A Stratigraphic Test Well, Martha's Vineyard, Massachusetts

GEOLOGICAL SURVEY BULLETIN 1488

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By RAYMOND E. HALL, LAWRENCE J. POPPE, *and* WAYNE M. FERREBEE

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Description of Pleistocene to Upper Cretaceous sediments recovered from 262 meters of test coring

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CONVERSION FACTORS

Metric unit		Inch-Pound equivalent
Length		
millimeter (mm)	= 0.03937	inch (in)
meter (m)	= 3.28	feet (ft)
kilometer (km)	= .62	mile (mi)
Area		
square meter (m^2)	= 10.76	square feet (ft^2)
square kilometer (km^2)	= .386	square mile (mi^2)
hectare (ha)	= 2.47	acres
Volume		
cubic centimeter (cm^3)	= 0.061	cubic inch (in^3)
liter (L)	= 61.03	cubic inches
cubic meter (m^3)	= 35.31	cubic feet (ft^3)
cubic meter	= .00081	acre-foot (acre-ft)
cubic hectometer (hm^3)	= 810.7	acre-feet
liter	= 2.113	pints (pt)
liter	= 1.06	quarts (qt)
liter	= .26	gallon (gal)
cubic meter	= .00026	million gallons (Mgal or 10^6 gal)
cubic meter	= 6.290	barrels (bbl) (1 bbl = 42 gal)
Weight		
gram (g)	= 0.035	ounce, avoirdupois (oz avdp)
gram	= .0022	pound, avoirdupois (lb avdp)
metric tons (t)	= 1.102	tons, short (2,000 lb)
metric tons	= 0.9842	ton, long (2,240 lb)
Specific combinations		
kilogram per square centimeter (kg/cm^2)	= 0.96	atmosphere (atm)
kilogram per square centimeter	= .98	bar (0.9869 atm)
cubic meter per second (m^3/s)	= 35.3	cubic feet per second (ft^3/s)

Metric unit		Inch-Pound equivalent
Specific combinations—Continued		
liter per second (L/s)	= .0353	cubic foot per second
cubic meter per second per square kilometer [$(m^3/s)/km^2$]	= 91.47	cubic feet per second per square mile [$(ft^3/s)/mi^2$]
meter per day (m/d)	= 3.28	feet per day (hydraulic conductivity) (ft/d)
meter per kilometer (m/km)	= 5.28	feet per mile (ft/mi)
kilometer per hour (km/h)	= .9113	foot per second (ft/s)
meter per second (m/s)	= 3.28	feet per second
meter squared per day (m^2/d)	= 10.764	feet squared per day (ft^2/d) (transmissivity)
cubic meter per second (m^3/s)	= 22.826	million gallons per day (Mgal/d)
cubic meter per minute (m^3/min)	= 264.2	gallons per minute (gal/min)
liter per second (L/s)	= 15.85	gallons per minute
liter per second per meter [(L/s)/m]	= 4.83	gallons per minute per foot [(gal/min)/ft]
kilometer per hour (km/h)	= .62	mile per hour (mi/h)
meter per second (m/s)	= 2.237	miles per hour
gram per cubic centimeter (g/cm^3)	= 62.43	pounds per cubic foot (lb/ft^3)
gram per square centimeter (g/cm^2)	= 2.048	pounds per square foot (lb/ft^2)
gram per square centimeter	= .0142	pound per square inch (lb/in^2)
Temperature		
degree Celsius (°C)	= 1.8	degrees Fahrenheit (°F)
degrees Celsius (temperature)	= [(1.8 × °C) + 32]	degrees Fahrenheit

A STRATIGRAPHIC TEST WELL, MARTHA'S VINEYARD, MASSACHUSETTS

By RAYMOND E. HALL, LAWRENCE J. POPPE, and WAYNE M. FERREBEE

ABSTRACT

A 262-m stratigraphic test well, ENW–50, was drilled for the U.S. Geological Survey on Martha's Vineyard, Mass., in the fall of 1976. Split-spoon samples were obtained every 3 m. The well penetrates sedimentary strata of Quaternary, Tertiary, and Cretaceous age, and it bottoms in Cenomanian strata. Kaolinite and mica/illite are the dominant clay minerals in the Cretaceous section; the Tertiary section contains an assemblage of mica/illite, mixed-layered illite-smectite, kaolinite, and chlorite. Nine lithostratigraphic and two biostratigraphic units correlate between well ENW–50 and USGS well 6001 drilled in 1975–76 by the U.S. Geological Survey on Nantucket Island.

INTRODUCTION

In the fall of 1976, the U.S. Geological Survey (USGS) drilled a 262-m well, ENW–50, on Martha's Vineyard, Mass., in order to identify production aquifers, to study the quality of ground water, and to collect sediment samples. The drillers attempted to take a core of 0.6 m maximum length every 3 m by means of a split-spoon coring device (length, 0.6 m; inside diameter, 36 mm). Core recovery was poor in the upper 55 m, but below 55 m, recovery was approximately 70 percent successful. In addition, we collected rotary cuttings from the 3-m drilled materials where possible. The ground-water studies are presently being made by D. F. Delaney and F. A. Kohout. On the basis of lithostratigraphy, paleontology, and mineralogy, we have correlated ENW–50 with two other stratigraphic wells (Nantucket USGS well 6001 and Fire-Island well).

SETTING

Martha's Vineyard, 5 km south of Woods Hole, Mass., is 32 km long and 14.5 km wide (area 250 km^2; fig. 1). Well ENW–50 is at lat 41°24′ N., long 70°35′ W., 2 km east of Martha's Vineyard Airport, in the Martha's Vineyard State Forest. The well head rests in a channel cut into the glacial-outwash plain, at an altitude of approximately 10 m above mean sea level. Tertiary and Cretaceous clay and sand are exposed nearby at Gay Head Cliffs (fig. 1); however, these exposed strata are complexly folded and faulted, and stratigraphic interpretation is difficult.

