WEST VIRGINIA EARTHQUAKES: CRUSTAL ADJUSTMENTS ALONG THE ROME TROUGH OR SOMETHING ELSE?

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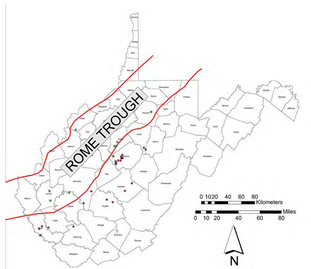
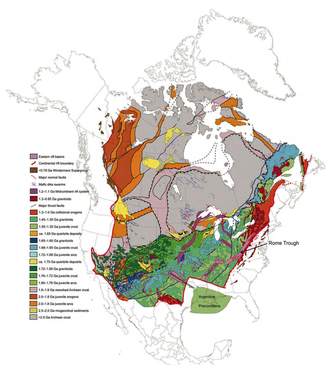
ABSTRACT

Since 1966, there have been 33 instrumentally recorded earthquakes recognized in western West Virginia within or adjacent to the structural feature known as the Rome Trough. This structure is a fault-bounded graben involving basement rocks thought to be related to failed rifting of the North American plate during the Precambrian. Eight earthquakes, with mean hypocentral depths of 10.5 km, were located within the boundaries of the Trough; the remaining 25 quakes, with mean depths of 5.8 km, were located to the east of the Trough. This latter group of quakes is bimodally distributed by depth with 11 earthquakes focused at depths of 4 km or less and 14 at depths greater than 4 km. Interestingly, 6 of 11 "shallow" earthquakes occurred in Braxton County, WV in a single year (2010). These seismic events are clustered geographically near a saltwater disposal well that injects at a depth of 1.7 km in close proximity to a recently discovered normal fault. We speculate that the "deeper" earthquakes are associated with isolated, recurrent fault movements in response to ancient crustal stress within and along the margins of the Rome Trough. The "shallow" earthquakes recorded in Braxton County may reflect slip related to injection activity on the newly discovered fault.



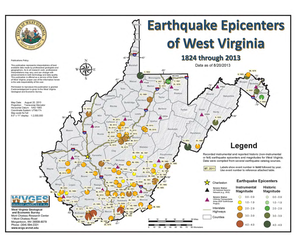
Since 1966, 33 instrumentally recorded earthquakes (stars) have occurred in western West Virginia, within or adjacent to the Rome Trough.



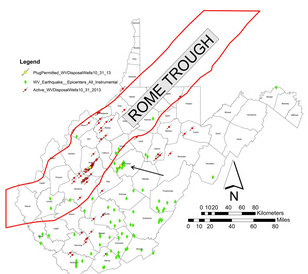
Episode of development and deformation of the Precambrian craton of North America, modified from Whitmeyer and Karlstrom, 2007, Figure 20. The Rome Trough is thought to be a failed attempt to "rift" or break apart the craton that occurred 720-680 million years ago (Whitmeyer and Karlstrom, 2007).

To the right is a short segment of a cross-section (Ryder and others, 2008) that cuts across the Rome Trough in west-central West Virginia. A number of earthquakes in the vicinity of the line of section have been projected onto the cross-section and their hypocenters plotted at the correct projected depths with vertical error.

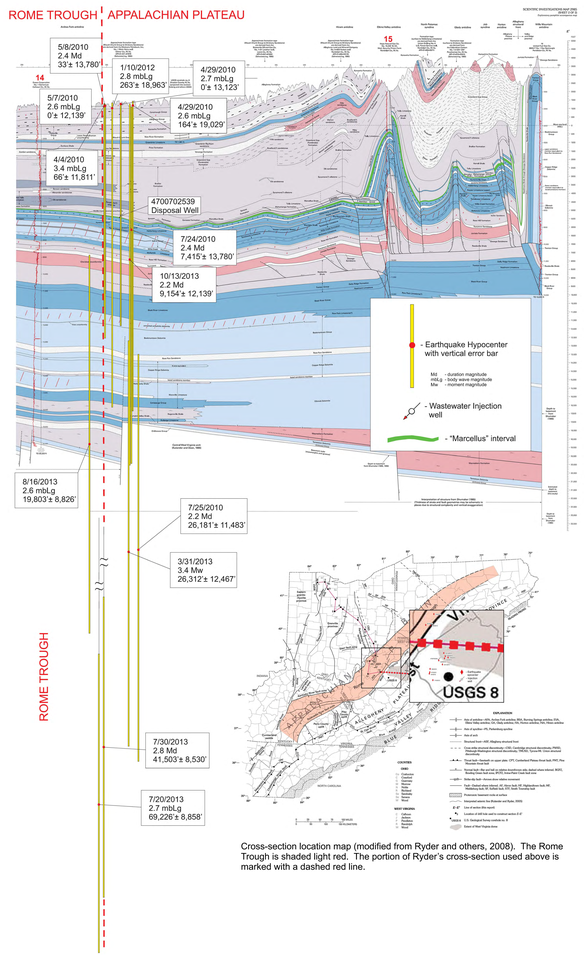
Quakes within the Rome Trough have a mean hypocentral depth of 10.5 km suggesting they are related to movements along the boundary faults of the Trough. Outside the Trough, but adjacent to the margin, two distinct groups of earthquakes have been recorded. The first group occurred at depths of 4 km or greater. These "deep" quakes are probably similar in origin to those within the Trough. The second group of earthquakes outside the Rome Trough occurred at hypocentral depths less than or equal to 4 km. Six of these "shallow" quakes were clustered in Braxton County, West Virginia and occurred in a single year, 2010.



