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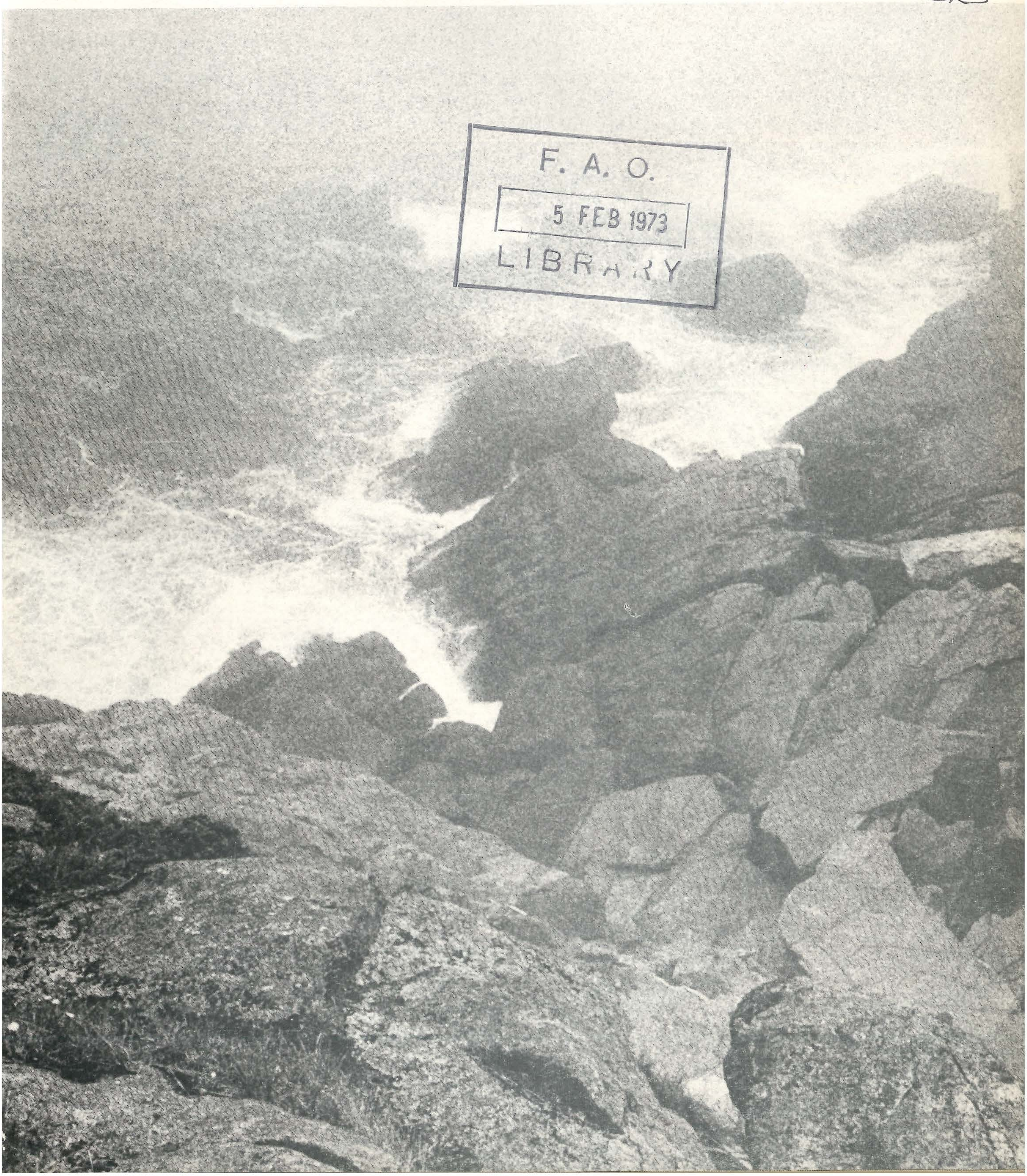

chance, we must suspect that the key to their evolution is a dissipative mechanism not present in the solar system today. It might have involved a viscous medium in the early solar nebula or the influence of a passing star. A study of evolutionary models with such alternate mechanisms might provide useful clues about conditions in the young solar system.

