DIATOM PALEOENVIRONMENTAL ANALYSIS OF SEDIMENTS FROM THE WATER CANYON PALEOINDIAN SITE (LA134764)

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INTRODUCTION

This investigation is part of an interdisciplinary research project of the Water Canyon Paleoindian site located in west-central New Mexico. The site, at about 1760 m elevation, is at the east edge of the Water Canyon basin, and is one of a series of early-to-middle Holocene age archaeological sites eroding out of sediments along the Water Canyon drainage at the toe end of a large alluvial fan that flanks the Magdalena Mountains (Dello-Russo, 2013). The goal of this part of the project is to investigate the diatom content of 16 samples (Table 1) submitted for diatom analysis and determine the nature of the paleoenvironments they represent.

Diatoms are unicellular, eukaryotic algae that are distinguished by the presence of a silica cell wall. They live in a wide variety of aquatic habitats, including rivers, streams, ponds, lakes, ditches, bogs, lagoons, marshes, swamps, mud flats, beaches, estuaries, bays and oceans. In addition to the aquatic forms, many species are aerial, capable of surviving and reproducing in a variety of non-aquatic (not submerged), moist, humid or dry habitats, such as soil, wet rocks, tree bark, moss, waterfall spray, springs, seeps, swales, fens, tundra, caves, wet meadows, cienegas and moors. These algae often derive their water from moisture in the air and rainfall. The availability of moisture, length of dry periods, substrate, pH, nutrient availability, conductivity, and available light all play a part in determining which of the aerial diatoms thrive in a particular habitat. The aerial environment is harsh in comparison to aquatic habitats and the number of taxa in an assemblage is often lower.

Many species are cosmopolitan, found in different parts of the world under similar environmental conditions, making it possible to predict their environmental requirements and tolerances. Diatoms can be identified to species level, and a large and growing body of information exists on the range and ecological tolerances of many of the common forms. Diatoms are good indicators of water chemistry, depth, pH, salinity, habitat, substrate, nutrient concentrations and pollution levels. Because of their silica cell walls they are often preserved in sedimentary deposits, making them well-suited for use in paleoenvironmental reconstruction.

METHODS

Approximately one cm^3 of sediment was oxidized with 35% H_2O_2 to remove organic material and decalcified with 31% HCl. After rinsing to a neutral pH, the material was dried onto cover slips and mounted on glass slides with Naphrax®. The slides were scanned at x1500 magnification, and the first 600 diatoms encountered were identified and recorded. When there were not sufficient diatoms to obtain this count, the entire 22 x 22 mm area of the coverslip was scanned and all diatom remains recorded.

RESULTS

The results of this analysis are variable, depending on the sample. The samples range from diatomaceous to barren of any diatom remains. All samples that have any diatoms are included on Table 2. A total of 1368 diatom valves and fragments of valves were found. Of these, 22 different diatom species could be recognized. Six other specimens were fragments that could only be identified with confidence to the genus level. In addition to diatoms, one specimen of Concentricystes, a distinctive microfossil of unknown affinity was found, and a few sponge spicules were recorded. Many of the diatoms are illustrated on Plates 1-3.

The most diatomaceous samples, FS1217, FS5059, and FS5095 provide the best information about the paleoenvironments represented by these samples. The 3 diatomaceous samples are very similar in diatom composition (Table 2), with the same taxa common in the three samples. These diatoms, in order of abundance, are *Diadesmis gallica* W. Smith, *Hantzschia amphioxys* (Ehrenberg) Grunow, *Denticula elegans* Kützing, *Luticola mutica* (Kützing) D.G. Mann, *Nitzschia amphibia* Grunow, *Pinnularia appendiculata* (Agardh) Cleve and *Pinnularia borealis* Ehrenberg. It is the association of these common diatom species and their ecological preferences that determines the interpretation of the paleoenvironment. The ecological preferences and tolerances of the rarer species, those diatoms that were recorded only a few times, or only in one or a few samples, are also taken into consideration to provide information about the entire range of conditions represented by the assemblage. Table 3 is a glossary defining the ecological terms used in this report.

DISCUSSION

<u>Ecological Characteristics of the Most Common Diatoms and their Significance to Paleoenvironmental Interpretation</u>

The autecological characteristics of each of the most abundant species are examined to produce a comprehensive description of the range of paleoenvironmental variability that is represented by the individual samples. Because the diatoms discussed are cosmopolitan there is a range of ecological characteristics reported by various authors working in somewhat different settings. Unless specified, ecological information comes from a collection of sources including: Round 1981, Vos and de Wolf 1993, Van Dam et al. 1994, Stoermer and Smol 1999, Johansen 1999, Lange-Bertalot and Genkal 1999, Winter and Duthie 2000, Van de Vijver et al. 2004, Potapova and Charles 2007, Porter, 2008, and others).

The most abundant diatom in these samples is a very small oval form called *Diadesmis gallica* (Plate 1 A, B). It is a typical aerial diatom (Johansen 1999). It dominates the assemblage on ice in caves of the northern Yukon Territory, Canada, where it is well-adapted to the aerial, humid, very low light intensity conditions near the entrance (Lauriol et al. 2006). In the Canadian High Arctic, *Diadesmis gallica* represented up to 1/4 of the diatom population living epiphytically on patches of moss surrounding and in shallow, mesotrophic, dilute, poorly buffered tundra ponds that evaporated seasonally (Antoniades et al. 2005). It forms a biofilm associated with moss in a cave in Spain (Hernández-Mariné and

Molina 2012), and It was found with other aerial diatoms in East Antarctica (Sabbe et al. 2003).

In Switzerland, *Diadesmis gallica* was found in an ephemeral, strongly shaded, low pH (3.95-5.3), low conductivity (46-61 μS cm^{-1}), low temperature (8.5-14.9^{o} C) sandstone stream 5-15 cm deep, that experienced long periods of episodic drying (Veselá 2009)*. Diadesmis gallica* was also part of the aerophilic group of diatoms found in a very small, upland, shallow (25 cm), moderate conductivity, circumneutral oligotrophic to mesotrophic limestone stream in South Poland, whose flow is partly underground (Wojtal 2009).

Diadesmis gallica was very abundant in an east central Utah early-mid Holocene (10,000 to 8,000 cal yr. BP) fen that lacked standing water most of the year and had vegetation that kept the light levels low (Steve Nelson, personal communication 5/23/2016). *Diadesmis gallica* was uncommon but present in a Bolivian cloud forest, on rocks in an alpine, shallow (< 50 cm deep), fast flowing stream that was clear, cold, mesotrophic to eutrophic, with circumneutral pH, probably high concentrations of organically bound nitrogen, oxygen levels above saturation and low conductivity water (Morales et al. 2009).

