[PS]Subsurface Geomechanics, Fracture Breakdown Pressures, and ‘Fracture-tunnels’ in the Midwest United States*

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Abstract

A great deal of new geotechnical information is available from shale gas wells, carbon dioxide storage research, and brine disposal wells. These data provide a better understanding of subsurface geomechanical conditions, which is an important factor for subsurface resource management. To characterize geomechanical conditions in the Midwest Region, a combination of geophysical image logs, fracture breakdown pressures, and horizontal shale gas well paths were compiled for analysis. Fourteen geophysical image logs were analyzed for breakouts, induced tensile fractures, and natural fractures. These data were processed to determine stress orientation and fracture density. Maximum horizontal stress axis was in an east-northeast to west-southwest orientation, consistent with regional stress records. The western part of the study area appears to be more fractured than the eastern part, and fractures tend to strike sub-parallel to the axis of SHmax. Over twenty thousand records from well treatment fracture breakdown pressures were compiled for evaluation. Maximum fracture breakdown pressures and instantaneous shut-in pressures were evaluated for different formations to constrain stress magnitudes. While data show a large amount of variation, instantaneous shut-in pressures averaged 0.85 psi/ft gradient. Data from shale gas wells had higher fracture shut-in pressure gradients due to hoop stress effects and other factors. Finally, well paths for 12,793 horizontal Devonian Marcellus Shale and Ordovician Utica-Point Pleasant formation wells were plotted, based on top- and bottom-hole locations. The horizontal wells provide an empirical indication of the regional stress directions, because the wells are drilled along the minimum stress orientation. Geospatially visualizing stimulated reservoir volumes suggests that horizontal wells with many fracture stages have resulted in swathes of ‘fracture tunnels’ along the horizontal well paths in certain areas. These zones should be noted for other subsurface applications where the fractured zones may be considered caprocks. Data were integrated to provide representation of geomechanical conditions in the Midwest U.S. Together, this information may be used to support carbon dioxide storage projects, brine disposal, and hydrocarbon production in the region.

Subsurface Geomechanics, Fracture Breakdown Pressures, and ‘Fracture-tunnels’ in the Midwest U.S.

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ABSTRACT

A great deal of new geotechnical information is available from shale gas wells, carbon dioxide storage research, and brine disposal wells. These data provide a better understanding of subsurface geomechanical conditions, which is an important factor for subsurface resource management. To characterize geomechanical conditions in the Midwest Region, a combination of geophysical image logs, well treatment fracture breakdown pressures, and horizontal shale gas well trajectories were compiled for analysis. Data were integrated to provide representation of geomechanical conditions in the Midwest U.S. Together, this information may be used to support carbon dioxide storage projects, brine disposal operations, and hydrocarbon production in the region.

OBJECTIVES

- Overall objectives include:
  - Characterizing the paleo-stress/strain setting in the Midwest U.S.
  - Defining geomechanical parameters for deep formations
  - Evaluating the potential for (and effects of) subsurface deformation
  - Assessing CO_2 storage processes based on rock core tests and geophysical logging in the regions being considered for large-scale CO_2 storage

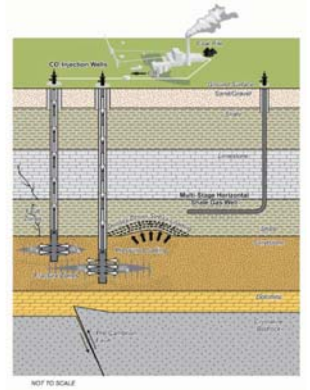
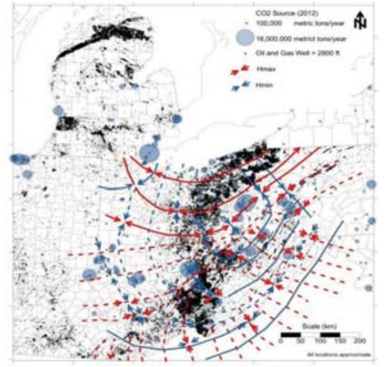


