



# Amistad National Recreation Area

## *Geologic and Soil Resources Inventory Summary*



On this page: The cavernous interior of Parida Cave in Amistad National Recreation Area. Two NPS staff stand within the overhang of the cave, which contains several Indigenous pictographs. The cave and surrounding cliffs consist of Cretaceous carbonate strata of the Salmon Peak Formation. In the background is the Rio Grande. NPS photograph/J. Johnson.

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# Abstract

This document summarizes the status of National Park Service (NPS) Geologic Resources Inventory (GRI) and Soil Resource Inventory (SRI) deliverables for Amistad National Recreation Area. It also provides information on current geology and soil resources management concerns, with a focus on identified inventory needs related to geologic heritage, geohazards, and related soil features and processes. This document is intended to assist park staff with prioritizing technical assistance or new inventory and assessment funding requests in the near term (roughly 1–5 years).

GRI hosted a baseline scoping meeting for Amistad National Recreation Area in 2008. Baseline bedrock and surficial geologic maps were delivered to the park in 2010. SRI delivered a legacy soil database and map in 2007, and an additional Natural Resources Conservation Service (NRCS) soil survey area encompasses the recreation area. The most up-to-date soil data is available via [Web Soil Survey](#).

Amistad National Recreation Area’s geologic heritage includes its cave and karst features, paleontological resources, Indigenous resources, water resources, historic structural remnants of the Southern Transcontinental Railroad and Pecos Viaduct, as well as former hydroelectric plants. The geology of the recreation area has been impacted by multiple tectonic episodes that formed several major structural features such as faults and folds. These features weakened the bedrock and helped develop the karst landscape that characterizes the region. The geologic and soil resources inventory needs for the recreation area include various data and/or GIS needs related to the inventory and monitoring of cultural resources, fossils, cave and karst resources, disturbed lands, and hydrological systems. Additional mapping needs have been expressed regarding the distribution of Cretaceous bedrock within and surrounding the recreation area.

Geologic hazards identified in the recreation area include flooding, disturbed lands (e.g., historic ranch lands, hydrocarbon development), karst development (e.g., sinkholes, caves), mass wasting (e.g., rockfalls, slumps), shrink-swell soils, seismicity, radon, toxicological soil, and climate change. Geohazard inventory information is needed to support monitoring strategies that help predict, quantify, and mitigate the damage caused by these processes.

Additional guidance for park staff regarding proposal processes and timeframes for the new Inventories and Assessment (I&A) program is available on the [GSRI](#) and [I&A](#) SharePoint sites.

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# Background of the GSRI

The Geologic and Soil Resources Inventory (GSRI) facilitates the collection of new data, or derives new information from existing data, regarding the presence, absence, abundance, distribution, and significance of geologic or soil features or processes to inform park management decisions and planning.

In the 1990s, the NPS Geologic Resources Inventory (GRI) and Soil Resource Inventory (SRI) programs were established as two of the original 12 baseline inventories in the Inventory and Monitoring (I&M) program. These baseline inventories compiled existing information, acquired new information, and helped establish a minimum level of data across more than 270 parks, which served as a common starting point for natural resource monitoring. For both the GRI and SRI, the primary deliverable was a digital (GIS) map. Between the 1990s and early 2020s, GRI scoping summaries, geologic map posters, and GRI reports were also produced for most of the 270 parks. As of 2024, the I&M program is transitioning from a baseline inventory strategy to a park-proposed inventory strategy.

The GRI and SRI are now unified as one inventory program, the Geologic and Soil Resources Inventory (GSRI), and will be integrated into the new Inventories & Assessment (I&A) Program, in which parks will submit geology- and soil-related project requests in PMIS during the Servicewide Comprehensive Call (SCC). This transition will begin in FY25, with new guidance enacted for GSRI. During this transition period, 13 “priority” parks, including Amistad National Recreation Area, were identified as missing a baseline GRI report.

This GSRI summary serves as a substitute for a baseline GRI report and is intended to support the national park’s participation in the new inventories program. As such, it summarizes the status of GRI and SRI deliverables for AMIS and provides information on current geology and soil resources management concerns with a focus on identified inventory needs. Information in this summary was compiled from existing reports, meetings with park staff, and the best professional judgment from GRI and WASO Geologic Resources Division (GRD) geoscientists.

## Baseline GSRI Products

### *Geology*

The geologic maps for the recreation area stored on the NPS Datastore and accessed via the Integrated Resource Management Applications (IRMA) portal represent legacy data from 2010 and consist of three component maps and one compiled map. These maps are products of the [Geologic Resources Inventory Project for Amistad National Recreation](#) on the NPS Datastore:

### Component Maps

- Digital Geologic Map of International Boundary and Water Commission Mapping in Amistad National Recreation Area, Texas and Mexico
- Digital Geologic Map of the US Geological Survey Mapping in the Western Portion of Amistad National Recreation Area, Texas
- Digital Geologic Map of the Carta Valley Fault Zone Area, Texas

# Compiled Map

- Digital Geologic Map of Amistad National Recreation Area and Vicinity, Texas and Mexico

As the GSRI team plans for the future migration of this data (currently scheduled for 2026), it is anticipated to be reorganized into eight component maps and one compiled map. The initial plan was to begin the migration process in 2024. However, recent communication with the Texas Bureau of Economic Geology and other mapping agencies in the AMIS area has revealed new and upcoming geologic mapping efforts under the USGS STATEMAP program. These efforts were scheduled for the 2023 and 2024 field seasons and focus on some of the quadrangles of interest near the recreation area. Three new 7.5’ quadrangle maps are expected to be completed in 2024 and include Bakers Crossing, Dolan Springs, and Telephone Canyon. Due to these updates, it is likely that the GSRI will postpone work until updated data is obtained, presumably fiscal year 2025 (James Winter, NPS GSRI, personal communication 13 March 2024).

## Soils

Soil maps provide information on soil types, including scores of different characteristics and management considerations, including linear extensibility (“shrink-swell”) potential, erosion potential, soil stability, suitability for site development, suitability for recreation development (e.g., trails), and many other topics. Perrone (2023) provides an overview of the use of soil data at the NPS WASO level and lists soil data currently available in the Natural Resources Conservation Service (NRCS) [Web Soil Survey](#) website along with NPS-specific uses for the data. The NRCS plans to complete all soil survey areas in the US by 2026 (Thompson et al. 2020).

The most up-to-date soils data for AMIS is available via Web Soil Survey, which is updated and maintained regularly. Management-focused maps for the park or potential project areas can be developed on demand on the website. The Web Soil Survey homepage gives instructions for how to view and download soil data. The Web Soil Survey data are broken down into county-level soil survey areas. Each soil survey area is assigned a code and a name. The recreation area includes one soil survey area that is complete (Table 1). To view the soil data for AMIS on the Web Soil Survey website, use the navigation pane on the left side of the homepage to select the soil survey “Area of Interest (‘AOI’)” tab. Under the “National Park Service” dropdown menu, select AMIS to view the soil data for the recreation area. The AOI icon along the top of the screen allows users to select specific areas of the map and generate detailed soil data (e.g., soil suitability and limitations, soil properties, soil qualities, and ecological sites). Use the “Soil Map” tab at the top to view the soil map and the “Soil Data Explorer” tab to view additional soil data, including linear extensibility and suitability for development. See additional Web Soil Survey guidance and FAQs or contact the NRCS state soil scientist for technical assistance.

Additional soil mapping by the NPS Soil Resources Inventory (SRI) was updated for AMIS in 2007 and is available on IRMA (<https://irma.nps.gov/DataStore/Reference/Profile/1048813>).

**Table 1.** Web Soil Survey areas related to AMIS.

| Web Soil Survey Area Code | Web Soil Survey Area Name | Status    |
|---------------------------|---------------------------|-----------|
| TX465                     | Val Verde County, Texas   | Completed |

## Possible Future GSRI Products

As the GSRI becomes integrated into the I&A, future GSRI products will be determined by the project proposals submitted by the parks. Moving forward, the GSRI program will fund inventory projects that include the following:

- Collect new data or derive new information from existing data regarding the presence, absence, abundance, distribution, and significance of geologic heritage, soil features or processes, or geohazards.
- Include features or processes on an individual feature or landscape scale.
- Include groups of features or maps of multiple features in a defined area of management needs.
- Are a snapshot in time and may set a baseline for monitoring or assessment.
- Typically include a geospatial (GIS) component.

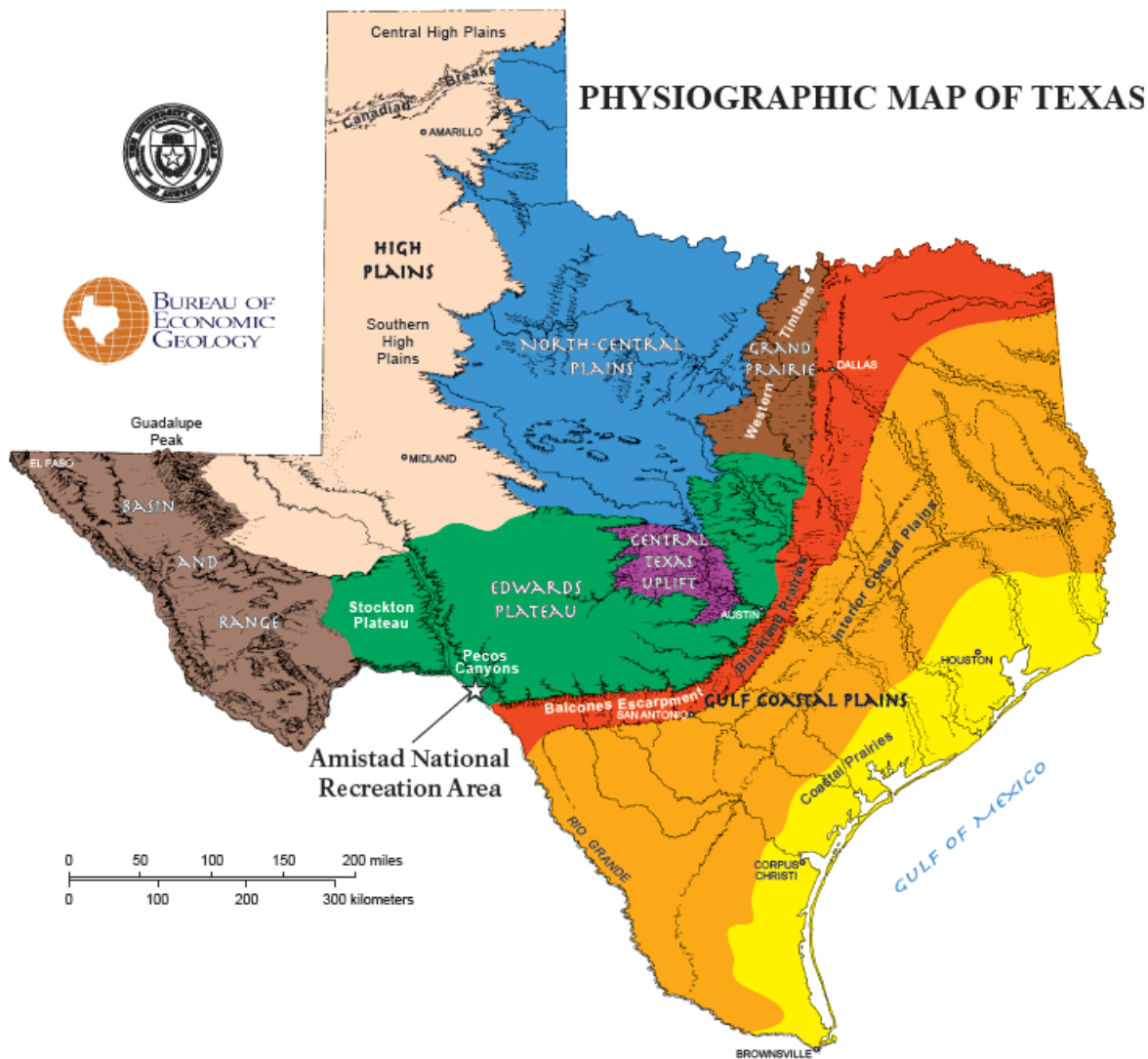
GSRI project examples:

- Features and processes eligible for funding through the GSRI program include cave/karst, geothermal, paleontological (fossils), landslides and rockfall, other geohazards (e.g., avalanche, permafrost, volcanoes, earthquakes, tsunamis, sinkholes), eolian, erosion, soil suitability and limitations for use, soil properties and qualities, ecological site descriptions, and other geologic or soil features or processes of management interest.
- Features and processes covered by other sources of funding and **not** eligible for GSRI funding are abandoned mineral lands (AML), orphaned oil and gas wells, coastal processes, coastal storm response, sea level change projections or mitigation, coastal engineering structures, or shoreline sediment movement.
- The GSRI will accept proposals for new baseline map products, such as funding a traditional geologic (bedrock or surficial) or soil mapping effort, especially at new or expanded parks outside the original 270 I&M parks. Parks requesting these products will need to indicate a management need that the baseline data will support.

# Geologic Setting and History

## Park Establishment and Setting

Amistad National Recreation Area (“AMIS”; also referred to as the “recreation area” herein) is located along the US–Mexico border in Val Verde County, southwest Texas. As a hydrological park, AMIS encompasses portions of the Rio Grande, the Pecos and Devils rivers, and the Amistad International Reservoir and includes over 540 mi (869 km) of shoreline (Labadie 1994; National Park Service 2006a). Created by the construction of the Amistad Dam in 1969, the reservoir and dam are mutually managed through an international treaty between the US–Mexico governments; the name “Amistad” is a Spanish term meaning friendship. Established on 28 November 1990, the recreation area provides for public recreational use associated with the American portion of the reservoir and protects scenic, scientific, cultural, and other resources contributing to the enjoyment of such lands and waters (National Park Service 2017). Prior to its enabling legislation, the NPS developed and managed recreation and resources on and around the reservoir since a 1965 agreement with the International Boundary and Water Commission (IBWC); in 1990, most of the IBWC’s reservoir lands were deeded to the NPS when AMIS was established. Located along the southwestern edge of the Edwards Plateau, the recreation area preserves a semi-arid, dissected karst landscape featuring cliffs, caves, rock shelters, alcoves, and sinkholes, and was once home to several Indigenous hunter-gatherer societies spanning the last 14,000 years (Figure 1). Cretaceous carbonate rocks that underlie AMIS were used by Indigenous cultures for many purposes, including domestic (e.g., rock shelters, springs), hunting (e.g., tools, projectile points), culinary (e.g., fire-cracked rock, hearths), and artistic or spiritual practices. The recreation area protects and interprets exceptional examples of Lower Pecos River Style pictographs that represent some of the most significant and densest concentrations in North America.



| PROVINCE                    | MAX. ELEV. (ft) | MIN. ELEV. (ft) | TOPOGRAPHY                               | GEOLOGIC STRUCTURE                 | BEDROCK TYPES                     |
|-----------------------------|-----------------|-----------------|------------------------------------------|------------------------------------|-----------------------------------|
| <b>Gulf Coastal Plains</b>  |                 |                 |                                          |                                    |                                   |
| Coastal Prairies            | 300             | 0               | Nearly flat prairie, <1 ft/mi to Gulf    | Nearly flat strata                 | Deltaic sands and muds            |
| Interior Coastal Plains     | 800             | 300             | Parallel ridges (questas) and valleys    | Beds tilted toward Gulf            | Unconsolidated sands and muds     |
| Blackland Prairies          | 1000            | 450             | Low rolling terrain                      | Beds tilted south and east         | Chalks and marls                  |
| Grand Prairie               | 1250            | 450             | Low stairstep hills west; plains east    | Strata dip east                    | Calcareous east; sandy west       |
| <b>Edwards Plateau</b>      |                 |                 |                                          |                                    |                                   |
| Principal                   | 3000            | 450             | Flat upper surface with box canyons      | Beds dip south; normal faulted     | Limestones and dolomites          |
| Pecos Canyons               | 2000            | 1200            | Steep-walled canyons                     |                                    | Limestones and dolomites          |
| Stockton Plateau            | 4200            | 1700            | Mesa-formed terrain; highs to west       | Unfaulted, near-horizontal beds    | Carbonates and alluvial sediments |
| <b>Central Texas Uplift</b> | 2000            | 800             | Knobby plain; surrounded by questas      | Centripetal dips, strongly faulted | Granites; metamorphics; sediments |
| <b>North-Central Plains</b> | 3000            | 900             | Low north-south ridges (questas)         | West dip; minor faults             | Limestones; sandstones; shales    |
| <b>High Plains</b>          |                 |                 |                                          |                                    |                                   |
| Central                     | 4750            | 2900            | Flat prairies slope east and south       | Slight dips east and south         | Eolian silts and fine sands       |
| Canadian Breaks             | 3800            | 2350            | Highly dissected; local solution valleys |                                    |                                   |
| Southern                    | 3800            | 2200            | Flat; many playas; local dune fields     |                                    |                                   |
| <b>Basin and Range</b>      | 8750            | 1700            | North-south mountains and basins         | Some complex folding and faulting  | Igneous; metamorphics; sediments  |

**Figure 1.** Physiographic map of Texas showing the location of AMIS. The recreation area is on the Edwards Plateau, a large karst region of southwest and central Texas underlain by carbonate bedrock. In Val Verde County, AMIS occupies the dissected, steep-walled canyonlands of the Pecos Canyons subprovince. Figure from Wermund (1996).

## Geologic History

The geologic history of the recreation area includes at least three regional tectonic episodes that are significant because cumulatively they created the karst bedrock, canyonlands, and steep cliffs visible on the landscape today. First, the Marathon orogeny created the southwestern equivalent of the Appalachian Mountains. During the Mesozoic Era, rifting opened the Gulf of Mexico. Finally, the Laramide orogeny created the Rocky Mountains. These events left their mark on the recreation area as well as large areas of the western United States. For example, the Cretaceous bedrock that underlies AMIS was deposited in an ancient shallow sea that formerly stretched across Texas. Following deposition, these marine carbonates were compressed, folded, and faulted during the Laramide orogeny. These same distorted strata can also be seen today in Big Bend National Park (Henderson 2024).

### *Bedrock and Surficial Geology*

The following geologic unit table (Table 2) and geologic time scale (Table 3) put the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. Likewise, rocks and unconsolidated deposits are listed stratigraphically. Information in the geologic time scale, including the timing of geologic events, is primarily from Sharps (1963), Freeman (1964a, b), Sharps and Freeman (1965), Barnes et al. (1977), Collins (2007), and Page et al. (2009).

