the degree of nutrient enrichment in the Great Lakes [R. A. Vollenweider, *Technical Report DAS/CSI/68.27* (Organisation for Economic Cooperation and Development, Paris, 1968)]. Before fertilization, the concentration of dissolved inorganic carbon in the epilimnion of lake 227 was about 50 μmole/liter in midsummer. This is only about 2 to 3 percent of that found in the lower Great Lakes.
6. Most experts consider a lake to be eutrophic when algal blooms with more than 30 μg of chlorophyll a per liter become common. Unfertilized lakes in the Experimental Lakes Area support a midsummer chlorophyll a concentration of only 1 to 5 μg/liter. In lake 227, after fertilization, blooms with more than 100 μg/liter have been common, and up to 300 μg/liter has been observed for short periods (7).
7. D. W. Schindler, F. A. J. Armstrong, S. K. Holmgren, G. J. Brunskill, *J. Fish. Res. Board Can.* **28**, 1763 (1971); D. W. Schindler, H. Kling, R. V. Schmidt, J. Prokopowich, V. E. Frost, R. A. Reid, M. Capel, *ibid.* **30**, 1415 (1973).
8. Because of the rapid turnover of phosphorus in many freshwater lakes [F. H. Rigler, *Limnol. Oceanogr.* **9**, 511 (1964)] and uncertain methods of measurment [F. H. Rigler, *Verh. Int. Ver. Limnol.* **16**, 465 (1966)] phosphate concentration appears to be unreliable as a widespread indicator of whether a lake will develop algal blooms (7).
9. D. W. Schindler, G. J. Brunskill, S. Emerson, W. S. Broecker, T.-H. Peng, *Science* **177**, 1192 (1972); S. Emerson, W. S. Broecker, D. W. Schindler, *J. Fish. Res. Board Can.* **30**, 1475 (1973); W. S. Broecker, unpublished results.
10. D. W. Schindler (unpublished data) has found that if phosphorus is not supplied, no algal increases occur. If sufficient phosphorus is supplied, algal increases do occur, the magnitude being determined by available nitrogen, which in some cases may be fixed from the atmosphere. When both phosphorus and nitrogen are supplied in excess, algae increase until light becomes limiting.
11. Additions equivalent to 3.16 g of NO_3-N and 6.05 g of sucrose C per square meter per year were made to both basins, in 20 equal weekly increments. The northeast basin also received 0.59 g m^{-2} $year^{-1}$ of PO_4-P. The N/P and C/P ratios are greater than in sewage, while the quantity of P added is not exceptionally high for a culturally affected lake.
12. Sedimentary phosphate has been thought to dissolve under anoxic conditions by reducing ferric iron and forming $Fe(OH)_3$-PO_4 complexes. C. H. Mortimer [*J. Ecol.* **29**, 280 (1941); *ibid.* **30**, 147 (1942)] and G. E. Hutchinson [*A Treatise on Limnology* (Wiley, New York. 1957), vol. 1, chap. 12] explain this cycle.
13. Our preliminary results suggest that dissolution of iron-phosphate complexes followed by release of phosphate to the water column is prevented by the high demand of sediment bacteria for phosphate, and formation of humic acid–phosphate complexes.
14. Rapid recoveries were observed in Lake Washington in the state of Washington [W. T. Edmondson, *Science* **169**, 690 (1970)]; Zellersee, Germany [R. Liepolt, *Verhandlungen Symposion über Gewassereutrophierung* (Salzburg, 1967)]; Pedersborg Sø and Lyngby Sø, Denmark [H. Mathiesen, *Mitt. Int. Verein. Limnol.* **19**, 161 (1971)]; and Little Otter Lake and Gravenhurst Bay, Ontario, Canada [M. F. P. Michalski, Ontario Ministry of Environment, personal communication; M. F. P. Michalski and N. Conroy, *Proceedings 16th Conference on Great Lakes Research* (1973), p. 934].
15. Additions equivalent to 0.40 g of PO_4-P, 5.2 g of NH_3-N, and 5.5 g of sucrose C per square meter of lake surface per year were made in 20 weekly increments.
16. D. W. Schindler, unpublished results.
17. This would hold true only for lakes that are phosphorus-limited. Some waterways appear to have been so overwhelmed with phosphorus that it no longer limits phytoplankton production, and inputs of the element must be reduced enough for it to limit phytoplankton growth before abatement would be proportional to phosphorus removal [I. Ahlgren, *Verh. Int. Ver. Limnol.* **18**, 355 (1972)].
18. Report to the International Joint Commission from the International Great Lakes Water Quality Board, March 1973.

