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HISTORICAL CORAL REPORT FOR MID- & NORTH ATLANTIC

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FINAL HISTORICAL CORAL REPORT

for the

CANYON ASSESSMENT STUDY IN THE MID- AND NORTH- ATLANTIC AREAS OF THE U.S. OUTER CONTINENTAL SHELF

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ABSTRACT

The abundance and distribution of the epibenthic and coral fauna of the mid and north Atlantic continental margin was studied by reviewing photographs from submersible dives. Particular emphasis was placed on the canyon areas. The depths covered ranged from 100 meters to 3200 meters. Three general faunal zones were identified. The shelf and shelf-break province had high faunal densities and was dominated by crustaceans and fish. The mid slope region had lower faunal densities and was dominated by fish. The lower slope was characterized by high faunal densities and was dominated by echinoderms. This pattern, though consistent on the slope, was somewhat different in the canyons. Higher faunal densities, particularly of filter feeding corals and sponges, attest to the greater substrate variability and nutrient enrichment of the canyon areas.

Results of community analysis yielded no discernable cohesive assemblages within our study area. Rather the results indicated that the dominant species are independently distributed with their ranges overlapping in some areas and not in others. On the whole, canyon assemblages tended to be more diverse in terms of trophic types. Some species tended to have discrete depth ranges, while others had very broad depth ranges. The fauna exhibited a pattern of gradual species replacement with increasing depth. Also noted was the tendency of some species to emerge with increasing latitude. This observation could be the result of a variety of environmental parameters. Our

ancillary information is not complete enough at this point to elucidate them.

Corals, both alcyonarians and scleractinians were seen throughout the survey. Coral populations tended to be denser and more diverse in canyon habitats. Some species,such as those restricted to hard substrates were found only in canyons while others, namely soft substrate types were found both in the canyons and on the slope. Discrete assemblages of corals were not identified. Here again, their distributions tended to be independent, such that the coral species were not uniformly associated throughout the study area. This finding indicates that the corals are cueing in to slightly different environmental parameters. However, our lack of ancillary information concerning the fine scale environmental variability within the study area makes it impossible to identify these factors.

Measures of species overlap yielded ambiguous results. Patchy distribution and substrate variability tended to obscure meaningful faunal comparisons. In general, the mid-slope depths indicated high faunal similarities between 50 meter depth intervals. This was also true of the deep slope fauna. The shelf and canyon walls yielded slightly different results. Faunal homogeneity on the shelf tended to be uniformly low between depth intervals. Species similarity in the canyons was extremely variable. This again points to the fact that the environmental heterogeneity of canyons provide unique habitats for their faunal constituents.

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INTRODUCTION

The purpose of this report is to determine the density and distribution of the coral and epibenthic fauna of the eastern United States continental margin. This was accomplished by reviewing all available submersible photographs taken within the study area and comparing the results to published literature. Special emphasis was placed on the epibenthic communities found in submarine canyons. Study of canyons habitats is particularly important in assessing the impact of future development of resources on the continental shelf, because canyons have been implicated as conduits for the channeling of materials from the shelf to the deep ocean (Rowe, 1972). Thus, a thorough understanding of canyon habitats and their fauna is potentially important in understanding the farther ranging impact of resource exploitation on the shelf.

The most striking feature of the continental margin of the eastern United States is that it is incised by dozens of submarine canyons. Most of these canyons are rather minor topographic features, but several, such as Hudson Canyon, occupy an extensive geographic area and are deeply incised. These canyons are the result of extensive denudation of Tertiary and early Cretaceous sediments which occurred primarily during the Pleistocene.

The zonation of epifauna on the continental margins is a relatively new field of interest. In a study of the isopod

fauna on the continental margin off Cape Hatteras, Menzies, George and Rowe (1973) found three major faunal zones. Their study identified a shelf faunal province extending to a depth of approximately 246 meters, which is slightly below the shelf break. On the upper continental slope (445-940 m) they found a zone of faunal transition between the shelf and abyssal faunal constituents. This zone is known as the archibenthal zone of transition and is characterized by a gradual replacement of fauna along isobaths (Markle and Musich, 1974). The deeper abyssal faunal province includes the lower portion of the continental slope, the rise and the abyss (1000-5315m). This zone is occupied by fauna with broad depth ranges and may be further subdivided into upper and lower assemblages. Two major faunal boundaries were identified, the upper one just below the shelf break and the lower one in the region between the upper and lower portions of the slope.

