Inputs of Tephra and Sulfuric Acid to an Ancient Great Plains Playa (Oligocene of Nebraska)

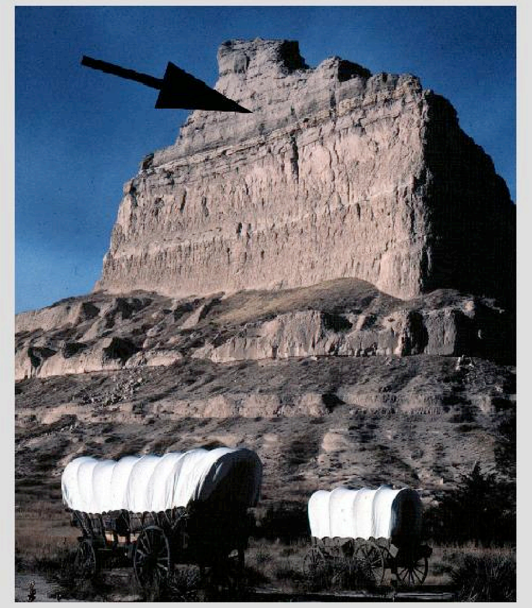
David Loope
Dept. of Geosciences
Univ. of Nebraska-Lincoln

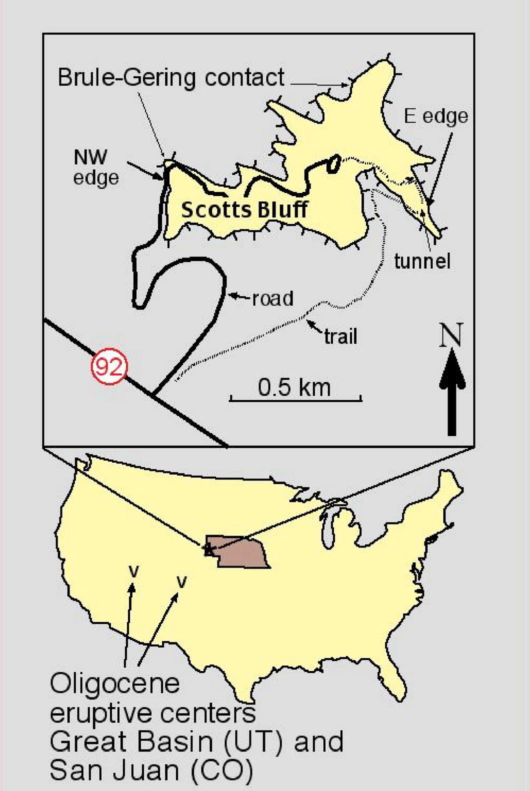
Joseph Mason
Dept. of Geography
Univ. of Wisconsin-Madison

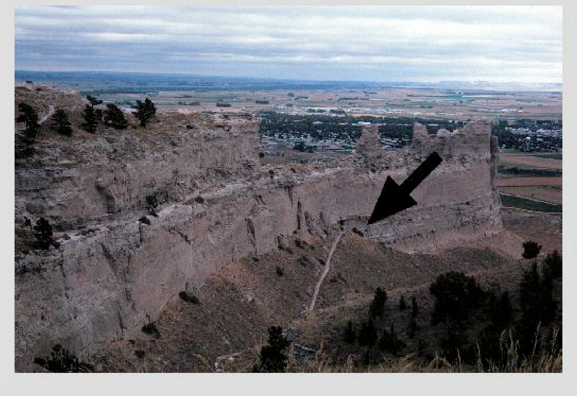
Huiming Bao
Dept. of Geology & Geophysics
Louisiana State University

Richard M. Kettler
Dept. of Geosciences
Univ. of Nebraska-Lincoln

William Zanner
School of Natural Resources
Univ. of Nebraska-Lincoln



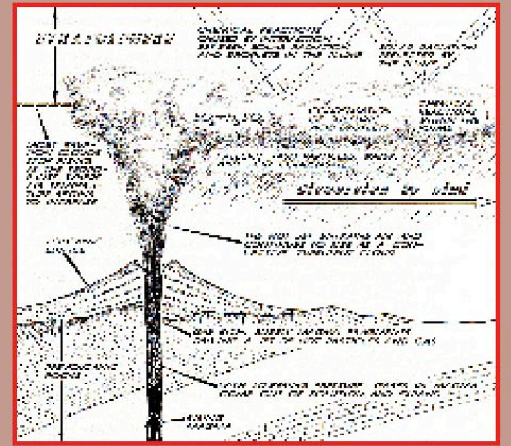




Many of the observations for this study were made within and near the tunnel for the summit-to-museum foot trail (arrow).