**Table 2.** Geologic units mapped within the recreation area.

The geologic time scale puts the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. Likewise, rocks and unconsolidated deposits are listed stratigraphically. Only geologic units mapped within the recreation area are included. Boundary ages follow the International Commission on Stratigraphy (2023).

| Geologic Time Unit                          | Age                                 | Geologic Units                                                                 | Geologic Events                                                                                                                                                                                                                                 |
|---------------------------------------------|-------------------------------------|--------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Holocene                                    | 11,700 years to present             | Modern alluvium                                                                | Erosion and downcutting related to the Rio Grande.                                                                                                                                                                                              |
| Quaternary Period: Holocene and Pleistocene | 2.58 million years ago to present   | Terrace gravels and alluvium                                                   | Extensive erosion, downcutting, and aggradation (elevation increase due to sediment infill) related to the development of the Rio Grande.                                                                                                       |
| Pliocene and Pleistocene                    | 5.33 million to 11,700 years ago    | Uvalde Gravel                                                                  | Stream deposition during the late Pliocene or early Pleistocene. Since deposition, the Uvalde Gravel has been fluvially incised, reworked, and now sits at a higher elevation relative to other terrace gravels.                                |
| Cretaceous Period                           | 145 million to 66 million years ago | Boquillas Formation<br>Buda Limestone<br>Del Rio Clay<br>Salmon Peak Formation | Cretaceous rocks record shallow marine carbonate shelf environments that experienced several fluctuations in sea level. A notable unconformity separates Cretaceous strata from overlying Cenozoic rocks and records a major period of erosion. |

**Table 3.** Geologic time scale.

The geologic time scale puts the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. Boundary ages are millions of years ago (MYA) and follow the International Commission on Stratigraphy (2023). Items in parentheses include GSRI map abbreviations for geologic time units. For example, “K” in a map unit symbol means that a map unit was deposited during the Cretaceous Period. “T” in a map unit symbol stands for Tertiary, which is a widely used but no longer formally recognized term for the geologic period from 66.0 million to 2.6 million years ago (Paleogene and Neogene Periods). Where no geologic time subdivision exists, “n/a” indicates not applicable.

| Eon         | Era(s)                          | Period(s)                                 | Epoch(s)                                       | MYA          |
|-------------|---------------------------------|-------------------------------------------|------------------------------------------------|--------------|
| Phanerozoic | Cenozoic                        | Quaternary (Q)                            | Holocene (H)                                   | 0.0117–today |
| Phanerozoic | Cenozoic                        | Quaternary (Q)                            | Pleistocene (PE)                               | 2.6–0.0117   |
| Phanerozoic | Cenozoic                        | Neogene (N)                               | Pliocene (PL)                                  | 5.3–2.6      |
| Phanerozoic | Cenozoic                        | Neogene (N)                               | Miocene (MI)                                   | 23.0–5.3     |
| Phanerozoic | Cenozoic                        | Paleogene (PG)                            | Oligocene (OL)                                 | 33.9–23.0    |
| Phanerozoic | Cenozoic                        | Paleogene (PG)                            | Eocene (E)                                     | 56.0–33.9    |
| Phanerozoic | Cenozoic                        | Paleogene (PG)                            | Paleocene (EP)                                 | 66.0–56.0    |
| Phanerozoic | Mesozoic                        | Cretaceous (K)                            | Upper, Lower                                   | 145.0–66.0   |
| Phanerozoic | Mesozoic                        | Jurassic (J)                              | Upper, Middle, Lower                           | 201.3–145.0  |
| Phanerozoic | Mesozoic                        | Triassic (TR)                             | Upper, Middle, Lower                           | 251.9–201.3  |
| Phanerozoic | Paleozoic                       | Permian (P)                               | Lopingian, Guadalupian, Cisuralian             | 298.9–251.9  |
| Phanerozoic | Paleozoic                       | Pennsylvanian (PN)                        | Upper, Middle, Lower                           | 323.2–298.9  |
| Phanerozoic | Paleozoic                       | Mississippian (M)                         | Upper, Middle, Lower                           | 358.9–323.2  |
| Phanerozoic | Paleozoic                       | Devonian (D)                              | Upper, Middle, Lower                           | 419.2–358.9  |
| Phanerozoic | Paleozoic                       | Silurian (S)                              | Pridoli, Ludlow, Wenlock, Llandovery           | 443.8–419.2  |
| Phanerozoic | Paleozoic                       | Ordovician (O)                            | Upper, Middle, Lower                           | 485.4–443.8  |
| Phanerozoic | Paleozoic                       | Cambrian (C)                              | Furongian, Miaolingian, Series 2, Terreneuvian | 538.8–485.4  |
| Proterozoic | Neoproterozoic (Z)              | Ediacaran, Cryogenian, Tonian             | n/a                                            | 1,000–538.8  |
| Proterozoic | Mesoproterozoic (Y)             | Stenian, Ectasian, Calymmian              | n/a                                            | 1,600–1,000  |
| Proterozoic | Paleoproterozoic (X)            | Statherian, Orosirian, Rhyacian, Siderian | n/a                                            | 2,500–1,600  |
| Archean     | Neo-, Meso-, Paleo-, Eo-archean | n/a                                       | n/a                                            | 4,000–2,500  |
| Hadean      | n/a                             | n/a                                       | n/a                                            | ~4,600–4,000 |

### *Marathon Orogeny*

The Marathon orogeny was a major mountain-building event that occurred during the Middle Mississippian–Early Permian (approximately 330 million to 285 million years ago) due to the collision of the North American and South American tectonic plates (Figure 2a). The Marathon orogeny represents one of several successive collisional events that culminated in the formation of the supercontinent Pangea. Uplifted rocks of the Marathon orogenic belt represent an extension of the larger Ouachita-Marathon-Sonora orogenic belt that extends along the Paleozoic continental margin from Mississippi and Arkansas (Ouachita segment), through Texas (Marathon segment), and into Chihuahua and Sonora, Mexico (Sonora segment; Turner et al. 2011). During the collision, deep marine sedimentary rocks originally deposited south of Amistad Reservoir were thrust northward onto the North American continental margin. Following the Marathon orogeny, these uplifted Paleozoic rocks were heavily eroded and unconformably overlain by younger Cretaceous sedimentary strata (see “Unconformities”). The collision also uplifted an ancient block of basement rocks called the Devils River Uplift. Faults, fractures, and folds within and surrounding AMIS are related to and overlie this uplift (Webster 1982; Webster and Calhoun 1984; Ferrill et al. 2022).

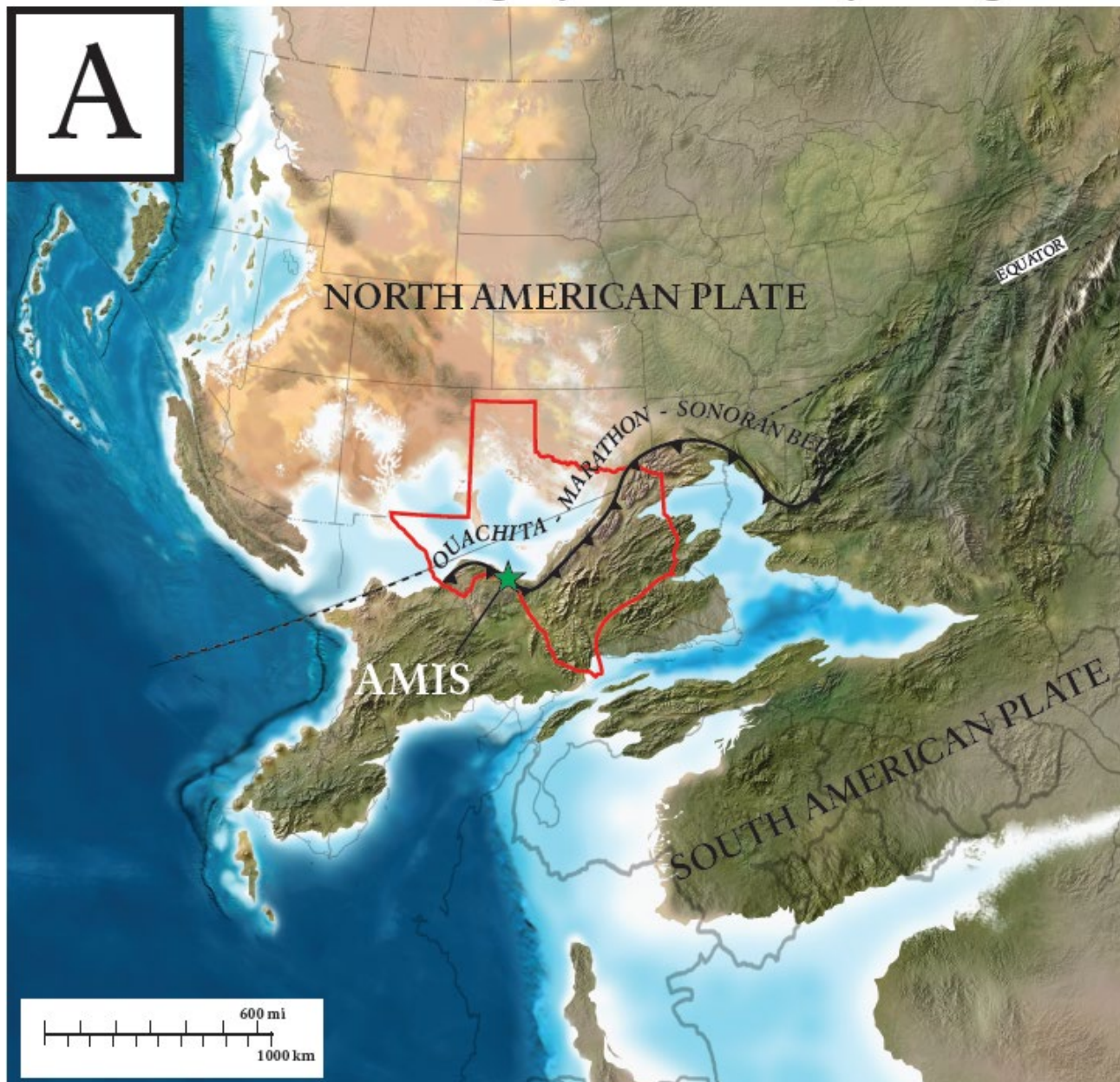
### *Mesozoic Rifting*

From the Late Triassic to Late Cretaceous (about 200 million to 85 million years ago), the recreation area experienced subtle effects related to rifting (the process where Earth’s lithosphere is extended or pulled apart) that controlled the opening of the Gulf of Mexico. Geologic mapping of the lower Pecos River by Gottardi and Mason (2018) documented several fractures in the Boquillas Formation adjacent to the recreation area boundary that are consistent with extensional stresses related to the opening of the Gulf of Mexico basin. During rifting, AMIS was part of the Maverick basin, a warm, shallow marine shelf environment (Figure 2b). Several Lower and Upper Cretaceous formations—notably the recreation area’s massive carbonate sequences—were deposited during this time and include the following (in chronological order): (1) Salmon Peak Formation; (2) Del Rio Clay; (3) Buda Limestone; and (4) Boquillas Formation. See “Bedrock and Surficial Geology” for more information about these geologic units.

### *Laramide Orogeny*

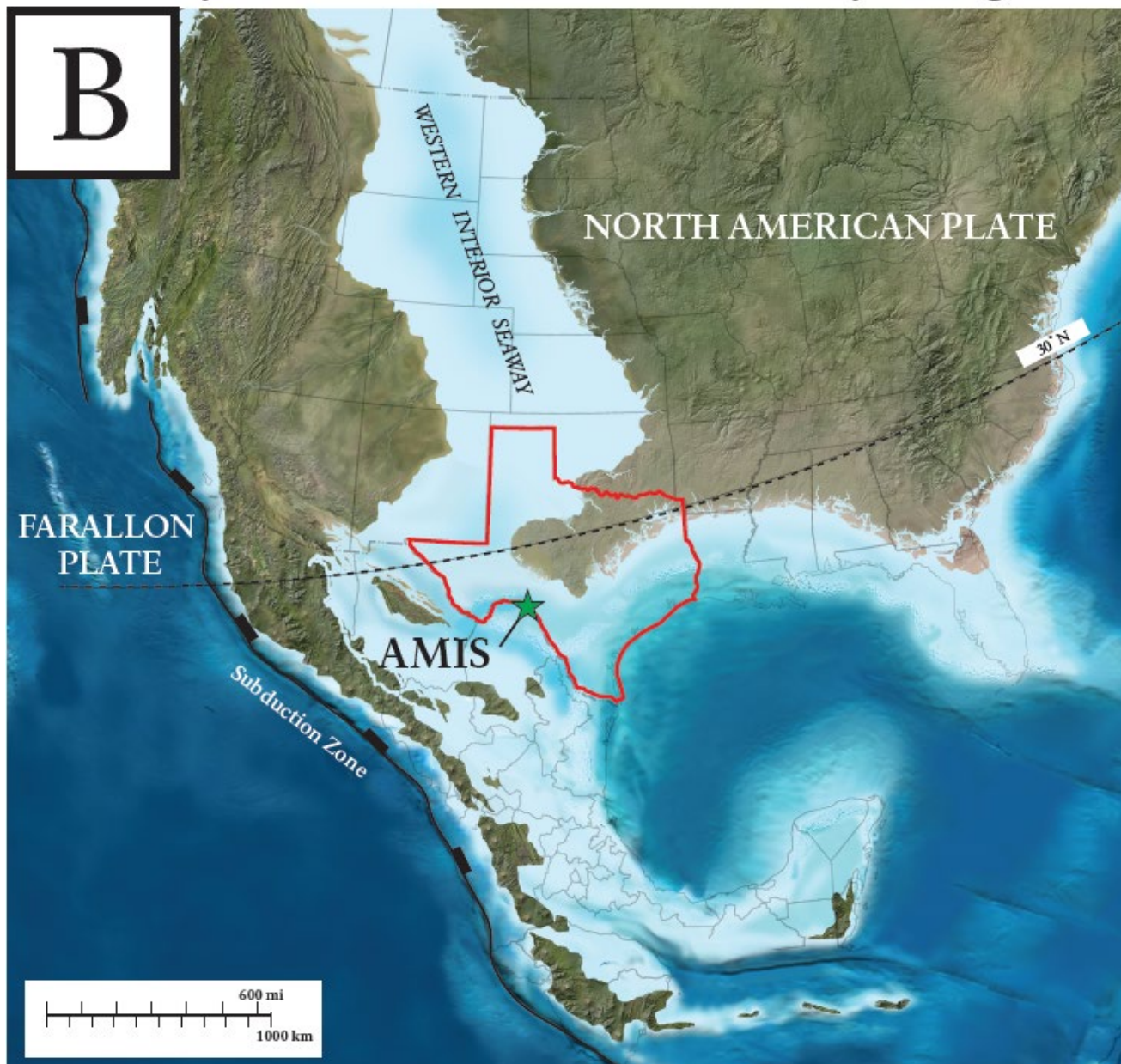
The Late Cretaceous–early Tertiary (approximately 70 million to 50 million years ago) Laramide orogeny was a period of compressional deformation related to the shallow subduction of the Farallon plate beneath the western margin of North America (Turner et al. 2011). Plate convergence uplifted rocks to form the American Cordillera, a chain of mountain ranges that extends from Canada to Mexico. Laramide compression is also responsible for the development of a foreland basin (an elongate depositional trough) east of the Rocky Mountains (Figure 2c). Deformation associated with the Laramide orogeny overprinted (tectonically obscured) earlier geologic structures related to the Marathon orogeny and likely produced many of the faults, fractures, and folds within and surrounding AMIS (see poster and “Structural Geology”; Webster 1982; Webster and Calhoun 1984; Ferrill et al. 2022).

## Post-Marathon orogeny ~280 million years ago



See caption on page 11.

## Early Cretaceous Period ~105 million years ago



See caption on page 11.

## Post-Laramide orogeny ~50 million years ago

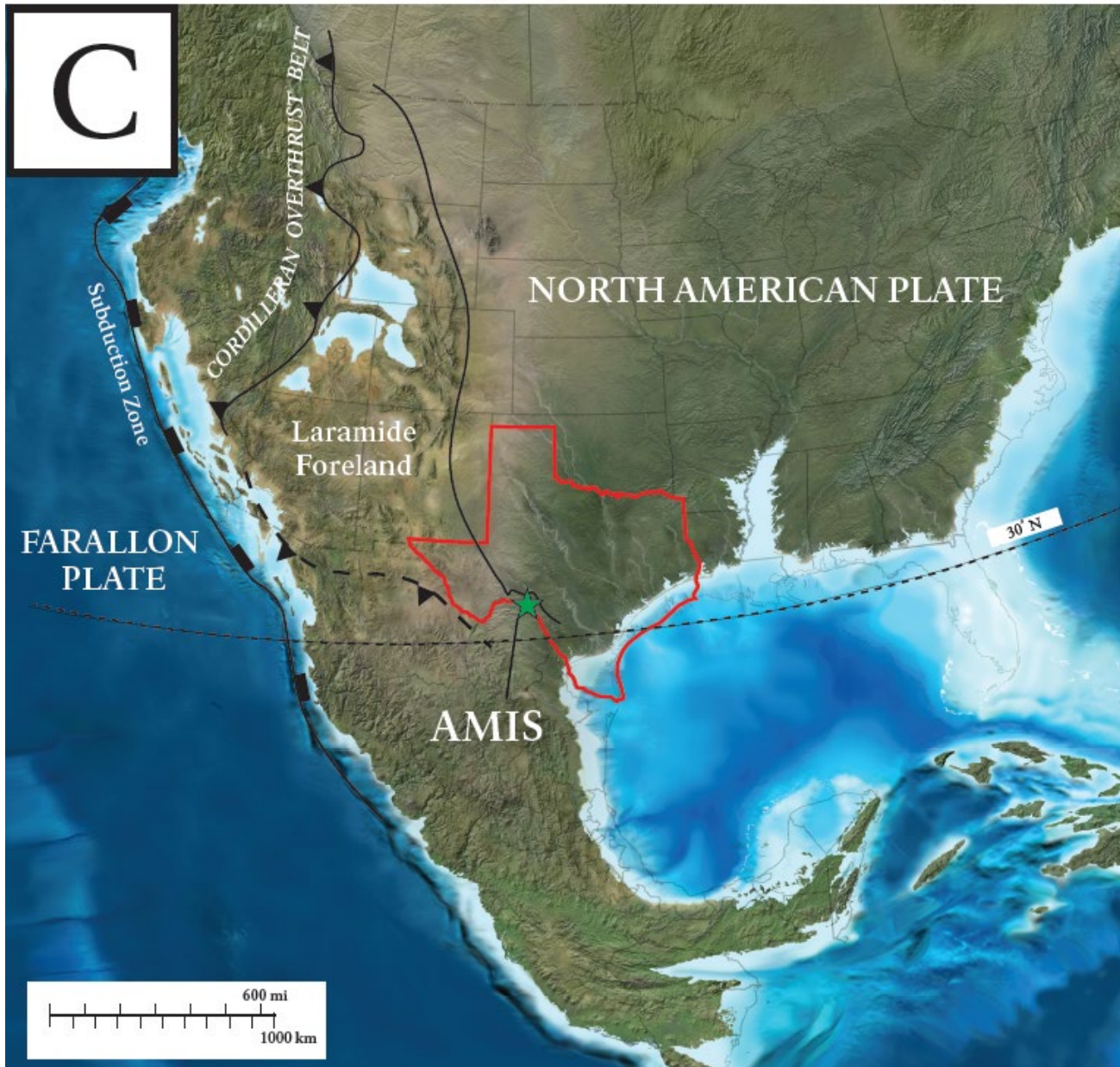


**Figure 2.** Paleogeographic reconstructions of North America during the late Paleozoic, late Mesozoic, and early Cenozoic eras. A) During the Permian Period, about 280 million years ago, the region of AMIS occupied a shallow, tropical carbonate reef along the suture zone between the North American and South American plates. Compression along the Ouachita-Marathon-Sonoran belt helped define the structural fabric of southwest Texas and created the Devils River Uplift. B) During the Early Cretaceous Period, approximately 105 million years ago, AMIS was covered by a shallow marine shelf environment that was a southern continuation of the Western Interior Seaway. The Cretaceous rocks underlying the recreation area were deposited in these shallow marine settings. C) By the Eocene Epoch, about 50 million years ago, the Cretaceous–early Tertiary Laramide orogeny had regionally deformed the bedrock of the western United States, including AMIS. The orogeny resulted from the subduction of the Farallon plate below the western margin of North America. Laramide tectonism reactivated basement faults associated with the Marathon orogeny and produced several transform fault zones and folds within and surrounding the recreation area. North American Key Time Slices © 2013 Colorado Plateau Geosystems Inc., modified by Tim C. Henderson (Colorado State University).

