SUPERFLUX I, II, and III EXPERIMENT DESIGNS:

WATER SAMPLING AND ANALYSES

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INTRODUCTION

Superflux, a joint National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA) study, with state and academic participation, involves both airborne remote sensors and sea-going oceanographic research vessels. Its purposes are to: 1) advance the development and transfer of improved remote sensing systems and techniques for monitoring environmental quality and effects on living marine resources; 2) increase our understanding of the influence of estuarine "outwellings" (plumes) on contiguous shelf ecosystems; and 3) provide a synoptic, integrated and timely data base for application to problems of marine resources, and environmental quality. As such it is a study which requires a multi-disciplinary and, consequently, a multi-organizational approach.

Chesapeake Bay is the largest estuary in the United States and is under ever-increasing use and stress by man. The potential for studying effects of increasing stress on offshore environments, plus the potential for developing a coherent study with a number of investigators, each providing different yet relevant talents, led us to select the Chesapeake Bay mouth and offshore plume as a primary area for studying estuarine-shelf interactions in conjunction with remote sensing. The use of airborne remote sensors in concert with sea-going oceanographic research vessels offered the potential to understand a tidally dynamic area. The remote sensors could provide a synoptic picture of the surface distributions and abundances of selected variables (temperature, salinity, chlorophyll a, phytoplankton color groups, and total suspended matter). Surface ships provide the data required to calibrate the remote sensors (as sea truth) as well as the three-dimensional view of the water column required to interpret remote sensing imagery. Additionally, ships can collect data not directly relatable to that from remote sensors (certain contaminants and biostimulants, as well as biological effects data) yet of high interest in terms of environmental quality and resource management. Such measurements, it would be hoped, would be relatable to certain of the variables measured by remote sensors. In that way, remote sensing imagery could help solve the temporal-spatial problems encountered by ships in tidally dynamic areas by providing, in conjunction with shipboard data for interpretability, synoptic information relevant to the determination of environmental quality and the management of resources. The goal of Superflux is to hasten the day when this would occur.

To date three experiments, timed to coincide with periods of high, medium, and low freshwater discharge, have taken place. These were 11-20 March 1980 (Superflux I), 17-27 June 1980 (Superflux II) and 13-22 October 1980 (Superflux III). Drought conditions existed during Superflux experiments II and III.

SUPERFLUX I

During the first experiment (11-20 March 1980), NASA flew four missions with airborne remote sensors. The missions were of two basic types: 1) plume mapping missions which overflew the Chesapeake Bay mouth and plume area, and 2) shelf transect missions which flew from the James River mouth east across the shelf to the continental slope/rise area. The low altitude missions across the shelf and over the plume collected data with two laser fluorosensors (Airborne Lidar Oceanographic Probing Experiment-ALOPE and an Airborne Oceanographic Lidar-AOL) for chlorophyll, phytoplankton color groups and total suspended matter, an L-band microwave radiometer for salinity, and a PRT-5 infrared radiometer for temperature. On the high altitude flights, a narrow swath width (nadir looking) Multichannel Ocean Color Scanner (MOCS) was used to sense chlorophyll and total suspended matter. The L-band microwave and PRT-5 infrared radiometers were also used.

The Northeast Fisheries Center (NEFC), National Marine Fisheries Service (NMFS), in conjunction with the NOAA, National Ocean Survey (NOS), the U. S. Coast Guard, Old Dominion University (ODU), and the Virginia Institute of Marine Science (VIMS), collected the required sea truth for these missions (figs. 1 and 2). As part of the experimental design, pre- and post-survey flights by a VIMS Beaver aircraft were made to provide visual information on the location and shape of the Chesapeake plume (figs. 3 and 4). The pre-survey flight information was used to establish station locations for a detailed cruise between the mouth of Chesapeake Bay and Oregon Inlet, North Carolina to define the three-dimensional structure of the plume in regard to temperature, salinity, dissolved oxygen, chlorophyll a, phaeopigments, and total plankton respiration (fig. 5). Additional independent studies (Bay Plex) were carried out in the bay mouth by Dr. George Oertel and colleagues, ODU, and in the plume for fine structure definition by Dr. John Ruzecki, VIMS.

SUPERFLUX II

The second experiment (17-27 June 1980), in terms of area flown, ships participating, sensors used, and oceanographic variables measured, was greatly expanded relative to the first operation. NASA flew seven missions which included four over the plume, one across the shelf, one over the Delaware Bay mouth, and one up the full length of the Chesapeake Bay. The low altitude flights over the Chesapeake and Delaware plumes and across the shelf involved the use of two laser fluorosensors (ALOPE and AOL), the MOCS, the L-band microwave radiometer, and the PRT-5. The high altitude flights over Chesapeake and Delaware bays, across the shelf and over the Chesapeake plume, used the nadir looking MOCS, the L-band and PRT-5 radiometers, as well as a relatively wider swath width scanner (Test Bed Airborne Multichannel Scanner-TBAMS), which was felt might be more suitable for two-dimensional mapping of chlorophyll and total suspended matter.

In conjunction with a large number of institutions including NOS, NASA, U. S. Naval Academy, State of Maryland Department of Natural Resources, University of Delaware, Anne Arundel Community College, University of Miami, Chesapeake Bay Institute (CBI), ODU, and VIMS, NEFC participated in the experiment to provide sea truth and other measurements. A total of 14 vessels participated (fig. 6). Again, a VIMS Beaver aircraft made pre- and post-survey overflights to provide information on the location and shape of the Chesapeake plume (fig. 7). Based on this information, the NOAA ship *Delaware II* occupied 26 stations from the mouth of the Chesapeake Bay south to Oregon Inlet, North Carolina (fig. 8) to gather data throughout the water column in regard to temperature, salinity, dissolved oxygen, nutrients, chlorophyll a, phaeopigments, phytoplankton species composition, total suspended matter (TSM) and total plankton respiration. Additional work under contract was carried out aboard the *Delaware II* at the 14 northernmost stations closest to the bay mouth. Contracts were given to: 1) ODU (Drs. Terry Wade and George Oertel) to study hydrocarbons associated with total suspended matter; 2) VIMS (Dr. Richard Harris) to examine selected heavy metals associated with total suspended matter; and 3) VIMS (Drs. Howard Kator and Paul Zubkoff) to study bacterial biomass and heterotrophic potential associated with the Chesapeake plume. Other contract work to ODU, including nutrients (Dr. George Wong), phytoplankton species composition (Dr. Harold Marshall), and TSM (Dr. George Oertel), was initiated to see if we could use remote sensing to tell us something about contaminants, biostimulants, and biological effects in the plume area.

During this experiment, NEFC also collected continuous underway and discrete samples (every 10-15 minutes) across the shelf and along several transects of the plume for chlorophyll a and phaeopigment determinations, both in conjunction with remote sensing overflights and independent of them (fig. 9).

Additional studies were undertaken by VIMS (Dr. John Ruzecki) to examine the fine structure of the plume in regard to temperature, salinity, and chlorophyll. This was accomplished by collecting continuous underway data with periodic stations for conductivity, temperature and depth (CTD) casts. ODU (Dr. George Oertel and colleagues) again performed a comprehensive set of experiments called Bay Plex in the Bay mouth. These experiments were designed to provide information about the source of the various water masses coming out of the mouth of Chesapeake Bay. During this same time, CBI (Dr. Bill Boicourt) moored some 50 current meters in lower Chesapeake Bay and adjacent shelf area. Finally, the University of Miami (Dr. Mitch Roffer) examined the distribution of certain fish in relation to sea surface temperature obtained via satellite and shipboard measurements.