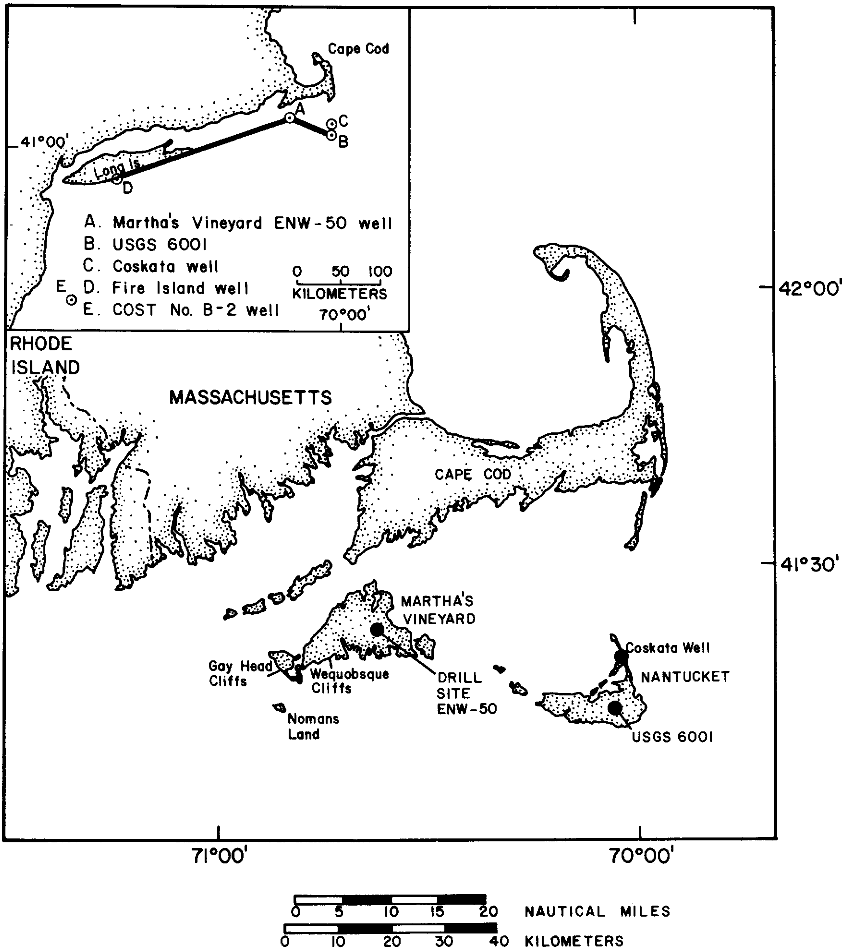

FIGURE 1.—Martha's Vineyard, Mass., and vicinity. Inset shows location of wells discussed in text.

PREVIOUS STUDIES

John Finch (1823) made the first sedimentological studies of Martha's Vineyard. Finch and later authors (Lyell, 1843; Desor and Cabot, 1849; Shaler, 1888) concluded that the strata exposed below the glacial drift at Gay Head Cliffs were part of the Tertiary System. Subsequent studies (White, 1890; Shaler, 1890; Woodworth, 1897; and Hollick, 1906) recognized Cretaceous rocks also at Gay Head Cliffs. The areal distribution of Tertiary sediments in the cliffs was mapped at about the same time (Dall, 1894). Bibbins (1910) and Berry (1915) dated the Cretaceous of Martha's Vineyard and assigned the leaf-bearing deposits to the Magothy Formation. The Pleistocene glacial deposits of Martha's Vineyard have been studied more extensively (Hitchcock, 1824; Hollick, 1894; Woodworth, 1898; Upham, 1899; Wilson, 1906;

Woodworth and Wigglesworth, 1934; and Kaye, 1964a, b). (See Folger and others, 1978, for additional references to geological and geophysical interpretations of the study area.)

ACKNOWLEDGMENTS

The authors thank Raymond Christopher, Page C. Valentine, C. Wylie Poag, and Norman Frederiksen for paleontological age dating and for helpful discussions of the biostratigraphy and paleoecology; and John C. Hathaway, Clifford Kaye, Charles J. O'Hara, Robert N. Oldale, Francis A. Kohout, David W. Folger, and C. C. Woo for discussions concerning environmental interpretations of regional geology. Judith A. Commeau was responsible for geochemical analyses, and Carol Bloom, for laboratory preparation.

STRATIGRAPHY

LITHOSTRATIGRAPHY

Well ENW–50 penetrates a sequence of clastic sedimentary strata whose constituent grains range in size from clay (< 0.004 mm) to cobbles (64–128 mm). Grain size was determined by means of a rapid sediment analyzer (Schlee, 1966) and a Coulter Counter Model TA II[1]. The sequence can be divided into three lithologic units (fig. 2). The upper unit, 0–128 m below the surface, is predominantly medium to coarse sand containing several beds (3–10 m thick) of silty clay (fig. 3). From 86 to 128 m, sorting is poorer than in the beds above, and silt and clay are more abundant. The middle unit, 128–220 m, is predominantly silty clay. This middle unit contains a 6-m bed of lignite between 174 m and 180 m. This lignite is similar to lignite/subbituminous coal found on Nantucket Island (Folger and others, 1978). The lower unit, 220–262 m, is predominantly sand.

Upper unit (0–128 m). – The upper 38 m of the upper unit is composed largely of medium-to-coarse white sand containing scattered pebbles and is similar to Pleistocene strata that crop out on Martha's Vineyard. A 3-m bed of micaceous sandy silt is present between 34 and 37 m. Olive-green glauconitic sand, cored between 42 and 68 m, and olive-green silty clay grading downward into poorly sorted silty gravel recovered from 60–61 m in the core are the only greensands found in the upper unit. The upper part of the gravel bed contains some shell fragments. Poorly sorted sand containing some gravel, silt, and clay dominates the cored interval between 73 and 128 m. Lignite recovered from cuttings between 73 and 74 m was not cored. The cores between

[1] Any trade names in this publication are used for descriptive purposes only and do not constitute endorsement by the U.S. Geological Survey.

