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OCEAN COLOR -

A THREE COMPONENT SYSTEM?

Research report

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OCEAN COLOR, A THREE COMPONENT SYSTEM ?

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INTRODUCTION

Most of the light energy entering the sea is absorbed by the water or substances in the water, particulate and dissolved. Phytoplankton are the most obvious particulate absorber while the yellow organics (Gelbstoff) is the dominate dissolved material. By knowing the general features of light transmission or absorption of these substances, one can empirically model ocean color, that is, predict color change from a change in concentration of either absorbing substance (Yentsch, 1960). When both substances are present in natural waters, which is frequently the case, then the prediction of the causes of color change is complicated because both substances absorb short wave lengths in a similar manner.

Generally speaking, the biochemical relationships between phytoplankton and yellow substances is poorly known and hence the ability to predict the distribution vis-a-vis of either substance throughout the oceans is hampered. There have been numerous physical-chemical relationships suggested between phytoplankton and yellow substances. But since much of the yellow substance is associated with fresh water (river inflow) which carries a wide variety of other compounds that can influence phytoplankton growth, these suggestions are difficult to test.

In this study we have measured the concentrations of phytoplankton chlorophyll and yellow substance in the coastal

waters of the Gulf of Maine. The questions we are trying to resolve concern:

- 1) Relationships of these substances, that is, how do concentrations of either substance vary with respect to one another? Is there a positive, negative, or no correlation between the two substances?
- 2) Is the relationship between absorbing characteristics of particulate matter and spectra of backscattered light compatible? That is, can one explain the spectral characteristics of backscattered light by the absorbing characteristics of particulates?

Since the study represents a cooperative effort with scientists at Goddard interested in the high altitude detection of water color, sea surface observations were laid on to delineate areas of high and low phytoplankton productivity with emphasis on the seaward extent of areas of high productivity.

SEA SURFACE OBSERVATIONS

Dr. Hovis, using a variety of remote sensing equipment, overflew the area on July 7 and 8, 1972. We had planned the overfly to directly coincide with the sea-surface observations made from the research vessel R.V. Bigelow, operating out of Cape Ann. Realistically, this was not always possible; communication with the N.A.S.A. aircraft was sporadic and some areas had low level cloud cover.

In this report, we attempt to delineate the principal biochemical parameters responsible for sea surface color. Some of these observations such as phytoplankton chlorophyll were made continuously while underway aboard the Bigelow. Other measurements, such as dissolved yellow substances and the spectra of upwelled light were made at selected stations. The choice of the location for these measurements was dependent upon previous sampling by our research group in the area.

The data was obtained along three legs of stations (Fig. 1). Leg 1 extends from the mouth of the Merrimack River to the sea. Leg 2 extends from the seaward extent of Leg 1 to the tip of Cape Cod. Leg 3 covers the region between Cape Cod Bay and Gloucester.

OBSERVATIONAL TECHNIQUES

1) Phytoplankton chlorophyll was measured continuously by pumping surface water through the Turner model 111 fluorometer. Excitation wave length was 450 nm; emission was measured at 670 nm. Output was recorded on a 10 MV stripchart recorder. The fluorometer was "zeroed" every hour using distilled water, and the unit calibrated against total chlorophyll measured by extractive technique. The fluorescence trace was reduced from the stripchart recorder for presentation in this document.

2) The dissolved yellow substances in surface waters was measured at 350 nm in a spectrophotometer using air as a reference. The sample was prefiltered with a one micron filter. The values used in this report are the percentage of light absorbed over the 10 cm light path.

3) The amount of visible light attenuated by particulate matter in the surface water was measured using the method of Yentsch (1962). One liter of water was filtered, and the filtrate was scanned spectrophotometrically in the region of 350-750 nm, using a plain filter as reference.

4) The spectra of upwelled light was scanned between 350-750 nm using a "downlooking" monochromator/photodetector combination which could be submerged just under the sea surface. Spectra resolution of this unit is about 2 nm over the entire region, while photometric accuracy (repetitive scans) is about 5%.

5) Water temperature was recorded continuously, and samples were taken for salinity approximately every 30 minutes during steaming.

SPATIAL DISTRIBUTION OF PHYTOPLANKTON CHLOROPHYLL
JULY 8 - 9 1972

Along this coast, large growths (blooms) of phytoplankton occur from nutrient enrichment either by upwelling of deep waters or by pollution. The distribution of phytoplankton chlorophyll along Leg 1, Merrimack River to sea (Fig. 2) is an example of coastal enrichment by river inflow. In this case, nutrients are supplied by the polluted river water. As the fresh water mixes with coastal in the tidal estuary, there is a net transport of this mixture seaward. The timing is such that maximum growth probably occurs somewhere near the mouth of the estuary and/or near the coast. In these regions, chlorophyll concentrations near the coast are as high as one ever observes in this area. A more representative level (normal) of chlorophyll concentration for this season occurs at the seaward stations. Water samples revealed that the phytoplankton bloom consisted of the common diatom species Skeletonema costatum. The width of the bloom (50% of maximum) was about seven nautical miles. The decrease of chlorophyll seaward was exponential, the rate of change leaving the maximum, going seaward, gradually decreased. This pattern of change is associated with increasing salinity in this section, which suggests that population size is the result of a gradual dilution of enriched river water moving seaward. At stations two and three, copepods were extremely abundant, suggesting that grazing pressure was also important.

