Small-scale folding related to detachment tectonics - Northern Snake Range, NV

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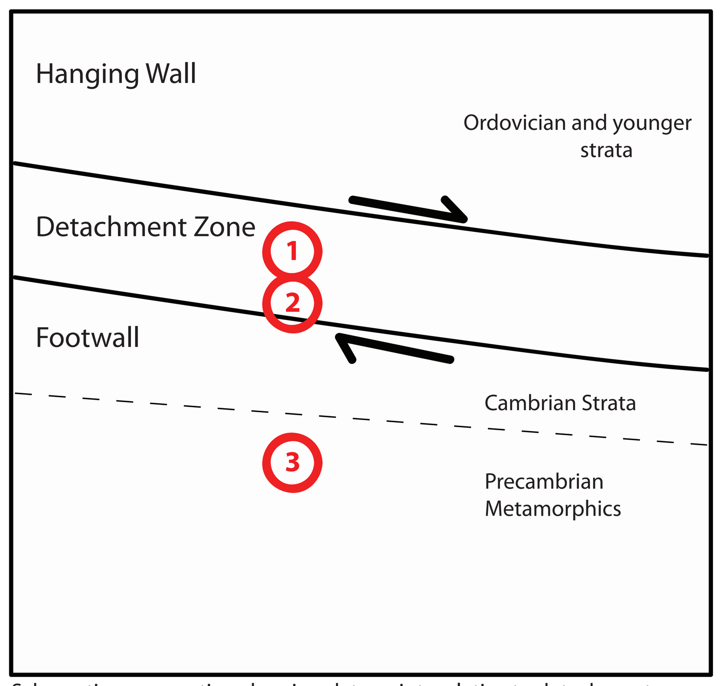
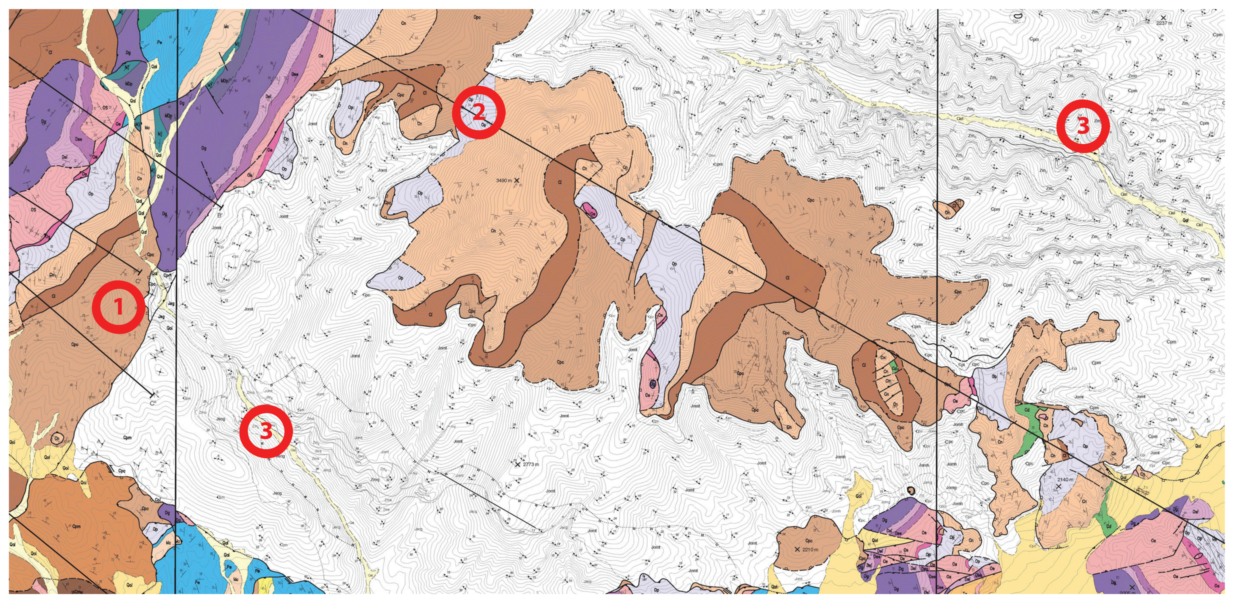
Background