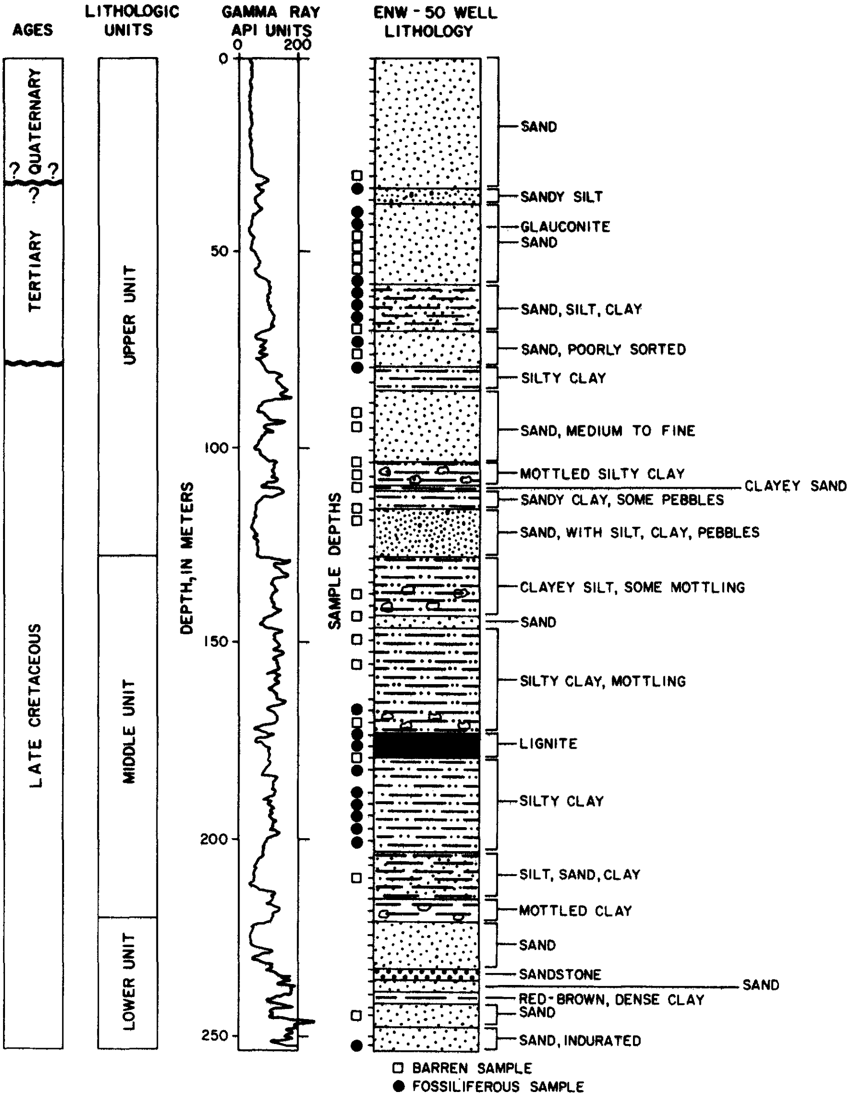

FIGURE 2.–Stratigraphic section penetrated by well ENW-50, on Martha's Vineyard, showing ages and lithologies. (API, American Petroleum Institute.)

105 and 112 m contain several beds, 1-3 m thick, of reddish-brown and gray-mottled silty clay.

Middle unit (128–220 m).–The middle unit consists mostly of mottled micaceous silty clay; silt is conspicuous in the lower 30 m of the zone. The clay and silty clay are gray, brown, red, yellow, olive, and black. A

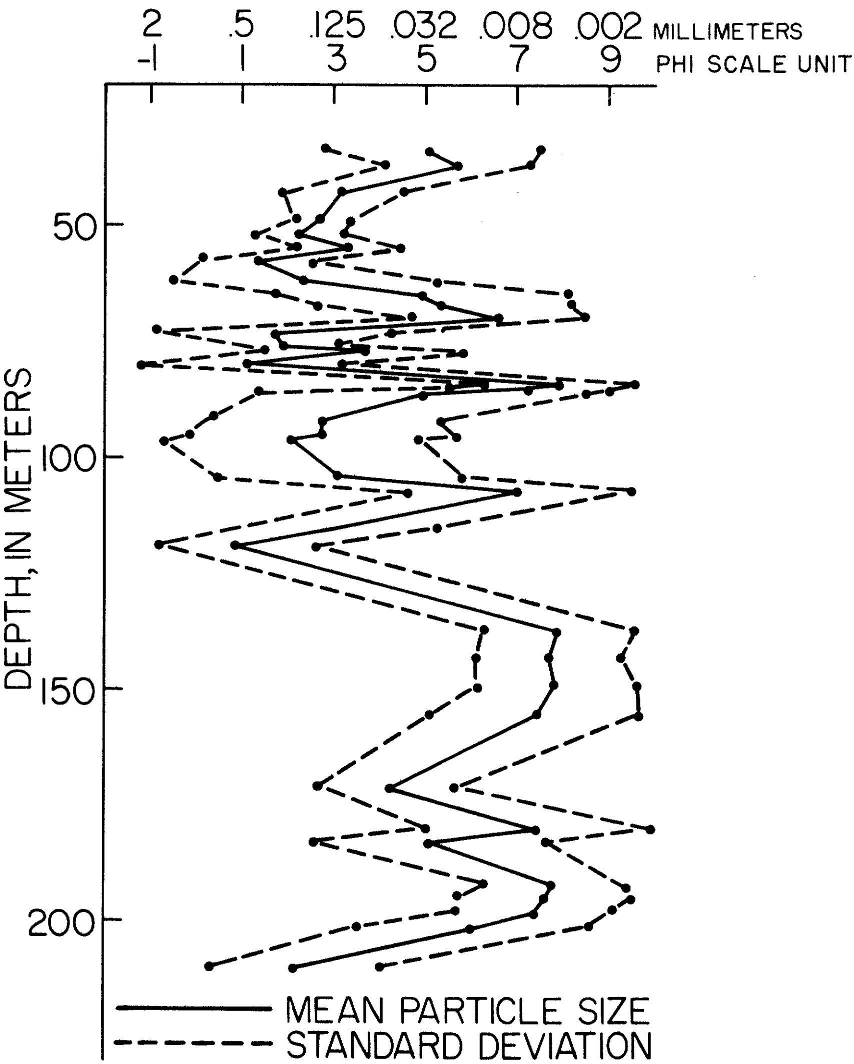

FIGURE 3.—Mean particle size, ± one standard deviation, at various depths in well ENW-50.

core recovered from 129 m consists of poorly sorted white micaceous sand, containing silt and clay. Lignite is present between 174 and 180 m. Approximately half the sediments recovered from the middle unit are semi-indurated.

Lower unit (220–262 m). –The lower unit is composed mainly of sand and sandstone, which lie on red arkosic sandstone at total depth. A dense red-brown clay was penetrated between 239 and 242 m.

