Taxonomy and Paleoenvironmental Indications of Fossil Diatoms from the Florissant Formation

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Introduction

In the field of freshwater diatom paleontology and biochronology, much has been accomplished for Neogene floras from the western lake basins of the U.S. Although freshwater diatoms are first recorded from early Cretaceous deposits, the early account of pre-Neogene diatoms is sparse throughout the world. As a result, the course and timing of freshwater diatom evolution and paleogeography are virtually uncharted. The rare pre-Neogene diatoms on record show a low diversity (taxonomic richness). This report presents current research on fossil diatoms from the Florissant Formation. Preliminary examination of the richly fossiliferous lacustrine shales in the late Eocene Florissant Formation of Colorado indicates that they contain the most diverse early freshwater diatom flora known within the fossil record. This highly diverse and well-preserved diatom flora has never been fully documented and described.

This report presents the current research results on fossil diatoms from the Florissant Formation. Four localities were examined during the course of this study, which sampled the lower, middle and uppers shale units of the Florissant Formation. Diatom genera were positioned within their biochronological framework among other pre-Neogene freshwater diatoms that have modern affinities. The findings extend the published geologic record of eight known freshwater diatom genera and show their earliest-recorded appearance in this paleogeographic province of western North America. These findings also contribute new taxa for consideration in future investigations of fossil links to freshwater diatom phylogenetics in an effort to understand diatom evolution. The paleoecological significance of the diatoms, along with sedimentary evidence, are used to interpret less well-known aspects of the lake history. These findings strengthen our understanding of the interplay between surface and groundwater hydrology, paleolimnology, lake sedimentation, and regional volcanism in a period of gradual, global, step-down cooling from the warmer and wetter climates of the early and middle Eocene epochs.

Project Objectives

The four primary objectives of this study are to document and characterize the diatom assemblages of the lacustrine shales of the Florissant Formation; to trace the paleolimnological changes within the ancient lake through time and space by using paleoecologic evidence from the diatoms; to relate changes in the diatom assemblages to sedimentologic events that likely affected their habitat and life cycle; and to assess and describe the variability of taphonomic states among the diatoms.

First, this investigation documents and describes the Florissant diatom assemblages from the “lower shale” unit at the privately-owned Florissant Fossil Quarry (known herein as the Clare’s Quarry site), the “middle shale” unit within the Florissant Fossil Beds National Monument at the Original Scudder Site (Figure 1) and the MacGinitie #3 site, and the “upper shale” unit within the Florissant Fossil Beds National Monument at the Northwest Corner site. Component diatom taxa are identified to genus and compared to the nearest known modern or fossil species using morphologic affinity; and, where indicated, new now-extinct species are named and formally described. The findings extend the published geologic and geographic record of many known freshwater genera.

Secondly, where possible, modern analogs are determined for the fossil diatoms and interpretations of habitat change in the lake are made using the diatoms as paleoecologic indicators. Implications for aspects of paleolimnology such as alkalinity/acidity, eutrophism/oligotrophism, water depth, planktonic/benthic habitats, tolerance for turbidity, and preference for soil-air-stream-or lake habitats are considered in the context of the broader ecosystem. Relationships between the occurrence of diatoms and associated flora and fauna are incorporated as further ecological evidence. Comparisons are made through published studies of similar fossil and modern lake sites.

The third objective is to evaluate the impact of depositional events upon the diatom community through time. This portion of the study focuses on the well-exposed stratigraphic section of "lower shale" at the Clare's Quarry site. For example, isolated thick units of volcanic tuff and massive beds of mudstone portray events that changed the parameters of the lake habitat and may have disrupted life cycles of diatoms that could have caused a progressive change in the population of the lake over time. Variability in diatom relative abundance, diversity, and assemblage composition are described and evaluated in relation to stratigraphic positions, lithologic characteristics, and associated organic remains. The focus is on cyclical patterns of deposition and the diatom response to such cycles. This further advances our knowledge of local depositional and tectonic history of the lake basin, as well as the relative tolerance for environmental stressors that elements of the diatom flora were able to endure.