From these records cited above, it appears that this diatom is a cold temperature form that thrives in dark, damp to wet shady environments, such as the underside of surface litter or moss, that may be occasionally, briefly submerged. It is reported at a pH range mostly from 6.4-7.2, in low to moderate conductivity (between 292 and 569 μS cm^{-1}), and well aerated conditions.

The second most abundant diatom, *Hantzschia amphioxys* (Plate 1 G)*,* is one of the most common soil diatoms in the world. It is rare in acidic soils, and reaches high densities in neutral to slightly alkaline soils, and *Hantzschia amphioxys*, as well as *Luticola mutica* and *Pinnularia borealis*, two other diatoms common in these samples, are absent or rare on strictly aerial lithic substrates unless there are mosses present (Johansen 1999). The ecological characteristics for *Hantzschia amphioxys* include a tolerance of different nutrient levels, an indicator of high total phosphorous, α-mesosaprobous, tolerant of organically bound nitrogen (OBN), and >75% DO saturation, fresh-brackish water, low chloride optimum (<15 mg/L), is motile, found in dry soil, and survives prolonged dry periods.

The next most common taxon, *Denticula elegans* (Plate 1 D, E), is usually classified as aquatic but is found in both submerged and dry settings. It is typically found in oligotrophic, shallow, carbonate-rich, sometimes seasonally flowing spring water, such as travertine encrusted canals and waterfalls, where it can live in a film of flowing water and adapts to drying conditions by producing a large, firm, mucilaginous envelope that retains water (Winsborough 2000). It is alkaliphilous, prefers low total nitrate and phosphate, occurs in fresh and brackish water, including inland saline lakes that become reduced or dry out seasonally such as small, ephemeral pools, seeps, shallow springs, prairie potholes and mud flats.

Denticula elegans, a Great Basin thermophile found in water and soil, was numerically dominant in Devil's Hole, a flooded, groundwater fed cave system in southwestern Nevada, that receives very little direct insolation, has physiochemical characteristics of the water, provided here because they are remarkably stable, including a temperature of 32-33 C, pH 7.1-7.5, dissolved oxygen of 2.0-8.1 mg L^{-1}, total dissolved solids (TDS) of 410-870 mg L^{-1}, conductivity of 820 μS cm^{-1}, SiO_2 of 21-23.5 mg L^{-1}, very low nitrate and phosphorous, Ca of 46-51 mg L^{-1}, HCO_3 of 300-311 mg L^{-1} (Shepard et al. 2000). It was also the dominant species in Blue Lake Warm Spring, Utah, with a temperature of 25-26 C, pH 8.1, TDS 4831 mg L^{-1}, conductivity 8163 μS cm^{-1}, low nitrate and phosphorous, Ca 153 mg L^{-1} (Kaczmarska and Rushforth 1984). This diatom would have been abundant during warm, moist seasons.

Luticola mutica (Plate 1 F, Plate 2 A), the next most abundant diatom, is a very common aerial taxon found in dry and moist soil, on mosses, liverworts and lichens. It is eutrophic, α-mesosaprobous, tolerant to OBN, tolerates low amounts of organic enrichment and nearly 100% DO saturation, circumneutral pH, brackish-freshwater, chloride optimum low (<15 mg/L), benthic, motile, dry soil, cosmopolitan, wide range of tolerance to nutrients, indicator of high total phosphorous, α-mesosaprobous , survives prolonged dry periods.

The next most abundant diatom, *Nitzschia amphibia* (Plate 1 G, Plate 2 H), is aerial and aquatic, cosmopolitan, tolerates a wide range from oligotrophic to eutrophic water, springs, creeks, lakes and ponds, and aerial on moss, wet surfaces, mud and floating algal mats, epiphytic, epipelic, epilithic, prefers high conductivity, indicator of high total and organic nitrogen and total phosphorous, α –mesosaprobous to eurysaprobous, requires periodic elevated concentrations of OBN, tolerates highly degraded conditions, and >50% DO saturation, alkaliphilous to alkalibiontic, fresh-brackish water, benthic, non-motile, tolerates higher salt contents and slight fluctuations in osmotic pressure, eurythermal, oligohalobous (indifferent), warm to cool water.

Pinnularia appendiculata (Plate 3 B, C) is aerial and aquatic, cosmopolitan, prefers mineralized waters, salt-rich inland waters, salines, soda lakes, generally in waters with an average to high electrolyte content, oligo-mesotrophic, oligosaprobous, generally intolerant to OBN, tolerates nearly 100% DO saturation, acidophilous, freshwater, conductivity optimum low (<200 μS/cm), chloride optimum low (<15 mg/L), benthic, motile, soil. It is an inhabitant of soil crust communities in Arizona, that include rocks, lichens, mosses and algae in crusted hummocks (Johansen et al. 1981)

Pinnularia borealis (Plate 3 D) is a typical aerial diatom, often found in slightly brackish habitats (Johansen 1999). It lives on moss, is frequent on wet and nearly dry walls, oligo-mesotrophic, β-mesosaprobous, tolerant to OBN, tolerates nearly 100% DO saturation, circumneutral pH, fresh-brackish water, benthic, motile, cosmopolitan, on soils, dry moss, and other extremely dry environments. It is common in Antarctic terrestrial habitats (Sabbe et al. 2003).

One significant environmental characteristic of the abundant diatoms is that all of these are aerial forms or aquatic species that are also found in aerial settings. In addition to these commonly occurring diatoms there were several other taxa, found in smaller numbers, that straddle the environmental boundary between submerged and just damp, and are adapted to shallow, aquatic settings that dry out regularly. *Epithemia adnata* (Kützing) Brébisson (Plate 1 H)*, Epithemia turgida* (Ehrenberg) Kützing (Plate 3 E, F)*, Rhopalodia brebissonii* Krammer (Plate 3 G, H)*, Rhopalodia gibba* (Ehrenberg) Müller, and *Rhopalodia gibberula* (Ehrenberg) Müller are aquatic, benthic diatoms. They, like *Denticula elegans*, have internal siliceous supports that may aid in withstanding osmotic stress and elevated conductivity or salinity, from either carbonate or chloride. These species are sometimes included in lists of diatoms from dry settings as well as aquatic because they are often found in lacustrine settings that fluctuate in size seasonally, leaving the margins dry.