## **Structural Geology**

AMIS and the surrounding area are underlain by many faults and folds related to multiple tectonic episodes that shaped the geologic evolution of the western United States and defined the structural framework of southwest Texas (see “Geologic History”). Faulting and folding created abundant fractures in the Cretaceous carbonate bedrock that have since developed into hundreds of cave and karst features in addition to groundwater springs.

### ***Faults***

The recreation area encompasses a unique structural region of southwest Texas referred to as the Devils River Uplift, a major fault-bounded basement uplift produced during the Paleozoic Marathon orogeny (see “Geologic History”). Measuring approximately 96 km (60 mi) long and 29 km (18 mi) wide, the Devils River Uplift overlies and is bisected by a series of buried faults that mark the frontal edge of the Marathon fold and thrust belt (Figure 3; Smith 2013). During the orogeny, Paleozoic and Precambrian rocks located south of AMIS were compressed, metamorphosed, and thrust northward. Today, these rocks overlie the Devils River Uplift along its southern boundary (Gottardi and Mason 2018). A northwest-trending thrust fault separates the Devils River Uplift from the Val Verde basin to the north and records approximately 3,050 m (10,000 ft) of offset (Figure 4; Webster 1982; Webster and Calhoun 1984; Smith 2013). According to several authors (Smith 2013; Gottardi and Mason 2018; Dickerson et al. 2024), the Devils River Uplift represents a differentially uplifted autochthonous or rooted block (a sequence of rock formed in its present location) that was partially rifted or severed from North America during the Cambrian Period and subsequently thrust back onto the southern margin during the late Paleozoic. It is speculated that during the Marathon orogeny, the uplifted block acted as a buffer to compressional tectonic forces that affected areas to the south (Webster and Calhoun 1984; Gottardi and Mason 2018).

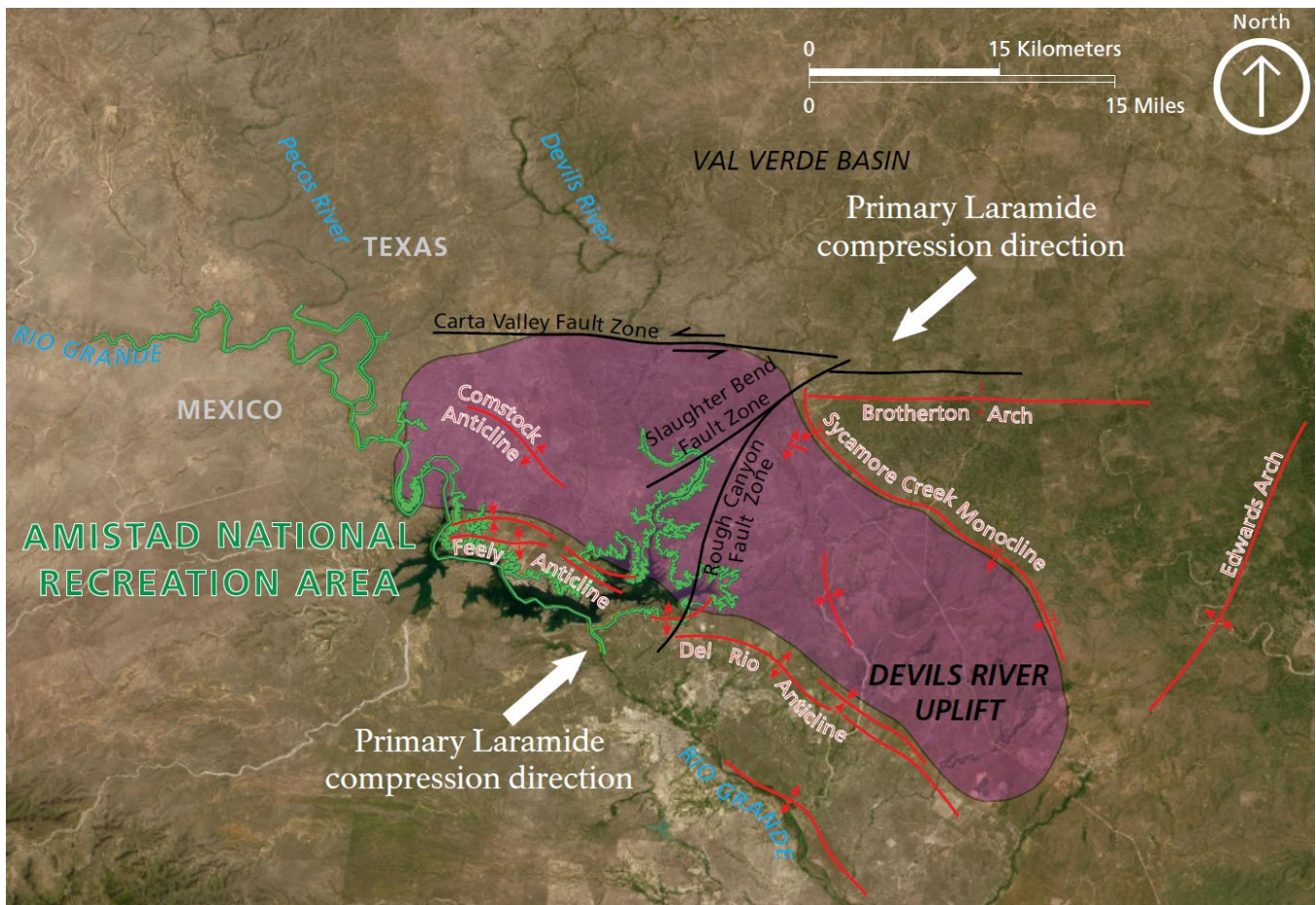


**Figure 3.** Generalized map showing major structural features surrounding AMIS. The recreation area lies along the structural front of the Marathon and Laramide orogenies, two major collisional events that shaped the structural fabric of the region. The Marathon orogeny produced the Devils River Uplift, a fault-bounded block that has been uplifted nearly 3,050 m (10,000 ft) relative to the Val Verde basin to the north. Pre-existing basement thrusts associated with the Marathon orogeny now underlie the Carta Valley and Rough Canyon Fault Zones, two surficial zones of strike-slip displacement attributed to the Laramide orogeny. Many of the regional folds within and surrounding AMIS are also Laramide structures that have developed along the periphery of the Devils River Uplift and were formed from northeast–southwest-directed compressional forces. Graphic created by Trista L. Thornberry-Ehrlich (Colorado State University).

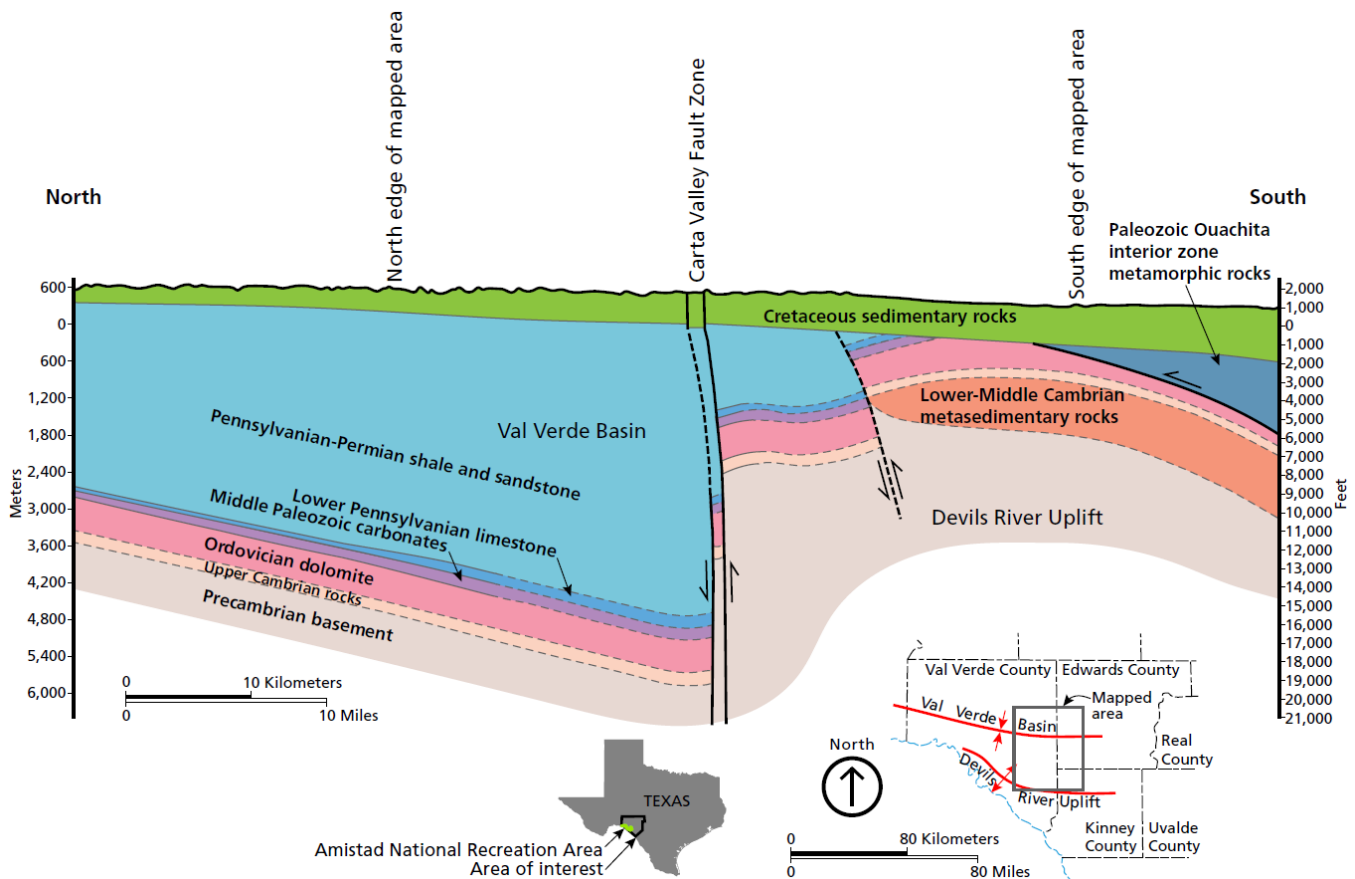


**Figure 4.** Generalized cross section along the Val Verde basin and the Devils River Uplift. Paleozoic and Precambrian strata of the Devils River Uplift have been uplifted along basement thrusts approximately 3,050 m (10,000 ft) relative to the Val Verde basin to the north. Following the Marathon orogeny, a major period of erosion is recorded by an unconformity with overlying Cretaceous rocks. During the Laramide orogeny, pre-existing structural zones separating the Devils River Uplift and Val Verde basin were reactivated and include the Carta Valley Fault Zone. Graphic created by Trista L. Thornberry-Ehrlich (Colorado State University).

Valuable sources of groundwater, such as springs or seeps, may be influenced by the presence of folds or faults that fracture the bedrock and allow water to mobilize. One of the most prominent surficial fault structures surrounding the recreation area is the Carta Valley Fault Zone, an east–west-trending zone of en echelon (closely spaced, parallel to subparallel) faults and folds nearly 89 km (55 mi) long and 1.5–3 km (1–2 mi) wide (Webster 1982). Located about 30 km (19 mi) north of Amistad Reservoir, the fault zone consists of several northeast–southwest-oriented faults that are crosscut by perpendicular, secondary faults. A series of northwest-trending folds parallels the trend of the fault zone. Although located north of Amistad Reservoir, the westward continuation of the fault zone could explain the distribution of springs near the mouth of the Pecos River. Subsurface investigations have revealed that the Carta Valley Fault Zone overlies a major basement thrust that separates the Devils River Uplift and the Val Verde basin (Webster 1982). Seismic data, combined with the configuration of faults and folds, strongly suggests that the fault zone formed through the reactivation of this pre-existing basement fault structure during a minor episode of uplift or left-lateral transform displacement during the Late Cretaceous–early Tertiary (approximately 70 million to 50 million years ago) Laramide orogeny (see Figure 3; Webster 1982; Webster and Calhoun 1984; Ewing 1985; Ferrill et al. 2022).

The Carta Valley Fault Zone intersects with two smaller fault zones to the south that transect portions of the recreation area. Located along the eastern side of AMIS, the Slaughter Bend Fault Zone is an area of minor faulting and fracturing that crosses the Slaughter Bend of the Devils River (see Figure 3). The fault zone is characterized by several northeast–southwest-trending normal faults that offset rocks of the Salmon Peak Formation. The most pronounced area of faulting is along the southwestern 10-km (6-mi) segment that crosses Slaughter Bend, which may explain the dense concentration of springs that occur in the area. Webster and Calhoun (1984) designated the Rough Canyon Fault Zone after a tributary of the Devils River, and is defined by intermittent surficial faults, fractures, and folds mapped across the eastern end of Amistad Reservoir (see Figure 3; Webster and Calhoun 1984). Both the Slaughter Bend and Rough Canyon fault zones merge and intersect with the Carta Valley Fault Zone near the US 277–US 377 intersection. Similar to the Carta Valley Fault Zone, it is believed that these fault zones overlie older, pre-existing basement uplifts that were possibly reactivated during the Laramide orogeny (Webster 1982).

### *Folds*

Major folds within and surrounding AMIS include anticlines, synclines, and monoclines formed during compressional uplift associated with the Laramide orogeny. Several large features, such as the Del Rio Anticline and Sycamore Creek Monocline, are within 20 km (12 mi) of the recreation area and are geographically distributed along faults bounding the Devils River Uplift (see Figure 3; Ferrill et al. 2022). According to several authors (Sharps and Freeman 1965; Webster and Calhoun 1984; Ferrill et al. 2022), a notable anticline and syncline pair (including the “Feely anticline” of Ferrill et al. 2022) are mapped along a portion of AMIS north of Amistad Reservoir. These folds are characterized by east–west-trending fold axes that extend approximately 30 km (18 mi) from La Bolsa eastward to Governor’s Landing.

### *Unconformities*

Layers of rock are referred to as “conformable,” where they are found to have been deposited essentially without interruption. Although rock exposures may exhibit conformable beds representing significant spans of geologic time, no place on Earth contains a full set of conformable strata. Breaks in conformable strata are called “unconformities.” Each unconformity represents a period of “missing” geologic time when deposition ceased or where erosion has removed an interval of the rock record.

Throughout the recreation area, several unconformities exist:

1. The Upper Cretaceous strata of the Del Rio Clay, Buda Formation, and Boquillas Formation unconformably overlie the Lower Cretaceous rocks of the Salmon Peak Formation (Figure 5).
2. The Buda Limestone rests unconformably on the Del Rio Clay.
3. The Boquillas Formation unconformably overlies the Buda Limestone. This boundary is sharp, disconformable (an unconformity between sedimentary units), and could be the result of microkarst dissolution (Gottardi and Mason 2018).

Although not exposed at the surface, a major unconformity exists between the Cretaceous bedrock and underlying Paleozoic strata. This interval of missing geologic time represents a significant period of erosion following the Marathon orogeny and the development of the Devils River Uplift (see “Geologic History”).

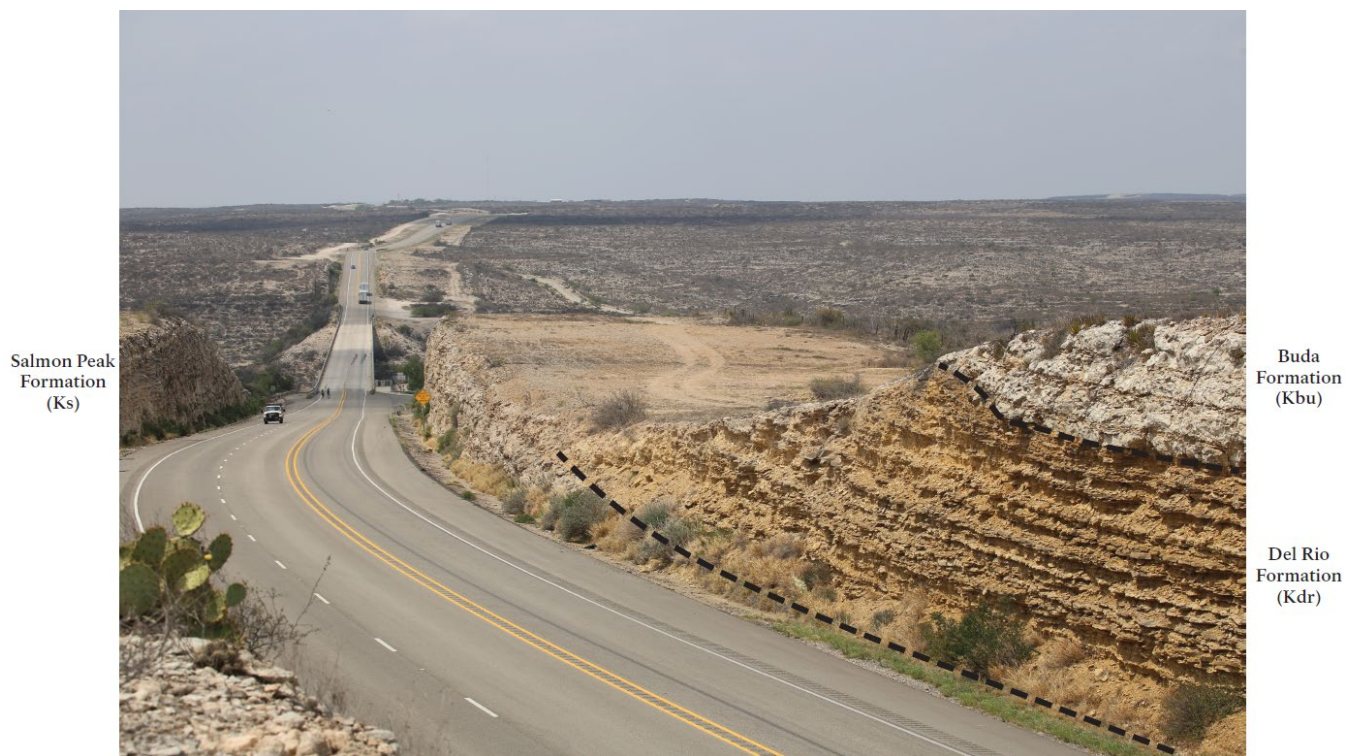


**Figure 5.** Cretaceous rocks exposed along US Highway 90 bridge near the Pecos River. View is facing northwest. Rocks of the Buda Formation unconformably overlie the Del Rio Formation, which in turn unconformably overlie the Salmon Peak Formation. NPS photograph/J. Johnson.

## Geologic Heritage

Geologic heritage (also called “geoheritage”) evokes the idea that the geology of a place is an integral part of its history and cultural identity. In 2015, the NPS's GRD staff, in cooperation with the American Geosciences Institute, published a booklet introducing the American experience of geoheritage, geodiversity, and geoconservation: *America's Geologic Heritage: An Invitation to Leadership*. This publication introduces key principles and concepts of America's geoheritage, which are the focus of ongoing collaboration and cooperation on geologic conservation in the United States. That booklet introduced the American experience of geologic heritage and outlined key principles and concepts, including the following five big ideas:

- America’s geologic landscape is an integral part of its history and cultural identity, and Americans have a proud tradition of exploring and preserving geologic heritage.
- America’s geologic heritage, as shaped by geologic processes over billions of years, is diverse and extensive.
- America’s geologic heritage holds abundant values—aesthetic, artistic, cultural, ecological, economic, educational, recreational, and scientific—for all Americans.
- America’s geologic heritage benefits from established conservation methods developed around the world and within the United States.
- America’s geologic heritage engages many communities, and involvement by individuals will ensure its conservation for future generations.