The fourth objective is to describe and interpret the relative quality of diatom preservation and address the preservation variability among and within samples. This portion of the study was performed at the Clare's Quarry site because of the excellent stratigraphic control in the section of "lower shale." These observations lead to a better understanding of chemically-controlled taphonomic conditions that may have existed at the lake surface, in the water column, at the sediment-water interface, and/or in the post-burial environment.

Participants

Five investigators from 3 institutions participated in this project

1. Dr. Herbert Meyer, Florissant Fossil Beds NM
2. Dr. Dena M. Smith, University of Colorado
3. Ms. Mary Ellen Benson, University of Colorado
4. Dr. Patrick Kociolek, University of Colorado
5. Dr. Sarah Spaulding, University of Colorado and USGS

Field work

Field work was conducted at four primary localities: 1) Clare's Quarry site which includes "lower shale", 2) Original Scudder site which includes "middle shale", 3) MacGinitie #3 site which also includes "middle shale", and 4) the Northwest corner site which includes "upper shale".

Selection of sample sites and systematic field collecting from stratigraphic sections of "lower," "middle," and "upper shales" were conducted during 2005, 2006, and 2007 field seasons. The "lower shale" was sampled only on private property, and all "middle" and "upper shale" samples were collected from within the Florissant Fossil Beds National Monument. A total of 26 meters of section has been measured and sampled for this study. Additional random samples were collected from exposures of "middle shale" from three other sites in the Monument.

Methods

After collection of materials from the field, biological slides were made from selected sample intervals of the papery shale and the mudstone from the three lacustrine shale units. Each slide was examined for diatoms. Reference literature on diatom taxonomy, consultations with diatom researchers as to taxonomy, and ME Benson's attendance at courses on diatom systematics and ecology were all important aspects for being able to identify diatoms to genus. Diatom specimens were measured, digitally photographed, and imaged using scanning electron microscopy. These specimens are now in the process of being formally named and described.

Several diatom sample preparation methods were used to attempt to disaggregate the matrix and to make biological slides for oil-immersion viewing at 1000x with a light microscope with the end-goal of quantifying relative abundances of taxa. These methods included the standard hydrogen peroxide method, sodium hexametaphosphate with sodium carbonate method, and treatment with sulfuric acid. In the end, complete matrix disaggregation was not achievable, and mechanical crushing was the preferred method, as it is believed to yield a more representative taxonomic sample. This method was augmented with scanning electron imagery and petrographic thin section examination for viewing diatom orientation and density within laminae.

Due to the difficulties of disaggregating diatoms from the matrix, specimens were evaluated on the basis of their relative frequency in a biological slide in the following way. Two transects were made across the cover slip: one lateral through the center and the other vertical through the center. The number of individuals of each diatom genus was recorded per view at 1000x in each transect. For the elongate pennates (such as *Synedra* and *Diatoma*) that tend to dominate the field of view with frustule hash resulting from the mechanical processing technique, a visual estimate was made using the standard AGI Data Sheets-Comparison Chart for Estimating Percentage Composition (Terry and Chilingar, 1955). For all other taxa, the whole valves and only those fragments greater than a half valve were counted. If both valves were detected making a single frustule, each valve was counted. Assignments of abundant, common, uncommon, and rare were made on the basis of the number of valves of each genus counted divided by the total number of views.

Lithologic samples were impregnated with colored epoxy to stabilize them for transit by mail to be cut into petrographic thin sections and polished sections. These were examined with transmitted and refracted light in a petrographic microscope. The polished sections containing unaltered volcanic glass or rimmed lapilli were analyzed with a scanning electron microscope and electron dispersive spectrometry to show the elemental composition of the source magma, an attempt to chemically fingerprint certain tuffaceous horizons for future stratigraphic correlation.

Although transported sanidine phenocrysts are evident in the debris-flow caprock, and rare, diminutive *in situ* sanidine and biotite phenocrysts are visible in a single tuff unit at Clare's Quarry, they are of insufficient volume and quality to be adequate for single-crystal $^{40}Ar/^{39}Ar$ dating.

