Geology of Proposed Consolidated Interim Storage Facility (CISF) for High Level Nuclear Waste, Andrews County, West Texas

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1. Introduction: The High-level Nuclear Waste Problem

The United States has a serious problem with its efforts to address its high-level nuclear waste (HLW). This is especially true with respect to spent fuel rods from nuclear reactors that currently provide about 20% of US electricity. Spent fuel rods are used nuclear fuel from a reactor that are no longer efficient in creating electricity because its fission process has slowed. However, it is still hot, highly radioactive, and potentially harmful (https://www.nrc.gov/waste/high-level-waste.html).

Today, most spent fuel rods are stored in more than 43 pools of water at 96 operating reactors at more than 70 sites in 34 US states. Some sites have multiple units that may share a pool, others have multiple pools. Every site has at least one pool, plus there are still some pools in use at sites that are in the process of decommissioning. About a third of US HLW has been moved to dry storage. Most operating reactors are actively moving spent fuel from their pools to dry storage on site to make room for more spent fuel as it comes out of the reactor.

Newly spent fuel rods are hot enough that they require the more efficient heat removal of wet (pool) storage for several years before going into dry storage. After 3-5 years, the short-lived fission products have decayed enough that the heat generation drops significantly. Thus, the fraction of HLW in dry storage is increasing, and dry storage is the current solution for decommissioning reactors to handle their spent fuel. From a safety and security perspective, dry storage can continue indefinitely.

Storage on-site (wet or dry) is not a good long-term solution and will become increasingly difficult as many of the 30+ year old nuclear power plants are decommissioned. The US desperately needs a secure site for storing HLW. Since the first National Academy of Science study in 1957, deep geologic disposal has been viewed as the best solution. In 1978, the Department of Energy (DOE) began studying Yucca Mountain, Nevada to evaluate its suitability for long-term geologic storage. 1982, the Nuclear Waste Policy Act (NWPA) (42 USC. §10101 et seq.) was enacted to establish procedures to evaluate, select and develop repositories for our nation's HLW. In 1987, Congress amended the NWPA, directing the DOE to select Yucca Mountain as the preferred site. Yucca Mountain lies in the western part of the Nevada Nuclear Test Site (https://fas.org/nuke/guide/usa/facility/nts.htm). The plan was to tunnel into Cenozoic volcanic rocks and store high-level nuclear waste in these tunnels. The Yucca Mountain Nuclear Waste repository project was approved by Congress in 2002 but federal funding for the site ended in 2011 because of public and political objections. Private industry has proposed other sites as Consolidated Interim Storage Facility (CISF) sites for storing HLW until a permanent disposal site is available.

It is important to distinguish between *storage* and *disposal* of HLW. Deep geologic repositories are designed for permanent disposal; HLW is fixed in place with no intent of removing the waste once the repository is closed and the surface facilities decommissioned. The engineered system and the geologic environment provide waste isolation with no further intervention or maintenance intended. In contrast, temporary storage facilities are short-term solutions, intended to maximize safety and security until permanent disposal is possible. Storage sites need to be maintained and monitored. They require active security measures in contrast to permanent disposal sites once they are sealed. The proposed west Texas site discussed below is designed for 40 years of temporary HLW storage. The site already disposes of low-level radioactive waste under license by the state of Texas. You can watch a short (3.3 minute) video about this site and the approval process at https://www.youtube.com/watch?v=UHwmV7RB7AE . This site is located above the northern Central Basin Uplift in the Permian Basin, which makes it of special interest to the UT Dallas Permian Basin Research Lab.

The following report summarizes the geology of the proposed west Texas HLW storage site. The geology of a proposed site is important because this makes the site more or less vulnerable to disruption by natural or human activities that could cause problems. For example, earthquakes, tornados, or flash floods could break HLW containers and cause radioactive materials to leak into groundwater or oil fields. This report is an unsolicited effort by a UTD MS student (Kleinman) and her research supervisors (Waite and Stern). It is not sponsored by any agency or group outside of the UTD Permian Basin Research Lab (https://labs.utdallas.edu/permianbasinresearch/). We make no case for or against the proposed CISF site; all we do here is summarize the geology of the proposed site, including seismic risk and resources, from published reports and maps, and briefly make some recommendations for further study.

2. The Proposed Facility to Store High-Level Nuclear Waste in Andrews County, Texas

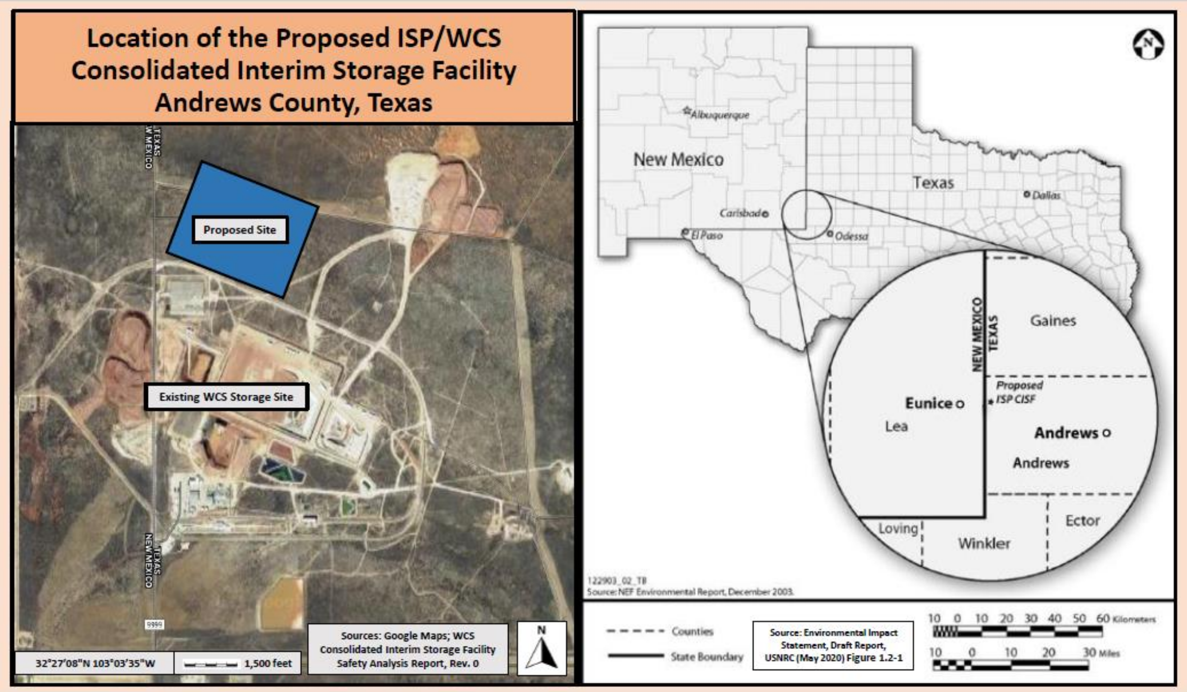
On April 28, 2016, Interim Storage Partners (ISP) and Waste Control Specialists (WCS) filed an application with the United States Nuclear Regulatory Commission (USNRC) to construct and operate a CISF for a period of forty years in west Andrews County, Texas

(Application Documents, Docket No. 72-150, 2016). The purpose of the proposed CISF site is to store spent HLW (primarily spent uranium-based reactor fuel) pending a permanent disposal solution (EIS, 2020). The initial 2016 application was withdrawn, resubmitted in 2018, and revised multiple times thereafter (Application Documents, 2021).

The USNRC held a series of public hearings to solicit public comment (Public Meetings, 2020). From 2016 to 2020, more than 47,000 comments and objections were submitted to the USNRC from individuals, elected officials (including current Texas Governor Abbott), representatives of the states of Texas and New Mexico, environmental protection advocacy groups, and oil and gas industry representatives (*e.g.*, Doggett, 2020 and Comments, 2016-2021). In May 2020, the USNRC issued a draft Environmental Impact Statement (EIS) (ISP, 2018; EIS, 2020). In response, ISP submitted a series of revised Safety Analysis Reports and Environmental Reports. At present the application is still pending before the USNRC.

3. Overview of the Proposed Project and Site Description

The proposed CISF site is located in Andrews County, Texas, approximately a half mile east of the Texas/New Mexico State line, and about 5 miles east of the closest town, Eunice, New Mexico (pop. ~3,000; Figure 1). Andrews County has a current population of about 19,000 and a population density of about 12 people per square mile. About 14,000 of these residents live in the county seat of Andrews (Wikipedia), about 32 miles southeast from the proposed CISF site. The site lies just north of Texas highway 176. The parcel where the existing and proposed facilities are located is known as the Flying “W” Ranch, comprising approximately 14,000 acres, and is owned by WCS. WCS currently operates a 1,338-acre facility on the property for disposal, treatment, processing, storage of low-level radioactive waste (LLRW). Examples of LLRW include items that have become contaminated with radioactive material or have become radioactive through exposure to neutron radiation. This waste typically consists of contaminated protective shoe covers and clothing, wiping rags, mops, filters, reactor water treatment residues, equipment and tools, luminous dials, medical tubes, swabs, injection needles, syringes, and laboratory animal carcasses and tissues (https://www.nrc.gov/waste/low-level-waste.html).



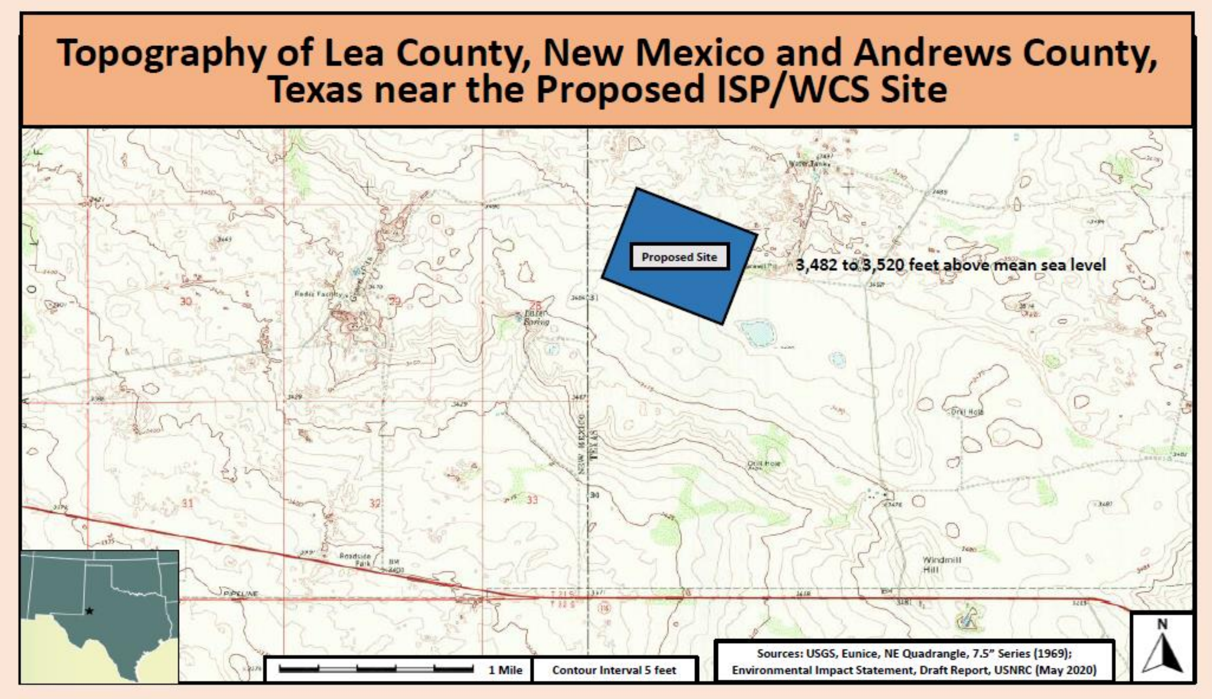
Sources: Google Maps; WCS Consolidated Interim Storage Facility Safety Analysis Report, Rev. 0

Source: NEF Environmental Report, December 2003.