Aulacoseira italica (Ehrenberg) Simonsen (Plate 1 I, Plate 2 I) , *Brevisira arentii* (Kolbe) Krammer (Plate 2 E, F) and *Stephanodiscus* sp. (Plate 2 B) are the only aquatic, planktonic diatoms found in the samples. *Aulacoseira italica* is aquatic, mesotrophic to eutrophic, β-mesosaprobous, tolerant to organically bound nitrogen (OBN), tolerates >75% DO saturation, alkaliphilous, fresh-brackish water, planktonic and benthic, non-motile, cosmopolitan. It is found commonly in lakes and ponds. Many species of *Aulacoseira* are found in large lakes but *A. italica* also grows in small ponds, and in wetlands with submerged areas. *Brevisira arentii* is found with *Aulacoseira* spp. It was dominant in a moss-lined, humic rich, high dissolved organic carbon, slightly acidic, oligotrophic, low alkalinity pond in New England (Köster and Pienitz 2006). The *Stephanodiscus* specimens were fragments and could not be identified further but they are planktonic and represent a submerged setting during which they form short-lived, periodic blooms (Goldsborough and Robinson 1996).

The remaining diatom species are benthic, aquatic species found in circumneutral to alkaline, nutrient rich, shallow ponds or streams. These include *Encyonema silesiacum* (Bleisch) D.G. Mann (Plate 3 A), a common epiphytic and epilithic, shallow water species tolerant of high nutrient concentrations; *Caloneis bacillum* (Grunow) Cleve, a β-mesosaprobous, mud species tolerant of organic pollution; *Nitzschia perminuta* (Grunow) Peragallo (Plate 2 G), an oligosaprobous species also tolerant of high levels of organics; *Nitzschia* cf *vermicularis* (Kützing) Hantzsch, another mud species; *Placoneis elginensis* (Gregory) E.G. Cox (Plate 2 C), also β-mesosaprobous and nutrient tolerant; *Stauroneis kriegeri* Patrick and *Stauroneis pseudosmithii* Van de Vijver & Lange-Bertalot, both found in small pools of water, moss, and soil; and *Ulnaria ulna* (Nitzsch) Compère (Plate 2 D), a common, broadly tolerant species found in temporarily submerged ditches, ponds, streams and lakes.

<u>Temporal Variability in Paleoenvironment</u>

All of the diatoms discussed above (except the planktonic cells) could easily have been living in essentially the same place, at different times of the year and under slightly different moisture regimes. During dry periods when water levels were low, the exposed sediments would have favored the aerial, epipelic (mud) diatoms such as *Hantzschia amphioxys* and *Luticola mutica*. The surface was colonized by grasses, mosses and sedges as in a wet meadow. As organic litter accumulated, the environment became more nutrient-rich and algal mats and crusts could develop beneath the macrophytes. Macrophyte growth increases shading. The amount of incident light reaching the subsurface can be significantly reduced by an emergent macrophyte canopy such as *Phragmites* or *Typha* or a thick floating mat of duckweeds (*Lemna minor*). *Diadesmis gallica* is not a typical component of a well illuminated assemblage so it must have become common only after a thick cover developed.

During wet periods, epiphytic, epipelic and epilithic diatoms could grow on vegetation, mud and submerged pebbles, but the numbers of these diatoms in the samples was low. These diatoms may have been transported from a nearby flowing water environment and ended up in the samples as overbank deposits. If the water was deep enough, for long enough, and adequately nutrient-rich, a phytoplankton population could develop, but there is no evidence of significant phytoplankton development in the Water Canyon samples other than the small numbers of centric, planktonic diatoms found. Sponge spicules, an indication of very humid conditions, were also observed in two samples (Table 2).

A possible analog to the Water Canyon assemblages is a core from Stonehouse Meadow, a spring-fed sedge meadow in Spring Valley, eastern central Nevada, dated between 8000 and 1750 cal. Yr BP. A large component of the assemblage during relatively moist conditions was dominated by *Epithemia* spp., *Rhopalodia* spp., *Nitzschia amphibia* and *Denticula* spp., diatoms that can survive in environments with elevated levels of total dissolved solids, often in sodium carbonated systems; and an assemblage dominated by aerial taxa including *Hantzschia amphioxys*, *Luticola mutica*, and *Pinnularia borealis* during drier conditions (Mensing et al. 2013). A diatom assemblage similar to that from wet intervals in Water Canyon is reported from black mats at Lubbock Lake and Blackwater Draw sites (Harris-Parks, 2014).

Reasons for Lack of Diatoms in Some Samples

There were few to no diatoms in some samples and many in others. There are several reasons for this. The absence of diatoms may indicate an environment that was not conducive to diatom growth such as a dry or aeolian surface, or a setting in which diatoms were originally present but later removed by diagenetic and pedogenic processes. Poor diatom preservation may be explained by silica dissolution, frequent wind-induced resuspension cycles and grazing by benthic invertebrates that can cause breakage of diatom frustules (Bennion et al., 2010).

Silica dissolution affects all siliceous microfossils, including diatoms, phytoliths, and sponge spicules, but diatoms are the group that is most sensitive to dissolution by oxidation and bacterial decay. While the diatom is alive there is an organic casing consisting of polysaccharides, proteins and lipids around the silica wall that protects it against dissolution. Dissolution of the siliceous exoskeleton is slow except in alkaline conditions or in the interstitial water of peat bogs (Round et al. 1990). In a setting with alternating wet and dry environments, a lowering of the water table, increases biological activity and decomposition processes, with diatoms rare in unsaturated soil environments and frequent in saturated conditions (Bouma et al 1990).

Three major types of black mats, depending on morphological and geochemical characteristics, were identified in a micromorphology study of 25 Younger Dryas age sediments from Arizona, New Mexico, Texas and Nevada, and diatoms were reported only from the black mat deposits at Lubbock Lake and Blackwater Draw (Harris-Parks 2014) so diatoms may not be present in certain types of black mats.

Mechanical breakage can be caused by transport or by the effects of grazing. Grazing pressures include insect herbivory, particularly fly larvae, oligochaete worms, microcrustacea (cladocerans, copepods, and ostracods,), amphipods, snails, tadpoles and fish. Diatoms produce high-energy lipids and provide essential fatty acids making them a desirable food source (Julius and Theriot, 2010).

<u>Comparison of Locus 1 (1000 Series Samples) to Locus 5 (5000 Series Samples)</u>

To investigate the possibility that Locus 5 could have been a paleo channel and Locus 1 a wet meadow, the characteristics of each setting are considered and compared to the autecological characteristics of the diatoms in samples from both loci. All samples in Locus 1 are older black mat samples from below the paleochannel deposits and those in Locus 5 are younger black mat samples from above the channel deposits. What is being compared therefore are the diatom assemblages in two black mat accumulations, separated in time by an interval favorable for paleochannel development. These paleoenvironments have in common a water table that intersects the ground surface near the distal toe of alluvial fans or where faults force ground water to the surface as seeps or springs, and differ in their specific sedimentary facies.