BIOSTRATIGRAPHY

Of the 41 core samples from well ENW–50 examined for foraminifers, calcareous nannofossils, and sporomorphs (spores and pollen), fossils were found in 19. Some samples were examined for only one of the three fossil groups.

The upper lithologic unit between 43 and 77 m (fig. 4) contained eight fossiliferous core samples. A few sporomorphs were found between 43 and 46 m; because they are structurally similar to modern *Betula*, they have tentatively been assigned a Neogene age (Norman Frederiksen, written commun., 1977). Small gray unidentified barnacle shells were found between 45 and 48 m. According to C. W. Kaye (written commun., 1977), the mineralogy between 45 and 53 m is similar to that of the "shelly sand" of Gay Head Cliffs, which Druid Wilson (oral commun., 1977) correlates with the Yorktown Formation (lower Pliocene).

Kaye also considered the mineralogy of the sediments between 53 and 60 m to be indicative of a Pleistocene age: "The inversion of normal stratigraphic position indicated here is a common occurrence in the large Gay Head moraine ['late Illinoian' in Kaye, 1964a], where the essential structure is an imbricated pile of thrust plates" (C. A. Kaye, written commun., 1977). Therefore, Kaye contended that the Gay Head moraine probably extends southeast as far as the well site. Sediments from 61 m, 64 m, and 70 m contain mixed sporomorph assemblages of Quaternary or Neogene age (younger forms) and of Paleogene (possibly early Eocene) age (older forms).

The younger forms are *Alnus, Betula, Carya (large), Castanea* (reworked?), *Celtis, Fagus, Ilex, Nyssa, Ostrya-Carpinus, Picea, Pinus, Quercus, Tilia, Tsuga, Ulmus, Cyrilla-Cliftonia (reworked?), Taxodiaceae-Cupressaceae-Taxaceae, Pterocarya, cf. Betula, Compositae, Gramineae, Myrica, Umbelliferae, Nuphar, Lycopodium, Osmunda,* and *Sphagnum.*

The older forms are *Carya* (small), *Casuarinidites* spp., *Cicatricosisporites dorogensis* Potonie and Gelletich, *Momipites microfoveolatus* group, *Nudopollis terminalis* (Pflug and Thomson) Pflug, *Plicatopollis lunata* and *P. plicata* types, *Triatriopollenites platycaryoides* Roche, *Pseudoplicapollis sp. A* of Tschudy 1975, *Pseudoplicapollis serena* Tschudy, *Thomsonipollis magnifica* (Pflug) Krutzsch, *Porocolpopollenites* sp., *Tricolpites* n. sp., *Micrhystridium* sp., *Kyandopollenites anneratus* Stover, *Plicapollis retusus* Tschudy, and *Platycarya* cf. *P. swasticoida* Elsik (Norman Frederiksen, written commun., 1977).

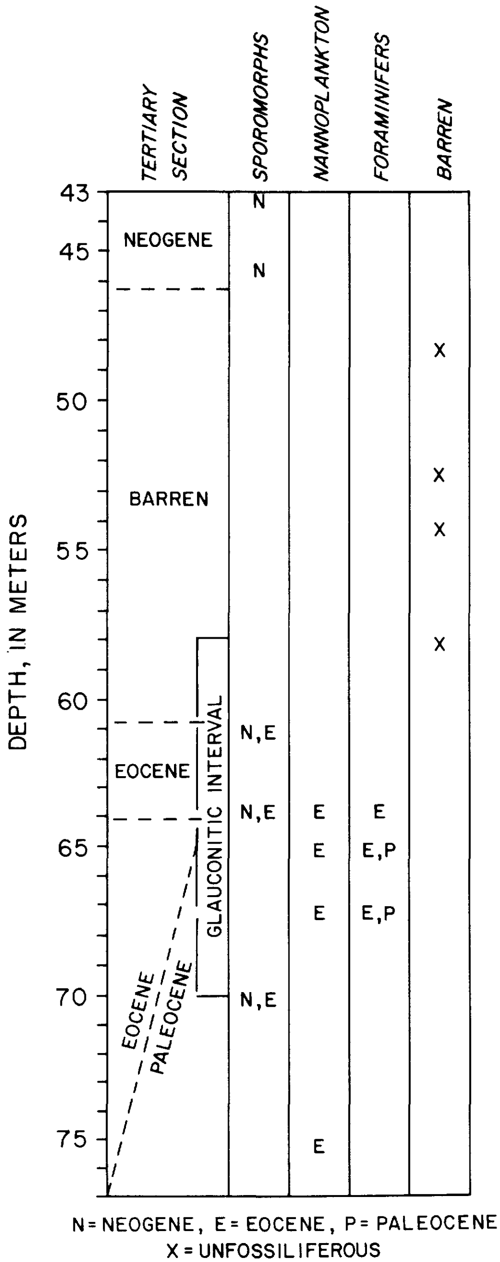

FIGURE 4.–Tertiary section in well ENW-50, showing paleontological sample depths and ages.

These listed assemblages of mixed Neogene and Paleogene sporomorphs are similar to those found in the Gay Head Cliffs within a Miocene greensand unit that is highly glauconitic and rich in phosphate nodules, fossil bone, quartz pebbles, Miocene megafossils, and, to a lesser extent, chert pebbles. A younger Cenozoic greensand unit crops out above the Miocene greensand. These two greensand units are also present at many other localities on Martha's Vineyard. The youngest greensand is sparsely glauconitic and overlies a till. Crystalline rock fragments within this greensand unit were glacially transported; thus, the unit is assigned a Pleistocene age. A till that separates the two greensand units contains Miocene and Cretaceous fossils, which were probably mixed by ice riding over Coastal Plain sediments (C. A. Kaye, written commun., 1977).

The glauconitic sediments in well ENW-50 resemble more closely the lowermost Pleistocene unit, a till, that crops out in the Wequobsque Cliffs, just east of the Gay Head Cliffs (C. A. Kaye, written commun., 1977). The lack of mineralogic similarity between Gay Head Cliffs and the samples from well ENW-50 may indicate that the Miocene greensand at Gay Head Cliffs does not extend to the area of the well. The maximum thickness of the greensand at Gay Head is approximately 6 m; however, exposures are generally less than 3 m thick. On the basis of a coring interval of 3 m for well ENW-50, the Miocene greensand at Gay Head Cliffs probably is missing in this area.