Source: Environmental Impact Statement, Draft Report, USNRC (May 2020) Figure 1.2-1

Fig. 1: Location of the proposed ISP/WCS Consolidated Interim Storage Facility, Andrews Co., TX

The WCS LLRW site is one of four LLRW disposal sites in the US (https://www.nrc.gov/waste/llw-disposal/licensing/locations.html). ISP proposes to store HLW nuclear waste at the WCS location in above-ground casks. The proposed storage pad area would be immediately north of the existing WCS LLRW disposal facility (Figure 1) (EIS, 2020; USNRC, 2021; WCS, 2021). The site varies in elevation from between 3,482 to 3,520 feet above sea level across the proposed CISF site (EIS, 2020) (Figure 2). The land surface in the area has a gentle slope of approximately 8 to 10 feet per mile. To construct the new facility, it will be necessary to excavate material from higher portions of the site to change the topography from gently sloping to flat (WCS, Revision 0, Environmental Impacts).



Sources: USGS, Eunice, NE Quadrangle, 7.5" Series (1969); Environmental Impact Statement, Draft Report, USNRC (May 2020)

Fig. 2: Topography of Lea County, NM and Andrews County, TX near the proposed ISP/WCS site

4. Geography and Climate

The WCS property is located in the High Plains of Texas. The High Plains Region (the boot-shaped orange area in Figure 3) is a large physiographic province consisting of a gently eastward-sloping plateau. This is the largest mesa-like region in the United States, rising gradually from about 2,700 feet above sea level in the east to more than 4,000 feet along the Texas/New Mexico border in the west (Physical Regions of Texas, 2018; Johnson, 2021).

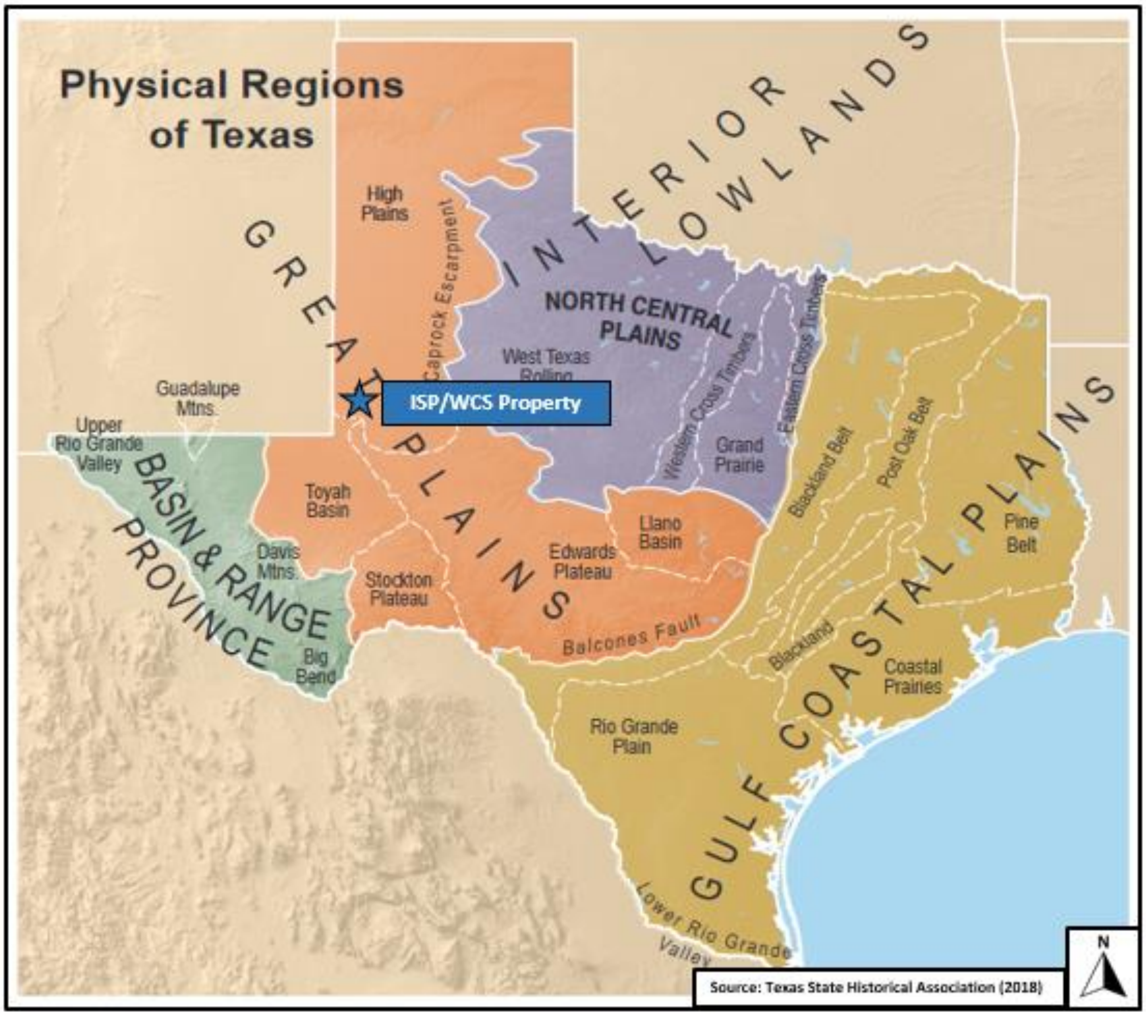


Fig. 3. Physiographic regions of Texas showing the location of the High Plains physiographic province and the proposed HLW site.

The National Climatic Data Center divides Texas into ten (10) regions that have similar characteristics including vegetation, temperature, humidity, rainfall, and weather. The CISF proposed site is located in Division 1, which is the High Plains climate division. The WCS is near the Chihuahuan Desert in a “semi-arid” region that experiences four seasons with dry summers and mild, dry winters. The landscape is characterized by thick layers of wind-blown dust and sand. The vegetation in Andrews County consists mainly of mesquite, catclaw, and sand shinnery, which is abundant in most areas. Volunteer trees and ground cover are scarce due to the semi-arid climate (https://andrews.agrilif.org).

Precipitation records of neighboring cities (Andrews, Texas and Hobbs, New Mexico) underscore the reason why the area is classified as semi-arid. Andrews is located about 32 miles southeast of the proposed CISF; Hobbs is located about 25 miles northwest. The average annual precipitation (1914 to 2010) for Andrews is 15.3 inches; for Hobbs it is 15.8 inches (1912 to 2012). The lowest recorded annual precipitation for Andrews was 7.60 inches in 1964; for Hobbs it was 1.85 inches in 2011. The highest recorded annual precipitation for Andrews was 31 inches in 1914; for Hobbs it was 32.2 inches in 1941(Andrews, WRCC, 2012; Hobbs, WRCC, 2012). For comparison, deserts average fewer than 10 inches of precipitation per year.

Wind data from four WCS weather stations from 2010 to 2015 show average wind speeds from about 7 to 12 miles per hour, mostly from the south (EIS, 2020). From 1950 to 2017, Andrews County experienced 24 tornadoes, 42 flash floods, 161 hail events, 236 episodes of heavy rain, 10 high wind events, and 203 thunderstorm wind events (Instruction 10-1605, 2018; NOAA Storm Events Database, 2020; EIS 2020, Table 3.7-2)

5. Geology

There are 3 main sequences of rocks beneath the proposed CISF site. In order of increasing age and depth beneath the surface, these are: 1) Cenozoic; 2) Mesozoic; and 3) Paleozoic sequences. Below these sedimentary rocks is Precambrian crust. These are described further below, with comments about the aspects of each that are of particular interest to the residents of the region and the economies of Texas and New Mexico. The Paleozoic section records information about subsurface structure and formation of the Permian Basin and the

Central Basin Uplift, which lies beneath the proposed CISF site. Stratigraphic units are presented below, from oldest and deepest (subsurface geology) to youngest and shallowest (surface geology).

A. Subsurface Geology:

1. Precambrian Crust:

Crystalline basement beneath the proposed CISF is composed of Mesoproterozoic igneous rocks. The basement map of Texas (Fig. 4) shows that the site lies above what Ewing (2016) calls the Hobbs Complex, based on the gravity high centered in it. The Hobbs Complex is thought to be the NNW continuation of a strongly positive gravity anomaly which was penetrated farther south at the North American Royalties Company #1 Nellie well and is known as the Pecos Complex (Ewing, 2016). This well penetrated 4,460 meters into Precambrian crust, recovering mafic and ultramafic igneous rocks including anorthosite, norite, and gabbro (Keller et al., 1989) and dated with U-Pb zircon techniques at 1,163±4 Ma (Keller et al., 1989). The Hobbs Complex appears to be the NNW continuation of this buried mafic-ultramafic complex on the north side of the Abilene gravity minimum (Fig. 4). The Hobbs-Pecos Complex may be the southern continuation of the Midcontinent Rift System (Adams and Keller, 1994).