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1. See, for example, P. Goldreich, *Mon. Notic. Roy. Astron. Soc.* **130**, 159 (1965).
2. A complete discussion is given by R. J. Greenberg, thesis, Massachusetts Institute of Technology (September 1972).
3. D. Brouwer and G. Clemence, *Methods of Celestial Mechanics* (Academic Press, New York, 1951), p. 492.
4. This qualitative aspect of the stability for relatively high values of e_2 was described by Goldreich (*1*) and by C. J. Cohen and E. C. Hubbard [*Astron. J.* **70**, 10 (1965)].
5. The time scale for the evolution of the Titan-Hyperion resonance presents certain problems; these are discussed in (*2*).
6. R. R. Allan, in *Symposia Matematica* (Istituto Nazionale di Alta Matematica, Città Universitaria, Rome, 1970), vol. 3, p. 75. Here the conjunction longitude librates about the average longitude of the satellites' ascending nodes on Saturn's equatorial plane, so the resonance involves the inclinations of both satellites.

30 June 1972

Polystyrene Spherules in Coastal Waters

Abstract. *Polystyrene spherules averaging 0.5 millimeter in diameter (range 0.1 to 2 millimeters) are abundant in the coastal waters of southern New England. Two types are present, a crystalline (clear) form and a white, opaque form with pigmentation resulting from a diene rubber. The spherules have bacteria on their surfaces and contain polychlorinated biphenyls, apparently absorbed from ambient seawater, in a concentration of 5 parts per million. White, opaque spherules are selectively consumed by 8 species of fish out of 14 species examined, and a chaetognath. Ingestion of the plastic may lead to intestinal blockage in smaller fish.*

Polystyrene spherules are widespread in the coastal waters of southern New England. We first observed spherical plastic particles in plankton tows in January 1971 while sampling to determine the effects of a nuclear power station on the ecology of Niantic Bay (northeastern Long Island Sound). The particles, although usually present in zooplankton samples throughout the year, were not investigated in detail until February 1972. The spherules are markedly different in size, shape, distribution, and chemical composition from the plastics on the Sargasso Sea surface (*1*).

Infrared spectrophotometry of the particles indicated that they were polystyrene plastic. Two types are present in seawater, in approximately equal proportions. One is a clear or crystalline polystyrene, and the other is a white, opaque form with pigmentation due to the presence of a diene rubber compound in the plastic, as indicated by infrared spectrophotometry and confirmed by a representative of the plastics industry (*2*). Both forms are virtually perfect spheres and average about 0.5 mm in diameter, ranging from 0.1 to 2 mm. They contain various sizes and numbers of gaseous voids. Thus, they are found at the sea surface, in the water column, and presumably in the sediments since polystyrene is of a greater density than seawater.

The spherules are present in coastal waters from western Long Island Sound to Vineyard Sound (Table 1), and may be more widespread since their total range was not delimited. All samples were collected with oblique plankton tows by using the National Academy of Sciences (NAS) reference net (0.5 m in diameter at the mouth; mesh size 333 μm) equipped with a flowmeter (*3*). The highest concentrations observed were in the Niantic Bay area with an average of about 1 spherule per cubic meter for 72 samples taken on six dates between February and May 1972. Concentrations up to 14 m^{-3} were observed in this area. At other stations sampled in February to March 1972 the average concentrations were as follows: Long Island Sound (stations 22 to 27), 0.07 m^{-3}; east of Block Island (stations 13 to 18), 0.03 m^{-3}; Great Salt Pond on Block Island and west to Long Island Sound (stations 19 to 21), 0.02 m^{-3}.

Bacteria and polychlorinated biphenyls (PCB's) are present on surfaces of the plastic particles. Freshly collected spherules from Niantic Bay were transferred through four washings of sterile seawater and plated onto A-C seawater medium (*4*), where rod-shaped gram-negative bacteria were observed after incubation. An extraction of the surface of the spherules from Niantic Bay with hexane showed that they contained PCB's (Aroclor 1254) in a concentration of 5 parts per million. Since PCB's are not added in the manufacture of polystyrene (*2*), it is probable that the source was ambient seawater.

Table 1. Sample location, date, volume filtered, and concentration of plastic spherules in coastal water. Stations 1 to 12 were in an area of about 10 km²; the averages and ranges of the spherule concentrations at these 12 stations are presented.