Through literature review and discussion with AMIS staff, six main geoheritage themes were identified that include the paleontological resources, caves and karst, indigenous connections, the Southern Transcontinental Railroad and the Pecos Viaduct, the historical Devils River hydroelectric plants, and water resources. Collectively, these themes address several geoheritage values that are intrinsic to AMIS.

### Paleontological Resources

Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). They may be body fossils (any remains of the actual organism such as bones, teeth, shells, or leaves) or trace fossils (evidence of an organism’s activity such as nests, burrows, tracks, or feces). Fossils may occur in rocks or unconsolidated deposits, in museum collections, or in cultural contexts, such as building stone.

#### *Mesozoic Fossils*

Fossils preserved within the recreation area date back nearly 100 million years and represent a diverse array of vertebrates, invertebrates, plants, microfossils, and trace fossils (Table 4; Visaggi et al. 2009). Although fossil resources have been reported from the Amistad region since the late 19th century, there is still considerable potential for discovery, as little research has been conducted within AMIS. Cretaceous carbonates and clays within the recreation area contain marine fossils that are extensively displayed along cliff and canyon exposures. Common marine taxa include rudistid bivalves, *Ilymatogyra* oysters (including the “Devil’s Toenail,” a characteristically curled shell), *Nerinea* gastropods, and *Cribratina* forams, along with examples of echinoids, ammonoids, scallops, and bryozoans (Figure 6; Visaggi et al. 2009).

Some of the most interesting fossils at AMIS include rudistid bivalves which are anomalously large, odd-shaped bivalves that formed reefs quite distinct from modern coral reefs (Figure 7). Although the Cretaceous–Paleogene mass extinction is often renowned for the demise of the dinosaurs, these rudist reef-builders also disappeared at the end of the Mesozoic Era. Rudist reef exposures along the lower Pecos River Valley display a range of development and morphology, ranging from hydrodynamic accumulations to isolated mounds up to 5 m (15 ft) thick (Kerans 2002; Visaggi et al. 2009). Limestone outcrops of the Salmon Peak Formation at Coontail Spin contain exceptionally rich examples of rudistid reefs.

**Table 4.** Paleontological resources by geologic unit. The following table shows paleontological resources associated with the geologic units within Amistad National Recreation Area. Information for the table was sourced from Santucci et al. (2001) and Visaggi et al. (2009).

| <b>Geologic age</b>      | <b>Geologic unit name</b>    | <b>Fossil reported within the recreation area</b>                                                                                  |
|--------------------------|------------------------------|------------------------------------------------------------------------------------------------------------------------------------|
| Holocene                 | Alluvium                     | None                                                                                                                               |
| Pleistocene and Holocene | Indigenous cultural deposits | Mammals, birds, reptiles, amphibians, fish, mollusks, plants, pollen, middens, coprolites, and more based on archeological reports |
| Pleistocene              | Fluvial terrace deposits     | None                                                                                                                               |
| Pliocene or Pleistocene  | Uvalde Gravel                | None                                                                                                                               |
| Late Cretaceous          | Boquillas Formation          | <i>Unknown</i> (see “Inventory Needs”)                                                                                             |
| Late Cretaceous          | Buda Limestone               | Bivalves, gastropods, cephalopods, echinoids, burrows                                                                              |
| Late Cretaceous          | Del Rio Clay                 | Bivalves, gastropods, foraminifera, borings, burrows                                                                               |
| Early Cretaceous         | Devils River Formation       | Bivalves, gastropods, burrows                                                                                                      |
| Early Cretaceous         | Salmon Peak Formation        | Bivalves, gastropods, echinoids, burrows                                                                                           |

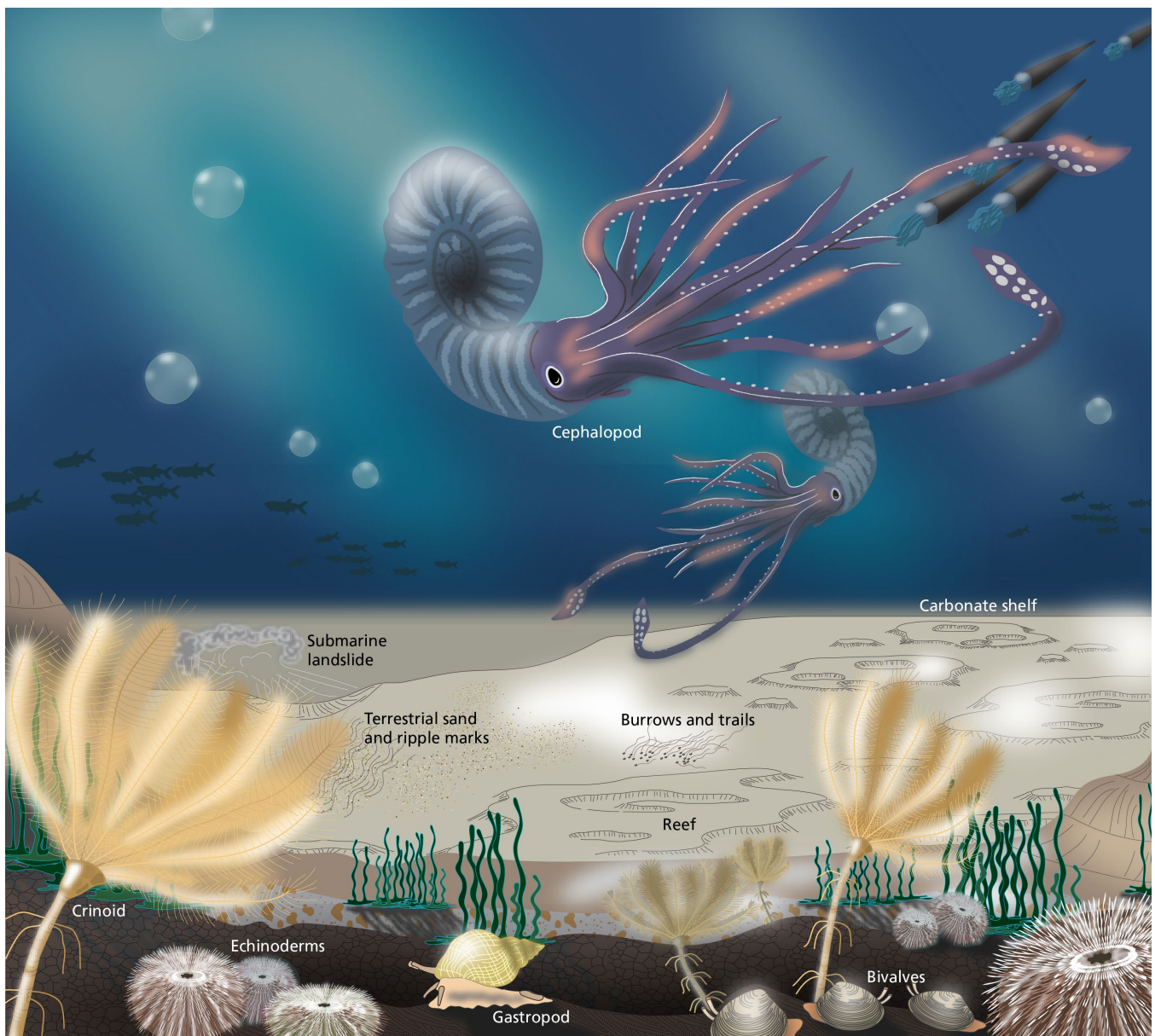


**Figure 6.** Artistic depiction of the Cretaceous carbonate shelf environment that formerly occupied AMIS. The reconstruction is based on paleontological specimens collected from within the recreation area combined with bedrock lithology. Graphic created by Trista L. Thornberry-Ehrlich (Colorado State University).



**Figure 7.** Photograph of a rudist bivalve fossil specimen from the recreation area’s paleontological collection. Rudists (rudistae) were ancient marine organisms that functioned similarly to modern corals, forming thick, vast reefs that are preserved in the carbonate bedrock of AMIS. Like the dinosaurs, rudists went extinct at the end of the Cretaceous Period, approximately 66 million years ago. Banana for scale. NPS photograph/J. Johnson.

### *Cenozoic Fossils*

Although numerous caves in central and west Texas have notable Cenozoic vertebrate paleontological assemblages, none are currently known within AMIS (Toomey 1994). An infilled cave that may contain Tertiary deposits with vertebrate remains was discovered near the mouth of the Pecos River just outside the recreation area during road construction for the US Highway 90 bridge (Cannon et al. 1959). The discovery of this nearby cave suggests the possibility that future investigations may find similar localities within AMIS.

Quaternary paleontological resources in AMIS are often preserved in deeply buried contexts such as rock shelters and river terraces that are sometimes associated with Indigenous cultural deposits. These resources have helped reconstruct the paleoclimate and paleoecology of southwest Texas during and following the last Ice Age. Pleistocene megafaunal remains were notably excavated from Cueva Quebrada (Lundelius 1984) and Bonfire Shelter (Dibble and Lorrain 1968) during the NPS-funded pre-reservoir archeological salvage investigations. Although these remains are important parts of the AMIS museum collections, these sites lie outside the recreation area’s administrative boundary (Jack Johnson, NPS AMIS, personal communication January 2025).

Cueva Quebrada is a small rock shelter along the Rio Grande, immediately adjacent to a large rock shelter (Conejo shelter, discussed later). Faunal remains from the locality yield an age of approximately 12,000 to 14,000 radiocarbon years before present and include extinct species of bison, horse, camel, mountain deer, pronghorn, and short-faced bear. It is important to acknowledge that radiocarbon dates are not equivalent to calendar dates and that radiocarbon years require calibration to yield calendar years. According to Lundelius (1984; p. 461), the presence of these species and the paucity of paleoenvironmentally sensitive fauna indicate the presence of “...open country, grasslands or savanna on the uplands” at the time. Only one extant taxon from the assemblage does not occur in the area today—the pygmy mouse *Baiomys taylori*—which suggests that the area had slightly moister conditions in the past compared to today. The paleontological resources at Cueva Quebrada include an accumulation of burned and misshapen bones that are disarticulated and show signs of predation from carnivores (Lundelius 1984; Santucci et al. 2001). Many bones are severely charred or broken in ways that suggest human involvement; one rare bone specimen has three V-shaped cut marks consistent with butchering with stone tools. However, no other tools, artifacts, or archeological features were found associated with these deposits. Although it appears both humans and predators had something to do with the bones in Cueva Quebrada, it is difficult to interpret the assemblage further.

Bonfire Shelter is a notable bison jump-kill drive site that preserves hundreds of animal specimens—including Pleistocene megafauna such as the extinct *Bison antiquus* (ancestor of the modern bison, *Bison bison*)—in addition to cultural materials such as hearths and projectile points (see “Indigenous Connections”). The site is widely regarded as the oldest and southernmost bison jump-kill site in North America (Dibble 1965; Dibble and Lorrain 1968; Bement 1986), though some scholars have argued that the animals were killed elsewhere and only butchered at the site (Byerly et al. 2005, 2007; see also Bement 2007 and Kilby et al. 2024).

Conejo Shelter contains a collection of vertebrate bones and plant remains but also represents one of the first localities in North America where desiccated human coprolites were recognized (Visaggi et al. 2009). With radiometric ages spanning approximately 6,500 years, these Holocene coprolites provide a superb record of paleoenvironment and Indigenous sustenance (Jack Johnson, NPS AMIS, personal communication January 2025; see also Sonderman et al. 2019).

## **Caves and Karst**

Amistad National Recreation Area lies within a semi-arid karst landscape featuring caves, enlarged fractures, groundwater aquifers, overhangs, rock shelters, sinkholes, solution cavities, and springs. Over millions of years, weak acids in rainwater have slowly dissolved the carbonate bedrock, making voids, holes, and interconnected conduits. The recreation area is known to contain over 350 karst features, of which Diablo Cave is the longest (1,290 m [4,000 ft]) and Goodenough Springs (also referred to as Hinojosa Springs) is the deepest (KellerLynn 2008; Howard and Gluesenkamp 2020). As the name implies, Goodenough Springs is not only a cave but also a groundwater spring submerged below the waters of Amistad Reservoir; the farthest that divers have penetrated to the current “end” of surveyed cave passage is about 76 m (375 ft) below its entrance (KellerLynn 2008; [Maps – Goodenough Springs Exploration Project](#); accessed March 2025). Cave and karst features in AMIS were utilized by Indigenous inhabitants for multiple purposes (e.g., domestic, artistic, spiritual) and contain important cultural and paleontological resources (see “Indigenous Connections”). Additionally, at least two caves within the recreation area are protected habitats of the endangered Mexican blindcat (*Prietella phreatophila*), a small (about 7.6 cm [3 in] long), blind, depigmented

fish species that is endemic to North American karst aquifers (Hendrickson et al. 2017; Howard and Gluesenkamp 2020; Jack Johnson, NPS AMIS, personal communication July 2024).

## Indigenous Connections

More than 10,000 years ago, long before the creation of Amistad Reservoir, the landscape encompassing the confluence of the Rio Grande, the Pecos River, and the Devils River was home to several Indigenous hunter-gatherer cultures. Geologic features within and surrounding the recreation area record the presence of these early human occupants. These include karst features (e.g., caves, enlarged fractures, overhangs, rock shelters, sinkholes, solution cavities, springs), pictographs (rock paintings), petroglyphs (rock carvings), bison drives (kill sites where herds of bison were driven off cliffs), hearths, stone tools, painted pebbles or clay figures, animal and plant remains, and coprolites (fossilized feces). Cretaceous carbonate strata that underlie AMIS host over 200 karst features and provide stable conditions necessary for the unique preservation of organic materials such as textiles, fibrous plants, wood, and DNA (see “Caves and Karst”; Howard and Gluesenkamp 2020). Many of these cultural and paleontological resources provide an invaluable window into the past and document humankind’s adaptation to the climatic and ecological evolution of the Chihuahuan Desert region following the last Ice Age (the last 11,700 years). These sensitive resources are susceptible to both natural and anthropogenic processes that can lead to their exposure, deterioration, and destruction (see “Paleontological and Cultural Resource Protection”).

### *Pictographs*

The Lower Pecos Canyonlands preserve one of the densest collections of Indigenous pictographs in North America (National Park Service 2006a, 2017). Painted on the carbonate walls of rock shelters and cliffs are various motifs, shapes, figures, designs, and scenes that have been interpreted to represent five distinct artistic styles (from oldest to youngest): (1) Red Linear; (2) Pecos River; (3) Red Monochrome; (4) Bold Line Geometric; and (5) Historic (Table 5; Figure 8; see <https://www.nps.gov/amis/learn/historyculture/howtorockart.htm>; accessed November 2024). Pigments used to create the pictographs were usually powdered minerals such as hematite, limonite, and manganese dioxide mixed with a liquid binder (animal fats) that were applied using fingers, plant fibers, or as “crayons” of pressed mineral powder; occasionally charcoal was used (Figures 9–10; Turpin 1984; Kaluarachchi et al. 1995).

In the thousands of years since they were painted, many Pecos River Style pictographs have become encased in a natural mineral crust that preserves and partially obscures these resources (see “Paleontological and Cultural Resource Protection”). The crust is composed mostly of whewellite (calcium oxalate monohydrate,  $\text{CaC}_2\text{O}_4 \cdot \text{H}_2\text{O}$ ), with some inclusions of calcite, gypsum, weddellite (calcium oxalate dihydrate,  $\text{CaC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ ), and a minor component of quartz (as a skin between the crust and the substrate) and other silicates. Microstructures within the crust are likely fossils of its source, an epilithic lichen such as *Circinaria calcarea* (formerly *Aspicilia calcarea*) or a similar species (Russ et al. 1996, 1999).

**Table 5.** Pictograph styles recognized within the area surrounding AMIS. Information provided in the table was sourced from Turpin (1984), Labadie (1994), Dering (2002), Boyd et al. (2013), National Park Service (2018), Roberts (2023), and Steelman (2023).

| Pictograph Artistic Style | Age                                   | Key Characteristic Features                                                                                                                                                           |
|---------------------------|---------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Historic                  | About 500 years before present (BP)   | The presence of domestic livestock, guns, Spanish conquistadors, and Christian symbology                                                                                              |
| Bold Line Geometric       | About 800 years BP                    | Abstract designs, usually painted in thick, glossy, red pigment; designs are a combination of straight lines and blank spaces to form zigzag, triangular, and diamond-shaped patterns |
| Red Monochrome            | Approximately 1,000 years BP          | Human figures with bows and arrows; life-size and life-like human or animal figures                                                                                                   |
| Pecos River               | About 5,500 to 1,400 years BP         | Multicolored anthropomorphic (human-like), therianthropic (part human, part animal), and theriomorphic (animal-like) figures resembling deer, mountain lions, fish, birds, and humans |
| Red Linear                | Approximately 5,600 to 4,700 years BP | Small, red stick figures of humans and animals associated in group activity (e.g., hunting, warfare, ritual, procession)                                                              |

### Amistad National Recreation Area Pictograph Styles



**Figure 8.** Artistic examples of pictograph styles preserved in AMIS. Each style represents a different time interval and contains unique depictions or themes. Figure modified from National Park Service (2018).



**Figure 9.** The mountain lion or panther pictograph of Panther Cave. The namesake panther pictograph is over 3 m (10 ft) long from nose to the tip of the tail and was painted using red mineral-based pigments (e.g., hematite) mixed with a liquid binder. As the region's most famous pictograph site, Panther Cave is covered from floor to ceiling with hundreds of pictograph motifs spanning more than 30 m (100 ft) in length. Although many pictographs appear to be on the surface of the cave's limestone walls, some are covered by a thin veneer of mineral accretion that has developed over thousands of years. NPS photograph.



**Figure 10.** Pictographs in Parida Cave. These cave paintings depict abstract, diamond-shaped patterns previously classified as Bold Line Geometric style but may also be interpreted as Pecos River style (bottom left). Additionally, these pictographs contain several small, multicolored anthropomorphic figures characteristic of both pictograph styles (bottom left and right). The pictograph panel is roughly 2 m (6 ft) tall. More information can be found at: Shumla Archaeological Research and Education Center - 3D Model (accessed April 2025). NPS photograph/J. Johnson.

### *Fire-Cracked Rock*

Scattered throughout AMIS are angular, thermally altered stones referred to as “fire-cracked rock” that are documented at over 700 archeological localities in the recreation area (Visaggi et al. 2009). Fire-cracked rocks largely consist of gray Salmon Peak limestone but also include oxidized, red fossiliferous pieces of Del Rio Clay (Figure 11). These rocks are fist-sized fragments of larger stones that were commonly used in underground earth ovens and heated for cooking purposes. Fire-cracked rocks were essential components of Indigenous earth ovens, which typically consisted of pits dug in the ground, lined with rocks, and loaded with firewood with more rocks stacked on top. After the fire burned down, the hot rocks were covered with an insulating layer, then a layer of food, and finally covered with soil to cook for up to three days using the stored thermal energy of the rocks (Figure 12; National Park Service 2018). Such long cooking times were essential for the preparation of wild desert plant foods such as sotol (*Dasyllirion texanum*) and lechuguilla (*Agave lechuguilla*). As rocks within the earth oven were heated, the high temperatures of 425–540°C (800–1000°F) needed for cooking would cause some of the rocks to crack, break, or even explode. It has been postulated that fossil-bearing rocks were preferential to non-fossiliferous limestone because they were less susceptible to explosion at high temperatures due to compositional differences (Visaggi et al. 2009). Once a rock had broken down to be about fist-sized, its ratio of surface area to volume was such that it cooled too

quickly to keep an oven at or above boiling for 72 hours. Therefore, whenever an earth oven pit was reused, the fist-sized broken rocks were removed, discarded, and replaced with new, larger ones. With enough repeated uses of a site over time, the discarded rocks accumulated into piles that archeologists call burned rock middens.



