# Geologic Resources Inventory Scoping Summary Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument, Texas

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U.S. Department of the Interior

The Geologic Resources Inventory (GRI) Program, administered by the Geologic Resources Division (GRD), provides each of 270 identified natural area National Park System units with a geologic scoping meeting, a scoping summary, a digital geologic map, and a geologic resources inventory report. Geologic scoping meetings generate an evaluation of the adequacy of existing geologic maps for resource management, provide an opportunity to discuss park-specific geologic management issues and, if possible, include a site visit with local experts. The purpose of these meetings is to identify geologic mapping coverage and needs, distinctive geologic features and processes, resource management issues, and potential monitoring and research needs.

The Geologic Resources Division held a GRI scoping meeting for Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument on May 11, 2011, at the headquarters/visitor center in Fritch, Texas. Participants at the meeting included NPS staff and volunteers from the national recreation area, national monument, and the Geologic Resources Division; and cooperators from the Texas Bureau of Economic Geology and Colorado State University (see table 2, p. 22).

During the meeting, acting superintendent Arlene Wimer welcomed the group and expressed her support of the GRI Program by saying, “geology is a fundamental characteristic of the park, so this is great; it fills a void.” Tim Connors (Geologic Resources Division) facilitated the group’s assessment of map coverage and needs, and Bruce Heise (Geologic Resources Division) led the discussion of geologic features, processes, and issues. Eddie Collins (Texas Bureau of Economic Geology) presented background information about the geology of the Lake Meredith area, and suggested numerous publications of relevance for the national recreation area and national monument. Hard copies of many of these publications are now part of the GRD library in Lakewood, Colorado. The author used some of these publications in preparing the scoping summary: Gustavson et al. (1980), McGillis and Presley (1981), Gustavson and Finley (1985), and Gustavson (1996); these are listed in “Literature Cited” section of this scoping summary. Other publications that were recommended by Collins, but not cited in this scoping summary, are listed in the “References of Interest” section.

During the site visit, participants drove to the Fritch Fortress area at the north end of the national recreation area and made several stops that highlighted chimneys (distinctive “collapse features” in the Permian strata) (fig. 1), mass wasting (slumps and scarps) around the lake (fig. 2), oil and gas operations (see fig. 9), a view of the dam, and the extreme reduction of water in the reservoir resulting in the formation of “seasonal wetlands.” Participants also traveled to the central part of the national recreation area to view the site of the potential geologic trail (figs. 3 and 10). Staff members at the national recreation area are proposing to build a trail that will highlight the area’s geology; the proposal will be an alternative in the general management plan (GMP), which is currently in the planning stages. Additionally, during the site visit, volunteer Glendon Jett led scoping participants on a walk to the quarries in Alibates Flint Quarries National Monument. The trail passed through colorful Permian (299 million to 251 million years ago) red beds (fig. 4).

On May 12, GRI team members toured the exhibits related to the Alibates Flint Quarries at the Panhandle-Plains Historical Museum in Canyon, Texas, and met with Jeff Indeck, chief curator at the museum, who showed them raw materials and tools made of Alibates flint. The Panhandle-Plains Historical Museum is the repository for artifacts from Alibates Flint Quarries National Monument and Lake Meredith National Recreation Area. In addition, Joe Rodgers, a volunteer at the museum, discussed his work using preserved chunks of daub (building material made of mud) to understand how houses of the Southern Plains villagers were constructed. Team members also met with Gerald Schultz, a vertebrate paleontologist and geology professor at West Texas A&M University in Canyon, Texas. At Palo Duro Canyon State Park, team members viewed and hiked through a more complete section of Permian, Triassic, and Pliocene strata, including formations exposed at Alibates Flint Quarries National Monument and Lake Meredith National Recreation Area.

**Figure 1. Chimney. Chimneys formed as a result of dissolution of salts in the Permian red beds and later collapse of overlying strata into these depressions. Most chimneys, such as this one near Fritch Fortress, are exposed in road cuts or bluffs, although some stand in relief (see fig. 10). Photo by Katie KellerLynn.**

**Figure 2. Mass wasting. Mass wasting in the form of rotational slumps and scarps, shown here at Fritch Fortress, occurs primarily around the perimeter of Lake Meredith. Mass wasting is induced by wave action and fluctuating water levels. Photo by Katie KellerLynn.**

**Figure 3. Site of potential geologic trail. As a result of lack of water in Lake Meredith, managers at the national recreation area are focusing their planning efforts on land-based recreation, including a proposed trail leading to geologic features characteristic of the area. Photo by Katie KellerLynn.**

**Figure 4. Permian red beds at Alibates Flint Quarries National Monument. As mapped by Barnes and Eifler (1981), the Permian red beds at Alibates Flint Quarries and Lake Meredith are composed of three undifferentiated rock units—the Quartermaster Formation, Cloud Chief Gypsum, and Whitehorse Sandstone. These are the oldest rocks exposed in the national recreation area and national monument. Photo by Katie KellerLynn.**

## Park Setting

Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument are located northeast of Amarillo, Texas, in the Texas Panhandle. The national recreation area covers parts of Hutchinson, Moore, and Potter counties. Alibates Flint Quarries National Monument is in Potter County. In 1962, the Bureau of Reclamation began construction of the Sanford Dam on the Canadian River, which created Lake Meredith. The lake was named for A. A. Meredith, an early promoter of the dam. The dam was named for the nearby town of Sanford, Texas. The reservoir was established primarily to provide a surface-water supply for 11 municipalities in the Texas Panhandle: Borger, Pampa, Amarillo, Plainview, Lubbock, Levelland, Brownfield, Slaton, Tahoka, O'Donnell, and Lamesa. The Canadian River Municipal Water Authority operates and maintains 518 km (322 mi) of pipeline, 10 pumping plants, and three regulating reservoirs. In 1965, the National Park Service became the steward of the land surrounding the reservoir—more than 18,203 ha (44,978 ac)—and has been responsible for developing recreational and interpretive facilities. Formerly "Sanford National Recreation Area," Congress renamed and established "Lake Meredith National Recreation Area" in 1972. Today, visitors enjoy hiking, fishing, hunting, picnicking, camping, and when lake levels allow, boating and other forms of water-based recreation.

Alibates Flint Quarries National Monument was established in 1965 to protect the prehistoric quarries of flint, prized for both its excellent tool-making properties and its beauty (see fig. 7). The national monument encompasses 555 ha (1,371 ac) of land adjacent to the east-central part of Lake Meredith National Recreation Area. The national recreation area and national monument are administered jointly by the National Park Service. The National Park Service shares some administrative responsibilities with the Bureau of Land Management (BLM) on lands surrounding Lake Meredith.