In a study of the epifauna of the continental slope south of Cape Cod, Haedrich, Rowe and Polloni (1975) found three similar faunal zones with the two major boundaries at 300-400 m. and 1000-1100 m. The authors correlate these boundaries with changes in substate type, sedimentation rate and gradient of the slope. The shallow faunal boundary occurs where the sandy sediment of the shelf is replaced by the silty sediment of the upper slope. The lower faunal boundary occurs near the start of the lower slope which is steeper, has a lower sedimentation rate and offers a greater degree of substrate variability than does

the upper slope. However, the authors do point out that while the zones and boundaries are indicative of the fauna as a whole, individual species may have depth ranges that extend into at least two of the zones. They also noted that the shallow and middle faunal assemblages are dominated by various species of fish, while the deeper zone is dominated by echinoderms.

Rowe and Menzies (1969) and Rowe (1971) studied the epibenthic fauna of Hatteras Canyon and the adjacent slope using a combination of trawls and bottom photographs. Rowe found that some of the dominant species of the continental slope are present in reduced abundances, or are altogether absent, in the canyon axis. This phenomena may be the result of habitat differences between the canyons and the adjacent continental slope. The canyons are characterized by a higher variability of substrate types, such as outcrop, and this provides a more heterogeneous environment. Additionally, canyons differ from slope regions in that they may be areas of nutrient enrichment due to the reported funneling characteristics of canyons (Rowe, 1972).

Haedrich, Rowe, and Polloni (1975) conducted their study of epibenthos using trawls. They found that the epifauna of a small submarine canyon (Alvin Canyon) was not very distinct from that found on the adjacent slope. However, they do concede that several species may be considered canyon indicators. Their conclusions on the similarity between canyon and slope epifauna might not be indicative of larger canyon systems.

Alvin Canyon is rather small and, therefore, may not provide as heterogeneous an environment as the more deeply incised canyons. Additionally, trawls do not adequately sample epifauna from regions of high relief and rock outcrops such as are found in the larger canyons. The investigators, however, did find higher population densities in the canyons. This increased abundance again substantiates the role of canyons in funneling nutrient matter.

The distribution of epifauna within canyons is largely determined by the availability of substrate types (Hecker et al., 1978). Thus an assessment of the density and distribution of fauna cannot be divorced from the geology of the region. There is a distinct difference between the canyon habitats found within our study area. The canyons off Georges Bank are currently sites of active erosion (Ryan et al., 1978), while the mid-Atlantic canyons are reported to be largely inactive (B. C. Heezen, unpublished data; Keller and Shepard, 1978). An exception to this trend is Norfolk Canyon which shows evidence of recent active erosion and unusually high current velocities (E. B. Forde, personal communication; Keller and Shepard, 1978).

Corals are an important constituent of the fauna found in canyons. Many of the coral species, though not all of them, are restricted to hard substrates, such as outcrop and glacial erratics. Additionally, they are suspension feeders relying on

the higher current activity for their nutrition. Thus, resource development that alters the characteristics of the water column in the vicinity of canyons might be detrimental to the coral communities. These characteristics make corals good "indicator organisms" for assessing potential environmental deterioration.

DATA SET

The data set for this report consists of information collected from previous ALVIN and DIAPHUS dives. This was accomplished by analyzing color slides taken of the seafloor during the dives. Additionally, the data was augmented by reviewing photographs obtained from camera lowerings within the study area. The study area encompassed the region between Cape Hatteras and Georges Bank from a depth of 100 to 3200 meters. All available submersible dives within this region were surveyed for the historical report.

Table I lists the location and depth of the dives viewed that had adequate picture quality and coverage for systematic review and analysis of the slides. Table II lists the location and maximum depth of dives that had very poor picture quality or photographs that were not available to us, but from which we collected qualitative data regarding the presence or absence of epifaunal species. Table III is a listing of the location and depth of the camera lowerings reviewed. For ease in visualizing the geographic location of this coverage all the

dives and camera lowerings are plotted on Fig. A1. Most of the dives were concentrated in or closely adjacent to submarine canyons while the camera lowerings were more widely scattered.

A thorough analysis was made of all dives in which picture quality and coverage warrented. The results of this analysis comprise the quantitative data on which this report is based. Unfortunately, the photographs from many of the submersible dives were of poor visual quality, were lost or were not available to us. Whenever possible these dives were then used to obtain qualitative information; particularly data that expanded the known geographic distribution of coral species. Camera lowerings were also utilized to assess the universality of some of the faunal assemblages viewed in the relatively restricted submersible coverage. The archives and sources that were reviewed include: the Smithsonian Institution, Washington, D. C.; Woods Hole Oceanographic Institution; Lamont-Doherty Geological Observatory; the U.S.G.S. (Woods Hole); NOAA (Miami and Washington, D. C.); and Dr. Richard Slater (U. of N. Col., Greely, Col.). Qualitative information concerning the occurrence of selected taxa was obtained from NMFS (Woods Hole).