**Figure 11.** Fossiliferous rocks of the Del Rio Formation compared to a fire-cracked rock of the Del Rio Formation. Fire-cracked rock, such as the one to the left, turns red after intense heating associated with Indigenous earth ovens. The original, uncooked Del Rio Formation is lighter in color for comparison and contains bivalve fossils. Ruler for scale. NPS photograph/J. Johnson.

# Earth Oven Cooking

National Park Service  
U.S. Department of the Interior  
Amistad National Recreation Area



**Figure 12.** Depiction of an Indigenous earth oven. Rocks were used to line oven pits and cook food using their stored thermal energy. As the rocks heated, the high temperatures needed for cooking could cause them to break or even explode. Today, these fire-cracked rocks are documented across 700 sites in the recreation area. Figure created by Amistad National Recreation Area.

## Stone Tools

Indigenous Peoples needed tools for various survival purposes (e.g., hunting, food processing, trade), and different kinds of stone found throughout AMIS have different properties that made them suitable for certain tasks. Stone tools are common artifacts found at the recreation area because of the geologic diversity of the regional Rio Grande–Pecos River–Devils River watersheds and also the local bedrock. River gravels and terrace gravels within AMIS contain a diverse array of rock types suitable for tools—including vesicular basalts, rhyolites, agate, jasper, and chert (flint is a type of chert)—that originated from upstream sources (Figure 13; Jack Johnson, NPS AMIS, personal communication July 2024). The recreation area and its archives preserve a large collection of Indigenous stone tools that includes projectile points, unifacial implements (knives, scrapers, and gouges used to process animal hides and plants), bifacial knives, drills (instruments used to perforate bones, shell, stone, and hide), manos (smooth, fist-sized rocks used for grinding or pounding), metates (grinding stones), and bedrock mortars (Figure 13; Turpin 1984; Labadie 1994; Dering 2002). At some sites, particularly deep mortars have been used for storing water and food or possibly for alcoholic fermentation (Labadie 1994).



**Figure 13.** River cobbles and cultural materials of various lithologies at AMIS. Many of AMIS’s cultural artifacts—including painted pebbles (top right), projectile points (middle right), drills (bottom right), and more—were made from stone that was quarried from river deposits and reflect the geologic diversity of the Edwards Plateau physiographic province. NPS photographs courtesy of Jack Johnson and the AMIS museum collection.

### Flaked Stone Tools

Two broad categories of stone tools in AMIS include flaked stone tools (tools generally intended to have a sharp cutting or scraping edge) and ground stone tools (tools generally intended to have rounded edges and broad surfaces for grinding). In the Lower Pecos Canyonlands, flaked stone tools are predominantly made from chert that is known to break with conchoidal fracture to produce an irregular, sharp edge; the process of chipping rock to make tools is referred to as knapping or flintknapping (Figure 14). The property of conchoidal fracture allows a skilled flintknapper to strike the rock with a hammerstone (a smaller rounded stone) at the right angle and with the right amount of force to shear off thin flakes. In the absence of a hammerstone, the base of a thick piece of antler tine would also suffice. Small tools, including numerous projectile points, are made on larger flakes, but additional flakes were used as-is for extra sharp cutting implements. The flintknapper would continue to strategically remove smaller and smaller flakes to thin and shape the tool until it had the desired overall shape and thickness. Lastly, a pointed piece of deer antler tine

was utilized for detailed pressure flaking work to straighten or sharpen the tool's cutting edge and to add features like the notches on a projectile point. Local sources of chert nodules include the Cretaceous Salmon Peak Formation and Pliocene–Pleistocene Uvalde Gravel (Page et al. 2009). According to Dering (2002), nine quarries have been recorded in AMIS that were utilized for the manufacturing of chipped stone tools. Occasionally, flaked stone tools were made of other similar cryptocrystalline quartz rocks like jasper, agate, or chalcedony, which can be found in the gravel bars of the Rio Grande. The gravel bars also contain finer-grained volcanic rocks like basalt or rhyolite. These materials do not knap particularly well, but large flakes were sometimes used to make simple unifacial cutting tools. Archeologists have found very few small flakes of obsidian, a natural volcanic glass. Although obsidian is exceptionally sharp and knaps very well, it does not occur anywhere near Amistad and was likely introduced to the region through trade. Trace element analyses of these obsidian artifacts have helped determine their geologic source, and three obsidian flakes from AMIS were found to have originated from the Pleistocene Cerro Toledo Rhyolite in the Jemez Mountains of northern New Mexico—a location almost 965 km (600 mi) away or closer to 1,290 km (800 mi) if following the Rio Grande (Hester et al. 1991).

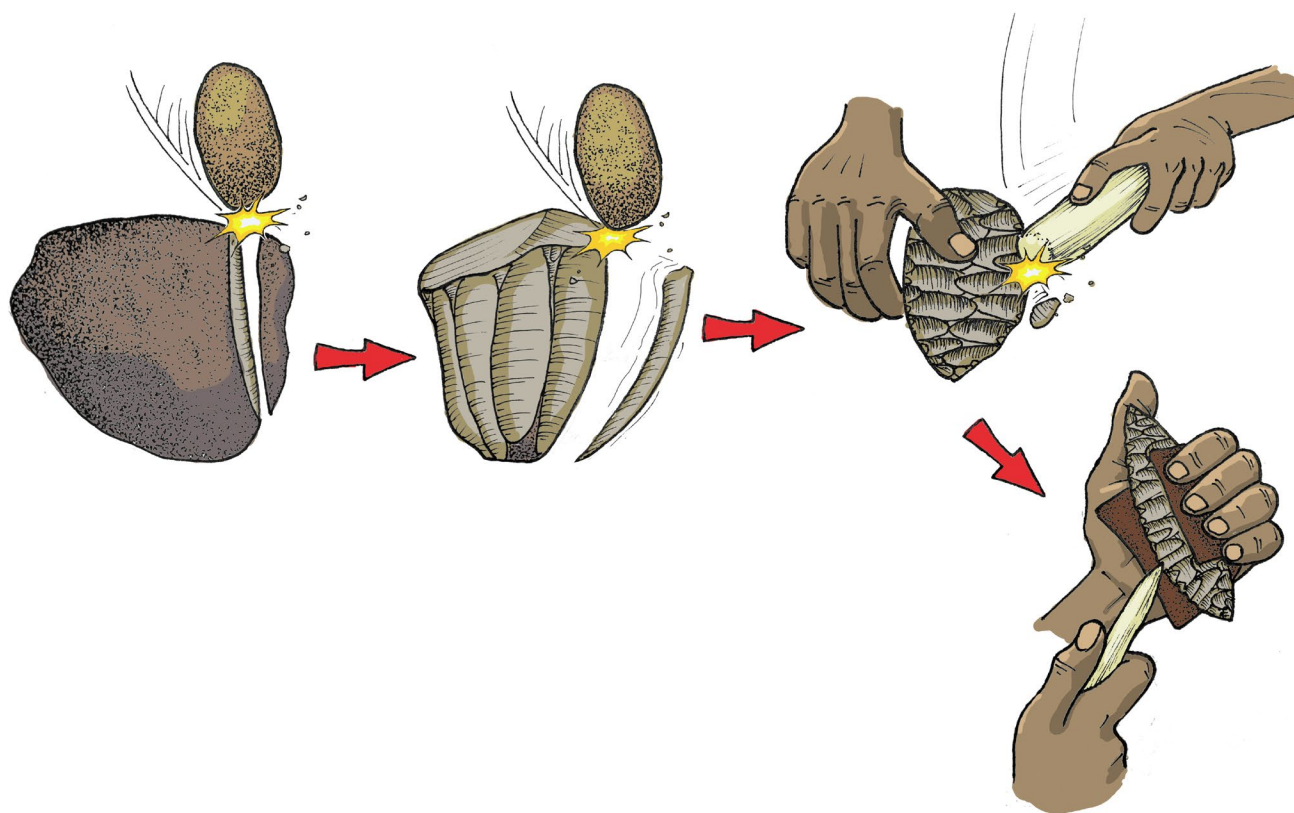


**Figure 14.** Depiction of the flintknapping process. Rocks such as chert are processed into flaked stone tools by being struck by a hammerstone to remove small pieces until they achieve a desired size or shape. Detailed pressure flaking was typically performed using deer antler tine to straighten or sharpen the tool's cutting edge or to add features such as notches and grooves. Figure courtesy of Jack Johnson (NPS AMIS).

## Ground Stone Tools

Ground stone tools are generally used for grinding or processing seeds and other plant foods. The two most common types of ground stone tools at AMIS are metates and mortars. These tools were shaped by being struck with hard, sharp stones to gradually pick away unwanted surficial material until they had the desired composition and shape; afterward, these stones were ground smooth. A metate has a large, flat to gently concave grinding surface on which food was placed and ground into flour with manos. Many people are familiar with the large, flat metates from Mexico that were (and in some places still are) used to grind corn or chocolate. In the Lower Pecos Canyonlands, metates tended to be smaller in diameter (roughly 15–30 cm [6–12 in]) and oval-shaped. Most often these tools were constructed out of bedrock located by the water but are also found along the tops of large boulders within rock shelters, where they often co-occur with bedrock mortars. At times, portable metates were constructed using oval-shaped, flat stone slabs with rounded edges. A mortar is a deep, usually round hole with sides that are steep if not vertical (Figure 15). Semi-portable mortars were sometimes made in thick stone slabs, while smaller portable ones were carved out of wood. Food would be placed into the hole and pounded with a cylindrical piece of stone or wood called a pestle. During the 16<sup>th</sup> century in southern Texas, the shipwrecked Spanish explorer Cabeza de Vaca observed large mortars being used with wooden pestles the size of a man's thigh to pound mesquite pods into flour; additional historic accounts by F.M. Buckelew noted the use of mortars to pound cooked sotol plant hearts in the Lower Pecos region in the 19<sup>th</sup> century (Jack Johnson, NPS AMIS, written communication April 2025). In addition to mesquite and sotol, mortars were used for processing acorns, small native walnuts, and other foods. Today, many people still use stone mortars and pestles in their kitchens for grinding spices or preparing dishes such as salsa and guacamole.



**Figure 15.** Bedrock mortars in AMIS. Mortars such as these are ground stone tools in which foods (e.g., mesquite, sotol, acorns) were processed or liquids were stored. The multitool for comparison is approximately 10 cm (4 in) long. NPS photograph/J. Johnson.

### *Painted Pebbles and Clay Figurines*

Although AMIS is better known for its rich collection of pictographs, other forms of artistic expression found in association with rock shelters include Early to Middle Archaic (about 8,500 to 3,000 years before present) painted pebbles and clay figurines. Painted pebbles are smooth, fist-sized stones averaging 5–13 cm (2–5 in) in length that are typically painted on both sides with black pigment. The designs depict a range of abstract geometric patterns as well as reproductions of the human face and body (Turpin 1984; Labadie 1994; Dering 2002). These painted stone artifacts have been interpreted as a form of mobile art (“art mobileur”) or material culture, although they may also have served spiritual purposes (Turpin 1984; Labadie 1994). Clay figurines are small masses of shaped, unfired clay that commonly depict headless human figures, including some with cone-shaped appendages interpreted as female (Turpin 1984; Labadie 1994; Dering 2002). Like painted pebbles, these clay objects are believed to be related to spiritual practices or ceremonies.

### *Bonfire Shelter*

Located at the base of the cliffs in Eagles Nest Canyon, Bonfire Shelter is one of the oldest and most significant cultural sites in proximity to AMIS. The rock shelter is a famous Paleoindian site that has long been held to be the oldest and southernmost bison jump-kill drive site in North America. The site preserves the remains of an estimated 800 animals (including Pleistocene megafauna and roughly 120 bison of the extinct species *Bison antiquus* or *occidentalis*), in addition to projectile points, hearths, and other cultural items (Turpin 1984; Dering 2002; Kilby et al. 2020). The site contains a layered, 3 m (10 ft) thick sequence of charred bone beds (hence the name, Bonfire Shelter) that preserves multiple hunting or bison drive events spanning thousands of years (Bement 1986, 2007; Dering 2002). Bonfire Shelter was originally excavated by the NPS-sponsored pre-reservoir excavations during the 1960s, and the park has many faunal bones and artifacts from the site in its museum collections, although Bonfire Shelter is located a few hundred meters beyond the AMIS boundary. An alternative interpretation of the faunal assemblage at Bonfire Shelter is that the site represents a secondary butchering location for bison that were driven up the box canyon and dispatched (Kilby et al. 2020). If the bison drive hypothesis is proven, Bonfire Shelter would represent the oldest and southernmost bison drive in North America.

The bone beds at Bonfire Shelter have been broken down into three distinct intervals (in order from oldest to youngest): (1) Bone Bed 1, containing Pleistocene megafauna such as horse (*Equus francisci*), mammoth (*Mammuthus sp.*), bison (*Bison antiquus*), camel (*Camelops hesternus*), pronghorn (*Capromeryx sp.*), and smaller fauna; (2) Bone Bed 2, an accumulation of *Bison antiquus* or *occidentalis*; and (3) Bone Bed 3, a layer of *Bison bison* up to 0.8 m (2.6 ft) thick (Kilby et al. 2020). Radiocarbon dating of the individual bone bed layers indicates Bonfire Shelter was episodically occupied approximately 14,000 years ago (Bone Bed 1), 12,000 years ago (Bone Bed 2), and around 2,500 years ago (Bone Bed 3; Turpin 1984; Kilby et al. 2020). Although chiefly recognized for their cultural and archeological significance, specimens collected from the site could be considered paleontological resources since they have been useful in paleoclimate and paleoecological reconstructions (Visaggi et al. 2009).

## **Southern Transcontinental Railroad and the Pecos Viaduct**

### *Southern Transcontinental Railroad*

The construction of the Southern Transcontinental Railroad and the Pecos Viaduct (Pecos River High Bridge) represent two transportation milestones that influenced the development and land use surrounding

AMIS. Although these projects were engineered to link the western and eastern parts of the United States, they were impacted by the steep, rugged canyonlands and river networks associated with the recreation area.

Following the American Civil War, some 90% of all railroad trackways in the United States lay east of the Mississippi River (see <https://www.nps.gov/amis/learn/historyculture/str.htm>; accessed November 2024). After the first transcontinental railroad was completed in 1869 (on land that is now Golden Spike National Historical Park, Utah), the first surveys for the Southern Transcontinental Railroad began in 1880 along the lower Pecos River valley region. The Southern Pacific Railroad Company built separate trackways extending eastward from California and westward from San Antonio, with the two lines merging near the confluence of the Rio Grande and the Pecos River (Labadie 1994). Completed in 1883, the railroad passed through the Amistad Reservoir basin, whose rugged topography required approximately 17 km (11 mi) of trackway blasted into the canyon walls. A tunnel segment located immediately upstream of Seminole Canyon State Park and Historic Site was once the oldest and longest railroad tunnel in Texas (Jack Johnson, NPS AMIS, personal communication July 2024). One of the most daunting engineering challenges related to the construction of the transcontinental railway was the crossing of the Pecos River at its confluence with the Rio Grande, which involved a winding trackway down into and out of the canyon along a series of steep and curvy grades that crossed numerous intervening side canyons. One of the historic railway stations—the Painted Cave Station—was named after Indigenous pictographs preserved at nearby Parida Cave; railroad passengers would often frequent the large rock shelter located above the station (Figure 16). Today, Painted Cave Station is gone, as it was either destroyed or inundated by Amistad Reservoir and covered with silt. However, evidence of the railway station remains in travelers’ graffiti in Parida Cave, including an advertisement painted on the rock shelter wall (see “Paleontological and Cultural Resource Protection”).



**Figure 16.** The historic Painted Cave Station. The railway station was named after Indigenous pictographs preserved at nearby Parida Cave and was only in operation from 1883 until shortly after the construction of the Pecos Viaduct in 1892. Railroad passengers would frequently visit Parida Cave, which was located above the station. Today, all evidence of Painted Cave Station is gone, as it was either destroyed or inundated by Amistad Reservoir. Photograph is part of the “Southern Pacific Sunset Route Photographs” collection, used with permission of the Briscoe Center for American History.

By 1892, the Southern Transcontinental Railroad was re-routed away from the Rio Grande for multiple reasons, including (1) high maintenance costs associated with flooding of the Pecos River bridge that only stood about 12 m (40 ft) above the river; (2) prevalent rockfalls; and (3) the advent of the Pecos Viaduct (Labadie 1994). The inherent and prevalent dangers posed by rockfalls convinced the railway company to employ “track-walkers” both day and night to prevent derailments caused by debris along the trackway (Labadie 1994). When the reservoir is at normal levels, an abandoned portion of the 1883 trackway can be seen by boat between Seminole Canyon and Shumla Bend on the Rio Grande arm of the Amistad Reservoir, and the downstream railroad tunnel now houses a large population of Mexican free-tailed bats.

#### *Pecos Viaduct*

Constructed in 1892, the Pecos Viaduct is among the most famous historic bridges in Texas and served as part of the Southern Transcontinental Railroad until it was replaced by a more modern design after World War II. In the late 19<sup>th</sup> century, the bridge held the distinction of being the highest in the United States (standing nearly 98 m [323 ft] tall) and the third highest in the world (see

<https://www.nps.gov/amis/learn/historyculture/viaduct.htm>; accessed November 2024). As the second engineered structure to span the Pecos River gorge, the Pecos Viaduct helped eliminate approximately 17 km (11 mi) of treacherous, pre-existing railroad grade leading in and out of the Rio Grande canyon and is responsible for closing several railway stations, including the historic Painted Cave Station near Parida Cave. In the 1920s, the Southern Pacific Railroad built a railway station east of the Pecos River adjacent to the bridge that consisted of a watchman's residence, pumping station, and storage tanks for water and oil. Situated in the canyon bottom below the floodplain of the Pecos River, the residence and pumphouse were periodically flooded until the construction of the Amistad Dam permanently inundated these historic structures (Labadie 1994). Masonry footings from the original Pecos Viaduct are still visible today by boat along the Pecos River.

### **Historical Devils River Hydroelectric Plants**

Prior to the completion of Amistad Dam and the infilling of Amistad Reservoir, several hydroelectric power plants were constructed along the Devils River to meet an ever-growing demand for energy in the 1920s (see <https://www.nps.gov/amis/learn/historyculture/devilslake.htm>; accessed November 2024). The Devils Lake Hydro Plant, completed in 1928, was located approximately 16 km (10 mi) upstream from the former confluence of the Devils River and the Rio Grande (near present-day Rough Canyon Campground). The dam stood nearly 13 m (45 ft) high, measured 259 m (850 ft) long, and was constructed out of massive limestone blocks of the Salmon Peak Formation quarried from the cliffs of the Devils River. The limestone blocks had interlocking ridges cut into the edges to increase their structural integrity (National Park Service 2014). Constructed several miles downstream from the Devils Lake Hydro Plant, the Lake Walk Hydro Plant was built in 1929 and was the smallest and most technologically advanced hydropower plant on the Devils River. Measuring 10 m (34 ft) high and 198 m (650 ft) long, the Lake Walk Hydro Plant featured one of the first completely automatic turbine engines in the United States. The third hydroelectric plant was constructed by 1929 and was simply known as the Steam Plant. This plant was located near the former mouth of the Devils River just west of present-day Southwinds Marina.

