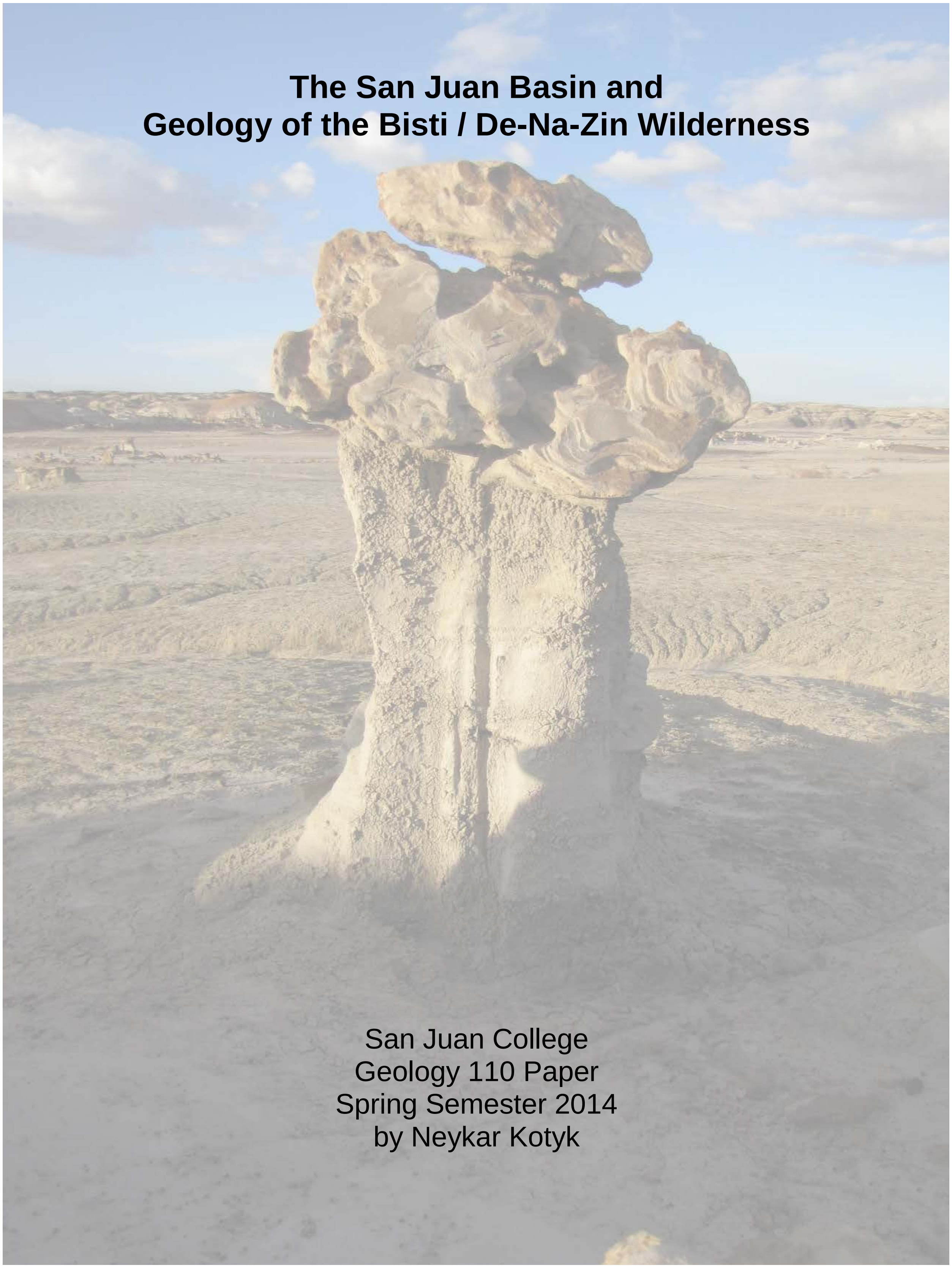
The San Juan Basin and
Geology of the Bisti / De-Na-Zin Wilderness



San Juan College
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Introduction

The San Juan Basin, located in the northwest corner of New Mexico, is part of a larger geologic feature known as the Colorado Plateau which covers portions of northeastern Arizona, southeastern Utah, and southwestern Colorado. The central part of the San Juan Basin is a bowl-shaped depression which contains sedimentary rocks over two and a half miles thick and ranges in age from 570 to 2 million years ago (Brister and Hoffman, 2002). The San Juan Basin has been researched for over 100 years as evident by some of the earliest writings by Brown (1910), Bauer (1916), and Gilmore (1916).