Chlorophyll concentrations somewhat less than $0.2 \mu\text{g}/\text{l}$ were recorded from the first 25 miles along Leg 2 (Fig. 3), which roughly paralleled the coast. However, off Cape Cod in the region of Stellwagen Bank, another phytoplankton bloom was encountered. This bloom was composed of an equal mixture of the diatoms Skeletonema costatum and Thalassiosira sp. The shape of the change in concentration with distance was somewhat more symmetrical than the coastal bloom; however, the width of the bloom (50% of maximum) was about the same.

The cause of this bloom must be some vertical mixing process associated with the hydrography of the area. Physical evidence is the lower water temperatures associated with the bloom. Most of Massachusetts Bay is thermally stratified at this time of year. Lower surface temperatures can only result from upward mixing of deeper waters.

Because of low level cloud cover, Leg 3 (Cape Cod to Wilkinson Basin) was abandoned. Leg 4 crossed Massachusetts Bay on a northeast course, ending in Gloucester Harbor. On this leg, a small increase in phytoplankton chlorophyll was encountered in the central region of the Bay (Fig. 4). This could have been a portion of the bloom observed on Leg 2. In the coastal waters off Cape Ann, another massive bloom was encountered. From past experience, we recognize this bloom to be a rather persistent feature at this time of year. It is largely the result of the wind system which generates coastal upwelling.

RELATIONSHIP OF YELLOW SUBSTANCE TO PHYTOPLANKTON CHLOROPHYLL ALONG LEG 1

First, and probably the most important point is that the amount of yellow substance (Fig. 2) is inversely related to salinity. Thus, the pattern of distribution must closely represent the mixing ratio between river and coastal ocean water. The second point is that Merrimack waters carry large amounts of nitrogen and phosphorus. Nitrogen is in limiting quantities in the coastal waters at this time. Therefore, the presence of fresh water means enrichment, and since fresh water and yellow substance are correlated, then the presence of yellow substance also means enrichment. The net result is that there is a positive correlation between yellow substance and phytoplankton chlorophyll.

CHARACTERISTICS OF VISIBLE LIGHT ATTENUATION BY PARTICULATE MATTER ON LEG 1

The red absorption band of chlorophyll a (672 nm) is apparent in the spectra of particulate matter in the section (Fig. 5). Also, the influence of the chlorophyll Soret band and carotenoids can be seen on the background of high short wave length attenuation. The high attenuation of short wave length has been seen in other samples of ocean particulate matter (see Yentsch, 1962). The difference between these spectra and pure phytoplankton (Fig. 6) suggest that the additional particulate absorber is very similar optically to dissolved yellow substances. Or to turn the statement around, not all of the yellow substances are dissolved, there are "particulate yellows".

The interrelationship between the absorbers can be summarized as follows:

- 1) There appears to be a positive correlation between phytoplankton chlorophyll (band intensity at 670 nm) and the "particulate yellows".
- 2) There is a positive correlation between the "particulate yellows" and dissolved yellows.
- 3) The source of the particulate yellows is not known. They could arise from the metabolic activities of the phytoplankton, or they may be a particulate form introduced with river water.

CHARACTERISTICS OF BACKSCATTERED LIGHT ALONG LEG 1

A change in water color was visible from the deck of the research vessel; off the Merrimack, waters were reddish brown, whereas the open Gulf was blue-green. Spectral (Fig. 7) characteristics of the upwelling light at Station 1 show a massive reduction of short wave length of light which agrees with the high attenuation by particulate matter at that station. Maximum backscattered light occurred at wave

lengths 600 nm or longer. As phytoplankton and yellow substances decrease moving seaward, the maximum backscattered light shifts from longer to shorter wave length, which is what would be predicted, knowing the attenuation characteristics of the particulates. The surprising thing is the large amount of backscattered light (Station 1) at wave lengths of 600 nm or longer. This means that in waters containing large amounts of phytoplankton and yellow substances the backscattered light spectra is categorized not only by a loss of short wave lengths, but long wave lengths are augmented due to scattering.

ABSORPTION VS. SCATTERING WITH REFERENCE TO IMAGERY AT ALTITUDE

To model ocean color based on two absorbers (phytoplankton pigments and yellow substance) plus water is an oversimplification. Absorbing materials other than the photosynthetic pigments are present in large quantities in the particulate matter. We label these as particulate yellows. Although their absorption spectra is not known, there is ample evidence that the spectra is not too different from dissolved yellow substances. However, it is doubtful that any simple scheme can be devised to predict the amounts of particulate yellows present. The other oversimplification concerns light scattering. It has been the practice of this laboratory as well as others, to consider ocean color the result of a constant level of backscattered light, where wave lengths are selectively removed by absorption. Our measurements show that water color also depends to a great extent upon the depth to which light penetrates in the water column. In areas of low transparency (e.g. Station 1), more light of lower wave lengths is backscattered than is the case for water of high transparency (e.g. Station 4). Since long wave lengths are strongly absorbed by water, this means that the scatterers are very near the surface.

The spectra of backscattered light is not known for all oceanic conditions; however, we submit that a rather general scheme to distinguish phytoplankton from yellow substances can be worked out using broad band sensors similar to those used by ERTS-A satellites. Our observations show that phytoplankton, in addition to absorbing blue wave lengths, strongly backscatter red wave lengths. Dissolved yellow substances alone will attenuate short wave lengths without augmentation of long wave lengths.

