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Does magmatism influence low-angle normal faulting?: Comment and Reply

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Notes

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COMMENT

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Parsons and Thompson (1993) raised the possibility that magmatic intrusion may cause initiation of low-angle normal faults. Although the model is mechanically viable, it is inconsistent with the known field relations. Magmatic emplacement as shown in their Figures 1 and 3 should produce a symmetric boundary condition and thus a symmetric stress distribution with respect to the intrusive body (Parsons and Thompson, 1993, p. 248). However, their Figure 3 shows only half of the solution and thus gives readers a wrong impression that magmatic emplacement can produce unidirectionally dipping low-angle normal faults. In fact, their model should predict that low-angle normal faults begin as conjugate sets dipping toward the intrusive body (Fig. 1). To my knowledge, nowhere have low-angle normal faults of regional extent with such a field relation been reported.

REFERENCE CITED

Parsons, T., and Thompson, G.A., 1993, Does magmatism influence low-angle faulting?: Geology, v. 21, p. 247–250.

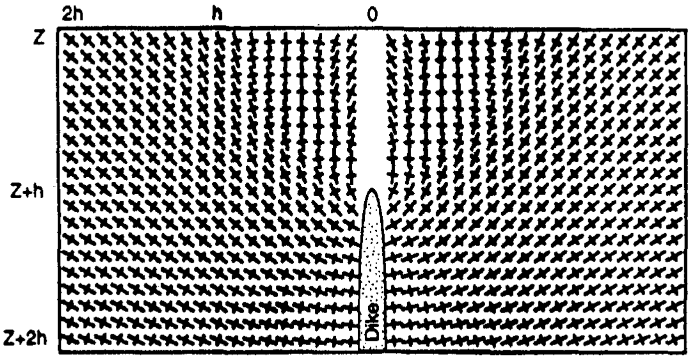

Figure 1. Parsons and Thompson's (1993) Figure 3, but with orientation of principal stresses shown on both sides of pluton.

REPLY

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We appreciate this chance to clarify and expand the discussion on the relation between magmatism and low-angle normal faulting. The primary purpose of our paper (Parsons and Thompson, 1993) was to show that magmatism can be a viable source of shear in the crust that alters the stress field significantly. For simplicity, we showed the stresses around a single dike, which as Yin correctly suggests (and we stated in our paper) will form a radial pattern around the dike (following standard practice we showed only half of the symmetrical pattern to save space). It is important to make clear that we are suggesting that a broad zone of intrusions at depth causes the development of a metamorphic core complex, not a single intrusion. We included the illustration to demonstrate the impact of magmatic intrusion on the stress field in the host rock.

A simple model of an intrusive zone in a perfectly homogeneous stress field does predict a conjugate set of low-angle faults dipping toward the center of the intruded zone. However, field examples abound showing that only one member of a conjugate set actually develops strongly. Under ideal conditions, obtaining symmetry is akin to balancing a coin on its edge; in faulting, the chance first rupture destroys the symmetry of stresses and favors one member of the set (heads or tails in the case of the coin). Under more realistic geologic conditions, topography or anisotropy commonly favor one member of a set. Similarly, the shape of an inflating pluton may predetermine faulting direction. In Figure 1, adapted from Coney (1980), the distribution of metamorphic core complexes in North America is shown. Two things stand out in this figure: (1) metamorphic core complexes occupy an almost insignificant part of the total extended area of the Western Cordillera, and (2) as Coney (1980) noted, "the belt developed either on or very close to the edge of the original North American Precambrian cratonic basement." Furthermore, to continue quoting Coney (1980), "The extension coincided with a vast plutonic-volcanic flare-up of magmatic arc affinity. . . ."