SUPERFLUX III

During the third experiment (13-22 October 1980), NASA flew four missions, two of which were for plume mapping and two shelf transects; all were high altitude. Two aircraft, a NASA P-3 carrying a nadir looking MOCS and a NASA Lear Jet carrying a wide swath width Ocean Color Scanner (OCS), participated to examine total suspended matter and chlorophyll concentrations both in the plume and across the shelf.

The NEFC, with NASA, VIMS, and ODU, collected required sea truth for each of these missions. The experiment started on 13 October with a pre-survey flight by the VIMS Beaver Aircraft (fig. 10). The results of that flight plus pre-mission satellite imagery of the area were presented at a pre-cruise meeting by Dr. John Ruzecki (VIMS) and Dr. Fred Vukovich (Research Triangle Institute, North Carolina), respectively. Dr. John Munday (VIMS), also under contract, presented preliminary information in regard to Landsat images of the area. Based on this information the R/V *Kelez* carried out a plume survey (fig. 11). At the northernmost 14 stations (excluding stations 822 and 824), samples were collected throughout the water column for determination of hydrocarbons (ODU) and heavy metals (VIMS) associated with total suspended matter, as well as for bacterial biomass and heterotrophic potential (VIMS), dissolved and particulate organic carbon and nitrogen (NEFC/Univ. Delaware), and algal bioassay (ODU). At 24 stations between the bay mouth and Oregon Inlet, North Carolina, samples were collected throughout the water column for temperature, salinity, dissolved oxygen, dissolved inorganic nutrients (ODU), chlorophyll a and phaeopigments, phytoplankton species composition (ODU), total suspended matter (ODU) and total plankton respiration.

Several new experimental approaches were initiated during this third experiment. The first of the three OCS overflights occurred on 15 October. For this overflight of the Chesapeake Bay plume, four research vessels were stationed along four transects perpendicular to the flow of the plume (fig. 12). The R/V *Langley* (NASA) collected data across the bay mouth, the R/V *Holton* (ODU) along a transect east northeast from Cape Henry, the R/V *John Smith* (VIMS) east from Rudee Inlet and the R/V *Kelez* (NOAA) east from the Dam Neck Firing Range. The object was to sample the plume - vertically and horizontally - with surface vessels during the same time interval as the OCS overflight, about two hours. This was accomplished successfully.

In addition, a 12 hour study was done along the plume transect running east northeast from Cape Henry to improve understanding of tidal influence on our data. Vertical casts using a CTD were made for temperature and salinity,and near high and at low tide at station 69 close to Cape Henry, samples were taken for dissolved oxygen, nutrients, chlorophyll a and phaeopigments, total plankton respiration, bacterial biomass and heterotrophic potential, total suspended matter, hydrocarbons and heavy metals.

On October 21 (fig. 13), discrete surface bucket samples for chlorophyll *a* and phaeopigments were collected every 10-15 minutes across the shelf from the bay mouth to the continental slope to provide detailed information in preparation for the NASA cross-shelf transects which occurred later that day (MOCS) and the following day (MOCS and OCS). Of particular interest was the aircraft-directed shipboard sampling (fig. 14) to ensure definition of the major hydrographic (chlorophyll) regimes across the shelf. Particular emphasis was placed on defining the so-called "green river" (chlorophyll) offshore.

As with the March and June experiments, additional studies were accomplished in October by VIMS (fine structure of the plume) and by ODU (Bay Plex).

STANDARDIZATION

To standardize sampling and analytical methods, a division of responsibilities was instituted at the time of the first experiment wherein each participating group became responsible for the sampling protocol and processing of particular types of samples. For example, the NEFC was responsible for chlorophyll *a* and phaeopigments, Dr. Marshall (ODU) for phytoplankton and Dr. Kator (VIMS) for bacteria. This standardization applied particularly to samples being collected from several research vessels at the same time. The various protocols and sampling procedures are discussed as appropriate in the succeeding papers.

CONCLUDING REMARKS

We have heard from Dr. John Walsh that the outflow of waters and nutrients from Chesapeake Bay during the summer may be the dominant factor in sustaining primary production in shelf waters off the bay. Such an effect on the contiguous shelf ecosystem could be labelled as positive. Dr. Jack Pearce noted that estuaries were major sources of pollutants to the continental shelf, and that certain of the living marine resources showed above-expected contaminant levels at widely distributed locations away from the estuary. This could be labelled a negative influence. He talked further about the potential role remote sensors could play, particularly over large or especially dynamic areas (e.g. estuarine plumes), by providing the temporal-spatial frequency and synopticity required for application to problems of marine resource and environmental quality. Sampling of the planktonic component of the marine ecosystem through traditional approaches (ships) has been labor intensive and is less than desirable because of the lack of temporal-spatial frequency and synopticity. In response, Dr. Janet Campbell discussed sensor development and outlined possibilities for technology transfer to help provide the required sampling "breakthrough". I mentioned the interaction between surface ships and remote sensors to enhance our ability to interpret the imagery in terms of the vertical water column and other variables not directly measureable via remote sensing.

Thus we may say that: estuarine outwellings influence contiguous continental shelf ecosystems both positively and negatively; the immediate area of influence is dynamic and therefore requires synoptic sampling for understanding; synopticity for the surface layer can be obtained using remote sensors; added capability for interpreting the imagery can be obtained by having surface vessels work in conjunction with the remote sensors; and this interaction aides further in the development of sensors and the transfer of technology to provide us with the "tools" we need to do our jobs.