Unfortunately there are large data gaps in the submersible coverage. Most of the usable photographic transects were restricted to the submarine canyons. This allows little opportunity for strict comparison between canyon and slope fauna at equivalent depths. Another problem is that the

footage from many of the earlier ALVIN dives is lost or footage was not even taken. Additionally, there is virtually no available photographic record between the depths of 400 to 800 meters and coverage at depths greater than 2000 meters is very sparse.

The photographic method for estimating abundance and distribution of epibenthos has various advantages over trawling or motion pictures. Both of these other methods tend to underestimate epifaunal density, while direct visual observation tends to overestimate it (Grassle et al., 1975). Barham, Ayer and Boyce (1967) compared measures of epifaunal density obtained by still photographs and 16 mm cinemaphotography along a transect in the San Diego Trough. The densities obtained from examination of the still photographs were nearly twice as high as those obtained from a study of the motion pictures. The investigators attributed this difference to the more critical examination possible with camera stills. A comparison of densities estimated from trawls versus still photographs shows that photographs yield densities an order of magnitude greater than those obtained from trawls (Haedrich, Rowe and Polloni, 1975). This is probably due to the fact that the more mobile components of the epifauna can readily avoid the net. Additionally, the uncertainty of the actual configuration of the net with respect to the bottom is a problem that excludes trawling as a valid quantitative sampling technique.

The main disadvantage of using submersible photographs to determine abundance of epibenthic organisms is that the fixed camera is at a low angle with respect to the bottom. This allows the camera to cover a large area, but also results in amplification of errors in estimates of the area observed. Thus, any deviation of elevation above the bottom can substantially alter the size of the field of view. In such instances estimates of the area viewed can be made in relation to the size of organisms and various topographic features.

METHODS

Slide Examination and Species Recognition

The photographs reviewed from the ALVIN consisted mainly of color slides taken with an externally mounted camera. These were augmented by transcripts of the observers' comments whenever they were available. To calculate abundances of the faunal constituents estimates of the number of square meters viewed were made. The method that was used is described in Grassle et al., (1975) and employs the use of a Canadian (perspective) Grid. Construction of the perspective grid requires knowledge of the elevation of the camera, the angle of the optical axis of the lens with respect to the image, and the focal length and acceptance angles of the lens in water. These parameters were then used to calculate the number of square meters of the bottom viewed on each slide. Prior to January, 1976 the ALVIN external camera was an EG & G camera which covered a viewable area of

approximately 6 m^2 per frame. ALVIN now uses a Benthos 35 mm camera which covers a viewable area of approximately 9 m^2. The foreground of the field which is obstructed by the sample basket, and the edges of the frame which are rather dark were not used. For the DIAPHUS dives estimates of approximately 3 m^2 viewed per slide were used (based on actual measurements).

Each slide was projected on a scaled up replica of the calculated grid and examined. The depth, area viewed, substrate, and species and their abundance was noted for each slide. This data compilation was aided by use of the data sheets given in Appendix 1. Species identification from photographs is extremely tentative. It is virtually impossible to positively identify all the fauna seen in the photographs to the species level. At present, the state of the art of taxonomy of much of the fauna found below the photic zone is sketchy at best. This is compounded by the fact that the characteristics separating closely related species are frequently too fine to be discernable on a photograph. Additionally, the problem of species recognition is further hampered in many coelenterates, because as a result of contraction dried or fixed specimens frequently look very different in life. Within these constraints every effort was made to make as precise an identification as possible. Identification was aided by compiling information on the distribution and known depth ranges of the various species found within the study area. The compilation of this information was greatly aided by

R. Haedrich and G. T. Rowe making their data on trawl collections available. Additionally, consultation with P. Polloni (W.H.O.I.) and various specialists in invertebrate taxonomy, particularly, F. Bayer and D. Pawson, was very helpful. Hand held photographs taken by observers during dives were also very useful, because they frequently afforded good close-ups of some of the major faunal constituents.

