighorn Dolomite in this model.

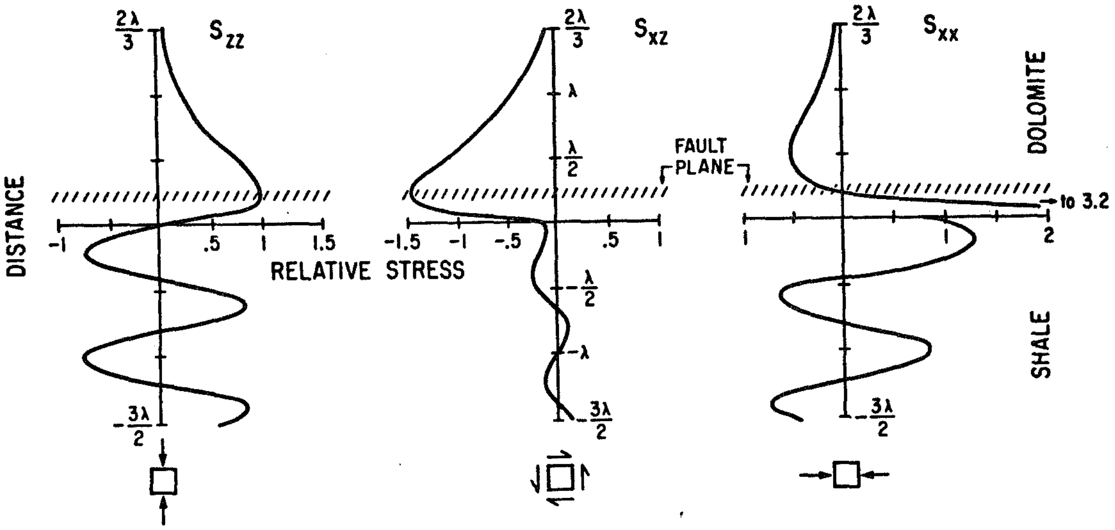

Figure 3. The relative magnitudes of three stress components are shown here as a function of distance away from the lithologic contact at one instant of time. Note that the maxima of both the vertical stress S_{zz} and the shear stress S_{xz} occur about 1/4 wavelength above the contact. This is the horizon where faulting is expected to occur.

The above analysis focusses attention on the partially trapped wave in the global sense, spanning many failure events. An equivalent, failure-by-failure, description can also be given from the viewpoint of renormalization theory (Allegre et al., 1982; Smalley et al., 1985) in which the elastic energy radiated from the failure of one element of the rock mass greatly enhances the probability of subsequent failure at a horizon one-quarter wavelength above the lithologic contact of the strong and weak units. The result is the same: sliding can take place under extremely small average stresses and is localized in the highest sound-velocity unit near a lithologic contact with a low sound-velocity unit.

The major difference between landslides or rapid decollement such as Heart Mountain and deeper-seated decollement such as the Keystone or Mormon Mountain systems is the source of the driving energy. In the first case it is gravitational potential energy, in the latter it is tectonically renewed elastic energy. The lubrication mechanism may be the same in both cases, one that dynamically relieves the overburden stresses by short-wavelength elastic waves radiated during sliding or episodic earthquakes on the fault plane.

This mechanism explains why motion (whether compressional or extensional) occurs preferentially along sub-horizontal fault planes that follow lithologic contacts rather than the steeply-dipping planes of the classic Anderson fault model. It also explains the otherwise emigmatic offset of the fault plane into the stronger (more exactly, higher velocity) of two adjacent geologic units.

Further elaboration of this model should proceed both theoretically, taking into account as much realistic detail as possible for well-studied decollement systems, and observationally, using either natural or artificial high-frequency sound sources to investigate the acoustic trapping properties of natural rock systems.

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