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Non-plane strain in near-surface normal faults in granular porous media

L.B. Goodwin (1), G.C. Rawling (2), P.R. Riley (1), C.J. Lewis (3),

(1) Dept. of Geology and Geophysics, University of Wisconsin – Madison, Wisconsin, USA, (2) New Mexico Bureau of Geology and Mineral Resources, New Mexico, USA, (3) Los Alamos National Laboratory, New Mexico, USA (laurel@geology.wisc.edu / Fax: +1 608-2620693)

High porosity granular geomaterials deform by one of three mechanisms in near-surface fault zones, depending on the magnitude of grain contact strength. In uncemented, poorly consolidated sediments, deformation occurs by particulate flow. With progressive consolidation and/or cementation, deformation bands accommodate shear. Strongly bonded grains allow discrete shear and extension fractures to form. For each of these three cases, we give an example in which fault-zone structures record non-plane strain, demonstrating three different reasons why it can occur in the shallow crust. For particulate flow in sand, grain-shape preferred orientation data from the Sand Hill fault of the Rio Grande rift, NM, USA imply non-plane strain that is penetrative at the grain scale. We attribute this non-plane strain in the fault core and flanking mixed zones to complex spatial and/or temporal patterns of deformation within the curviplanar fault zone. Another rift-related structure, the Pajarito fault, cuts the mechanical stratigraphy of the high porosity Bandelier Tuff, producing damage zones formed of deformation bands in nonwelded glassy units and fractures in welded units. The pre-existing mechanical anisotropy represented by columnar joints in the welded units influences the orientation of damage zone fractures, most of which strike oblique to the dip-slip fault. Deformation bands in non-welded glassy units form conjugate sets, with main-fault-parallel orientations dominant directly adjacent to the fault. However, they become progressively more irregularly oriented in portions of the damage zone further from the main fault, probably reflecting spatial variations in stress. These processes collectively produce a triclinic damage zone around the Pajarito fault. Our observations suggest that non-plane strain is common in the shallow crust. It may

reflect pre-existing anisotropy, spatial variations in stress, and/or spatial or temporal variations in strain. Plane strain should not be assumed without substantiating evidence.