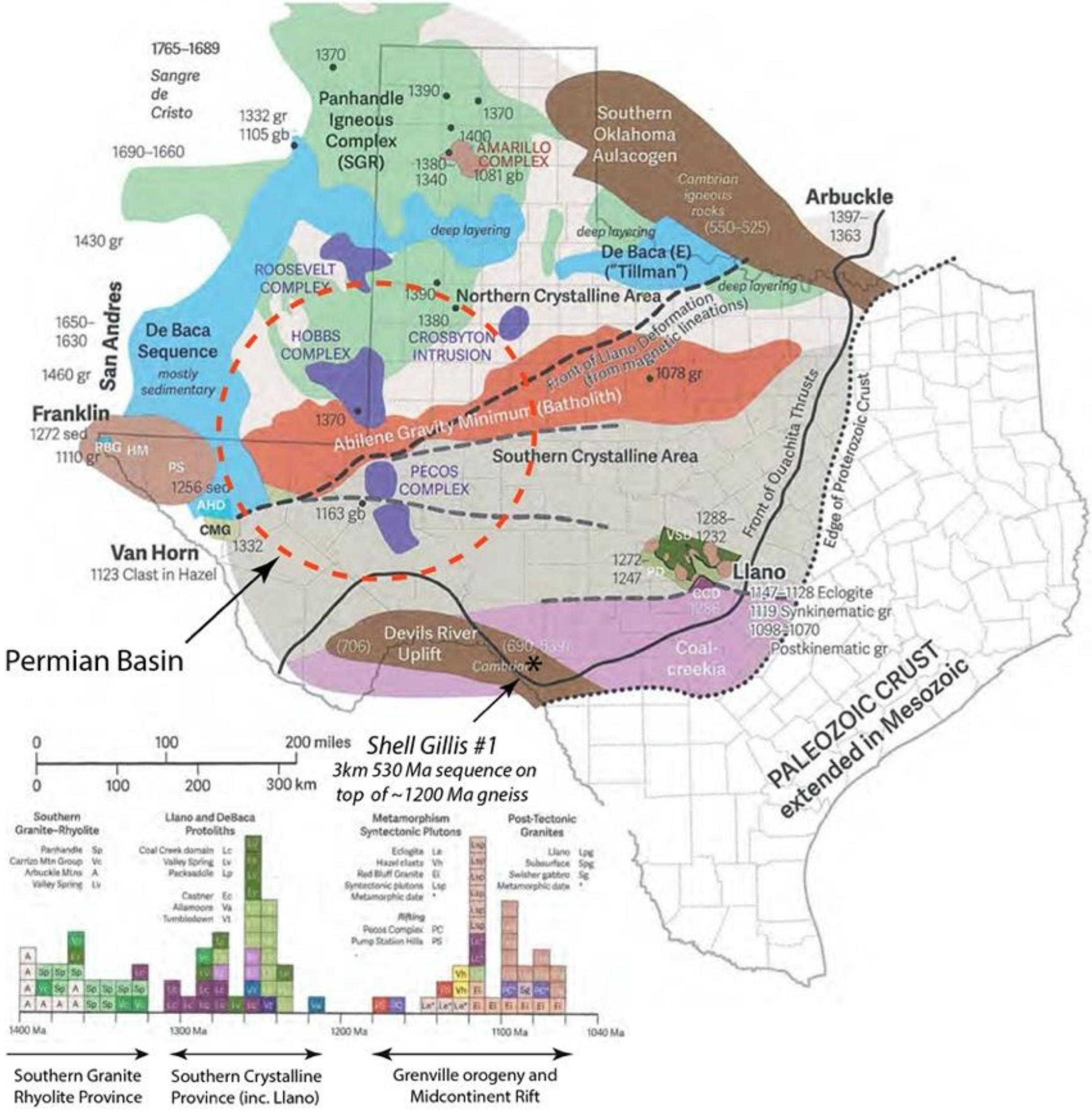


Fig. 4: Geology of Mesoproterozoic crust beneath Texas and E. New Mexico (Ewing 2016). Red dashed circle approximates location of the Permian Basin. Inset shows available radiometric ages, also from Ewing (2016).

2. Paleozoic Sedimentary Rocks

Paleozoic rocks beneath the proposed CISF site were deposited in the Permian Basin, a large and deep sedimentary basin (Fig. 5) beneath west Texas and southeast New Mexico. The basin is huge, covering 57,500 square miles (Ruppel, 2019), about the size of the state of

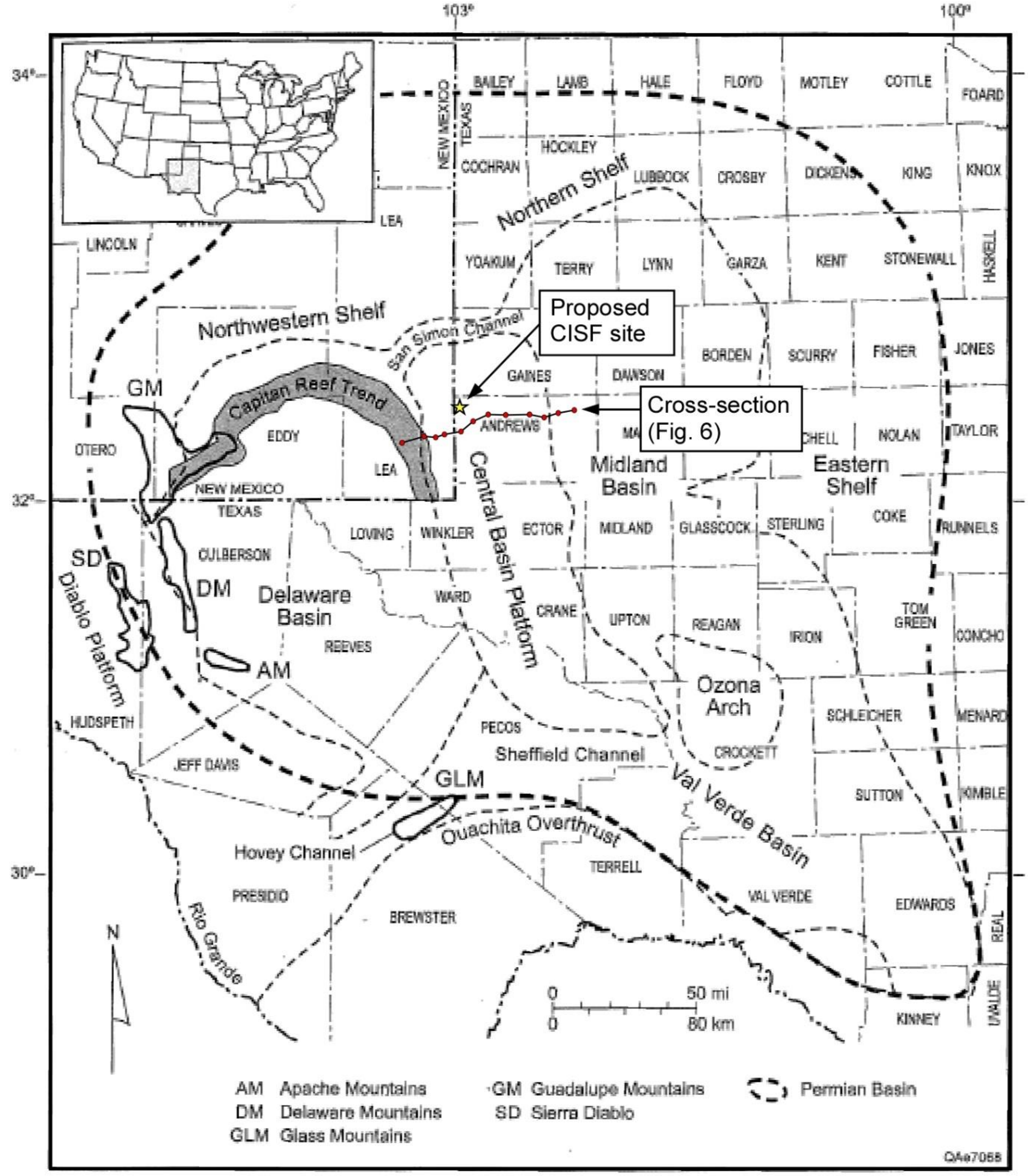


Fig. 5: Map of W. Texas and SE New Mexico showing principle structural features of the buried Permian Basin (modified from Ruppel, 2019).

Michigan or Georgia. The Permian Basin is well known for its rich petroleum and natural gas reserves. Ruppel (2019) reports that since its discovery 100 years ago, its more than 500,000 wells have produced more than 39 billion barrels of oil and 75 trillion cubic feet of natural gas. The Permian Basin is one of seven US onshore sedimentary basins for which the US Energy Information Agency reports activity; it is by far the most active of the seven in terms of new wells drilled and new oil produced. In early May 2021, the US produced 11.9 million barrels of oil per day (https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=WCRFPUS2&f=W); the Permian Basin was responsible for 4.5 million barrels of this (https://www.eia.gov/petroleum/drilling/pdf/permian.pdf) – 38% of total US production. The Permian Basin is dominated by the deep (~20,000 feet deep) Delaware Basin in the west and the shallower (~10,000 feet deep) Midland Basin in the east, separated by the NNW-SSE trending Central Basin Uplift, also referred to as the Central Basin Platform (CBP).

The Permian Basin evolved during 3 stages. The first stage (Tobosa Basin) lasted a duration of approximately 300 million years, from the Early Cambrian through Mississippian, when the region subsided like a typical cratonic basin, with sediments thickening inward from the margins. The second stage (Permian Basin) took all 20 million years of Pennsylvanian time when the region was doubly deformed, once by N-directed thrust sheets of the Ouachita-Marathon orogen in the south, the other by NNW-trending uplifts and foreland basins of Ancestral Rocky Mountain orogen. This reactivated the old basin forming the Central Basin Uplift separating the deeper Delaware Basin in the west from the Midland Basin in the east. Oil and gas is concentrated in both basins. The third stage in the evolution of the Permian Basin was subsidence and accumulation of Permian sediments. You can watch a video about the geologic evolution of the Permian Basin at https://www.youtube.com/watch?v=mSJO5Xr2zgU&t=227s . The Permian Basin stopped subsiding at the end of Paleozoic time and these sediments are covered by 300-500 meters of Mesozoic and Cenozoic sediments.

