Distributed normal faults in the Niobrara Chalk and Pierre Shale of the Central Great Plains

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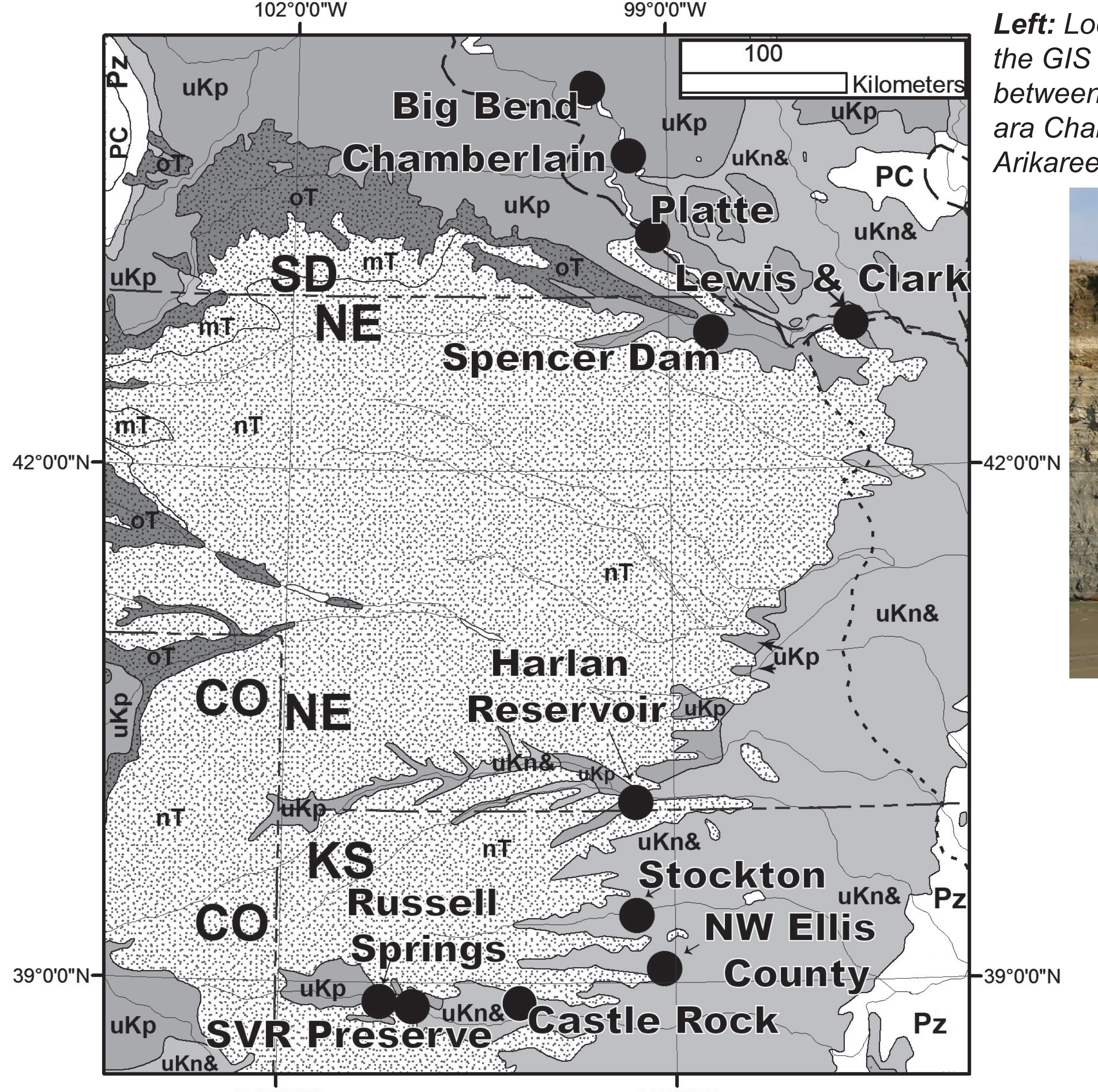
Abstract: Normal faults occur in the Niobrara Chalk and Pierre Shale in the following areas: Francis Case and Sharp lakes in central South Dakota, in the Lewis and Clark Lake area of northeast Nebraska, in the Harlan Reservoir area of central-south Nebraska, and in western Kansas. Most of these localities are ones where lakeshore outcrop coverage is fairly extensive. A variety of criteria were used to distinguish faults associated with mass wasting versus those described here that reflect deeper processes. In any one area these faults have variable strikes and dip directions and throws that vary from centimeters to several tens of meters. In the Niobrara chalks the fault zones typically display well developed striae, occasional slickensides, limited fractured damage zones, and dilational jogs with greenish, coarse calcite fill. In some places the faults are associated with very gentle monoclines, but elsewhere occur in horizontal strata. There is likely a weathering bias so that the faults are actually more common than observed.

At any one locality these faults have or could be attributed to local deeper seated tectonism, differential compaction, and/or glacial rebound. If due to tectonism, taken in aggregate they indicate fairly widespread (albeit minor) tectonism since the late Cretaceous. This would be consistent with the idea of a critically stressed continental interior with migrating sites of faulting. An alternate hypothesis is that these are polygonal faults due to diagenetically driven deformation in fine-grained mudrocks. Based on seismic and other data literature suggests subsurface polygonal faults occur in the Niobrara Chalks in the Denver-Julesburg basin area in eastern Colorado. The faults seen in outcrop here could represent a more eastern equivalent fault assemblage, but one substantially less developed due to shallower burial depths and attendant decreased diagenesis. Smectitic clays associated with polygonal faulting elsewhere, are also abundant in these units. The fault kinematics (extension in multiple directions) and widespread character is consistent with a diagenetic origin. Such polygonal faults would be expected to be stratabound and not extend to depth. Timing is uncertain, but a multistage diagenetic history associated with deposition and changing pore water chemistry provides context. For these strata the possibility of diagenetically driven deformation should be considered when faulting is found.