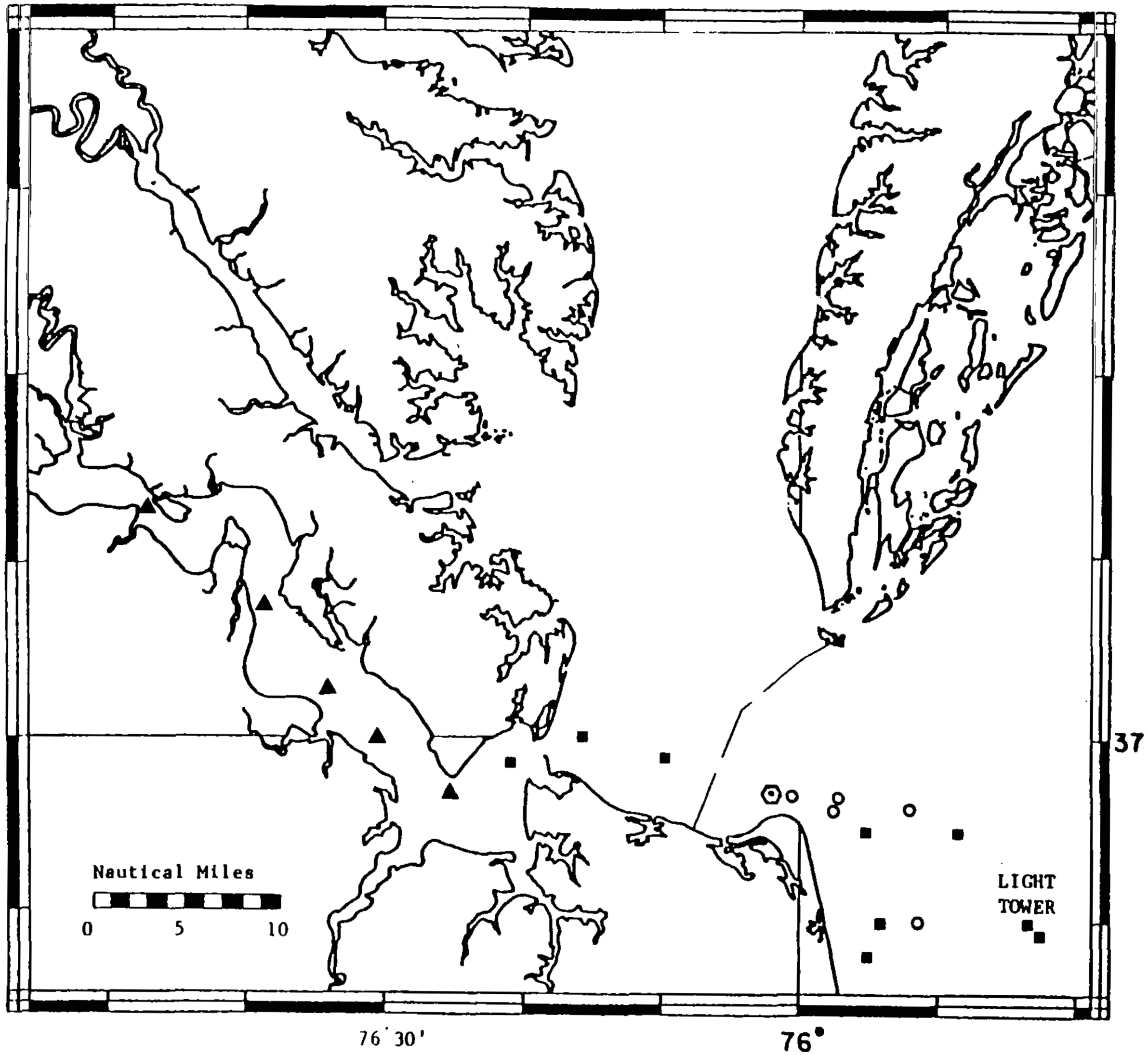

Figure 1.- Station locations for sea truth sampling during Superflux I, 11-20 March 1980. ▲ U. S. Coast Guard Launch; ■ NOAA-NOS Launch; ⊙ ODU R/V *Holton*; ○ VIMS R/V *John Smith*.

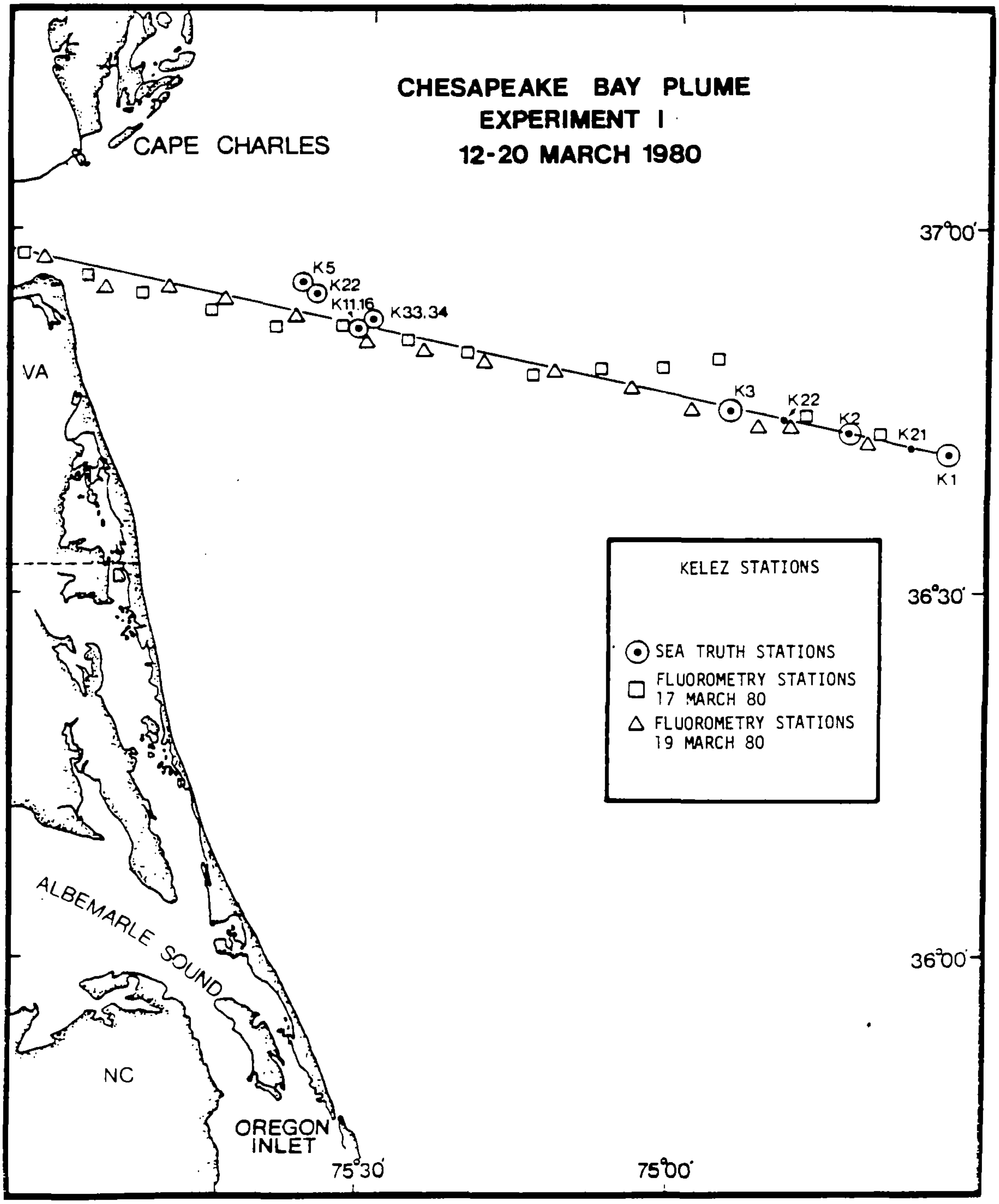

Figure 2.- Station locations sampled by NOAA Ship *Kelez* to provide sea truth for remote sensors.