Abstract

Historic, sulfur-rich volcanic eruptions have altered global climate for as much as five years, and much larger events known from the geologic record are widely considered as contributory factors to several of the planet's greatest mass extinctions. At Scotts Bluff, Nebraska, early Oligocene strata of the lower Arikaree Group contain several tephra beds. One of these contains abundant calcite pseudomorphs after gypsum. Previous work has shown that sulfate from this tephra bears a strong ^{17}O anomaly indicative of oxidation of reduced sulfur species by ozone or hydrogen peroxide in the atmosphere. A possible source of the tephra was a caldera eruption at about 28 Ma in the San Juan volcanic field of southwestern Colorado (500 km WSW of the study site). The present sedimentologic study shows that tephra and volcanogenic sulfate were deposited and preserved within a small, surface-discharging playa that developed on the irregular upper surface of aeolian siltstones of the subjacent White River Group. Sulfuric acid percolated downward within the vadose zone, dissolving smectite cement within underlying sandstones, reddening these rocks along an irregular alteration front. Preserved fine-scale stratification within the sandstones precludes the possibility that reddening took place during pedogenesis. Displacive growth of gypsum at the playa center folded surficial tephra beds and forced tephra into underlying sandstones, forming elongate cones. The large mass fraction of gypsum (now mostly replaced by calcite) in the playa sediments suggests a huge, long-distance delivery of sulfate aerosols. This sulfate may have arrived concurrently with the tephra, or the fine-grained tephra may simply have aided preservation of dry-fog sulfate derived from an unrelated, effusive eruption of lava.