This region was formed by deposits of sand, silt, and clay as a result of a massive inland sea that extended from the Gulf of Mexico to the Arctic Ocean. This inland sea was approximately 3,000 miles long by 1,000 miles wide and had divided the North American landmass into two large continental areas (Figure 1). The San Juan Basin lies on the western margin of this seaway and was intermittently inundated by the advances and retreats of the sea (Robinson et al 1982).

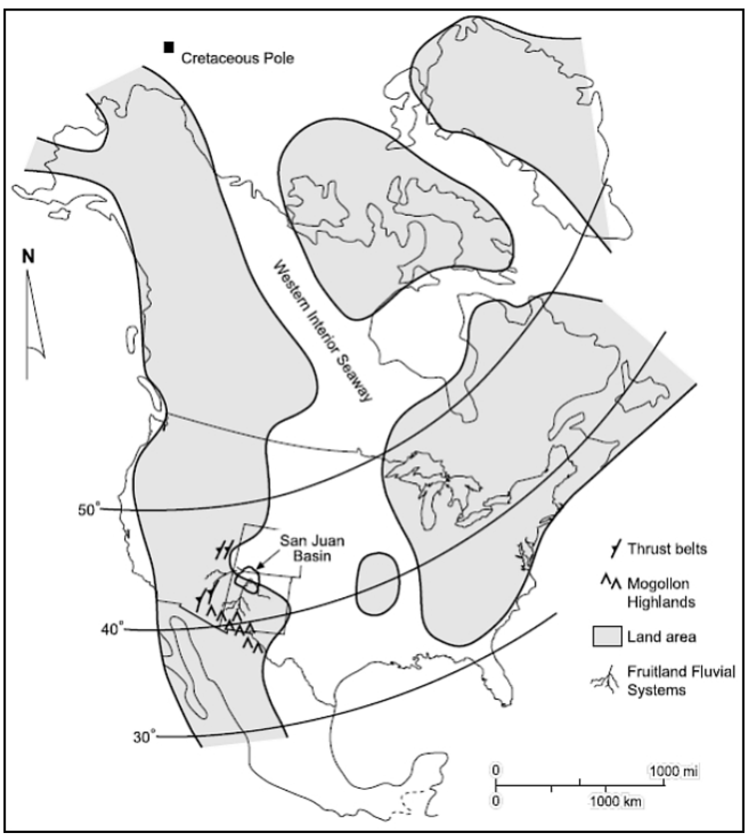

Figure 1. San Juan Basin relative to the Western Interior seaway (adopted from Ambrose and Walter 2007, pg 1100).

The San Juan Basin which forms the lower south central portion of the Colorado Plateau is a major source of oil, gas, coal, and uranium for New Mexico. Within the San Juan Basin, are various geological formations as shown in Table 1. The landscape of the San Juan Basin was formed through millions of years of various uplifts, volcanic activity, and erosion in the form of rivers and broad expanses of erosional badlands. One such "badland" and the focus of this paper is located in the west central portion of the San Juan Basin: Bisti / De-Na-Zin Wilderness area.

Table 1. Stratigraphic Formations of the San Juan Basin.