Left: *Localities with faulting discussed in this poster. Base is the GIS map from Garrity and Solar (2009). The boundary between uKn& and uKp is the boundary between the Niobrara Chalk and Pierre Shale. oT = White River Group, mT = Arikaree Group, and nT = Ogallala Group.*

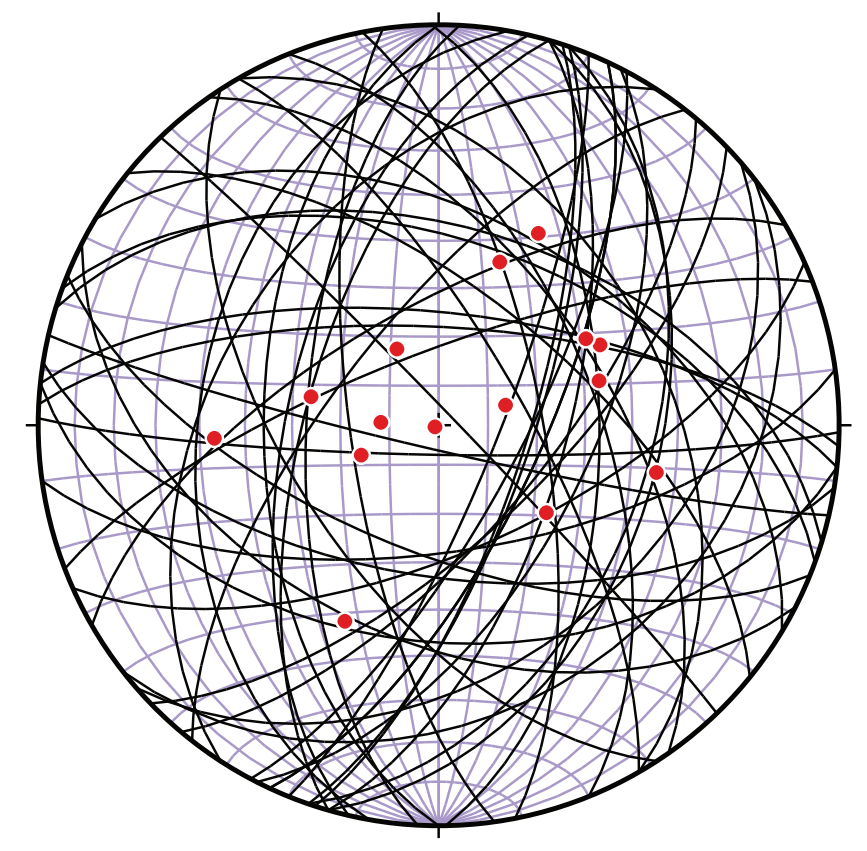
Above: *Photograph of normal fault exposed in Pierre Shale strata just below Spencer dam on the Niobrara river in NE Nebraska. Upper truncating sediments are terrace deposits, and whitish coloration reflects weathering.*

Criteria for distinguishing mass wasting vs. faults that formed at depth:

a) movement sense and/or orientation opposed to the modern or paleo-slope direction.
b) position in weathering profile and cliff.
c) fault geometry: planar versus curved.
d) associated coarse vein material in dilational jogs.
e) offset of weathering profiles vs. overprinting.
f) fault truncation by younger deposits.
g) mass wasting styles in the Niobrara chalks versus the Pierre shale.

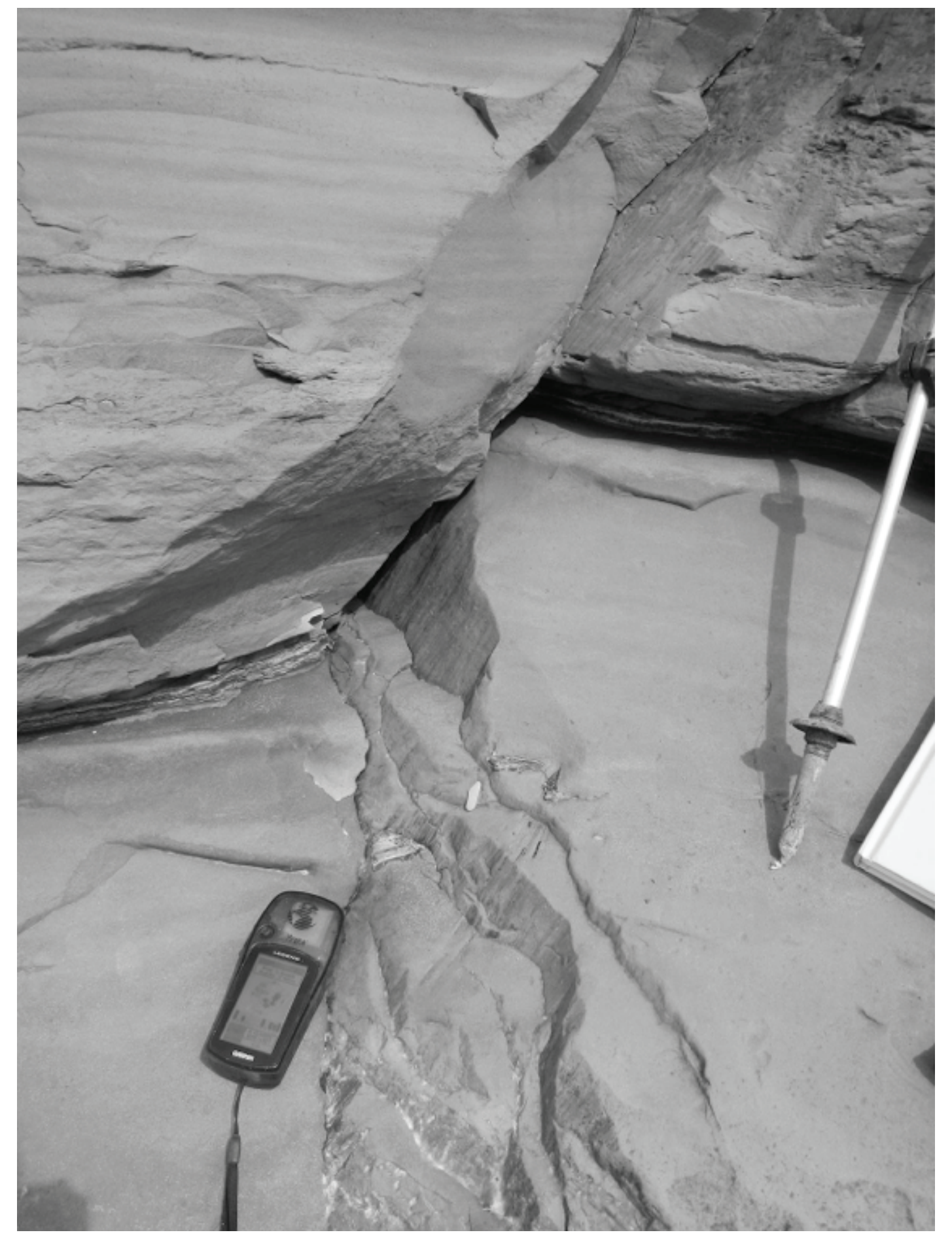
Slump in Pierre Shale with basal slip surface along the contact with the underlying Niobrara Chalk (arrow).