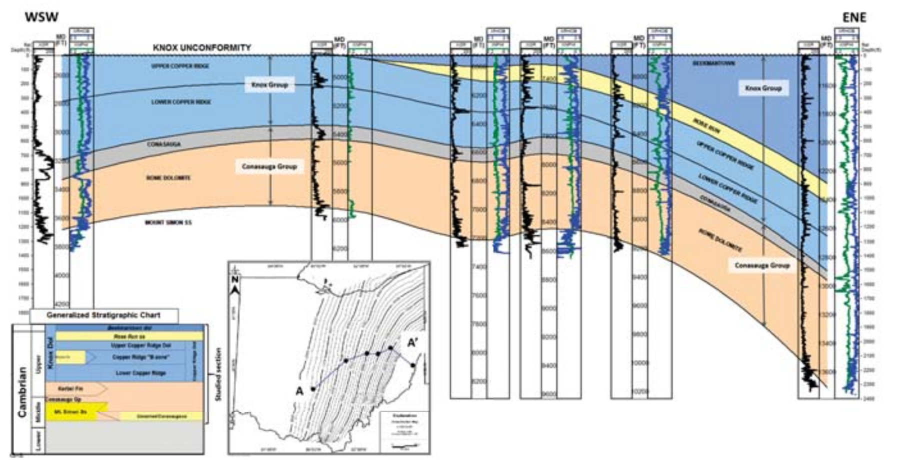
Diagram Illustrating Subsurface Geomechanical Processes



Conceptual Geomechanical Stress-Strain Setting in Midwest U.S. In Relation to Large CO_2 Sources and Oil & Gas Wells

- This work was designed to perform realistic analysis of geomechanical performance factors related to CO_2 storage:
  - Which reservoir rock formations are more fractured in the region?
  - Which caprocks have larger risk factors related to fracturing?
  - What are the key methods and tools for evaluating fractured zones in deep layers?
  - How can we better understand basin-scale stress-strain regime to more accurately define stress magnitude at depth?

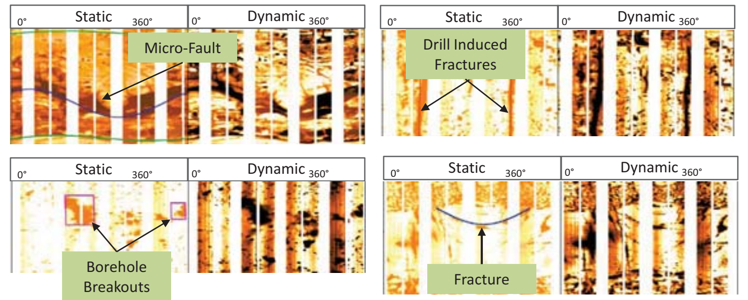
STUDY AREA



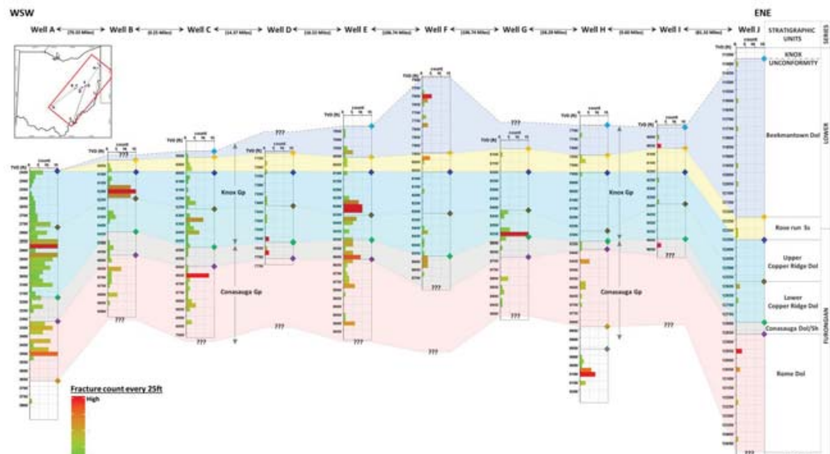
WSW to ENE (A-A') Cross Section of the Study Area Showing Change in Sediment Thickness in an Eastward Direction (Note: Knox Unconformity surface was used as datum)

FRACTURE INTERPRETATION AND ANALYSIS

- 10 resistivity/acoustic image logs were collected within the Cambrian-Ordovician interval, and interpreted to identify natural fractures and well-bore failures
- **An additional 9,700 ft. of image log data from three wells were processed and interpreted to supplement regional data**