21 December 1973

Opaline Sediments of the Southeastern Coastal Plain and Horizon A: Biogenic Origin

Abstract. *Scanning electron microscope techniques show that Eocene opaline claystones (fuller's earth and buhrstone) of the Atlantic and Gulf Coastal Plain, deposits long considered volcanic in origin, are actually highly altered diatomites formed as transgressive facies in normal marine continental shelf environments. These findings are in agreement with a biogenic origin for time-equivalent horizon A and A″ deep-sea cherts of the North Atlantic and Caribbean.*

Opaline (cristobalite-rich) Eocene claystone deposits of the Atlantic and Gulf Coastal Plain have recently been cited in *Science* (*1*) and elsewhere (*2*) as examples of altered rhyolitic ashes which accumulated in nearshore or brackish coastal environments. Such ashes are also thought to have been distributed by atmospheric and water currents into the North Atlantic Ocean basin where they were presumably responsible for the formation of the cristobalite-rich, horizon A Eocene cherts (*1, 3*). We present evidence here to show that opaline claystones of the coastal plain are altered diatomites, not ashes, and that they formed in normal marine rather than in restricted coastal environments. Our evidence is compatible with a biogenic rather than a volcanic origin for the horizon A cherts and their Caribbean equivalents (horizon A″).

Opaline claystones are unusually porous, lightweight siliceous rocks which possess oil clarification properties (*4*). Accordingly, they have been referred to locally as fuller's earth (*5*) or buhrstone (*6*). Scanning electron microscopy of fracture surfaces of opaline claystones from 14 Southeastern Coastal Plain localities (Mississippi to South Carolina; see Table 1) reveals siliceous microfossils which occur as molds in 90 percent of the samples examined. The fossils are most abundant in samples which contain 60 to 90 percent SiO_2. The opaline material is unidimensionally disordered alpha-cristobalite (*7*) in the form of bladed microspherulites (*8*). Most of the microfossil molds are of marine diatoms including large and small centrics (Fig. 1A), pennates and forms which resemble *Triceratium* (Fig. 1B), and *Actinoptychus* (Fig. 1C). Sponge spicule (Fig. 1D) and radiolarian molds (*9*) are interspersed in the South Carolina and Alabama material. Clearly, the opaline claystones represent highly altered diatomite deposits rather than ash beds. Most microfossils in the deposits, however, have been completely destroyed by dissolution.

Siliceous microfossils have not been reported previously in South Carolina

Table 1. Opaline claystone samples which contain siliceous microfossil molds. The Black Mingo and McBean units were collected by S. D. Heron. All other samples were collected by the authors.

Formation	Samples and localities	Age
Nanafalia (Grampian Hills member)	GH-1 (Wilcox County, Ala.)	Late Paleocene
Black Mingo (opaline facies)	9-6-1 (Sandy Run Creek, S.C.); 9-9-1 (Big Beaver Creek, S.C.); 6-10-4, 9-11-4 (Little Beaver Creek, S.C.); 9-18-1, 9-18-2 (Bates Mill Creek, S.C.); 9-67-1, 9-67-2, 9-67-3 (Thelma Hill property, Calhoun County, S.C.); 9-68-2 (Dicks Swamp, S.C.); A-183-1 (Williamsburg Bridge, S.C.); 43-6-1, (Tavern Creek, S.C.); 43-7-5 (Holy Cross Church, Sumter County, S.C.)	Early-Middle Eocene
McBean	A-3-1, A-3-2 (Early Branch, S.C.)	Middle Eocene
Tallahatta	T-3 [Choctaw County, Ala.; locality 135 of Toulmin and LaMoreaux (*17*)]; I-10-12, I-10-13, 33-1 (U.S. Highway I-10, Meridian, Miss.)	
Barnwell (Twiggs Clay member)	KL-1 (Georgia-Tennessee Clay Corporation pit, Wrens, Ga.)	Late Eocene