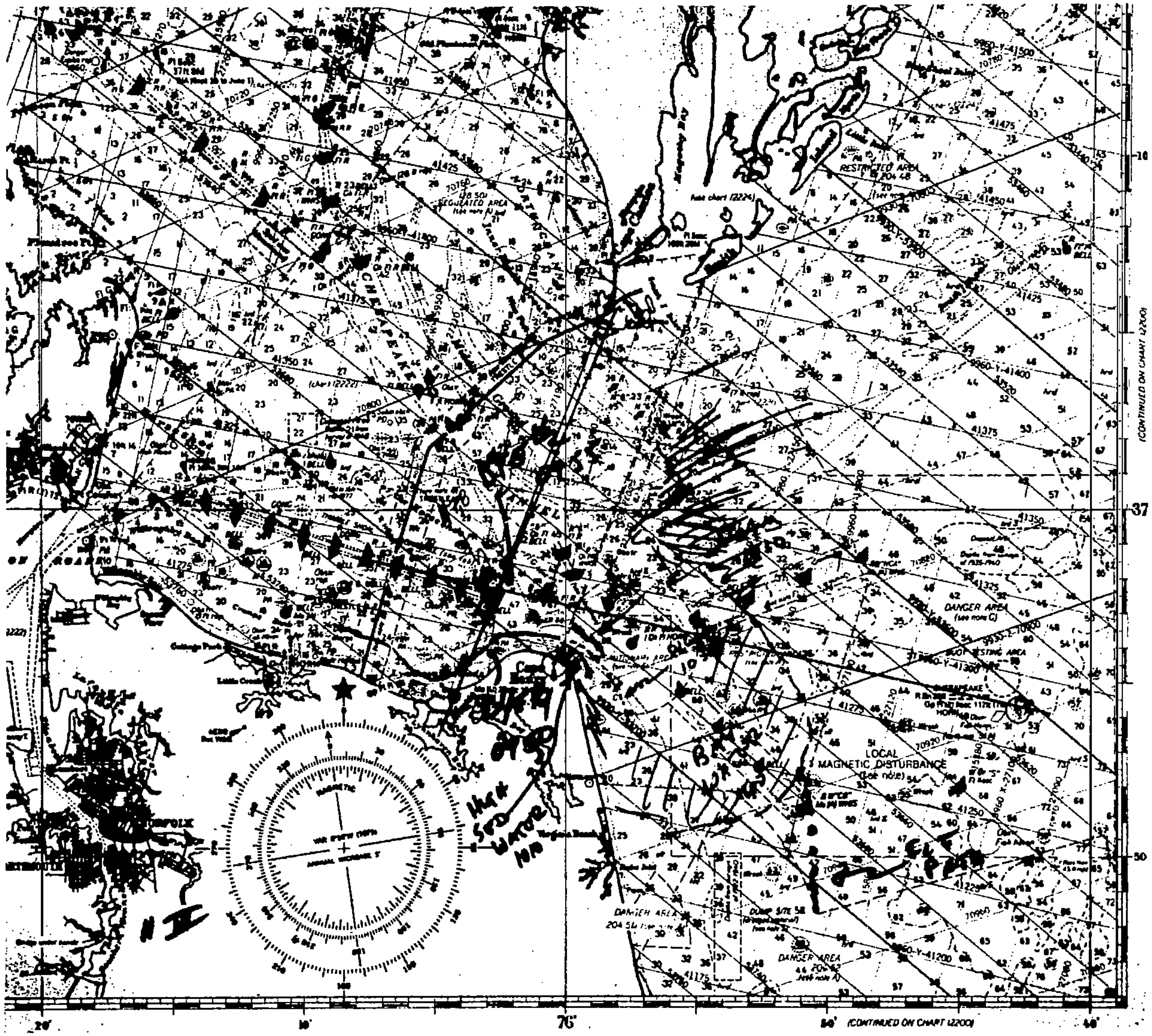

Figure 3.- Map showing locations and shape of Chesapeake Bay plume during pre-survey flight by a VIMS Beaver aircraft on 11 March 1980. Visual observations made by Dr. John Ruzecki, VIMS.

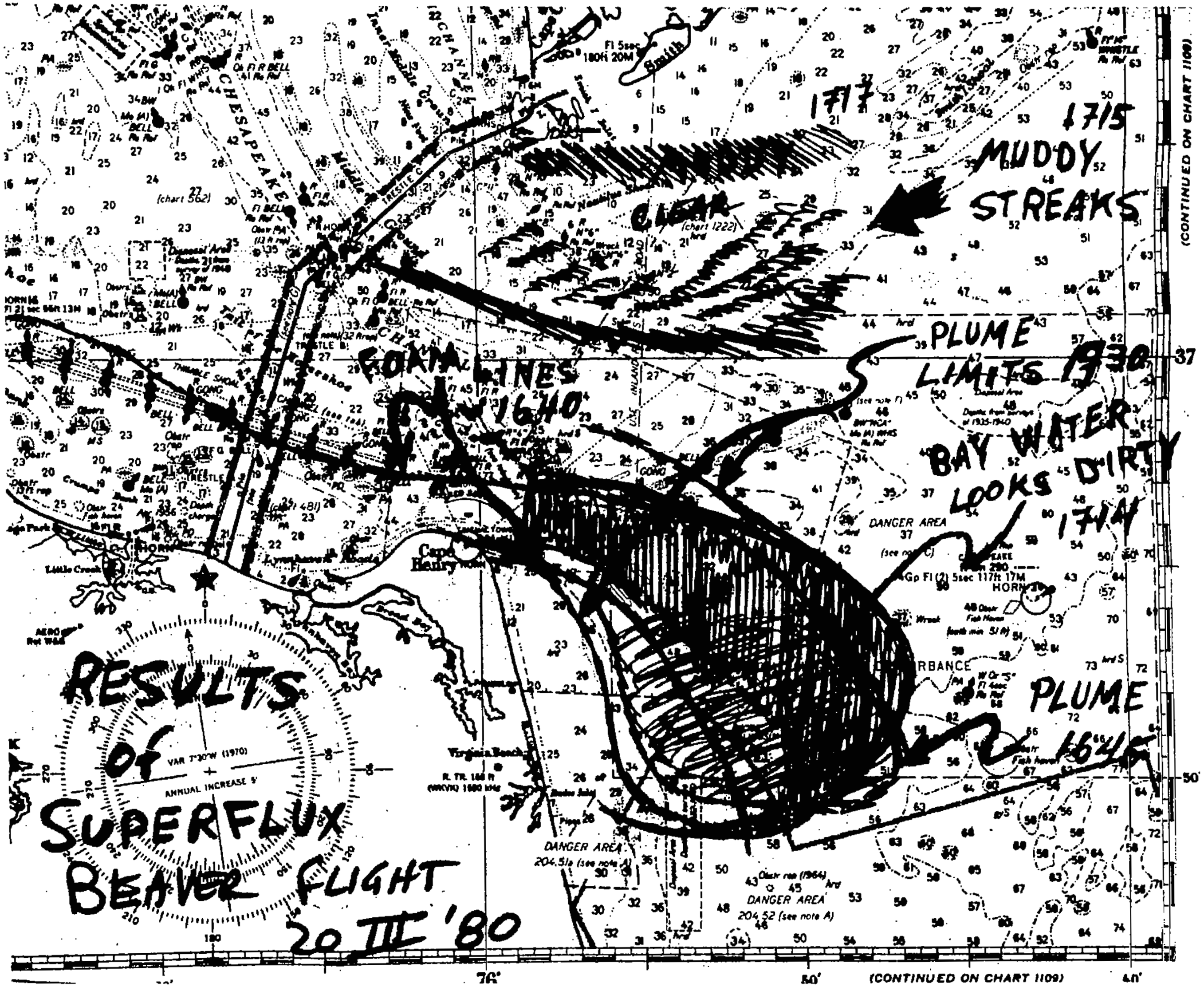

Figure 4.- Map showing location and shape of Chesapeake Bay plume during post-survey flight by a VIMS Beaver aircraft on 20 March 1980. Visual observations made by Dr. John Ruzecki, VIMS.