A major disadvantage of using submersible photographs to assess epibenthic faunal abundances is that biases may be created by the mere presence of the vehicle and its lights. For instance it has been noted that some fish are attracted to the disturbance created by the submersible, possibly to feed on the infauna exposed by the vehicles displacement of sediment. Study of photographs would then tend to overestimate the abundance of these species. This was compensated for by not counting individuals that were seen in successive frames. Other organisms, such as the large crab *Geryon quinquidens* and various fish, obviously try to avoid the path of the submersible. Nothing could be done to aleviate this bias, because it is impossible to determine what organism has caused a dust cloud seen in a photograph. Another bias which could not be compensated for is that the habitat of some organisms, such as burrowers or ones that hide beneath rocks, precludes an accurate assessment of their abundances because they are rarely out on the substrate and thus are not seen on the photographs.

Statistical techniques

The species, their abundance and the m^2 viewed were summed for 50 meter depth intervals for each dive. This data was then standardized by calculating the number of individuals per 100 m^2, for each species and for the total fauna. The relative percent that each species contributed to the total fauna seen was also calculated for each depth interval. Percentage faunal similarity was calculated between 50 meter depth intervals within a dive and for similar depth intervals between dives. The index used was percentage similarity (Whittaker and Fairbanks, 1958) given by the formula

$$PS = 100\ (1.0 - 0.5 \quad \left| p_{ia} - p_{ib} \right|) = 100 \ \min \left| p_{ia}, p_{ib} \right|$$

where p_{ia} is the proportion of sample a composed by species i and p_{ib} is the same for sample b. These values were then used to assess faunal similarities between depths and various locations. This method basically measures the degree of faunal overlap, in terms of species composition, between various samples.

To identify patterns of community similarity and species distribution we subjected the data to rotated principal components analysis. Each dive was divided into 50-meter depth intervals. All species seen, and their abundance, within that depth interval were then combined into a composite sample. After elimination of 50-meter depth intervals in which fewer than 50 m^2 were viewed, we retained 169 composite samples. Of 133 recognizable taxa possibly occurring in our study area 30

were not encountered. This resulted in a data matrix of 169 samples and 103 taxa. To facilitate computation, while still analyzing all 169 samples at the same time, we needed to reduce the number of taxa to 60. The 43 species that were dropped were taxa that were represented by fewer than 23 individuals in the entire data set. This should not substantially alter the results of the analysis, because generally each sample was dominated by only a few species.

Distributional patterns of faunal assemblages were studied by analyzing the degree of species similarity between samples. This type of community analysis is usually referred to as Q-mode analysis (Poole, 1974). For this type of analysis the sample compositions are normalized to a standard unit length, so that the sum of squares of the species abundances within each sample is one. As a result each sample contributes equally to the analysis. It should be noted that this normalization of the data does not change the proportional contribution of the species to the sample composition.

The cosine-theta statistic was used as a measure of sample similarity. This measure can be visualized as the cosine of the angle between sample vectors, where the vectors are a geometrical representation of the samples' species composition in a hyperspace having dimensions equal to the number of species. The cosine-theta statistic is computed by postmultiplying the now-normalized data matrix by its transpose. This statistic ranges from zero when samples are very dissimilar (forming a

large angle) to unity when the samples are identical (forming a small angle). The cosine-theta matrix was then analyzed for its eigenvalues (amounts of the sample variance accounted for by successive axes) and eigenvectors (composite-species axes defining faunal assemblages). The method allows for the fewest possible assemblages describing the maximum amount of the data, by constructing new component species axes so that each successive axis accounts for the greatest fraction of the remaining total sample variance.

These new principal component axes were rotated to a "best fit" position, defined by the Varimax criterion (Kovan and Imbrie, 1971). The principal components represent mathematically independent end-member samples (species or groups of species), with each real sample being described to a lesser or greater degree by an appropriate mixture of these end-members. Rotation of the components to a "best-fit" position introduces no distortion or loss of information. The value of this technique is that the composition of the mathematically independent end-members tends to be close to real, and therefore more readily interpretable, samples. Each sample was then classified in terms of its faunal composition with respect to the identifiable end-member assemblages.

RESULTS AND DISCUSSION

Substrates

A variety of different substrates and habitats were found within the study area. On the whole canyons offer a more heterogeneous environment in terms of substrate variability than does the slope. Silty sediment is the major substrate found within this area, both in canyons and on the slope. Sandy sediment is generally confined to the shelf, the upper slope and canyon heads. It is also intermittently found on canyon walls and in their axes. Consolidated clay outcrop is found in canyons and on the lower continental slope. Loose hard substrates, such as cobbles and glacial erratics, are primarily found in the heads and on the walls of the northern canyons. Rock outcrops are usually restricted to canyon axes, with occasional outcrops on the canyon walls.