The two units of the National Park System straddle a major structural boundary between two basins, the Palo Duro Basin and the Anadarko Basin. This structural boundary is referred to as the "Amarillo uplift," which extends southeast-northwest from New Mexico to central Oklahoma (fig. 5). As a result of the Amarillo uplift, the stratigraphy of the southwestern end of Lake Meredith National Recreation Area is distinct from the rest of the recreation area and Alibates Flint Quarries National Monument. In particular, Triassic strata, namely the Tecovas and Trujillo formations, are only preserved in the southwest part of the national recreation. These formations are part of the Palo Duro Basin stratigraphy to the south.

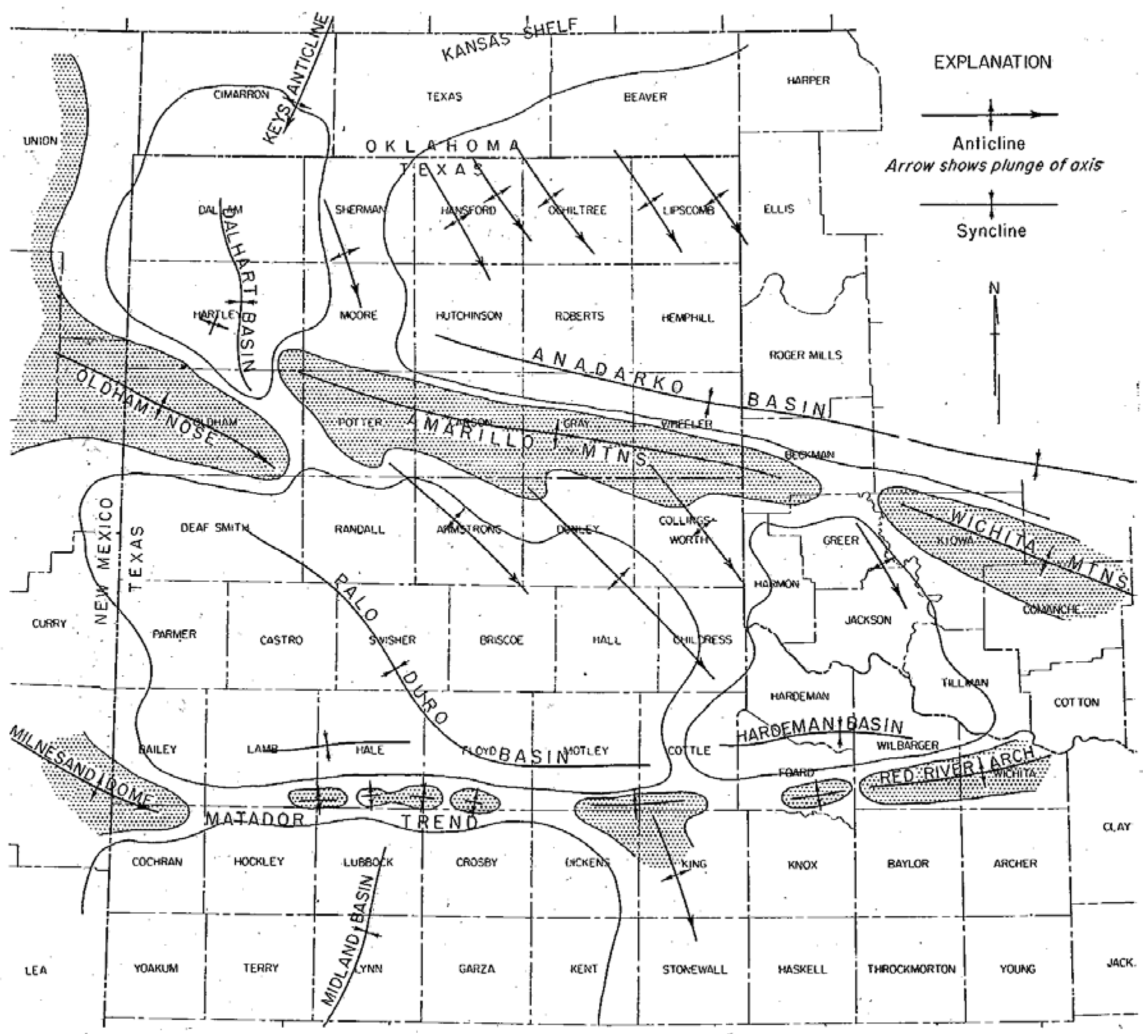


Figure 5. Major structural features of the Texas Panhandle. Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument straddle a major structural boundary between two basins—the Palo Duro Basin and the Anadarko Basin. The structural boundary is referred to as the "Amarillo uplift" (indicated as "Amarillo Mountains" on the figure), which extends southeast into central Oklahoma. The Wichita Mountains in Oklahoma are part of the uplift. The national recreation area covers parts of Hutchinson, Moore, and Potter counties. Alibates Flint Quarries National Monument is in Potter County. From Nicholson (1960).

Distinctive geologic features of this area of the panhandle are the Permian red beds exposed in the "breaks" of the Canadian River. The breaks were formed when the Canadian River cut through the "caprock" and the underlying Triassic strata into the Permian beds below. The caprock is a widespread layer of caliche (erosion-resistant, calcium-carbonate rock) that marks the top of the Tertiary Ogallala Formation in Texas and New Mexico. The Ogallala Formation, which underlies much of the Great Plains, makes up the land surface above the breaks. The Ogallala Formation has particular significance for the area because it contains the Ogallala aquifer—the major source of water for agricultural and domestic use on the Southern High Plains of Texas and New Mexico (Gustavson 1996). Notably, the Ogallala Formation also yields fossils (see "Paleontological Resources" section).

## Geologic Mapping for Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument

During the scoping meeting, Tim Connors (Geologic Resources Division) presented some of the main features of the GRI Program's digital geologic maps, which reproduce all aspects of paper maps, including notes, legend, and cross sections, with the added benefit of being GIS compatible. The NPS GRI Geology–GIS Geodatabase Data Model incorporates the standards of digital map creation for the GRI Program and allows for rigorous quality control. Staff members digitize maps or convert digital data to the GRI digital geologic map model using ESRI ArcGIS software. Final digital geologic map products include data in geodatabase and shapefile format, layer files complete with feature symbology, Federal Geographic Data Committee (FGDC)–compliant metadata, a help file that captures ancillary map data, and a map document that displays the map and provides a tool to directly access the help file.