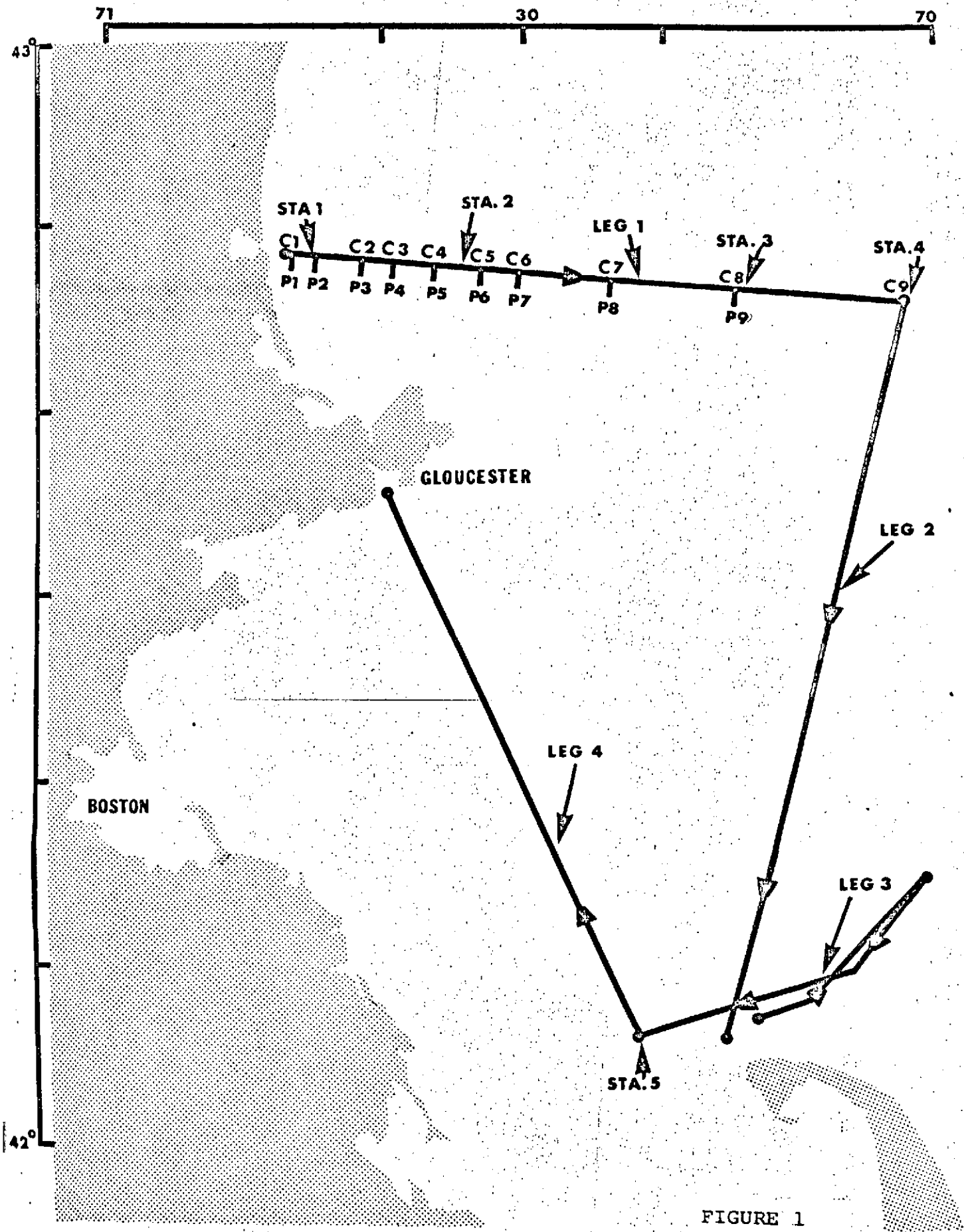
The usefulness of such a predictive system is worth documenting. We are already on record advocating the use of chlorophyll measurement in oceanic fisheries. We feel strongly that satellite sensing will be a useful tool for coastal waters. Some examples are mapping the red tide, and general studies of coastal eutrophication. In this report, we have demonstrated how measurements of dissolved yellow substances are used to interpret the causative factors for phytoplankton growth (see page 5 on yellow substance distribution). The key in this exercise is the interrelationship between the dissolved yellow substances and fresh water. Therefore, the yellow substance offers the opportunity to perform a flushing experiment using yellow substance as a natural dye indicator. This opens the possibility of making large aerial estimates of the influence of fresh water discharge in coastal areas a problem heretofore unattainable.

LITERATURE CITED

- Yentsch, C.S., "The Influence of Phytoplankton Pigments on the Color of Sea Water", *Deep-Sea Research*, 7 1-9 (1960)
- Yentsch, C.S., "Measurement of Visible Light Absorption by Particulate Matter in the Ocean", *Limnol. Oceanog.* 7: 207-217, 1962

FIGURES

- Figure 1. Area of study, July 8-9
- Figure 2. Leg #1, Merrimack to sea
A. temperature and salinity
B. continuous chlorophyll fluorescence (solid line). Black dots, extracted chlorophyll; dotted line, dissolved yellow substance
- Figure 3. Leg #2, Station 4 to Cape Cod
A. temperature and salinity
B. continuous chlorophyll fluorescence
- Figure 4. Leg #4, Massachusetts Bay to Gloucester
A. temperature and salinity
B. continuous chlorophyll fluorescence
- Figure 5. Attenuation of light by particulate matter
- Figure 6. Attenuation of light by four species of cultured phytoplankton (Yentsch, 1960).
- Figure 7. Spectra of backscattered light, stations 1-4