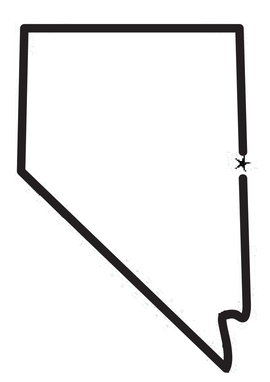
The Snake Range Décollement is an extensional low-angle detachment in east-central Nevada, the footwall of which forms much of the Northern Snake Range itself. It bounds a metamorphic core complex formed as a result of Tertiary extension of the Basin and Range province (Miller et al., 1999). On the eastern flank of the Northern Snake Range exposures of various parts of the detachment zone and footwall exhibit different rheologies and types of deformation, as indicated by styles and orientations of folds and other features. Regional extension trends approximately 305°-125° (Miller et al., 1983). In the region of Hendry's Creek, crustal thinning and extension also involves top-to-the-east shear.



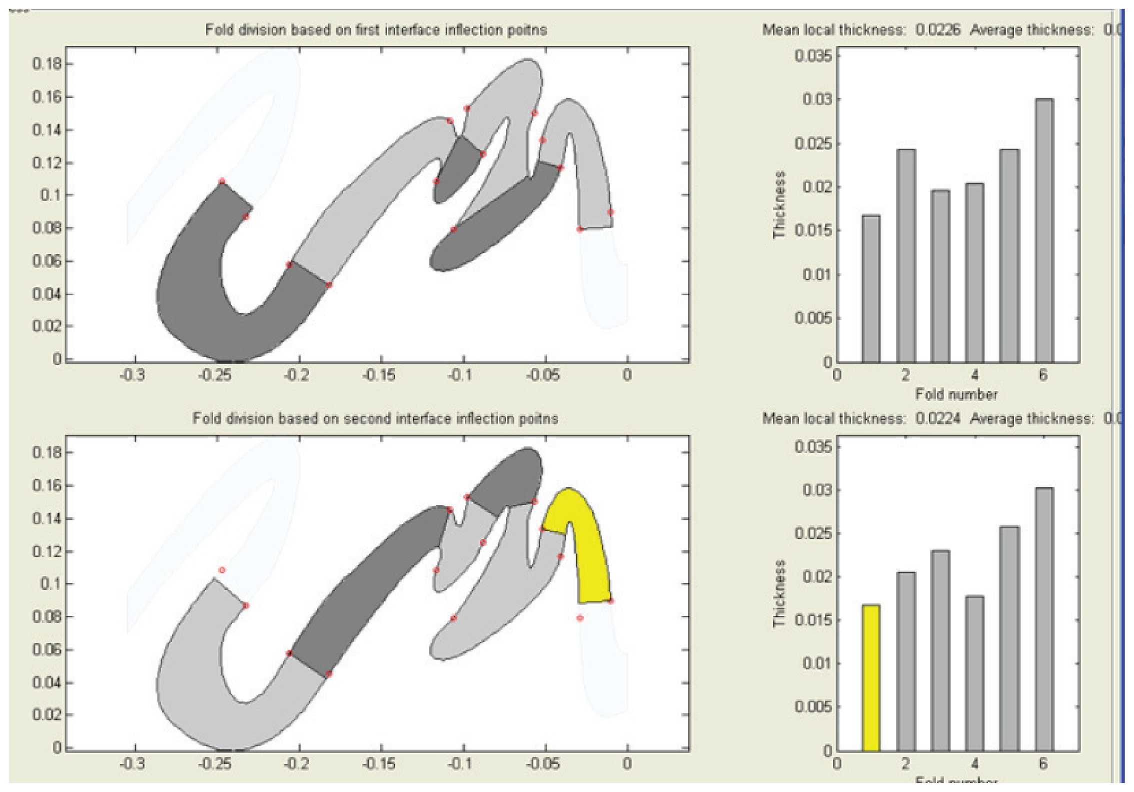
Schematic cross-section showing data points relative to detachment