In four samples within the greensand interval in well ENW-50, 64 m (one from upper part and one from lower part), 67 m, and 77 m, calcareous nannofossils are rare and are only moderately well preserved in highly quartzose sediments. The 17 identified species are *Cepekiella lumina* (Sullivan), *Chiasmolithus expansus* (Bramlette and Sullivan), *C. solitus* (Bramlette and Sullivan), *Coccolithus pelagicus* (Wallich), *Cyclicargolithus floridanus* (Roth and Hay), *Cycloccolithina formosa* (Kamptner), *Discolithina* sp., *Reticulofenestra coenura* (Reinhardt), *R. reticulata* (Gartner and Smith), *R. umbilica* (Levein), *Transversopontis exilis* (Bramlette and Sullivan), *T. fimbriatus* (Bramlette and Sullivan), *T. obliquipons* (Deflandre), *Coccolithus eopelogicus* (Bramlette and Riedel), *C. petrinus* (Stradner), *Zygrhablithus bijugatus* (Deflandre), and ?*Dictyococites scrippsae* (Bukry and Percival). The calcareous nannofossils from the upper three samples are of middle Eocene age; the sample from 77 m is possibly middle Eocene in age (P. C. Valentine, written commun., 1977).

Foraminifers examined from 64 m and 67 m contain Eocene and Eocene-Paleocene assemblages. The sample from 64 m contains an Eocene assemblage consisting of the following listed shallow-water marine species (C. W. Poag, written commun., 1977): *Pseudohastigerina sharkriverensis* (Berggren and Olsson), *Cibicidina blan-*

piedi (Toulmin), *Gyroidinoides octocameratus* (Cushman and Hanna), *Guttulina irregularis* (Cushman), *Eponides jacksonensis* (Cushman and Applin), *Alabamina wilcoxensis* (Toulmin), *Acarinina* sp., *Cibicidoides pippini* (Cushman and Garrett), *Cibicidoides mexicanus* (Nuttall), *Cibicidoides cocaensis* (Cushman), and *Cibicidina* cf. *cooperensis* (Cushman).

Samples from the base of 64 m and of 67 m contain Eocene-Paleocene assemblages composed of the following species: *Turrilina robertsi* (Howe and Roberts), *Alabamina wilcoxensis* (Toulmin), *Pseudohastigerina sharkriverensis* (Olsson and Berggren), *Gyroidinoides octocameratus* (Cushman and Hanna), *G. Danvillensis* (Bandy), *Textularia* sp., *Cibicidina* cf. *mississippiensis* (sharp keel), *Cribrononion mauricensis* (Howe and Ellis), *Acarinina pentacamerata* (Subbotina), *A. tribulosa* (Loeblich and Tappan), *A. aquiensis* (Loeblich and Tappan), *A. irrorata* (Loeblich and Tappan), *Cibicidoides mexicanus* (Nuttall), *Cibicidoides lisbonensis* (Bandy), *Buccella inusitata, Elphidium clavatum* (Cushman), *Cibicidina* cf. *cooperensis, Cibicidoides* sp., *Lenticulina* spp., *Nodosaria* sp., *Eponides* sp., and *Rosalina* cf. *tallahatensis* (Bandy).

Thus, the interval from 61 to 64 m contains Eocene foraminifers, nannoplankton, and Neogene sporomorphs. The base of the interval from 64 to 77 m contains Eocene and (or) Paleocene calcareous nannoplankton, benthic and planktic foraminifers, and mixed though predominantly Neogene sporomorph assemblage (fig. 4).

Glauconitization has apparently destroyed most of the calcareous assemblages from the Tertiary section and left only small amounts of calcareous material. The Neogene sporomorphs found between 61 and 70 m are contaminants from the 43- to 46-m interval. However, we conclude that the Tertiary greensand interval in well ENW–50 is in place and contains two, possibly three, biostratigraphic units (fig. 4). The interval between 43 and 46 m is Neogene in age, whereas the intervals from 61 to 64 m and from the base of 64 to 77 m are respectively Eocene and Eocene-Paleocene in age.

A sample from 85 m contains a sparse, mixed assemblage of sporomorphs. The young forms are the same Quaternary or Neogene species found above, but Late Cretaceous species also are present.

The Tertiary-Cretaceous contact, regarded as a diastem in the Nantucket USGS well 6001, is placed between a black clay zone (containing lignite) and a sand and gravel unit (Folger and others, 1978). The Tertiary-Cretaceous contact, also a diastem in the Martha's Vineyard well ENW–50, is placed approximately 5 m above the first identified Cretaceous fossils (sporomorphs), at approximately 80 m. We placed the contact between a poorly sorted sand, containing traces of glauconite, and a grayish-white silty clay.

Three pollen samples were examined from a dark-gray to black silty clay collected at a depth of 168 m, a poorly sorted dark-brown sand, at 183 m, and a feldspar-rich sand, at 255 m. The upper sample came from the middle lithostratigraphic unit, and the lower two came from the lower lithostratigraphic unit (fig. 2). All three samples contain similar pollen assemblages, comprising the following named species: *Ajatipollis tetraedralis* (Bolchovitina) Krutzsch, *Atlantopollis verrucosus* (Groot and Groot) Krutzsch, *Tricolporopollenites aliquantulus* Hedlund, *T. triangulus* (Groot, Penny, and Groot), *"Retitricolpites" vulgaris* (Pierce), *Gleicheniidites confossus* (Hedlund), and *Complexiopollis* sp. On the basis of the concurrent ranges of the species, these samples belong to Cenomanian Pollen Zone IV, which is present in the Woodbridge Clay and Sayreville Sand Members of the Raritan Formation of New Jersey (Raymond Christopher, written commun., 1977).

Single specimens of the middle to late Tertiary foraminifers *Globigerinoides* sp. and *Cassigerinella chipolensis* recovered from 174 and 177 m, respectively, are contaminants. An assemblage of marginal-marine agglutinated foraminifers (*Ammobaculites* and *Haplophragmoides*) is present in an olive-green to olive-gray silty clay between 189 and 199 m. This assemblage is similar in species composition, paleoenvironment, and stratigraphic position to a Cenomanian assemblage identified in the Nantucket USGS well 6001 (Folger and others, 1978). This unit may be correlative with the subsurface Bass River Formation of Petters (1976) of New Jersey; the formation was deposited in a continental-shelf environment during the major Cenomanian transgression.