Francis Case Lake (Platte & Chamberlain), S.D.



Left: *Lower hemisphere stereonet plot of 44 fault planes and 14 striae (red dots).* **Right**: *Plot of poles to faults along with Kamb contour lines. All plots created with software program by Allmendinger et al. (in press).*

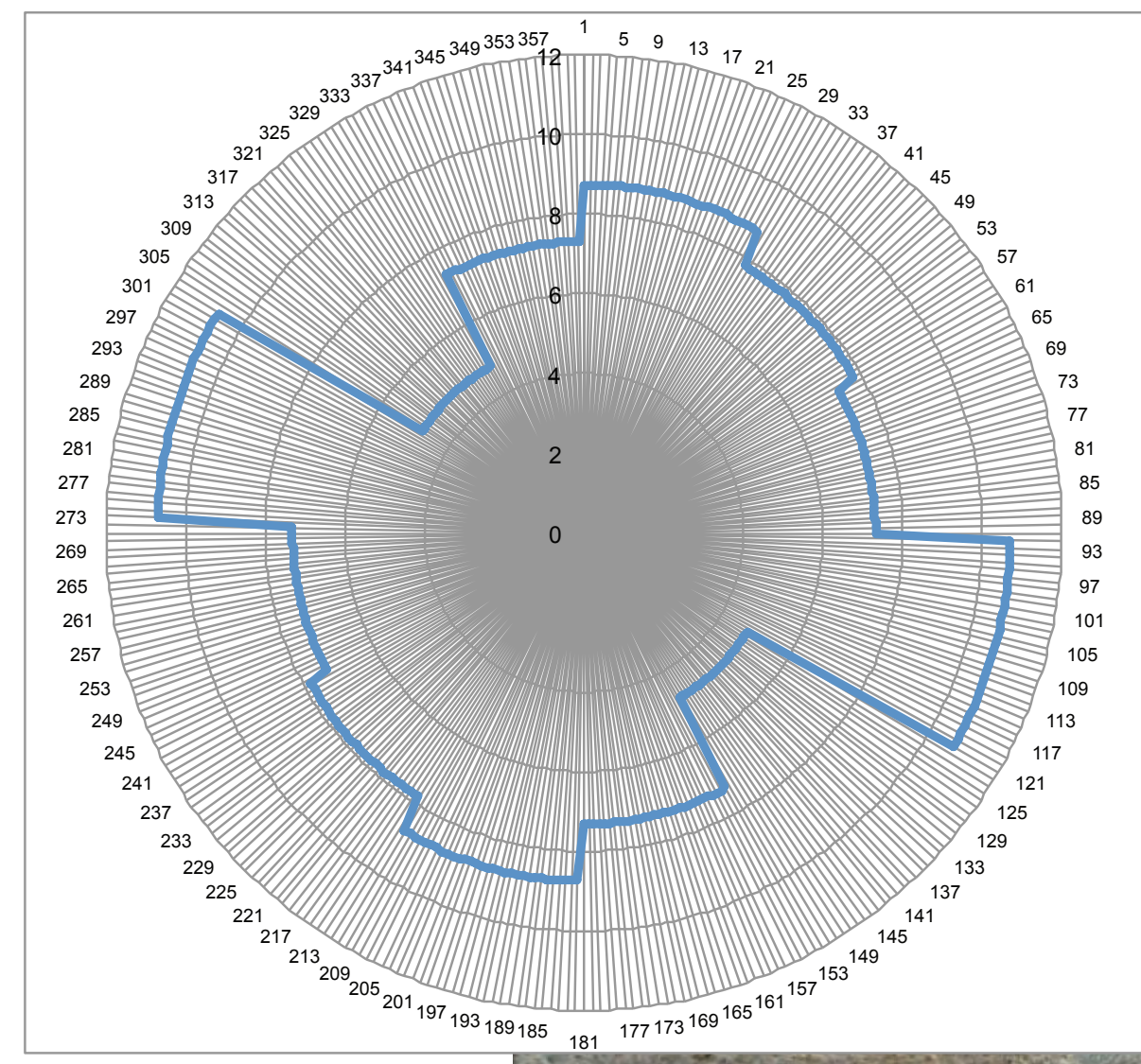
Above: *Faults (lines with longer dashes) exposed along E shore of lake in Niobrara chalk deposits (43.84523 N and -99.31047 W offshore position). Upper dashed line is contact with overlying and unfaulted loessal and colluvial deposits. Small-dash line is a distinctive thin darker layer that provides an indication of offset.*