When possible, the GRI Program provides large-scale (1:24,000) digital geologic map coverage for each unit's area of interest, which is generally composed of the 7.5' quadrangles that contain NPS-managed lands. In the lower 48 states, large-scale mapping is usually defined as "one inch to 2,000 feet" or quadrangles produced at a scale of 1:24,000 on a 7.5' × 7.5' base. There are thirty-two 7.5' quadrangles on a 30' × 60' (scale 1:100,000) sheet. Maps of this scale (and larger) are useful for resource management because they capture most geologic features of interest and are spatially accurate within 12 m (40 ft). The process of selecting maps for resource management begins with the identification of existing geologic maps in the vicinity of the National Park System unit. Scoping participants then discuss mapping needs and select appropriate source maps for the digital geologic data or, if necessary, develop a plan to obtain new mapping.

Prior to the scoping meeting, the National Park Service had identified twelve 7.5' quadrangles of interest for Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument: Little Blue Creek, Pollard Creek, Camp Creek, Spencer Draw, Evans Canyon, Sanford, McDowell Creek, Alibates Ranch, Deal, Chunky, Berry Sand Draw, and Pomeroy (fig. 6). Considering that managers at Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument have joint management responsibilities on BLM lands surrounding the national recreation area for helium extraction, fire management, and law enforcement, Lake Meredith staff proposed the following 18 quadrangles for inclusion in the final map product: Dumas South, Little Blue Creek, Pollard Creek, Camp Creek, Stinnett, Masterson, Spencer Draw, Evans Canyon, Sanford, Borger, Marsh, McDowell Creek, Alibates Ranch, Deal, Boden, Puente, Chunky, and Berry Sand Draw (fig. 6). All of these quadrangles are in Texas. Parts of Lake Meredith National

Recreation Area or Alibates Flint Quarries National Monument intersect most of these quadrangles. The "non-intersecting" quadrangles are upstream from the national recreation area and are of interest due to steamflow and erosion potential (Steve Fisher, GIS specialist–fire/biologist, Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument, e-mail communication to Tim Connors, geologist, Geologic Resources Division, June 14, 2011). All but the Boden 7.5' quadrangle are part of the Amarillo 1° × 2° sheet. The Boden 7.5' quadrangle is part of the Tucumcari 1° × 2° sheet. Both the Amarillo and Tucumcari sheets are available from the Texas Bureau of Economic Geology as part of the *Geologic Atlas of Texas* (scale 1:250,000). The Texas Water Development Board has digitized the Amarillo and Tucumcari 1° × 2° sheets as part of the "Geologic Database of Texas." These data are available at [http://www.tnris.state.tx.us/datadownload/download.jsp](http://www.tnris.state.tx.us/datadownload/download.jsp) (accessed June 28, 2011). GRI staff plans to convert these data to the NPS data model.

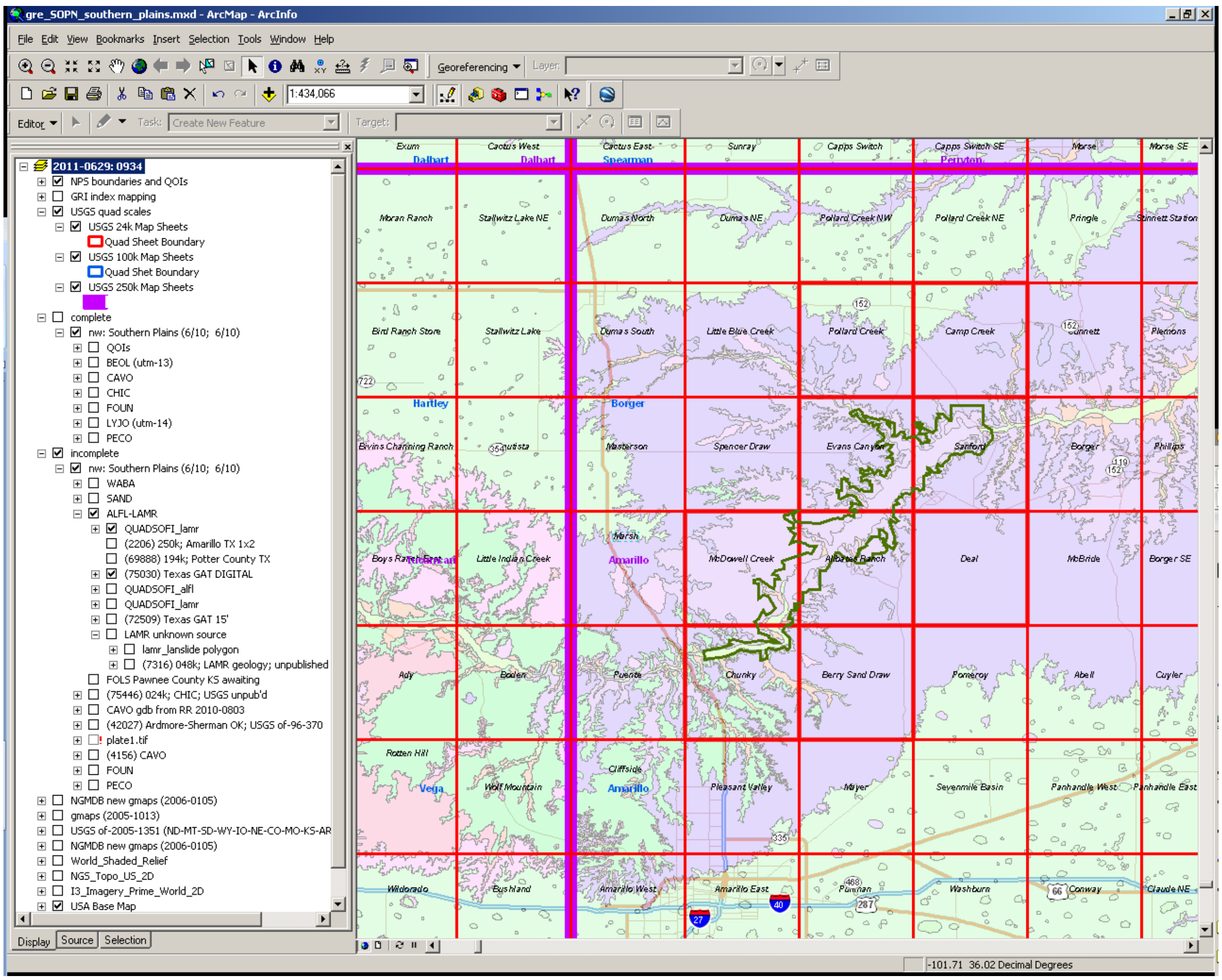


**Figure 6. Geologic data for Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument. The figure shows portions of the Amarillo and Tucumcari 1° × 2° sheets of the *Geologic Atlas of Texas* (scale 1:250,000). The NPS boundaries are outlined in green. The red boxes indicate USGS 7.5-minute quadrangles. The figure shows a screen capture of Barnes and Eifler (1981) (Amarillo sheet) and Eifler et al. (1983) (Tucumcari sheet).**

During the scoping meeting, Eddie Collins (Texas Bureau of Economic Geology) pointed out that the Amarillo 1° × 2° sheet, originally published in 1969 (Eifler et al. 1969), was revised in 1981. The Barnes and Eifler (1981) revision shows the Alibates Dolomite as a map unit. Since scoping, GRI staff noticed that the Amarillo sheet was reprinted in 1998. Hence, GRI staff will need to insure that the data in the final GRI product include the Alibates Dolomite as a designated unit. For the Amarillo 1° × 2° sheet, potential source publications are Eifler et al. (1969), Barnes and Eifler (1981), and Eifler and Barnes (1998). For the Tucumcari 1° × 2° sheet, Eifler et al. (1983) is the source.

