SIGNFICANCE OF AN ESE FRACTURE DIRECTION IN TERTIARY STRATA OF SOUTH DAKOTA AND NEBRASKA?

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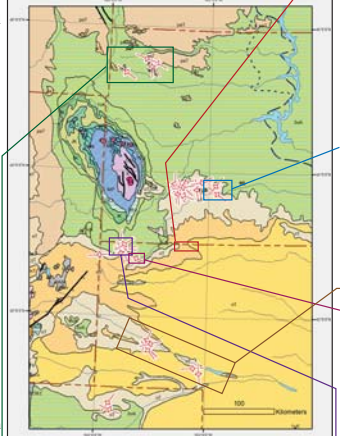
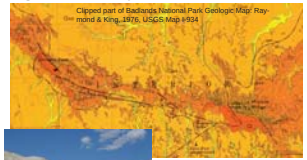
ABSTRACT: A rich array of fracture types in the Tertiary strata of Nebraska and South Dakota includes faults (predominantly normal), clastic dikes, veins (chalcedony, calcite and gypsum), joints, and occasional deformation bands. These fractures show a diverse array of morphologies orientation distributions and complex age relationships. Generally north trending features can be associated with reactivation of Laramide features (a 'Black Hills' trend). More NE to ENE trending structures have been associated with reactivation of basement features such as those along the Colorado Lineament. The Toadstool fault in northwest Nebraska falls in this category. However, a significant ESE to SE trending and regionally distributed set of features is largely unrecognized and unexplained. These features include normal faults and conjugate joints at Slim Buttes and Pine Hills in NW South Dakota, faults and clastic dikes in Badlands National Park, the White Clay fault in NW Nebraska, one of several fault and joint and chalcedony vein directions at Toadstool Geologic Park in NW Nebraska, and a joint set in Brule Formation strata in the North Platte River valley area of Nebraska. The faults and joints at Slim Buttes clearly formed before the unconformably overlying Arikaree Group strata were deposited. The White Clay fault is argued to have been active during and influenced the deposition of the basal Ogallala Group strata. The ESE trending faults at Toadstool postdate diagenetically produced silica mobilization and chalcedony vein formation, which is possibly coeval with Arikaree Group deposition and loading. Explanations for the regional ESE direction of fracturing include: a) reactivation over time of a consistently oriented, but unidentified, structural element; b) loading by a regionally consistent stress field that persisted from pre- to post- Arikaree Group deposition times; or c) loading by a regionally consistent stress field during an earlier and shorter time frame, followed by subsequent reactivation. The third possibility is favored at present with a pre-Arikaree inception of fracturing.

Overview Map of Various Study Areas

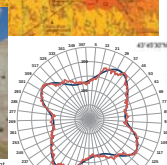


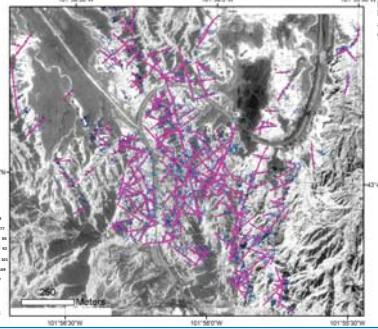
Base map: Garrity, C. P. & Soller, D. R., 2009, Database of the Geologic Map of North America – Adapted from the Map by J. C. Reed, Jr. and others (2005); United States Geological Survey Data Series 424, 1 CD. http://pubs.usgs.gov/ds/424/ and pubs.usgs.gov/ds/424/ds424_text.pdf . Strike symbols of dominant vein/joint directions. Inset boxes are color coded to study areas discussed.

Big Badlands Study Area



Clipped part of Badlands National Park Geologic Map: Raymond & King, 1976, USGS Map I-934



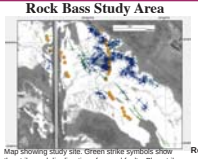


Above: Normal faults showing soft-sediment style. **Right**: Sliding sector plot of dike strikes modeled as two preferred orientations and a uniform component.

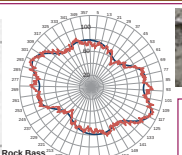
Left: Map showing dike strikes and interpreted dike pattern. The pattern is complex, but a distinct ESE trend exists. **Below**: Example of cross cutting relationships. Different directions are basically coeval.

