Multiphase Deformation of the Paleozoic and Mesozoic Units Within the Panhandle of Nebraska*

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Search and Discovery Article #30365 (2014)**
Posted October 6, 2014

*Adapted from oral presentation given at AAPG Rocky Mountain Section Meeting, Denver, CO, July 20-22, 2014

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Abstract

Renewed interest in the hydrocarbon systems of the Nebraska Panhandle stems from the increasing economic viability of unconventional plays, which must be understood in terms of regional geologic structure. We present preliminary interpretations of a seismic dataset from the northeastern margin of the Denver-Julesburg (D-J) basin. The study area is in the Alliance sub-basin, partially separated from the main D-J basin by the Morrill County High. Other local highs create similar, partially isolated basins. The regional stratigraphic succession includes two targets for exploration: (1) Pennsylvanian-Permian carbonate-dominated cyclothems and clastic sediments, and (2) the Cretaceous succession. Hydrocarbon plays have traditionally targeted the latter, but interest in the Paleozoic succession is increasing. The present study analyses a series of 2D seismic lines, dominantly oriented NE-SW, with sufficient crossing lines to build a 3D representation of the survey area. Formation tops were picked from key wells and associated velocity profiles, and then mapped across the remaining lines. The basal Cenozoic unconformity, as well as Mesozoic and late Paleozoic strata, are clearly imaged on these lines. Pre-Cenozoic units dip to the SW, consistent with the position on the margins of the D-J basin. The late Paleozoic section is subtly folded with both normal and reverse offset faults visible in the overlying Cretaceous section. Subtle folds within the late Paleozoic section may be zones of enhanced porosity due to fold-related fracturing, making them suitable as targets for unconventional exploration. In addition, folded and fractured zones may have been further deformed in subsequent tectonic events.

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Marshak, S., K. Karlstrom, and J.M. Timmons, 2000, Inversion of Proterozoic extensional faults: An explanation for the pattern of Laramide and Ancestral Rockies intracratonic deformation, United States: Geology, v. 28, p. 735-738.

Sims, P.K., R.W. Saltus, and E.D. Anderson, 2008, Precambrian basement structure map of the continental United States –an interpretation of geologic and aeromagnetic data: USGS Scientific Investigations Map 3012.

Sonnenberg, S.A., and R.J. Wiemer, 1981, Tectonics, sedimentation, and petroleum potential, northern Denver basin, Colorado, Wyoming, and Nebraska: Colorado School of Mines Quarterly, v. 76/2, 45 p.

Websites

Blakey, R., Paleogeographic map sourced from http://cpgeosystems.com/paleomaps.html.

NOGCC data files sourced from http://www.nogcc.ne.gov/NOGCCPublications.aspx.

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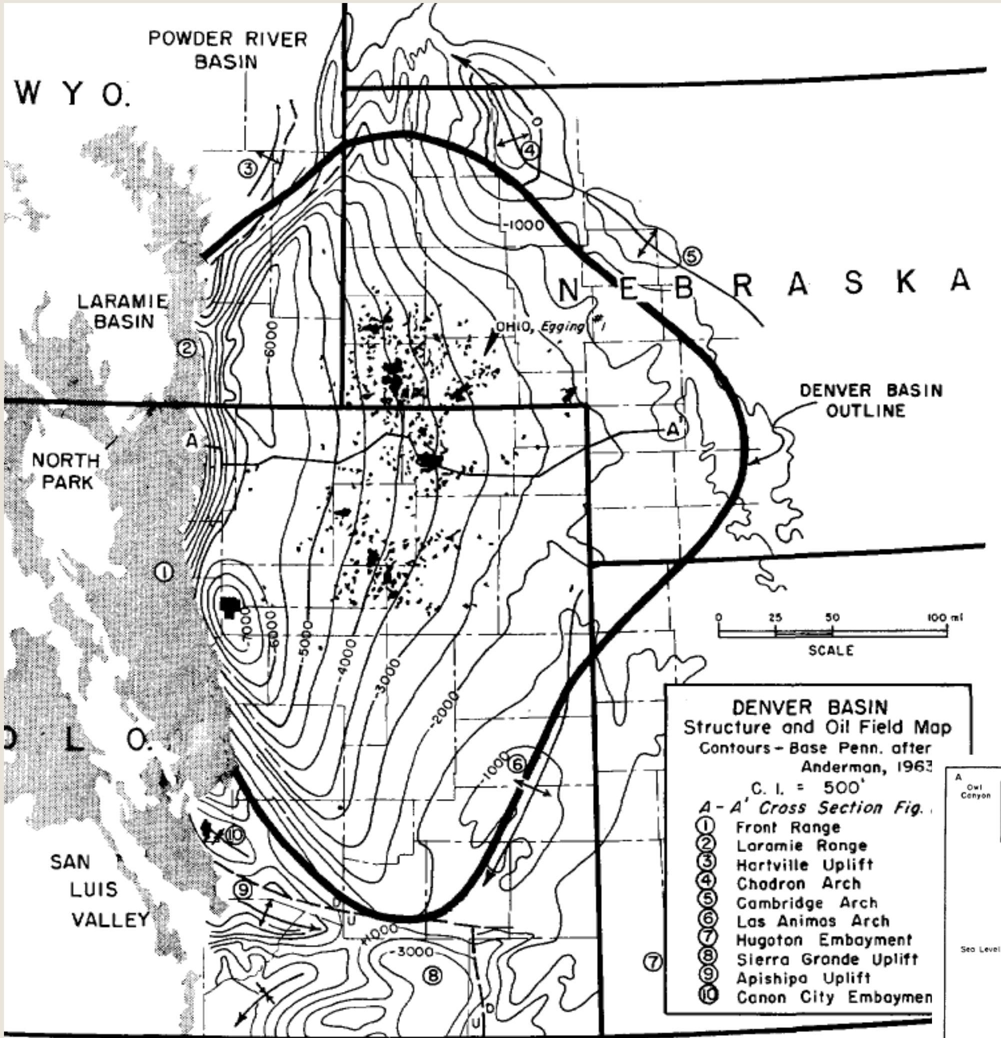
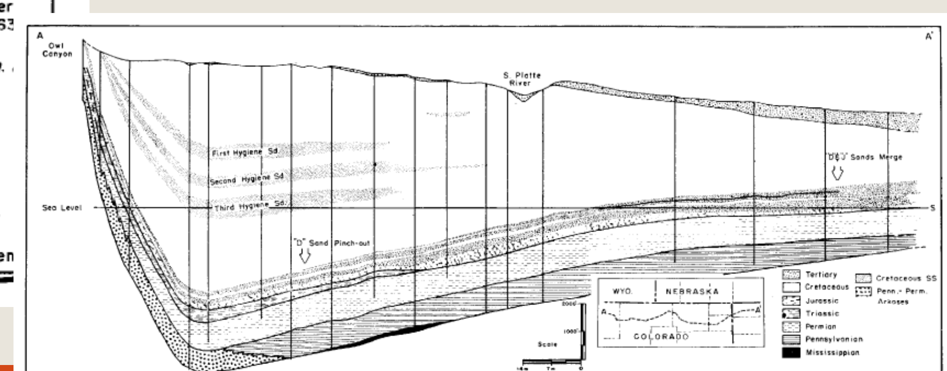
UNIVERSITY OF NEBRASKA-LINCOLN