and Georgia fuller's earth deposits to our knowledge, although they are mentioned in an 1894 report on the Tallahatta buhrstones of Alabama (*6*). The significance of that early observation of siliceous microfossils, however, was overlooked during later mineralogical studies (*10*), particularly x-ray studies (*2*) which established the presence of zeolite (clinoptilolite), montmorillonite, and alpha-cristobalite in the Tallahatta formation. Mineralogists concluded (*1, 2, 4*) that the clinoptilolite, cristobalite, and at least a portion of the montmorillonite in Eocene coastal plain sediments represent a suite of alteration products from devitrified volcanic glass. Most of the montmorillonite, however, may be detrital [(*4*); see also (*11*)], and zeolites are generally rare or absent in the cristobalite-rich beds of the Tallahatta formation (*2*) and of the Black Mingo formation of South Carolina (*4*). Instead, zeolites are concentrated in the soft clay units of the Alabama material (*2*), and no zeolites are present in the Twiggs Clay (Barnwell formation) of Georgia (*12*).

Early diagenesis of the Eocene diatomites of the coastal plain probably followed a pattern recently postulated for deep-sea siliceous ooze diagenesis, that is, in situ dissolution of biogenous opal with silica reprecipitated inorganically as authigenic disordered alpha-cristobalite (*8, 13*). In places where the opal contents of deep-sea oozes are extremely high, molds of microfossils may not be preserved. Significantly, once diagenesis begins, practically all available biogenous opal in the affected material may be converted to cristobalite with little trace remaining of the original substance (*14*). Radiolarians and certain diatom taxa (for example, *Actinoptychus*) which occur in our coastal plain material do not tolerate fresh or brackish water; therefore, these deposits must have formed in open marine, nonrestricted shelf environments. Abundant pteropods in the buhrstones of the Tallahatta formation (*15*) and the lithostratigraphies of the opaline claystone formations in question also suggest normal marine environments. At all outcrop localities studied, opaline claystones overlie quartz sands or montmorillonite-rich clays, or both, which can be interpreted as beach, tidal flat, or offshore bar facies of transgressive sequences [for example, see (*16*)]. The opaline sediments represent near- to offshore, normal marine facies of these transgres-