In the years following the completion of the hydroelectric plants, several major floods occurred in 1932, 1948, and 1954 that inflicted extensive damage to all three power facilities (National Park Service 2014). Although repairs were made and these facilities remained operational, they were all shut down by 1965 and replaced when Amistad Dam went operational in 1968. Amistad Reservoir reached its conservation level (water storage volume needed to meet domestic, agricultural, recreational, and industrial [e.g., hydroelectric] needs) by 1972, resulting in the inundation of all three power plants.

### **Water Resources**

Water is a vital resource to AMIS and is supplied through a variety of springs, seeps, tinajas (bedrock depressions that hold water), groundwater aquifers, and the Rio Grande system. Seasonal changes in precipitation and temperature govern the recharge and discharge of these hydrological resources, many of which belong to an interconnected network that ultimately flows into Amistad Reservoir. In the Chihuahuan Desert region, groundwater is a critical resource that is highly susceptible to the impacts of climate change, especially when coupled with anthropogenic diversions (see "Groundwater Resource Protection").

### *Fluvial Features*

Major fluvial features of AMIS include the Rio Grande and its major tributaries, the Pecos River and the Devils River. The modern landscape of southwest Texas has been extensively modified by erosion, downcutting, and aggradation related to the Rio Grande system since the Pleistocene Epoch around 2 million years ago (Turner et al. 2011). Natural features surrounding Amistad Reservoir—including its steep cliffs, rugged canyonlands, and karst landscape—are formed within the Cretaceous bedrock and are testament to the persistent erosive power of the river system (Figure 17). Quaternary deposits record the fluvial evolution of the region and consist of modern river alluvium, older terrace gravels and alluvium, as well as the Uvalde Gravel.



**Figure 17.** Aerial view looking south at the confluence of the Pecos River and the Rio Grande. The US Highway 90 bridge crosses the Pecos River just north of its mouth. The semi-arid landscape of AMIS is dissected by steep-walled river canyons that experience routine flooding and drought, as well as occasional rockfall events. Major tributary mouths are sites of enhanced sedimentation, especially during flood stage and can accumulate thick sequences of fine-grained silt and organic debris. NPS photograph.

In the Chihuahuan Desert, the Rio Grande system provides a valuable source of water that is supported by tributary watersheds and groundwater sources, such as springs or seeps. The Rio Grande, the Pecos River, and the Devils River are unique waterways, as each is distinctly sourced and contains different flow regimes, sediment supplies, water qualities, geologic landforms, and cultural resources (Valentine-Darby et al. 2016). With its headwaters in the Rocky Mountains, the Rio Grande flows over 3,000 km (1,900 mi) from Colorado

to the Gulf of Mexico and is supported by one of the largest drainage areas in the United States. In the recreation area, the Rio Grande section begins 58 km (36 mi) above the confluence with the Pecos River and is characterized by a low-gradient channel that meanders through high canyon walls. Sedimentation along the river channel is a known issue, as silt deposits measuring up to 26 m (85 ft) thick have accumulated near the mouth of the Pecos River (KellerLynn 2008).

Originating from the Sangre de Cristo Mountains of New Mexico, the Pecos River is impounded and regulated by the Red Bluff Reservoir before it joins the Rio Grande upstream of Amistad Reservoir. In contrast to the Rio Grande and the Pecos River, the Devils River is an unregulated, spring-fed tributary that is largely unimpaired by land use practices and invasive plant species (see “Disturbed Lands”; National Park Service 2006a). As a result, the Devils River watershed maintains the highest fluvial water quality within the recreation area. Both the Pecos and Devils Rivers are susceptible to periodic flooding events associated with major storms or hurricanes. During flood stage, the Pecos River water level can change dramatically by up to 15 to 25 m (50–80 ft; see “Flooding”; Valentine-Darby et al. 2016). Additionally, both rivers preserve slack-water deposits that record a paleoflood history spanning the last 10,000 years (Kochel and Baker 1982).

The flow of the Rio Grande system dramatically fluctuates in response to seasonal changes in temperature and precipitation, in addition to anthropogenic diversions that impact groundwater. Over several decades, the flow regime of the Rio Grande and its tributaries has been negatively impacted by dam construction, increased water usage, and the establishment of invasive species. Today, the Rio Grande is no longer a free-flowing river system, as human alterations have diminished the river’s mean flow rate to the extent that certain segments experience periods of intermittent flow. These modifications in flow have reduced sediment transport, increased water pollution, and modified the morphology of the river system (Kochel and Baker 1982; KellerLynn 2008; Valentine-Darby et al. 2016).

#### *Amistad Reservoir*

Created following the completion of the Amistad Dam in 1969, Amistad Reservoir is the recreation area’s predominant landscape feature. At a conservation pool level (the measure of a reservoir’s operational volume determined by water surface elevation) of 340 m (1,117 ft) above sea level, the dam impounds a 26,652-ha (65,860-ac) reservoir that extends approximately 118 km (73 mi) up the Rio Grande, 22 km (14 mi) up the Pecos River, and 40 km (25 mi) up the Devils River (Labadie 1994). The reservoir is supplied with water from drainages within the US and Mexico (including the Rio Grande, the Pecos River, and the Devils River on the American side), in addition to groundwater contributions from seeps and springs.

As a critical source of water in the semi-arid Chihuahuan Desert, there is concern that future development (e.g., residential, agricultural, mining, hydrocarbon) and climate change may further stress the Amistad Reservoir as well as the regional groundwater system (see “Groundwater Resource Protection”). The reservoir level fluctuates in response to changes in precipitation, upstream flows, groundwater withdrawals, evaporation, transpiration, infiltration, and controlled downstream releases. Although average annual water level fluctuations are roughly 4 m (13 ft), several years have recorded reservoir level adjustments as much as 9 m (30 ft) (<https://waterdatafortexas.org/reservoirs/individual/amistad>; accessed November 2024). These fluctuations limit reservoir access, recreation, and visitation but also introduce issues relating to navigational hazards, invasive species, slope instability, failing infrastructure, and geologic resource inundation or exposure (Figure 18; Porter et al. 2009; National Park Service 2017). Since May 2013, Amistad Reservoir

has met and surpassed its historic reservoir low on three separate occasions—the current record was set in July 2024, when the reservoir was 319.17 m (1,047.15 ft) above sea level.



**Figure 18.** Photograph of Indian Cliffs along the east bank of the Devils River. The steep cliffs rise approximately 61 m (200 ft) above the water and consist of Cretaceous limestone and mudstone of the Salmon Peak Formation. Rocks at the base of the cliffs are partially exhumed during periods of drought and can pose a potential navigational and safety concern. NPS photograph/J. Johnson.

Amistad Reservoir is underlain by Cretaceous carbonate bedrock that has been dissolved over geologic time to form several karst features, such as sinkholes that are known sources of reservoir seepage or loss (see “Caves and Karst”). Amistad Reservoir is hydrologically connected to local groundwater systems, as demonstrated by increased groundwater flow and spring discharges following the initial filling of the reservoir (Stanton et al. 2007; Raymond et al. 2019). Some groundwater levels in the vicinity of Amistad Reservoir increased by nearly 30 m (100 ft) following the filling of the reservoir (Raymond et al. 2019). It is speculated that groundwater wells up to 32 km (20 mi) away may have fluctuated in response to the increased pressure head of the reservoir (Raymond et al. 2019). Additional geochemical studies have shown that groundwater sources downstream from Amistad Reservoir have been displaced by the waters of the reservoir (Raymond et al. 2019).

### *Springs*

Prior to the construction of the Amistad Dam, there were a total of 105 springs mapped in Val Verde County, including 45 within AMIS (George 1950). However, several springs—including Goodenough Springs

(previously the third largest spring in Texas)—were flooded by the infilling of Amistad Reservoir. As of 2016, there are 39 documented springs within AMIS, some of which are permanently inundated or only periodically exposed by the fluctuating water levels of Amistad Reservoir (Figure 19; Valentine-Darby et al. 2016). Springs are important hydrological, ecological, and cultural features that are common throughout Val Verde County. By contributing a source of cool, clear groundwater, these valuable spring environments help maintain water quality within the reservoir and along the Rio Grande, the Pecos River, and the Devils River (Valentine-Darby et al. 2016). In fact, the Devils River is largely supported by several springs or seeps (including Willow Springs, Indian Springs, Big Satan Springs, and Lowry Springs) and represents the highest quality watershed in the recreation area (National Park Service 2006a). Additional springs are located along the Rio Grande (Goodenough Springs, Pump Canyon Springs, and Eagle Nest Springs) and the Pecos River (Dead Man Springs and Pecos Springs) (National Park Service 2006a; Valentine-Darby et al. 2016). The distribution of springs within AMIS, especially in the area of Slaughter Bend, may be attributable to faults or fractures associated with the Slaughter Bend Fault Zone (see “Structural Geology”).

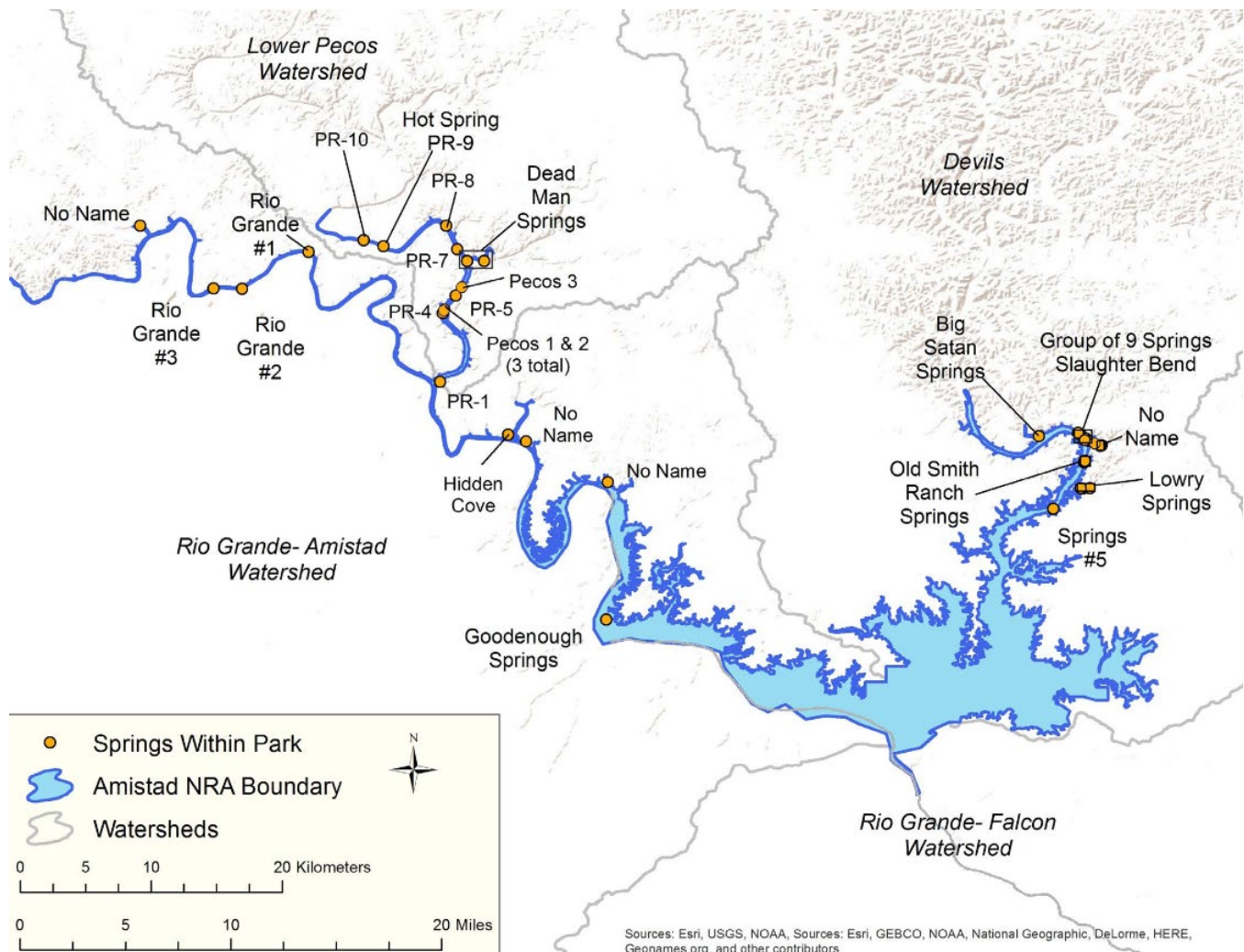


**Figure 19.** Map of springs in AMIS. These features are distributed along the shores of Amistad Reservoir but also along the watersheds of the Rio Grande, the Pecos River, and the Devils River. Figure 4.5.1-4 from Valentine-Darby et al. (2016).

### *Groundwater Aquifers*

Val Verde County is underlain by the Edwards-Trinity Plateau aquifer, a major source of groundwater that spans nearly 40 counties in southwest Texas (Valentine-Darby et al. 2016). In the area of AMIS, the aquifer consists of Early Cretaceous strata of the Devils River and Salmon Peak Formations (Porter et al. 2009). Four of the five groundwater wells owned or operated by the recreation area source their water from the Salmon Peak Formation; the fifth well is located along the Pecos River and sourced from the Devils River Formation (Valentine-Darby et al. 2016). High evaporation rates are characteristic of the Chihuahuan Desert region where the recreation area is located, suggesting that large or recurrent storms are needed to generate effective groundwater recharge to the Edwards-Trinity Plateau aquifer. This recharge occurs primarily through precipitation, surface runoff into karst, and stream loss (water infiltration into the subsurface) by numerous intermittent tributaries (Valentine-Darby et al. 2016).

Regional aquifers along the US–Mexico border are a critical source of water but are also known habitat for endangered species such as the Mexican blindcat (*Prietella phreatophila*). Although this freshwater catfish had previously been restricted to the Mexican side of the Rio Grande, it was recently discovered in two separate groundwater caves of AMIS (Hendrickson et al. 2017; Howard and Gluesenkamp 2020). In the semi-arid Chihuahuan Desert region, the availability of groundwater and the sustainability of groundwater aquifers (and their ecosystems) at AMIS may be negatively impacted by climate change, karst development, and increased anthropogenic diversions (see “Groundwater Resource Protection”).

### *Wetlands*

Wetlands represent a critical component of the Chihuahuan Desert ecosystem because they provide habitat, promote biodiversity, help purify water, and serve as buffers against flooding and erosion (Valentine-Darby et al. 2016). Within the recreation area, wetlands are located along the Rio Grande, the Pecos River, and the Devils River, with some associated with local springs or seeps. As a hydrologically dependent environment, wetlands are vulnerable to fluctuations in groundwater availability, surface water discharge, and the introduction of invasive species (Valentine-Darby et al. 2016). Alterations to the natural flow regime of the Rio Grande system (including drought and flooding) have resulted in issues with sedimentation and water quality degradation that have negatively impacted riparian wetlands.

# Geologic Resource Management Issues and Inventory Needs

## Summary of Geologic and Soil Hazards

Park resources are not only visitor attractions but may also be potentially hazardous. The recreation area presents a variety of geologic hazards, or “geohazards”—naturally occurring, dynamic geologic processes that have the potential to cause damage, loss of property, and/or injury and loss of life. The *Addressing Climate Change and Natural Hazards Handbook* (National Park Service 2015, 2023), grounded in NPS Policy Memorandum 15-01 (Jarvis 2015), provides a process and information to help teams and decision-makers identify, avoid, and mitigate risks associated with environmental change hazards and effects on proposed and planned facility investments. The handbook supports NPS planning guidance, policy directives, and executive orders and does not supersede existing mandated compliance processes and policies. Additional guidance for facility management (e.g., [Climate-Smart Planning Principles](#) and [Recommended Practices](#)) has been developed to support effective decision-making.

According to PM 15-01, managers should apply the handbook guidance to identify options to manage natural hazard and climate change risks throughout all levels of facility planning and design. Project teams are required to submit the completed Natural Hazards Checklist (Table 6) as part of Regional and Bureau Investment Review Board submissions. This information can also be used as part of the updated (2024) Automated Investment Review Board (AIRB) submittal process at the Investment Concept (IC) stage. Table 6 includes selected geologic and soil hazards listed in Part 1 of the handbook (National Park Service 2023). The GSRI team has added additional hazards where appropriate for the park. If needed, Part 2 of the handbook could inform the completion of the checklist, such as whether a hazard is applicable. Contact the NPS GRD with any questions.

**Table 6.** Geologic hazards checklist.

This summary table is a synthesis of existing GSRI-compiled map data and information, as well as published US Geological Survey and other government agency information. It is suitable for use at park-scale discussions and assessments. It is not a substitute for site-specific investigations or NEPA analysis. Ground-disturbing activities should neither be approved nor denied based on the information here. This table is modeled after the Natural Hazard Checklist (see National Park Service 2015, 2023 and Jarvis 2015). It is meant to provide general information to identify the full range of natural hazard-based risks for the recreation area.