Station	Location	Date (1972)	Volume filtered (m^3)	Spherules per cubic meter	
				Avg.	Range
		Niantic Bay			
1–12	41°18′N, 72°10′W	1 February	475	0.75	0.39–1.94
1–12	41°18′N, 72°10′W	17 February	140	2.58	0.62–14.1
1–12	41°18′N, 72°10′W	16 March	513	0.79	0.00–2.52
1–12	41°18′N, 72°10′W	7 April	603	0.13	0.00–0.51
1–12	41°18′N, 72°10′W	25 May	387	0.61	0.03–2.44
		Buzzards Bay			
13	41°34′N, 70°43′W	9 March	59	0.03	
14	41°34′N, 70°43′W	9 March	50	0.02	
		Vineyard Sound			
15	41°30′N, 70°39′W	10 March	48	0.02	
16	41°30′N, 70°39′W	10 March	31	0.00	
		Rhode Island Sound			
17	41°20′N, 71°03′W	24 March	108	0.10	
18	41°13.5′N, 71°18′W	25 March	76	0.00	
		Great Salt Pond			
19	41°09′N, 71°33′W	25 March	94	0.04	
		Block Island Sound			
20	41°12′N, 71°44′W	25 March	191	0.01	
21	41°12′N, 72°00′W	25 March	104	0.01	
		Long Island Sound			
22	41°10′N, 72°20′W	25 March	280	0.10	
23	41°09′N, 72°36′W	25 March	122	0.05	
24	41°08′N, 72°52′W	25 March	48	0.10	
25	41°16′N, 72°01′W	23 March	109	0.05	
26	41°17′N, 72°03′W	23 March	125	0.07	
27	41°17′N, 71°59′W	23 March	151	0.04	

Spherules are consumed by fish in the Niantic Bay area; only the white, opaque form has been found ingested, which indicates selective feeding. Fourteen species of fish, totaling 270 individuals, were collected by oblique plankton tows with the NAS net in the bay or at the cooling water intake of the Millstone Point nuclear power station, also on Niantic Bay. Of these, eight species contained spherules in their gut contents. The species, common name, and occurrence of plastic, of fish with spherules for which at least five individuals were examined are: *Myoxocephalus aenus*, grubby, 4.2 percent; *Pseudopleuronectes americanus*, winter flounder, 2.1 percent; *Roccus americanus*, white perch, 33 percent; and *Menidia menidia*, silversides, 33 percent (*5*). In addition, one chaetognath, *Sagitta elegans*, was collected on 12 July 1972; it was 20 mm long and had a spherule 0.6 mm in diameter in its intestine. The effects on fish of consuming the spherules themselves or the accompanying PCB's are unknown; however, it is likely that they can cause intestinal blockage in some of the smaller fish. Winter flounder and grubby larvae, 5 mm in length, contained spherules 0.5 mm in diameter. The percentage consumption of plastics by some species of fish may be greater than observed here if ingestion of the spherules directly or indirectly causes mortality through blockage, thereby preventing sampling of these fish.

The spherules appear identical to polystyrene plastic "suspension beads." These beads are not usually marketed commercially (*6*), but are molded into a pellet shape before being sold to plastic fabricators. Thus, the source of the spherules is probably a manufacturer and may be any of the many polystyrene producers in southern New England. Although the situation may be confined to this area, the bead suspension process is widely employed for the manufacture of polystyrene, and contamination of both marine and fresh waters and their sediments may occur in other areas as well.

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5. The total number of fish examined, average total length in centimeters, and standard deviation of the total length for fish containing spherules are: *M. aenus*, 47, 0.58, 0.12; *P. americanus*, 95, 0.46, 0.44; *R. americanus*, 12, 24.9, 3.98; *M. menidia*, 9, 1.61, 1.89; *Tautogolabrus adspersus*, 6, 9.16, 1.81. Two herring, *Clupea harengus*, each 4.2 cm; one pollack, *Pollachius virens*, 3 cm; and one sea robin, *Prionotis evolans*, 32.7 cm, were collected; each contained a spherule.
6. R. Harding, Society of Plastics Industry, New York, personal communication. Polystyrene beads also have some limited usage as absorbants for industrial water purification.
7. We thank R. Harding for his cooperation and for notifying all polystyrene manufacturers in the United States of the presence of plastic spherules in coastal waters. Gratitude is also expressed to F. Doohan and S. Young for allowing one of us (E.J.C.) to collect samples from the R.V. *Verril*. We also appreciate the critical review of this manuscript by P. H. Wiebe, N. S. Fisher, J. H. Tuttle, V. Vreeland, and R. S. Scheltema. Woods Hole Oceanographic Institution Contribution 2920.