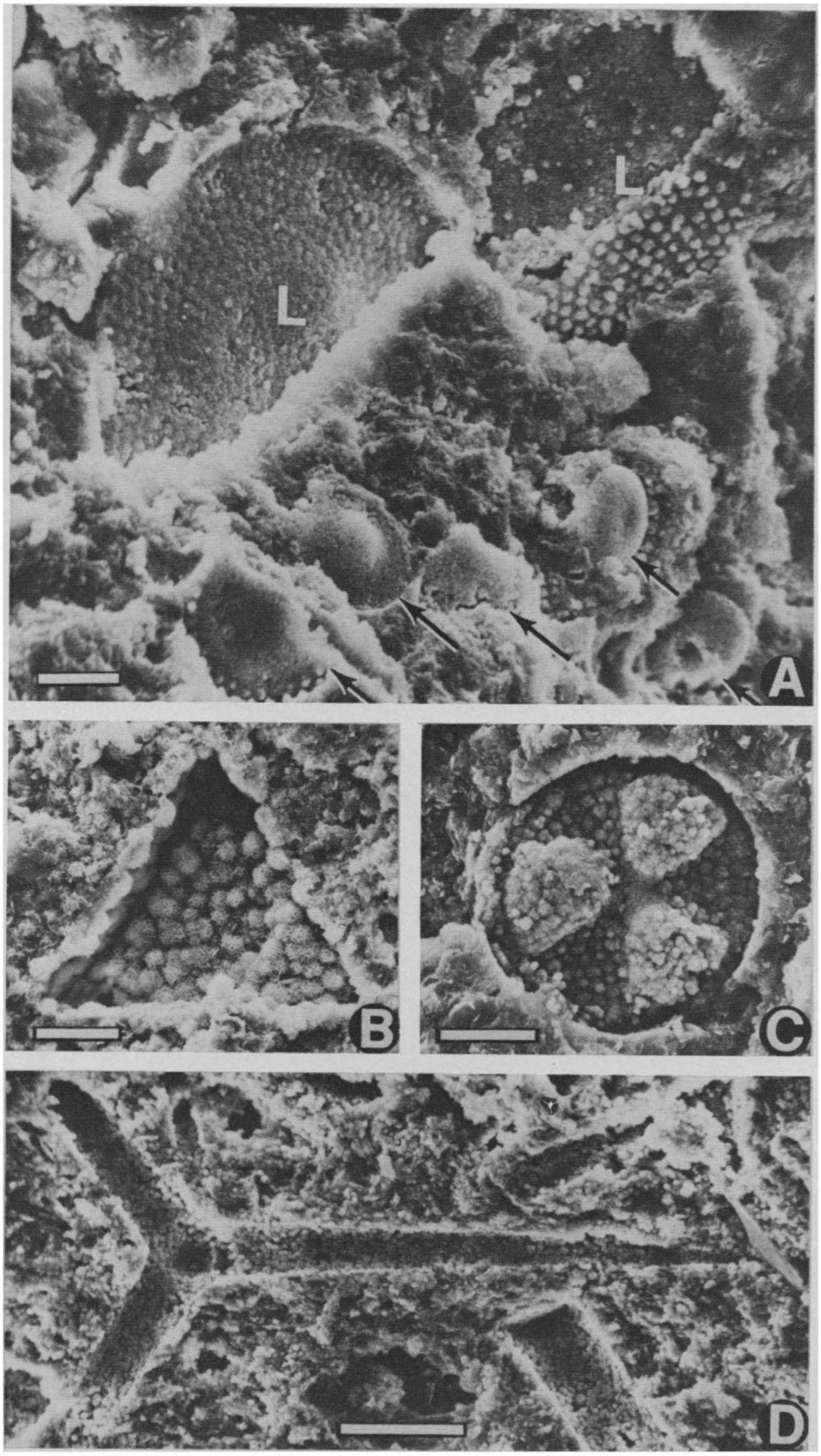

Fig. 1. Microfossil molds in Eocene opaline claystones of the Southeastern Coastal Plain. (A) Centric diatoms (arrows indicate small centrics; *L*, large centrics); sample KL-1, Twiggs Clay member (scale, 20 μm). (B) *Triceratium* sp. (diatom). Note bladed microspherulites of cristobalite which line mold interior; sample 43-7-5, Black Mingo formation (scale, 5 μm). (C) *Actinoptychus* sp. (diatom); sample KL-1, Twiggs Clay member (scale, 5 μm). (D) Sponge spicule; sample 9-67-3, Black Mingo formation (scale, 50 μm).

sive sequences. In Alabama (*17*) and Georgia (*12, 18*), opaline claystones are overlain by regressive sand units which complete the record of what may be considered classic transgressive-regressive depositional cycles.

Our evidence makes it necessary to revise presently accepted paleoenvironmental interpretations and models of Eocene coastal lithofacies. For instance, Reynolds' (*2*) proposal of restricted back-bay coastal lagoons as sites of cristobalite deposition is incompatible with the open marine environment we demonstrate. His model of direct chemical precipitation of cristobalite from circulating bottom waters, therefore, is invalid and unnecessary in view of the fact that the immediate silica source was diatomite rather than volcanic ash. Similarly, the Twiggs Clay of Georgia should be considered not a regressive unit composed of detrital clastics (*18*) of a deltaic complex (*19*) but rather a diatomaceous member of a transgressive sequence which also includes the time-equivalent outer shelf marls and limestones illustrated by Carver (*12*) in his figure 3. We believe such reinterpretations will aid (i) location of additional deposits of economically important fuller's earth in the coastal plain and (ii) more faithful reconstruction of Eocene paleoenvironments of deposition in the western Atlantic-Caribbean area.