Finally, x-ray diffraction was performed on pulverized shales, mudstones, and tuffs for bulk mineralogic analysis.

Preliminary Results

"Lower Shale" at Clare's Quarry

The paper shale in which the diatoms are typically found is principally a series of submillimeter-thick sheets of compressed matrix-free diatoms (microdiatomite). The sheets are separated by clays and fine volcaniclastic debris. As the unstable clays and volcanic minerals become altered, the paper shale splits along bedding planes freeing the microdiatomite into brittle sheets that easily break up into flakes. This microdiatomite is dominated by filamentous centric and/or elongate pennate taxa of generally only two or three genera. The remaining diatom taxa also occur within these microdiatomite sheets, but they tend to show up less commonly. Diatoms are also found in the mudstone units, but are more rare and include genera known for aerophilic environments.

The current investigation has resulted in the identification of a minimum of 21 diatom genera, many with multiple species, from the shales and mudstones of a stratigraphically-controlled vertically-continuous section of interbedded laminated shale, volcanic tuff, and homogeneous mudstone at the Clare's Quarry site.

The list of diatom taxa observed at Clare's Quarry includes the following genera: *Aulacoseira, Orthoseira, Actinoptychus, Fragilaria, Staurosirella, Staurosira, Diatoma, Synedra, Tetracyclus, Eunotia, Cymbella, Gomphonema, Achnanthidium, Planothidium, Psammothidium, Diadesmis, Frustulia, Pinnularia, Navicula, Stauroneis,* and *Nitzschia*. Although the relative abundance of taxa varied among sample intervals, the overall most abundant genera were *Synedra*, *Diatoma*, and *Aulacoseira. Achnanthidium, Navicula, and Gomphonema* genera were uncommon. *Staurosira* genus was very uncommon, and the remaining genera were rare. The appearance of *Actinoptychus* signifies it as a first occurrence in freshwater deposits, as it has been found in marine deposits of late Cretaceous (Campanian) age in western Siberia (Strelnikova, 1975). The following 8 genera are first-time occurrences in the fossil record: *Orthoseira*, *Synedra*, *Cymbella*, *Gomphonema*, *Achnanthes*, *Achnanthidium*, *Psammothidium*, and *Diadesmis*.

Cursory studies on the Florissant diatom floras at Clare's Quarry by Round and Williams (Harding and Chant, 2000) and by Stoermer (Meyer, 2003) that pre-date this investigation also include the following genera that were not observed in the current study: *Ellerbeckia*, *Epithemia*, and *Rhopalodia*. The current study adds 7 genera to those observed in the previous lists. From the three above-noted studies, a total of 29 genera are recorded from the Florissant Formation at the Clare's Quarry locality. The following 11 genera are first-time occurrences in the fossil record: *Ellerbeckia*, *Orthoseira*, *Synedra*, *Cymbella*, *Gomphonema*, *Achnanthes*, *Achnanthidium*, *Psammothidium*, *Diadesmis*, *Epithemia*, and *Rhopalodia*.

"Middle Shale" at MacGinite #3 and Original Scudder sites

Selected samples from the "middle shale" localities were examined for diatoms. Three slides from the MacGinitie #3 site in a previous collection at the California Academy of Sciences and six slides during this study from the "Original Scudder Site" were examined. Many of the same genera in the "lower shale" at Clare's Quarry appear in the "middle shale" samples with the addition in the "middle shale" of possible *Actinocyclus*, several more species of *Fragilaria* and *Navicula*, several more species of *Aulacoseira*, and the highly suspect *Stephanodiscus.*

"Upper Shale" at Northwest Corner site

Fossil diatoms in the "upper shale" are most similar to the taxa found in the "lower shale" at Clare's Quarry, but with the apparent absence of *Diatoma* and *Tetracyclus*.   The list of genera from samples of "upper shale" at the Northwest Corner includes the following: *Synedra*, *Aulacoseira*, *Achnanthidium*, *Achnanthes*, *Cymbella*, *Eunotia*, possible *Fragilariaforma*, *Frustulia*, *Gomphonema*, possible *Neidium*, *Pinnularia*, *Planothidium*, and *Staurosira*. Ostracods and gastropods are also present.