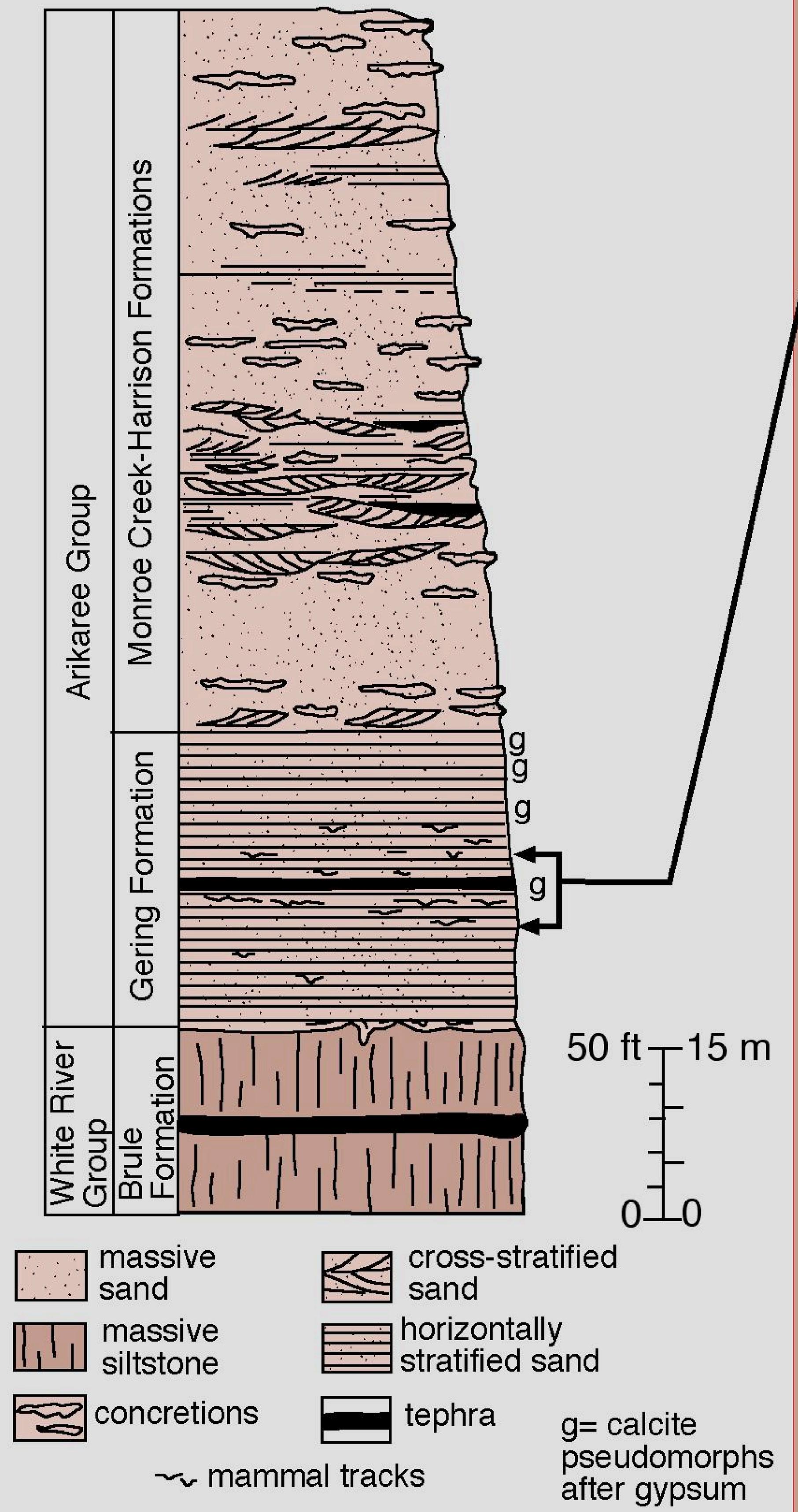


Fisher, Heiken & Hulen, 1997 fig 9-2

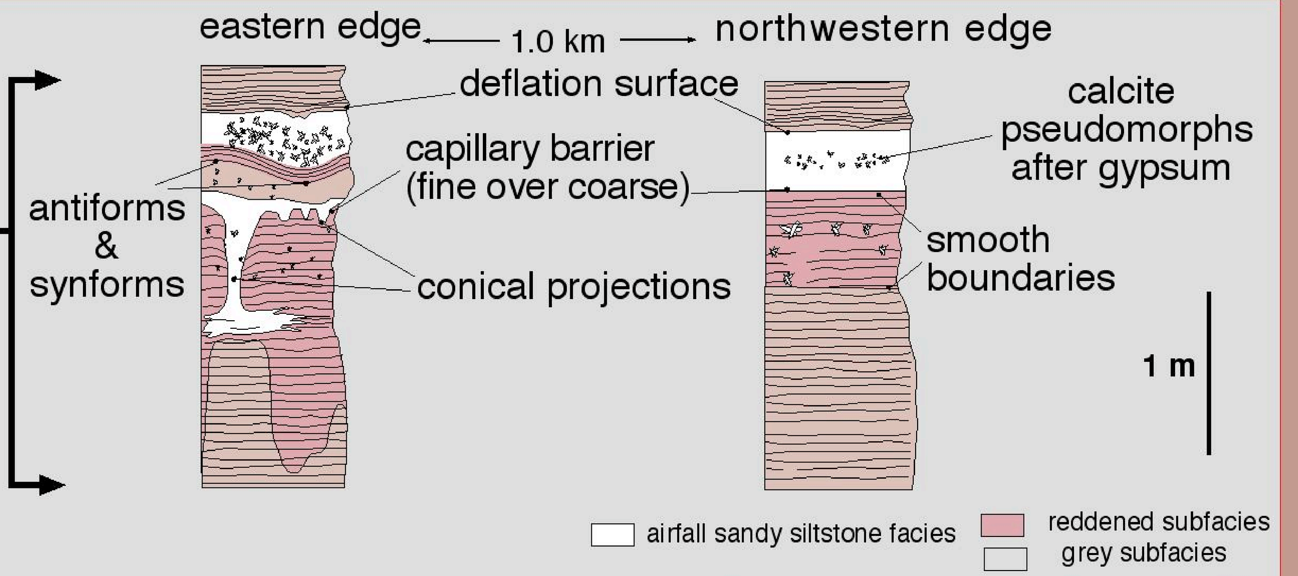
Bao et al. (2000, 2003) showed that sulfate ions from Scotts Bluff strata bear a strong ^{17}O anomaly.This anomaly is evidence that the sulfate is volcanogenic and derived from the atmosphere. Acid rain and dry fogs are likely mechanisms for deposition of the sulfuric acid. The purpose of this paper is to show that the Oligocene depositional setting at Scotts Bluff allowed both accumulation and preservation of this anomalous sulfate.