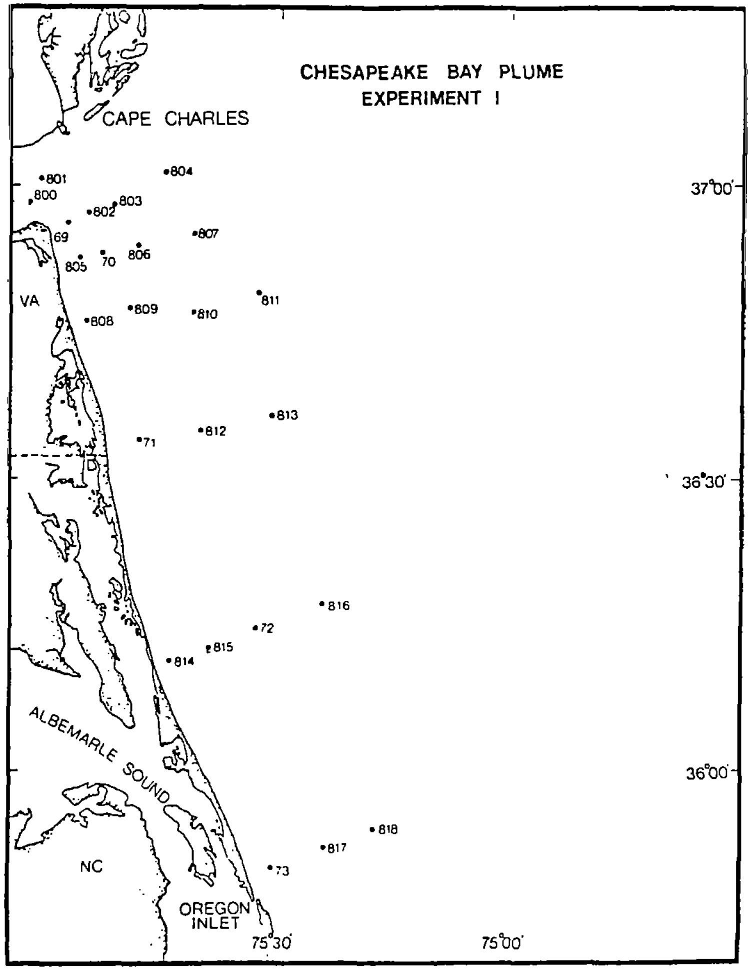

Figure 5.- Station locations sampled by NOAA Ship *Kelez* during detailed survey of Chesapeake Bay plume, 12-20 March 1980.

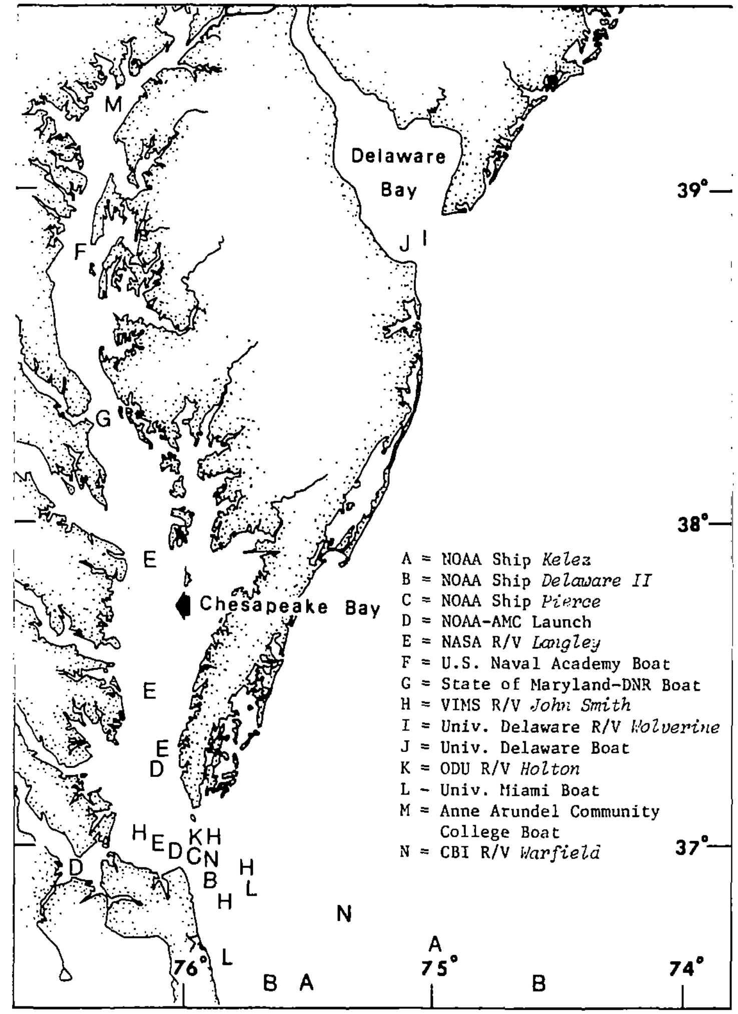

Figure 6.- Map showing locations of vessels participating in the collection of sea truth during Superflux II, 17-27 June 1980.

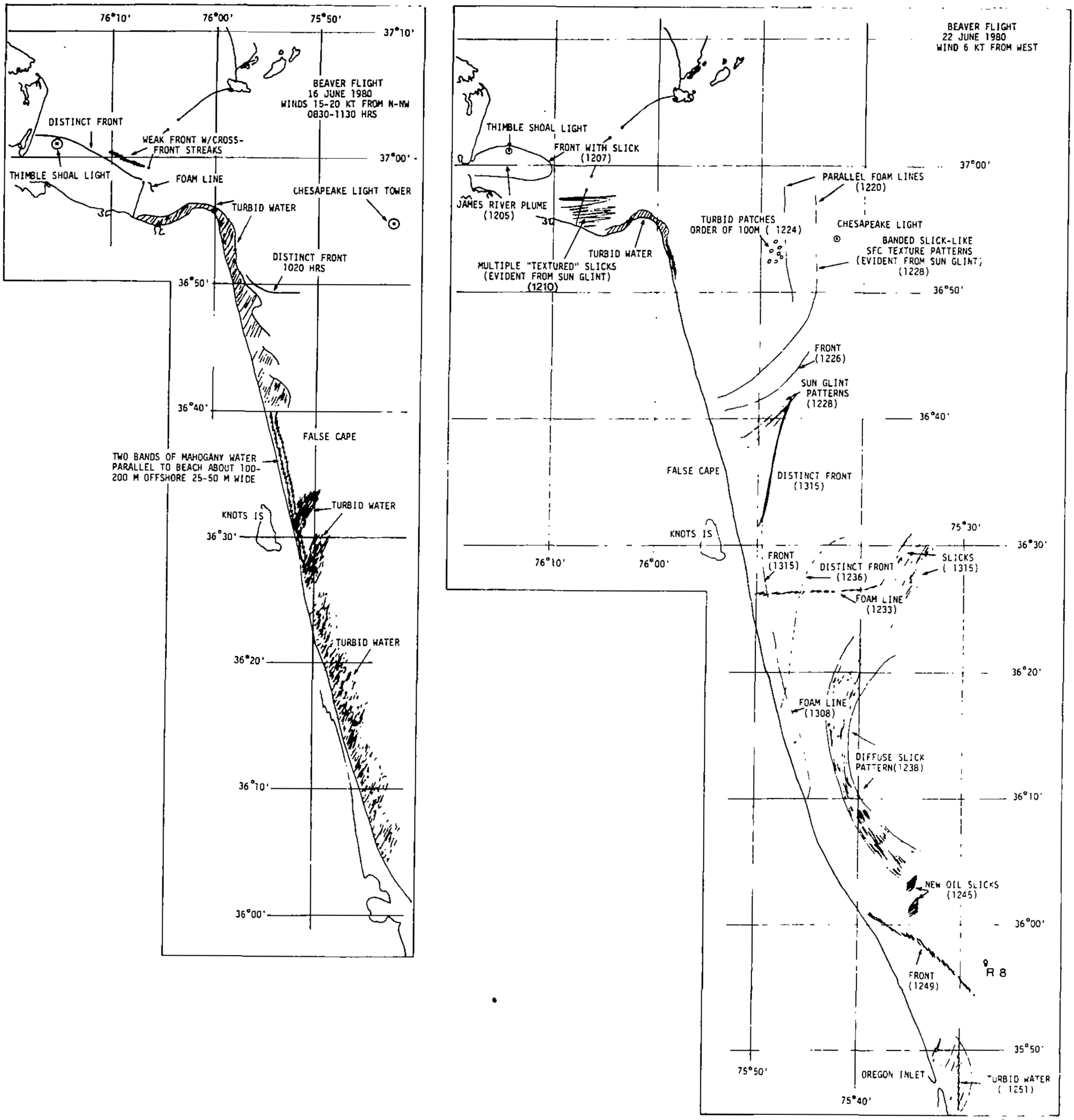

Figure 7.- Map showing location and shape of Chesapeake Bay plume during pre- and post-survey flights by a VIMS Beaver aircraft on 16 and 22 June 1980. Visual observations made by Dr. John Ruzecki, VIMS.