Overall Taxonomic and Paleoenvironment Assessment

There are as many as 11 genera in the Florissant diatom flora that are first-time occurrences in the fossil record. Multiple, newly-recognized species of previously known genera are to be recorded only for the Florissant lake deposit. Although the diatom flora in the Florissant Formation is taxonomically diverse and is quite variable in taxonomic composition, relative abundance, and quality of preservation within and among the sampled sections, overall the flora is dominated by the two genera *Synedra* and *Aulacoseira*. The second most primary genus is *Diatoma*, appearing in all sites of "lower" and "middle shales," but apparently absent in the "upper shale" site examined in this study. While these three genera are not particularly diagnostic of the lake water conditions, their modern analogs all thrive in planktonic habitats in acidic to pH-neutral lakes. With the exception of certain species of *Fragilaria*, *Gomphonema*, and *Stauroneis* that are found in modern planktonic and benthic habitats, the remaining (but very rare) taxa tend to live as benthics attached to plants, other organisms, or sediment substrate. The strictly benthics observed in this flora are variously associated with either high or low pH conditions in the modern environments, so they do not restrict the habitat. For the diatom-rich shale units, the diatom data alone would suggest that the lake was relatively deep at the timing of deposition of these horizons. As the occurrence of the benthic taxa is volumetrically extremely low, they do not limit the water depth. Such benthic forms are commonly found as transported grains into the deep basin in modern lakes. Only the genera *Orthoseira* and *Diadesmis* are the anomalous contra-indicators to a deep-water setting, as these genera in the modern setting thrive in aerophilic conditions such as in association with mosses in intermittently wet acidic habitats. These two anomalous genera are characteristically found in the mudstone units of the "lower shale" at Clare's Quarry. They may suggest either a possible episodic shallowing of the lake or abrupt influxes of sediment carrying floral elements from wetland or up-stream into a deep-lake environment.

Once all the remaining data in this study becomes available, the relationships among the diatoms, the associated biota, and the sedimentary events will be more fully understood.

Future Work

Formal descriptions with publication-quality images of diatom genera and species are in the process of being completed. This will be the core of the floristics manuscript being prepared for submittal for publication in *Bibliotheca Diatomologica*.

A biochronology of the pre-Neogene freshwater diatoms has been generated that forms the basis of a manuscript that compares the diatom taxa from the pre-Neogene freshwater localities with the taxa observed at Florissant. It visually illustrates the data that supports the claim of first-occurrences of 11 genera at Clare's Quarry. This chart was presented as a poster at the 2009 North American Diatom Symposium in Milford, Iowa. The completed manuscript will be submitted for publication in *Micropaleontology*.

X-ray diffraction has been run on the shales, mudstones, and tuff units at Clare's Quarry. Petrographic thin sections and polished sections of the lithologic facies at Clare's Quarry have been made and are scheduled to arrive for analysis in the upcoming week. These will be examined to determine the nature of entry of tuffaceous material into the lake (air-fall into the lake or water-lain after transport). The polished sections under SEM and electron dispersive spectrometry will give clues to the minerologic make-up of the source magma for the tuffaceous units. Evidence for diagenetic alteration of unstable minerals in the tuffaceous beds will be examined. A determination as to the likely impact of the resultant ions on the lake water and pore-water chemistry will be made. The diatomaceous laminations will be more visible at the thin-section scale and will be examined to determine rates of sedimentation of the normal lake deposits between the episodes of mudstone and volcanic tuff deposition. A manuscript describing the cyclical depositional history of the lake that impacted the living conditions and the diagenetic processes that influenced the preservation of diatoms and other fossils will be forth-coming. This will be submitted for publication in the *Journal of Sedimentary Geology*.