ERA	PERIOD	EPOCH	DEPOSITION TIME (in millions of years ago)	SOUTHEASTERN SAN JUAN BASIN	
CENOZOIC	Neogene	Holocene		//	
		Pleistocene		Volcanics	//////////////////////
		Pliocene		Santa Fe Group	//////////////////////
		Miocene		//	
	Paleogene	Oligocene		//	
		Eocene		//	
			54 - 38	San Jose	
		Paleocene		//	
			64 – 60	Nacimiento	
			65 - 64	Ojo Alamo	
MESOZOIC	Cretaceous	Late		//	
			73 – 70	Kirtland	
			75 - 73	Fruitland	
				Pictured Cliffs Sandstone	
				Lewis Shale	
				Mesa Verde Group	
				Mancos Shale	
				Gallup Sandstone	
			94 – 80	Mancos	
			97 – 94	Dakota	
		Early		//	
	Jurassic	Late	150 - 144	Morrison	
		Middle		Summerville Formation Todilito Formation Entrada Sandstone	
		Early		//	
	Triassic	Late	230 - 213	Chinle Group	
		Middle		Moenkopi Formation	//////////////////
		Early		//	

Note: Time table not to scale.
Colored Areas are present in the Bisti.
Gray Shaded Areas represents "unconformities" or missing layers (time gaps) in sequence.
Sublayers or members within a formation not fully listed.

Geology of the Bisti Wilderness in General

Within the region in and around the Bisti Wilderness, rocks of the Late Cretaceous period include the Lewis Shale, Pictured Cliffs Sandstone, Fruitland Formation, and Kirtland Shale (see Tables 1 and 2, Figure 2). Further north and east, early Paleogene period (Palocene Epoch) rocks of Ojo Alamo and Nacimiento can be found. The following sections discuss the major characteristics of these formations.

Table 2. Upper Cretaceous Stratigraphic Units and Thickness in the Bisti Region.

STRATIGRAPHIC UNIT	THICKNESS (in meters)	
Ojo Alamo Sandstone	20	
Naashoibito Member	20	
Upper shale member	30	Non-marine
Kirtland Shale		
Farmington Sandstone Member	120	
Lower shale member	250	
Fruitland Formation	50	
Pictured Cliffs Sandstone	25	Final marine regression from San Juan Basin
Lewis Shale	20	