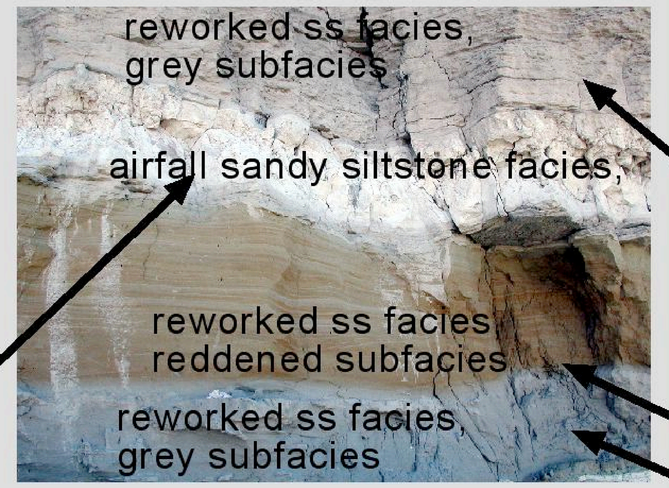
The eruptive source of the tephra and the acid is not yet known. The tephra bed that bears the most gypsum lies within a zone of reversed magnetic polarity that has been correlated to Chron 9, suggesting deposition took place within a time interval of about 300,000 years that ended at about 28 Ma (Tedford et al., 1996, fig. 7). The largest volcanic eruption known from the geologic record (5000 cubic km of ejecta), produced the Fish Canyon Tuff (San Juan Volcanic Field, SW Colorado) and has been dated at 28 Ma. This unit, however, has normal polarity.

Thordarson and Self (2003) estimate that sulfuric acid deposition from the 1783 eruption of Laki was about 1000 kg km^{-2}, averaged over the Northern Hemisphere north of 30º N. Those authors noted that deposition was actually concentrated in western Europe, where it probably occurred at "many times" the zonal average of 1000 kg km^{-2}. For the center of the Oligocene playa (eastern edge of Scotts Bluff), we calculate that the original mass of gypsum was 180 to 200 kg per square meter--2 x 10^8 km^{-2}. If all the sulfate in the gypsum was volcanogenic, and the catchment of the playa was 1000 times the area of the playa center, the the average sulfuric acid deposition across the playa and its catchment could still have exceeded 100,000 kg km^{-2}.



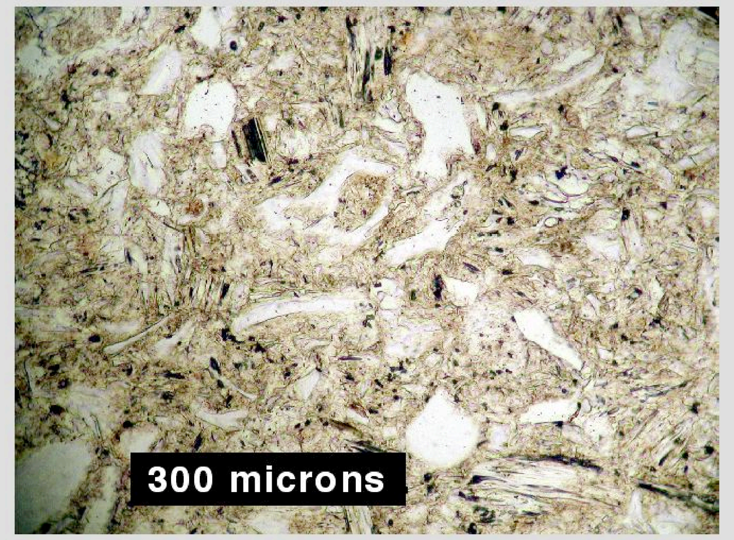
We interpret the flat-bedded strata that make up the Gering Formation at Scotts Bluff as the fill of a **playa** that formed at the irregular upper surface of the Brule Formation--a volcaniclastic eolian deposit strongly resembling loess. Supporting evidence for a playa origin include: 1) multiple horizons of gypsum crystallization; 2) thin, extensive sheets of current-rippled fine sandstone, and 3) absence of channel fills. Thousands of small playas are present today on the surface of the Great Plains where wind erosion has scoured depressions into the Late Pleistocene Peoria Loess.