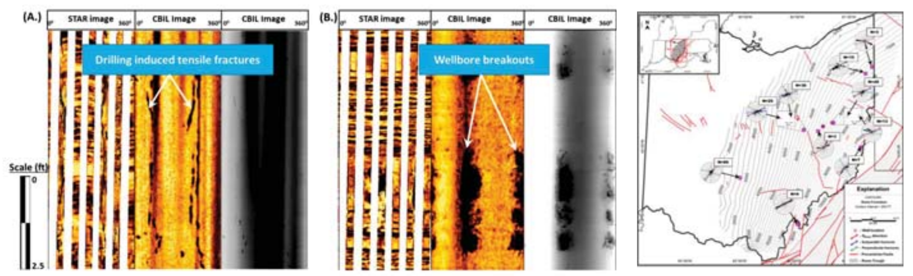
- Histograms of observed fractures were produced for each well and used to generate a cross section in order to analyze fracture intensity variation from west to east of the study area



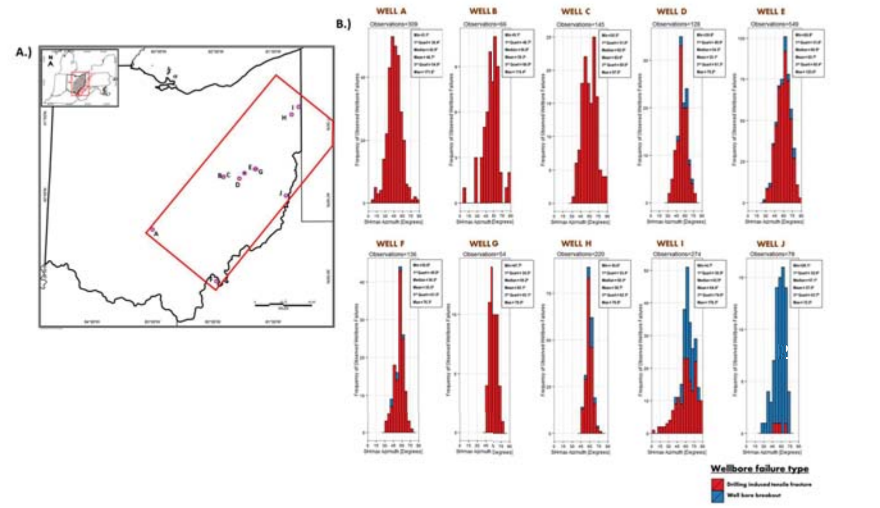
Cross Section Showing Fracture Distribution/Intensity on a Well-by-Well Basis (Note: Fractures were counted at every 25-ft interval & Upper Copper Ridge surface was datum but shifted downward in Well J)

DETERMINATION OF AZIMUTH FOR MAXIMUM HORIZONTAL STRESS

- Subsurface stress field orientation and magnitude is important in evaluating fracture stability and other geomechanical related aspects associated with injection of CO_2 into fractured reservoir

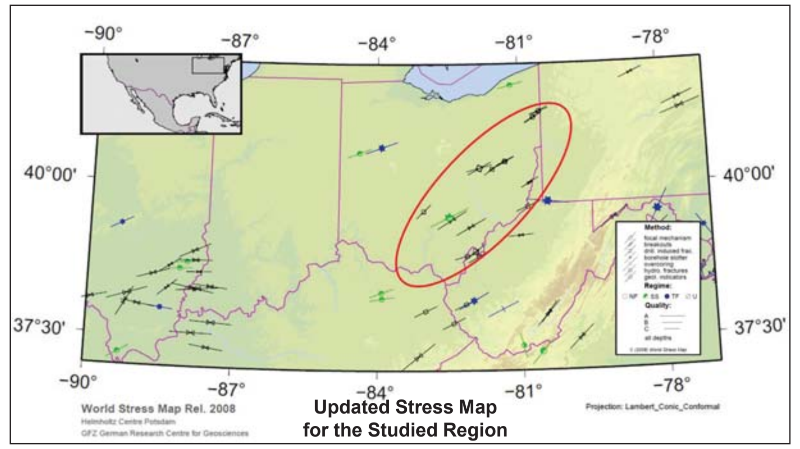


- Subsurface stress field orientation was determined from breakouts, drilling induced fractures, and natural fractures observed in image logs