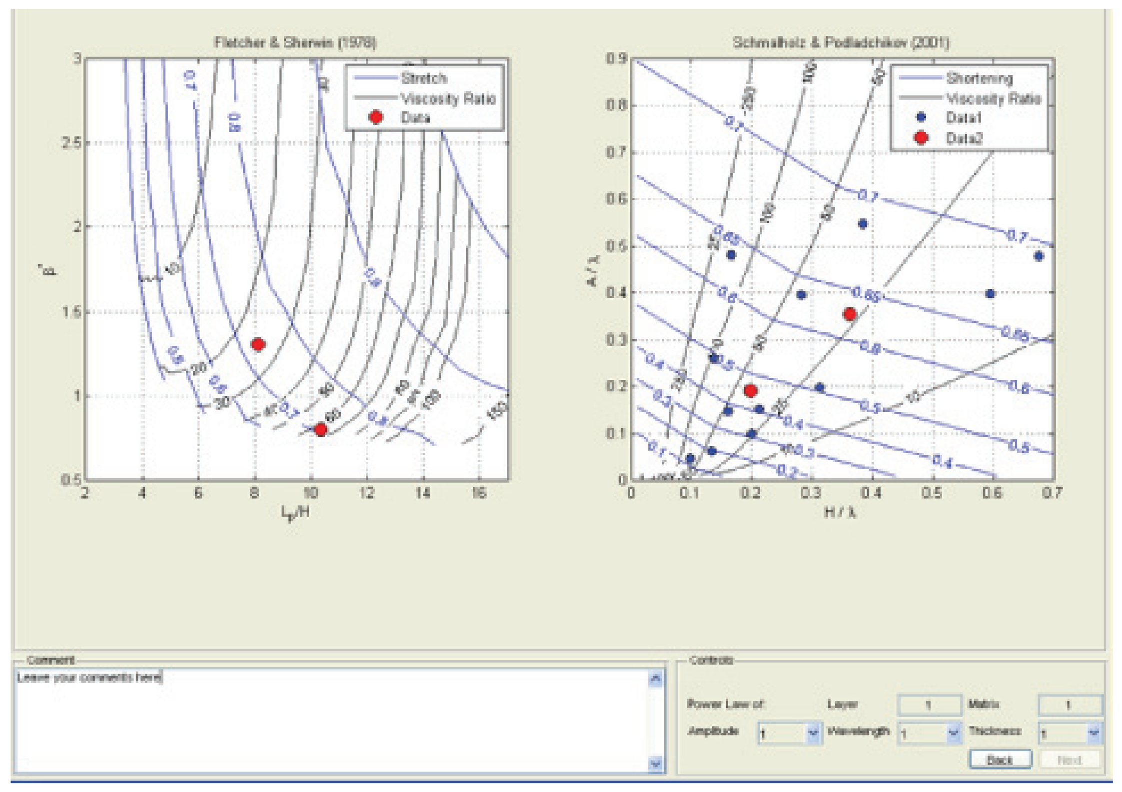
Quadrangle Location



Map of the field area, consisting of portions of the Cove, Old Man's Canyon, and Sacramento Pass Quadrangles (Johnston, 2000).



Digitization of the garnet fold image shown below in "Metamorphic Units". Fold division is based on inflection points after filter selection.