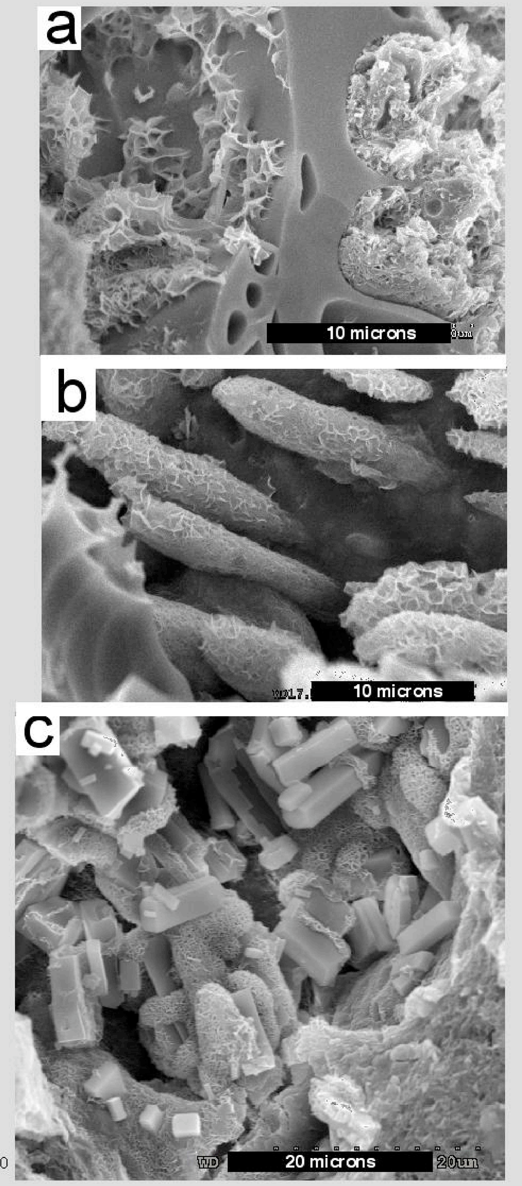




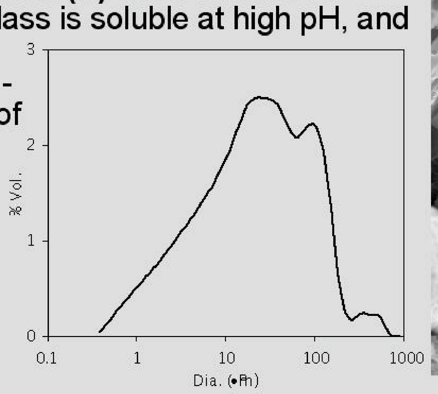
At the eastern edge of Scotts Bluff (left), the airfall facies is deformed into broad folds, the base of the facies has numerous conical projections, and a thick irregular reddened zone is developed in the reworked sandstone below. At the northwestern edge of the butte (right), the airfall facies lacks folds and projections, and the underlying reddened zone is thin and has a smooth lower boundary