Take aways:
- ESE oriented array of normal faults
- ESE oriented array of clastic dikes
- faults preceded dikes (?).
- dikes reactivated earlier grain
- dikes post-Sharps Fm. in age

Rock Bass Study Area



Map showing study site. Green strike symbols show the strike and dip direction of normal faults. Blue strike symbols are strike of subvertical chalcedony veins. The orange dots represent the axis of shoe-string sandstone channels.



Rock Bass n= 498

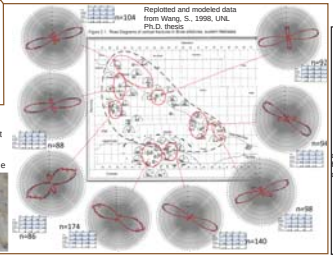
Imge of chalcedony vein and fault

Take aways:
- there is a dominant SE trending faults in Chadron Fm. strata .
- these faults post-date chalcedonay vein formation and associated diagenesis.
- fault coeval with later calcite phase
- modeling indicates a significant preferred chalcedony vein orientation at 115

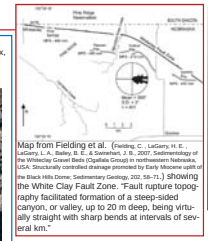
North Platte River valley

Take aways:
- ESE joint set here.
- may be pre-Arikaree in age

Images: Fractures beneath the Arikaree-Brule Fm. contact. Note erosional scour along fracture to right.

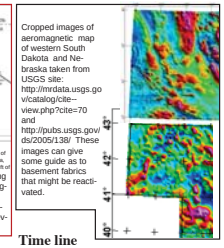


Replotted and modeled data from Wang, S., 1998, UNL Ph.D. thesis

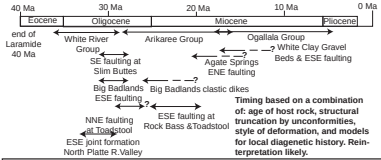


Map from Fielding et al. (Fielding, C., LaGarry, H. E., LaGarry, L. A., Bailey, B. E., & Swinehart, J. B., 2007, Sedimentology of the Whitetail Gravel Beds (Ogallala Group) in northwestern Nebraska, USA: Structurally controlled drainage promoted by Early Miocene uplift of the Black Hills Dome: Sedimentary Geology, 202, 58–71.) showing the White Clay Fault Zone. "Fault rupture topography facilitated formation of a steep-sided canyon, or valley, up to 20 m deep, being virtually straight with sharp bends at intervals of several km."

Cropped images of aeromagnetic map of western South Dakota and Nebraska taken from USGS site: http://mrdata.usgs.gov/catalog/cite--view.php?cite=70 and http://pubs.usgs.gov/ds/2005/138/ These images can give some guide as to basement fabrics that might be reactivated.

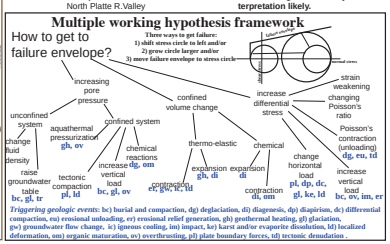


Time line

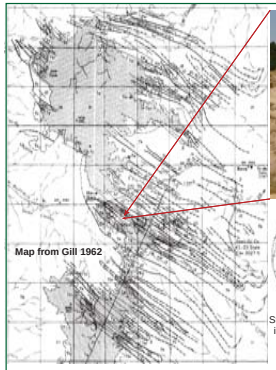


Timing based on a combination of: age of host rock, structural truncation by unconformities, style of deformation, and models for local diagenetic history. Reinterpretation likely.

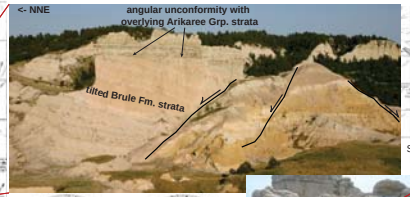
Multiple working hypothesis framework

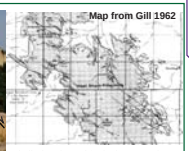


Triggering geologic events: **bc) burial and compaction, dg) deglaciation, di) diagenesis, dp) diapirism, dc) differential compaction, eu) erosional unloading, er) erosional relief generation, gh) geothermal heating, gl) glaciation, gw) groundwater flow change, ic) igneous cooling, im) impact, ke) karst and/or evaporite dissolution, ld) localized deformation, om) organic maturation, ov) overthrusting, pl) plate boundary forces, td) tectonic denudation .**



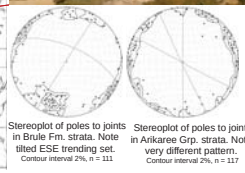
Map from Gill 1962





Map from Gill 1962

Similarly oriented faults in West Short Pine Hills 50 km to W of Slim Buttes.