Strain contour diagrams

The Fold Geometry Toolbox

The Fold Geometry Toolbox (Adamuszek et al., 2011) produces pre- and post-nucleation viscosity ratios as well as raw geometric data for images of buckle folds. Assuming a down-plunge perspective, a path created in Adobe Illustrator representing each interface of the fold is analyzed via existing mathematical theories (e.g. Sherwin & Chapple, 1968 and Schmalholz & Podladchikov, 2001). User bias is limited to defining the fold interfaces and filter selection. This is minimal on relatively long and consistent fold trains. However, on short irregular sections as seen in the Snake Range there can be drastic variations between different filter selections, and it is sometimes unclear what filter width should be chosen. Image resolution can also be an issue during the digitization process when it is unclear where the layer interface lies.

Practical Application

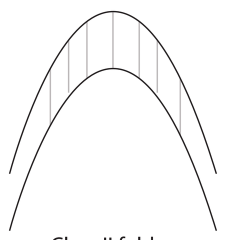
The viscosity ratio provided by FGT can be compared to other methods. Folded garnet layers in the Northern Snake Range (pictured below) consist largely of rigid inclusions, giving the layer an effective viscosity much greater than that of the schist matrix. The Einstein-Roscoe equation can be used to estimate effective viscosity from inclusions based on percent composition:

$$\beta = \frac{1}{(1-f_i)^2}$$

f is the percent area of the layer consisting of inclusions (Adamuszek, 2012). Using a thin section of a garnet fold, we calculated the percent inclusions to be approximately 64%, resulting in an effective viscosity enhancement by a factor of only 8. This is inconsistent with results obtained on these folds based on wavelength/thickness ratios using FGT; a higher viscosity contrast is suggested by their general shape as well. The Einstein Roscoe equation is inadequate here since it assumes non-interacting round inclusions, whereas the garnets in these folds are touching and have angular shapes, providing additional resistance to shortening and shearing the layer. Both factors serve to increase viscosity, in this case substantially. FGT analysis indicates an effective viscosity ratio between 25 and 50, and shortening between 30% and 60%.

1. Detachment Zone

- Ductile similar folds (Class II)
- Scattered hinge orientations
- Chert folds - FGT viscosity contrast <5



Class II fold

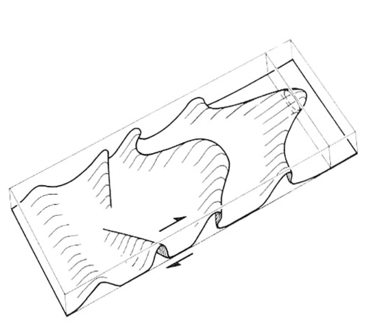


Figure 11. Sketch to illustrate the progressive amplification of folds in a shear zone and the development of sheath folds. The state of lowest shear strain is at the left, that of highest shear strain at the right. A cross section through the sheath fold at the location shown in the figure would appear as in Figure 13. (Hudleston, 1986)

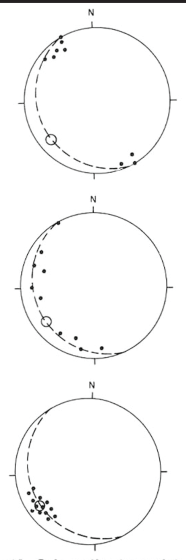
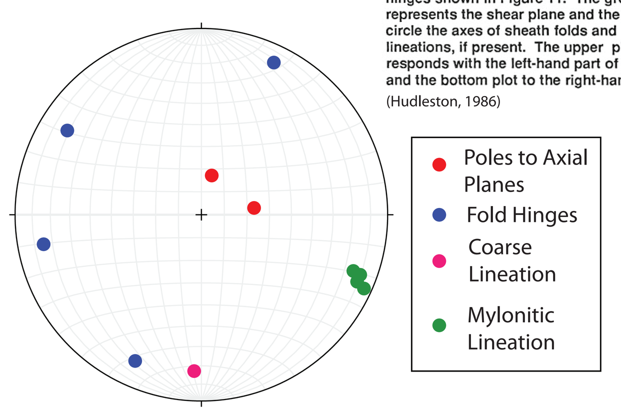