The Amarillo and Tucumcari sheets are relatively small scale. No large-scale geologic data have been published for Lake Meredith National Recreation Area or Alibates Flint Quarries National Monument. However, an option for providing larger scale data (i.e., larger than scale 1:250,000) may be Wilson (1988)—a Master's thesis from West Texas State University (now West Texas A&M University). Wilson (1988) mapped four of the quadrangles of interest: Alibates Ranch, Chunky, Berry Sand Draw, and McDowell Creek (see fig. 6). Hunt and Santucci (2001) mentioned Wilson (1988) as an "important reference" that includes a "detailed study and mapping" of these four quadrangles. GRI staff members assume that these quadrangles were mapped at a scale of 1:24,000, but they will need to obtain the thesis to verify. The Alibates Ranch quadrangle covers Alibates Flint Quarries National Monument, so it may be of interest to national monument staff. Wilson (1988) may provide details of the Alibates Dolomite (and outcrops of flint) not available at the scale of the Amarillo 1° × 2° sheet. GRI staff will evaluate Wilson (1988), consult with staff at Alibates Flint Quarries National Monument, and decide whether to include the Alibates Ranch (and the other three quadrangles) as part of the final GRI product.

## Geologic Features, Processes, and Issues

The scoping meeting for Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument provided an opportunity to discuss geologic features and processes, many of which have associated issues of management concern.

### Stratigraphy

During the scoping meeting, Eddie Collins (Texas Bureau of Economic Geology) introduced scoping participants to the rocks units exposed at Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument. The Texas Panhandle is encumbered with a variety of stratigraphic names derived from the mid-continent region, Rocky Mountains, west Texas, north and central Texas, the Amarillo uplift, and the various basins in the immediate area, including the Palo Duro, Dalhart, and Anadarko basins. Correlation could drive a person mad, but in an attempt at simplicity, this scoping summary uses the units shown on Barnes and Eifler (1981) (table 1).

**Table 1. Rock units at Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument**

| Age | Map unit (symbol) | Rock and sediment type | Depositional setting |
|---|---|---|---|
| Holocene Epoch | Alluvium (Qal) | Floodplain deposits | Fluvial |
| | Windblown sand (Qs), locally formed into dunes (Qsd) | Sand and silt | Eolian |
| Pleistocene Epoch | Fluviatile terrace deposits (Qt) | Gravel, sand, and silt | Fluvial |
| Tertiary*<br>Pliocene Epoch | Ogallala Formation (To) | Sand, silt, clay, gravel, and caliche | Fluvial, eolian, and lacustrine |
| Triassic Period | Trujillo Formation ($T_R$dj) | Conglomerate, sandstone, and shale | Fluvial |
| | Tecovas Formation ($T_R$dv) | Shale, clay, siltstone, and sand | Fluvial |
| Permian Period | Alibates Dolomite (Pqwa) | Two dolomite layers separated by shale | Intertidal |
| | Quartermaster Formation, Cloud Chief Gypsum, and Whitehorse Sandstone, undivided (Pqw) | Interbedded sandstone, sand, siltstone, shale, gypsum, and dolomite | Restricted marine/closed basin |

*The term "Tertiary" is now used informally. The Paleogene (65.5 million to 23.0 million years ago) and Neogene (23.0 million to 2.6 million years ago) periods are the formally designated terms to cover this segment of geologic time.

The Permian units are the oldest units in the national recreation area and national monument; they are the distinctive "red beds," which are composed of three undifferentiated rock units—the Quartermaster Formation, Cloud Chief Gypsum, and Whitehorse Sandstone. The Alibates Dolomite is a component of these red beds. "Alibates Dolomite" and "Alibates Formation" are both formally recognized names in the geologic lexicon, "GEOLEX," of the U.S. Geological Survey (U.S. Geological Survey 2007). Gould (1907) named the Alibates Dolomite for Alibates Creek in Potter County and considered the unit as a member of the Quartermaster Formation. According to Bowers (1975), "Alibates" was a modification of the name Allen Bates, the son of a local rancher. The movie shown in the visitor center at the national monument says "Ali Bates" was a local ranch hand.

According to McGillis and Presley (1981), Alibates strata accumulated during a transgressive-regressive episode. Initial transgression (sea level rise/shoreline retreat) is recorded as an extensive basal dolomite. Subsequent regression (sea level fall/shoreline advance) resulted in deposition of thick deposits of evaporite rocks.

In any given exposure at the national recreation area or national monument, the Alibates Dolomite may comprise an upper and lower dolomite bed separated by shale. However, the upper dolomite bed is commonly absent, having been eroded away. The lower, thicker layer is very resistant to erosion and often forms ledges with an average thickness of 5 m (15 ft). These ledges form a capstone on the bluffs throughout the national recreation area and national monument. This "capstone" should not be confused with the regional-scale caprock that marks the top of the Ogallala Formation throughout the Texas Panhandle. On average, the caprock is twice as thick as the capstone; that is up to 10 m (33 ft) thick (Hunt and Santucci 2001).

#### Alibates Flint

Significant for the Alibates Flint Quarries, silica replaced dolomite in various locales, resulting in the formation of "Alibates flint," also referred to as "Alibates chert," "Alibates agate," "Alibates agatized dolomite," and "Alibates silicified dolomite" (Quigg et al. 2009). In keeping with the name of the national monument, this scoping summary will use "Alibates flint." The source of the silica in the Alibates flint is unknown, but various investigators have hypothesized about its origin, for instance, Bowers and Reaser (1996). Hypotheses also include Joseph Cepeda's (West Texas A&M University in Canyon, Texas) ideas about volcanic ash as the source. These hypotheses will be investigated and presented in the final GRI report.