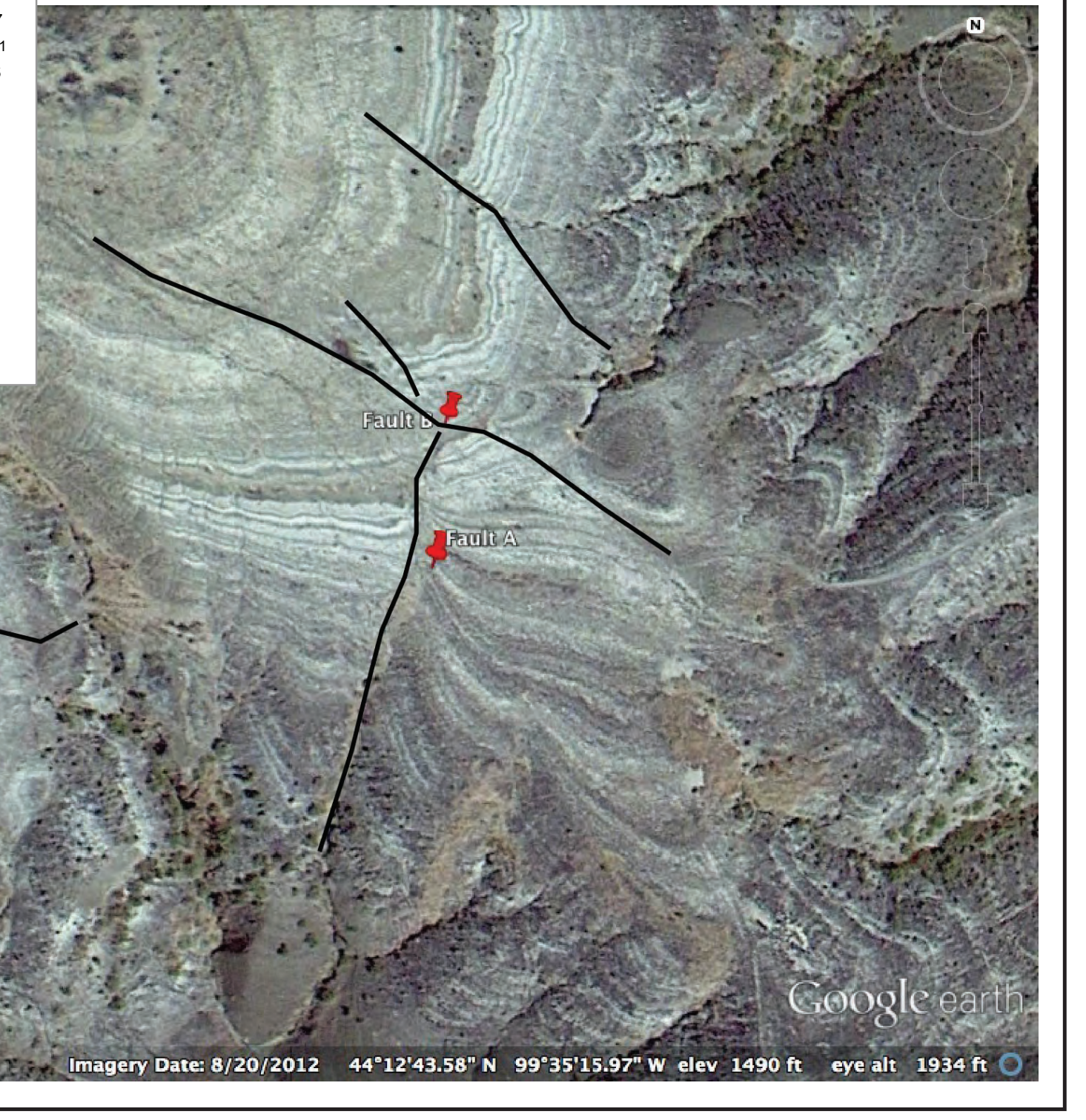
Left: *Close up of fault on east side of river, roughly 5 miles W of Academy (43.44556 N, -99.16986 W). The host rock is relatively unweathered Niobrara chalk. The recessive unit is a thin ash layer, which is downthrown by about 15 cms on the left side. Dip-slip fault striae and parallel fault corrugations are visible on the multiple, branching slip surfaces.*

Above: *Outcrop displaying stratigraphy. 1 = contact between Niobrara chalk underneath & Pierre shale above. 2 = Ardmore ashes in Pierre shale. 3 = vein network in Pierre shale. 4 = loess mantle.*

Google Earth photointerpretation of faults in Big Bend area, S.D.