MINERALOGY

METHODS

A split from each sample was mounted as a randomly oriented powder and X-rayed (table 1). The clay fraction from each sample was separated by centrifuge and mounted as an oriented aggregate on a silver filter. Four treatments were performed on the oriented silver-filter mounts: air drying, glycolation with ethelene glycol, heating to 400° C, and heating to 550° C. After each treatment, the samples were X-rayed between the angles of 2° and 40° two theta on a Philips X-ray diffractometer fitted with a graphite curved-crystal monochromator. This study used CuKα radiation, a scanning rate of 2° per minute, and a chart scale of 1,000 counts per second full scale. The term "mica" in this paper describes all minerals whose (001) reflection occurs at 10 angstroms. We used an automated Diano XRF 8000 X-ray fluorescence unit for quantitative elemental analysis to check the X-ray diffraction data.

In addition, a split was taken from the 500 μm to 63 μm fraction of each sample; each split was separated into light-mineral (sp gr < 2.85) and heavy-mineral (sp gr > 2.85) components by use of the heavy liquid tetrabromethane. We mounted the light minerals on slides using Piccolite ($n = 1.52$), and stained them according to the method described by Hayes and Klugman (1959). The heavy minerals were mounted on slides by means of Piccolite and were analyzed with the aid of a point-counting stage attached to a petrographic microscope; at least 300 grains were counted on each slide.

QUATERNARY

The Quaternary sediments (0–42 m) contain a mica/illite, chlorite, kaolinite, and mixed-layered illite-smectite assemblage (table 1). Glauconite is present in the Quaternary beds and may represent mixing or redeposition of Tertiary greensands due to glacial scour.

TABLE 1.–*Estimated mineral modes, in percent, determined from X-ray diffraction for rocks penetrated by well ENW–50*

[Tr, < 1 percent]

Depth (meters)	Quartz	Feldspar	Mica/Illite	Kaolinite	Chlorite	Smectite and mixed-layered illite-smectite	Mixed-layered nonswelling clays	Other
Quaternary age								
34	60	15	10	3	5	6	--	Tr
37	45	27	5	2	5	8	--	8
Tertiary age								
43	65	25	4	Tr	2	4	--	Tr
49	75	15	5	--	Tr	5	Tr	--
55	70	20	6	--	Tr	3	Tr	Tr
61	45	5	10	10	15	15	--	Tr
65	27	7	15	12	18	15	Tr	6
73	55	5	12	8	3	12	--	5
Cretaceous age								
83	15	Tr	Tr	80	--	Tr	--	2
92	46	--	Tr	52	--	Tr	–	Tr
104	55	Tr	Tr	45	--	--	--	--
107	18	Tr	Tr	78	--	Tr	--	Tr
116	30	--	Tr	70	--	Tr	Tr	Tr
119	75	--	Tr	24	--	--	--	Tr
129	80	Tr	--	20	--	--	--	Tr
131	20	2	5	67	--	Tr	--	5
141	10	--	--	85	--	--	--	5
147	30	--	5	65	--	Tr	--	Tr
149	18	Tr	Tr	79	--	Tr	--	Tr
159	32	Tr	17	39	--	2	--	10
171	25	3	5	65	--	--	--	Tr
180	20	--	--	80	--	--	--	Tr
183	22	Tr	5	67	--	Tr	--	5
192	12	Tr	10	67	--	5	--	5
195	45	5	--	50	--	--	--	Tr
202	30	Tr	Tr	65	--	Tr	--	Tr
210	73	6	Tr	19	--	--	--	Tr
220	35	--	3	55	--	2	--	5
226	55	Tr	Tr	40	--	Tr	--	5
229	81	--	--	19	--	--	--	--
238	45	--	10	45	--	--	--	--
241	15	Tr	30	15	--	30	--	9
247	24	9	28	38	--	--	--	Tr
255	40	25	30	Tr	--	--	--	5

TERTIARY

The mineralogy of the Tertiary sediments (42–80 m) is similar to that of the Quaternary, and Tertiary beds contain contributions from multiple sources. The light-mineral fraction is arkosic to subarkosic, containing an average of 75 percent quartz. The potassium feldspars are more abundant than the sodium-calcium feldspars. Indicolite, the blue variety of tourmaline, occurs with the potassium feldspar and indicates a granitic pegmatite source (Krynine, 1946).

The nonopaque, heavy-mineral fraction is composed predominantly of minerals derived from low- to medium-grade metamorphic rocks (table 2). High percentages of garnet, epidote, blue-green hornblende, sillimanite, tourmaline, and staurolite are common in the Tertiary section.

Mica/illite and mixed-layered illite-smectite are the most abundant layered silicates in the less-than-2 μm fraction (table 1). Smectite, kaolinite, and chlorite are common between 58 and 73 m. Smectite in the clay fractions and pyroxenes in the heavy-mineral fractions may have been derived from a volcanic source. Although glauconite is present throughout the Tertiary section, it is minor except in a zone between 58 and 70 m.

CRETACEOUS

The mineralogy of the Cretaceous sediments (80–262 m) is significantly different from that of the Tertiary. Kaolinite dominates the clay mineralogy of the Cretaceous; minor amounts of mica/illite and traces of mixed-layered illite-smectite also occur (table 1). Kaolinite often forms under conditions of severe chemical weathering by the alteration of feldspars and clay minerals. The Upper Cretaceous kaolinite of well ENW–50 probably formed by this process. Although the occurrence of nodular siderite in these sediments might indicate an in situ origin for at least a part of the kaolinite (Kaye, 1967), some or all of it may have been transported from another source.

This weathering, which depleted the feldspars and altered the clay minerals, also diminished most of the nonopaque, detrital heavy minerals (table 2). Three exceptions are the ultrastable minerals, zircon, tourmaline, and staurolite. Anatase, which is probably of authigenic origin, occurs in samples at 235 and 238 m and makes up 77 percent of the heavy minerals in the deeper sample. Micaceous sands are scattered throughout the Cretaceous section and are composed of muscovite and, in a few places, traces of biotite, both of which are partly altered.