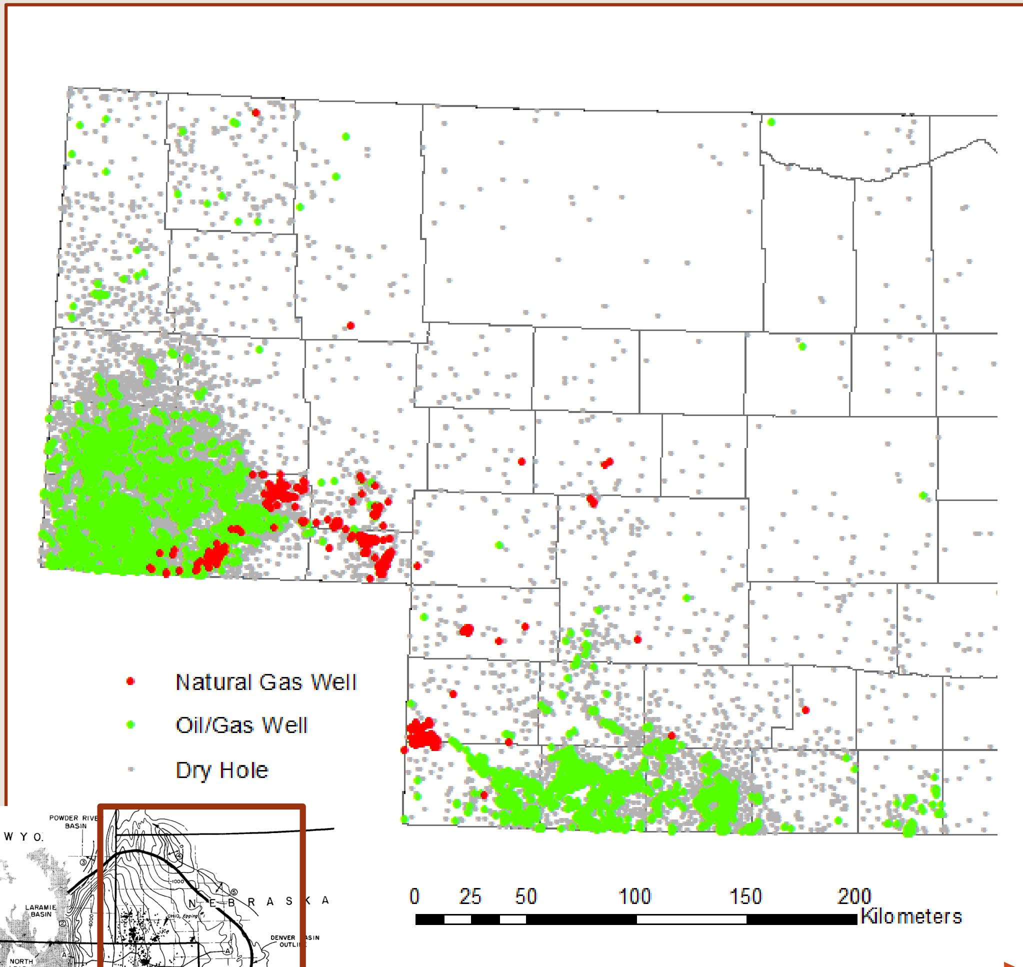
Setting the scene – the Denver-Julesburg Basin

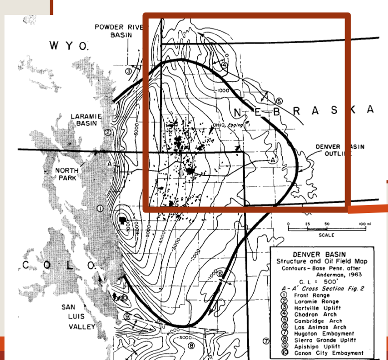


- W Nebraska (site of study area) forms the northern limit to the asymmetric D-J basin.
- images from Martin, 1965. Contours on the map are on the base Penn units/aka "top basement"



Setting the scene – H/C in the NE Panhandle





- W Nebraska (site of study area) forms the northern limit to the asymmetric D-J basin.
- This study focuses on an area within the NE “Panhandle”
- Hydrocarbon accumulations clustered in two parts of the northern D-J in Nebraska, dominantly oil/gas, but some prominent gas-only trends

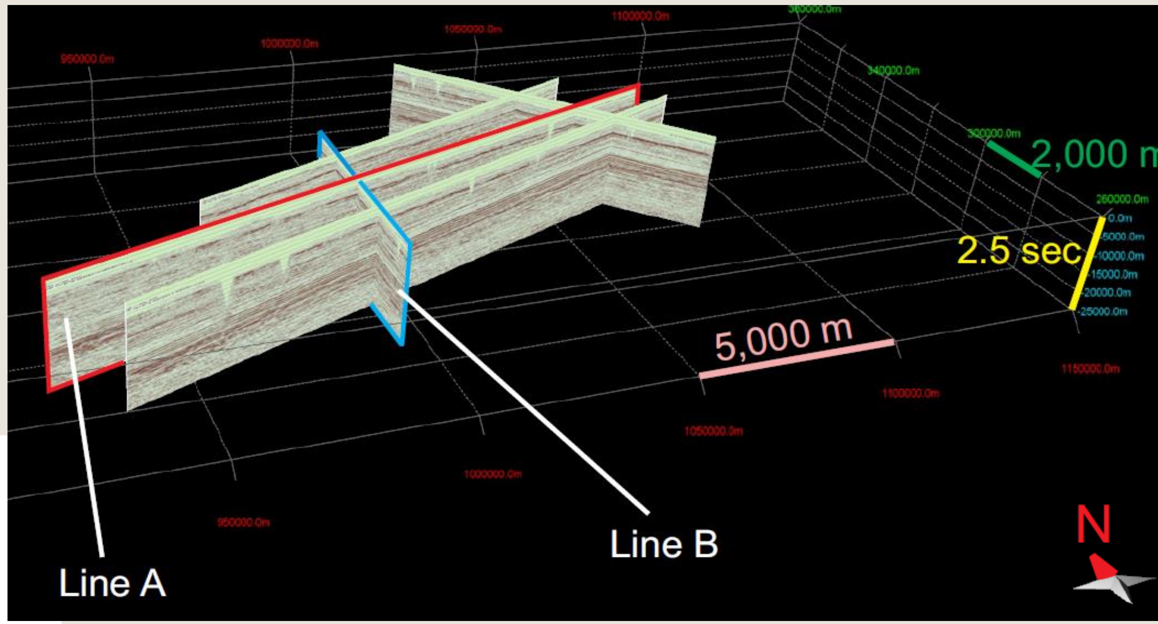
Image created from NOGCC datafiles

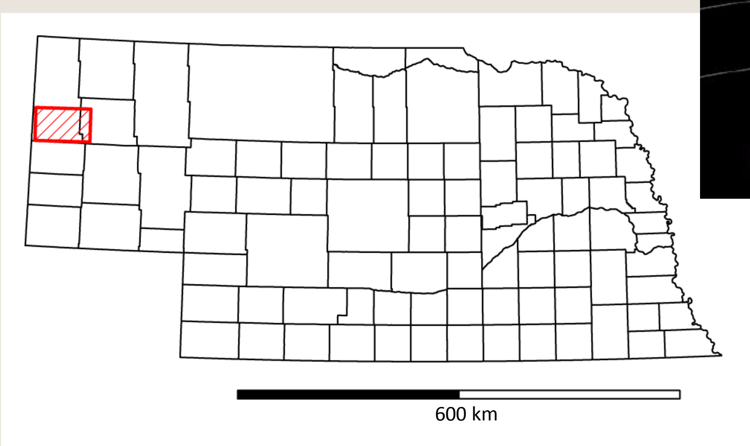
Setting the scene – H/C in the NE Panhandle

- Exploration in the Nebraska Panhandle has previously targeted the Cretaceous (Albian-Cenomanian) "D" and "J" sandstones, with regional interest in the overlying, fractured, chalky limestones of the Niobrara Formation (Coniacian-Santonian).
- Much deeper unconventional systems in Paleozoic strata, namely fractured carbonates and shales, are now being targeted.
- Several relevant questions need to be answered in order to encourage and direct ongoing exploration:
  - How can subtle structural traps be detected?
  - How can drilling needs be assessed?
  - What is the stratigraphic and sedimentological context of traps?
  - What is the timing of trap development relative to petroleum charge?
- We present preliminary results from an analysis of reprocessed seismic data, which illuminates some aspects of the <u>development and timing of traps</u> and the <u>multiphase deformation of strata</u> in the study area.