Adapted from Robinson et. al. 1982

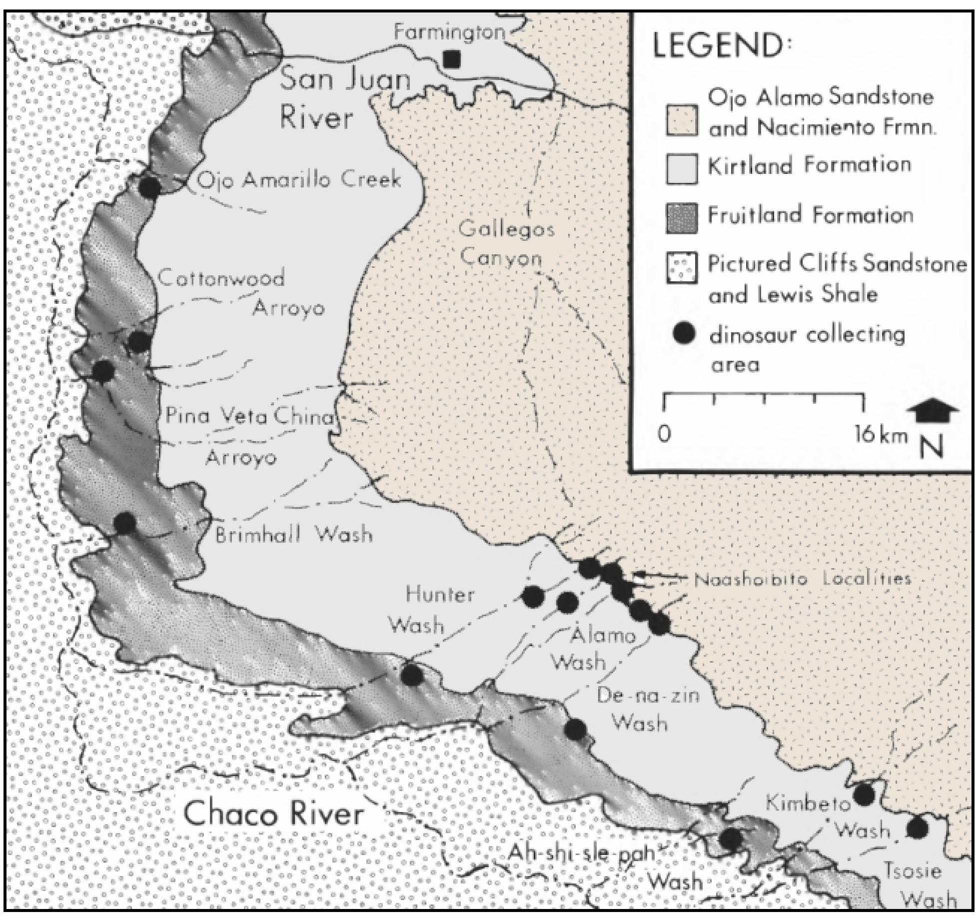

Figure 2. Distribution of formations in the southwestern portion of the San Juan Basin (adapted from Hunt and Lucas 1992, pg 218).

Lewis Shale and Pictured Cliffs Sandstone

The Lewis Shale is stratigraphically the highest layer of marine shale in the San Juan Basin (Fassett and Hinds 1971). The color of the Lewis Shale varies from light to dark gray with interbeds of light brown sandstone, sandy to silty limestone, calcerous concentrations and bentonite (Fassett and Hinds 1971). In some parts of the San Juan Basin it is overlaid by and at times intertongued by the Pictured Cliffs Sandstone. The Pictured Cliffs Sandstone was deposited as a complex of offlapping shoreface and wave-dominated coastline deposits during the last retreat of the Cretaceous sea from the San Juan Basin area (Ambrose and Walter 2007). The Pictured Cliffs Sandstone are grey to white in color peppered by fine to medium grained quartz with some ferromagnesium minerals, calcite, and bentonite (Brown 1978). Neither the Lewis Shale nor the Pictured Cliffs Sandstone formations are exposed in the Bisti region.

Fruitland Formation

The Fruitland Formation is composed of shale, siltstone, coal, carboneous shale and rare instances of sandstone (Fassett 1974). It is the primary coal-bearing formation in the San Juan Basin (Ambrose and Walters 2007). There are three members within the Fruitland Formation: The lower shale overlain by the Farmington Sandstone which is overlain by the upper shale member.

According to Robinson et al (1982), the presence of aquatic gastropods and bivalves, the fern Salvinia, and the fine grained texture of the sediments containing the fossils, indicates the deposition of the Fruitland Formation probably took place in open, standing water likely in the form of small lakes or ponds. Stream channels are represented by linear stretches of sandstone and swampy areas are represented by the dark layers of lignite coal. The areas in the Bisti which show red to orange rocks are actual lignite coal beds which were oxidized through underground burning (Figure 3).

Figure 3. Photo showing “clinkers” and coal seam (photo by Neykar Kotyk, April 2014).

In the Fruitland Formation, erosion has exposed silicified wood and logs which is a useful tool in separating out the Fruitland from the underlying Lewis Shale (Fassett 1974). In addition, invertebrate fossils are abundant (unionid bivalves and nonmarine gastropods), along with turtle carapaces, crocodilian scutes (armored skin, see Figure 4), bony fish, and late Cretaceous dinosaurs. The dinosaur fauna includes ornithomimus, dromaeosauridae, tyrannosaurids, a nodosaurid, ankylosaur, pachycephalosaur, ceratopsian, ceratopsid, hypsilophodontid and hadrosaurids (Lucas et. al., 2000). In addition, the first appearance of mammalian remains is found within the Fruitland Formation. Such mammalians included: multituberculata (rodent-like mammals), marsupialia (similar to opossum), and insectivora (rodent like mammals) (Wolberg 1981).

Kirtland Formation

The Kirtland Formation was deposited later than the Fruitland and is indicative to the seaway receding and going back eastward. According to Robinson et al (1982), swamps were far less represented in the Kirtland formation which suggests that the area had better drained conditions.