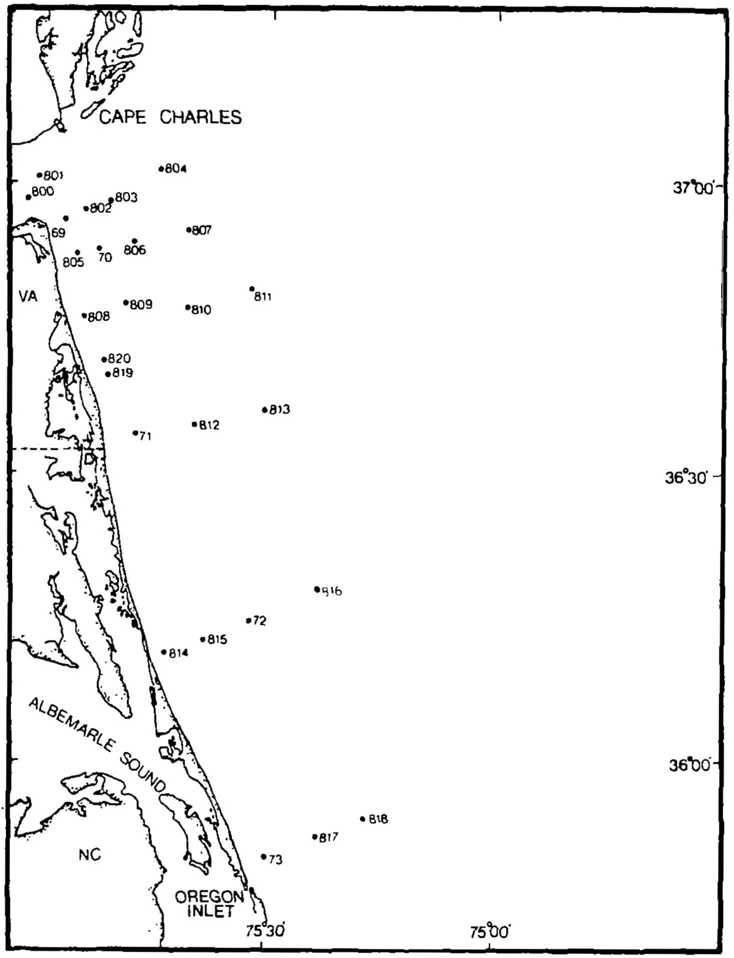

Figure 8.- Station locations sampled by NOAA Ship *Delaware II* during detailed survey of Chesapeake Bay plume, 17-27 June 1980.

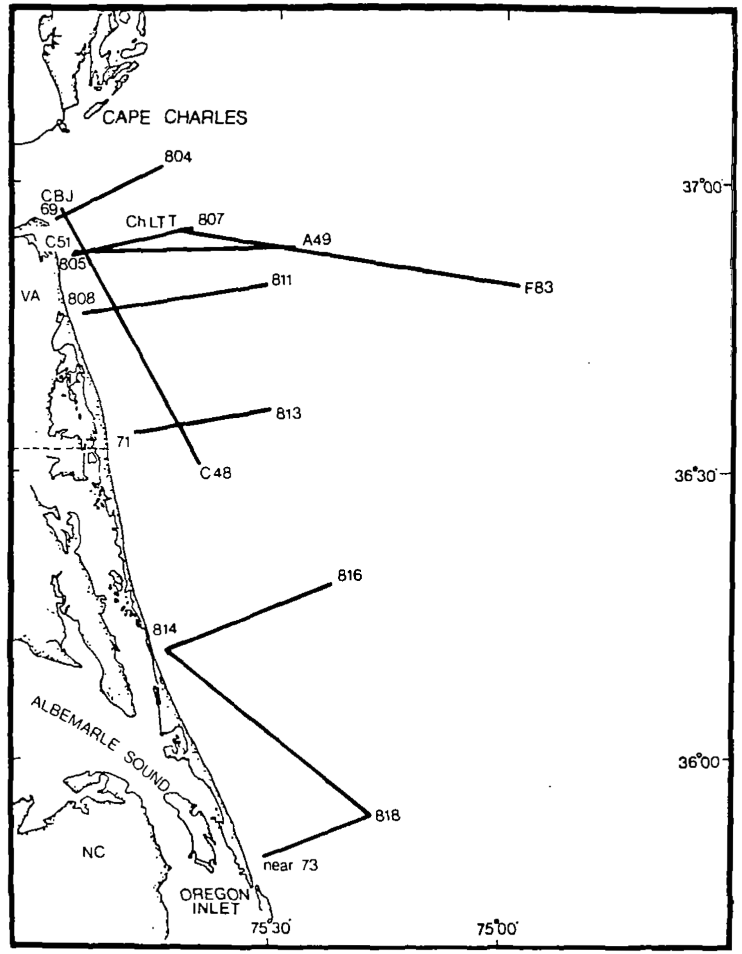

Figure 9.- Map showing locations of transects along which continuous and discrete underway chlorophyll a and phaeopigment samples were collected during Superflux II. All samples were collected from a depth of 3 meters.