Dataset used in this study: Sioux county

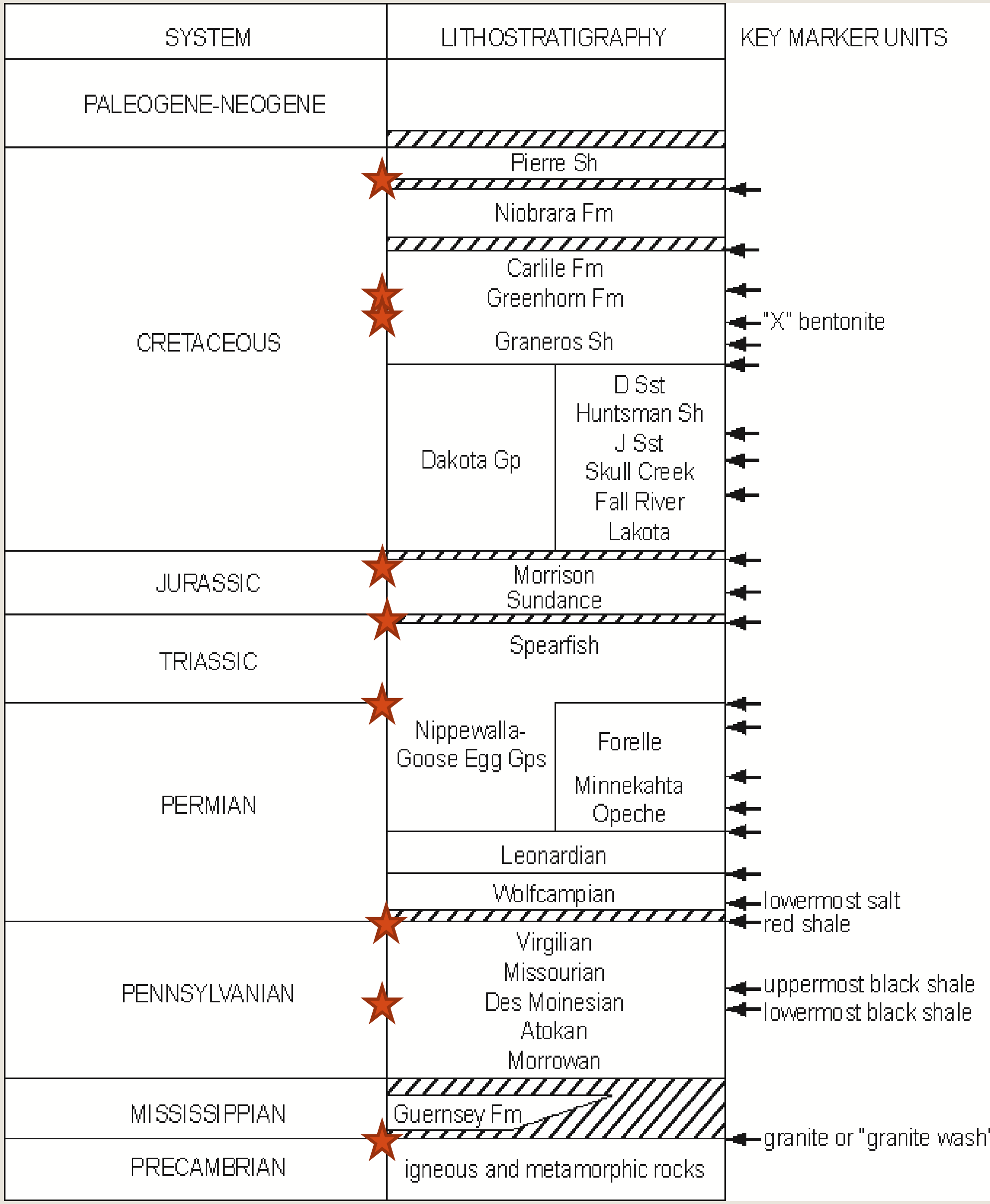
- Seismic dataset obtained from southern Sioux county, NE
- Lies on the northern limit of the D-J basin; some hydrocarbon production in the area





- Select seismic lines shown above
- Key lines A & B will be shown in this presentation

Sedimentology & well control

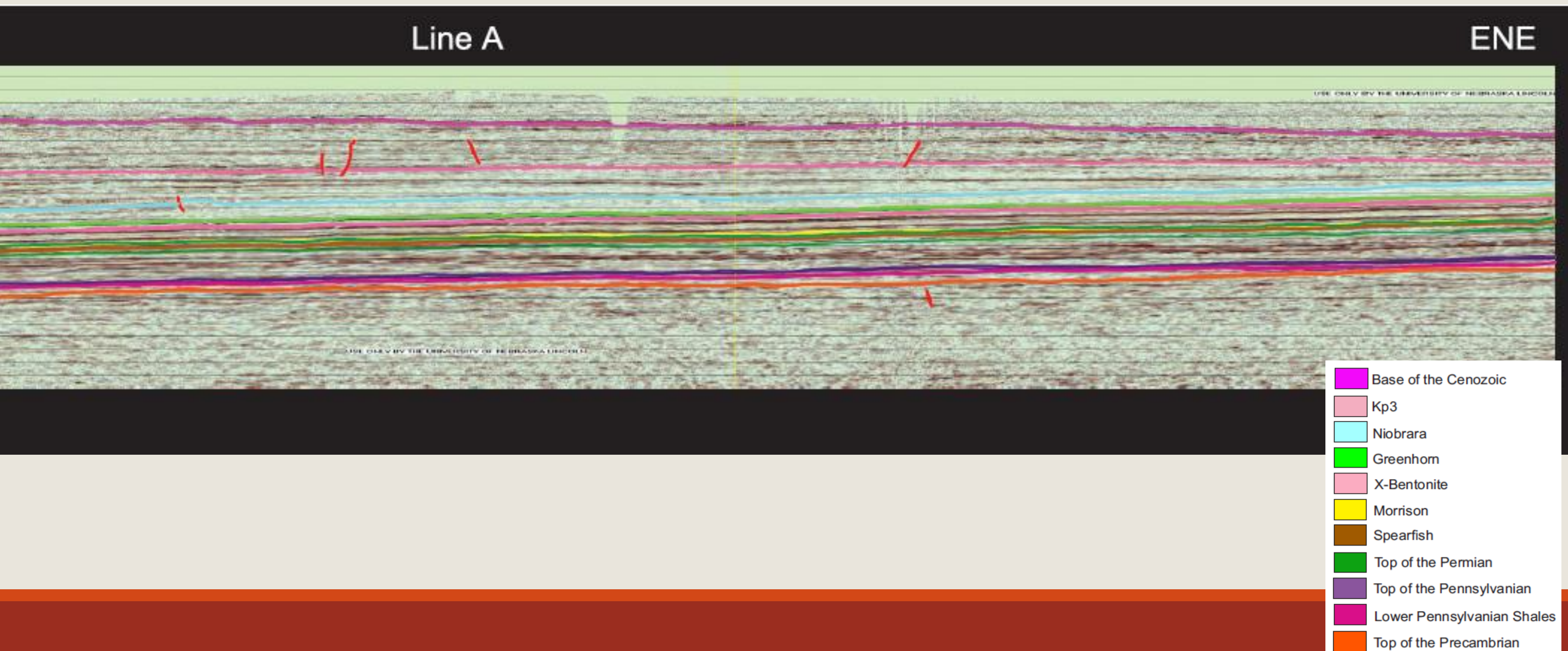


- Well control from 14 wells located close to seismic lines
- All wells penetrated to at least the Pennsylvanian, four wells penetrate to the Precambrian
- Units were correlated using clearly identifiable geophysical log signatures or lithologies described from cuttings
- Correlations were propagated through the study area in multiple iterations
- Key marker layers starred