With respect to the source of the diatomite deposits, profuse blooms of siliceous plankton along the continental shelves at various times during the Eocene could have been stimulated by nutrients supplied by favorable ocean current systems. Ramsay (*20*) presents a paleocurrent model which explains high Eocene siliceous plankton productivity not only in the Gulf of Mexico and Caribbean but also in the North Atlantic where the horizon A cherts formed. Our data, which include a failure to detect textural or structural features that would suggest ash deposition, are compatible with Ramsay's model. Some zeolites do occur in Eocene coastal plain deposits, and these may owe their origin to the deposition of various types of volcanic ash; nevertheless, these ashes were certainly not as volumetrically important as mineralogists (*1, 2, 10*) have suggested. Any ash deposition was apparently incidental to rather than causative of a general pattern of biogenic silica deposition (*21*), as indicated by the fact that the times of formation of the Paleocene Grampian Hills member of the Nanafalia formation and of the Upper Eocene Twiggs Clay (15 m thick) are not coincident with the schedule of rhyolitic volcanic activity in the Caribbean defined by Gibson and Towe (*1*) and Mattson and Pessagno (*3*). We conclude, therefore, that the opaline claystones of the coastal plain, which are all essentially identical in hand specimen, mineral content, and microstructure, owe their unusual character to a biogenic mode of deposition.

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21. Gibson and Towe's interesting suggestion (*1*) that rhyolitic volcanic activity could possibly stimulate high productivity of siliceous plankton in deep-sea areas has yet to be substantiated by independent evidence. Nevertheless, any such activity on a regional scale in the Caribbean, even if it did somehow serve as a stimulus, would be entirely inadequate to account for the extensive Eocene chert deposits which have now been encountered by the Deep Sea Drilling Project in the Pacific, Indian, and Southern ocean basins as well as in the Atlantic and Caribbean.
22. We thank S. D. Heron (Duke University) for numerous opaline claystone samples, L. D. Toulmin (Florida State University) for helpful discussion and guidance in the field, D. S. Cassidy (Florida State University) for photographic enlargements, and W. I. Miller and P. F. Ciesielski (Florida State University) for participation in the electron microscope studies. Support for this research was provided by a Sigma Xi research grant to F.M.W., a Florida State University faculty research grant to S.W.W., and a grant from the Donors of the Petroleum Research Fund administered by the American Chemical Society.

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Jovian Atmosphere: Structure and Composition between the Turbopause and the Mesopause

Abstract. *The occultation of the star Beta Scorpii by Jupiter was observed at high time resolution in three wavelength channels. The results imply a temperature of 220°K at an altitude in the Jovian atmosphere corresponding to 10^{14} molecules per cubic centimeter, and temperature fluctuations of 2° to 10°K over vertical scales of 2 to 10 kilometers. They suggest that the vertical eddy diffusion coefficient near the turbopause has a lower limit of 7×10^5 square centimeters per second, and that the turbopause lies above the altitude where the density is 5×10^{13} molecules per cubic centimeter. Below the turbopause, the ratio of hydrogen to helium is consistent with cosmic abundances.*

On 13 May 1971, the planet Jupiter occulted the multiple star system Beta Scorpii. The visual magnitude of Beta Scorpii A is 2.76, and an occultation of so brilliant a star by Jupiter is estimated to occur once every 10^3 years (*1*). We observed the occultation event with the 152-cm Rockefeller reflector of Boyden Observatory (Bloemfontein, South Africa), with a three-channel photometer having the following central wavelengths: channel 1, 3530 Å; channel 2, 3934 Å; channel 3, 6201 Å. The time resolution of the observations was 0.01 second. A detailed description of the instrumentation has been published elsewhere (*2*). While the occultation event was widely observed