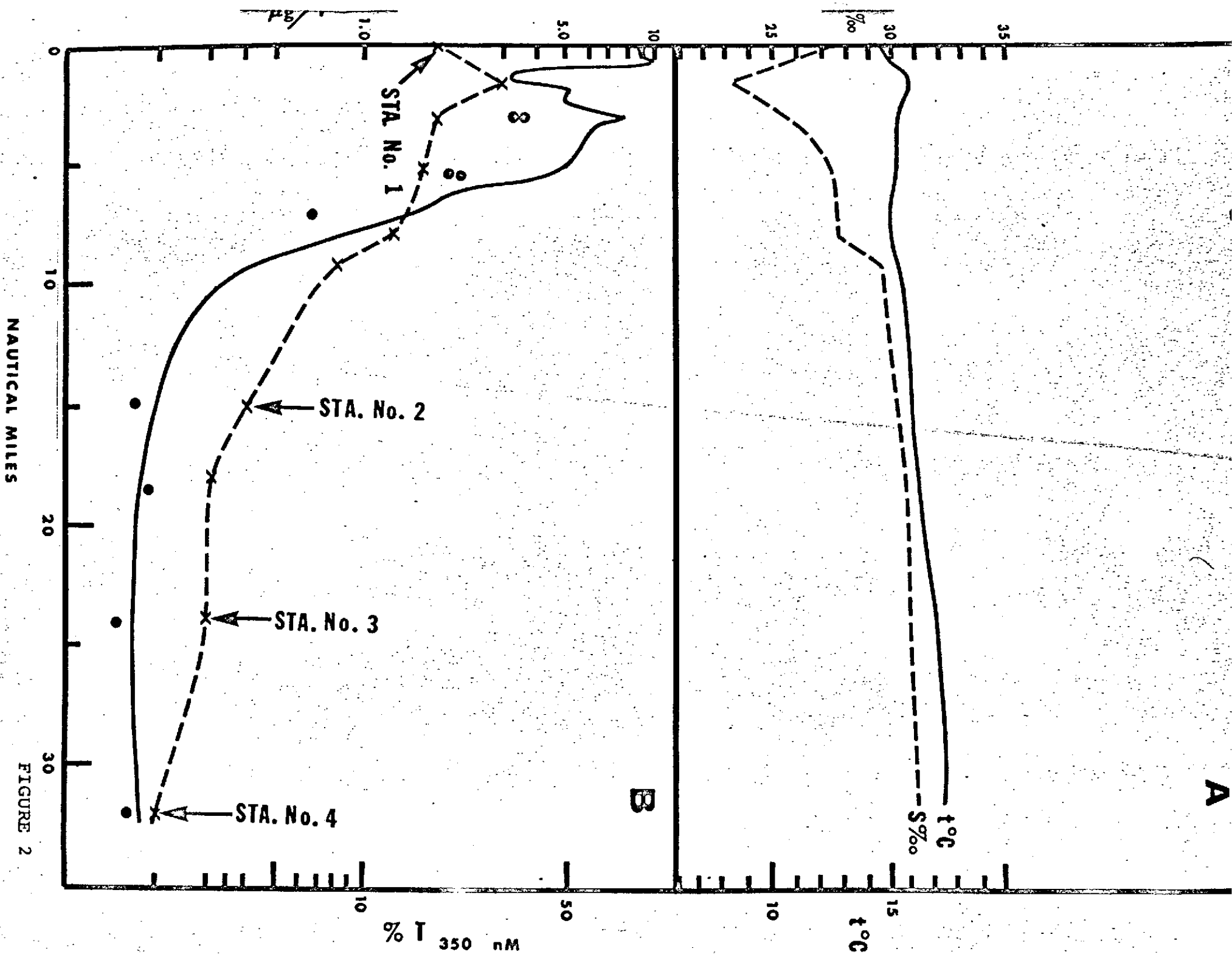
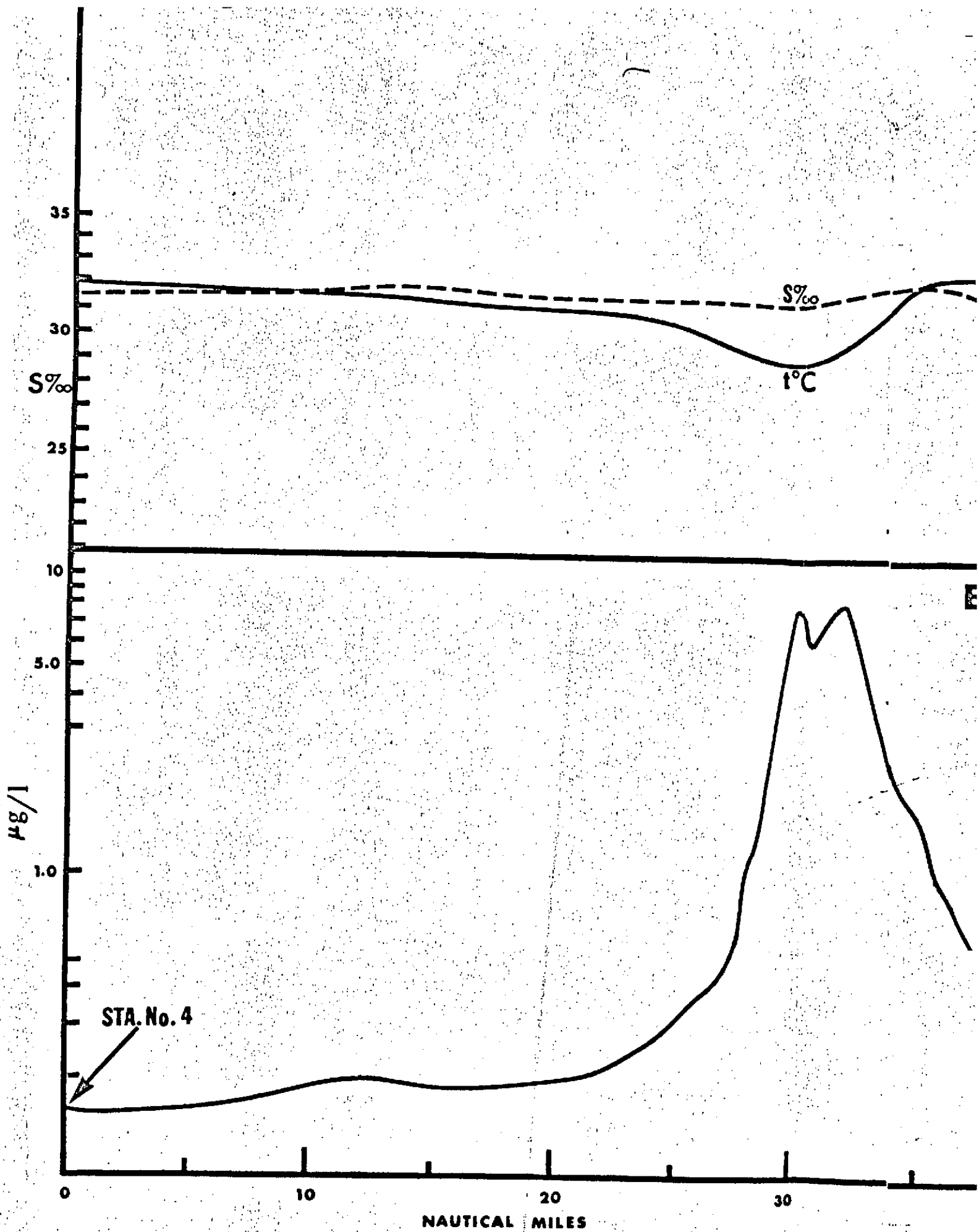