The core penetrated three zones of red or mottled red and gray sediments in the well. Iron oxide, in the form of hematite and minor

TABLE 2.—*Nonmicaceous heavy minerals (sp gr >2.85), in percent, contained in 500 μm to 63 μm fraction of samples from various depths in well ENW-50*

[Frequency percentages based on 300 or more grain counts per sample. Tr, <1 percent]

Depth (meters)	Amphibole	Epidote	Garnet	Glauconite	Hematite	Opaques	Other	Pyrite	Pyroxene	Siderite	Sillimanite	Staurolite	Tourmaline	Zircon
Quaternary age														
37	13	2	3	Tr	38	3	22	2	4	4	3	3	3	
Tertiary age														
43	11	9	4	1	--	36	6	--	8	--	8	3	10	4
49	11	4	9	1	--	42	1	1	5	0	7	4	5	10
55	13	6	10	1	--	37	5	Tr	8	--	7	3	7	3
61	10	7	2	4	--	34	5	14	8	3	2	4	2	5
68	6	7	1	4	--	37	8	15	6	2	2	4	2	6
73	5	2	1	Tr	--	71	4	6	5	1	1	2	1	1
Cretaceous age														
83	4	3	1	--	--	53	2	19	3	Tr	2	4	7	2
92	8	4	Tr	Tr	--	23	2	34	3	Tr	2	7	13	4
104	8	2	--	Tr	--	58	2	2	3	--	--	8	11	6
116	7	4	--	Tr	--	67	3	Tr	2	Tr	Tr	4	10	2
129	9	2	--	--	Tr	53	4	9	1	--	1	9	10	2
141	2	--	--	Tr	77	17	2	Tr	Tr	--	--	Tr	1	Tr
147	4	2	--	--	--	69	2	5	2	Tr	--	3	5	8
159	--	--	--	--	Tr	Tr	1	--	--	97	--	--	Tr	Tr
171	2	--	Tr	--	--	7	2	2	Tr	81	--	Tr	5	Tr
183	7	2	4	--	1	52	5	Tr	3	Tr	--	4	21	1
195	8	Tr	6	--	--	51	2	--	1	17	--	1	5	9
202	11	2	--	--	--	36	1	--	2	27	Tr	4	12	5
208	9	5	Tr	--	Tr	24	Tr	Tr	1	27	1	11	17	5
220	Tr	--	Tr	--	Tr	7	2	3	Tr	84	--	--	1	1
226	Tr	--	--	--	Tr	98	Tr	Tr	Tr	Tr	--	--	Tr	--
238	2	Tr	--	--	Tr	3	77	--	Tr	Tr	--	--	Tr	17
241	Tr	Tr	--	--	14	40	2	--	Tr	39	--	--	Tr	3
247	2	--	--	--	20	54	4	--	1	7	--	--	1	11
255	3	--	Tr	--	21	32	--	2	Tr	39	Tr	--	Tr	3

amounts of goethite, is responsible for the red color and occurs as stains and as relatively pure grains. Below 238 m, the sediments are arkosic; the light fraction averages 38 percent feldspar, and as in the Tertiary, the potassium feldspars dominate. The major clay minerals in the lower lithologic unit are mica/illite and kaolinite (table 1). Mixed-layered illite-smectite, which is abundant in the sample at 241 to 244 m, is absent from the sample at 247 m to the bottom of the well. Calcite, present in trace amounts in the red sandstone at 255 m, may represent an initial stage of calcification in a caliche.

REGIONAL CORRELATION

Some of the lithostratigraphic and biostratigraphic units recognized in well ENW–50 are correlative with those penetrated by USGS well 6001 and with the Fire Island well on Long Island (fig. 5). Recovery was poor from the Quaternary sediment of both well ENW–50 and USGS well 6001. Coarse, poorly sorted sand containing stringers of silty clay predominate in the Pleistocene section of both wells, though in USGS 6001 it is more than twice as thick. The Pleistocene section in the Fire Island well is thinner than in either wells ENW–50 or USGS 6001; however, the lithology is similar. Recovery was insufficient to permit correlations within the Pleistocene.

Tertiary strata are absent from the Fire Island well. Upper Cretaceous rocks there contain middle-shelf sediments, whereas at well ENW–50 they contain nonmarine and marginal-marine sediments. Sporomorphs show that the section below 152 m in well ENW–50 is part of the same palynological zone as is a correlative of the Woodbridge Clay Member of the Raritan Formation at 533 m in the Fire Island well.

A generalized correlation may be made between sediments penetrated by well ENW–50 and those penetrated by the COST No. B–2 well, which was drilled on the outer part of the Atlantic Outer Continental Shelf (Baltimore Canyon trough), approximately 91 km east of Atlantic City, N.J. The sediments deposited during the Neogene and penetrated by the COST No. B–2 well are predominantly marine, but sediment deposited during the Neogene at the site of well ENW–50 are mainly nonmarine. The Eocene and Paleocene sediments in the COST No. B–2 well were deposited in an upper-slope environment; Eocene and Paleocene sediments from well ENW–50 show a shallow-marine environment of deposition. This difference in paleobathymetry during the Tertiary probably reflects the proximity of Martha's Vineyard to the coast.

The Upper Cretaceous sediments from the COST No. B–2 well are predominantly indicative of a shallow-water marine environment. Upper Cretaceous sediments in well ENW–50 are mainly nonmarine, but