Modified from Sonnenberg and Weimer, 1981

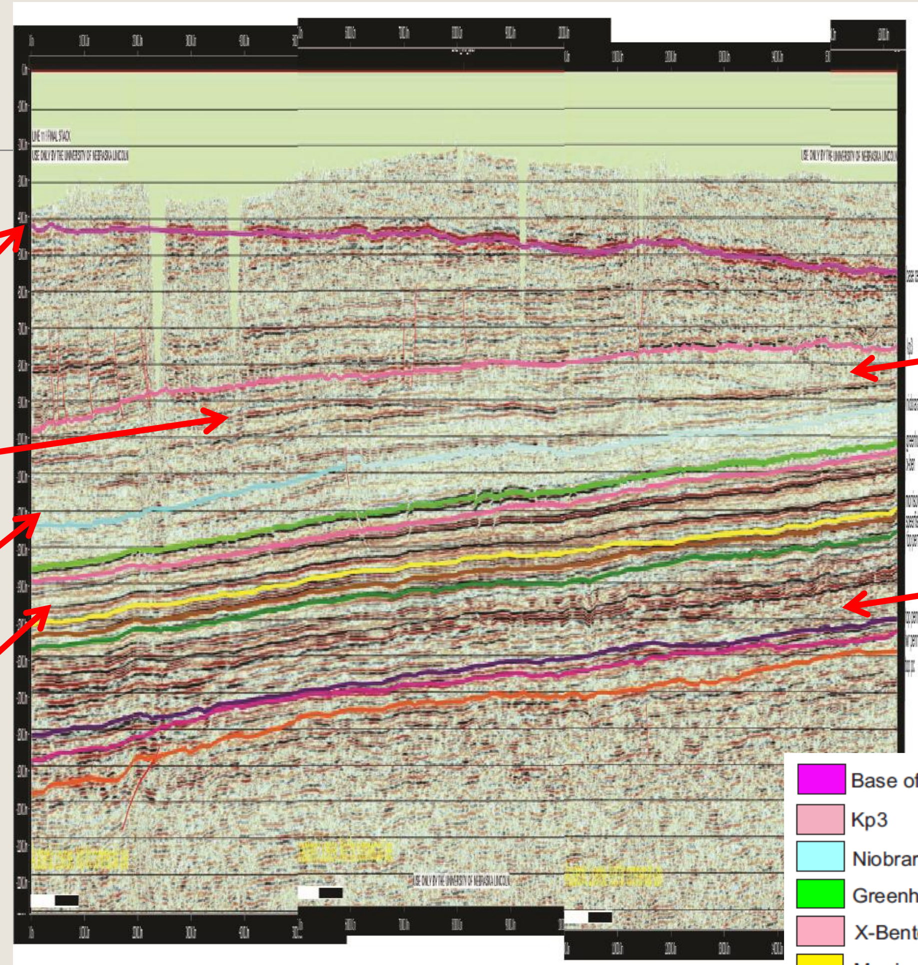
First-pass inspection: Key Line A

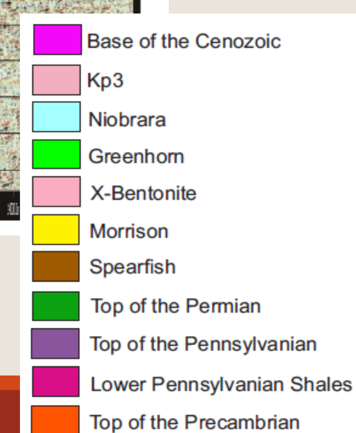
- Several prominent reflectors, identifiable from well-control
- Line orientation parallels expected maximum horizontal stress direction



Line A: more detail

- Reveals complex subunit relationships within the Pierre Shale
- Reveals changes in thickness between units (e.g. Lwr K thins W; Upr K thickens W)
- Reveals subtle angular unconformities

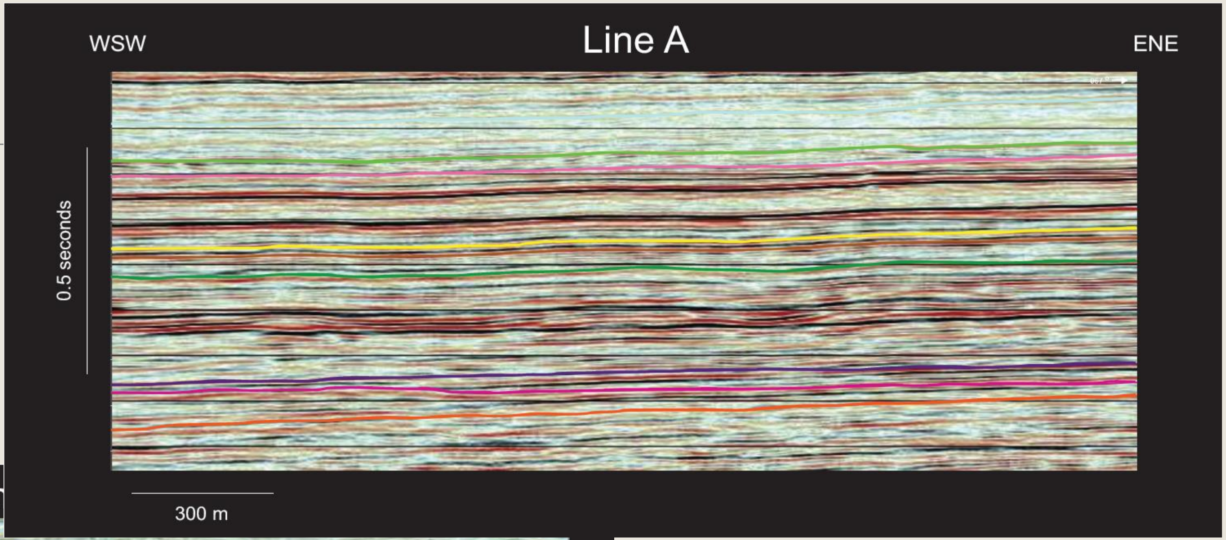


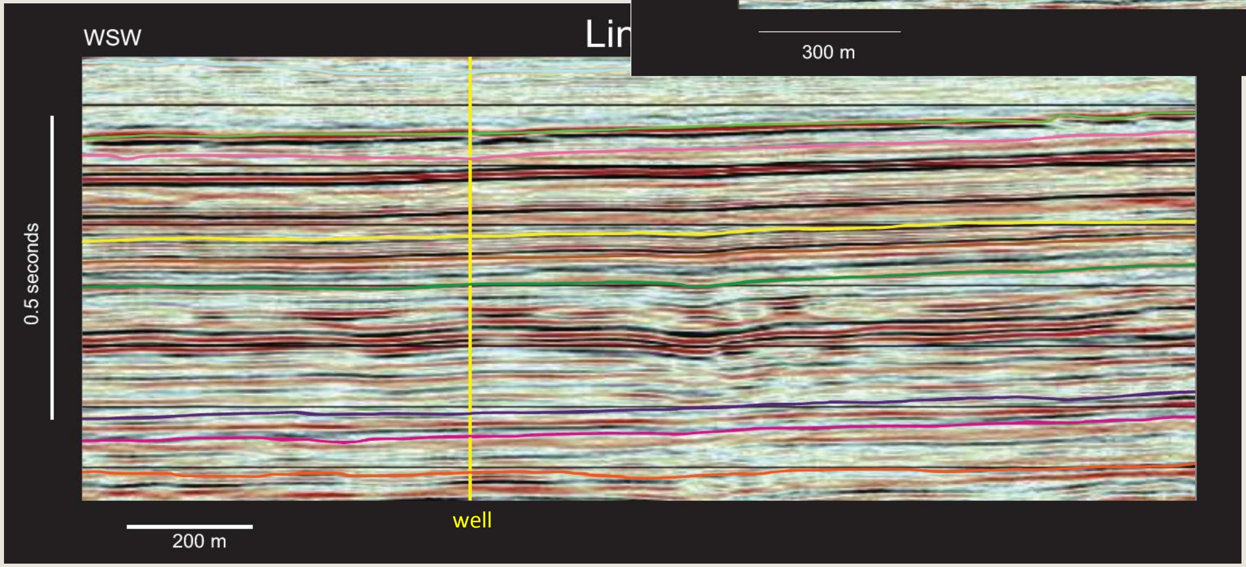


Line is vertically exaggerated

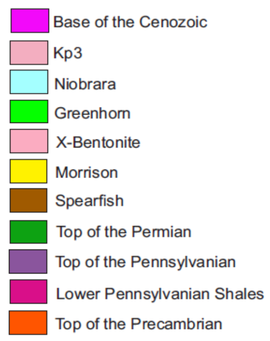
Line A: more detail

- Topography on Precambrian (orange) units – potentially deformation related?



