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COMMENT ON "ORIGIN OF REGIONAL, ROOTED LOW-ANGLE NORMAL FAULTS: A MECHANICAL MODEL AND ITS TECTONIC IMPLICATIONS" BY AN YIN

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Yin [1989] has done an excellent analysis of an interesting mechanical model; however, the conclusion that the model can explain the origin of normal faults dipping less than 20° is not justified. Either the models do not produce nearly enough shear stress for motion on a low-angle normal fault, or they require that the crust maintain tensile stresses an order of magnitude greater than the measured tensile strength of rocks. The mechanical analysis shows how shear tractions at the base of an elastic layer affect the principal deviatoric stress axes within that plate. It is claimed that shear tractions as low as 10 MPa can make low-angle normal faults be the preferred mode of faulting in the upper crust and thus explain the "paradox" of low angle faults. This paradox exists because simple rock mechanics theory predicts that normal faults should be active at high dip angles (45°- 70°), yet these faults are observed to have lower dips, even 0° or negative dips.

The calculations in this paper correctly show that the principal deviatoric stress directions in elastic crust can be altered by the shear stresses applied at the base of the upper crust. The upper crust is assumed to be 15-20 km thick and to behave elastically. The shear stresses are taken to be caused by ductile flow in the lower crust. No models are done to show how a consistent shear traction would arise in the lower crust or what would control the magnitude of these shear stresses. Shear tractions of small magnitude compared to the deviatoric stress level in the upper crust will not appreciably rotate the principal stresses. In the model, the shear stress applied is taken to be between 10 and 50 MPa. It should be noted that such large shear stresses would be very hard to maintain in flowing lower crust if the crust were as hot as the present-day Basin and Range. The abundance of synextensional rhyolitic magmatism where low-angle normal faults are observed [e.g. Zoback et al., 1981] argues for an even hotter lower crust, close to its melting point. Since the basal shear is central to the tectonic implications of the paper Yin should show that such stresses could arise in a tectonically reasonable setting. For the sake of argument, we will assume that such high shear tractions might arise in some circumstances.

When Yin considers relatively small shear tractions (10 MPa), it is implied that small deviatoric stresses will lead to fault motion. Surprisingly, the magnitude of shear stress required to produce fault slip is not discussed in the paper. Yin's Figure 6b illustrates the simplest model which is claimed to result in low-angle normal faults and shows the maximum shear stresses in the upper crust. In the region where low-angle normal faulting is indicated, the maximum shear stresses are 10 MPa at a depth of about 10 km. Brace and Kohlstedt [1980] have calculated the shear stress required for normal fault motion based on laboratory measurements. They estimate that at 10 km depth a shear stress of between 80 MPa and 120 MPa is needed, depending on whether the crust is dry or wet. Brace and Kohlstedt [1980] consider only the case of high-angle normal faults. Higher shear stresses will be required for slip on low-angle faults. In the limit that normal faults are horizontal the shear stress must be about 85% of the normal stress [Byerlee, 1978]. For this case, shear stresses of about 200 MPa would be required at 10 km depth. The shear stresses in the model shown in Figure 6b are low by about a factor of 20.

When greater applied shear tractions are modelled, the shear stresses within the crust are larger. In the model shown in Figure 7c of Yin, the shear stresses are

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within a factor of 3 of the stress level needed to produce slip on low-angle normal faults. This model has the highest level of applied basal shear stress (50 MPa) and a particularly complex stress field applied at the sides of the upper crust. The most severe problem with this model is that it results in rocks in the top several kilometers of the crust being in a state of absolute tension. The tensile stresses are as high as 200 MPa at the surface. Rocks simply cannot maintain such a level of tensile stress. Typical rock tensile strengths are about 10 MPa [Jaeger, 1969]. If the crust contains pre-existing fractures, as is often assumed, then the rocks will support essentially no tensile stress. All of the models shown in the paper which are claimed to lead to active low-angle normal faulting have regions in tension, but this case has the highest level of tensile stress. Failure of these rocks will alter the stress field for the remainder of the elastic upper crust in the model.

A related problem with the paper is that low-angle faulting is always indicated in the places where the model shear stress is the smallest. Fault displacement and stress release should take place on the adjacent high angle faults where the shear stresses are greater. Even assuming low coefficients of friction on all preexisting fractures does not get around this problem: the high angle fractures would still be the preferred sites for fault slip.

In conclusion, these model calculations show that even with specially constructed stress fields the last place for slip to occur is in the area where a normal fault would dip at a low angle. The calculations are elegant and clearly described, but caution should be exercised in applying the results to tectonic problems.

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