FIGURE 2



FIGUR

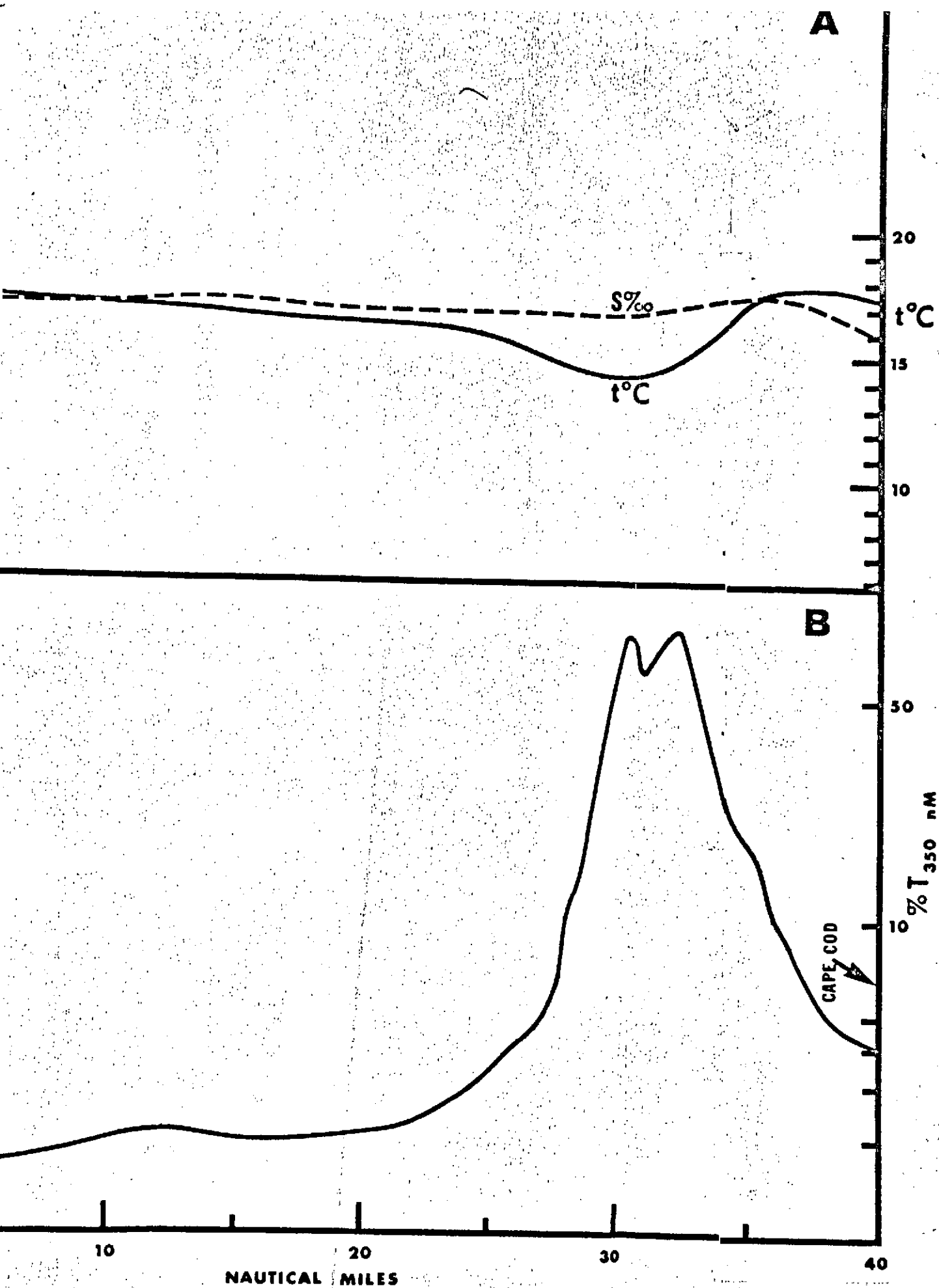


FIGURE 3