A paleochannel is often filled with coarse, clastic sediments as the finer material was carried off by the current. Sand and gravel, however, can also find their way into a wet meadow in localized, lobate overbank deposits (Miller et al. 2011). A wet meadow is saturated ground along perennial streams where water from spring and groundwater discharge moves over the surface without ponding (Hall et al. 2012). Wet meadows are essentially large seeps, but do not have standing water except seasonally or for brief periods after heavy precipitation events, and the sediments are mostly silt with variable amounts of fine to medium sand that originates from both local and aeolian sources (Pigati et al 2014). Related to the wet meadow, and associated with perennial springs and headwater streams, is the ciénega, perpetuated by permanent, scarcely-fluctuating sources of water forming saturated soils (Hendrickson and Minckley 1985). This setting differs in lacking the fluctuating water levels of the wet meadow but has the typical shallow braided channels between pools and saturated ground that trap organic materials and nutrients.

If discharge from the distal end of an alluvial fan is localized at a point source that is higher than the water table downstream incision should create a distinct confined channel. If the channel bed fills up with coarse material, such as arroyo flood deposits, it will have a different porosity from the surrounding sediments and, at that time, would not have supported the same diatom community as a wetland. The transition to an unconfined wet meadow, (with channel stabilization leading to plant productivity, soil production and organic matter accumulation) could have been abrupt or gradual. Complicating this story is the fact that basins with low-gradient meadow complexes contain discontinuous gullies and stream channels on the valley floor as well as slope failures along banks, seepage erosion, and piping, a phenomenon associated with burrows, decaying roots or other openings created by plants and animals, that involves the enlargement of existing macropores and cavities by groundwater flow, and if prevalent can be the dominant mechanism of meadow degradation (Miller et al. 2011).

One possible scenario for the deposition of repeated generations of black mats at Water Canyon involves a history of repetitive wetland formation and drainage processes associated with multiple sequences of lake-wet meadow impounding followed by catastrophic failures possibly due to slope erosion or outburst flood deposits that extended downstream from the landslide dam. This happened at White Rock Canyon, New Mexico (Reneau and Dethier 1996) where sands and gravels are directly overlain by silt, sand and clay.

At Water Canyon there could have been a terminal Pleistocene landslide or other sediment influx downstream (possibly induced by long periods of heavy rain) that backed up the water forming a basin that eventually filled with wetland vegetation, creating the sediments in Locus 1. Subsequent drainage of the wetland, perhaps triggered by extreme precipitation, heavy snowmelt events or earthquakes, would allow for erosive, rapid channel incision, scour and deposition of coarse sediments. Seismic activity could also have contributed to abrupt landform adjustment in the absence of regional climate change. Reestablishment of the wetlands would have followed when another landslide blocked outflow and dammed up the water, repeating the cycle. Because of the low relief, the channels would have been capped with fine sediment and became part of a new wet meadow (Locus 5), with shallow, meandering, braided streams. In this case, if the climate and water table were the same during the deposition of Loci 1 and 5, the predominant diatoms in the black mats at each locus should be similar, allowing for differences due to allochthonous diatom material that was eroded, transported and added to the wet meadow as runoff, and overbank deposits.

The diatomaceous samples in each locus contain the same dominant species, but the proportions of each species are somewhat different. Locus 5 contains fewer aerial diatoms and greater numbers of aquatic species. This is based on comparison of 600 diatom cells from the most diatomaceous locus 1 sample and 600 diatoms from the best Locus 5 sample. These differences may indicate slightly wetter conditions in locus 5.

CONCLUSIONS

Although there were fluctuations in water level due to periods of drying and flooding, this wetland ecosystem appears to have been repeatedly reestablished during the time interval of 12,327 cal yr BP thru 9730 cal yr BP since the three diatomaceous samples FS1217 (Locus 1)with a modeled age of 12,327 cal yr BP, FS5059 (Locus 5) at 9,730 cal yr BP, and

FS5095 (Locus 5)at 9,999 cal yr BP, covering a time span of about 2600 years, all have very similar diatom assemblages. The samples in Locus 5 contain an assemblage that may represent slightly wetter conditions. These assemblages define the mosaic of micro-habitats that were available to the diatoms during the period covered by the samples. There is not enough diatom data to draw any conclusions about the post- 9730 cal yr BP and there is no data for pre-12,327 cal yr BP.

The diatoms are a combination of aerial species and aquatic forms, many adapted to temporarily submerged or wetted settings that dry out. The assemblage indicates that there was not permanent standing water. The lack of significant numbers of aquatic diatoms means that the climate was probably predominantly dry, with the aquifer sustained by snowmelt. Groundwater discharge may have been in the form of diffuse seeps where the water table intersected the ground surface. This moisture supported moss or similar cover, as well as larger emergent plants. The ground surface was probably very shallowly submerged, for brief intervals but not long enough for a typical aquatic flora to develop, other than taxa adapted to fluctuating moisture. Most likely, rather damp, humid conditions defined the site at the time these diatoms were alive.

The overall climate may have been cold and dry in the winter and warmer and wetter in the summer. The diatoms living on the sediment surface and in the detrital mat reflect an environment that was exposed to the entire seasonal temperature range, but the most abundant diatom, *Diadesmis gallica*, is an aerial species reported from cold or cool climates. Another abundant diatom, *Denticula elegans* is abundant in warm, shallow water, suggesting that the ground surface was warm or temperate and wet part of the year.

The conductivity of the groundwater-fed system was low to moderate, possibly increasing during evaporitic periods. The pH was never very acidic, probably circumneutral to somewhat alkaline in freshly submerged water bodies, but as these submerged meadows dried out or the water table dropped, mineral salts accumulated, making the pH more alkaline. This is reflected by the presence of alkaliphilous diatoms, such as

Epithemia spp., Rhopalodia, and *Denticula elegans* that are adapted to aquatic settings that dry out. Mosses can create locally slightly more acidic habitats, even when growing on limestone or travertine, but these pH differences are localized.

Depending on the vegetation, particularly the grasses and emergent water plants, and the degree to which the water table fluctuated, this diatom assemblage could describe a spring-fed wet meadow, or cienega, with saturated soils supporting abundant macrophytes. The combination of canopy, vegetation, and accumulated organic matter would have limited substantially the amount of light available to the diatoms at the sediment surface.