The Kirtland Formation is characterized by gray shale with bands of brown, bluish-greenish and yellowish shales. Like the Fruitland Formation, the Kirtland Formation also has dispersed bands of sandstone which formed by stream channels. Because of how similar the Kirtland Formation appears to the Fruitland Formation, it is often difficult to distinguish the two formations especially when the brown-capped sandstone (referred to as the Bisti Member) above the last coal-bearing strata is absent (Hunt and Lucas, 1992). The widespread brilliant, red layers visible on many of the hill tops in the Bisti are the result of underground coal fires which created brittle, iron oxide colored rock from the surrounding siltstone and shale. These rocks are commonly referred to as “clinkers” by geologists (Richie, 2007, see Figure 3).

The fossils that can be found in the Kirtland Formation is a continuation of silicified wood and logs, nonmarine gastropods are present (but more rare than the Fruitland Formation), turtle carapaces, crocodile scutes (armored skin, Figure 4), boney fish, and various dinosaur fauna such as: sauropod, ornithomimids, dromaeosaur, tyrannosaurids, nodosaurid, ankylosaurid, a pachycephalosaur, the ceratopsid and the hadrosaurids (Lucas et. al., 2000). In addition small mammalian fossils like those in the Fruitland Formation continue to be found in the Kirtland Formation.

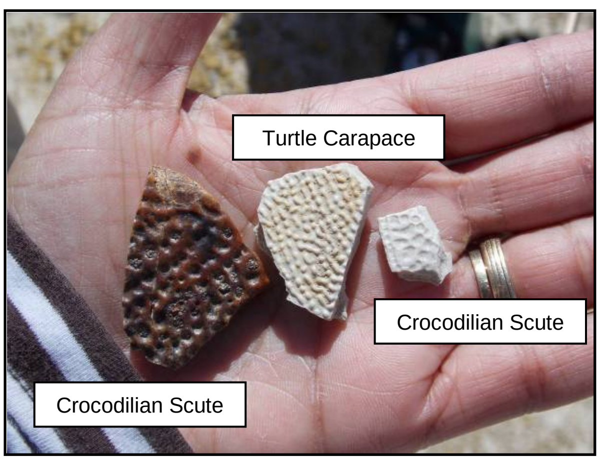

Figure 4. Photo of fossils from Kirtland Formation (photo by Neykar Kotyk, April 2014).

Ojo Alamo Formation

The Ojo Alamo sandstone overlies Kirtland and Fruitland Formations. The cretaceous-tertiary boundary is assumed to be at the base of the overlaying Ojo Alamo sandstone (Fassett 1974).

Silicified woods and logs are extremely abundant within this formation (Fassett 1974, Figure 5). There is much debate as to whether the Ojo Alamo Formation has yielded any dinosaur bones. Those fossils found have been argued to be fragmentary and/or abraded and were reworked from underlying strata. Only one exception to date which includes a hadrosaurs femur found along the San Juan River which was stratigraphically above Paleocene pollen (Lucas, et.al 2000).

Figure 5. Photo of silicified wood log and stump in the Ojo Alamo Formation. (photo by Neykar Kotyk, April 2014)

In addition, mammalian bone fragments can be found in abundance in the upper Ojo Alamo Formation (Kimbeto Member).

Fossil Record

The area in and around the Bisti Wilderness has produced a considerable amount of fossils from plant material, invertabrates and vertabrates (dinosaur, reptilian and mammalian).

<u>Plants</u>

Plant leafy material is found most abundant in the lower Kirtland shale, primarily in the dark, blackish lignite coal deposits. Also common in this zone are fragments of amber which is silicified wood sap.