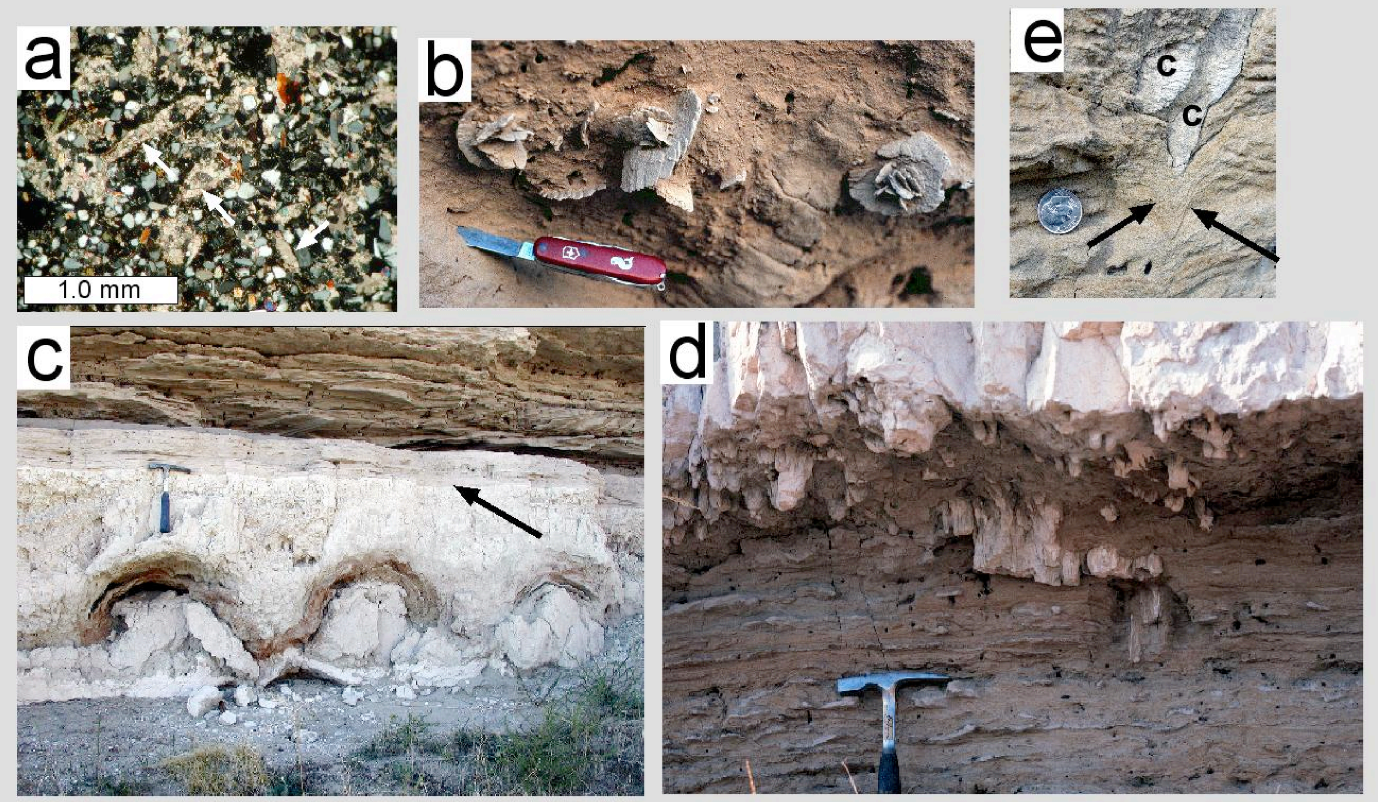
Airfall Sandy Siltstone Facies





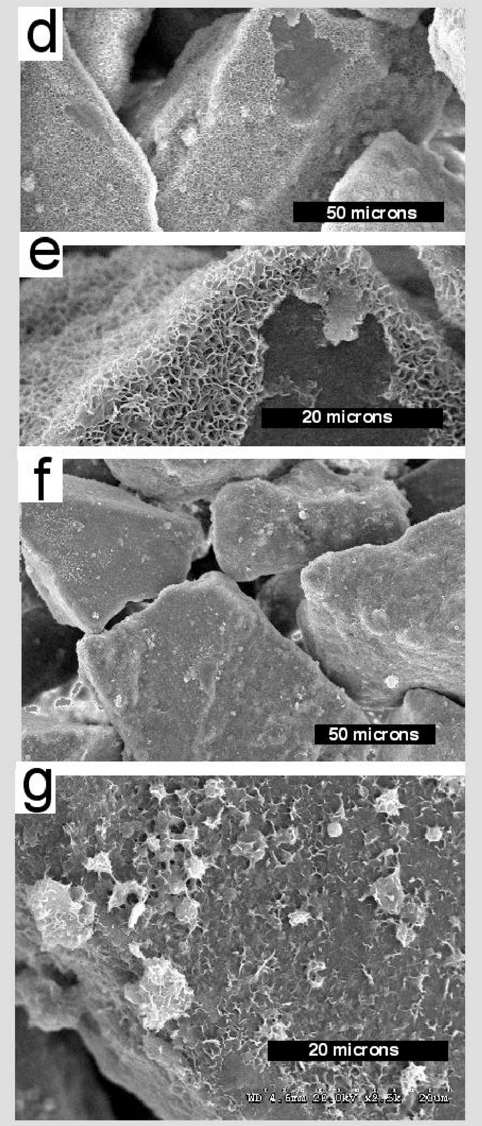
This facies is texturally bimodal: a coarse mode (about 100 microns) composed of glass shards, quartz, and biotite floats in a finer glassy matrix. It is interpreted as a distal airfall deposit. Under the SEM, glass shards are coated with smectite **(a)**. External molds of vesicles **(b)** are evidence for dissolution of glass. Glass is soluble at high pH, and clinoptilolite (zeolite group) crystals **(c)** provide further evidence of alkaline conditions during diagenesis.





Effects of gypsum crystal growth: **a)** lensoid, calcite spar-filled pseudomorphs after displacive gypsum in reworked sandstone facies. **b)** Sand crystals (growth of gypsum surrounded, rather than displaced sand grains). **c)** Antiforms and synforms produced by displacive growth of gypsum in airfall sandy siltstone facies. **d)** Conical projections from base of airfall facies. Displacive gypsum growth in water-saturated airfall material pushed this light-colored sediment downward into unsaturated reworked sandstone that had developed "finger-flow" as water moved along irregular wetting front. **e)** Tips of projecting cones (c) bend laminations in reworked ss (arrows)