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Rous Sarcoma Virus Nucleotide Sequences in Cellular DNA: Measurement by RNA-DNA Hybridization

Abstract. *Kinetic analysis of the hybridization of 71S RNA from Prague strain of Rous sarcoma virus with an excess of DNA from virus induced sarcomas indicated the presence of the majority of the viral genome sequences in cellular DNA with a very low average frequency per cell. About one-third of the viral sequences were at least partially complementary to DNA sequences with a higher average frequency on the order of 50 to 100 per cell. Normal chick embryo DNA was distinctly different, but contained sequences at least partially homologous to some fraction of the viral RNA.*

The proposal by Temin (*1*) that RNA tumor viruses replicate through a DNA intermediate has been supported by an increasing body of indirect evidence. The discovery of RNA-dependent DNA polymerase activity within tumor virus particles strengthened this "provirus" hypothesis. The direct detection of viral nucleotide sequences by annealing viral RNA with cellular DNA seems to be a reasonable approach for testing this idea. However, RNA-DNA hybridization studies have yielded conflicting results. Although most investigators have found viral complementary sequences in cellular DNA, some have found evidence for more complementary DNA in virus-transformed cells (*2, 3*), while others report no significant differences between normal and virus-infected tissue (*4–8*). Technical problems may underly the varying conclusions since, in all cases, only a very small fraction of the viral RNA was detected in the RNA-DNA hybrids. Furthermore, the conditions under which the hybridization reactions were carried out would not be expected to reveal small numbers of complete viral genomes per cell genome, particularly if multiple copies of DNA in the cell complementary to a small fraction of the viral RNA were present. The rate of hybridization reported in these previous studies suggests the presence of such repetitive virus-related DNA (*3*). A method has been described for detecting full complements of RNA in cellular DNA and for obtaining reasonable estimates of frequency even when very low (*5–7*). The method is based upon hybridization in the presence of an excess of DNA large enough for the kinetics of RNA-DNA interaction to be determined by the relative number of complementary sequences in the DNA. By this approach, it is possible to detect most, if not all, of the base sequences of Rous sarcoma virus in the DNA of virus-induced sarcomas, and to demonstrate major differences with DNA sequences complementary to viral RNA in normal embryos.

Prague strain of Rous sarcoma virus subgroup C (Pr RSV-C) was selected as the source of viral RNA because it is a helper-independent avian sarcoma virus that replicates efficiently in cell culture and produces rapidly growing sarcomas in newborn chicks (*8*). Chick embryo fibroblast cultures transformed by Pr RSV were incubated in medium 199 (prepared without unlabeled nucleosides and made 5 percent in fetal calf serum) with 100 μc of [^{3}H]uridine, [^{3}H]cytidine, and [^{3}H]adenosine per milliliter (22, 26, and 9 c/mmole, respectively). Culture fluid was harvested after 24 hours, and labeled virus particles were purified from culture fluids by banding in sucrose gradients (20 to 60 percent). Viral RNA was extracted by the sodium dodecyl sulfate–phenol technique (*9*). The 71*S* viral genome, separated from low-molecular-weight nucleic acids by sedimentation in sucrose gradients (5 to 20 percent) in 0.01*M* tris buffer containing 0.001*M*

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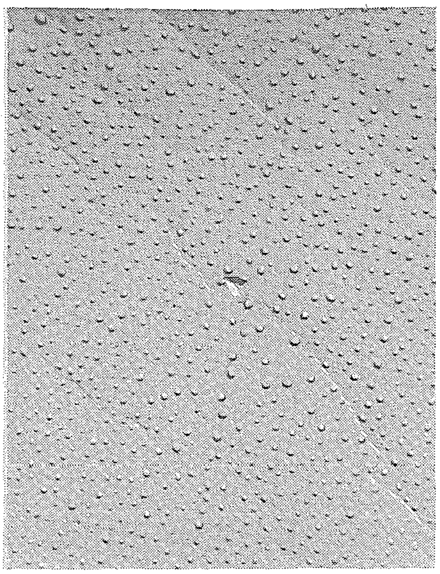

Fig. 2. Electron micrograph of wax particles generated from a pine needle at 20 kv (the torn area in the center is 0.7 μm long).

from the cuticle only while a leaf is growing (*5*), and, because of the lack of seasonal variation in wax composition (*6*), the wax coating apparently is not further affected by the plant metabolism (*7*). Although the wax layer on the tips of some pine needles is relatively smooth, other needles of comparable age from the same or from another pine tree may exhibit shapes similar to those shown in Fig. 1 (*Pinus echinata*). Wax fingers are also found on other species of trees. The tips exhibiting the elongated wax fingers tend to be in exposed areas such as on the tops of trees, on the outside of a lone tree, or on the margin of a stand. Melting of the wax cannot be invoked as an explanation for the observed configuration for several reasons, chief among which is that the tips point upward.