There were low numbers of planktonic diatoms in these diatom samples. They are a combination of *Aulacoseira* spp., taxa found in somewhat permanent lakes with a slightly acidic to slightly alkaline pH, and fragments of *Stephanodiscus* sp. another planktonic diatom, that is alkalibiontic, meaning that it only occurs in alkaline water with a pH above 7. *Stephanodiscus niagare* Ehrenberg was abundant in core samples between 18,000 and 15,000 yr B.P. in the San Agustin Basin in western New Mexico, that was interpreted as a large, freshwater, alkaline lake with salinity levels of less than 3000 ppm, and possibly consisting of several short duration intervals of high and low lake stands (Markgraf et al. 1983, Markgraf et al. 1984).

Abundant planktonic diatoms, particularly sturdy, heavy-celled *Aulacoseira* spp. were found in the pollen samples, particularly in Locus 1 (Chad Yost, personal communication 5/24/2016). These planktonic diatoms represent a lake setting. This is a different environment than that indicated by the diatom assemblage. The planktonic diatoms either were transported from a nearby lake, or were reworked or eroded from an older paleolake. These diatoms would have accumulated on the surface when a lake dried out and resisted dissolution, much the same as *Denticula elegans, Epithemia* spp*.* and *Rhopalodia* spp. Transport mechanisms include wind, birds, turtles and mammals. The larger sample volume and different preparation used in pollen extraction may contribute to the difference in the quantity of *Aulacoseira* spp. recovered.

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TABLE 1

LIST OF DIATOM SAMPLES ANALYZED FROM THE WATER CANYON PALEOINDIAN SITE (LA134764)

FS No.	Test Unit/ Level	N. Grid Co. (m)	E. Grid Co. (m)	Grid Elev. (m)	Modeled Age (cal yr BP)	Diatom Summary
1195	Unit 1-6 Lev. 9	509	509	48.00-47.90	10,214	few diatoms
1197	Unit 1-6 Lev. 10	509	509	47.90-47.80	10,568	few diatoms
1202	Unit 1-6 Lev. 11	509	509	47.80-47.70	10,956	no diatoms
1203	Unit 1-6 Lev. 12	509	509	47.70-47.60	11,379	no diatoms
1211	Unit 1-6 Lev. 13	508	509	47.60-47.50	11,836	no diatoms
1217	Unit 1-6 Lev. 14	508	509	47.50-47.40	12,327	very many diatoms
1219	Feat. 1-6 Lev. 15	508	509	47.40-47.30		no diatoms
1229	Unit 1-6 Lev. 16	509	509	47.30-47.20	13,412	no diatoms
1249	Unit 1-6 Lev. 17	509	590?	47.30-47.10	14,006	no diatoms
1632	Unit 1-46 Lev. 15	512.501	511.349	47.317		few diatoms
1633	Unit 1-46 Lev. 15	512.506	511.319	47.368		no diatoms
1634	Unit 1-46 Lev. 14	512.502	511.346	47.490		no diatoms
5005	Unit 5-3 Lev. 1	521.93	527.91	45.980	9,513	few diatoms
5059	Unit 5-3 Lev. 2	521.903	527.843	45.871	9,730	very many diatoms
5095	Unit 5-3 Lev. 4	527.838	521.778	45.696	9,999	many diatoms
5123	Unit 5-3 Lev. 6	527.841	521.9	45.479	10,196	few diatoms

TABLE 2

DIATOM TAXA RECOVERED FROM THE WATER CANYON PALEOINDIAN SITE (LA134764)

FS Number	1195	1197	1217	1632	5005	5059	5095	5123
Aulacoseira italica (Ehrenberg) Simonsen				1			2	
Aulacoseira sp. fragments							4	
Brevisira arentii (Kolbe) Krammer			2					
Caloneis bacillum (Grunow) Cleve						2		
Cymbella sp.		1						
Denticula elegans Kützing			31			82	25	1
Denticula sp.		1						
Diadesmis gallica W. Smith			191			230	32	
Encyonema silesiacum (Bleisch) D.G. Mann				1	1			
Epithemia adnata (Kützing) Brébisson			7			12	7	
Epithemia turgida (Ehrenberg) Kützing	2		3				2	
Epithemia sp.		2						1
Hantzschia amphioxys (Ehrenberg) Grunow		2	181	4	1	151	45	1
Luticola mutica (Kützing) D.G. Mann			89	2		37	8	
Nitzschia amphibia Grunow			40			44	7	
Nitzschia perminuta (Grunow) Peragallo			12			2		
Nitzschia cf. *vermicularis* (Kützing) Hantzsch	1							
Placoneis elginensis (Gregory) E.J. Cox			2					
Pinnularia appendiculata (Agardh) Cleve			18			10		
Pinnularia borealis Ehrenberg			15			8	4	
Rhopalodia brebissonii Krammer			6			18	1	
Rhopalodia gibba (Ehrenberg) Müller						2	1	1
Rhopalodia gibberula (Ehrenberg) Müller							3	
Stephanodiscus sp.			2				1	
Stauroneis kriegerii Patrick						2		
Stauroneis pseudosmithii Van de Vijver & Lange-Bertalot			1					
Surirella sp.							1	
Ulnaria ulna (Nitzsch) Compère	1				1			
Total count	4	6	600	8	3	600	143	4
Concentricystes [unknown affinity]	1							
Sponge spicule		3		1				1

TABLE 3

GLOSSARY OF DIATOM ATTRIBUTES AND WATER QUALITY TERMS

Definitions adapted primarily from Van Dam et al. 1994, Potapova and Charles 2007, Lange-Bertalot and Genkal 1999, Porter 2008, Winter and Duthie 2000.

pH

acidobiontic- optimal occurrence at pH <5.5, occurs below pH

acidophilous- mainly occurring at pH <7

circumneutral- mainly occurring at pH-values about 7

alkaliphilous- mainly occurring at pH >7

alkalibiontic- exclusively occurring at pH >7

indifferent- no apparent optimum, tolerates a wide pH range

Salinity (halobion or salt spectra) concentration of sodium chloride (related to conductivity in brackish and fresh water)

	Cl^- (mg/L)	Salinity (ppt)
fresh	<100	<0.2
fresh-brackish	<500	<0.9
brackish-fresh	500-1000	0.9-1.8
brackish	1000-5000	1.8-9.0
brackish-marine	5000-30,000	9.0-30

marine	30,000-40,000	30-40
hypersaline	over 40,000	over 40

halophobous- occurs only in fresh water

halophilous- freshwater form stimulated by small amounts of salt

oligohalobous- freshwater, indifferent to small amounts of salt

mesohalobous- brackish water form 500-30,00 mg/l Cl, (mesosaline or mesohaline)

β-mesohalobous- 500-10,000 mg/l

α-mesohalobous- 10,000-30,000 mg/l

polyhalobous- can withstand salt concentrations greater than those of the sea and tolerate concentrations of 5-35 ppt

euryhalobous- occurring over a broad range of salt concentrations

stenohalobous- occurring within a narrow range of salinities

euhalobous- marine

pleio-euryhaline- tolerates a salinity range of 5-35 ppt

conductivity- the concentration of dissolved salts (electrolytes), made up of cations calcium, magnesium, sodium and potassium, and anions bicarbonate, sulfate and chloride (used primarily in inland, continental settings with variable anions.