Reworked Sandstone Facies

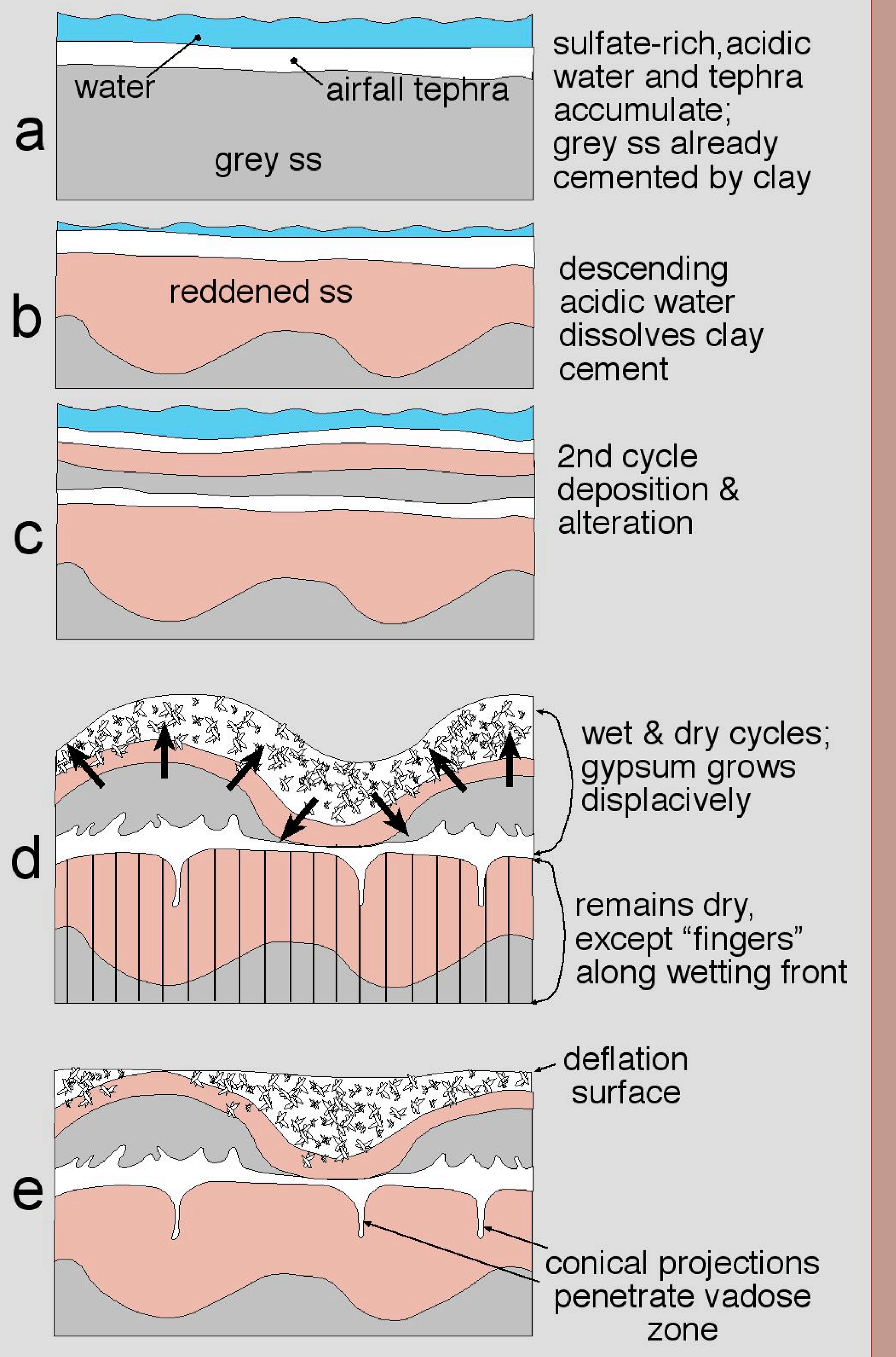


Plane polarized light; blue dye used in epoxy resin

This facies is well sorted and lacks a fine-grained matrix. It is laminated or cross-laminated and is interpreted as a product of the reworking of airfall tephra by wind and flowing water. In the **grey subfacies**, glass shards pumice fragments, quartz, and mica grains are coated by smectite (**d** & **e**).

In the **reddened subfacies**, smectite is either absent or has a corroded appearance (**f** & **g**). The smectite coatings are early cements generated under high pH conditions when glass is undergoing dissolution. The reddening is interpreted to a result of smectite dissolution by acidic water descending through the vadose zone.

Sequence of Events at Playa Center



References

Bao, H., Thiemens, M.H., Farquhar, J., Campbell, D.A., and **Loope, D.B.**, 2000, Anomalous ^{17}O compositions in massive sulfate deposits on the Earth. *Nature*, 406, 176-178.

Bao, H., Thiemens, M.H., and **Loope, D.B.,** and **Yuan, X-L.,** 2003, Sulfate oxygen-17 anomaly in a Cenozoic Oligocene ash bed in mid-North America: Was it the dry fogs? *Geophysical Research Letters,* 30 (16) article #1843.

Fisher, R.V., Heiken, G., and **Hulen, J.B.,** 1997, *Volcanoes: Crucibles of Change*: Princeton University Press: 317p.

Swinehart, J.B. and **Loope, D.B.,** 1987, Late Cenozoic geology of the summit to museum trail, Scotts Bluff National Monument, Nebraska: Geological Society of America Centennial Field Guide-- North Central Section, pp. 13-18.

Tedford, R.H., Swinehart, J.B., Swisher, C.C., III, Prothero, D.R., King, S.A., and Tierney, T.E., 1996, The Whitneyan-Arikareean transition in the High Plains. In *The Terrestrial Eocene-Oligocene Transition in North America* (Eds. D.R. Prothero, and R.J. Emry). Cambridge University Press, Cambridge, pp. 312-334.

Thordarson, T., and **Self, S**., 2003, Atmospheric and environmental effects of the 1783-1784 Laki eruption: A review and reassessment. *J. Geophys. Res.*, **108**, D1, 4011