It is suggested that the wax fingers represent the preserved record of a conduction path which became molten during the atmospheric phenomenon usually referred to as brush discharge. To test that hypothesis, pine needle specimens were mounted on one of a pair of electrodes in a closed system and subjected to various electrical gradients in the laboratory. In each case carbon-coated disks were attached to the opposite electrodes, and the collected particulates were replicated and examined with an electron microscope. Particles collected when the pine needle was raised to a potential of 20 kv with respect to a flat plate 20 cm away are shown in the electron micrograph (Fig. 2). At lower potentials the particles were similar in size but less concentrated, whereas at 30 kv the wax fingers began to shatter and irregular strips and chunks were collected. The small wax particles released under low to moderately high potential gradients have diameters in the size range < 0.6 μm; particles in this size range may be a major factor in the production of blue haze.

Chalmers (*8*) has measured a significant conduction current passing through a small tree. The local, flat-field potential gradient easily can reach several thousand volts per meter as electrified clouds pass overhead; in an electrical storm gradients much higher than this may be recorded. These observations suggest that discrete wax particles in the appropriate size range to produce blue haze are generated by natural forces in the environment. Other types of vegetation, including grasses, could, in principle, emit wax particles under similar conditions. In the brush discharge phenomenon, high potential gradients occur at the sharp edges and tips of leaves, producing a blue glow at night. Undoubtedly, such factors as the dielectric strength of the wax, its melting point, the ambient temperature, the radius of curvature of the underlying conductive surface, and the exposure of the plant all have some bearing on the rate of production of wax aerosols. Other extrinsic factors, such as gaseous or particulate air pollutants, may affect the properties of the wax so as to reduce or enhance the rate of wax attrition, possibly leading to the denudation of the needle tip and the eventual loss of the needle because of excessive drying.

Went (*2*) has suggested that the blue haze aerosols, returned to the ground by various natural processes, may be a source of the petroleum formed in earlier geological periods. The presence of significant quantities of waxes in crude oil and the observation of a mechanism for the generation of wax aerosols in the environment suggest that the wax particles, which may serve as condensation nuclei for terpenes and other organic gases, may be a complementary factor in the phenomena described by Went. Another implication is that radioactive fallout collected on the sharp edges and tips of vegetation may be reemitted to the atmosphere during the next thunderstorm after its initial deposition. In this same connection, particulate silver iodide from cloud-seeding operations may be retained locally for a period of time and be reentrained into an unseeded cloud, producing the "memory effect" that has been observed by some atmospheric scientists (*9*).

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22 November 1971

Plastics on the Sargasso Sea Surface

Abstract. *Plastic particles, in concentrations averaging 3500 pieces and 290 grams per square kilometer, are widespread in the western Sargasso Sea. Pieces are brittle, apparently due to the weathering of the plasticizers, and many are in a pellet shape about 0.25 to 0.5 centimeters in diameter. The particles are surfaces for the attachment of diatoms and hydroids. Increasing production of plastics, combined with present waste-disposal practices, will undoubtedly lead to increases in the concentration of these particles. Plastics could be a source of some of the polychlorinated biphenyls recently observed in oceanic organisms.*

While sampling the pelagic *Sargassum* community in the western Sargasso Sea, we encountered plastic particles in our neuston (surface) nets. The occurrence of these particles on the sea surface has not yet been noted in the literature [we also collected petroleum lumps, which have received attention (*1, 2*)].

The plastics were collected with a neuston net (*3*), 1 m in diameter with 0.33-mm meshes, towed at 2 knots (1 knot = 1.85 km/hour) on cruise 62 of the *Atlantis II* (27 September to 18 October 1971). The particles of plastic were manually sorted from the contents of the neuston tows; they were counted and their weights were determined on shore with a Mettler H 15 balance. Plastics were present in all 11 neuston tows (Table 1). Their occurrence was widespread, since the distance from the southernmost to the northernmost tow was 1300 km.

There were, on the average, about 3500 plastic particles per square kilometer (the range was from 50 to 12,000). This density gives a mean of one particle per 280 m^2 and a maximum of one particle per 80 m^2. The weight per square kilometer was from 1 to 1800 g and averaged about 290 g. The lowest concentrations were observed at stations 10 and 11, as we began to enter the Gulf Stream.