The proposed CISF site rests atop the north-central portion of the Central Basin Uplift/ Platform (CBP; Figure 5). The CBP consists of a number of tectonically uplifted basement blocks that are capped by shallow marine carbonate reef and shallow marine clastic deposits. The greater Permian Basin region was the site of marine sedimentary deposition through Paleozoic time but some lower Paleozoic units were eroded from the CBP when it was uplifted in Pennsylvanian time ~310 Ma. The CBP is the southern extension of the Ancestral Rockies, which can be traced NW into New Mexico, Colorado, and Utah (Leary et al., 2017). Fig. 6 shows a simplified cross-section from the eastern part across the CBP into the western Midland Basin. Notice that the oil fields are well to the east and west of the proposed CISF and several thousand feet below the surface. Notice also that ancient faults with large displacements flank the CBP. These faults do not seem to have been very active in the last 300 million years, although minor movements may

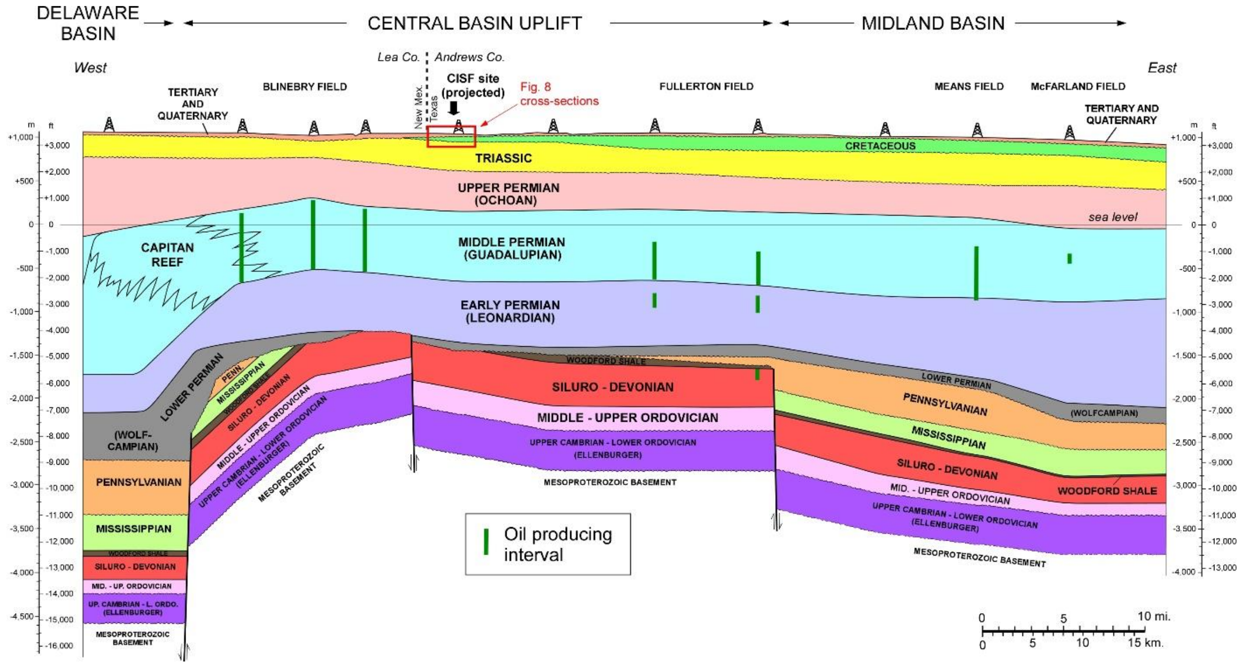


Fig. 6: Simplified E-W cross-section just south of the proposed CISF site showing subsurface geology, position of oil-bearing horizons and oil fields. Note that the proposed CISF is located above the Central Basin Uplift with relatively little oil production in the immediate vicinity. Location of cross-section is shown in Fig. 5 (modified from Bebout and Meador, 1985).

have occurred during Laramide thrusting ~60 million years ago and Rio Grande Rift extension and uplift ~30 million years ago.

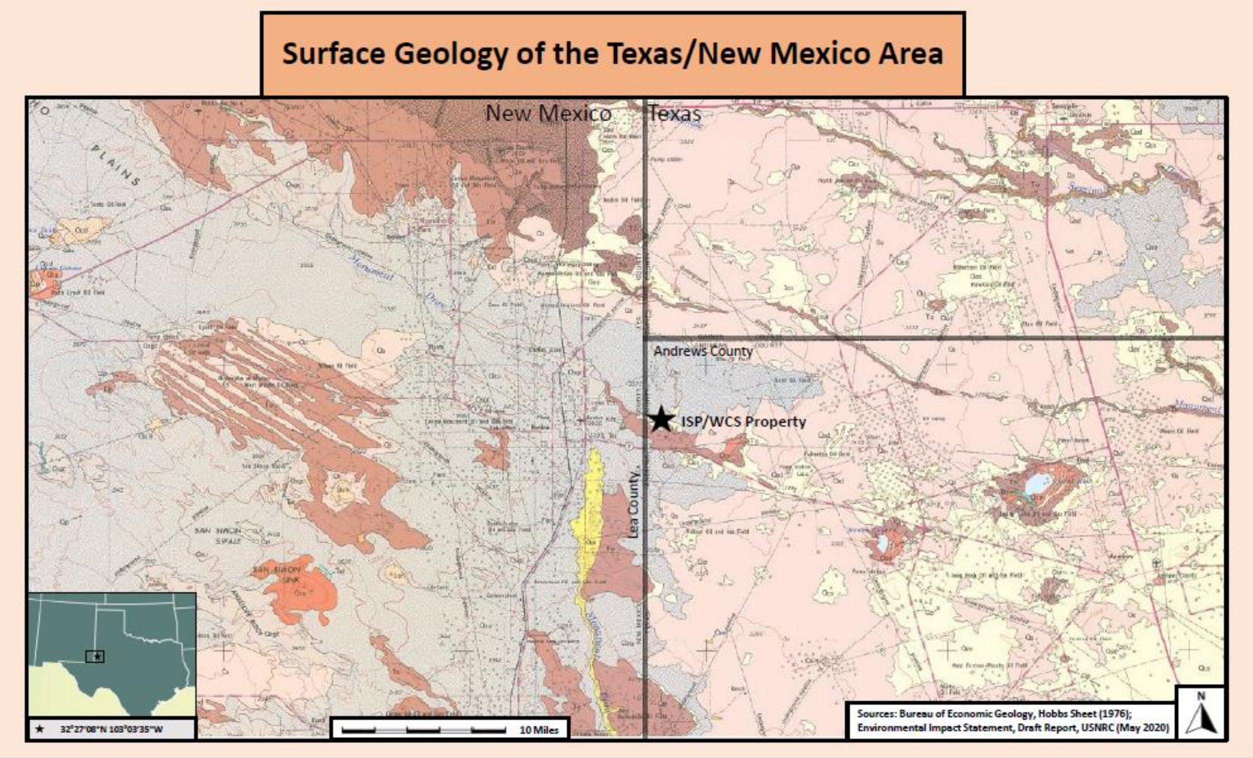
3. Mesozoic Sedimentary Rocks

Two great Mesozoic sedimentary sequences were deposited above Paleozoic sediments of the Permian Basin and underly the proposed CISF: Chinle/Dockum Group (Triassic) and Antlers Sand (Cretaceous)(Fig. 6). The Triassic sediments are called the Dockum Group in Texas and Chinle Group in New Mexico. These are clastic sediments eroded from uplifts in central Texas associated with early opening of the Gulf of Mexico and transported west by braided streams (Dickinson et. al., 2009). The sequence is dominated by siltstone and shale along with minor sandstone-mudstone, limestone, and conglomerate. The Chinle/Dockum Group is as much as 1,200 feet thick (Dockum Group, 2021; Texas Geology, 2021; Hobbs Sheet, 1976). It is about 1,000 feet thick beneath the proposed CISF (Figure 6).

Jurassic sediments are missing from the section beneath the proposed CISF. The next youngest units are Cretaceous sediments. The Antlers Sand is an Early Cretaceous deposit comprised of layers of sand, clay, and conglomerate. The major lithological constituents are sandstone and claystone. The Antlers Sand grades northward to interbedded sand and clay and is up to between 500 and 650 feet thick. Its thickness varies because it was deposited upon an irregular, eroded surface (Antlers Sand, 2021; Texas Geology, 2021; Hobbs Sheet, 1976)

B. Surface and Near-Surface Geology

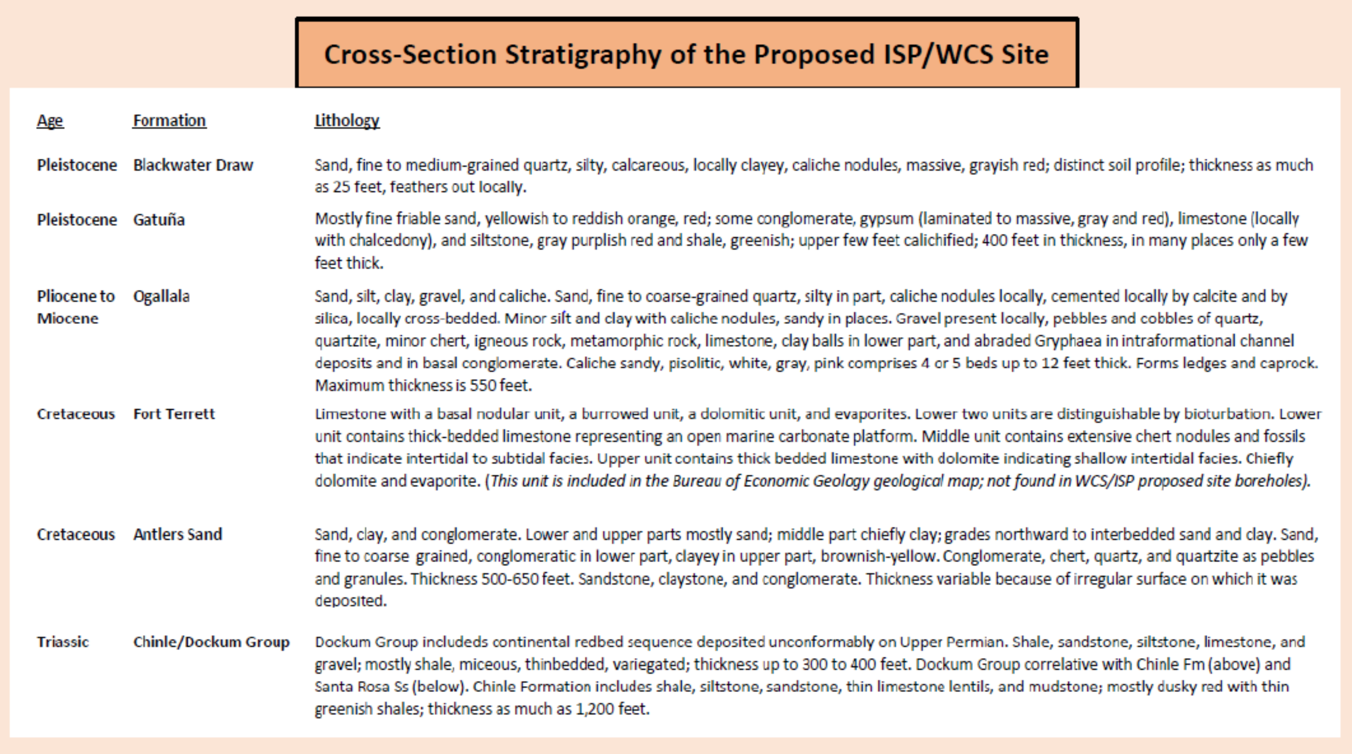
Surface Geology: Surface and near-surface geology is dominated by Mesozoic and Cenozoic sediments. Fig. 7 shows the surface geology within 10 - 20 miles of the CISF site. The surface geology reflects abundant Quaternary windblown sands, as expected for this semi-arid region. These sands vary from 1 to 10 feet thick, thicker north of the site and thinner south and west of the site (EIS, 2020; WCS, Revision 0, Environmental Impacts). Also covering much of the area is a veneer of unconsolidated, reddish-brown sand, silt, and minor clay (Lehman & Rainwater, 2000). Under these surficial deposits is the "Caprock Caliche," a consoidated layer of cemented calcium carbonate within a sand matrix, comprising resistant beds up to 12 feet thick. The Ogallala Formation of Mio-Pliocene age also crops out around the proposed CISF. This unit is described in Table 1.