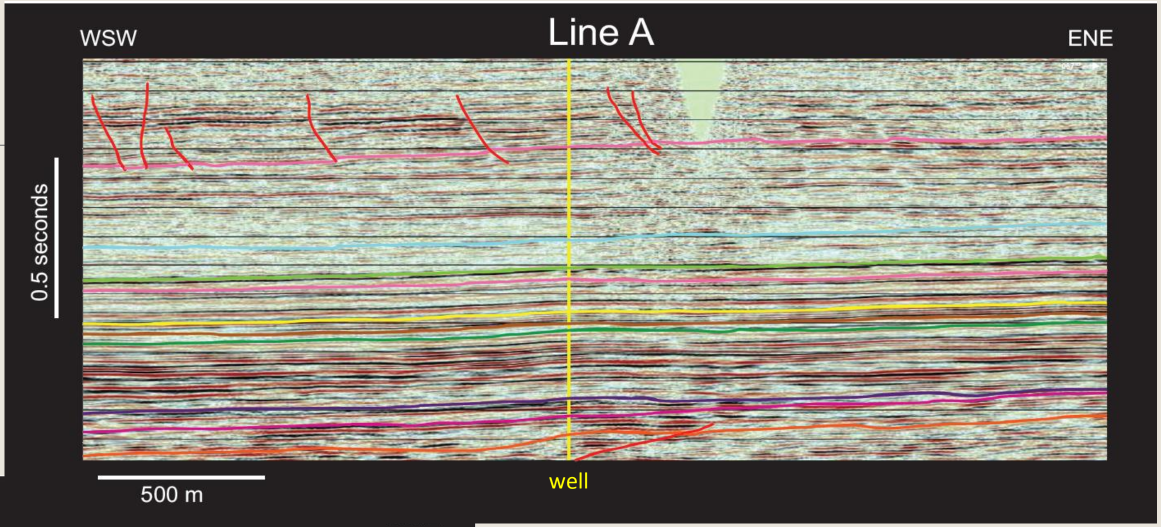


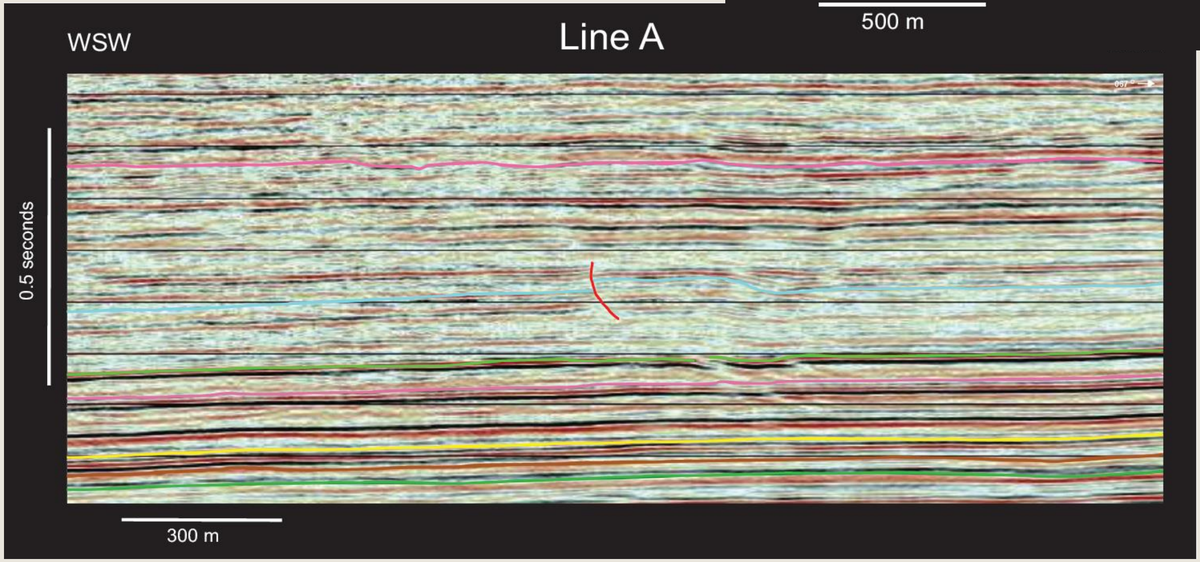
- Intra-Permian salt deformation as noted
- Series of Pennsylvanian subtle angular unconformities



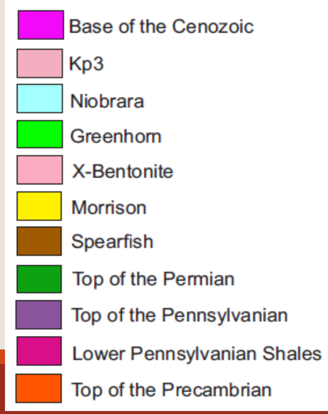
Line A: more detail

- Complex, reactivated/inverted faulting in the post-Kp3 marker time-frame, with spatial correlation to deformation in Precambrian units?



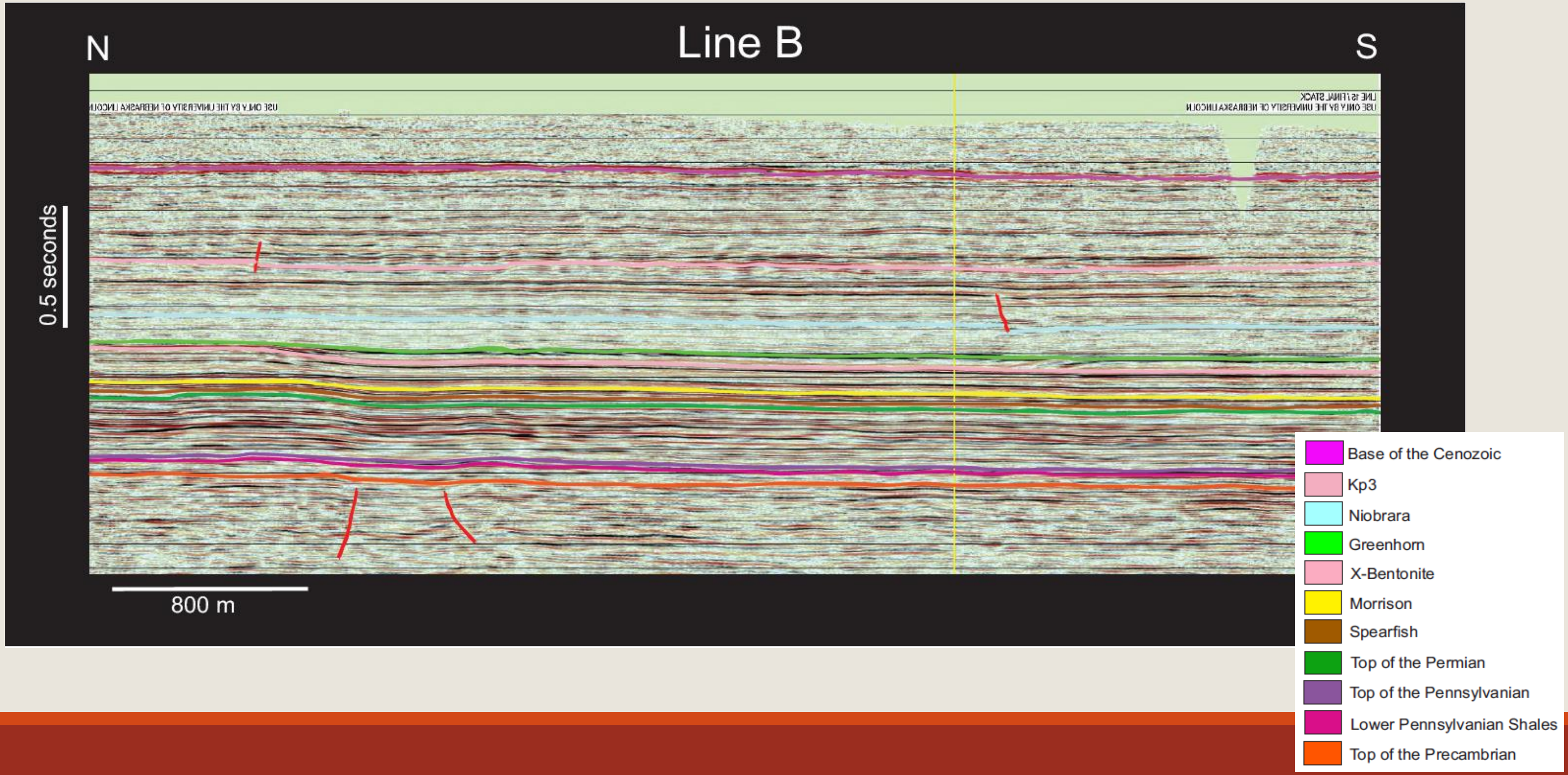


- Minor faulting offsets Niobrara Fm; geometry suggests fault inversion
- Fold in overlying Kp3 suggests inversion synchronous with post-Kp3 faults