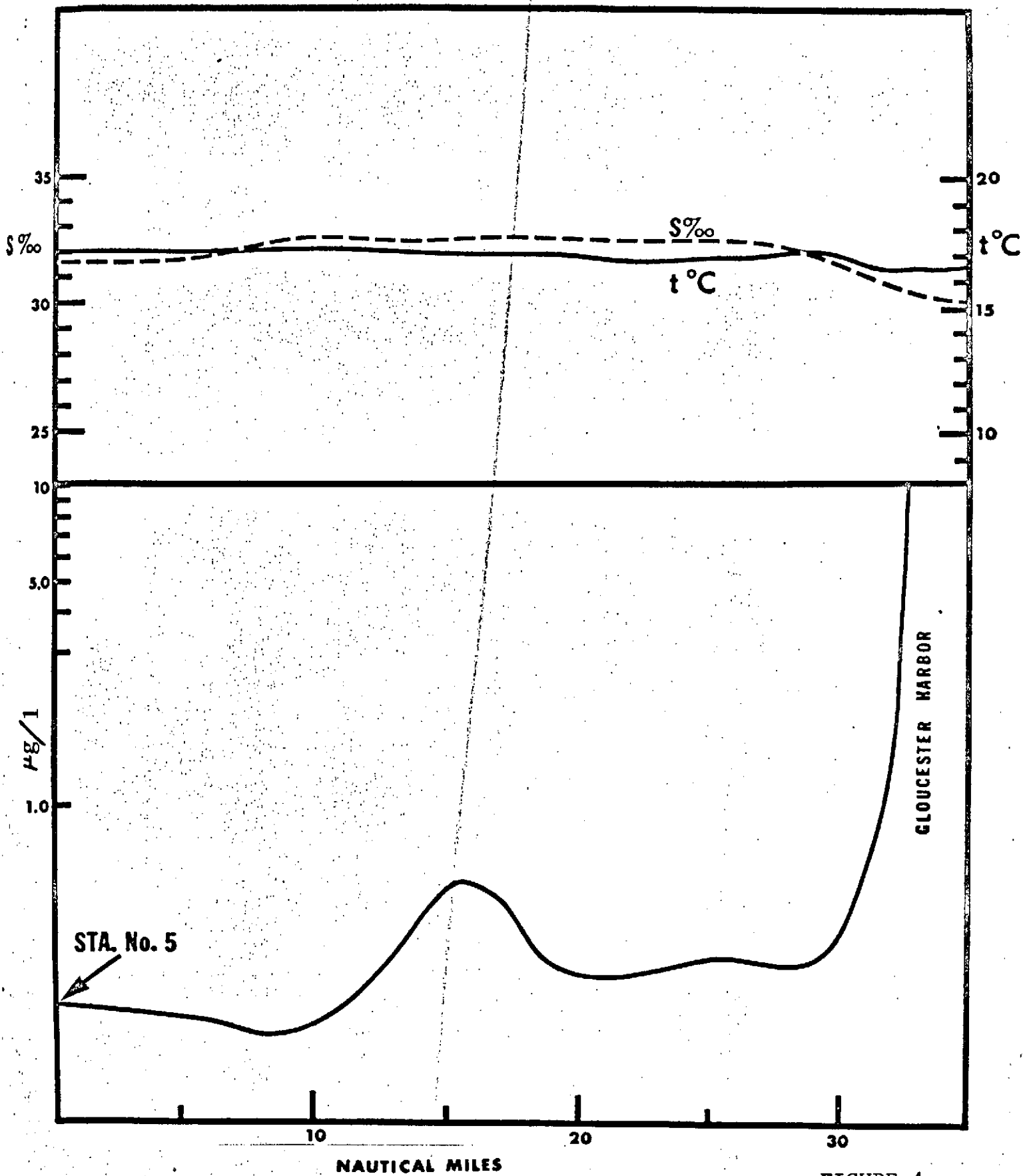


FIGURE 4

