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LOW-ANGLE NORMAL FAULTS - LOW DIFFERENTIAL STRESS AT MID CRUSTAL LEVELS?

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A simple model for frictional slip on pre-existing faults that considers the local stress state near the fault and the effect of non-hydrostatic fluid pressures predicts that low-angle normal faulting is restricted to areas of the crust characterized by low differential stress and nearly lithostatic fluid pressures. In part following (1), the model considers frictional slip on a cohesionless low-angle normal fault governed by the failure criterion $\tau = \mu_f \sigma^*_n = \mu_f(\sigma_n - P_f)$ where τ and σ_n are the shear and normal stresses across the fault plane, μ_f is the static coefficient of friction, and P_f is the pore fluid pressure (Fig. 1). As a first approximation, the model considers a vertical greatest principal compressive stress, σ_1. It is apparent that if slip on low-angle normal faults is governed by the above frictional failure criterion, slip on the low-angle normal fault occurs only if the least effective principal stress, $\sigma^*_3 = \sigma_3 - P_f$, is tensile, whenever $\tan^{-1}(\mu_f) > d$, where d is the dip of the fault (Fig. 1). If detachment faulting occurs at any significant depth in the crust, $P_f > \sigma_3$ is required. In light of this conclusion I allow P_f to vary as necessary to allow slip on the low-angle normal fault.

An additional criterion for long term viability of the low-angle fault surface as a significant tectonic feature is that no failure occur in the wall rock. Following (2), the failure criterion for the intact wall rock can be approximated by the parabolic Griffith criterion in the tensile field (T = the tensile strength of the rock), and as a linear Coulomb envelope in the compressive field (C = 2T = the cohesive strength and μ_i is the coefficient of internal friction). The failure envelope for the intact rock limits the level of differential stress expected near active low-angle normal faults (Fig. 2). Most notably, low-angle normal faults which dip $< 15^{0}$ and have frictional sliding coefficients > 0.4, will only be viable tectonic elements in extending lithosphere if total differential stress near the faults is less than about four times the tensile strength of the rock.

The model has potentially important and interesting implications. Areas of the crust with active low-angle normal faults should have strengths comparable to the tensile strengths of the rocks involved. Active low-angle normal faults should be characterized by smaller earthquakes than any "Andersonian" fault at comparable depths, because the elastic strain energy of distortion stored in the wall rock of a fault is proportional to the square of the differential stress. Although evidence for seismic faulting on low-angle normal faults is rare (3,4), Jackson (4) has observed long period seismic signals radiated from nearly flat surfaces immediately following major earthquakes on nearby steep normal faults. Perhaps these long period signals are related to movement of fluids in sub-horizontal fault zones.

Because the model predicts that mid-crustal low-angle normal fault zones will have low strengths and low levels of seismicity, I suggest that the transition to macroscopic ductility in regions with active low-angle normal faults is controlled at least in part by fluid pressure enhanced cataclastic flow and fluid assisted stress corrosion cracking, rather than solely by thermally activated diffusion and dislocation creep. Interestingly, a recent description of chloritic breccia zones along low-angle fault surfaces in the Basin and Range province (5) preferred to describe the zones as "fluidized media" rather than as fault breccias.

Although the model assumes a pre-existing low-angle fault surface, and cannot explain the *initiation* of such surfaces, I speculate that many of the conditions which cause the initiation of low-angle normal fault surfaces are the same as the conditions needed to ensure their survival. I suggest a number of features that have been observed along low-angle faults in the southern Basin and Range province are consistent with the high fluid pressures and low differential stress levels predicted by the model; these include a) the common association of mineralization and low-angle faulting (6), b) the development of extensive cataclastic zones along low-angle fault surfaces, and c) the development of primary wavelike undulations of the fault surfaces (7).

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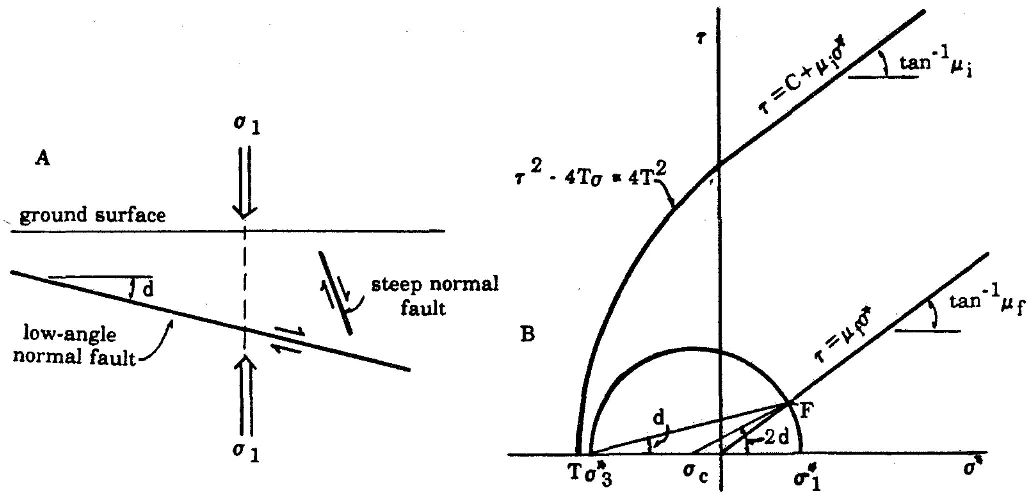

Figure 1. a) Angular relationships between σ_1, low-angle normal fault, and steep normal fault in the two-dimensional model. b) Mohr circle condition for slip on low-angle normal fault, in part after Sibson (1985). State of stress at fault surface represented by circle with center σ_c. Low-angle fault surface represented by point F.

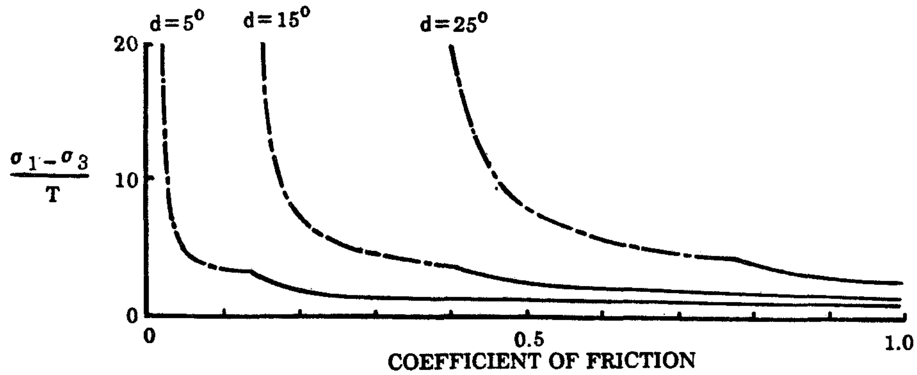

Figure 2. Normalized differential stresses for simultaneous failure of intact wall rock and slip on low-angle normal fault, as a function of μ_f. In the region below the curves slip on the low-angle normal fault alone is possible, while above the curves failure of the wall rock in either tension or shear occurs. Dashed lines represent condition for simultaneous shear failure and slip on the low-angle surface; solid lines the condition for simultaneous tension failure and slip on the low-angle surface.