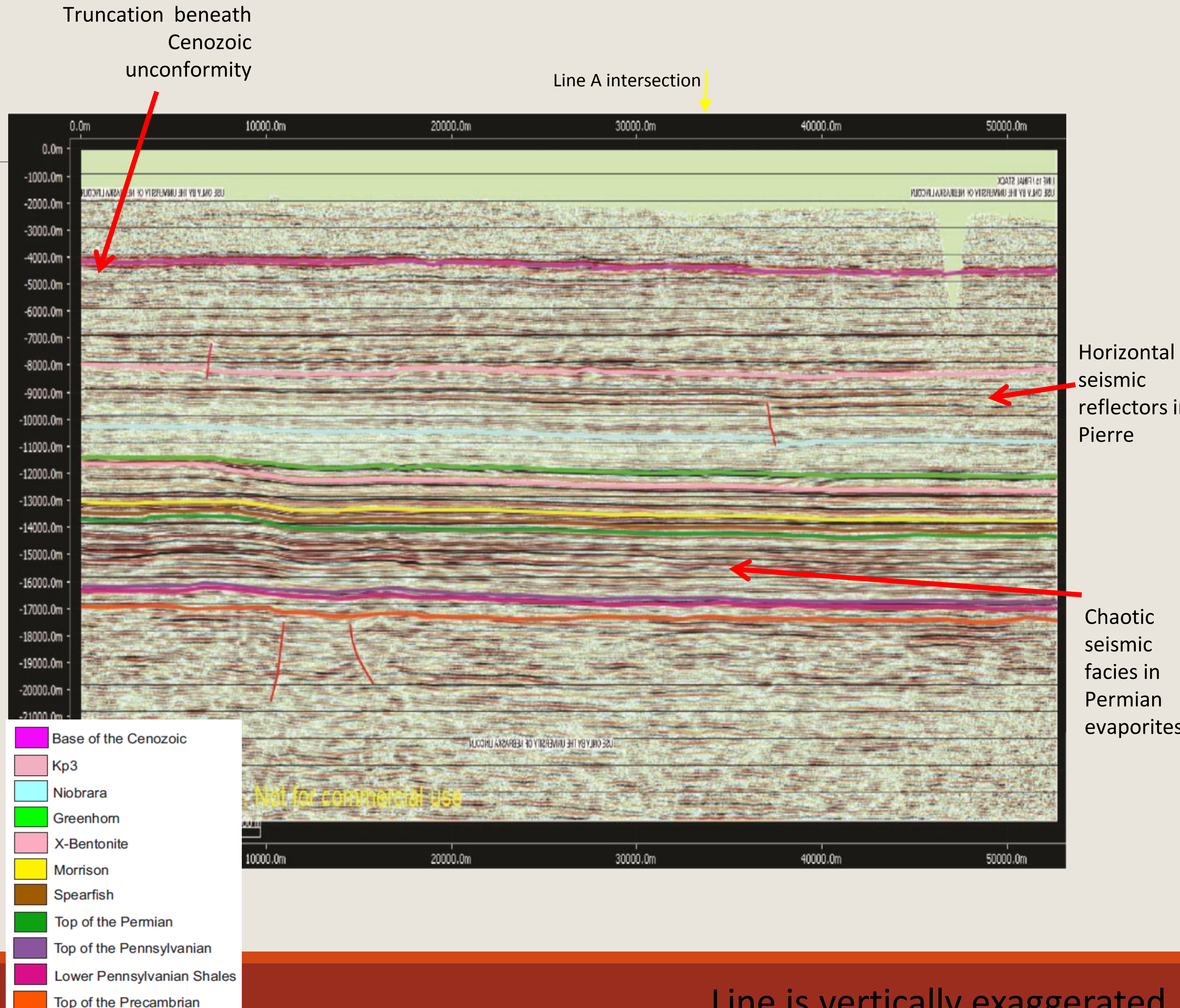
First-pass inspection: Cross-line B

- Horizons picked by correlation from Line A (yellow post); results consistent



Line B: more detail

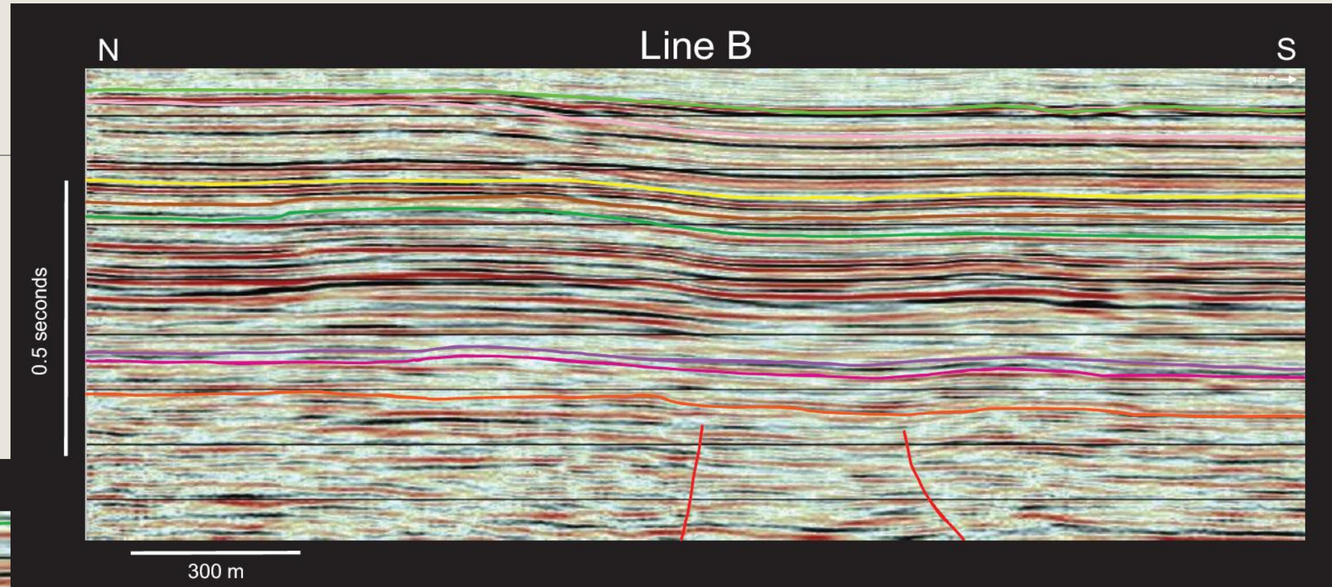
- Lapping relationships, thickness variations and mounded reflectors not as prominent as in Line A – but Line B is oriented N-S; right angles to sediment input direction

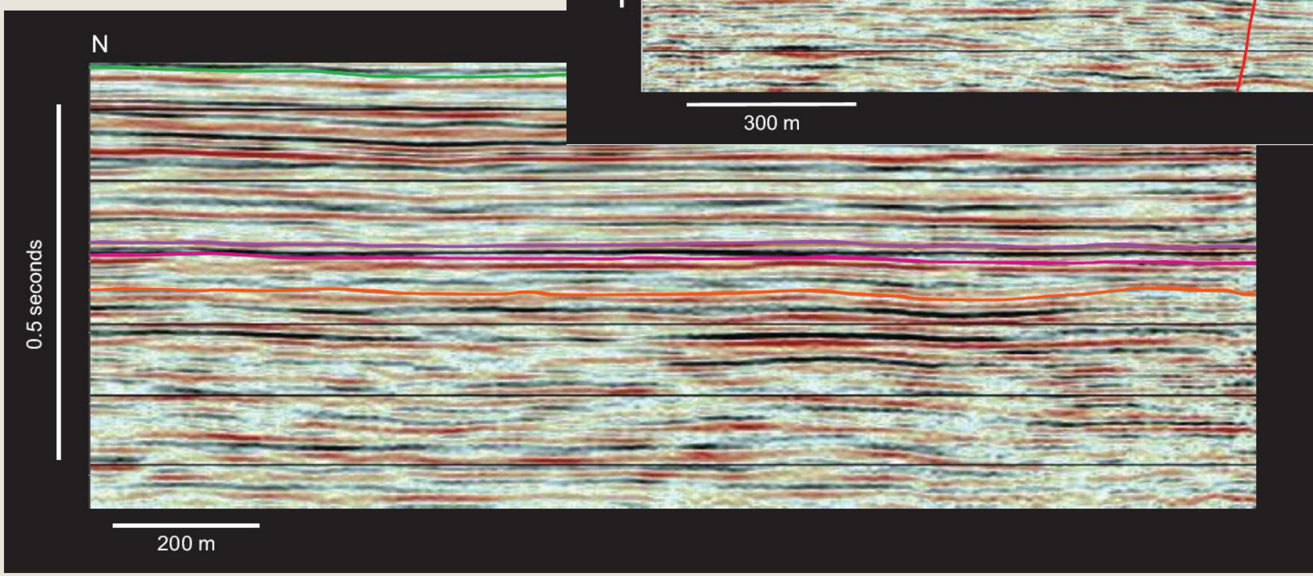


Line is vertically exaggerated

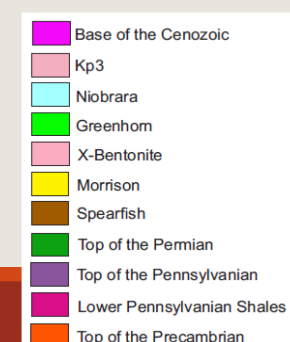
Line B: more detail

- Topography on Precambrian (orange) units – potentially deformation related?