Most of the pieces were hard, white cylindrical pellets, about 0.25 to 0.5 cm in diameter, with rounded ends (Fig. 1). Chemical weathering and wave action may have produced the pellet shape. Many pieces were brittle, which suggests that the plasticizers had been lost by weathering. Some had sharp edges, which indicates either recent introduction into the sea or the recent breaking up of larger pieces. A few particles (6 percent by number) were colored green, blue, or red, and there were also a small number of clear sheet plastics. Several larger pieces could be identified as a syringe needle shield, a cigar holder, jewelry, and a button snap. From the variety of identifiable objects, it was evident that many types of plastics were present. Solvent assays and burning properties of some of the white pellets indicated that they were not polystyrenes, acrylics, or polyvinyl chlorides.

Most plastics had populations of hydroids and diatoms attached to their surfaces. We noted the hydroids *Clytia cylindrica* and *Gonothyraea hyalina* and the diatoms *Mastogloia angulata, M. pusilla, M. hulburti, Cyclotella meneghiniana,* and *Pleurosigma* sp. With the exception of the last, these species have previously been observed on pelagic *Sargassum* (*4*). Hydroids and diatoms have not been reported on petroleum lumps, whereas goose barnacles *(Lepas)* and isopods *(Idotea)* have (*1*).

The source of the particles may have been the dumping of waste from cities or by cargo and passenger ships. However, no metropolitan dumping occurs in the areas sampled, although some of the southernmost sample areas are within major shipping lanes from Europe to Central America and the Panama Canal. The station closest to land, station 6, was 240 km northeast of Bermuda. Stations 10 and 11, the closest to the continent, were about 900 km southeast of New York City.

Plastics have been produced in large quantities only since the end of World War II. The increasing production of plastics, combined with present waste-disposal practices, will probably lead to greater concentrations on the sea surface. At present, the only known biological effect of these particles is that they act as a surface for the growth of hydroids, diatoms, and probably bacteria.

Many plastics contain considerable concentrations of polychlorinated biphenyls (PCB's) as plasticizers. If the plasticizers have been lost to seawater, as suggested above, the incorporation of PCB's by marine organisms is possible. Polychlorinated biphenyls have recently been observed in pelagic *Sargassum* and oceanic animals (*5*).

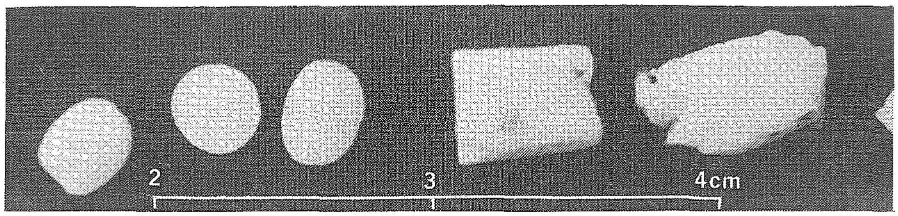

Fig. 1. Typical plastic particles from tow 2. White pellets are on the left.

Table 1. Neuston tow data.

Tow number	Date (October 1971)	Towing time (hours)	Location at start	Number collected	Weight collected (g)	Concentration	
						Number/km^2	g/km^2
1	12	2.25	30° 10.5′N 60° 02.5′W	5	0.31	601	37.7
2	12	2.66	30° 19.4′N 60° 00.9′W	48	2.48	4,877	251.9
3	12	4.08	30° 55.6′N 59° 57.1′W	22	1.06	1,457	70.2
4	13	1.00	31° 51.7′N 60° 37.8′W	4	0.22	1,081	60.0
5	13	0.50	32° 25.2′N 61° 14.6′W	8	0.73	4,324	395.1
6	14	6.50	33° 32.5′N 62° 30.9′W	62	2.48	2,579	103.3
7	14	0.85	34° 21.8′N 62° 53.0′W	38	5.57	12,080	1,770.7
8	15	1.00	35° 15.4′N 63° 46.3′W	17	0.96	4,595	258.9
9	15	0.85	35° 37.4′N 64° 20.8′W	22	0.64	6,994	201.9
10	16	1.00	37° 02.0′N 65° 41.0′W	1	0.22	270	4.9
11	16	5.75	37° 00.5′N 65° 34.8′W	1	0.08	47	0.6
					Mean	3,537	286.8

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6. Supported by Northeast Utilities Service Co. and NSF grant GZ 1508. We thank Dr. J. M. Teal for allowing us to participate on R.V. *Atlantis II*, cruise 62, and Ralph Vaccaro and Drs. H. Jannasch, J. Ryther, W. Deuser, and C. Remsen for their review of the manuscript. Woods Hole Oceanographic Institution contribution 2756.

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