Context:
geology fractures

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Author:
Nick Doe, 1787 El Verano Drive, Gabriola, BC, Canada V0R 1X6
Phone: 250-247-7858
E-mail: nickdoe@island.net

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Thoughts on Riedel microfractures

by Nick Doe

This note is a supplement to the article:

Nick Doe, *Stress on Gabriola*, *SHALE* 20, pp.13–28, April 2009 and in particular on Appendix 2, pp.27–28.

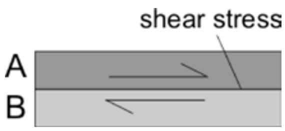
Also a supplement to the article:

Nick Doe, *It's about pointy rocks*, *SHALE* 7, pp.26–31, January 2004.

Please be warned that this is not an authorative account; it is just an attempt by an amateur geologist to explain to himself Riedel microfractures.

Riedel microfractures, and fractures closely associated with them, occur in the shear zones of major strike-slip faults. They are commonly too small to be of any significance, assuming they exist at all, but in some of the larger shear zones, those that are a few metres or more in width, you can see fractures whose orientation is offset from the axis of the strike-slip fault.

Here's how it might happen.



In the strike-slip fault shown above, block A slides to the right, and block B slides to the left. The plane of this diagram is the horizontal surface of the rock. This fault would be called a right-hand fault because if you were standing on B, A would appear to have slipped to your right; and if you were to step over the fault to A and turn around, B would also appear to have slipped to your right.

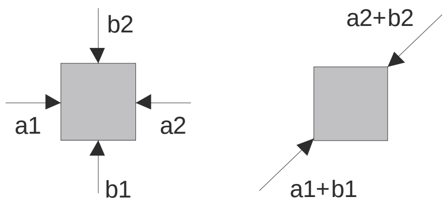
The only stress involved in this simple picture is the shear stress created by the force trying to move the blocks and the friction that opposes the motion. There is no shear zone because the blocks are in perfect contact.

In real life, rocks don't glide passed one another with hardly any interaction. The two bodies of rock, A and B are separated by a "shear zone", within which many complicated things can happen.

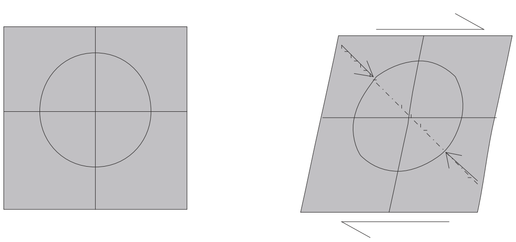
Before starting to think about shear zones, let's get two principles straight.

First, when thinking about the forces involved when a rock is stressed, you have to remember that all the forces must be equal and opposite. If they aren't, the rock will move. Mr. Isaac Newton said so. Each equal and opposite pair of forces constitute what I call a "stress pair". In a slip fault, there are brief moments when the forces are not balanced. The force attempting to move the rock may gradually grow until it is bigger than the forces of friction or gravity opposing it. The rock does then move, but almost immediately this movement relieves the stress and the force moving the rock diminishes, and, simultaneously, as the rock moves, the friction increases. This restores the equal and opposite balance of the forces and the rock is again stationary.

Second, you can't combine stress pairs in the way you can forces. The stress being experienced by the cube of rock below, is NOT the same in the two pictures, even though vector additions of the forces, when not members of a stress pair, are allowed.



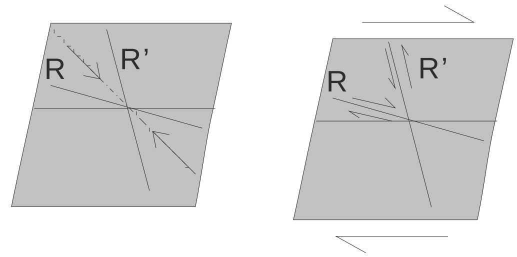
> This method of analysis is <u>not allowed</u> when thinking about stress, even though it is valid for forces. Stress can only be reduced to two orthogonal stress pairs in two dimensions, three in three dimensions. If combining in this way were allowed, you could equally well have combined a1 and b2, and b1 and a2, but then the composite stress would have been different.



The easiest way to see what stresses apply in a shear zone is to examine the *strain* (the deformation resulting from the stress) in the rock.