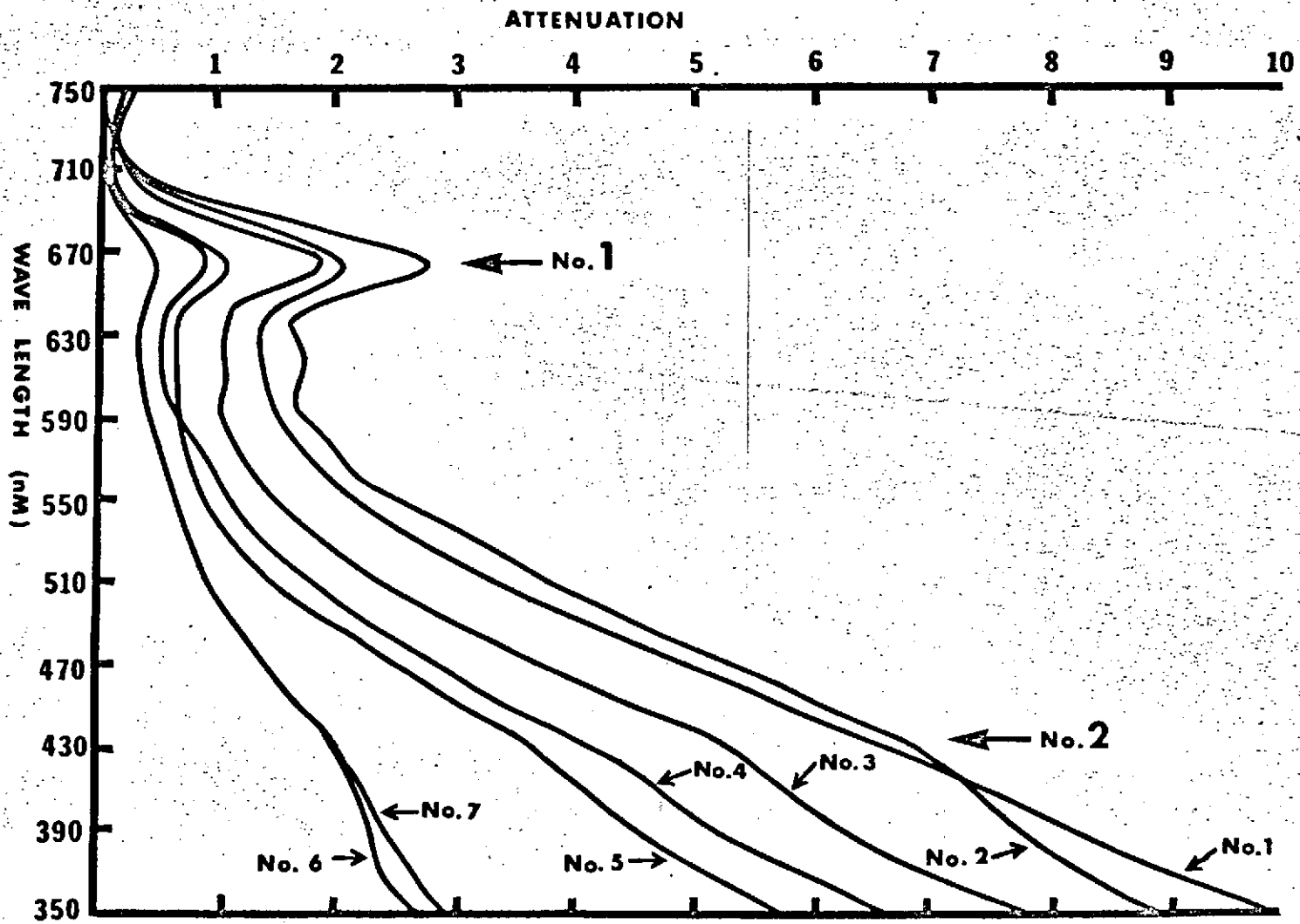


FIGURE 5

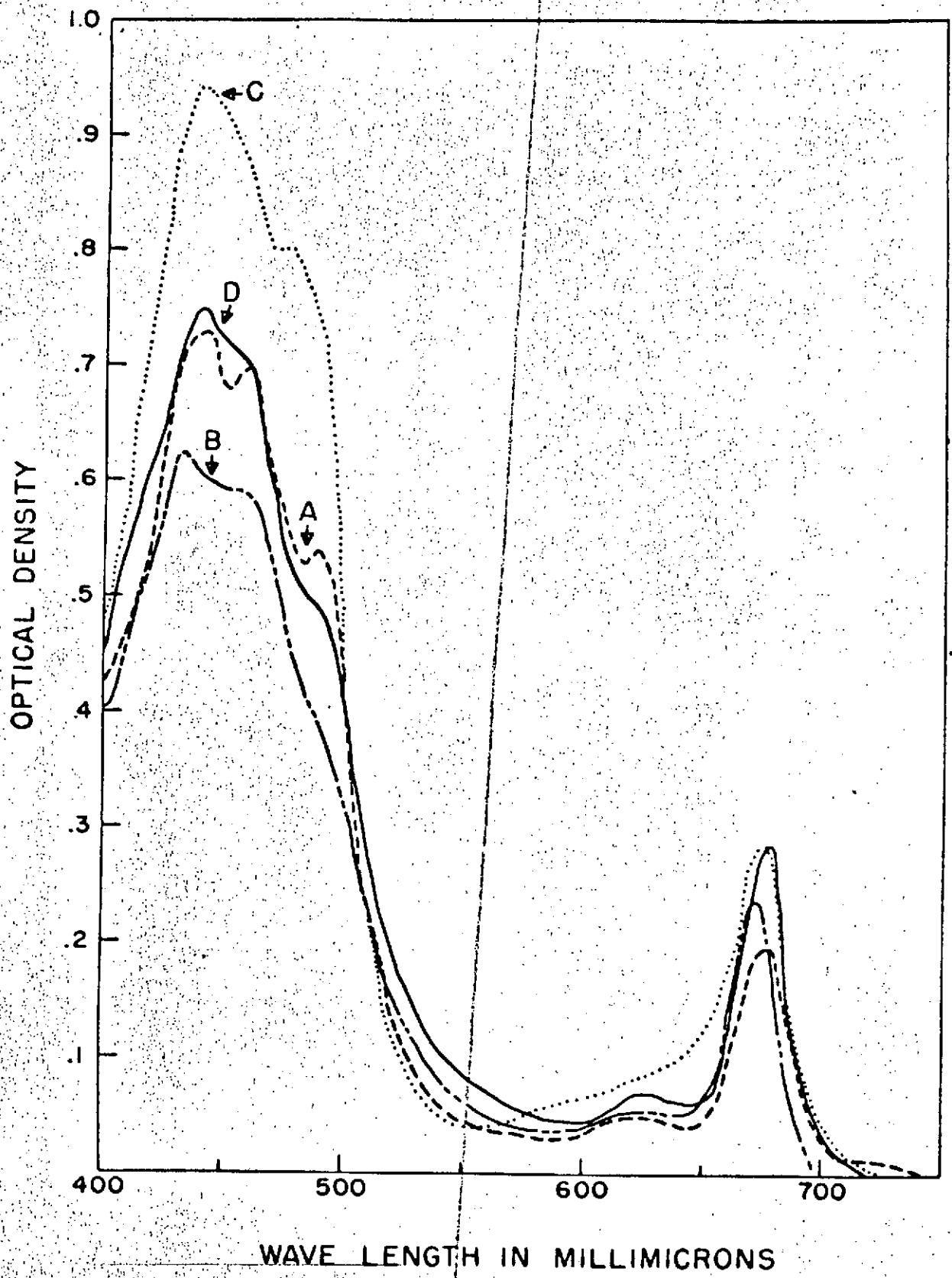