As described by Barnes and Eifler (1981), the Alibates Dolomite is composed of two layers of dolomite, separated by shale. Only the upper dolomite layer has been completely replaced by silica. The lower dolomite member contains minor amounts of flint in the form of spheres and nodules (Bowers and Reaser 1996). At Alibates Flint Quarries National Monument, the upper dolomite unit forms massive, tabular sheets that range in thickness from 0.2 m (0.7 ft) to 0.6 m (2 ft) and extend laterally for more than 1,000 m (3,280 ft) in an outcrop (Bowers and Reaser 1996) that was the source for the quarries. The flint is mottled or banded red, pink, pale blue, pale purple, gray, brown, and black (fig. 7). With the advent of Google Earth, the locations of protected sites of Alibates flint are accessible for public viewing. The primary concern is theft. Staff members at the national monument are particularly vigilant after fires, when the quarries really "stand out" with the lack of protective vegetation.

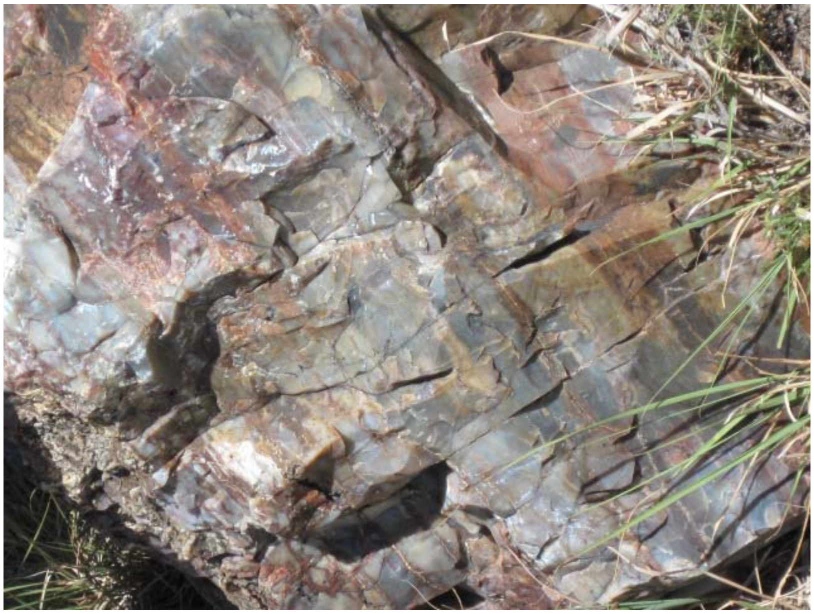

**Figure 7. Alibates flint. Where the Alibates Dolomite was replaced by silica, Alibates flint formed. The flint can be mottled or banded red, pink, pale blue, pale purple, gray, brown, and black. Photo by Katie KellerLynn.**

The distinctive appearance of the flint makes it readily identifiable to archeologists at sites all over the country (Parent 1993). Scoping participants noted that specimens of Alibates flint have been identified at Pecos National Historical Park in New Mexico, making a nice connection between these two National Park System units. Some evidence suggests that Alibates flint has appeared in sites in Minnesota. However, until recently, a method for absolutely identifying the material had not been established. In 2009, Michael Quigg and others presented a paper at the 67th Annual Plains Anthropological Conference in Norman, Oklahoma. This paper described the Alibates flint ("agatized dolomite"), Tecovas jasper, and a method (using geochemistry) for distinguishing between them. The Tecovas material occurs in outcrops at the west end of the national recreation area, as well as in Caprock Canyon State Park in Quitaque, Texas. Future studies will strive to make quarry-specific identifications of the materials. According to Quigg et al. (2009):

> The visual distinction between these two Southern Plains chert types partially overlaps in color, banding patterns, texture, and translucency. To help resolve this visual identification problem, samples from five spatially distinct Tecovas outcrops and two spatially distinct Alibates outcrops and one gravel source were obtained and submitted for instrumental neutron activation analysis (INAA) at the University of Missouri Research Reactor (MURR) Archaeometry Laboratory. The INAA results geochemically separate Tecovas and Alibates and further differentiate geochemical signatures of multiple Tecovas source areas. These chemical results can now be used to correctly identify and sort chipped stone tools and debitage [waste material produced during the production of stone tools] from archeological contexts beyond the two source areas.

In addition to human transport of this high-quality material, the Canadian River, which cuts into the Permian red beds, has transported pieces of Alibates flint downstream into western Oklahoma. Fluvially transported flint appears in gravel deposits along the Canadian River as far as 275 km (170 mi) away. Some of the material is cobble-sized and would be suitable for the production of stone tools (Quigg et al. 2009). However, these specimens should not be confused with those transported by humans. In general, Alibates flint transported downstream by fluvial processes will have the rounded and polished surfaces of “river rock,” in contrast to quarried sources that exhibit rough or pitted surfaces.

### Fluvial Features and Processes

In the Texas Panhandle, the flat surface of the Great Plains is broken by the valley of the Canadian River. This valley is referred to as the “Canadian Breaks.” The breaks are as much as 64 km (40 mi) wide and 300 m (1,000 ft) deep (Gustavson 1986). The valley formed mostly from regional subsidence following dissolution of salts in the Permian red beds (Gustavson 1986) (see “Cave and Karst Features and Processes”). Continued dissolution and subsidence helped to deepen the valley (Gustavson 1986).

Today, the Canadian River is a small stream that intermittently flows in this large valley. Human activities such as irrigation diversion and dam construction have affected the hydrology of the Canadian River and caused significant changes in channel morphology (Buchanan 1994). Within Lake Meredith National Recreation Area, the river channel of the once braided stream has silted in. Streamflow has been reduced to sheet flow during times of heavy rainfall. Because floods no longer scour the “lake bottom,” as they did in the 1950s, salt cedar (tamarisk) has invaded thousands of acres of the riparian corridor, resulting in the loss of habitat and native species such as cottonwood. The National Park Service is using herbicides to treat the invasion, and currently 3,600 ha (9,000 ac) at the national recreation area host “skeletal remains” of this invasive plant.

The headwaters of the Canadian River are in the Sangre de Cristo Mountains of New Mexico. Two dams upstream in New Mexico, domestic use for 11 municipalities, stock ponds, and irrigation have intercepted streamflow and lowered the water table. Human activities have also affected the side streams of the Canadian River. Most of the side streams at Lake Meredith are spring fed, with springs serving as the headwaters. The springs/headwaters are outside the national recreation area, and most host stock ponds, which intercept streamflow at the source. Additional water wells for Amarillo will likely result in the loss of flow in some of the tributaries, for example Chicken Creek, near the south end of the national recreation area. Bonita Creek, south of Chicken Creek, sometimes hosts ponds as a result of beaver use. One of the only side streams that has consistently flowing water is Big Blue Creek, at the north end of the national recreation area. This creek flows seasonally in the winter but is dry during other times of the year.