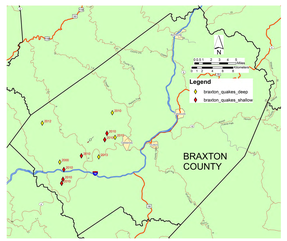
Epicenters of historical and instrumental earthquakes in West Virginia from 1824 through 2013.



Locations of all Instrumental Earthquakes in West Virginia (magnitude 2.0 and greater) plotted against the locations of all currently active disposal wells (as of 10/31/2013). NOTE: the only apparent geographic correspondence is in Braxton County (arrow).

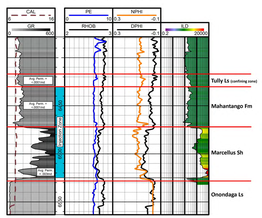


Cross-section location map (modified from Ryder and others, 2008). The Rome Trough is shaded light red. The portion of Ryder's cross-section used above is marked with a dashed red line.



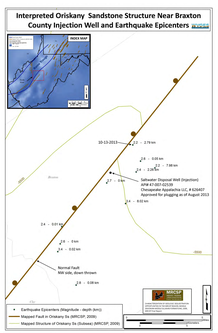
Eleven earthquakes have occurred in Braxton County, WV since 2000. Of these, 6 quakes with projected hypocenters less than 4 km deep occurred in a single year - 2010. Braxton County has a single saltwater disposal well that went online in 2009.

API #: 47-007-02539

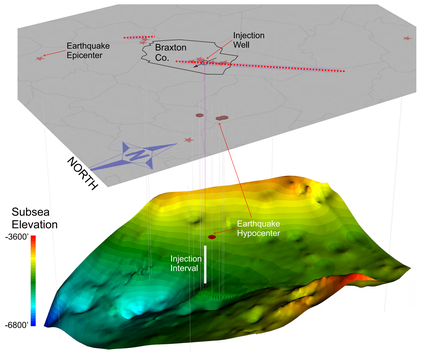


Virgin reservoir pressure in target formation: 1200 psig
Estimated reservoir fracture pressure: 7058 psig
Maximum proposed injection volume: 300 Bbl/hr (7200 Bbl/day)
Bottom hole pressure: 5437 psig

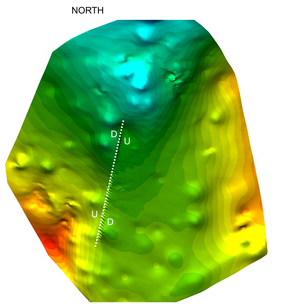
Detailed geophysical log and engineering details for the Braxton County disposal well API# 4700702539.



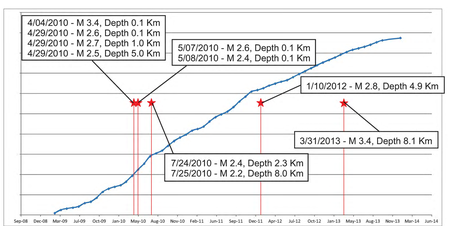
Work by the Midwest Regional Carbon Sequestration Partnership (MRCSP, 2009) suggested the presence of a fault in the vicinity of the Braxton County disposal well based on the subsurface structure of the Devonian Oriskany Sandstone.



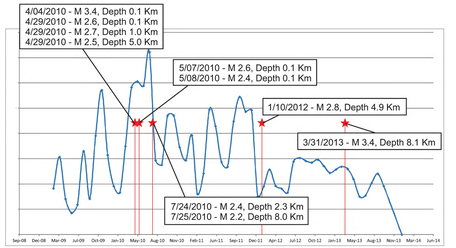
3-D modeling of the Oriskany structure in the Braxton County area indicates that the suspected fault is down-thrown to the west in the vicinity of the disposal well. Epicenters and hypocenters for earthquakes in and around Braxton County are shown as is the targeted injection interval for disposal well API# 4700705239. Vertical exaggeration is 75:1.



Another view of the 3-D model of the Oriskany subsea structure suggests that the suspected fault in the Braxton County area is actually a wrench fault with west side down at its north end and east side down at the south end of the fault.



Graph of cumulative injection volume vs time for well API# 4700702539. Also plotted are all Braxton County earthquakes that occurred after the well went on line in 2009. Cursory examination of this graph does not immediately indicate a connection to larger injection volumes. A time lag correspondence might be revealed by statistical analysis but if such a connection exists it must be for an extremely irregular time interval.



Graph of incremental injected volume vs time for well API# 4700702539. Also plotted are all Braxton County earthquakes that occurred after the well went on line in 2009. Cursory examination of this graph does not immediately indicate a connection to larger injection volumes. A time lag correspondence might be revealed by statistical analysis but if such a connection exists it must be for an extremely irregular time interval.

DISCUSSION

Earthquake activity in western West Virginia is most easily attributed to recurrent "adjustments" of the faults bounding the Rome Trough. While this may be the case for quakes with hypocenters deeper than 3 - 4 km, shallower earthquakes are not so easily explained. Of recent interest are a series of earthquakes in Braxton County, WV that began in 2010 and whose epicenters are clustered geographically around the county's single waste-water disposal well.

Further complicating the situation is a previously unsuspected fault, discovered during detailed mapping of the subsurface structure of the Oriskany Sandstone. This fault appears to underlie Braxton County and intersects the target injection interval of the disposal well. This raises the possibility of seismicity induced as a result of injection activity.

Available injection data, when compared to the timing of earthquake events in the county, do not immediately suggest a direct link between injection volume/time nor a more subtle link involving a recognizable time lag. Detailed statistical analysis of these data might confirm such a link but the near-cessation of earthquake activity in the area, the difficulty in pinpointing the "true" vertical depth of earthquake hypocenters, and the quality of available data makes this confirmation difficult, if not impossible.

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