Oxygen requirements

continuously high (about 100% saturation)

fairly high (above 75% saturation)

moderate (above 50% saturation)

low (above 30% saturation)

very low (about 10% saturation)

Saprobity (organic pollution, harmful substances)

	Oxygen saturation (%)	BOD_5^{20}(mg/L)	
saprophobous			clean, unpolluted water
oligosaprobous	>85	<2	low amounts of organic enrichment, clean water
mesosaprobous			occurring in moderate to highly polluted water
β-mesosaprobous	70-85	2-4	somewhat degraded conditions, rich in diatoms and green algae
α-mesosaprobous	25-70	4-13	degraded conditions, preponderance of cyanobacteria, tolerant diatoms and some green algae
α-meso-polysaprobous	10-25	13-22	highly degraded conditions, cyanobacteria and a few diatoms

polysaprobous	<1	>22	extremely degraded conditions, very polluted, few algae

Trophic state (growth promoting substances such as nitrate and phosphate, often from animals)

oligotrophic- nutrient poor

oligo-mesotrophic- low nutrient concentrations

mesotrophic-moderate nutrient concentrations

meso-eutrophic- rather high nutrient concentrations

eutrophic- high nutrient concentrations, nutrient rich

eurytrophic- indifferent to nutrients

Life form

planktonic- always suspended in the water column

euplanktonic- usually suspended in the water column

tychoplanktonic- facultatively planktonic but usually associated with benthic habitats

benthic- occurring on the bottom of a water body

sessile- directly attached to substrate

epiphytic- attached to aquatic plants or other algae

epilithic- attached to rocks and pebbles

epipelic- in or on mud

epipsammic- attached to sand grains

aerial (aerophilis, subaerial)- habitats that are not submerged, such as soil, moss, wet walls and mud

aquatic- submerged

edaphic- associated with sediments, particularly intertidal sand and silt

epontic- sessile, firmly attached to substratum, including macrophytes, rocks and sand

cosmopolitan- found in various parts of the world under similar environmental conditions

Water flow characteristics

limnobiontic- characteristic of non-flowing (standing) waters (lakes, ponds, lagoons)

limnophilous- optimum development in non-flowing waters

rheophilous- characteristic of flowing waters

PHOTOMICROGRAPHS OF THE COMMON OR ECOLOGICALLY SIGNIFICANT DIATOMS IN THE WATER CANYON SAMPLES

PLATE 1

All images at 1000x magnification. A, B. *Diadesmis gallica* W. Smith, different focal levels. C. *Nitzschia amphibia* Grunow. D, E. *Denticula elegans* Kützing, front and side views. F. *Luticola mutica* (Kützing) D.G. Mann. G. *Hantzschia amphioxys* (Ehrenberg) Grunow. H. *Epithemia adnat*a (Kützing) Brébisson . I. Two cells of *Aulacoseira italica* (Ehrenberg) Simonsen.

PLATE 2

Images A, B, C, E, F, G, H, I at 1000x, D at 400x. A. *Luticola mutica* (Kützing) D.G. Mann. B. *Stephanodiscus* sp. fragment. C. *Placoneis elginensis* (Gregory) E.G. Cox. D. *Ulnaria ulna* (Nitzsch) Compère. E, F. *Brevisira arentii* (Kolbe) Krammer, different focal levels. G. *Nitzschia perminuta* (Grunow) Peragallo. H. *Nitzschia amphibia* Grunow. I. *Aulacoseira italica* (Ehrenberg) Simonsen.

PLATE 3

Images A, B, C, D, F, G, H, I at 1000x, E at 400x. A. *Encyonema silesiacum* (Bleisch) D.G. Mann. B, C. *Pinnularia appendiculata* (Agardh) Cleve. D. *Pinnularia borealis* Ehrenberg. E, F. *Epithemia turgida* (Ehrenberg) Kützing. G, H. *Rhopalodia brebissonii* Krammer. I. broken sponge spicule.