During the scoping meeting, participants mentioned that terraces are a significant fluvial feature at Lake Meredith. Barnes and Eifler (1981) mapped prominent Pleistocene “fluviatile terrace deposits” on the Amarillo 1° × 2° sheet. These deposits are composed of gravel, sand, and silt, and occur northeast and southwest of Lake Meredith. Cepeda and Allison (1997) discussed the geologic history and geomorphology of terraces along West Amarillo Creek—a 48-km- (30-mi-) long tributary to the Canadian River near the southwestern end of the national recreation area. Scoping participants mentioned Joseph Cepeda (West Texas A&M University) as a potential source of information about terraces (and ash deposits). His findings about West Amarillo Creek may be applicable for the geologic history and development of the tributaries of the Canadian River within the national recreation area.

## Hillslope Features and Processes

The topography within Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument is relatively rugged because of the Canadian Breaks. The breaks make up an area of undulating hills, slopes, and canyons in sharp contrast to the flat prairies of the High Plains. Steep slopes, especially around the perimeter of Lake Meredith, are susceptible to mass wasting (gravity-driven processes). Rotational slumping is the most common type of mass wasting at the national recreation area and national monument (National Park Service 2000). Most of the slumps are on the north side of Lake Meredith on south-facing slopes, for example at North Turkey Creek. At higher pool levels, wave action and fluctuating water levels are factors in mass wasting. During the site visit, scoping participants noted slump features at Fritch Fortress (fig. 2). In addition, boulders of Alibates flint up to 2 m (7 ft) in diameter commonly roll down slopes and settle on the lake bed, for example at Cedar Canyon. Slumping also occurs at the borrow pit between North Canyon and the road; sand extraction created this site during construction of the Sanford Dam.

In June 2000, staff from the Geologic Resources Division (GRD) conducted a site visit to the national recreation area in response to a technical assistance request. The trip report associated with this site visit presented preliminary alternatives and cost estimates for stabilization at the three highest priority sites: Stilling Basin road (located downstream of the Sanford Dam spillway between a steep slope and a stilling basin pool), Blue West boat ramp, and Sanford-Yake boat ramp (Pranger 2000). The national recreation area spent between $100,000 and $200,000 to upgrade the parking area at Sanford-Yake. Unfortunately, the long-term use of this area for boating is likely not viable.

## Lacustrine Features and Processes

Although the reservoir filled during the first year after construction of the Sanford Dam, it has never reached its projected capacity level of 39 m (127 ft). According to scoping participants, the highest pool level ever reached was 31 m (103 ft). The last "high"—27 m (90 ft)—was reached in 1999 after a period of heavy flooding in the Canadian River watershed. Covering an area roughly between Blue West and the Sanford Dam at the time of scoping, lake waters were a fraction of that depicted on the park guide printed in 2004. No boats have launched from the Harbor Bay ramp since 2008.

Today, there are "seasonal wetlands" where the lake used to be. Islands are now peninsulas and can be reached by foot. For example, visitors now can walk out to Rattlesnake Island (labeled as "Arrowhead Island" on the park map/guide). Also, there are a growing number of beaches for recreation, and direct water access for visitors without boats. As a result of lower lake levels, future plans for the national recreation area are focusing on land-based activities.

## Eolian Features and Processes

Wind is ubiquitous across the Texas Panhandle. For this reason, Texas is first in the nation in wind farms, surpassing California in 2006 (Krauss 2008). Dumas, Texas, is currently a hot spot for wind-energy development, and wind farms are closing in on Fritch. According to scoping participants, "everything blows away here." Participants saw eolian processes in action during the site visit, as steady winds churned up dust and transported it across the seasonal wetlands south of Fritch Fortress (see fig. 9).

Receding lake levels are exposing large, formerly submerged areas of lake bed to eolian processes; this is particularly apparent in the Big Blue Creek area. In addition, oil and gas activities can denude vegetation and expose the ground surface to wind erosion. On some pads, oil and gas operators have placed mats to reduce the amount of material available for eolian transport. Windblown dust is filling in the historic quarries with an estimated 23 cm (9 in) in the last 500 years (GRI scoping notes, Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument, May 11, 2011).

The Amarillo 1° × 2° sheet shows three types of eolian features: windblown sand (sand sheets), sand dunes, and loess. Loess (windblown silt) covers a vast expanse south of the national recreation area, but was not mapped within the national recreation area or national monument. Participants surmised that playa lakes, which are a significant feature in the Texas Panhandle, may be the source of the loess. During the scoping meeting, participants mentioned that sand dunes occur at Rosita in the south part of the national recreation area. These dunes are large enough to appear on the Amarillo sheet (scale 1:250,000). Some of the dunes are now stabilized with vegetation.