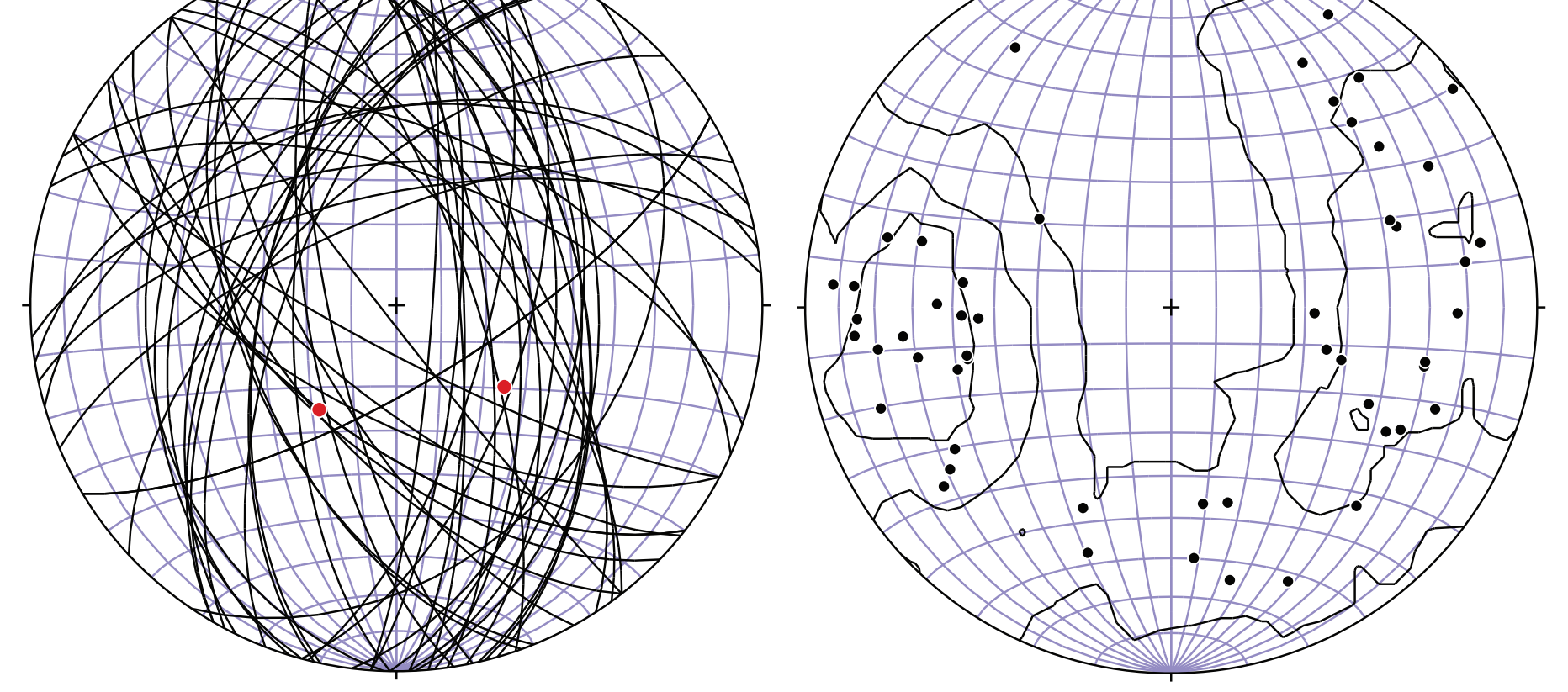


Left: *Area proportional rose diagram of 50 strikes of faults in Pierre shale identified by photointerpretation of Google Earth images as being of deeper seated origin. Chi-squared test for uniformity leads to acceptance of null hypothesis.*



Right: *Example of faults evident on Google Earth that are interpreted not to be of mass wasting, but of deeper seated origin.*

Lewis and Clark Reservoir, NE and S. D.



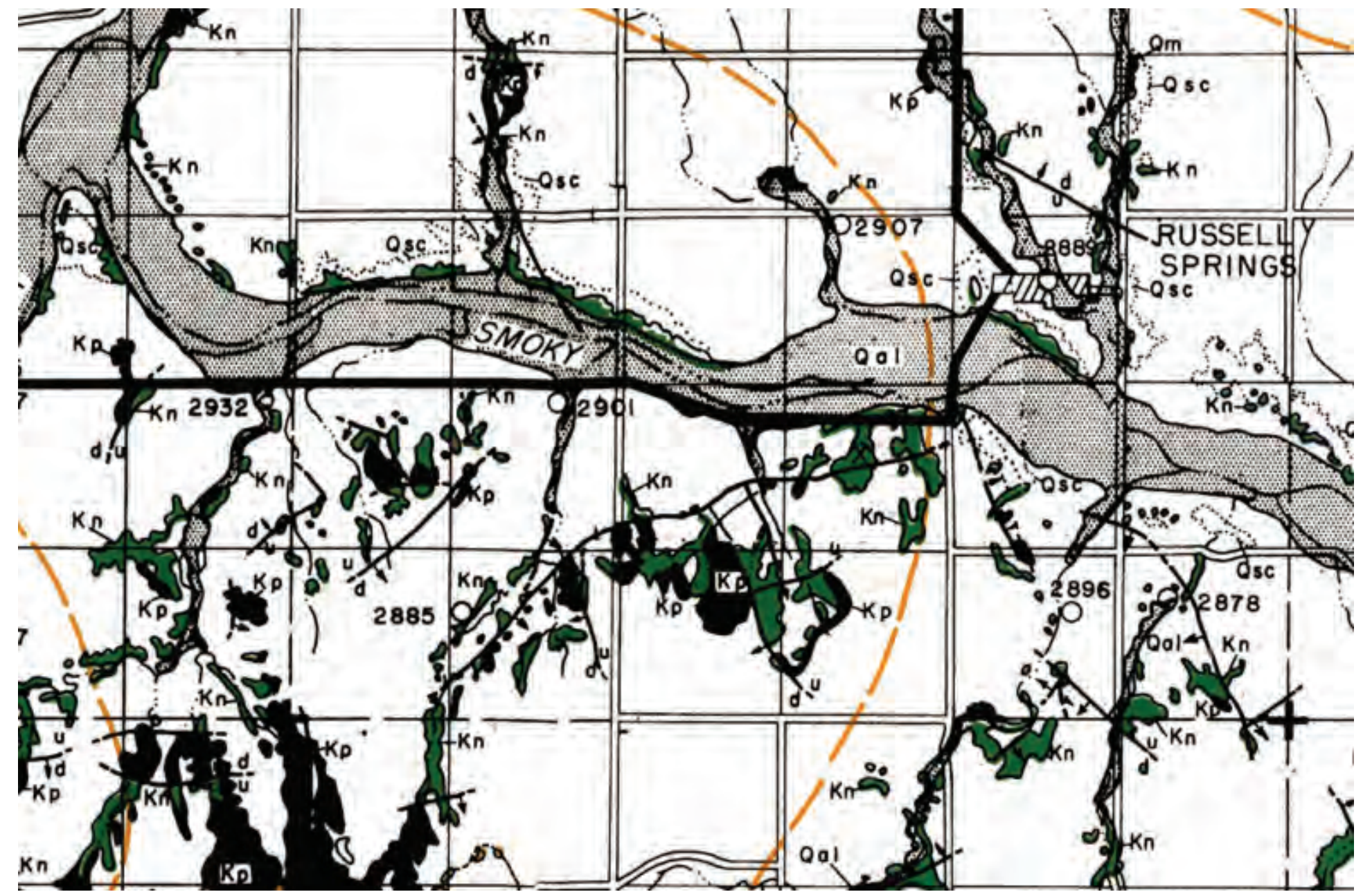
Left: *Lower hemisphere stereonet plot of 54 fault planes and 2 striae (red dots) from Lewis and Clark Reservoir area.* **Right**: *Plot of poles to same faults along with Kamb contour lines. Possible weak pole concentration associated with faults striking approximately north-south is consistent with observational bias due to the orientation of the shoreline outcrops. .*