| Hazard                               | Examples of Risk or Secondary Hazard                                                                                                                                                                                                                                | Best Professional Judgment                                             | Sources of Geohazard Information                                                                                                                                                                                                                                                                |
|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Earthquake                           | Falling objects<br>Collapsing structures<br>Inoperability of major building systems (e.g., power, sewer, water)<br>Trigger to other hazards (e.g., landslides, rockfalls)                                                                                           | <b>Potential hazard (very low)</b>                                     | <a href="#">DOI Strategic Hazard Identification and Risk Assessment (SHIRA)</a> Risk Mapper<br>United State Geological Survey (USGS) Earthquake Hazard Probability Map (Petersen et al. 2023)<br>The University of Texas at Austin Texas Seismological Network and Seismology Research (TexNet) |
| Slope movements (landslide/rockfall) | Rockfalls and slope instability<br>Partial constriction of the Rio Grande system<br>Damage or destruction to infrastructure<br>Damage to or loss of natural or cultural resource sites or features<br>Motor vehicle navigational hazard<br>Human injury or casualty | <b>Known hazard (susceptible to landslides, rockfalls, and slumps)</b> | DOI SHIRA Risk Mapper<br>GRI Scoping Summary (KellerLynn 2008)<br>National Park Service (2006a) draft general management assessment                                                                                                                                                             |
| Permafrost                           | Not applicable                                                                                                                                                                                                                                                      | Not applicable                                                         | Not applicable                                                                                                                                                                                                                                                                                  |
| Cave/karst                           | Sinkholes<br>Surface or ceiling collapse<br>Seepage and infiltration leading to limited water storage capability of Amistad Reservoir<br>Compromised integrity of the Amistad Dam                                                                                   | <b>Potential hazard (moderate)</b>                                     | DOI SHIRA Risk Mapper<br>International Boundary and Water Commission (2008)<br>Stanton et al. (2007)                                                                                                                                                                                            |
| Shrink/swell soils                   | Damage to infrastructure<br>“Heaving” of ground beneath roads, trails, or structures<br>Increased susceptibility to mass wasting events                                                                                                                             | <b>Known hazard (moderate)</b>                                         | USDA Web Soil Survey<br><a href="https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/">https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/</a><br>(look for “linear extensibility” interpretation)                                                                             |

| Hazard                                                          | Examples of Risk or Secondary Hazard                                                                                                                                                                                                                                                                                                            | Best Professional Judgment                     | Sources of Geohazard Information                                                                                                                                                                                                                       |
|-----------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Coastal storm surge/ sea or lake level change/shoreline erosion | Water level fluctuations within Amistad Reservoir risk exposing or flooding cultural sites and paleontological resources while also enhancing slope instability<br>Elevated reservoir levels can flood the lower canyons of the Rio Grande, Pecos River, and Devils River, including campsites, boating docks, and other infrastructure         | <b>Known hazard</b>                            | National Park Service (2017) Foundation Document<br>NPS Incident Reports<br>Porter et al. (2009)<br>Visaggi et al. (2009)                                                                                                                              |
| Tsunami                                                         | Not applicable                                                                                                                                                                                                                                                                                                                                  | Not applicable                                 | Not applicable                                                                                                                                                                                                                                         |
| Riverine Flood                                                  | Flooding (i.e., rainfall, flash flooding, hurricanes, tropical storms, etc.) compounded with rising water levels at Amistad Reservoir<br>Destruction of cultural or paleontological sites<br>Destruction of infrastructure<br>Stream channel migration<br>Stream bank erosion<br>Endangerment or loss of life                                   | <b>Known hazard (extreme; DOI SHIRA)</b>       | Dering (2002)<br>DOI SHIRA Risk Mapper<br>Federal Emergency Management Agency (FEMA) Map Service Center<br>GRI Scoping Summary (KellerLynn 2008)<br>National Park Service (2017) Foundation Document<br>Turpin (1984)<br>Valentine-Darby et al. (2016) |
| Flash Flood                                                     | Sudden rising water (i.e., dry wash or tributary valley)<br>Enhanced tributary flow regime and erosion capable of carrying large debris<br>Increased sedimentation along major tributary mouths<br>Destruction of cultural or paleontological sites<br>Destruction of infrastructure<br>Endangerment or loss of life due to unexpected flooding | <b>Known hazard</b>                            | DOI SHIRA Risk Mapper<br>Labadie (1994)<br>Valentine-Darby et al. (2016)                                                                                                                                                                               |
| Volcanic eruption                                               | Not applicable                                                                                                                                                                                                                                                                                                                                  | Not applicable                                 | Not applicable                                                                                                                                                                                                                                         |
| Hydrothermal activity                                           | Not applicable                                                                                                                                                                                                                                                                                                                                  | Not applicable                                 | Not applicable                                                                                                                                                                                                                                         |
| Radon                                                           | Health hazard                                                                                                                                                                                                                                                                                                                                   | <b>Potential hazard (low – Zone 3; US EPA)</b> | DOI SHIRA Risk Mapper<br>US Environmental Protection Agency (EPA) Map of Radon Zones                                                                                                                                                                   |

| Hazard                                                                                                                                                        | Examples of Risk or Secondary Hazard | Best Professional Judgment                                                                                                                                     | Sources of Geohazard Information |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|
| Toxicological soil (arsenic <sup>1</sup> , <i>Bacillus anthracis</i> [causes anthrax], cadmium <sup>2</sup> , lead <sup>2</sup> , and selenium <sup>3</sup> ) | Health hazard                        | <sup>1</sup> Potential hazard (very high; DOI SHRIA)<br><sup>2</sup> Potential hazard (high; DOI SHIRA)<br><sup>3</sup> Potential hazard (moderate; DOI SHIRA) | DOI SHIRA Risk Mapper            |

## Flooding

### Historic Flooding and the Creation of Amistad Dam

Flooding along the Rio Grande corridor is a natural phenomenon that led to the creation of the Amistad Dam and the subsequent establishment of AMIS. Prior to the dam, several historic floods occurred in 1932, the mid-1940s, and 1954 that inflicted extensive damage to pre-existing bridges and hydroelectric plants located along the Pecos River and the Devils River (see “Historical Devils River Hydroelectric Plants”). The 1954 flood was a major event driven by Hurricane Alice that destroyed the US Highway 90 bridge over the Pecos River, prompted the formation of the IBWC, and led to the impoundment of the Rio Grande by the late 1960s (Turpin 1984; KellerLynn 2008). Today, the Amistad Dam helps regulate the flow of the Rio Grande Valley and provides flood control, water storage, power generation, and recreational opportunities (National Park Service 2017; Raymond et al. 2019). Following the construction of the dam, the infilling of Amistad Reservoir inundated the former confluence of the Rio Grande, the Pecos River, and the Devils River, including numerous cultural sites and karst features. The establishment of the reservoir detrimentally impacted Goodenough Springs, resulting in the extinction of the Amistad gambusia (*Gambusia amistadensis*) (Valentine-Darby et al. 2016). As reservoir levels continue to fluctuate in response to flood and drought, additional geologic resources (e.g., springs, fossil localities, cultural sites) are threatened, in addition to recreation area facilities, infrastructure, staff, and visitors.

### Modern Flooding

Since the construction of the Amistad Dam, the recreation area is still negatively affected by floods associated with tropical storms and hurricanes. Since the late 1960s, overall daily water level recordings of Amistad Reservoir indicate the average level to be roughly 334 m (1,095 ft) above sea level. In 1974, Hurricane Carmen raised the reservoir level approximately 5 m (16 ft) and set the record for the highest water levels within Amistad Reservoir at nearly 346 m (1,136 ft) above sea level. Tropical Depression Charley in 1998 produced approximately 0.63 m (2.1 ft) of rain, which raised reservoir level by 4.3 m (14 ft) and exposed numerous cultural resource sites along the river canyons (see <http://www.npshistory.com/morningreport/incidents/amis.htm>; accessed November 2024). Record-breaking floods caused by Hurricane Alex in 2010 elevated the reservoir level by 4.6 m (15 ft), setting the highest reservoir level (344 m [1,129 ft] above sea level) since Hurricane Carmen. The hurricane and associated flooding heavily impacted recreation area facilities, including boat ramps, docks, and camping sites; additional flooding downstream of the dam resulted in over 10,000 home evacuations (Figure 20; see <http://www.npshistory.com/morningreport/incidents/amis.htm>; accessed November 2024).



**Figure 20.** Photograph of flood conditions along the Pecos River in 2010. View is facing upstream (east) toward the US Highway 90 bridge. The Pecos River flood stage has overwhelmed the floodplain, including the boat ramp and other infrastructure. NPS photograph.

As major reservoir contributors, the Rio Grande and its tributaries undergo recurrent flooding and flash flooding events during the late summer and fall as the recreation area experiences an increase in seasonal storm-related precipitation. Low-lying portions of the Rio Grande and the lower canyons of the Pecos and Devils Rivers are situated within the 100-year floodplain, a designation that predicts which areas will experience one major flood event every century (or a 1% annual chance; <https://www.fema.gov/flood-maps/national-flood-hazard-layer>; accessed November 2024). Heavy storms combined with narrow river canyons and low permeability soils produce a torrent of water that quickly overwhelms tributary valleys, resulting in flash flooding. These rapid flood events increase discharge into the Rio Grande—and ultimately Amistad Reservoir—and may negatively impact low elevation regions along the river corridor or at reservoir level. Enhanced fluvial discharge often leads to sedimentation issues, especially along major tributary mouths. For example, flooding has produced a 26-m (85-ft)-thick accumulation of silt along the mouth of the Pecos River; these deposits slowly migrate downstream and are referred to as “creeping silt” (KellerLynn 2008).

According to Kochel and Baker (1982), the presence of slack-water sediments along the lower Pecos and Devils Rivers has recorded a paleoflood history that spans the last 10,000 years. These sediments were deposited as tributaries were temporarily backflooded from the main fluvial channel. In some instances, floods would fill bedrock channels to depths of up to 30 m (100 ft; Kochel and Baker 1982). Sediment-laden water that moved up the tributary canyons has accumulated a series of layers consisting of fine-grained silt and organic detritus ranging from 5 cm (2 in) to 1.5 m (4.9 ft; Kochel and Baker 1982). These flood deposits have helped reconstruct the paleoflood history along the Rio Grande and determine the flood recurrence interval of modern storm events.

### *Disturbed Lands*

Disturbed lands are those park lands where the natural conditions and processes have been directly impacted by development, including facilities, mining, roads, dams, and abandoned campgrounds; agricultural activities such as farming, grazing, timber harvest, and abandoned irrigation ditches; overuse; or inappropriate use. Restoration returns a site, watershed, or landscape to some previous condition, commonly some desirable historic baseline. Usually, lands disturbed by natural phenomena such as landslides, earthquakes, floods, and fires are not considered for restoration unless influenced by human activities. Lands disturbed by human activity often cause unwanted and long-lasting problems that affect other resources. Many of these disturbances obliterate soil profiles, exacerbate the invasion of exotic plants, result in contamination of water and soil, and/or cause erosion and sedimentation. These damages, in turn, frequently impair the quality of habitats, disrupt ecosystem functions, and cause problems for parks managing areas as wildlands.

### Historic Ranching

The completion of the Southern Transcontinental Railroad in the 1880s opened portions of west Texas to settlement, economic development, and widespread livestock (cattle, sheep, goats, and horses) ranching. Historic ranching practices within and surrounding the recreation area have altered several natural features and processes, including its ecosystems, hydrology, soils, and erosion rates. Extensive livestock overgrazing, combined with associated stock tanks and water diversions, removed vegetation cover and soil that negatively impacted grasslands throughout the area (National Park Service 2006a; Valentine-Darby et al. 2016). Overgrazing suppressed the occurrence of natural grass fires, and by World War II much of the surrounding countryside was transformed into scrub and thorn brush environments that characterize the modern landscape (Turpin 1984; Labadie 1994; National Park Service 2006a).

Today, grazing practices continue to modify the geologic features and processes of AMIS, as livestock from surrounding ranches trespass onto parklands, and herds of native species (e.g., mountain sheep, goats, feral pigs, white-tail deer) are known to inhabit the area (Figure 21; KellerLynn 2008). In 2004, AMIS staff had approximately 2,400 sheep removed from the park (Valentine-Darby et al. 2016). Together, both native species and trespass livestock promote enhanced erosion through grazing and trail development that can impact cultural and paleontological resources.



**Figure 21.** European mouflon sheep (*Ovis aries*) at the 277 South day-use area at AMIS. Spotted in June 2014, this herd contained approximately 80–150 individuals. NPS photograph/G. Garetz.

### Hydrocarbon Development

Southwest Texas is underlain by hydrocarbon-rich Paleozoic and Mesozoic strata that are attractive targets for exploration and development. East of Amistad Reservoir, the Cretaceous Ellenburger Formation is a local hydrocarbon reservoir prospect, and further southeast, oil and gas production occurs from Cretaceous units along the margins of the Devils River Uplift in Kinney County (KellerLynn 2008). Although hydrocarbon production does not occur within the recreation area, surrounding oil and gas activities—including fracking—may divert significant water resources and deplete the regional Edwards-Trinity aquifer (see “Water Resources”). As surrounding development drives an increased need for water, enhanced groundwater withdrawals threaten the water supply and put increased pressure on the Rio Grande system, Amistad Reservoir, wetland or riparian ecosystems, and spring networks (Valentine-Darby et al. 2016).

### Mining

The recreation area contains multiple borrow pits that were previously used for highway construction purposes. The Rock Quarry (of the Rock Quarry campsite) is an old limestone borrow pit that was exploited for fill material during the creation of the new US Highway 90 and railroad bridges that cross the Devils River, after the creation of Amistad Reservoir inundated their old crossings (Jack Johnson, NPS AMIS, personal communication July 2024). Another former borrow pit exists within AMIS, about 1.6–2.4 km (1.0–1.5 mi) downstream of the Amistad Dam. Prior to the 2000s, park managers collected river gravels from the site until it was discovered the gravels contained a significant amount of archeological debris (KellerLynn 2008).

### Karst Development

Karst development is widespread throughout Val Verde County, and as of the end of 2024, over 350 cave or karst features had been documented within AMIS (Jack Johnson, NPS AMIS, written communication April

2025). These various caves, sinkholes, alcoves, solution-enlarged fissures, and springs provide important habitat for wildlife, including some cave-adapted and endangered species. Some are direct conduits to the regional groundwater aquifer and are especially vulnerable to spills or other environmental impacts. Others were extensively used by Indigenous Peoples and contain sensitive cultural resources. All cave and karst features present management concerns. Karst development historically affected the construction of the Amistad Dam and continues to affect its operation and safety.

During the early engineering stages of Amistad Reservoir in the 1960s, several dissolution features, such as depressions, sinkholes, and caverns, were documented in the Rio Grande valley walls, river terraces, and adjacent floodplains. Prior to filling the reservoir, numerous karst features (e.g., sinkholes, caverns, other solution conduits) within the impoundment area were filled with concrete to minimize seepage (Stanton et al. 2007; Raymond et al. 2019). However, karst features on the Mexican side of the Rio Grande are overlain and partially obscured by a thin veneer of surficial deposits or soil that inhibited efforts to detect, plug, or seal these cavities (Jack Johnson, NPS AMIS, personal communication July 2024). To further prevent seepage, construction crews excavated the dam foundation area and built a grout curtain (a protective foundation barrier) to a depth of about 50 m (164 ft) in the Cretaceous bedrock underlying the centerline of the dam (Stanton et al. 2007; Raymond et al. 2019). Despite these efforts, as the infilling of Amistad Reservoir commenced in 1968, an early increase in local spring discharge was observed beginning in 1969. These enhanced spring discharges were indicative of a substantial hydrologic connection between the reservoir and shallow groundwater systems downstream of the dam (Stanton et al. 2007). Thus, seepage and infiltration into sinkholes and other karst features likely represent a substantial source of water loss at the reservoir (Raymond et al. 2019). The US Geological Survey (USGS), in cooperation with the IBWC, continues to actively monitor springs in the vicinity of the dam.

Following the construction of Amistad Dam, the creation and expansion of sinkholes in the carbonate bedrock is undermining the integrity of the dam and threatening the storage potential of Amistad Reservoir. Since 1992, several sinkholes have developed northwest of the dam, driving an increase in spring discharge downstream of the dam on the western (Mexico) side of the Rio Grande (Stanton et al. 2007). A geological and geophysical investigation by Stanton et al. (2007) revealed a concentrated zone of weathered limestone features approximately 18 to 40 m (59 to 131 ft) thick that exists in the Salmon Peak Formation underlying the dam. While the Salmon Peak Formation is associated with karst development on the American side of the reservoir, there have been problematic sinkholes mapped in association with the Buda Limestone and Del Rio Clay on the Mexican side (Page et al. 2009). Over many years, these sinkholes have undermined the integrity of the dam and pose a considerable threat that will require costly repairs (Gleason 2023; Sanchez 2023). According to the IBWC (2008, p. 1), the dam is "...potentially unsafe, and that the entire dam foundation is in need of further evaluation and study." The report also states that "...urgent actions are needed based on the high risk in terms of the combination of potential loss of life and economic damages" (International Boundary and Water Commission 2008, p. 5). An additional inspection of the Amistad Dam in 2017 also found the structure to be potentially unsafe. Together, both the United States and Mexico are working on the repairs, which will potentially cost hundreds of millions of dollars (Sanchez 2023).

### *Mass Wasting*

The term "mass wasting" is used to describe downhill movements of rock or soil and includes events such as landslides, slumping, slope creep, rockfalls, and debris flows. Mass wasting is driven by natural processes

such as erosion, precipitation, flooding, and seismicity (earthquakes), but they can also be artificially induced by construction, mining, undercutting, vegetative clearing, and other projects that destabilize the ground. The recreation area's modern landscape and topography are the result of dynamic erosional processes that include fluvial incision, flooding, preferential weathering (the selective breakdown of less competent rocks), thermal expansion/contraction, frost wedging, and dissolution. Each of these erosional processes has the potential to generate mass wasting events such as landslides, slumps, or rockfalls.

The Rio Grande was introduced to the region during the Pleistocene Epoch about 2 million years ago, and its development is recorded in the steep canyon cliffs, unconsolidated terraces, and rockfalls consisting of large boulders and boulder fields. Rockfalls have been known to impact roadways and trails within AMIS and generally occur near natural cliffs, roadcuts, and along portions of the historic railroad grade (Figure 22). In areas such as the Pecos River boat ramp, large boulders are commonly dislodged following heavy rainstorms and are known to cause roadway damage and require heavy machinery removal (Jack Johnson, NPS AMIS, personal communication July 2024). For example, a large slab of bedrock sits precariously above the Pecos River boat ramp and is currently held in place by cement support buttresses (Figure 23). Previous roadway engineers thought the rock looked unstable and attempted to blast it down to no avail. Instead of additional blasting, workers installed the cement buttresses (Jack Johnson, NPS AMIS, written communication August 2024). Although the bedrock slab is located upslope and beyond the park boundary elevation, any potential slope failure could pose a significant threat.



**Figure 22.** Photograph of a rockfall at the Pecos River boat ramp. Rockfalls are a common phenomenon along the steep cliffs flanking the river corridors in AMIS. NPS photograph/J. Johnson.



**Figure 23.** A massive limestone block supported by cement buttresses at the Pecos River boat ramp. Following a failed removal attempt by engineers, a large unstable block of the Salmon Peak Formation was supported using concrete buttresses (circled). NPS photograph/J. Johnson.

Additional rockfall sites are located near the railroad tunnels immediately upstream from Seminole Canyon State Park and Historic Site (KellerLynn 2008). Historically, the dangers posed by rockfalls convinced the Southern Pacific Railroad Company to employ around-the-clock “track-walkers” to prevent derailments caused by debris along the trackway (see “Southern Transcontinental Railroad”; Labadie 1994). The combined damage and maintenance costs associated with flooding and mass wasting events persuaded engineers to re-route portions of the Southern Transcontinental Railroad away from the rocky terraces flanking the Rio Grande and the Pecos River.

Following the advent of the Amistad Dam, fluctuating water levels within Amistad Reservoir have influenced the stability of its slopes. One notable slump site has developed along the San Pedro arm of the reservoir near the San Pedro bridge (KellerLynn 2008). As water levels dropped, changes in hydrostatic pressure within the substrate caused the slope to fail and slump downward. According to KellerLynn (2008), the slump occurred near an archeological site and may represent a management concern.

#### *Shrink-Swell Soils*

Soils present within AMIS predominantly consist of a thin veneer of loams and clay loams that are considered gravelly or rocky (Valentine-Darby et al. 2016). These soils are highly susceptible to erosion, especially in areas where they form steep, unvegetated slopes (Valentine-Darby et al. 2016). Data from the NRCS Web Soil Survey indicates that several soils within AMIS are rated “moderate” in linear extensibility (a determination of shrink-swell potential of soils), meaning they can expand in the presence of water. The

expansion and contraction of shrink-swell soils can potentially lead to slope instability and failure while also causing damage to buildings, roads, and other structures. Anthropogenic modifications that redirect the flow of water should consider the distribution and extent of swelling clay deposits, as these activities can impact recreation area infrastructure.

Soil erosion is a management concern at AMIS, as historic land use practices—primarily ranching and railroad development—combined with modern livestock trespassing have negatively impacted the quality of soils and vegetation in Val Verde County (see “Disturbed Lands”).

### *Seismicity*

The Edwards Plateau physiographic province of southwest Texas is an area characterized by low seismicity. Although seismic activity induced by oil and gas production occurs in the surrounding Eagle Ford play, Midland Basin, and Delaware Basin, all of these earthquakes are more than 100 km (62 mi) away from the recreation area and pose little to no concern (<https://texnet.beg.utexas.edu/>; accessed November 2024). The nearest seismic monitoring station is located approximately 48 km (30 mi) away in Bracketville, Texas.

