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Theory of formation and extension of compaction bands in porous rock

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Thin, approximately planar bands of localized compaction have been observed both in the field and laboratory samples. Because the permeability of these bands is several orders of magnitude less than the adjacent material, understanding their formation and evolution is important to a variety of applications involving subsurface fluid injection or withdrawal. A theory that treats the formation of these bands as an alternative solution to uniform compression shows that such localization is possible for inelastic compacting materials and for stress states on a "cap" yield surface. Extension of the bands to lengths of 10's of meters observed in the field is less well understood. The stress state immediately ahead of the band can be calculated by modeling the band as a narrow elliptical inclusion of stiffer material (because of decreased porosity) subject to an imposed inelastic compressive strain and loaded by stresses in the far field. For aspect ratios and inelastic strain values inferred from field data and plausible values for the stiffness contrast, the calculations show that the bands can reasonably be approximated by an "anti-crack" which neglects the stiffness of the inclusion and idealizes the compactive strain as interpenetration of the surfaces of a negligibly thin crack. This result is supported by a calculation of the elastic strain energy released per unit advance of a compaction band in an infinite layer of thickness h. If the elastic moduli of the band and the surrounding host material are similar and the band is much thinner than the layer, the energy released is simply $\sigma_{+}\xi h\epsilon^{p}$ where σ_{+} is the compressive stress far ahead of the band edge, ξh is the thickness of the band and ϵ^{p} is the uniaxial inelastic compactive strain in the band. Using representative values inferred from field data yields an energy release rate of 40 kJ/m^2, which is roughly comparable with compaction energies inferred from axisymmetric compression tests on notched sandstone samples.