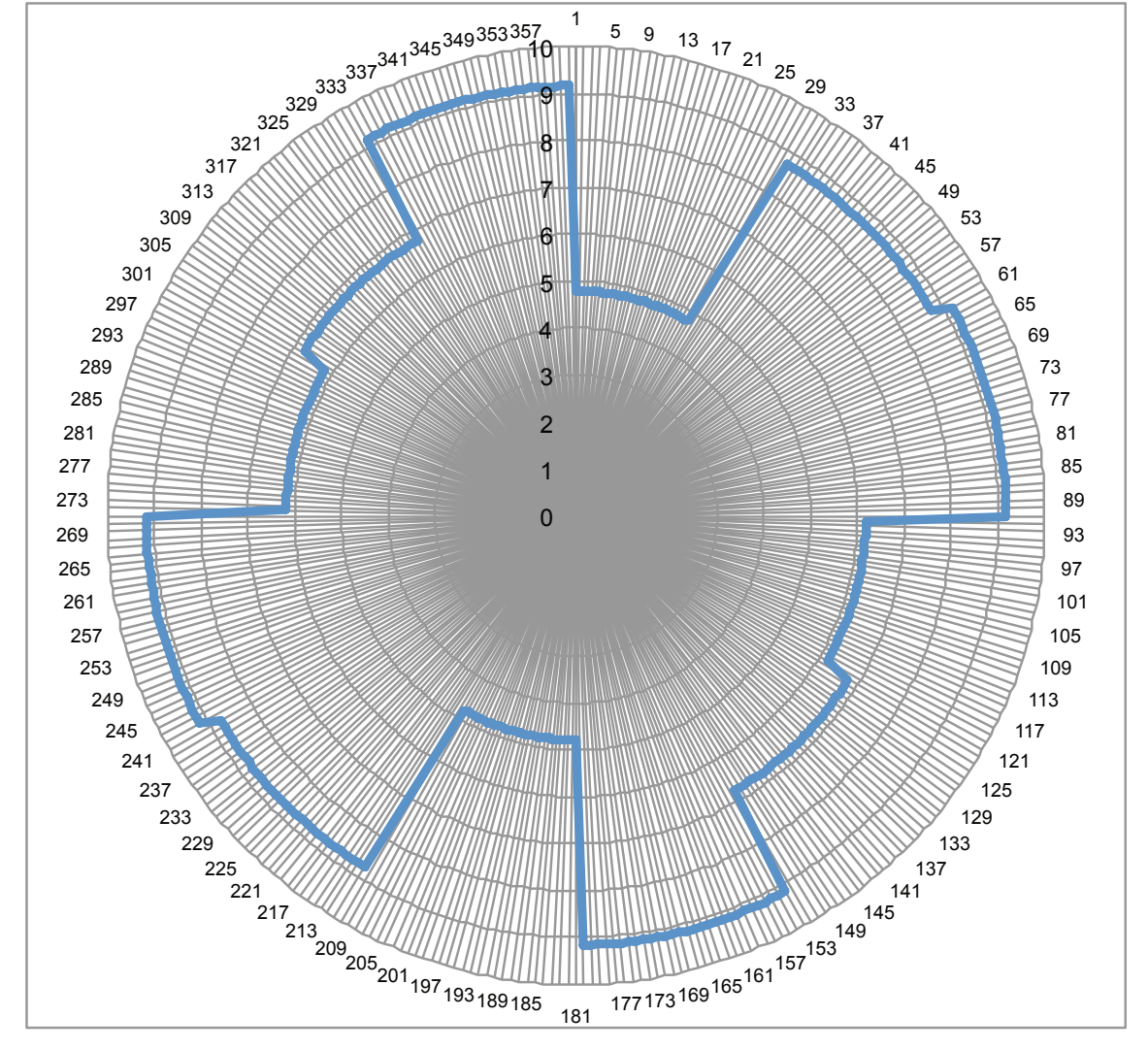
Above: *Photograph of small scale normal fault from along south shore of the lake. Offset orange layer is bentonitic ash layer. White coloration is due to weathering of the chalk, which is organic rich and dark grey when fresh.*

Western Kansas

Above: *Normal fault in Castle Rock area (Kansas). Recent field work found in excess of 10 normal faults of varying orientation in the badlands exposures of Niobrara Chalk in this area.*