The most easily observed plant remains are silicified wood and logs which is commonly found in all three major stratigraphic units in the Bisti Wilderness: Ojo Alamo, Kirtland and Fruitland formations. Some have been found with intact lengths greater than 35 feet and trunks three feet in diameter with evidence of root systems extending out. The swampy environment of San Juan Basin was rich in minerals and ground water that supplied ample silicates or calcites for the tree once buried. The process of the silicification (or petrification) of the wood included the slow replacement of biological structures by a combination of silica and calcite, both of which are colorless. The various colors of the silicified wood is the result of metallic impurities like copper, cobalt, iron oxides, carbon and manganese oxides and silica embedded in the crystal matrix of the silica or calcite.

Invertabrates

The most common invertebrates include unionid bivalves and nonmarine gastropods (mollusks). As one gets higher in the stratigraphy (from Lewis Shale to Ojo Alamo), the presence of mollusks does decrease to becoming almost completely absent in Ojo Alamo Formation.

Vertabrates – Dinosaurs/Reptilians

Numerous dinosaur bones have been found most of which are partials or fragments. Partial skeletons or complete, skulls are rare. But such recoveries have included *Pentaceraptops sternbergii*, partial skeletons and cranial parts of ceratopsians, hadrosaurs, tyrannosaurs and ankysaurs. Without doubt, dinosaur fossils can be found throughout the Fruitland and Kirtland Formations; however there is much debate as to whether dinosaur fossils are present within the Ojo Alamo Formation (Lucas, et.al 2000). Reptilian fossils are best represented by a variety of crocodile and turtle species, probably the most abundant fossil remains that can be found in the Bisti Wilderness.

Vertabrates - Mammals

The first appearance of mammalian remains is found within the Fruitland Formation and extends into the Kirtland Formations as well. Such mammalians included: multituberculata (rodent-like mammals), marsupialia (similar to opossum), and insectivora (rodent like mammals) (Wolberg 1981). By the time one gets into the Ojo Alamo formation, there is greater species diversification among the mammalian fossil assemblage, however it must be noted that such mammalian finds are limited in the San Juan Basin region.

Coal

The San Juan Basin is rich in resources like natural gas and coal which has been the reason for extensive studies in the area. According to Edward L. Heffern (Lucas et al 1992), the coal beds generally are in the upper strata of the Fruitland Formation. The coal beds were formed by organic material accumulated mostly in a belt along relatively narrow coastal swamps which were formed behind the hurdle beaches of the sea. The belt of swamps was dissected by rivers which accounts for the discontinuity of coal beds (Allen, J.E, and Black 1954). In the Bisti area, there are numerous coal seams varying from thin lenses to several feet thickness as observed by the black strata seen. A study had been conducted in 1998 to determine the quality and feasibility of coal mining in and around the Bisti Wilderness area (Hoffman and Jones 1998). Hoffman and Jones identified four coal zones that were highly variable in thickness, most of the zones contained high-ash and low-sulfer, Subbituminous A-rank coals.

Erosional Landscapes

The Bisti Wilderness is a stark, yet spectacularly unique landscape resulting from millions of years of deposition and thousands of years of erosion. Considered as part of the “badlands” of the San Juan Basin, the Bisti was created through water deposition by seas, rivers, and swamps over the course of 550 million years and shaped over the last two million years through the combination of land uplifting and erosion (Brister and Hoffman, 2002). With varied stratigraphic deposits of soft clay and silt stones, hard sandstones, lack of vegetation, and numerous dissecting waterways, erosion has formed numerous features that include domes, odd stone anomalies, and infamous hoodoos.

Hoodoos

Hoodoos are a result of differential erosion whereby their shape is affected by mechanical weathering of freezing and thawing cycles and erosion through wind and water (New Mexico Bureau of Geology and Mineral Resources). The harder sandstone layers fracture and break into irregular shapes through freezing and thawing and are also eroded by wind and rain. The lower, softer clay and silt stone materials also undergo similar mechanical and erosional process, but due to their softness eroded more quickly. As such, the combination of the erosional process at different rates often creates shapes that look like mushrooms or hoodoos. The combination of different minerals deposited in the clay or silt stone causes hoodoos to have different colors throughout their height. Hoodoos geological process takes hundreds, even thousands of years to form.

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