Given the tectonic and structural evolution of southwest Texas, there are numerous faults that underlie and traverse the recreation area that were previously active but lack evidence of modern seismicity (see “Structural Geology”). Many of these fault structures were formed millions of years ago during the Marathon and Laramide orogenies.

### *Climate Change*

Although climate change planning is beyond the scope of this GSRI summary, a discussion of climate change is included because of the potential disruption it may cause to the recreation area’s geologic features and processes. In the Chihuahuan Desert, climate change and water availability are two major management concerns. While the summer and early fall are exceptionally hot and can lead to drought, they are punctuated by heavy thunderstorms that produce episodic flooding and erosional events (KellerLynn 2008; Raymond et al. 2019). The climate at AMIS is already changing; all future climate model projections include temperatures above the recent historical average (1979–2012), and average annual precipitation is projected to be highly variable (Valentine-Darby et al. 2016; Climate Change Response Program 2024). Projected increases in temperature, evaporation rate, and drought or storm frequency and intensity may negatively impact (1) aquifer recharge and spring or seep persistence; (2) the water level and quality of Amistad Reservoir; and (3) the water quality and flow of the Rio Grande, the Pecos River, and the Devils River (Figure 24). These modifications to water availability are likely to impact additional geologic processes (e.g., erosion, flooding, sedimentation), ecological processes (e.g., invasive species, phenology), recreational opportunities, visitation, and park management procedures (National Park Service 2017; Raymond et al. 2019; Climate Change Response Program 2024).

Climate change manifestations that may impact geologic resources or intensify geohazards include the following:

- More frequent and intense droughts
- More frequent and intense storms, including hurricanes and tropical storms
- Increased frequency and magnitude of flooding and flash flooding

- Enhanced wind and water erosion along the Rio Grande system
- Enhanced sedimentation along major tributary mouths
- Enhanced reservoir fluctuations that may exacerbate slope instability and inundate, expose, or threaten paleontological and cultural resources
- Decreased water availability as fluvial and groundwater sources dissipate



**Figure 24.** Dried-up springs in Indian Springs Canyon. Projected climate change models forecast higher than average temperatures that may exacerbate the effects of drought and its impact on the regional groundwater system. NPS photograph.

### *Radon*

Radon is a naturally occurring gas created by the radioactive decay of the element radium. Although radon is usually ubiquitous (present in small amounts) in soil and rocks, some types of rock (i.e., volcanic rocks, granites, dark shales, phosphate-rich rocks, and metamorphic rocks) have the potential to produce above average amounts of radon gas that can pose a known health risk (Otton 1992). According to the US Environmental Protection Agency (EPA) map of radon zones, Val Verde County is identified as a zone of low potential (zone 3) for elevated indoor radon levels.

### *Toxicological Soil*

According to the DOI SHIRA risk mapper report, the soils of the recreation area contain potentially dangerous amounts of arsenic, cadmium, lead, and selenium. They also contain *Bacillus anthracis*, a naturally occurring soil pathogen that is known to cause anthrax. Soil maps show that potentially hazardous elements occur within the top 5 cm (2 in) of soil based on 2010 sampling (DOI SHIRA). For more information on naturally occurring arsenic, cadmium, lead, and selenium, as well as their potential health

impacts, visit the US Department of Health and Human Services Agency for Toxic Substances and Disease Registry (see <https://www.atsdr.cdc.gov/>; accessed November 2024). For more information on the public health risks associated with naturally occurring anthrax, visit the US Centers for Disease Control and Prevention's anthrax website (see <https://www.cdc.gov/anthrax/about/index.html>; accessed November 2024).

## **Geologic Resource Protection**

### *Legislatively Required Geologic Inventories*

The NPS GRD has developed an article series (<https://www.nps.gov/articles/series.htm?id=FA0A8F89-CD67-1CCE-5A6608B444E8A7C0>; accessed March 2025) that summarizes the laws, regulations, and policies that specifically apply to geologic and soil resources or processes. These protection measures were established to maintain the integrity of these resources or processes while minimizing the impacts of natural or human activity.

The core responsibility of the NPS is to preserve and protect park resources, processes, systems, and values unimpaired for present and future generations. According to National Park Service (2006b), the NPS will preserve and protect geologic resources, features, and processes as integral components of park natural systems. The goals of the NPS are to assess the impacts of natural processes and human activities on geologic resources; maintain and restore the integrity of existing geologic resources; integrate geologic resources management into NPS operations and planning; and interpret geologic resources for the benefit and enjoyment of park visitors (National Park Service 2006b). Various management protection policies applicable to geologic resources, features, and processes are included in National Park Service (2006b) and are also organized at the following website: <https://home.nps.gov/subjects/geology/geoheritage-nps-management-policies.htm> (accessed February 2025).

### *Paleontological and Cultural Resource Protection*

The recreation area's paleontological and cultural resources are invaluable and provide a unique window into the geologic and historic past. Scattered across the uplands, cliffs, and river canyons surrounding Amistad Reservoir, these sensitive resources are susceptible to both natural and anthropogenic activities that can lead to their degradation or destruction. Dynamic reservoir fluctuations and erosional processes (e.g., flooding, mass wasting, wind and wave damage, livestock trespassing) can aid in the discovery of these resources but can also have the potential to inundate or expose them to theft, vandalism, or neglect (National Park Service 2006a; Raymond et al. 2019). Although scientific research permits are required to sample or investigate paleontological or cultural materials, there have been several instances of vandalism (e.g., carving, scratching, pecking, spray painting, target practice) and illegal collection for personal or commercial use (Kaluarachchi et al. 1995; Visaggi et al. 2009; National Park Service 2017; see <http://www.npshistory.com/morningreport/incidents/amis.htm>; accessed November 2024). Certain resources, such as the Pecos River Style pictographs of Panther Cave, are actively monitored and protected by a high-fenced, sensor-equipped visitation deck enclosure (Visaggi et al. 2009).

Throughout the recreation area, pictographs have deteriorated through several anthropogenic and natural means. Historically, early photographers commonly applied water or kerosene to enhance the contrasts observed in the pictographs without knowing the long-term effects these liquids would have (Kaluarachchi et al. 1995). Other pictograph sites have been damaged by graffiti, vandals, or modern campfires (Figure 25; Kaluarachchi et al. 1995). Although pictographs appear to be on the surface of the rock, the paint pigments

are preserved within the limestone walls by a thin (typically >0.5 mm [0.02 in]) veneer of mineral accretion consisting of whewellite (a calcium oxalate mineral), gypsum, quartz, and clays (Kaluvarachchi et al. 1995; Dering 2002). As the veneer slowly thickens over time, accretions with high concentrations of clay can cause pictographs to become faded, obscured, or blocked from view (Kaluvarachchi et al. 1995). Additionally, another major force driving the deterioration of these resources is related to frost action within the carbonate bedrock.

For additional information regarding paleontological resource laws, regulations, and policies, the NPS GRD developed the following summary article: <https://www.nps.gov/articles/paleontology-legal-instruments.htm> (accessed November 2024).

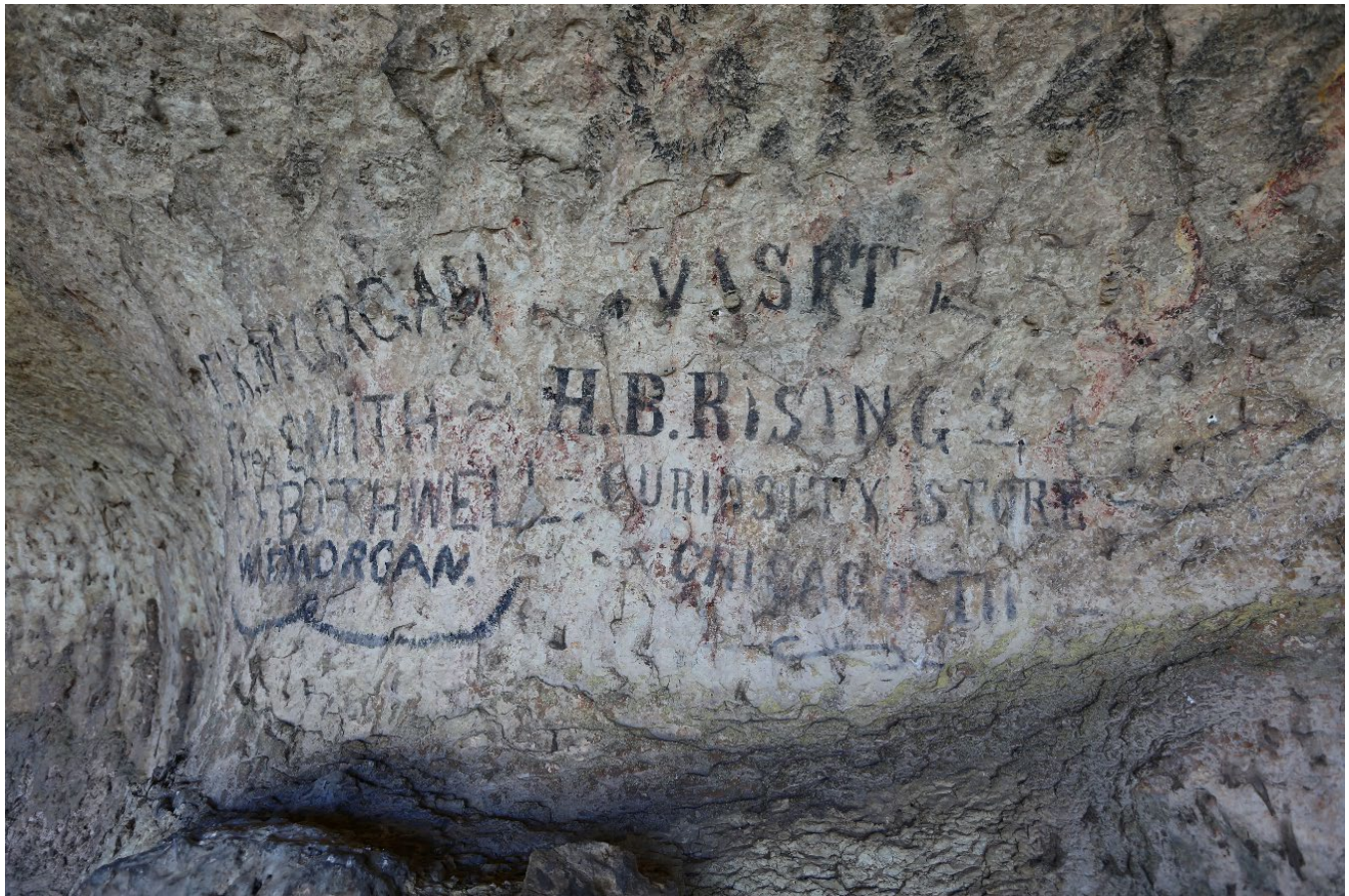


**Figure 25.** Vandalism and historic graffiti at Parida Cave. The dark gray or black graffiti obscures Indigenous pictographs that were done in red pigment. NPS photograph/J. Johnson.

#### *Groundwater Resource Protection*

In the semi-arid Chihuahuan Desert environment, groundwater is a critical resource that helps sustain the Rio Grande system and Amistad Reservoir and is vital to the ecology and biodiversity of the region. There are several issues impacting the recreation area's groundwater availability, as subsurface reservoirs and surface waters have experienced issues related to climate change, karst development, and increased anthropogenic diversions. Projected increases in temperature throughout southwest Texas may enhance the erratic behavior of droughts and floods, potentially increasing their magnitude, frequency, and impact on groundwater

systems. As population and development (e.g., residential, agricultural, mining, energy exploration and production) continue to grow, these activities will add to the demand for water and may potentially introduce sources of groundwater contamination, degradation, or dissipation (KellerLynn 2008). Increased groundwater withdrawals will further stress the flow regime of the Rio Grande and its tributaries. Reductions in the flow of the Rio Grande system, in addition to springs or seeps, will further impact Amistad Reservoir, including its operational storage capacity, recreational opportunities, and visitor use.

## Inventory Needs

Moving forward, the GSRI program will fund inventory projects that

- Collect new data or derive new information from existing data regarding the presence, absence, abundance, distribution, and significance of geologic heritage, soil features or processes, or geohazards.
- Provide information about features or processes on an individual feature or landscape scale.
- Provide data about groups of features or maps of multiple features in a defined area of management needs.
- Are a snapshot in time and may set a baseline for monitoring or assessment.
- Typically include a geospatial (GIS) component.

For information about the GSRI and guidance for submitting a project proposal, refer to the [GSRI SharePoint](#) (NPS access only). The following table (Table 7) presents several geologic and soil resource inventory needs that were identified during the 2024 follow-up meeting, in NPS planning documents, or through literature review.

**Table 7.** List of identified geologic and soil resource inventory needs for AMIS.

| Subject                  | Inventory Need(s)                                                                                                                                                                                                                                                                                                                                                 | Reference(s)                                                                   |
|--------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Cave and karst resources | Create a cave and karst management plan. Existing cave resources need to be surveyed, inventoried, and managed to respond to safety issues and recreational uses.                                                                                                                                                                                                 | KellerLynn (2008); Valentine-Darby et al. (2016); National Park Service (2017) |
| Climate change           | Conduct a climate change vulnerability assessment.                                                                                                                                                                                                                                                                                                                | National Park Service (2017)                                                   |
| Cultural resources       | Conduct cultural resource surveys and condition assessments. Site condition assessments are needed for 124 of the 144 sites on AMIS property. Literature searches have yet to be completed for 94 sites within federal boundaries, and site evaluations are needed for 32 sites. Data are needed for parkwide planning to inform resource conditions and impacts. | Dering (2002); National Park Service (2017)                                    |
| Cultural resources       | Apply state-of-the-art dating techniques to sites that have been adequately reported. There are several data deficiencies in both cultural chronology and settlement/subsistence studies in the region.                                                                                                                                                           | Dering (2002)                                                                  |

| Subject                   | Inventory Need(s)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Reference(s)                          |
|---------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|
| Cultural resources        | Geoarcheological (geology and archeology) studies are needed to determine the types and distribution of cultural materials within AMIS and their relationship to geologic landforms or soils. For example, the prediction is made that large fire-cracked rock features are more likely to occur on colluvial terraces adjacent to the confluence of main river channels and intervening side canyons than along any other portion of the side canyons. In addition, it is predicted that the greater the distance away from canyon rims, the lower the probability for surface lithic scatters.                     | Dering (2002); 2024 follow-up meeting |
| Disturbed lands           | Develop a livestock management/trespass grazing damage assessment plan.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | National Park Service (2017)          |
| Flooding                  | Conduct backcountry campsite and/or upland area damage assessments related to reservoir flood-stage events. Provide data to inform management planning and consider fluctuating lake levels and visitor access priorities.                                                                                                                                                                                                                                                                                                                                                                                           | National Park Service (2017)          |
| Geomorphology             | Since 1998, no recent geomorphological or geoarcheological studies have been completed in the region. Therefore, although detailed descriptive studies of a well-preserved material record are available, they lack an adequate temporal context. Geomorphological studies constitute a data set that would complement both environmental and cultural historical research. These studies can also provide temporal context to published descriptive studies. The lack of comprehensive geomorphological studies constitutes a major data deficiency for the study of archeological site distribution in the region. | Dering (2002)                         |
| Mapping                   | Further investigation is needed to confirm the presence and/or extent of the Boquillas Formation, Eagle Ford Group, and Austin Chalk inside park boundaries.                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Visaggi et al. (2009)                 |
| Mapping                   | Conduct LiDAR mapping during periods of drought or low reservoir levels. Although LiDAR was flown as recently as 2019 ("West Texas LiDAR" on the Texas Natural Resources Information System [TNRIS]), the recreation area should consider new mapping efforts when water levels in Amistad Reservoir are at or near a significant low. Mapping at periods of low water elevation may capture more of the inundated topography, especially in high slope canyon regions.                                                                                                                                              | 2024 follow-up meeting                |
| Paleontological resources | Heightened protection of in situ paleontological resources at the park is needed. Further research is needed to confirm published fossil locations relative to NPS boundaries. Relevant information should be filed in park archives, and documentation or relocation of fossils to current park repositories should be completed.                                                                                                                                                                                                                                                                                   | Visaggi et al. (2009)                 |
| Paleontological resources | Investigate the paleontological resource potential of the Cretaceous Boquillas Formation. Although fossil resources have been reported from the Amistad region since the late 19th century, there is still considerable potential for discovery, as little research has been conducted thus far within AMIS.                                                                                                                                                                                                                                                                                                         | Visaggi et al. (2009)                 |
| Paleontological resources | Monitor paleontological resources for damage, loss, or theft. Fossils in the recreation area are impacted by erosion, reservoir fluctuations, and theft. Theft is a significant concern and has been previously reported within AMIS.                                                                                                                                                                                                                                                                                                                                                                                | Visaggi et al. (2009)                 |

| Subject                   | Inventory Need(s)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Reference(s)          |
|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Paleontological resources | Rudist reef type sections and specimens referenced by Scott (2002) from the Pecos River valley may have originated in rock now under NPS jurisdiction; further investigation is needed to confirm precise locations.                                                                                                                                                                                                                                                                                                                          | Visaggi et al. (2009) |
| Paleontological resources | Quaternary fossils presently located at various institutions need to be consolidated, and archeological localities containing recent paleontological resources should be cross-referenced.                                                                                                                                                                                                                                                                                                                                                    | Visaggi et al. (2009) |
| Paleontological resources | Create a paleontological resource management plan. A paleontological resource management plan could be helpful in identifying threats and, as appropriate, suggesting actions such as instituting patrols, restricting access, building physical barriers, and salvaging important specimens as needed. Maintenance staff should be able to recognize and understand the significance of park fossils and know the location of paleontological exposures so proper avoidance procedures can be practiced if ground-disturbing work is needed. | Visaggi et al. (2009) |

## Prior NRSS-Supported Work

### Geologic or Soil Research Permits

Table 8 is a compilation of completed research projects related to the geology or soils of the recreation area. These items are located on the NPS Research Permit and Reporting System of IRMA (see <https://irma.nps.gov/RPRS/Search>; accessed November 2024) but may require government access or assistance. Since 2000, there have been numerous (>20) geoscience research permits issued that include cultural, hydrogeological, karst, and paleontological investigations; and resource monitoring (e.g., fossils, karst, springs).

**Table 8.** Completed geology or soil-related research investigations within the recreation area.

| Year(s)                            | Title                                                                                                             |
|------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| 2003                               | Pecos River Style: An Analysis of the Iconography                                                                 |
| 2006                               | Amistad National Recreation Area Paleontological Survey                                                           |
| 2010                               | Hydrogeology of Goodenough Springs                                                                                |
| 2010, 2011, 2015, 2016             | Goodenough Springs Exploration Project                                                                            |
| 2011                               | The Panther Cave Project                                                                                          |
| 2012                               | CHDN Seep and Spring Inventory                                                                                    |
| 2012                               | Petrophysical Study of Tempestite Deposits in the Del Rio Formation of West Texas                                 |
| 2014, 2015, 2016, 2017, 2018, 2021 | CHDN Seeps and Springs Monitoring                                                                                 |
| 2017                               | Documentation of Lower Pecos Canyonlands rock art: The Alexandria Project within Amistad National Recreation Area |
| 2019, 2020, 2022, 2023             | The Dragonfly Mercury Project                                                                                     |
| 2020                               | Karst Survey and Biological Inventory of Cave Ecosystems at Amistad National Recreation Area                      |
| 2022                               | Origins and Tenacity of Myth, Ritual, and Cosmology in Archaic Period Rock Art of Southwest Texas                 |
| 2022                               | Developing a Binational Understanding of Spring Flow from a Transboundary Aquifer along the Rio Grande            |

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