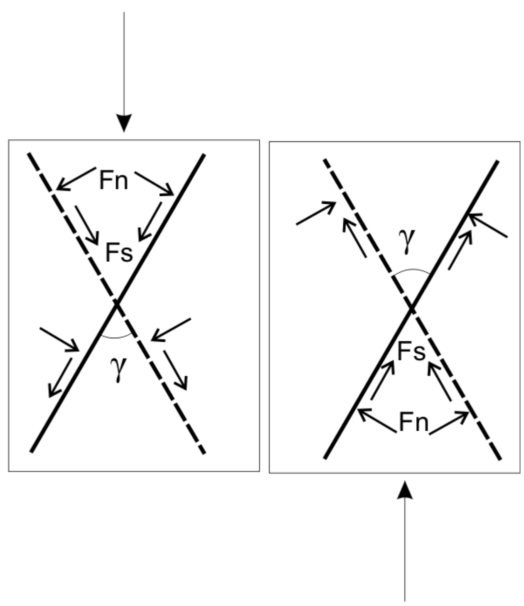
The picture on the left shows the unstrained rock, and the picture on the right, the same rock after being strained in a right hand strike-slip shear zone.

The circle has become an ellipse with a short axis at approximately 45° to the horizontal (indicated by the arrows). This short axis corresponds to the direction of the maximum stress. In text book explanations of Riedel fractures, you will often see this stress σ_1 as being marked at 45°. Although it is not exactly 45°, in practice the strain is so small that it is a good enough approximation.



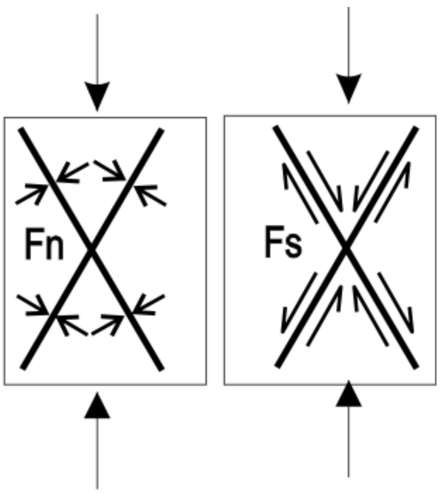
For those familiar with conjugate fractures, you can perhaps see immediately that the compressive stress σ_1 will generate shears at R and R', these being offset by about ±30° from the compressive stress axis. The shear R thus appears offset by (45–30)=15° to the horizontal, and R' appears offset by (45+30)=75° to the horizontal.

R are right-hand faults (<u>synthetic</u>, they have the same handedness as the master fault) and R' are left-hand faults (<u>antithetic</u>, they have the opposite handedness to the master fault)



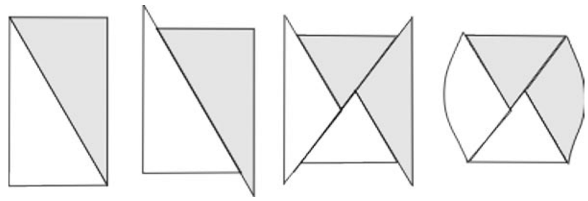
For those unsure of conjugate fracturing, here's a brief explanation. The diagrams above show compressive stress acting on a vertical axis. For clarity, the two equal and opposite forces are shown separately.

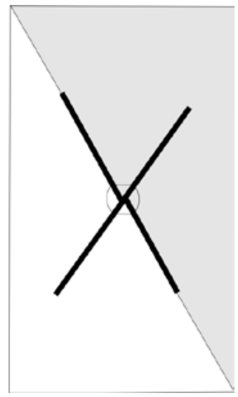
Looking just at the diagram on the left, think about the forces acting on arbitrarily chosen planes within the rock inclined equally to the vertical. The applied force on these planes has two components, one acting normal to the planes, Fn, and one acting parallel to the plane, Fs. The Fn component acts to compress the rock, while the Fs component acts to shear it.



The normal component Fn is at a maximum when the planes are horizontal, but the component Fs acting parallel to the planes is maximum when the planes are inclined by 45° and the angle γ is 90°.

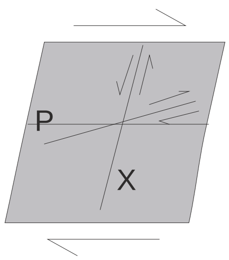
In practice, the shear planes are commonly inclined by 30° and the angle γ is 60°. This is because internal friction opposes the external shearing force. By reducing the angle, Fn is reduced, and this in turn reduces the internal friction. The combination of the external shearing force Fs and the internal friction opposing it is at a maximum when the planes are inclined ±30° to the vertical and γ is 60° rather than 90°.