Surface Geology of the Texas/New Mexico Area

Sources: Bureau of Economic Geology, Hobbs Sheet (1976); Environmental Impact Statement, Draft Report, USNRC (May 2020)

Fig. 7: Surface geology of SE New Mexico and W Texas around the proposed CISF site (See Fig. 9 for explanatory legend).



Cross-Section Stratigraphy of the Proposed ISP/WCS Site

Age	Formation	Lithology
Pleistocene	**Blackwater Draw**	Sand, fine to medium-grained quartz, silty, calcareous, locally clayey, caliche nodules, massive, grayish red; distinct soil profile; thickness as much as 25 feet, feathers out locally.
Pleistocene	**Gatuña**	Mostly fine friable sand, yellowish to reddish orange, red; some conglomerate, gypsum (laminated to massive, gray and red), limestone (locally with chalcedony), and siltstone, gray purplish red and shale, greenish; upper few feet calichified; 400 feet in thickness, in many places only a few feet thick.
Pliocene to Miocene	**Ogallala**	Sand, silt, clay, gravel, and caliche. Sand, fine to coarse-grained quartz, silty in part, caliche nodules locally, cemented locally by calcite and by silica, locally cross-bedded. Minor silt and clay with caliche nodules, sandy in places. Gravel present locally, pebbles and cobbles of quartz, quartzite, minor chert, igneous rock, metamorphic rock, limestone, clay balls in lower part, and abraded Gryphaea in intraformational channel deposits and in basal conglomerate. Caliche sandy, pisolitic, white, gray, pink comprises 4 or 5 beds up to 12 feet thick. Forms ledges and caprock. Maximum thickness is 550 feet.
Cretaceous	**Fort Terrett**	Limestone with a basal nodular unit, a burrowed unit, a dolomitic unit, and evaporites. Lower two units are distinguishable by bioturbation. Lower unit contains thick-bedded limestone representing an open marine carbonate platform. Middle unit contains extensive chert nodules and fossils that indicate intertidal to subtidal facies. Upper unit contains thick bedded limestone with dolomite indicating shallow intertidal facies. Chiefly dolomite and evaporite. (*This unit is included in the Bureau of Economic Geology geological map; not found in WCS/ISP proposed site boreholes).*
Cretaceous	**Antlers Sand**	Sand, clay, and conglomerate. Lower and upper parts mostly sand; middle part chiefly clay; grades northward to interbedded sand and clay. Sand, fine to coarse grained, conglomeratic in lower part, clayey in upper part, brownish-yellow. Conglomerate, chert, quartz, and quartzite as pebbles and granules. Thickness 500-650 feet. Sandstone, claystone, and conglomerate. Thickness variable because of irregular surface on which it was deposited.
Triassic	**Chinle/Dockum Group**	Dockum Group includeds continental redbed sequence deposited unconformably on Upper Permian. Shale, sandstone, siltstone, limestone, and gravel; mostly shale, miceous, thinbedded, variegated; thickness up to 300 to 400 feet. Dockum Group correlative with Chinle Fm (above) and Santa Rosa Ss (below). Chinle Formation includes shale, siltstone, sandstone, thin limestone lentils, and mudstone; mostly dusky red with thin greenish shales; thickness as much as 1,200 feet.

Table 1: Lithologies of the youngest sediments identified in boreholes (Fig. 9).

Near Surface Geology: Figure 8 shows where 29 shallow (~100 feet deep or less) boreholes were taken beneath the region within 10 miles of the proposed CISF. The extent of the Ogallala Aquifer on the site, the nature of Baker Spring, the amount of water within and a delineation of the formations beneath the site, and the implications of these data for determining the suitability of the site merit further study.

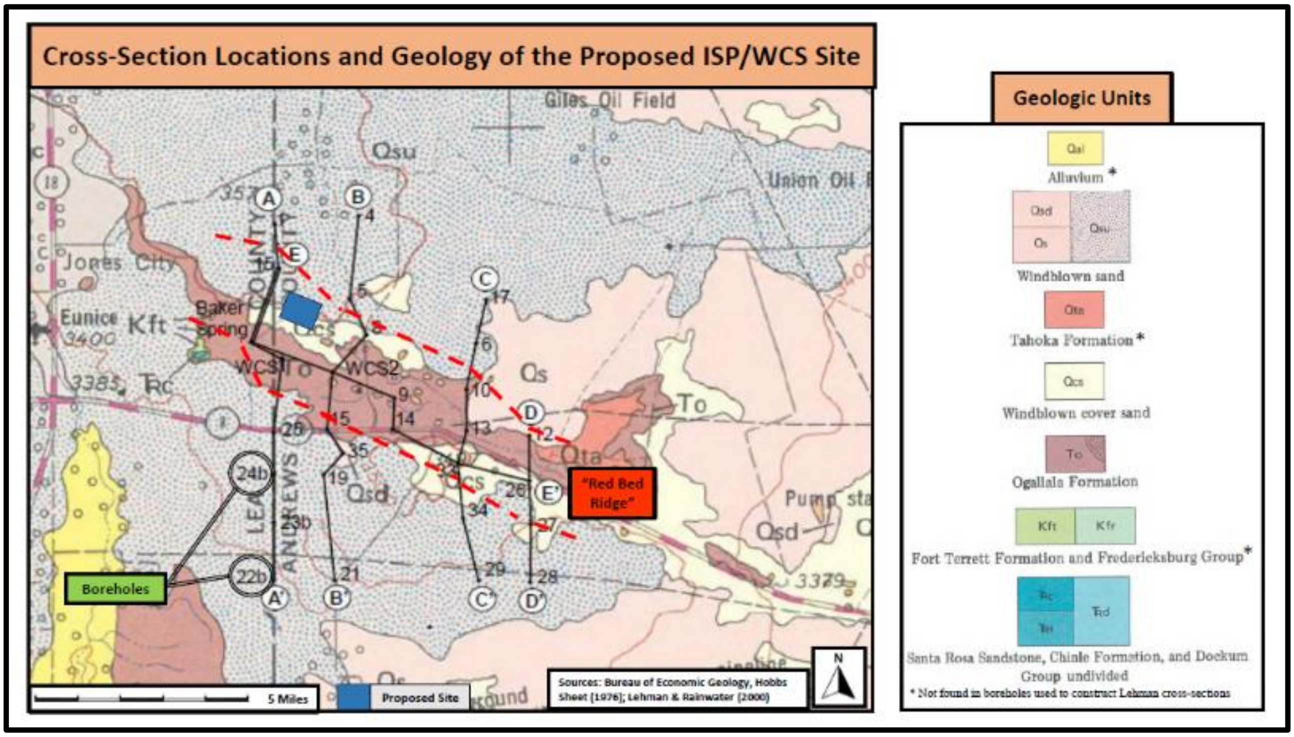


Fig. 8: Surficial geology and shallow boreholes around the proposed CISF site. Boreholes are shown as numbered dots. These boreholes constrain 5 cross-sections shown in Fig. 9. Red dashed line is the approximate trend of the Red Bed Ridge (see text for further discussion).

Fig. 9 shows profiles constructed by Lehman and Rainwater (2000) from these boreholes. Beneath the area, from oldest to youngest, they identified the following formations: Dockum Group (Triassic), Antlers Sand and Shale (Cretaceous), the Gatuña Formation (Late Cenozoic), Ogallala Formation (Pliocene to Miocene), Caprock caliche, and Blackwater Draw (Pleistocene). Some interesting discrepancies between the BEG Hobbs sheet (Fig. 8) and the units identified in boreholes by Lehman and Rainwater (2000) are noted. 1) The Cretaceous-aged Fort Terrett Formation, mapped in the BEG Hobbs Sheet (Fig. 8), was not identified by Lehman and Rainwater (2000) in the boreholes shown in Fig. 9; they identified the Cretaceous Antlers Shale and Sand instead. 2) The Tahoka Formation, mapped in the Hobbs sheet, was not identified in the boreholes. 3) The Gatuña Formation, identified in the boreholes, is not mapped in the Hobbs sheet. 4) The Tahoka Formation, mapped in the Hobbs sheet, was not identified in the boreholes.

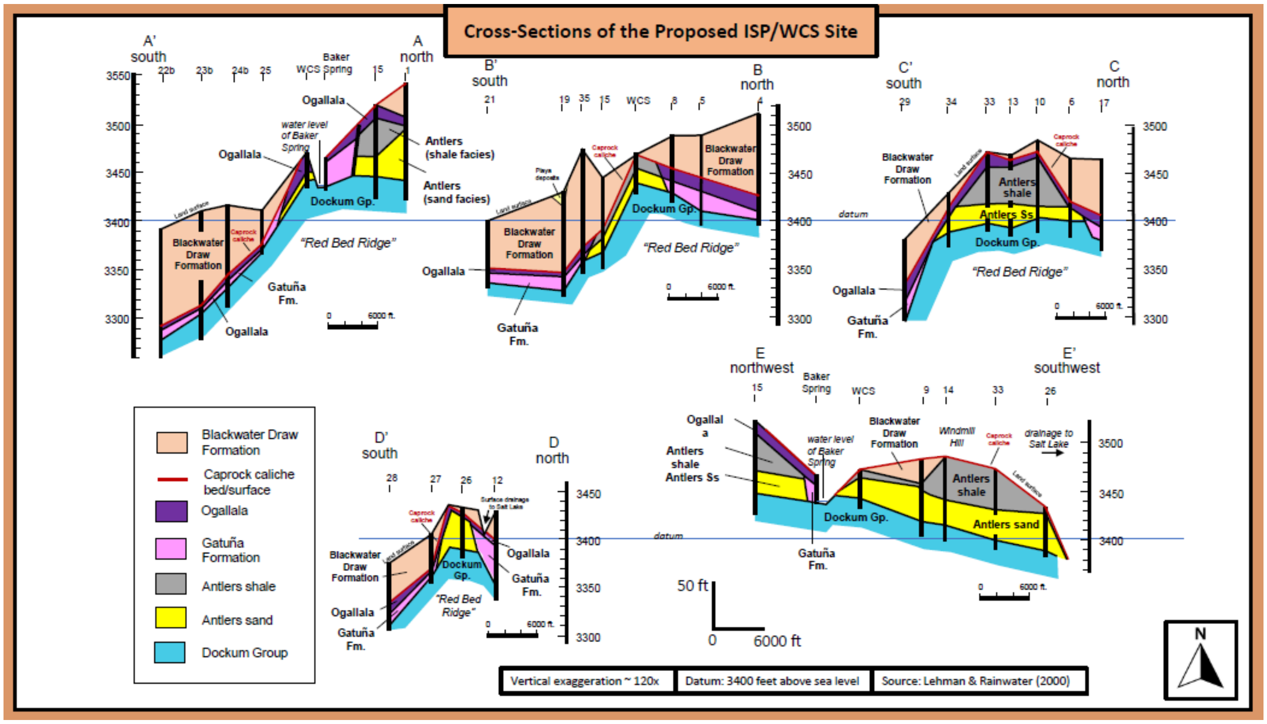


Fig. 9: Five cross-sections based on 29 boreholes studied by Lehman and Rainwater (2000). Locations shown on Fig. 8; lithologies described in Table 1.