The diatoms are sometimes, but not always found in association with leaf, insect, ostracod, mollusk, and fish fossils at Florissant. These associated fossils can suggest aspects of lake conditions and may be used in conjunction with the diatoms to interpret paleolimnology and lake basin history. The temporal and spatial relationships of the fossil diatoms with the associated lithology and fossil fauna and flora are being examined at the Clare's Quarry site with the goal of a comprehensive overview of the paleoecologic conditions and their variability within the lake ecosystem. Implications for the relative timing of Florissant within the period of global climate transition will be proposed. These findings will be presented in a manuscript to be submitted for publication in *Palaeogeography, Palaeoclimatology, and Palaeoecology.*

Reprints of these manuscripts will be submitted to the park upon publication.

Literature Cited

Harding, I.C., and L.S. Chant. 2000. Self-sedimented diatom mats as agents of exceptional fossil preservation in the Oligocene Florissant lake beds, Colorado, United States. Geology 28 (3): 195-198.

Meyer, H.W., 2003, The Fossils of Florissant, Smithsonian Institution, 258 pp.

Terry, R.D., and Chilingar, G.V., 1955, AGI Data Sheets-comparison chart for estimating percentage composition. Journal of Sedimentary Petrography 25 (3): 229-234.

Figures

Figure 1. Draft of ME Benson's stratigraphic section of the Original Scudder Site.

Figure 2. Images of centric diatoms commonly found in at the Original Scudder Site. These taxa are poorly represented at the Clare's Quarry. Photo Credit: University of Colorado Nanomaterials Characterization Facility.

Stratigraphic Log

Page # / # Pages: 1/ 6

Section Name/#: Original Scudder Site Field Measurer/Describer(s): ME Benson/M Gorman Lithologic Log by: Mary Ellen Benson Date(s): 07 /15 /06 and 07/11/06, 07/16/06.
Formation: Florissant Member/Unit: Middle Shale Age: Late Eocene
Topo. Quad. Lake George Sec/Twn/Rng swnwsw Sec.13, T13N, R71W
Landowner: Nat'l Park Service County: Teller State: CO
(Top of Section) UTM Long./Lat. 0475010W, 4307638N (Top of Section)Elevation (ft.) 8400
(Base of Section) UTM Long./Lat. 0475013W, 4307922N (Base of Section)Elevation (ft.) 8350
(Top)Orientation of Bedding: Strike 221 AZ°; Dip 4° to 311 AZ° →N49°W (Base)Orientation of Bedding: Strike AZ°; Dip increasing?to NW °
Thickness of Interval Described in this Section (meters): ~~8.25~~ 12.975 General Comments: Trench on N slope of BigStumpHill to bench at base; fractured; dip appears to change down section - Thk of Lake depos. = 11.975

Depth (centimeters)	Unit Thickness	Unit #	Graphic Lithology	Paleo Sample Type (Leaf, Insect)	Color (Fresh)	Rock Type	Bedding Thickness	Structures	Mud	Silt	Fine Sand	Medium Sand	Coarse Sand	V. Coarse Sand	Fine Gravel	Medium Gravel	Coarse Gravel	> Coarse Gravel	Calcareous	Gypsum	Pumiceous	Leaves/Stems	Insects	Spiders	Ostracods	Mollusks	Fish	Org. Debris	Other	Comments
0 – 50 – 100	>100	1				Caprock Conglomerate	Massive	horizontal flow texture w/ up-turned areas; blocks of lam shale as inclusions																						fine groundmass w/gravel of pink feldspar, qtz, chert? etc. and occas. very thin lenses of discontinuous lam. shale along subhorizontal direction. weathering to creme buff. w/abundant vertical irreg tube-like lineations on weathered surfaces. dominant joint patterns observed along surface -blocks of lam. shale as inclusions.
103	3	2				Laminated Shale	Thin																							
115	12	3				Tuff																								
126	11	4				Laminated Shale	Thin																							
133	7½	5			orange brn	Soft, altered paper shale?																								feO stained, gummy clay.
151	18	6			lgt gry-brn	Mudstone	Massive																							conchoidal fracture - (ash fall?)
180	29	7			lgt gry-brn	Mudstone	Massive																					S		Conchoidal fracture slightly coarser grn w/coffee grounds (ash fall?)
181	1	8			orange brn	Soft, altered paper Sh?																								feO stained, gummy clay
187	6	9			gry-brn	Lam. Tuffaceous Shale	Thin																					C		coffee grounds
197½	10½	10				Tuffaceous Mudstone coarse																✓									poorly sorted w/coarse pumice
		11				Lam. Tuffac. Shale																								