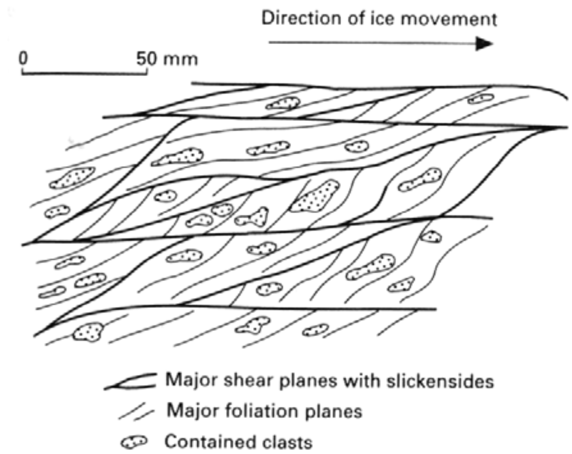


The geometry of conjugate fractures does not allow the shears to happen simultaneously. The rock first shears one way, then the other. This results in a small offset in the first shear, but usually this so small, it cannot be seen. Rock is almost incompressible, so even a sub-millimetre movement can be sufficient to relieve the stress.

Note the net effect of the shearing is to compress the rock in the direction of the maximum stress (the diagram on the right of the sequence of four is not so tall as that on the left). This reduces stress in this direction. It also expands the rock in the direction of the minimum stress (the diagram on the right of the sequence of four is fatter than that on the left). This increases stress in this direction. The stress is redistributed in conjugate fracturing so that the difference between the maximum stress and minimum stress is reduced.



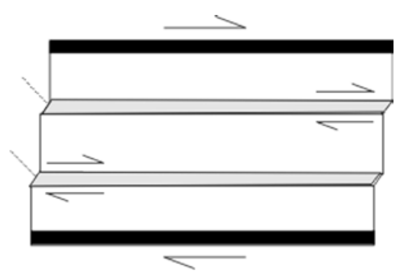
Some papers on Riedel fractures refer to secondary fractures that have different orientations to the R and R' shear set. One pair you sometimes see is labelled P and X. The synthetic P shears are more commonly observed than the antithetic X shears, and this asymmetry is probably a result of them being secondary shears formed only after stress has been re-distributed by movement along the primary R and R' shears. The geometry of P and X shears is as if they had been generated as conjugate fractures around the long axis of the strain ellipse. The symmetry is neat, but tensional stress couldn't create such conjugate fractures, so the proper explanation for them must be more complicated.



In a note on shearing in glacial till, I came across this diagram,[1] which is interesting as the shear planes are somewhat similar to the P and X shears. I don't know though that this related or just coincidence.

Here's another way that what look like P and X shears might develop, and this is something I have observed.

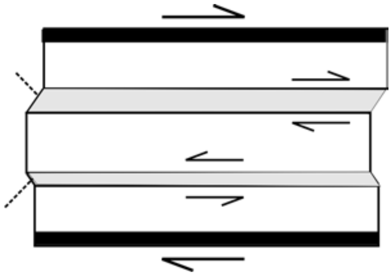
A single strike-slip fault might in fact be an amalgam of several parallel or subparallel faults running cIose togther. Like this:



No problem. They're all right-hand faults.

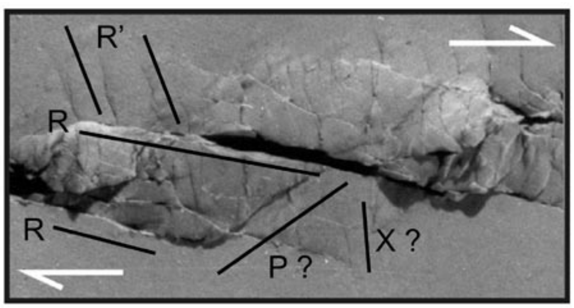
But what about this?

[1] J.M.G. Miller, *Glacial sediments*, in H.G. Reading (ed.), *Sedimentary Environments—Process, Facies and Stratigraphy*, p.461, 3rd Edition, Blackwell Science.



Still a right-hand fault overall, but with an internal left-hand slip. If R and R' fractures develop in the internal left-hand fault, they'll look from the perspective of the overall fault as P and X fractures. This might be what is happening if you see what appear to be P and X fractures, but with no R and R' fractures in sight (as was my case).

And that, for the moment, is as far as my expertise goes. ◊



Photograph of fractures in a clay model. Annotations indicating fracture orientations are mine. From the cover of: Nassima Atmaoui, *Development of pull-apart basins and associated structures by the Riedel shear mechanism: Insight from scaled clay analogue models*, Ph.D. thesis, Ruhr-Universität Bochum, 2005.