The Triassic and Cretaceous sedimentary rocks are described in the previous section. Significant erosion occurred between deposition of Cretaceous ~110 Ma and younger sediments deposited in the last 10 Ma or so. As Fig. 9 shows, sometimes the Antlers is not present and younger sediments rest directly on the Dockum.

Cenozoic sedimentation began with deposition of the Gatuña Formation. The Gatuña Formation in Texas is mostly unconsolidated, fine sand, yellowish to reddish orange and red, containing evaporites, limestone and conglomerate. The upper few feet of the Gatuña is calichified (Gatuña, 2021; Texas Geology, 2021; Lehman & Rainwater, 2000; Hobbs Sheet, 1976). The age of the Gatuña Formation is controversial but seems to be older than the Ogallala

Formation (Kelley, 1980; Hawley, 1993). The Gatuña Formation is often missing from borehole penetrations.

The Ogallala Formation lies above the Gatuña Formation. It is a thick, sheet-like braided stream deposit of Late Miocene and Pliocene age from many streams that flowed eastward from the Sangre de Cristo and Rocky Mountains. It is comprised of sand, silt, clay, gravel, and caliche. Its major lithologic constituent is unconsolidated, coarse-grained detrital sand. Minor constituents include fine-grained clay and silt. It reaches thicknesses of up to 550 feet (Ogallala Formation, 2021; Texas Geology, 2021; Hobbs Sheet, 1976). The Ogallala Formation spans some 134,000 square miles and is the principal geologic unit in the High Plans Aquifer (Gutentag, *et al.*, 1984). See section 7B below for further discussion about the High Plains aquifer.

The Blackwater Draw Formation is the youngest of the sedimentary sequences identified in borehole penetrations. It is dominated by unconsolidated sand and silt and contains a variety of fine to medium-grained quartz, silt, clay, caliche nodules and calcareous deposits. It is up to 25 feet thick (Blackwater Draw, 2021; Texas Geology, 2021; Hobbs Sheet, 1976).

The primary impact to CISF site geology and soils will be land disturbance during construction, grading and site preparation. Soils will be reworked by excavation and grading for building sites, access roads, and for the rail sidetrack. The cannisters will be stored above ground, so site excavation will not exceed ten feet. The impact will be on the Blackwater Draw and Caprock Caliche formations. The average excavation depth will be shallower, or about three (3) feet (EIS Introduction, p. xxvii; p. 4-3, section 4.2.1.1; p. 4-26, 4.4.1.1, 4-27, p. 4-34, 4.5.2.1.1.).

C. Near-Surface Structure and The Red Bed Ridge

There does not appear to be significant post-Permian faulting in and around the proposed CISF site. Consultants who evaluated the site in connection with a prior permit application concluded that no significant faulting is present in the upper 2,000 feet of sediments within 3 to 4 miles of the WCS site (Cook-Joyce, Inc. & Intera, Inc., 2004). They reported that faulting in the upper Dockum Group occurred within the Triassic beds and did not affect the overlying Cretaceous Antlers Formation and younger sedimentary rocks.

The region around the proposed CISF overlies a buried structural ridge that trends WNW-ESE (Figures 8 and 9) referred to as the “Red Bed Ridge” (EIS, 2020; Cook-Joyce, 2004; Lehman & Rainwater, 2000; Hawley, 1993) because Dockum Formation redbeds are very near the surface here. The crest of the ridge is about 1 mile wide and extends for approximately 100 miles from northern Lea County, New Mexico, through Andrews, Winkler, and Ector Counties, Texas. Red Bed Ridge is described as a drainage divide separating two major fluvial systems that drain into the Colorado and Pecos Rivers (EIS, 2020). It is unclear if the origin of the buried high is erosional or structural. A combination of factors including dissolution of deeply buried Permian salt beds, movement along the faults on the west side of the CBP, and subsidence in the underlying Triassic strata may be responsible (EIS, 2020; Cook-Joyce, 2004; Lehman & Rainwater, 2000; Dutton, 1999; Hawley, 1993). Red Bed Ridge experienced significant post-Triassic erosion both northeast and southwest of the ridge (Lehman & Rainwater, 2000). The first continuous red bed sandstone, which occurs approximately 225 feet below surface, has a south/southwestward dip of about 80 feet per mile, and may represent the southwestern limb of an anticline or monocline with the Red Bed Ridge as the fold axis (Cook-Joyce, 2004).

6. Seismicity

A. Regional Seismicity and Seismic Hazard

The region around the proposed CISF site has little seismicity (Lund Snee & Zoback, 2018) and the USGS shows this as a region of low seismic hazard (Fig. 10). Small earthquakes have occurred in the region. Faulting in and around the CBP is mostly normal and strike slip. (Lund Snee & Zoback, 2018).

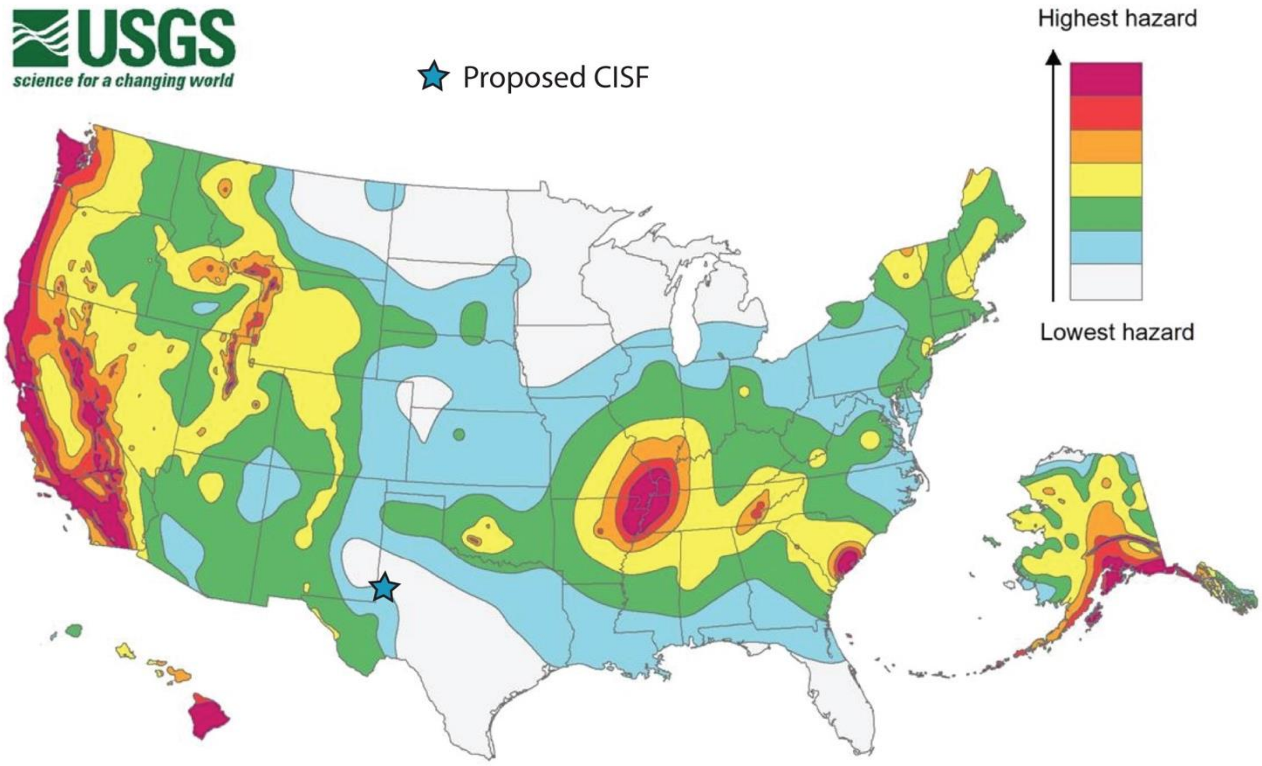
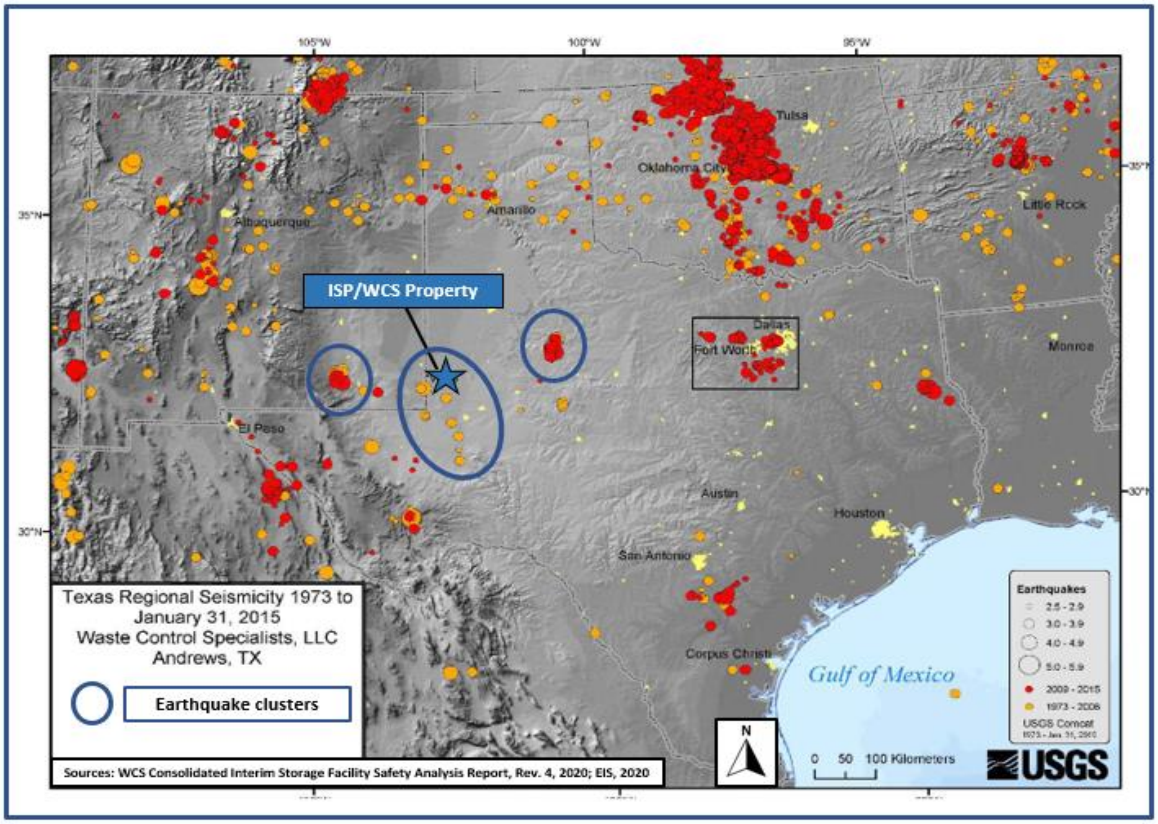