FIGURE 6

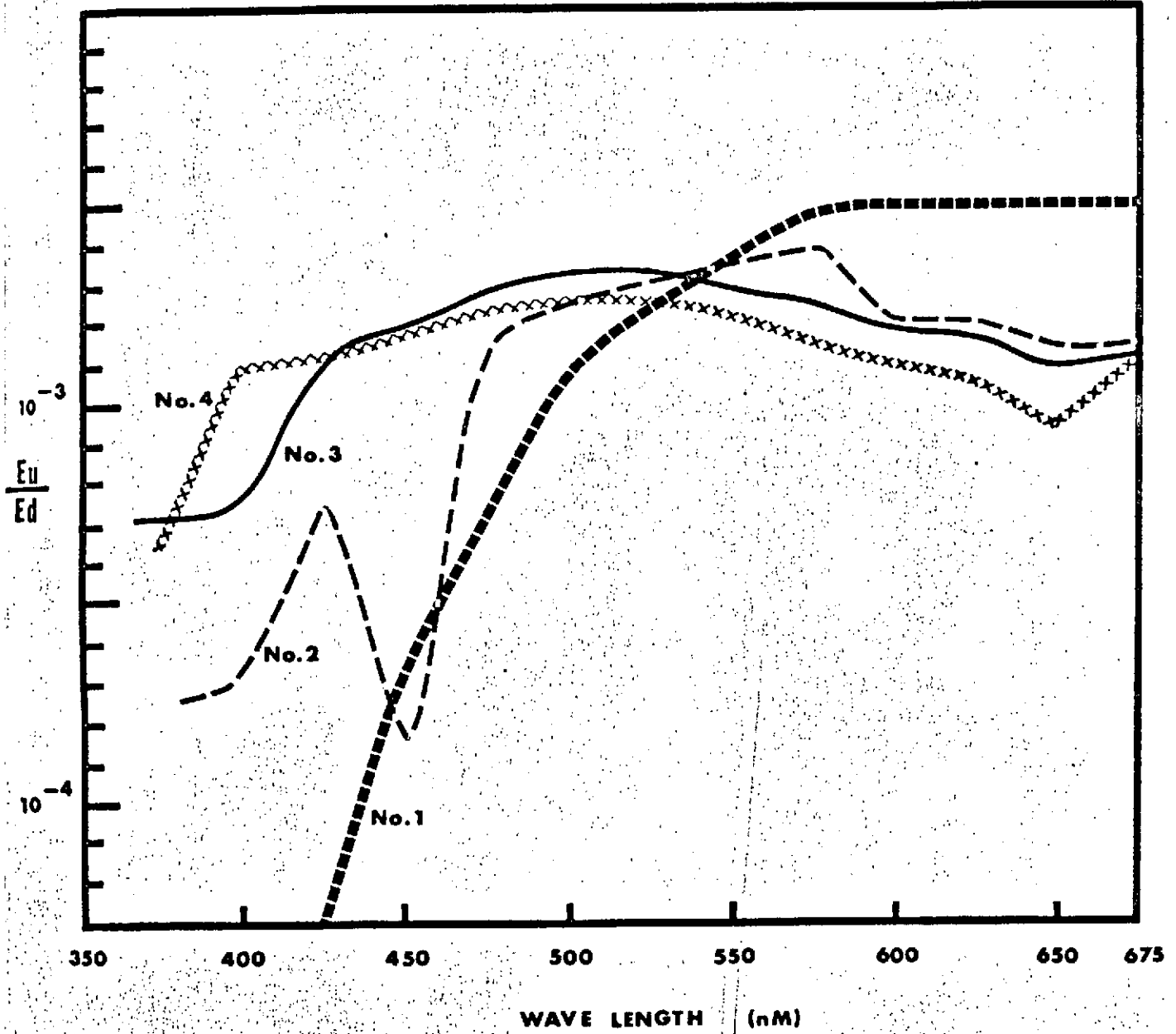


FIGURE 7