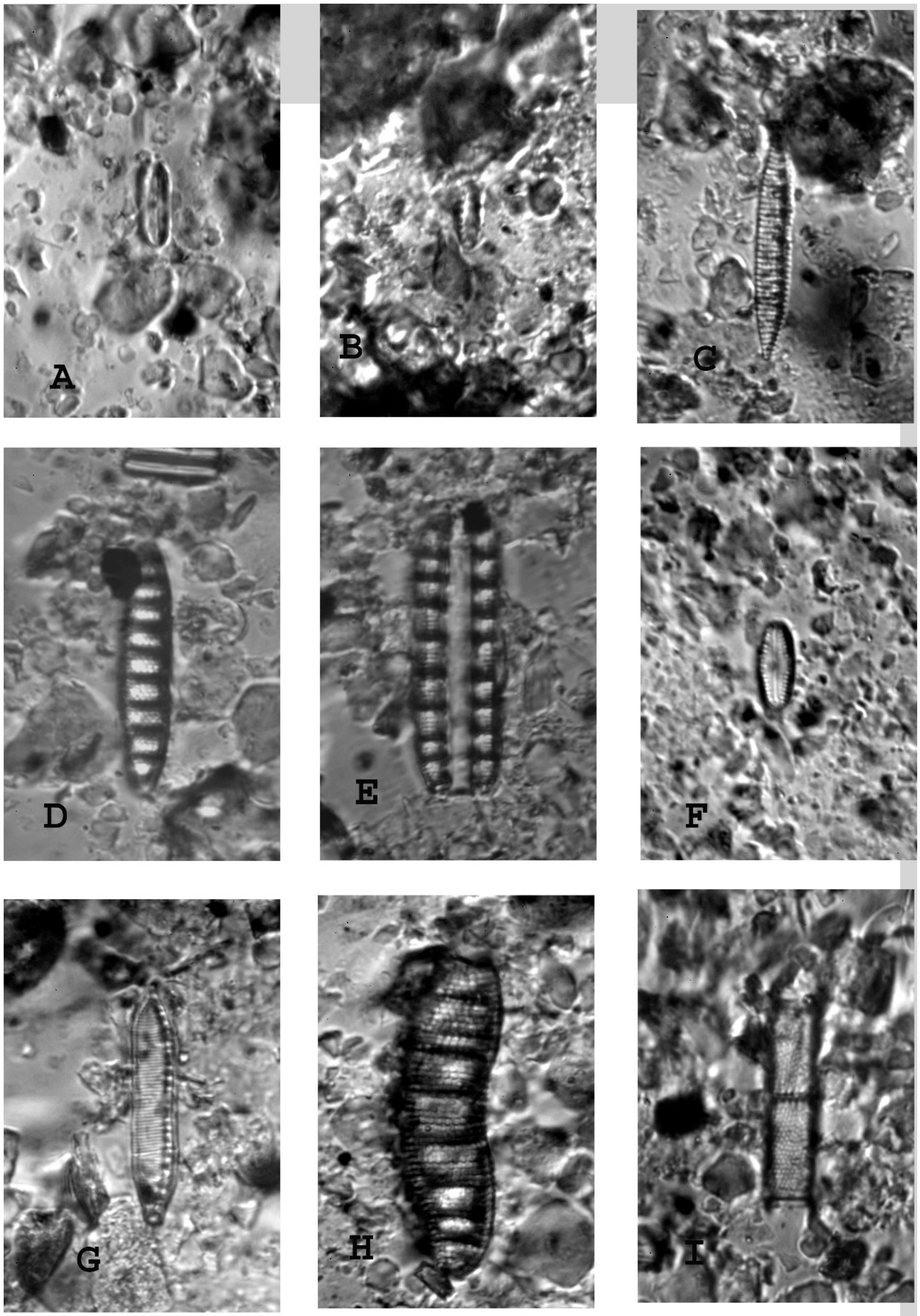

PLATE 1

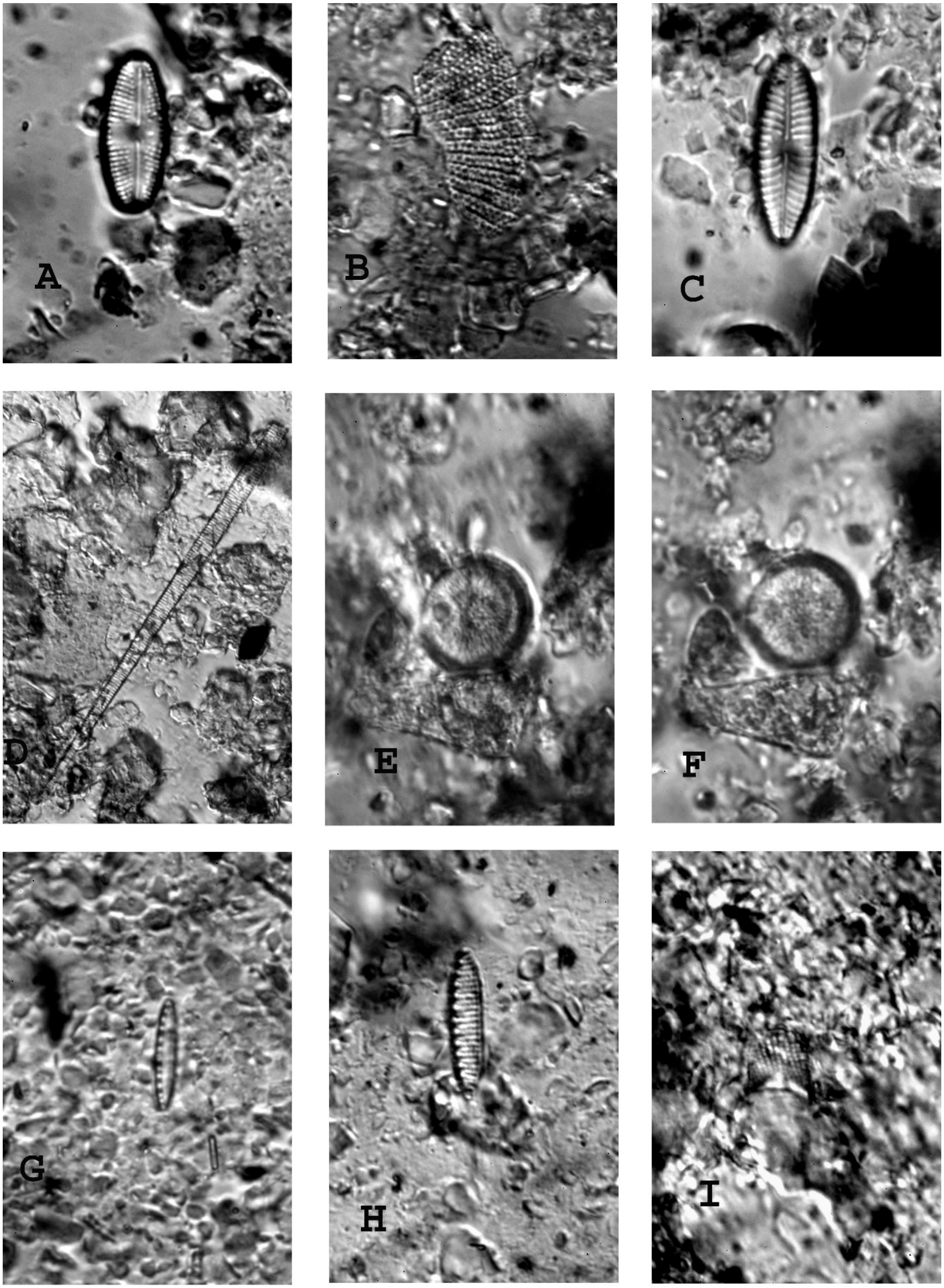

PLATE 2

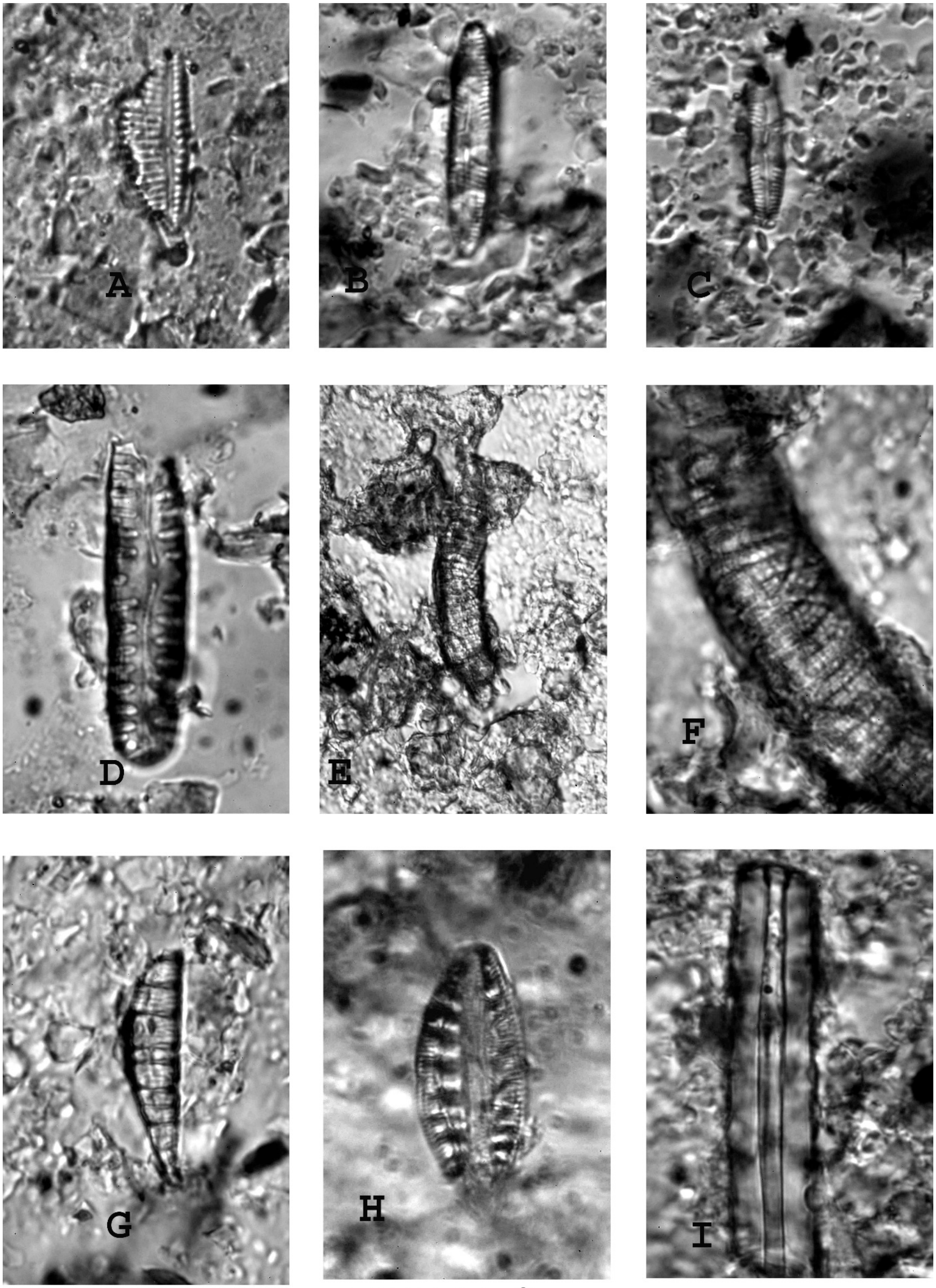

PLATE 3

ADDITIONAL NOTES ON DIATOM PALEOENVIRONMENTAL ANALYSIS OF SEDIMENTS FROM THE WATER CANYON PALEOINDIAN SITE (LA134764)

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INTRODUCTION

This note is an addition to the diatom paleoenvironmental report on sediments from the Water Canyon Paleoindian site located in west-central New Mexico. The site, at about 1760 m elevation, is at the east edge of the Water Canyon basin, and is one of a series of early-to-middle Holocene age archaeological sites eroding out of sediments along the Water Canyon drainage at the toe end of a large alluvial fan that flanks the Magdalena Mountains (Dello-Russo, 2013). Two samples from LA 134764 were submitted for diatom analysis to investigate the paleoenvironment associated with the bone bed between Locus 1 and Locus 5.

Sample 1: FS 5161, 520.482 N, 525.894 E, Level 4, Unit 5-08, Grid Elev. (m) 45.50 to 45.48, 6-3-15.

Sample 2: FS 1371.1, 506.333 N, 511.553 E, Level 6, Unit 1-21, Grid Elev. (m) 48.050 to 48.020, 6-5-15.

METHODS

Approximately one cm^3 of sediment was oxidized with 35% H_2O_2 to remove organic material and decalcified with 31% HCl. After rinsing to a neutral pH, the material was dried onto cover slips and mounted on glass slides with Naphrax®. Two slides of 22 x 22 mm area were scanned at x1500 magnification, and all diatoms encountered, including fragments, were identified and recorded.

RESULTS AND DISCUSSION

Sample 1: There were no diatoms at all and the few phytoliths observed were extensively pitted and fragmented.