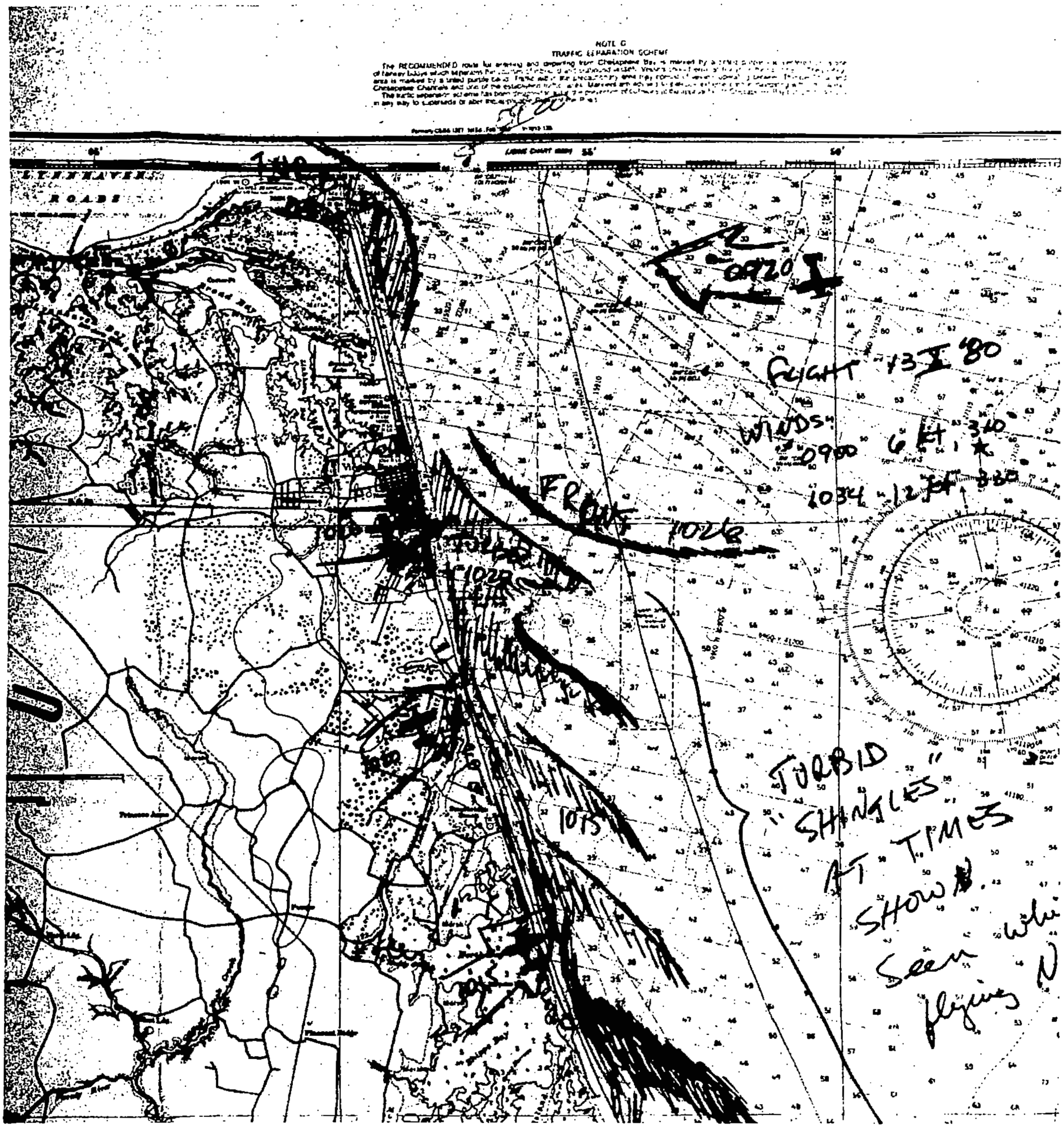

Figure 10.- Map showing location and shape of Chesapeake Bay plume during pre-survey flight by a VIMS Beaver aircraft on 13 October 1980. Visual observations made by Dr. John Ruzecki, VIMS.

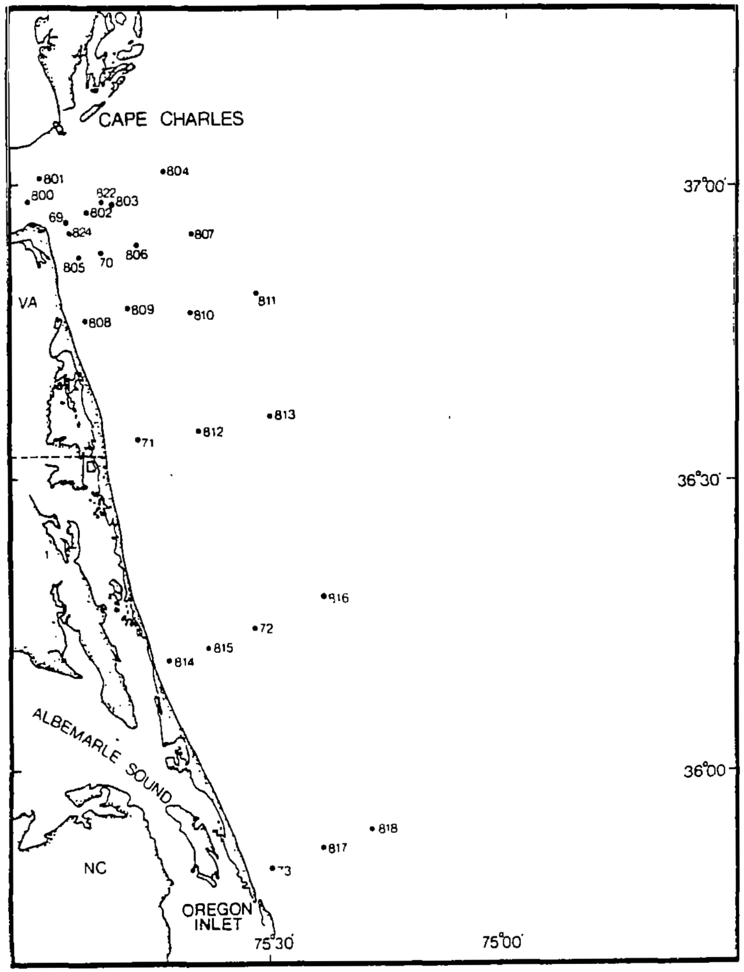

Figure 11.- Station locations sampled by NOAA Ship *Kelez* during detailed survey of Chesapeake Bay plume, 14-22 October 1980.

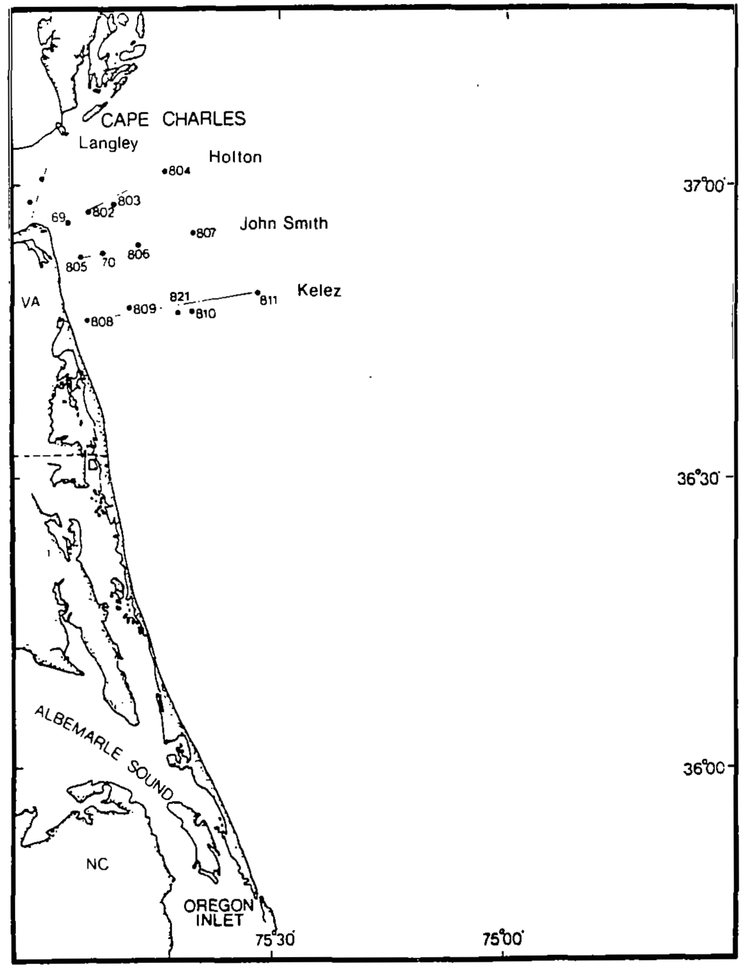

Figure 12.- Locations of transects and stations sampled concurrently with a two hour Ocean Color Scanner overflight on 15 October 1980.