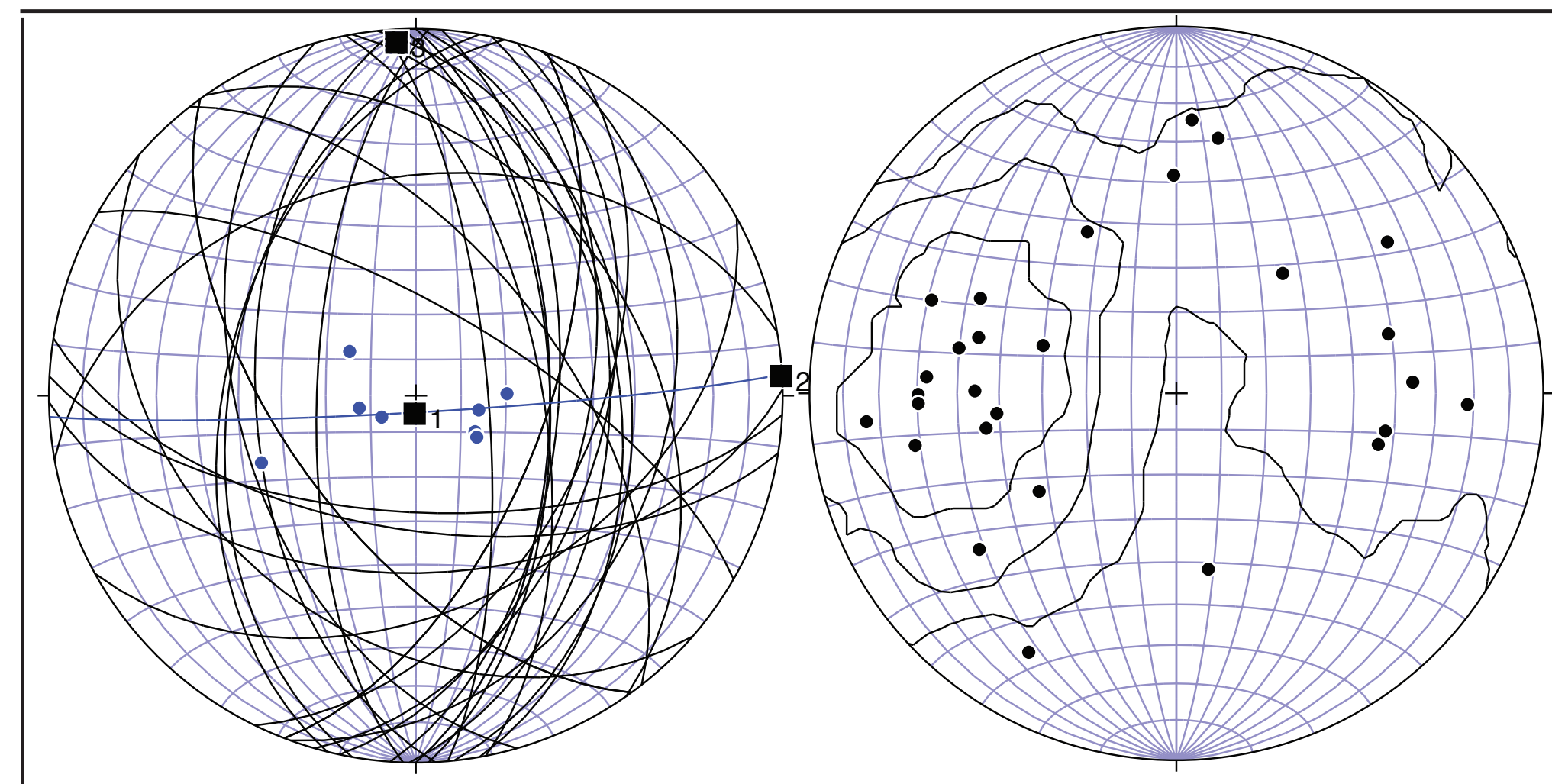
Below: *Example of common calcite slickensides and veins that adorn the fault zones in these and other areas.*





Above: *Part of geologic outcrop map of Logan County showing mapped array of faults in the Niobrara Chalks (green) and Pierre shale (black) in Russell Springs area. From Carlton (1954).*
Left: *Area proportional rose diagram of 53 faults strikes extracted from above map. A chi-squared test for uniformity leads to the acceptance of the null hypothesis. In addition, facing directions tested as uniform.*

Harlan County Reservoir, NE



Left: *Plot of 30 fault planes, along with plots of poles to bedding (blue dots) and a best fit fold girdle to the bedding (blue plane great circle and black squares.* **Right**: *Kamb contour plot of same fault planes.*

Left: *Pierre Shale in hanging wall juxtaposed against Niobrara Chalk in footwall. This outcrop is from the south shore of the lake.*