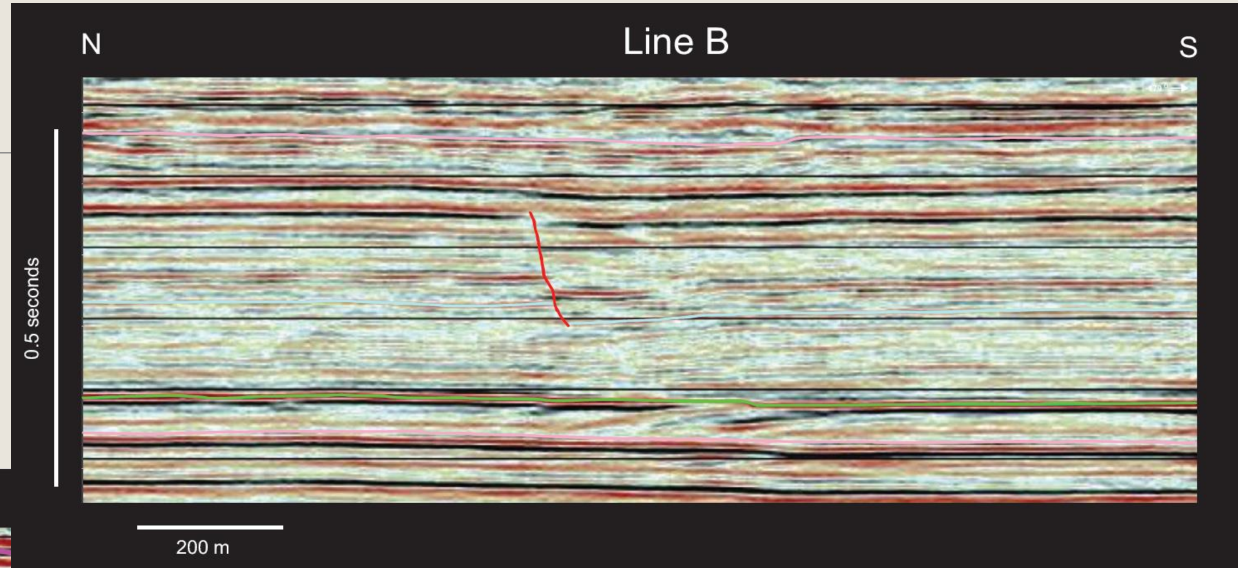


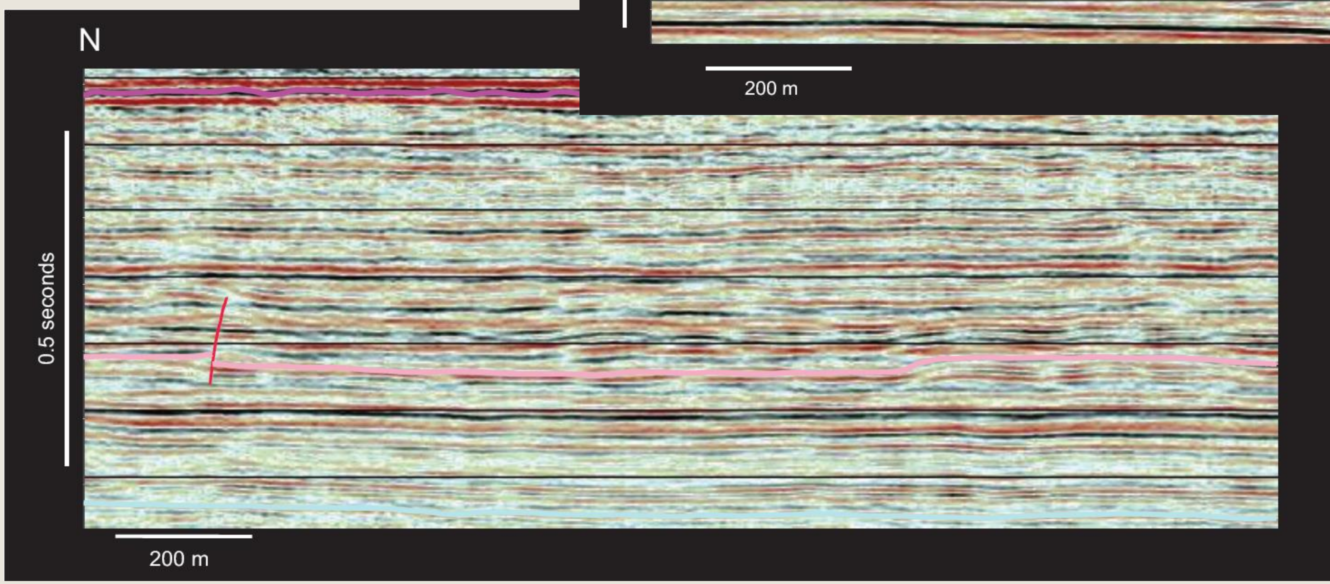
- Folding in Penn-Lwr K sequence related to 2x reactivation of Precambrian faulting



Line B: more detail

- Minor faulting affects Niobrara and Kp3 marker horizons, not as pronounced as in Line A





- Timing presumed post-Kp3, as for Line A

Synthesis of observations: A Geologic History

STAGE 1

- ❖ Precambrian faulting seen on both lines A and B

- ❖ Potential correlation with deep-seated Proterozoic-aged features, related to the Central Plains Orogen (approx. 1.7 Ga)

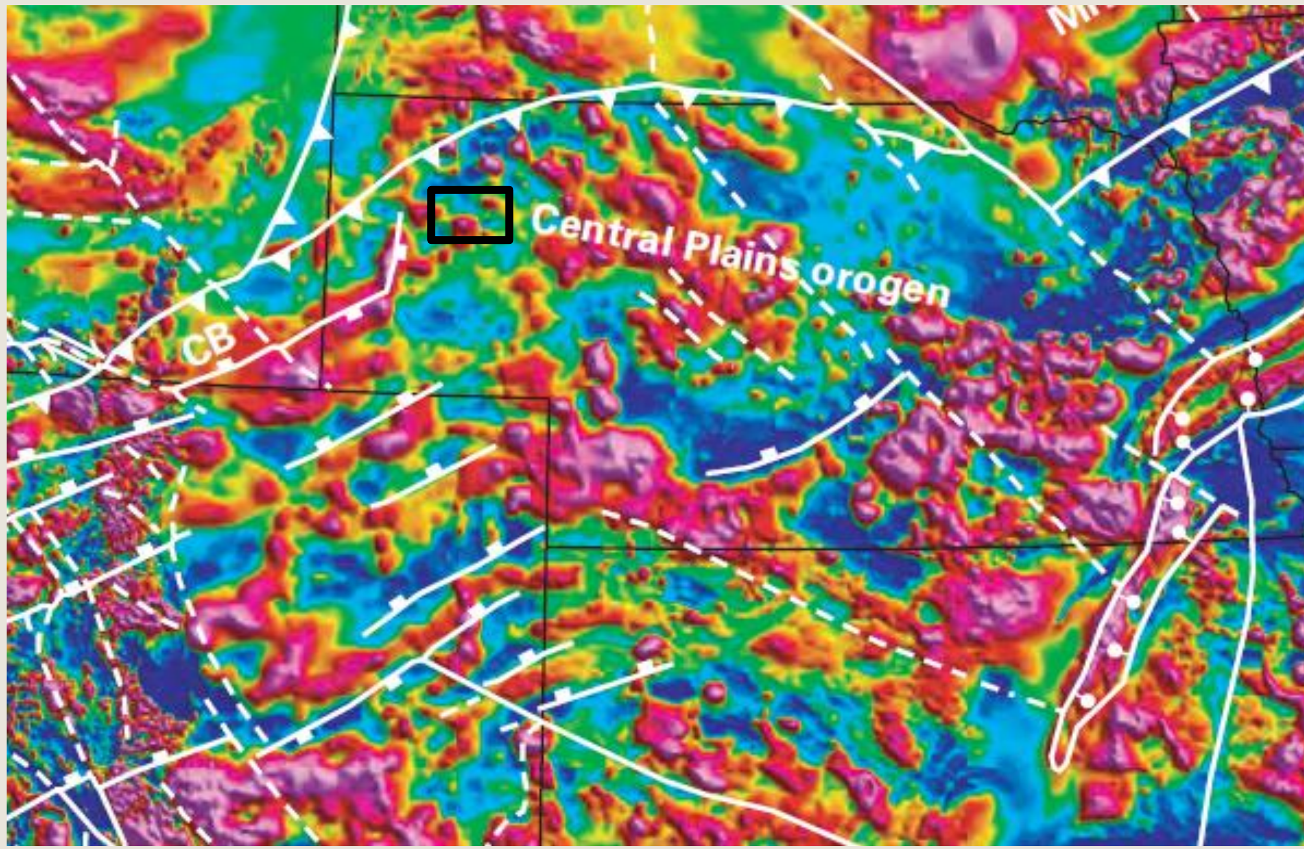


Image from Sims et al., 2008

Synthesis of observations: A Geologic History

STAGE 2

- Deformation within the Paleozoic section (Penn-Perm)
- Folds with strike approx. E-W, S_{Hmax} direction N-S?
- NEW ARM-age structures previously unrecognized?
- Area influenced by ARM (approx. 300 Ma) with the potential to reactivate Proterozoic structures
- cf. Nemaha Uplift further east