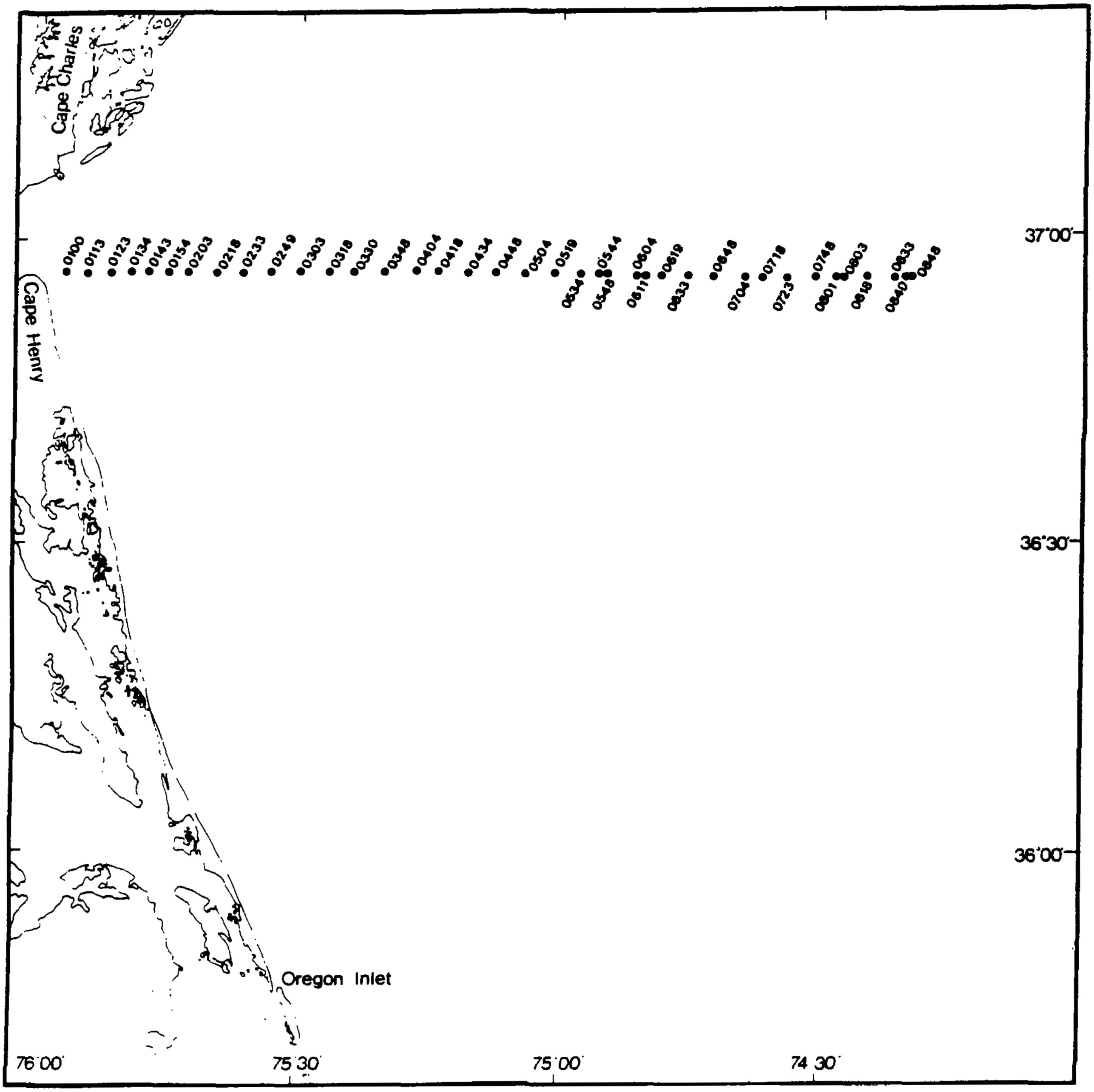

Figure 13.- Surface bucket stations sampled for chlorophyll a, phaeopigments, and temperature on 21 October 1980.

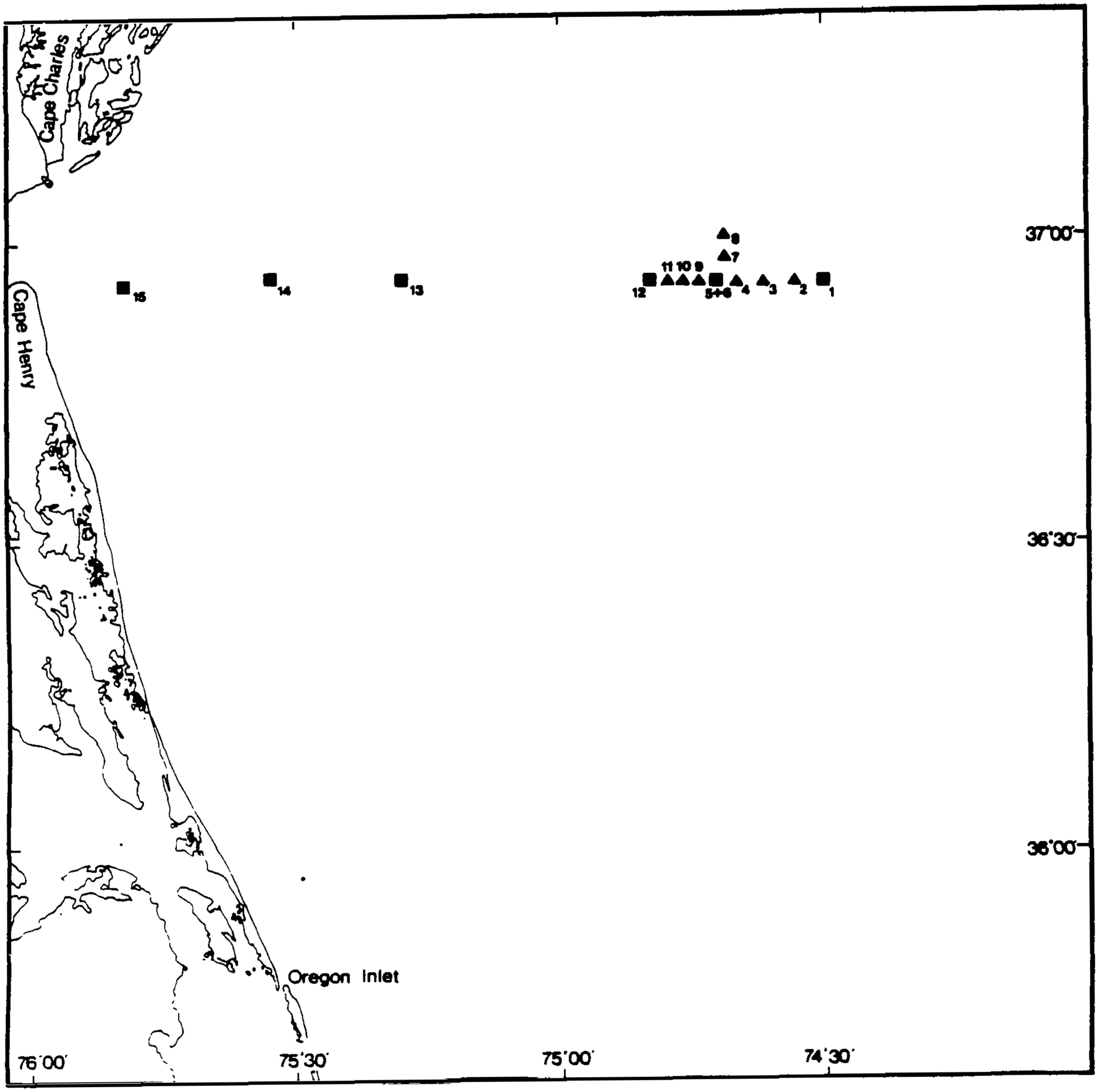

Figure 14.- Stations sampled by NOAA Ship *Kelez* during MOCS-OCS overflights on 22 October 1980. Squares indicate locations of hydrocast samples from 1 meter and 3 meters. Triangles indicate locations of surface bucket samples only.