UPDATING STRESS MAP IN THE REGION

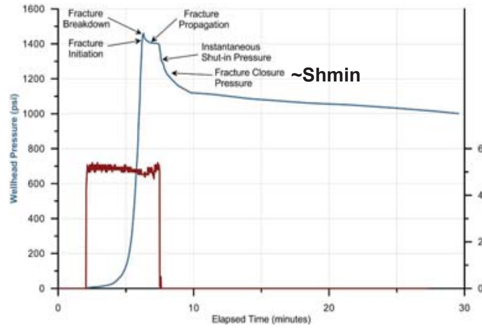
- Results on analysis of well-bore failure observations from each well were used in updating stress map of the region
- The research determined that the axis of the maximum horizontal stress is approximately in an east-northeast to west-southwest orientation (between 46 degrees and 71 degrees), consistent with regional stress records in the area



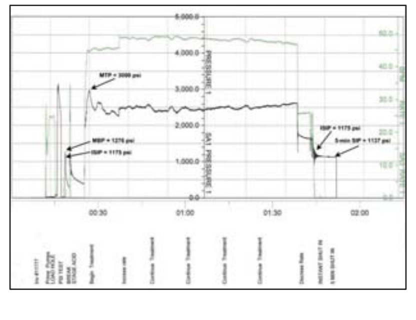
Updated Stress Map for the Studied Region

FRACTURE BREAKDOWN – PRESSURE ANALYSIS

- Pressures observed during well treatment (fracture breakdown pressure, shut-in pressure, and fracture closure pressure) can help constrain the *in situ* stress magnitude



Conceptual Fracture Breakdown Pattern



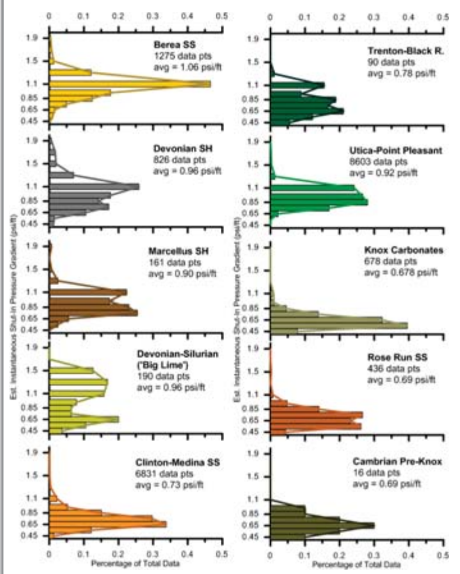
Vertical Well Treatment Field Data

- Over 20,000 records from well treatment fracture breakdown pressures were also compiled for evaluation
- Maximum fracture breakdown pressures and instantaneous shut-in pressures were evaluated based on reported wellhead pressures for different formations to constrain horizontal stress magnitudes

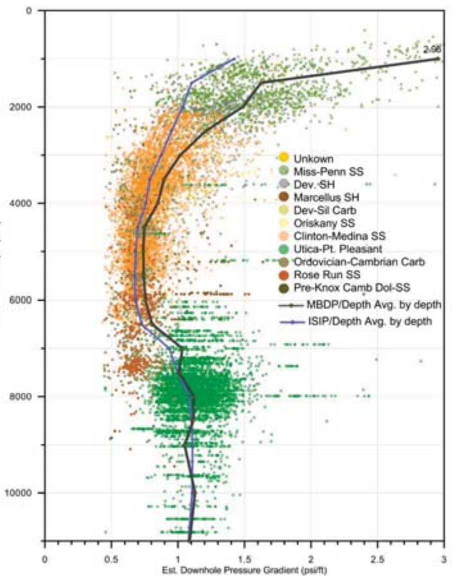
Pressure Gradient Parameter	Estimation Calculation
Best Depth (ft)	Best available depth = perf midpoint, true vertical depth, driller's total depth, logger's total depth (TVD used for horizontal wells)
Breakdown Pressure Gradient (psi/ft)	(breakdown pressure + (0.4333 psi/ft • best depth)) / best depth
Instantaneous Shut-in Pressure Gradient (psi/ft)	(ISIP + (0.4333 psi/ft • best depth)) / best depth
5-minute shut-in pressure Gradient (psi/ft)	(5-min SIP + (0.4333 psi/ft • best depth)) / best depth
Bottom-hole Pressure Gradient (psi/ft)	(BHP + (0.4333 psi/ft • best depth))/ best depth

- Data were fairly variable
- Shale gas wells had significantly higher fracture shut-in pressure gradients due to hoop stress effects and other factors associated with large, multiple stage fracture treatments

Inst. Shut-in Pressure Gradient (psi/ft)