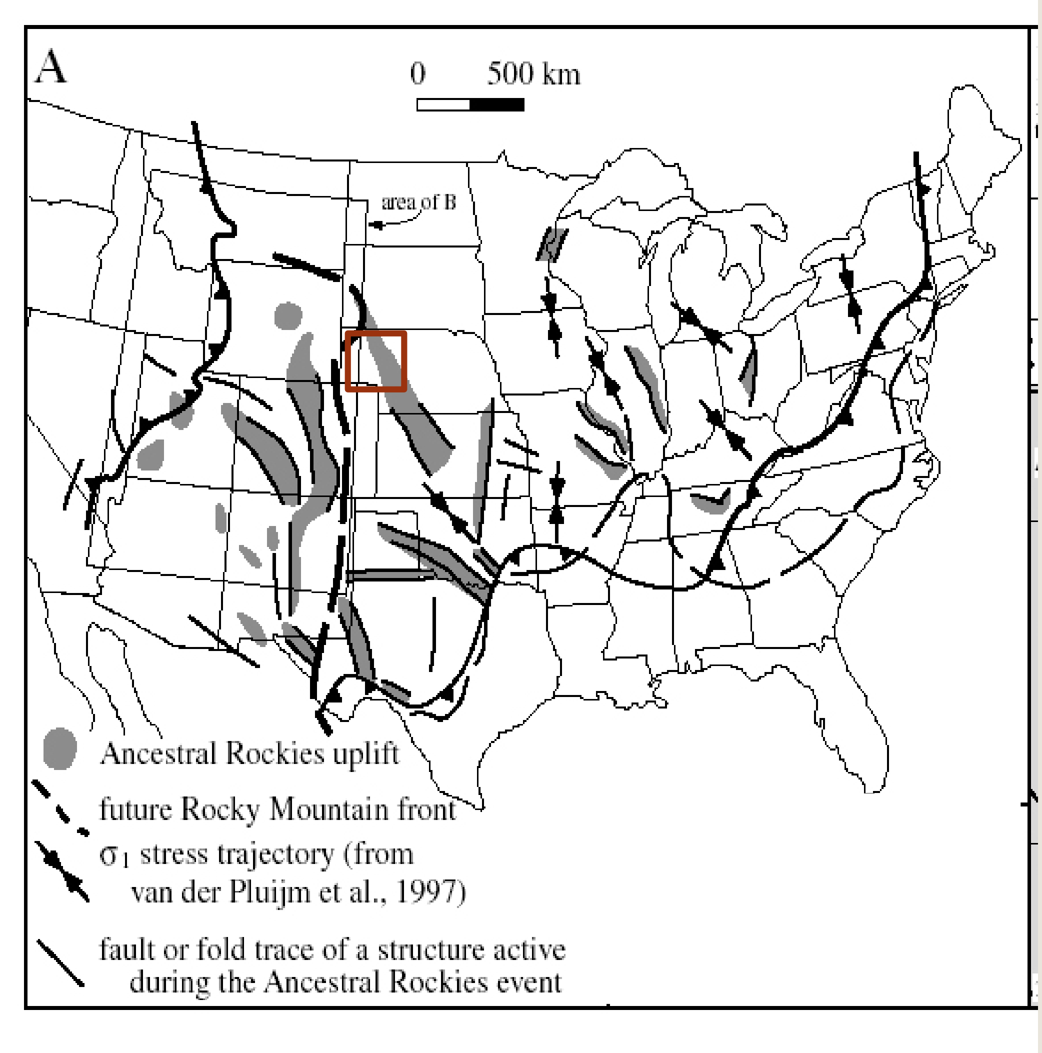


Image from Marshak et al., 2000

Synthesis of observations: A Geologic History

STAGE 3

- Deformation, lapping relationships and thickness changes within the Mesozoic section, S_{Hmax} direction W-E?
- Area influenced by Laramide Orogeny (Late K) with the potential to reactivate older structures, also records the passage of the forebulge?
- Additional influence from KWIS waxing and waning (cf. Pierre Shale)
- Prominent change in deformation ~95Ma (thickness changes in Greenhorn Fm)

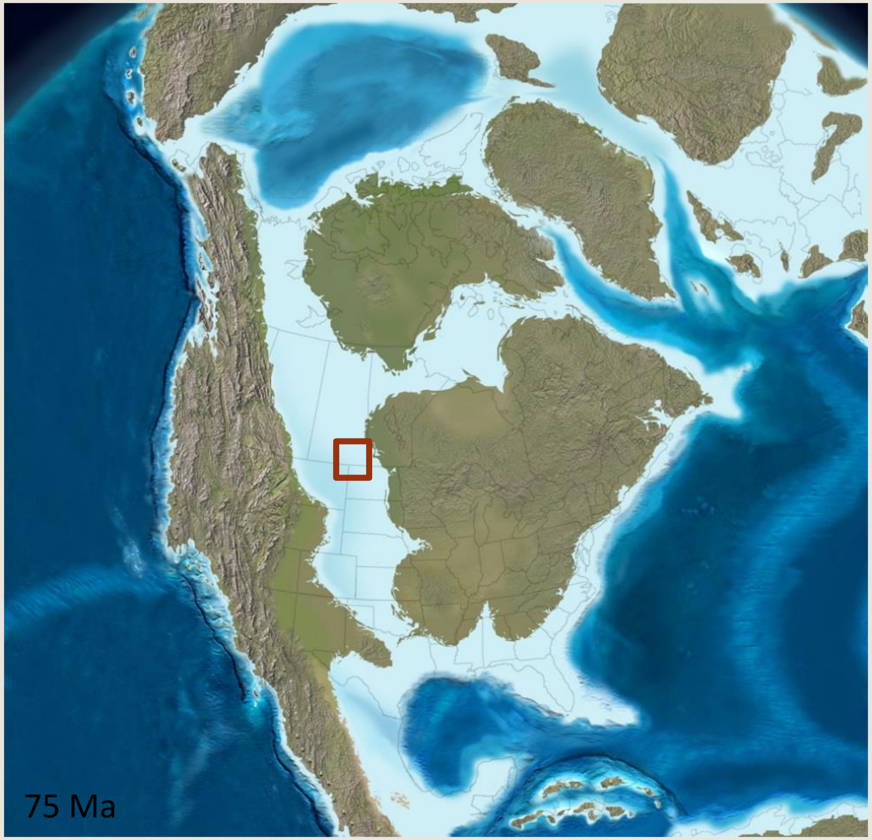


Image: http://jan.ucc.nau.edu/~rcb7/nam.html

Preliminary Conclusions/Implications

- Multiple stages of deformation have affected this area

  - Proterozoic Central Plains Orogen
  - Influences location of ARM-related deformation in the Penn-Perm sequence
  - Potentially influences location of Laramide-related deformation in the Cretaceous sequence, ending before the start of the Cenozoic

- Generates subtle folds in the Paleozoic sequence, forming targets for hydrocarbon exploration, as these zones of deformation may be zones of enhanced fracturing/porosity, suitable as targets for the unconventional systems being explored

QUESTIONS?

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Marshak, S., Karlstrom, K. & Timmons, J. M., 2000. Inversion of Proterozoic extensional failts: An explanation for the pattern of Laramide and Ancestral Rockies intracratonic deformation, United States. Geology 28, p 735-738

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Blakey, R. Paleogeographic map sourced from http://cpgeosystems.com/paleomaps.html

THANKS DUE TO:

American Geophysical Corporation (data) & Midland Valley Ltd (software)