Continued...Stratigraphic Log

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Section Name/#: Original Scudder Site Field Measurer/Describer(s): ME Benson/M Gorman Lithologic Log by: Mary Ellen Benson Date(s): 07 /15 /06

Depth (centimeters)	Unit Thickness	Unit #	Graphic Lithology	Paleo Sample Type (Leaf, Insect)	Color (Fresh)	Rock Type	Bedding Thickness	Structures	Grain Size (Mud / Silt / Fine Sand / Medium Sand / Coarse Sand / V. Coarse Sand / Fine Gravel / Medium Gravel / Coarse Gravel / > Coarse Gravel; Cm 2-4/ 4-10/ 10-30/ >30)	Calcareous	Gypsum	Pumiceous	Leaves/Stems	Insects	Spiders	Ostracods	Mollusks	Fish	Org. Debris	Other	Comments
200	24	11				Laminated Tuffaceous Shale	Thin						stems S	R							
221	1½	12				Tuff	Thin														Slightly coarser tuff than above
223	17	13				Laminated Shale w/paper thin layers	Thin												C		w/occas. interbeds of paper shale lam. w/ FeO stain and "Coffee grounds"
240	26	14				Laminated Shale w/cone-in-cone calcite /b/ layers	Thin			poss ✓			R								very fine layers of vertically fibrous x/s grown /b/ shale laminae becoming thickest about middle of unit where it forms a 2 cm thick discrete bed. Fizz reaction to HCl.
266	4	15				Coarse Tuff						✓									w/ pumice grns.
270	12	16				Laminated Shale w/paper thin layers	Thin														w/altered paper shale lams. w/ FeO clay
282 (300)	63	17			lgt grey	Mudstone	Massive														Conchoidal fracture (ash fall?)
345	31	18				Interbedded Tuff, Laminated shale, & paper shale															Some altered FeO stained paper shales?
376	24	19				Coarse Tuff															-altered FeO tuff? layer in middle
400	38	20				Laminated Shale w/minor tuff interbeds	Thin						C								interbedded w/ at least 5 major thin tuffs. leaves: Juniper, rosaceae, Cedrelospermum, Pinus, Bursera, ? unidentified fruit.
438	7	21				Laminated Shale w/ tuff lam.															
445		22				Tuff															

Continued…Stratigraphic Log

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Section Name/#: Original Scudder Site   Field Measurer/Describer(s): ME Benson/M Gorman   Lithologic Log by: Mary Ellen Benson   Date(s): 07 /15 /06

Depth (centimeters)	Unit Thickness	Unit #	Graphic Lithology	Paleo Sample Type (Leaf, Insect)	Color (Fresh)	Rock Type	Bedding Thickness	Structures	Mud	Silt	Fine Sand	Medium Sand	Coarse Sand	V. Coarse Sand	Fine Gravel	Medium Gravel	Coarse Gravel	> Coarse Gravel	Calcareous	Gypsum	Pumiceous	Leaves/Stems	Insects	Spiders	Ostracods	Mollusks	Fish	Org. Debris	Other	Comments
450	23	22				Tuff																								
468	10	23				Laminated Shale w/ Tuffaceous Lams.	Thin															5								leaf: Fagopsis?
478	9	24				Tuff																								
487	6	25				Tuff w/ Lam. Shale	Thin																							
493	93	26				Lam. Shale w/ interbedded Tuff	Thin																					C		FeO stain, mica grains, leaf debris - "coffee grounds"
586	24	27				Coarse Tuff																								
610	56	28			brn gry	sucrosic? Shale	Mass.																					C		irreg. fracture, highly fractured (in zone of tree roots) w/ "coffee grounds"
666	1	29				coarse Tuff																								
667		30			brn-gry	Mudstone	Mass																					C		Subconchoidal fracture highly fractured (in zone of tree roots) w/ "coffee grounds"
700																														