Stereoplot of poles to joints in Brule Fm. strata. Note tilted ESE trending set. Contour interval 2%, n = 111

Stereoplot of poles to joints in Arikaree Grp. strata. Note very different pattern. Contour interval 2%, n = 117

rotated conjugate joints
joint cluster w fault core
clastic dikes

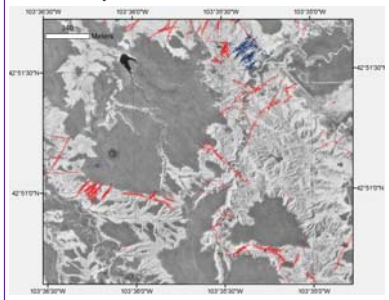
Take aways:
- ESE oriented array of normal faults
- ESE oriented array of joints
- both formed before Arikaree Grp. deposition.
- associated detachment
- cause enigmatic, but not river valley slumps

Cause?

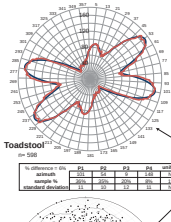
Gill (1962) -> landslide blocks along pre-Arikaree valleys. Gill, J. R., 1962, Tertiary Landslides, Northwestern South Dakota and southeastern Montana, GSA Bulletin, 73, 725-736

Lillegraven (1970) -> 15 reasons not landslide blocks, gravity controlled detachment fault perhaps akin to Heart Mountain detachment. Lillegraven, J. A., 1970, Stratigraphy, Structure and Vertebrate Fossils of the Oligocene Brule Formation, Slim Buttes, Northwestern South Dakota: GSA Bulletin, 81, 831-850.

Toadstool Study area



Map showing normal fault strikes (red) and strikes of local chalcedony vein array (blue), from the southern portion of the Toadstool Geologic Park study site. Note the fairly well developed SE to ESE trend. Underlying image USGS air photos.

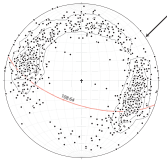


Toadstool n= 598

Images of ESE trending normal faults in Brule Formation strata at Toadstool

Above: Sliding sector plot of chalcedony veins. The blue line represents the model with model parameters given in the table below. Note the 101 trending preferred orientation.

Below: Stereoplot of Kamb contour plot of poles to 748 faults. A complex distribution exists. Shown in red is a representation of the ESE and south dipping fault set. These faults cut the NE trending set.



Take aways:
- there is a ESE chalcedony vein preferred orientation in Chadron Fm. strata.
- faults are normal and multidirectional, but a SE to ESE trending and asymmetric array exists (similar to the relationships seen at Rock Bass).
- An earlier set of NE trending normal faults is part of the Colorado lineament as defined by Werner, L. A., 1978, The Colorado Lineament: A middle Precambrian wrench fault system; Geol. Soc. Am. Bulletin, v. 89, 161-171.

Conclusions:

- The Tertiary fracture history of the Great Plains is complex and polyphase, requiring an extensive data acquisition campaign and a multiple hypothesis framework to understand.
- A suite of similarly oriented normal faults, clastic dike, chalcedony veins and joints at Slim Buttes, the Big Badlands, the White Clay area, Toadstool Geologic Park suggest a regionally coherent SE to ESE oriented fracture system exists.
- At Slim Buttes faulting is clearly pre-Arikaree Group. At the Badlands it preceded lithification and clastic dike emplacement. At Toadstool it is syn- to post- chalcedony vein formation which is associated with signficant diagenesis and silica mobilization. At White Clay it is of Ogallala Group age. ESE oriented normal faulting, veining and jointing persisted for a significant period of time.
- While N to NE oriented structures may reflect Colorado Lineament basement reactivation trends, and more N-S oriented structures may reflect reactivation of Laramide trends, the significant ESE orientation may reflect local reactivation of a basement grain and/or a persistent Tertiary regional stress field.

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