Fig. 10: Earthquake hazard map showing peak ground accelerations having a 2 percent probability of being exceeded in 50 years, for a firm rock site. The map is based on the most recent USGS models for the conterminous US (2018), Hawaii (1998), and Alaska (2007). The models are based on seismicity and fault-slip rates, and take into account the frequency of earthquakes of various magnitudes. Locally, the hazard may be greater than shown, because site geology may amplify ground motions. Notice that the proposed CISF is in a region of low seismic hazard https://www.usgs.gov/media/images/2018-long-term-national-seismic-hazard-map.

Regional Texas and New Mexico earthquakes from 1973 to 2015 are plotted as red and tan circles (size related to magnitude) on Figure 11 (WCS Consolidated Interim Storage Facility Safety Analysis Report, Rev. 4, 2020, Figure 2-18; EIS, 2020, Figure 3.4-8). Two clusters of earthquakes are located to the west and northeast of the proposed CISF. The swarms in red occurred from 2009 to 2019. Another somewhat linear cluster occurred from 1918 to 2008 (tan circles) south of the proposed CISF site. The largest earthquake recorded in the vicinity occurred in 1992, a 5.0 magnitude earthquake with an epicenter about 18 miles SW of the proposed CISF.

B. Induced Seismicity

Oil and gas production activities related to fluid injection and hydrocarbon production can trigger or "induce" earthquakes. Fluid injected at depth can flow to nearby faults, lubricating them and allowing these to slip and cause an earthquake. Some induced seismicity has occurred around the proposed CISF. Skoumal et al. (2019) found that the seismicity rate in the Delaware Basin has increased by orders of magnitude since 2015. They found that the vast majority of the



Sources: WCS Consolidated Interim Storage Facility Safety Analysis Report, Rev. 4, 2020; EIS, 2020

Fig. 11. Earthquakes around the proposed CISF site, 1973-2015.

seismicity was associated with wastewater disposal, while at least ~5% of the seismicity was induced directly by hydraulic fracturing. Wastewater injection and hydraulic fracturing is common where oil is being produced, but no oil is produced for 10-15 km around the proposed CISF.

7. Hydrogeology

A. Surface Water

No natural perennial surface water features are located within the proposed CISF project area. Nearby transient surface water features include Baker Spring in New Mexico to the west (Fig. 8), and draws, basins, and surface depressions that contain water for short durations following some rainstorms. For the most part, the surface depressions at the WCS site are dry. Water that ponds following heavy rainfall dissipates through evapotranspiration and infiltration. Such ponding can serve as isolated recharge zones for shallow groundwater aquifers (EIS, 2020).

A surface feature, “Baker Spring,” is located in New Mexico just west of the proposed CISF. It appears in both the Lehman and Rainwater (2000) (Fig. 9) cross-sections referenced in the draft EIS and in published USGS topographic maps. (Figures 2, 7, and 8). Baker Spring is not included on published lists of hydrothermal springs. (Thermal Springs, 1980) It is described as either a seasonally intermittent surface water feature sourced by rainfall, or as a Gatuña Formation groundwater-sourced spring. In the draft EIS, the USNRC described it as a man-made ephemeral pond, a remnant of a former quarry on the WCS property that seasonally contains water for short durations. According to ISP, Baker Spring was formed by excavation of the caliche caprock and underlying red bed clays. Water ponding in Baker Spring is infrequent. Since 2017, water was only noted there four times, the last instance in January 2017 (EIS, 2020).

Lehman and Rainwater (2000) observed that water appears to discharge from the Gatuña Formation at Baker Spring. This suggests that it is a groundwater-sourced spring and not a seasonal feature. According to ISP, Baker Spring is not an aquifer-sourced spring (Environmental Requests for Additional Information). These differing characterizations merit further study.

B. Groundwater

A regional hydrologic divide lies near the proposed CISF. Groundwater west of the ridge flows into the Pecos River valley. Groundwater east of the ridge flows into the Colorado River drainage. It is unknown if this divide also compartmentalizes the High Plains Aquifer.

Most of Andrews County is underlain by the High Plains aquifer (Dutton, 1999). The High Plains aquifer consists primarily of the Ogallala Formation including Cretaceous and Triassic water-saturated sediments that contain potable water (Dutton, 1999; Knowles, *et al.* 1984) (Urbanczyk, *et al.*, 2001). These include the Dockum Group and Antlers Formation which were present in some of the boreholes used to construct the cross-sections shown in Figure 8).

The High Plains aquifer is the principal source of groundwater for several major agricultural areas as well as residential users, including Andrews and other cities around the proposed CISF. The Ogallala Formation is especially important to the residents of Andrews, TX, because this is the city's water source. Currently, the city operates 19 wells; nine in the Florey Field and 10 in the University Fields. Average monthly production is 60 million gallons. Similarly, the city of Eunice, NM, gets its drinking water from 6 groundwater wells in the Ogallala Aquifer. The wells are located SW of Hobbs, NM. Other residents in the region get their water from the Ogallala Formation as well.

In most of Andrews County, the saturated thickness of the High Plains aquifer (the height between the water table and the base of the aquifer) is less than 100 feet, often less than 20 feet thick. Unfortunately, data to help determine whether the saturated thickness relates to high elevation on the base of the aquifer, or to a low elevation of the water table, is not readily available from regional maps (Dutton, 1999). Given that Redbed Ridge lies near and parallels the drainage divide, the Redbed Ridge/Pecos-Colorado divide may also be present at depth.

The High Plains aquifer is thin beneath the proposed CISF site (Dutton, 1999). Documents submitted with a 1993 permit application and comments by WCS representatives indicate that saturated ground-water conditions do not exist beneath the proposed site. However, available maps do not unambiguously identify any area of Andrews County where the High Plains aquifer is absent (Dutton, 1999). Maps that show the extent of the Ogallala aquifer in Andrews County vary considerably (Dutton, 1999). The maps reviewed by Dutton indicate that the Ogallala Formation or High Plains aquifer occur across most of Andrews County. Quaternary windblown sand covers bedrock in most of Andrews County, making a determination of whether the Ogallala Formation is present or absent more difficult. Lehman (1996) offers a different interpretation and indicates that the Ogallala is absent at the WCS site, a finding based on his observations from outcrop exposures in the area and in a WCS excavation. Absent logged sections, drawings, or photographs of outcrops, it is difficult to evaluate these interpretations. (Dutton, 1999)

8. Conclusions

The geology of the subject proposed CISF for SNF in Andrews County, Texas consists of Mesoproterozoic crust overlain by thick Paleozoic and especially Permian sedimentary rocks, covered by a veneer of Mesozoic and Cenozoic deposits. Paleozoic sediments were deposited in the most oil-rich basin in the US, the Permian Basin. The proposed CISF lies above the Central Basin Platform of the Permian Basin and does not overly known oil deposits. Mesozoic and Cenozoic formations contain the High Plains Aquifer, essential for human habitation and agriculture in this arid region. The proposed CISF is in a region of low seismic risk.

Given the uncertainty regarding geologic interpretation of shallow borehole data within the site, as well as inconsistencies between published geologic maps units described in previous WCS reports, it seems that further geologic study of the site is warranted. At a minimum, existing discrepancies regarding interpretation of site near-surface borehole data, the nature of Baker Spring, and the amount of water within the formations beneath the site merit further study.

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References

5 Fast Facts about Spent Nuclear Fuel. March 20, 2020. United States Department of Energy, Office of Nuclear Energy. Website. (accessed 6/27/2021) https://www.energy.gov/ne/articles/5-fast-facts-about-spent-nuclear-fuel

About the Permian Basin. University of Texas Permian Basin. 2021. Website. (accessed 4/18/2021) https://www.utpb.edu/about-us/about-the-permian-basin

Adams, D.C., and Keller, G., 1994. Possible extension of the Midcontinent Rift in west Texas and eastern New Mexico. Can. J. Earth Sci. 31, 709-720.