Sample 2: One complete aquatic, benthic diatom was found. This is *Navicula reichardtiana* Lange-Bertalot. This small benthic diatom is found in eutrophic, moderately electrolyte rich water, particularly those rich in calcium carbonate and also rarely in brackish water. It is pollution tolerant to critical levels making it a good indicator of eutrophy, (high nutrient concentrations) and is β-mesosaprobous (tolerant of somewhat degraded conditions).

There were also 14 small fragments of *Hantzschia amphioxys* (Ehrenberg) Grunow. This one of the most common soil diatoms in the world. It is rare in acidic soils, and reaches high densities in neutral to slightly alkaline soils, The ecological characteristics for *Hantzschia amphioxys* include a tolerance of different nutrient levels and organically bound nitrogen. It is an indicator of high total phosphorous and α-mesosaprobous (degraded) conditions. It is found in dry soil, and survives prolonged dry periods, and also in fresh-brackish temporary water.

In addition to diatoms, 3 chrysophycean statospores were recorded in sample 2. These are green algal resting spores that are produced in water, often in settings that dry out.

CONCLUSIONS

Because there were few diatoms or other microfossils, it is hard to say much about the paleoenvironments that characterized the deposition of the samples. In sample 2 there is evidence from the presence of an aquatic diatom and the statospores that there was water present, at least temporarily but it may have been turbid flood water. One possible reason for the lack of diatoms may be due to an environment that was temporarily flooded, followed by muddy then dry conditions. The degree of dissolution reflected by the fragments of *Hantzschia amphioxys*, a sturdy diatom, and the phytoliths suggests a combination of mechanical breakage, grazing, and post depositional diagenesis. These processes are typically responsible for the dissolution of the delicate diatoms, leaving a depauperate assemblage.

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