The regionally small fraction of crust that has been greatly extended on low-angle normal faults suggests that core complexes occur only in anomalous conditions. Indeed, Jackson (1987) noted that large earthquakes are not observed on low-angle normal faults anywhere in the world today. The localization of North American core complexes near the cratonic edge and the rim of the Colorado Plateau suggests a possible asymmetry in the stress field at the time a core-complex begins to form; this asymmetry results from variations in crustal rheology across tectonic boundaries. The coincidence of metamorphic core complex formation with associated magmatism has been noted by a list of authors too exhaustive to quote here. Putting these factors together (Fig. 2) yields the following set of special circumstances that could cause a unidirectionally verging low-angle normal fault. (1) A large zone of intrusion expands faster than tectonic extension at mid-crustal depths; (2) the intrusions occur near a major tectonic boundary and hence expand asymmetrically into the crust with the greatest deviatoric stress; and (3) shear stresses applied by the asymmetric plutonic expansion rotate the greatest principal stress away from vertical and favor a unidirec-

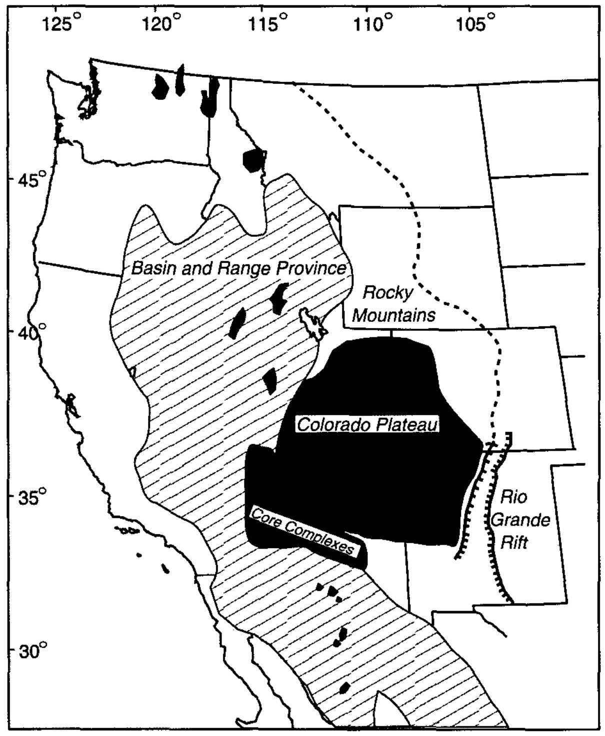

Figure 1. Tectonic provinces of western North America and northern Mexico. Black areas are major zones of metamorphic core complexes (where low-angle normal faulting has exposed mid-crustal core rocks).

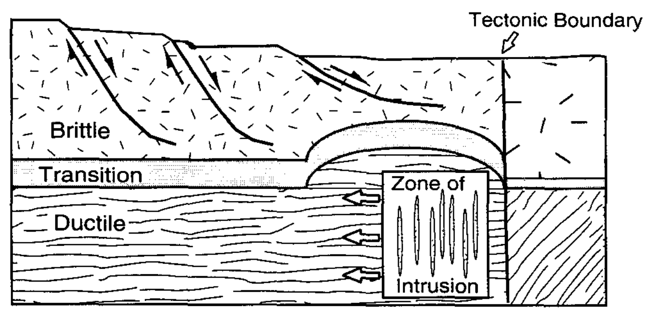

Figure 2. Cross section of strain distribution for core complex that is beginning to form. Rapid, asymmetric expanding zone of intrusion at depth causes rotation in stresses and elevates brittle-to-ductile transition. Tectonic boundary shown is meant to be symbolic of any crustal heterogeneity that might preferentially influence formation of one of the two favored fault planes.

tional set of low-angle fault planes in the crust above the intruded zone.

The above is simply one way in which magmatic bodies might expand asymmetrically. Any lateral variation or transition in the magnitude of horizontal stress would favor magmatic growth toward the least horizontal stress, and the shear imposed could drive low-angle faulting. Horizontal shear applied by an underlying ductile layer may cause a rotation of the principal stresses (e.g., Bradshaw and Zoback, 1988; Melosh, 1990), but what is the source of the shear? Induced shear within a ductile layer caused by gravity apparently drives the low-angle faults off the Gulf Coast of Texas, but tilted topography alone could not drive the mid-crustal faults that cause metamorphic core complexes. We suggest that rapidly expanding overpressured magma can provide a powerful source of shear in the crust that may provide the driving mechanism for core complexes.

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