Grain Size — Cm 2-4/ 4-10/ 10-30/ >30

Fossil Types R = rare, S = several, C = common

Continued…Stratigraphic Log

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Section Name/#: Original Scudder Site Field Measurer/Describer(s): ME Benson/M Gorman Lithologic Log by: Mary Ellen Benson Date(s): 07 /15 /06

Depth (centimeters)	Unit Thickness	Unit #	Graphic Lithology	Paleo Sample Type (Leaf, Insect)	Color (Fresh)	Rock Type	Bedding Thickness	Structures	Mud	Silt	Fine Sand	Medium Sand	Coarse Sand	V. Coarse Sand	Fine Gravel	Medium Gravel	Coarse Gravel	> Coarse Gravel	Calcareous	Gypsum	Pumiceous	Leaves/Stems	Insects	Spiders	Ostracods	Mollusks	Fish	Org. Debris	Other	Comments
700		30			brn-gry	Mudstone	Mass																							subconchoidal frax - highly fractured @ tree roots "coffee grounds"
	143																													
800																												C		
810	?	?																												
		31			brn-gry	Mudstone	Mass																							
900																														
950																														

Grain Size: Cm 2-4/ 4-10/ 10-30/ >30

Fossil Types: R = rare, S = several, C = common

Continued…Stratigraphic Log

Page # / # Pages: 5/6

Section Name/#: Original Scudder Site Field Measurer/Describer(s): ME Benson/M Gorman Lithologic Log by: Mary Ellen Benson Date(s): 07 /15 /06

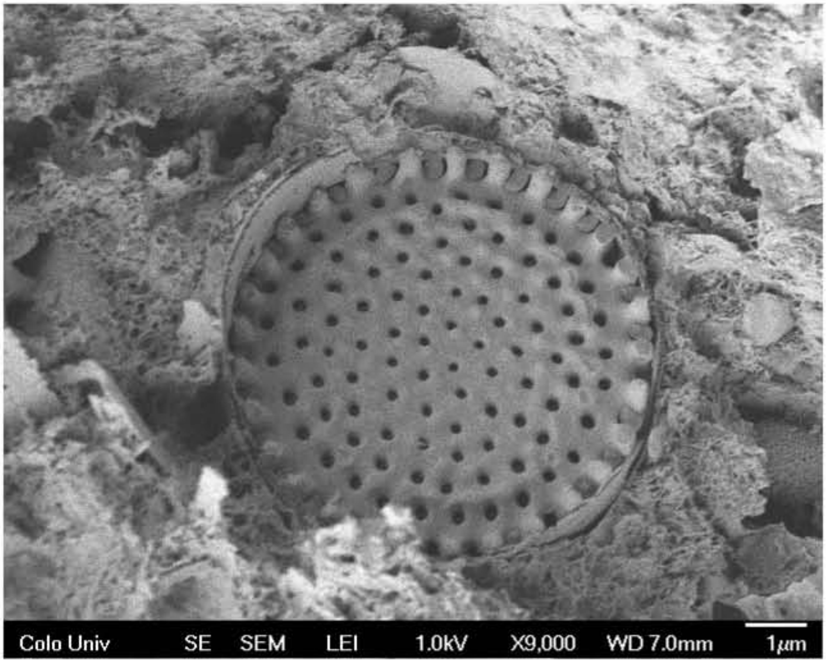
Depth (centimeters)	Unit Thickness	Unit #	Graphic Lithology	Paleo Sample Type (Leaf, Insect)	Color (Fresh)	Rock Type	Bedding Thickness	Structures	Grain Size: Mud	Silt	Fine Sand	Medium Sand	Coarse Sand	V. Coarse Sand	Cm 2-4/ 4-10/ 10-30/ >30: Fine Gravel	Medium Gravel	Coarse Gravel	> Coarse Gravel	Calcareous	Gypsum	Pumiceous	Fossil Types R = rare, S = several, C = common: Leaves/Stems	Insects	Spiders	Ostracods	Mollusks	Fish	Org. Debris	Other	Comments
950					brn gry	Mudstone	Mass																							subconchoidal frac. w/ "coffee grounds"
1000	286	31																										C		
																														occas. fine tuff intermixed at base
1096						Lam. shale w/interbedded Tuff.																						C		—org. debris at top
	89	32																												
1185																														
		33			white	Silty Tuff																								bench-forming
1200																														