Figure 12. Schematic stereoplots of the fold hinges shown in Figure 11. The great circle represents the shear plane and the open circle the axes of sheath folds and mineral lineations, if present. The upper plot corresponds with the left-hand part of Figure12, and the bottom plot to the right-hand part. (Hudleston, 1986)

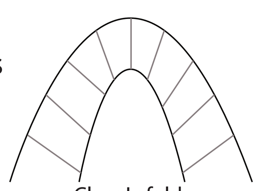
Marbles with mylonitic foliation display similar folds, while chert layers within the marble buckle folds. Locally the marble and chert layers are involved in late-stage less ductile folding and faulting.

Boudinage of cherty layer

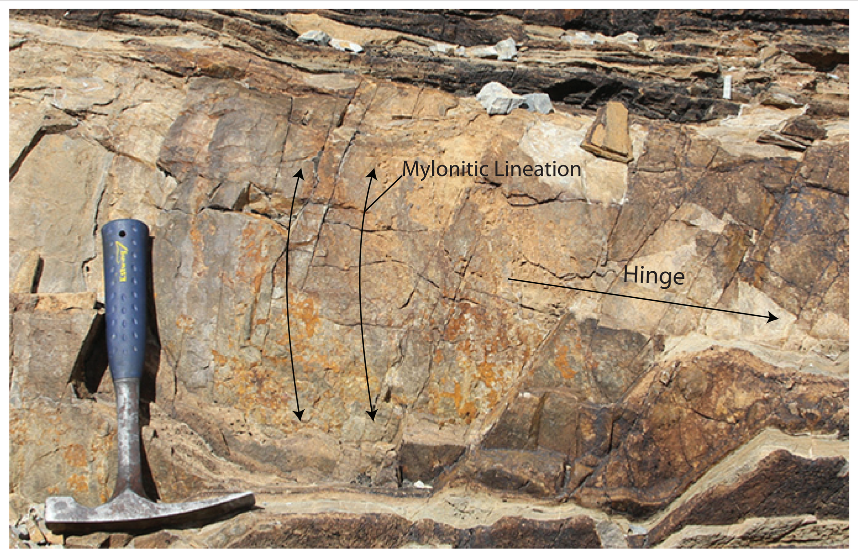


2. Lower Detachment Zone

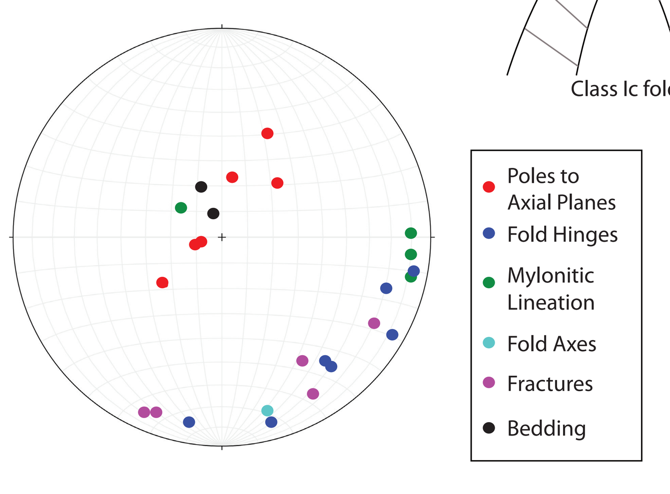
- Buckle Folds – Class Ic
- More consistent NW-SE orientations