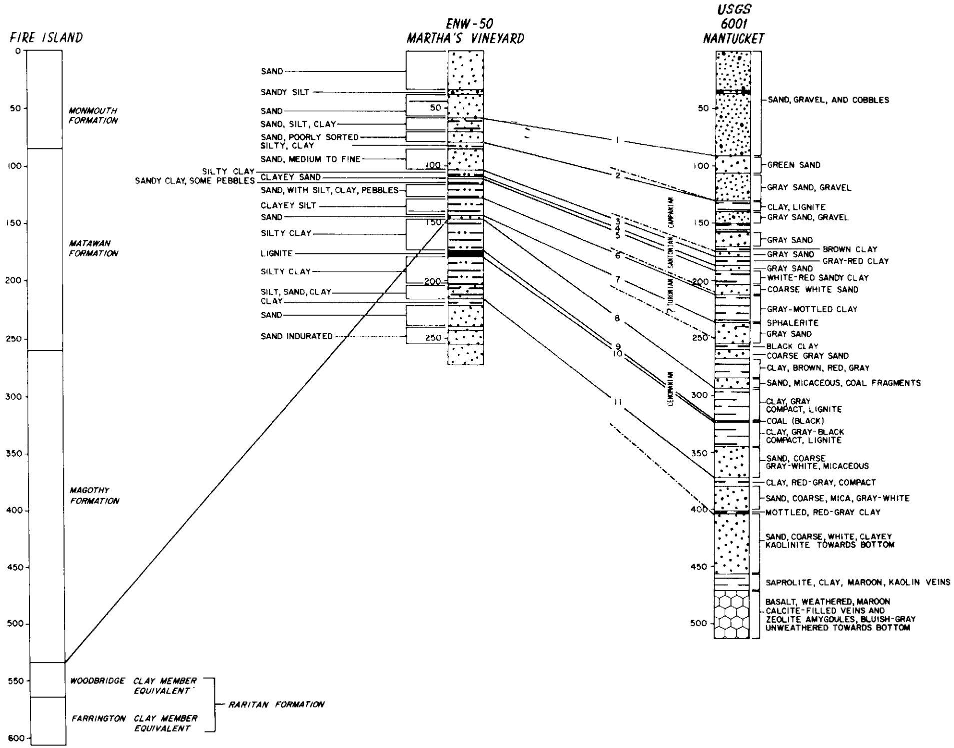

FIGURE 5. – Correlation among sections penetrated by the Nantucket, Martha's Vineyard, and Fire Island wells. Depths are in meters. Numbered lines (1-11) represent first-order and second-order correlations, which are explained in the text. Dash-dot lines represent silty clay or clayey silt.

a small interval of marginal-marine sediments were deposited in the middle of the Upper Cretaceous unit. Lignite is found in the Upper Cretaceous sediments in both wells. In COST No. B–2 well, lignite is found in the nonmarine to marine section. The lignite is present in both wells in the middle of the Upper Cretaceous section. Again, the differences in paleobathymetries during the Upper Cretaceous is probably due to the deeper water position of the COST No. B–2 well.

Nine lithostratigraphic and two biostratigraphic units are common to the ENW–50 well and USGS well 6001. Four units, two lithostratigraphic and two biostratigraphic, are considered to be first-order correlations; seven lithostratigraphic units are second-order correlations. Numbered in the sequence in which they appear on figure 5, the first-order correlations are described as follows:

1. Poorly sorted greensand having a silty matrix between depths of 61 and 64 m in well ENW–50 is equivalent to the 91- to 106-m interval in USGS well 6001. This material has been assigned an Eocene age on the basis of planktic and benthic foraminifers identified in both wells. The Neogene interval from depths of 42 to 46 m in well ENW–50 has no correlative in the USGS well 6001, but a similar unit was penetrated at 40–55 m in the Coskata well on Nantucket (Folger and others, 1978).
7. The occurrence of sphalerite in a moderately sorted white micaceous sand at 143–146 m in well ENW–50 is correlated with a light-gray micaceous moderately sorted sand, also bearing sphalerite, between 236 and 254 m in USGS well 6001. These units contain the only sphalerite recorded in either well.
9. Lignite at 174 to 180 m in well ENW–50 correlates with the lignite/subbituminous coal at 321–323 m in USGS well 6001.
10. Olive-green to olive-gray clay at 180–204 m in well ENW–50 contains an agglutinated benthic foraminiferal fauna that correlates with a similar fauna found in a compact, lignitic gray-black clay 323–344 m in USGS well 6001.

The second-order correlations are:

2. Dark-gray poorly to moderately sorted silty sand from 70 to 80 m in well ENW–50 correlates with a black lignitic clay at 130–138 m in USGS well 6001. In well ENW–50, lignite was present in cuttings retrieved from this interval, though none was recovered in the cores.
3. Poorly sorted white silty clay mottled with red and gray from 103 to 109 m in well ENW–50 and at 178–186 m in USGS well 6001 is correlative on the basis of similar lithology.

4. Whitish-gray clayey sand present in well ENW–50 from 109 to 111 m is correlative with sand of comparable lithology at 186–191 m in USGS well 6001.
5. Mottled reddish-brown and gray sandy clay penetrated between 111 and 115 m in well ENW–50 correlates with the mottled red and white sandy clay at 191–203 m in USGS well 6001.
6. The yellow and gray mottled clay between 138 and 143 m in well ENW–50 is correlated with the gray silty clay mottled with light olive-brown and red present at 212–236 m in USGS well 6001.
8. Grayish-black clay containing some lignite is present in well ENW–50 at 146–174 m. Its correlative lithology occurs from 294 to 321 m in USGS well 6001.
11. Red, yellow, and light-gray mottled clay between 215 and 221 m in well ENW–50 correlates with a similar lithologic unit at 321–379 m in USGS well 6001.

On the basis of sporomorphs from the two wells, we correlate the well ENW–50 interval at 168–262 m, believed to be Cenomanian in age, with the sand and clay between 250 m and 405 m in the USGS well 6001.

SUMMARY AND CONCLUSIONS

1. We have divided the section penetrated by Martha's Vineyard well ENW–50 into three lithostratigraphic units: upper, middle, and lower. The upper and lower units are predominantly sand, and the middle unit is predominantly silty clay. The lithologies and textures are similar to the three lithologic units described in Nantucket USGS well 6001 (Folger and others, 1978).
2. Evidence for the uppermost Tertiary sediments is from Neogene sporomorphs collected at 43 m. On the basis of in situ microfossils, we consider the interval between 43 and 46 m to be Neogene in age, whereas the intervals from 61 to 64 m and 64 to 77 m are Eocene and Eocene-Paleocene in age. The Tertiary section in well ENW–50 is similar in thickness to the Tertiary in USGS well 6001, and deposition took place under similar shallow-water marine conditions.
3. The Upper Cretaceous sediments in wells ENW–50 and USGS 6001 are mainly nonmarine mottled red and gray clay, which probably formed as gley soils in an anaerobic swamp or a river delta. The mottling is probably caused by periodic subaerial exposure followed by saturation below the water table. Mineralogical analyses show evidence of chemical weathering that probably took place during times of subaerial exposure.

4. Kaolinite dominates the clay mineralogy of the Cretaceous section; a mica/illite, mixed-layered illite-smectite, smectite, kaolinite, and chlorite assemblage occurs in the $<2\mu m$ fraction of the Tertiary.
5. We made nine lithostratigraphic and two biostratigraphic correlations between well ENW-50 and USGS well 6001. Four units are first-order correlations, and seven units are second-order correlations.

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