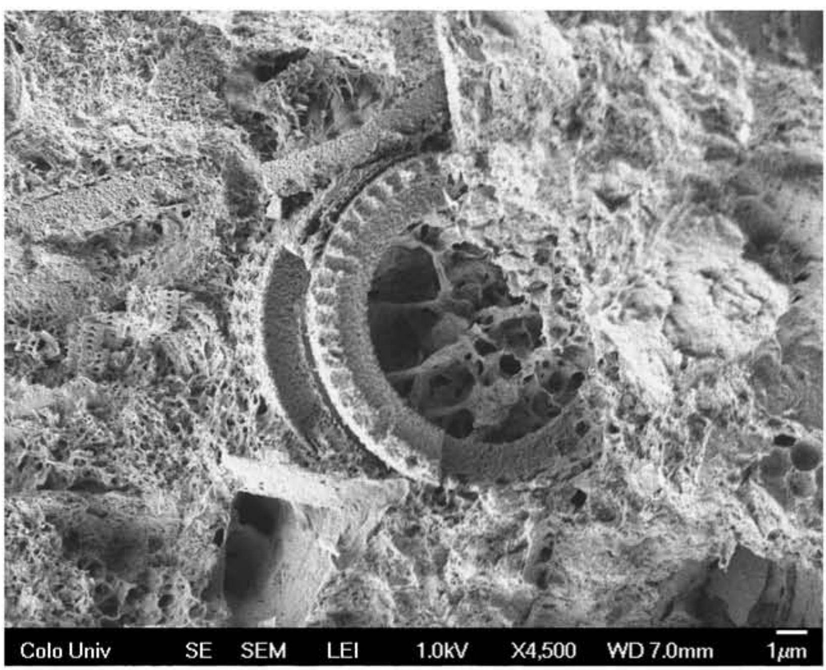
Continued…Stratigraphic Log

Section Name/#: Original Scudder Site Field Measurer/Describer(s): ME Benson/M Gorman Lithologic Log by: Mary Ellen Benson

Page # / # Pages: 6/6
Date(s): 07 /15 /06

Depth (centimeters)	Unit Thickness	Unit #	Graphic Lithology	Paleo Sample Type (Leaf, Insect)	Color (Fresh)	Rock Type	Bedding Thickness	Structures	Grain Size: Mud	Silt	Fine Sand	Medium Sand	Coarse Sand	V. Coarse Sand	Fine Gravel (Cm 2-4/)	Medium Gravel (4-10/)	Coarse Gravel (10-30/)	> Coarse Gravel (>30)	Calcareous	Gypsum	Pumiceous	Fossil Types (R = rare, S = several, C = common): Leaves/Stems	Insects	Spiders	Ostracods	Mollusks	Fish	Org. Debris	Other	Comments
1200	43	33			white	Silty Tuff																								bench former
1228	68	34				Mudstone	Mass																							highly fractured, covered, conchoidal chips from soil
1296		35			white	Tuff coarse																								med. grn-sandy w/ grains of feldspar, qtz, pumice forms discrete bench near trees along base of slope
temporary end of section						continued in outcrop																								


Colo Univ
SE
SEM
LEI
1.0kV
X9,000
WD 7.0mm
1μm


Colo Univ
SE
SEM
LEI
1.0kV
X4,500
WD 7.0mm
1μm