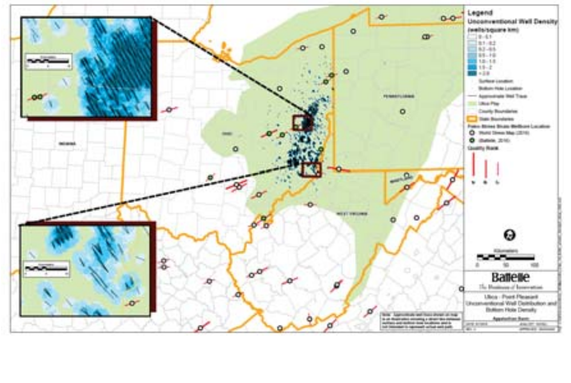


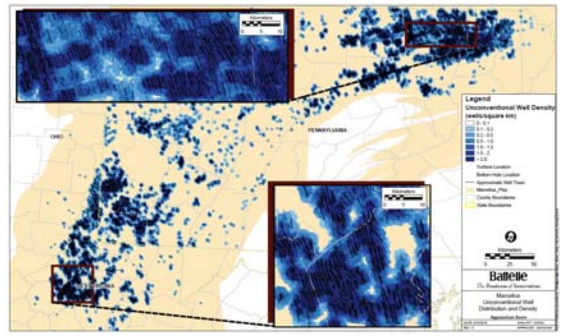
Breakdown, Inst. Shut-in Pressure versus Depth (psi/ft)



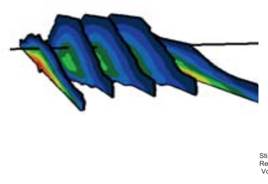
FRACTURE IMPACT OF HORIZONTAL SHALE GAS WELLS

- Well paths for 12,793 horizontal Devonian Marcellus Shale and Ordovician Utica Point Pleasant formation wells were plotted based on top hole and bottom hole locations
- The horizontal wells provide an empirical indication of the regional stress directions, because the wells are drilled along the minimum stress orientation
- The overall stimulated reservoir volume was estimated based on other research on well stimulation extents
- 3D geospatially visualizing these data suggest that horizontal wells with many fracture stages have resulted in swathes of ‘fracture tunnels’ along the horizontal well paths in certain areas
- These zones should be noted for other subsurface applications, but they appear to have little impact on primary caprock units

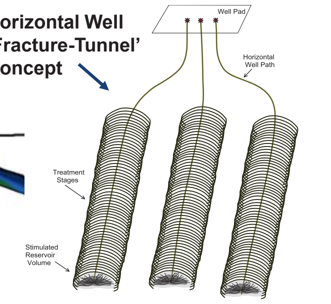




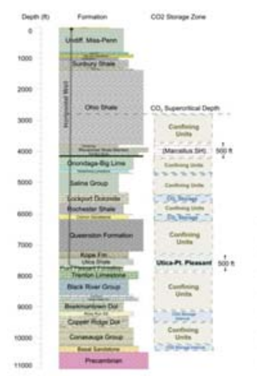
Horizontal Well Treatment Stages SRV



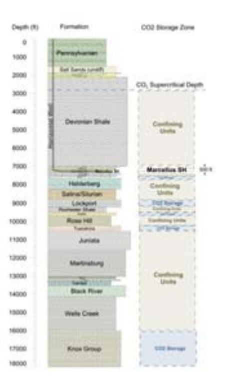
Horizontal Well ‘Fracture-Tunnel’ Concept



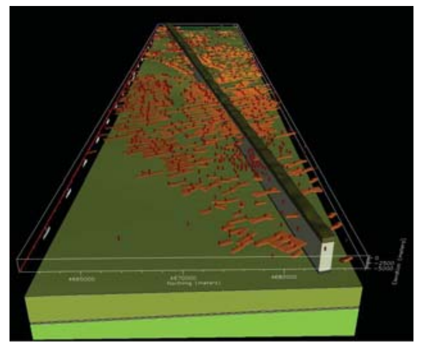
Typical Pt. Pleasant-Utica Well



Typical Marcellus Well



Swath of Marcellus Wells in Subsurface



CONCLUSIONS

- Geomechanical data were integrated to provide representation of geomechanical conditions in the Midwest U.S.
- Together, this information may be used to support carbon dioxide storage projects, brine disposal operations, and hydrocarbon production in the region

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