Andrews, Texas. *Period of Record General Climate Summary – Precipitation.* October 31, 2012. Western Regional Climate Center, Desert Research Institute, National Centers for Environmental Information. Website. (accessed 4/21/2021) https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?tx0248

Antlers Sand. United States Geological Survey. Website. (accessed 4/18/2021) https://mrdata.usgs.gov/geology/state/sgmc-unit.php?unit=TXKa%3B0

Application Documents for ISP's WCS Consolidated Interim Storage Facility. April 28, 2016 to March 10, 2021. Website. (accessed 4/21/2021) https://www.nrc.gov/waste/spent-fuel-storage/cis/wcs/wcs-app-docs.html

Application for a License for a Consolidated Interim Spent Fuel Storage Facility. April 28, 2016. United Stated Nuclear Regulatory Commission. Submitted by Waste Control Specialists, LLC. Docket No. 72-150. (accessed 4/17/2021) https://www.nrc.gov/docs/ML1613/ML16133A100.pdf

Bebout, D.G., and Meador, K.G., 1985. Regional cross sections – Central Basin Platform, West Texas – CD-ROM. University of Texas, Bureau of Economic Geology CS0006CD. Regional Cross Sections: Central Basin Platform, West Texas - CD - ROM - The Bureau Store (utexas.edu)

Climate at a Glance. *Andrews County, Texas.* 2019. National Oceanic and Atmospheric Administration, National Centers for Environmental Information. (accessed 4/30/2021) https://www.ncdc.noaa.gov/cag/county/rankings/TX-003/tavg/201904

Climate of Texas. 2012. Texas Water Development Board. Water for Texas 2012 State Water Plan. Ch. 4, p. 147. (accessed 4/17/2021) https://www.twdb.texas.gov/publications/state_water_plan/2012/04.pdf

Comments. Docket ID NRC-2016-0231. Unites States Nuclear Regulatory Commission. Website. (accessed 423/2021) https://www.regulations.gov/search/comment?filter=Docket%20ID%20NRC-2016-0231

Cook-Joyce, Inc. & Intera, Inc. *Section IV Geology Report.* August 2004. Prepared for Waste Control Specialists, LLC. Andrews, Texas. (accessed 4/17/2021) https://www.nrc.gov/docs/ML0501/ML050130449.pdf

Dallas, Love Field, Texas. *Period of Record General Climate Summary – Precipitation.* October 31, 2012. Western Regional Climate Center, Desert Research Institute, National Centers for Environmental Information. Website. (accessed 4/21/2021) https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?tx2244

Dickinson, W.R., Gehrels, G.E., and Stern, R.J., 2010. Late Triassic Texas uplift preceding Jurassic opening of the Gulf of Mexico: Evidence from U-Pb ages of detrital zircons. Geosphere. v. 6; no. 5; p. 641–662; doi: 10.1130/GES00532.1

Dockum Group, undivided. United States Geological Survey. Website. (accessed 4/18/2021) https://mrdata.usgs.gov/geology/state/sgmc-unit.php?unit=TXTRd%3B0

Dutton, A. Letter Report. *Review of Data on Hydrogeology and Related Issues in Andrews County, Texas.* February 1999. Prepared for Low Level Radioactive Waste Disposal Authority under Interagency Contract No. CON-99-021. University of Texas at Austin, Bureau of Economic

Geology. (accessed 4/17/2021) https://www.beg.utexas.edu/files/publications/contract-reports/CR1999-DuttonA-1.pdf

Environmental Requests for Additional Information. RAIs and Responses – Public. Enclosure 3 to E-55363. RAI WR-3. Pages 33-36. (accessed 4/20/2021) https://www.nrc.gov/docs/ML1933/ML19337B505.pdf

Ewing, T., 2016. Texas through Time. Texas Bureau of Economic Geology, 431 p.

Gatuña Formation. United States Geological Survey. Website. (accessed 4/18/2021) https://mrdata.usgs.gov/geology/state/sgmc-unit.php?unit=TXQg%3B0

Geologic Atlas of Texas, Hobbs Sheet. (1976) National Geologic Map Database. University of Texas at Austin, Bureau of Economic Geology. (accessed 4/18/2021) https://ngmdb.usgs.gov/Prodesc/proddesc_19381.htm

Geologic units in Andrews county, Texas. United States Geological Survey. Website. (accessed 4/18/2021) https://mrdata.usgs.gov/geology/state/fips-unit.php?code=f48003

Gutentag, E., Heimes, F., Krothe, N., Luckey, R. and Weeks, J. *Geohydrology of the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming.* 1984. United States Geological Survey Professional Paper, 1400-B. https://pubs.usgs.gov/pp/1400b/report.pdf

Hawley, J. 1993 *The Ogallala and Gatuña Formations in the southeastern New Mexico region: A progress report*. New Mexico Geological Society 44th Annual Fall Field Conference Guidebook, 261-267.

High Plains aquifer. United States Geological Survey. Website. (accessed 4/22/2021) https://www.usgs.gov/mission-areas/water-resources/science/high-plains-aquifer?qt-science_center_objects=0#qt-science_center_objects

Hoak, T, Sundberg, K, & Ortoleva, P. December 31, 1998. *Overview of the structural geology and tectonics of the Central Basin Platform, Delaware Basin, and Midland Basin, West Texas and New Mexico*. United States. https://doi.org/10.2172/307858

Hobbs, New Mexico. Period of Record General Climate Summary – Precipitation October 31, 2012. Western Regional Climate Center, Desert Research Institute, National Centers for Environmental Information. Website. (accessed 4/21/2021) https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?nm4026

Hon. Lloyd Doggett, 35th District, Congress of the United States, House of Representatives. June 16, 2020. *Letter to USNRC*. (accessed 4/17/2021) https://www.nrc.gov/docs/ML2016/ML20169A689.pdf

Houston, N., Gonzales-Bradford, S., Flynn, A., Qi, S., Peterson, S., Stanton, J., Ryter, D., Sohl, T., and Senay, G. 2011. *Geodatabase compilation of hydrogeologic, remote sensing, and water-*

budget-component data for the High Plains aquifer, 2011. Data Series 777. United States Geological Survey. (accessed 4/22/2021) https://doi.org/10.3133/ds777

How does the injection of fluid at depth cause earthquakes? United States Geological Survey. Website. (accessed 4/23/2021) https://www.usgs.gov/faqs/how-does-injection-fluid-depth-cause-earthquakes?qt-news_science_products=0#qt-news_science_products

Interim Storage Partners. June 11, 2018. *Interim Storage Partners submits renewed NRC license application for used nuclear fuel consolidated interim storage facility in West Texas*. Website. (accessed 5/2/2021) https://interimstoragepartners.com/2018/06/11/interim-storage-partners-submits-renewed-nrc-license-application-for-used-nuclear-fuel-consolidated-interim-storage-facility-in-west-texas/

Johnson, E. *High Plains*. Handbook of Texas Online. Published by the Texas State Historical Association. (accessed 4/22/2021) https://www.tshaonline.org/handbook/entries/high-plains

Keller, G.R., Hills, J.M., Baker, M.R., and Wallin, E.T. 1989. Geophysical and geochronological constraints on the extent and age of mafic intrusions in the basement of west Texas and eastern New Mexico. Geology, 17: 1049- 1052.

Kelley, V.C., 1980. Gatuna Formation (Late Cnozoic), Pecos Valley, New Mexico and Trans-Pecos Texas. New Mexico Geological Society Guidebook, 31st Field Conference, 213-217

Knowles, T., Nordstrom, P. and Klemt, W. (1984). *Evaluating the Ground-Water Resources of the High Plains of Texas, Volume 1*. Texas Department of Water Resources. Report 288.

Leary, R.J., P. Umhoefer, M.E. Smith, & N. Riggs. (2017). A three-sided orogen: A new tectonic model for Ancestral Rocky Mountain uplift and basin development, *Geology*, *45*(8), 735-738. doi:10.1130/G39041.1

Lehman, T. and Rainwater, K . April 2000. *Geology of the WCS - Flying "W" Ranch, Andrews County, Texas.* https://www.nrc.gov/docs/ML0419/ML041910475.pdf

Low-Level Waste. March 12, 2020. Unites States Nuclear Regulatory Commission. (accessed 4/17/2021) https://www.nrc.gov/waste/low-level-waste.html

Lund Snee, J. and Zoback, M. February 2018. *State of stress in the Permian Basin, Texas and New Mexico: Implications for induced seismicity.* The Leading Edge. https://scits.stanford.edu/sites/g/files/sbiybj13751/f/3702_tss_lundsnee_v2.pdf

National Weather Service Instruction 10-1605. July 16, 2018. National Oceanic & Atmospheric Administration, National Weather Service. (accessed 4/30/2021) https://www.nws.noaa.gov/directives/sym/pd01016005curr.pdf

Permian Basin. Wolfcamp Shale Play. October 2018. United States Energy Information Administration, United States Department of Energy. (accessed 4/17/2021) https://www.eia.gov/maps/pdf/PermianBasin_Wolfcamp_EIAReport_Oct2018.pdf

Physical Regions of Texas. III. Great Plains. 2018. Texas Almanac. Texas State Historical Association. (accessed April 23, 2021) https://texasalmanac.com/topics/environment/physical-regions-texas

Public Meetings. Unites States Nuclear Regulatory Commission. November 4, 2020. Website. (accessed April 23, 2021) https://www.nrc.gov/waste/spent-fuel-storage/cis/wcs/public-meetings.html

Ruppel, S.C., 2019. Anatomy of a Paleozoic basin: The Permian Basin, USA: Introduction, Overview, and Evolution. In Ruppel, S.C., ed. Anatomy of. A Paleozoic basin: the Permian Basin, USA (vol. 1, ch. 1). UT Austin Bureau of Economic Geology Report of Investigations; AAPG Memoir 118, p. 1-27.

Skoumal, R. J., Barbour, A. J., Brudzinski, M. R., Langenkamp, T., and Kaven, J. O., 2020. Induced seismicity in the Delaware Basin, Texas. Journal of Geophysical Research: Solid Earth, 125, e2019JB018558. https://doi.org/10.1029/2019JB018558

Storm Events Database. 2020. National Oceanic and Atmospheric Administration, National Centers for Environmental Information. (accessed 4/30/2021) https://www.ncdc.noaa.gov/stormevents/textsearch.jsp?q=andrews#

Texas Geology Map. Rock Units. United States Geological Survey, Bureau of Economic Geology. Website. (accessed 4/18/2021) https://txpub.usgs.gov/txgeology/

Thermal Springs List for the United States. June 1980. National Oceanic and Atmospheric Administration Key to Geophysical Records Documentation No. 12. (accessed 4/21/2021) https://www.osti.gov/servlets/purl/6737326

Urbanczyk, K., Rohr, D. and White. (2001). *Aquifers of West Texas. Geologic History of West Texas.* Department of Earth and Physical Sciences, Sul Ross State University, for the Texas Water Development Board. Ch. 2, p. 20. http://www.twdb.texas.gov/publications/reports/numbered_reports/doc/r356/chapter2_3.pdf

Waste Control Specialists LLC, Chapter 4, Environmental Report, Revision 0, Environmental Impacts, Section 4.3, p. 4-27. (accessed 4/18/2021) https://www.nrc.gov/docs/ML1613/ML16133A158.pdf

Waste Control Specialists LLC (WCS). *Licenses/Permits.* 2021.Website. (accessed 4/17/2021) https://wcstexas.com/customer/licenses-permits/

WCS Consolidated Interim Storage Facility Safety Analysis Report, Revision 0, Chapter 2, Site Characteristics. (accessed 4/17/2021) https://www.nrc.gov/docs/ML1613/ML16133A109.pdf

WCS Consolidated Interim Storage Facility Safety Analysis Report, Revision 4, Section 2.4, Surface Hydrology, p. 2-23. (accessed 4/17/2021) https://www.nrc.gov/docs/ML2026/ML20261H452.pdf

What is a fault and what are the different types? Website. United States Geological Survey. (accessed 5/1/2021) https://www.usgs.gov/faqs/what-a-fault-and-what-are-different-types?qt-news_science_products=0#qt-news_science_products