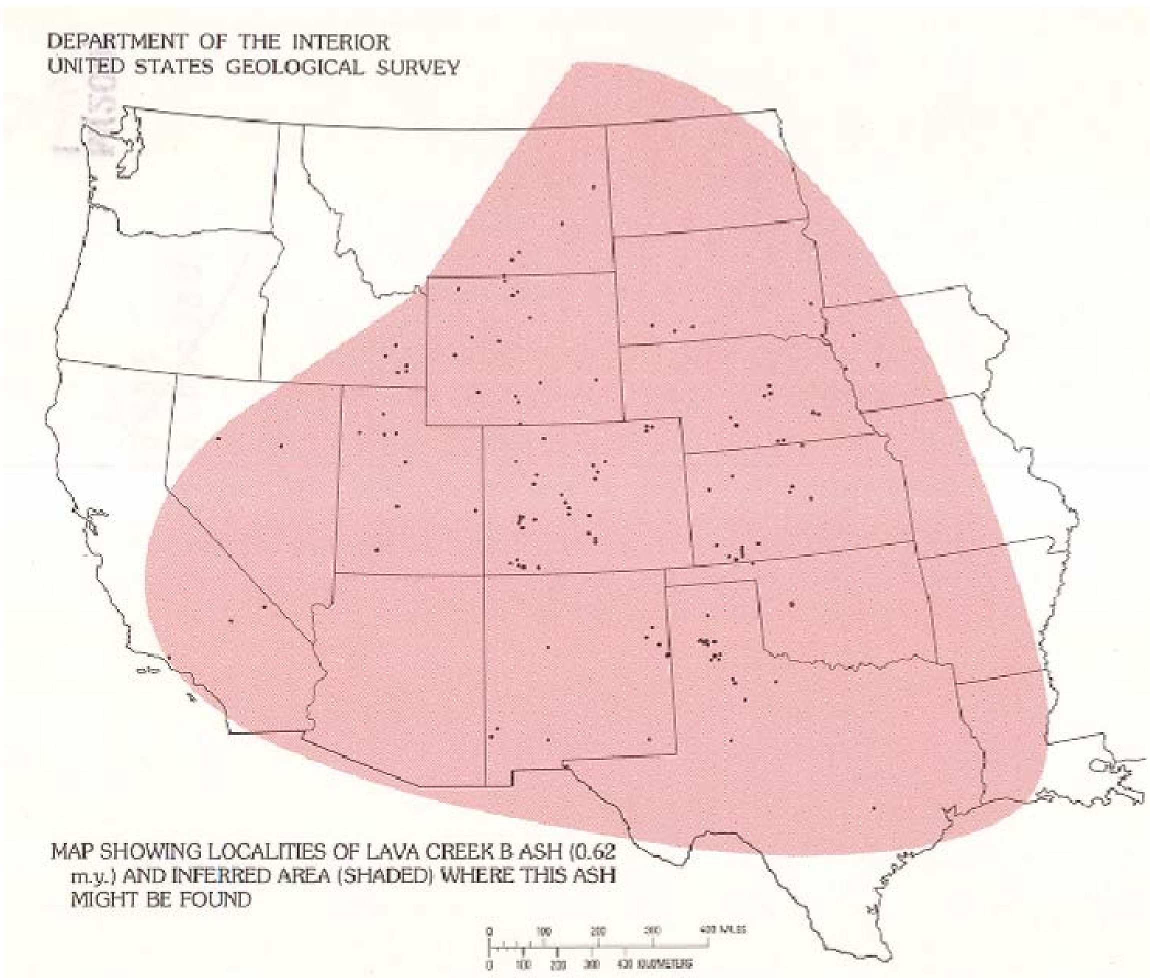


**Figure 8. Lava Creek B ash. The red shading on the figure shows the estimated area of coverage of the Lava Creek B ash that erupted from the Yellowstone caldera approximately 620,000 years ago. A sample site for the ash occurs on the border of Moore and Potter counties. An older ash layer from the Huckleberry Ridge eruption (2.02 million years ago) was sampled in Moore County (sample site not shown on this figure). From Izett and Wilcox (1982).**

A distinctive eolian feature in the Texas Panhandle is windblown ash from the Yellowstone caldera. Izett and Wilcox (1982) mapped late Cenozoic ash fall tephra from the Huckleberry Ridge, Mesa Falls, and Lava Creek volcanic fields (known as the "Pearlette family" of ash) across the Great Plains and parts of the western United States, including Texas, New Mexico, Oklahoma (fig. 8). These ashes are from the Pliocene (5.3 million to 2.6 million years ago) and Pleistocene (2.6 million to 11,700 years ago) epochs. Two of the sampling sites of Izett and Wilcox (1982) are in vicinity of Lake Meredith: investigators obtained a Huckleberry Ridge ash in Hutchinson County, and a Lava Creek B ash on the border of Moore and Potter counties. Additionally, Cepeda and Perkins (2006) identified an ash bed on the east bank of West Amarillo Creek in Potter County. This 9.5-million-year-old ash was deposited during the Miocene Epoch. Occurrences of ash from the Miocene Epoch are rare in Texas compared to ash of the Pearlette family. Cepeta and Perkins (2006) suggested that the source of the West Amarillo Creek ash was the Twin Falls volcanic field in southern Idaho, which is part of an earlier explosive stage of volcanism than the Pearlette ashes along the Yellowstone hot-spot track.

A further distinction of the ash is that it was used in making Borger cordmarked pottery. This style of pottery is best known from the 160-km (100-mi) stretch of the Canadian River and its tributaries in the north-central part of the Texas Panhandle (Lynn and Black 2003). The exterior surface of a cordmarked pot has hundreds of parallel indentations—cord impressions—left by the use of a cord-wrapped paddle in concert with an anvil stone. Because pure clay may be too flexible to hold its shape, shrinking and cracking as it dries, ash is used to "temper" the clay (Lynn and Black 2003).

### Oil and Gas Activities

Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument lie within the enormous oil and gas–producing Panhandle Field, which extends into Oklahoma and Kansas. Locally, the field is called the Panhandle West Field and is continuous with the Panhandle Field and Panhandle East Field to the east, and the Hugoton Field to the north (National Park Service 2000). The field is a structural trap that is draped over fractured Precambrian basement rocks of the Amarillo uplift (National Park Service 2000). The first well of the Panhandle Field, south of the national recreation area, was drilled in 1918. This well came about through initial mapping efforts of Gould (1906, 1907). Oil and gas exploration and development have been actively pursued at Lake Meredith and Alibates Flint Quarries since the late 1920s (National Park Service 2000). The earliest well on record in the vicinity of Lake Meredith is the W. T. Mudget well in the Sanford-Yake area, which was completed in 1927.

Today, there are 168 active well sites in Lake Meredith and Alibates Flint Quarries (GRI scoping notes, May 11, 2011) (fig. 9). In addition, evidence of 15 abandoned oil and gas–operation sites, 64 km (40 mi) of active oil field access roads, 167 km (104 mi) of abandoned roads, and 63 km (39 mi) of pipelines occur within the national recreation area and national monument (National Park Service 2000). In 2000, managers at Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument completed an oil and gas management plan. The Geologic Resources Division assisted in development of the plan and prepared a reasonably foreseeable development (RFD) scenario for future oil and gas exploration and production.

Oil and gas access roads, especially unmaintained ones on steep slopes, can cause severe erosion. Many of the access roads to oil and gas pads are unsurfaced, not adequately sloped, and lack drainage structures such as culverts and ditches (National Park Service 2000). During rainstorms, the roads serve as spillways for flowing water, cutting gullies into the road surface and adjacent slopes. In the past decade, the National Park Service has improved many of the problem roads by installing water bars and diversion ditches to more adequately handle heavy rains.

**Figure 9. Oil and gas operation. At present, 168 wells and associated pads occur at Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument. The one pictured is near Fritch Fortress. Note the eolian processes (i.e., windblown dust) in the upper right corner of the photo. Photo by Katie KellerLynn.**

## Disturbed Lands

Off-road vehicles are allowed in two areas within Lake Meredith National Recreation Area: Big Blue Creek, covering 79 ha (194 ac); and Rosita, covering 980 ha (2,421 ac). Recreationists may use motorcycles, three- and four-wheelers, and dune buggies (National Park Service 2000). Some restoration efforts are occurring at Big Blue Creek, namely minimizing and closing unauthorized trails. The Geologic Resources Division has expertise in restoration, if technical assistance is needed in the future.