Class Ic fold

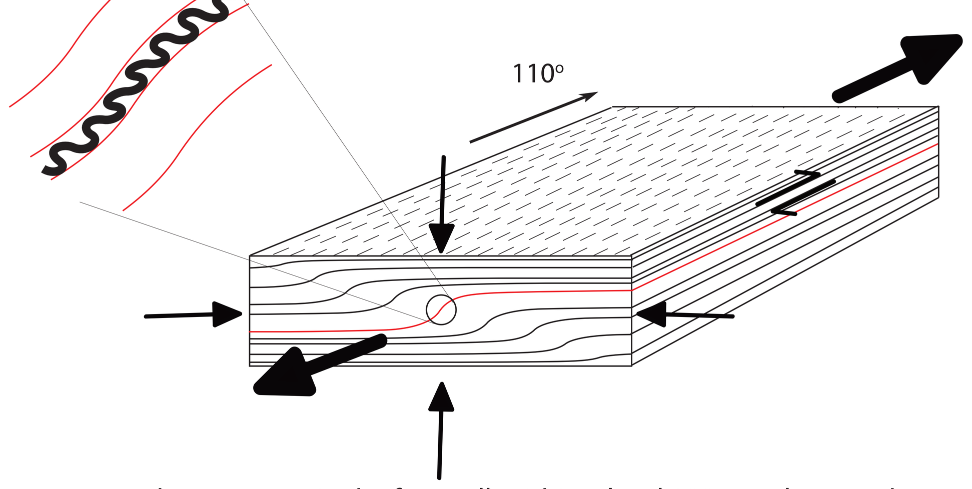


A subtle mylonitic lineation is overprinted by folding. In this exposure the fold hinge is in the plane of the photograph.



3. Metamorphic Units

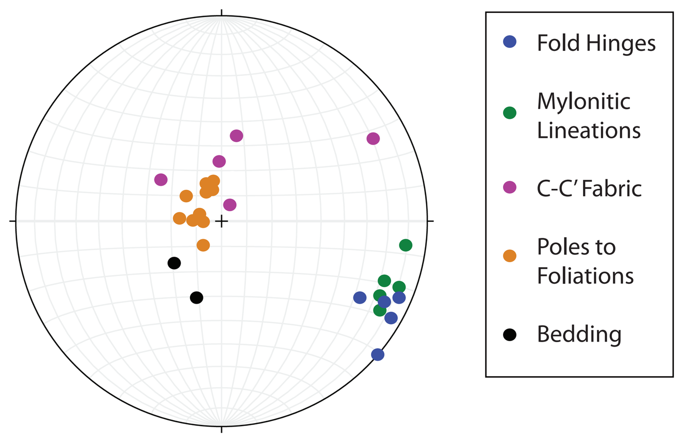
- Garnet buckle folds (Class Ic)
- FGT viscosity contrast: 20-35
- Tighter distribution of orientations



Above: Lower in the footwall, within a local 100m scale recumbent fold with axis parallel to the extension direction, centimeter-scale garnet fold trains in a schist unit of the McCoy Creek Group have hinges parallel to the direction of shear and extension. Schistosity is axial planar to these folds.

Large-scale boudinage in the southern wall of Hendry's Creek canyon

C-C' fabric in schist



Conclusions

1. The garnet fold trains clearly indicate buckling and suggest that components of both vertical shortening and horizontal shortening normal to the extension direction occurred, at least locally, resulting in constriction. Sullivan (2008) illustrates a similar scenario in the Raft River Shear Zone.

2. If all shortening experienced by the garnet layers is compensated for by extension parallel to the lineation, this would imply an extension of between 40% and 150%.

3. Rheological contrast within the detachment zone between marble and chert is modest, with early very ductile structures being followed by later, more brittle ones.

4. There is evidence for multiple stages of deformation that likely developed progressively as the core complex formed. Folded mylonitic lineation in the upper footwall indicates an initial more ductile stage, followed by later brittle deformation resulting in buckle folds.

5. Boudinage on multiple scales indicates extension in the direction of the stretching lineation. Also, the orientation of C-C' fabric in schist layers suggests top-to-the-ESE shear; fold orientations and the dominant lineation suggest this as well. Taken together, these features are all consistent with a NNE-SSW striking, gently dipping extensional shear zone, with top-to-the-ESE shear.

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Acknowledgements

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