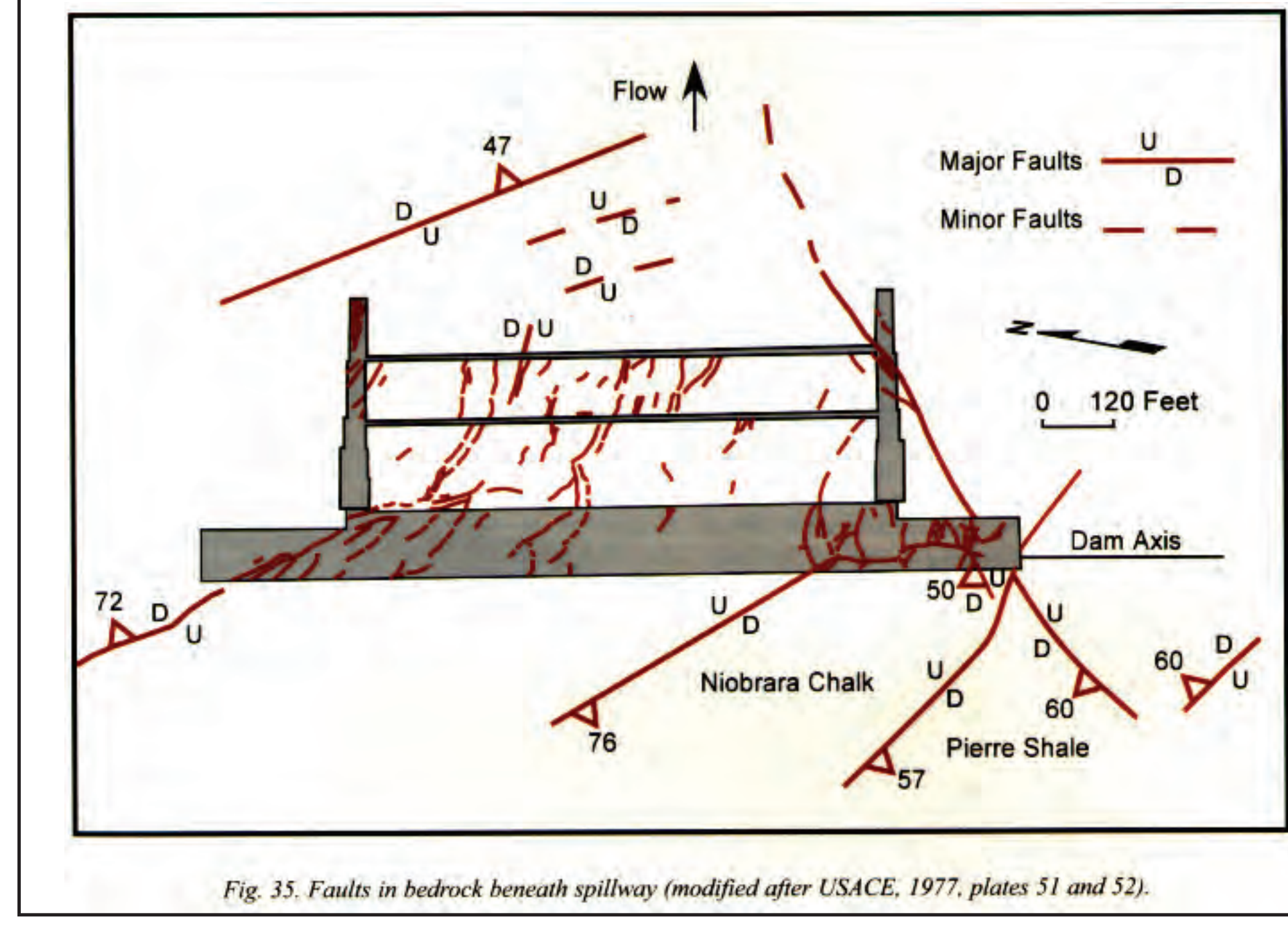
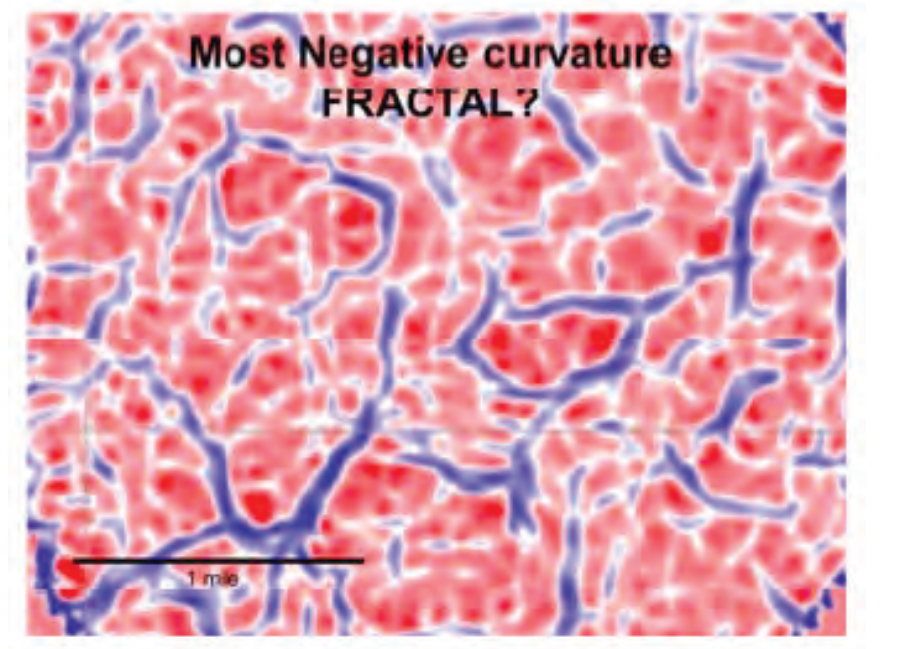


Fig. 35. Faults in bedrock beneath spillway (modified after USACE, 1977, plates 51 and 52).

Lower left: *Army Corp of Engineers map showing faults beneath dam and spillway structure. Figure taken from Diffendal et al. 2002.*



Above: *Sonnenburg & Underwood (2012) propose that polygonal fault systems are well developed in the Niobrara Chalk and Pierre Shale in the subsurface of the Denver-Julesburg basin. Image to right from their work displays the polygonal geometry. In addition, at a recent AAPG conference Kernan (2013) has also suggested the faults exposed in western Kansas are polygonal, as is suggested in this presentation.*

Polygonal fault systems are arrays of stratabound normal faults that are relatively common in fine-grained marine sediments and which are thought to be due to diagenetically driven volume shrinkage associated with compaction, fluid expulsion and possible changes in clay chemistry (e.g. Cartwright & Lonergan 1996; Dewhurst, et al. 1999).

Conclusions

1) Relatively small scale normal faults are broadly distributed throughout the Niobrara Chalk and Pierre Shale of South Dakota, Nebraska and Kansas.
2) Their widespread distribution, complex orientation distribution, and kinematics are consistent with formation by diagenetically driven deformation as a weakly developed polygonal fault system, similar to what has been postulated for better developed fault systems in the subsurface Niobrara Chalks of the Denver Julesburg Basin to the W.
3) In addition to basement reactivation, diagenetically driven deformation should be entertained as a possibility for normal faults found in fine-grained stratigraphic units.
4) Abundant possibilities exist for the specific diagenetic processes driving polygonal fault development, but future research is needed to identify the drivers.

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