## Caves and Karst Features and Processes

Scoping participants identified a cave feature (overhang) in the Rosita area of the national recreation area, but generally speaking, caves are not a significant resource at either Lake Meredith National Recreation Area or Alibates Flint Quarries National Monument. The carbonate rocks (limestone and dolomite) that are part of the Permian red beds are not of sufficient thicknesses to host caves or karst. However, in addition to dolomite and limestone, evaporite rocks—salt, primarily halite but also anhydrite and gypsum—are components of the red beds. Significantly, evaporite rocks are prone to dissolution and collapse, processes characteristic of "karstic systems." Regionally, a broad zone of salt dissolution occurs beneath the Canadian River valley (Gustavson et al. 1980). Much is known about dissolution in this area because in the 1980s the Permian salt beds were investigated for potential long-term storage of nuclear waste. Today, saline springs and sinkholes are evidence of the ongoing dissolution of salt in the area. Scoping participants noted a sinkhole in the Plum Creek area of Lake Meredith National Recreation Area. There is some concern that sinkholes could cause enhanced erosion at this site. However, at the present time, staff members at the national recreation area do not think any sinkholes are in need of mitigation for the protection of infrastructure or visitor safety.

Chimneys are a distinctive dissolution/collapse feature at the national recreation area. Salt dissolution in Permian strata has resulted in the collapse of overlying beds to form chimneys filled with collapse breccia. Most chimneys have remained underground, exposed only in road cuts or bluffs (see fig. 1). However, some chimneys stand in relief. Erosion stripped away the rock surrounding the collapse breccia, leaving a solid column of consolidated material above the ground surface. One such chimney may be highlighted along the proposed geology trail (fig. 10).

**Figure 10. Chimney. This distinctive chimney stands in relief. It is a potential "stop" on the proposed geology trail at the national recreation area. Photo by Katie KellerLynn.**

## Paleontological Resources

Koch and Santucci (2003)—the paleontological resource inventory for the Southern Plains Network—documented information about the paleontological resources at Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument. In addition, Hunt and Santucci (2001) reported on the fossils from the Triassic, Miocene-Pliocene, Pleistocene, and Holocene strata within the national recreation area and national monument. Furthermore, Santucci et al. (2001) provided information about procedures for locating and protecting paleontological resources in areas with oil and gas operations.

Perhaps the most notable fossil-bearing unit within Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument is the Ogallala Formation. The national recreation area and national monument host six fossil localities within this formation. These sites have yielded the following: (1) mastodon tooth (probably from gomphothere); (2) turtle specimens; (3) a bone bed with multiple specimens; (4) root casts, silicified grass anthoecia, endocarps of *Celtis* sp., and insect burrows; (5) gastropods, imprints of two fish, and Clarendonian (late middle Miocene) vertebrate fossils; and (6) oysters, fossiliferous limestone, and bone scraps (Hunt and Santucci 2001).

Terrace gravels, fluvial and alluvial sandstone, fluvial conglomerate, and loess have yielded Pleistocene fossils such as *Bison latifrons*, gastropods, a rodent burrow, mammoth remains, petrified wood, and shell fragments within the national recreation area and national monument (Anderson 1977; Hunt and Santucci 2001). A rare, well-preserved skull of a female *Bison latifrons* from Lake Meredith National Recreation Area is displayed at the Panhandle-Plains Historical Museum in Canyon, Texas. This museum is the repository for both paleontological and archaeological materials from Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument. Gerry Schultz, vertebrate paleontologist at West Texas A&M University, told GRI team members that in addition to *Bison latifrons*, there is potential for *Ischrocyon gidleii* ("bear dog" from the Miocene Epoch) within the boundaries of the national recreation area (Gerry Schultz, vertebrate paleontologist, West Texas A&M University, personal communication, May 12, 2011).

Holocene (less than 11,700 years old) deposits of alluvium, eolian sand, and soils have produced some fossil material within the national recreation area. Many of these paleontological resources are associated with archeological sites and include fossil remains of fish, turtle, snake, crow, antelope, rabbit, badger, gopher, mole, squirrel, rat, and prairie dog (Hunt and Santucci 2001).

Generally speaking, the Permian rocks in Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument do not host fossils. However, the Alibates Dolomite preserves algal mats. During the Permian Period on supratidal mud flats, algae bound together aragonite mud and gypsum crystals to form laminated dolomite and interlaminated anhydrite and dolomite (McGillis and Presley 1981). During the site visit to the national monument, scoping participants saw examples of these fossils along the trail to the quarries (fig. 11).

**Figure 11. Algal mat. During the Permian Period, algae in supratidal mud flats bound together aragonite and gypsum, forming the algal mats seen today along the trail to Alibates Flint Quarries. Photo by Katie KellerLynn.**

The Triassic Tecovas and Trujillo formations within the national recreation area host petrified wood. Investigators such as Lucas (1993, 2001) and Hunt and Santucci (2001) correlated these rocks to the famous Chinle Formation of Petrified Forest National Park in Arizona. Also, a deposit of Lava Creek B ash (Pleistocene) at the national recreation area hosted crayfish burrows and abundant plant material (Hunt and Santucci 2001).

### Seismic Features and Processes

Tectonic activity created the Amarillo uplift that defines the Palo Duro and Anakarko basins in the vicinity of Lake Meredith (see fig. 5). However, this activity occurred primarily during the Pennsylvanian Period (318 million to 299 million years ago) and was largely completed by the end of that period (Gustavson et al. 1980). Folding and faults in the Permian beds record minor movement since Permian time (251 million years ago), but this movement may have resulted from differential compaction of the basin sediments (Gustavson et al. 1980).

Scoping participants mentioned that earthquakes (estimated magnitude 4) have been felt at Lake Meredith, but no seismic-related damage has occurred. As an example, one of the last recorded earthquakes in Texas was a magnitude-3.9 quake on May 2, 2011, with an epicenter near Snyder, Texas (http://earthquake.usgs.gov/earthquakes/eqarchives/last_event/states/states_texas.php; accessed June 10, 2011). The U.S. Geological Survey (USGS) Earthquake Hazards Program posts information about seismicity in Texas, including earthquake history, seismic hazard maps, notable earthquakes, and recent earthquakes (http://earthquake.usgs.gov/earthquakes/states/?region=Texas; accessed June 10, 2011).

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**Table 2. Scoping Meeting Cooperators**

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