The continental shelf and upper slope (100-350m) of the mid-Atlantic region is characterized by a sandy substrate with shell fragments and coral debris. From 350 to 500 meters depth the substrate is silty with occasional cobble patches and boulders. The lower continental slope (850-2550) of the mid-Atlantic region consists mainly of silty substrate with occasional minor consolidated clay outcrops below 1000 meters.

Data was obtained for the depth intervals of 1050 to 1550 meters and 2150 to 2350 meters in the axis of Norfolk

Canyon. The predominant substrate is a silty sediment. Substantial outcrops were seen in the depth interval from 1050 to 1500 meters, while only occasional outcrop was seen deeper. The head of Carteret Canyon is characterized by predominantly sandy sediment with occasional shell fragments on its north flank (150-350 m). Outcrop of consolidated Pleistocene clay is found at a depth of 250 meters on the south flank of the canyon head. The head of Toms Canyon has sandy sediment with shell fragments throughout the 150 to 350 meter depth range. Hudson Canyon consists mainly of a silty sediment, with minor consolidated clay outcrops throughout its axis. In the deeper part of Hudson Canyon (2900-3000 m) substantial outcrops were seen.

The continental slope between Hudson Canyon and Georges Bank is characterized by silty substrate between 1250 and 1400 meters. From 1700 to 2250 meters the sediment is also silty, with minor consolidated clay outcrops throughout this depth interval.

The head of Veatch Canyon consists of sandy sediment between the depths of 100 to 250 meters. Major consolidated clay outcrops were seen between 150 and 200 meters in this canyon. The head of Lydonia Canyon (150-400 m) offers a slightly more heterogeneous habitat. It has a predominantly sandy substrate interspersed with gravel, cobbles and glacial erratics. Large ripple marks were also observed indicating

strong current activity.

The northern canyons offer the most heterogeneous environment in terms of substrate variability. The wall of Oceanographer Canyon consists of silty sediment with some sandy areas between 900 and 1200 meters. Consolidated clay, cobbles, glacial erratics and extensive coral rubble were found between 700 and 1350 meters, while outcrop was seen at 1050 and 1400 meters. The axis of Oceanographer Canyon consists of a silty sediment with occasional sandy patches. The axis is flanked by extensive outcrops on both sides with frequent talus blocks at the base of these outcrops. The wall of Heezen Canyon, a very narrow and deeply incised canyon, consists of silty sediment with minor consolidated clay outcrops between 800 and 1300 meters. The axis of this canyon is extremely narrow and has a silty floor heavily littered with large talus blocks. The axis is flanked by massive outcrops with numerous sediment dusted ledges. The wall of Corsair Canyon is characterized by silty sediment with minor outcrops at 900, 1150 and 1300 meters.

Faunal Density

The density of epibenthic fauna showed a marked variation with depth. Faunal density is uniformly high in the shallower region, with a peak between 350 and 500 meters (Fig. B 1). The density then drops and remains relatively uniform from 600 to 1600 meters, There is a secondary peak between 1600 and 2300

meters, after which it shows a marked decline to 3150 meters. The shelf and shelf-break region are areas of high nutrient flux and the fauna is composed of a variety of trophic types. The peak in faunal density between 350 and 500 meters is mostly the result of high concentrations of the scavenging quill worm *Hyalinoecia artifex*. This species has a very patchy distribution and occurs in high concentrations when it is present. Thus, the peak may be artificially inflated and not indicative of the true density at that depth. The coverage is not complete enough to determine if this is the case. The slope fauna is dominated by fish which are mostly predators and carnivores, while below 1600 meters most of the animals are smaller deposit feeders.

This pattern is somewhat less apparent in canyons. Faunal densities were calculated separately for slope and canyon habitats and the results are shown in Fig. B2. Faunal densities within canyons are consistently higher than densities at corresponding depths on the slope. In fact, they do not show the marked decrease in faunal density between the depth of 600 and 1600 meters. However, they do show the peak below 1600 meters which decreases at depth greater than 2300 meters. The higher faunal density in the middle depth range may be explained by the more varied habitats found within canyons when compared to the slope. The canyons offer a variety of substrates and are thought to be conduits for nutrients,

they would thus be able to support a greater variety and abundance of organisms.

Faunal components

The major faunal components seen during the survey were fish, crustaceans, echinoderms and corals. Distinct variations in the relative abundance of these components were noted and several patterns are discernable. Figure C1 is a diagramatic representation of the numerical percentage of the fauna accounted for by these groups. The most obvious pattern is the increasing dominance of echinoderms with depth. The shallow fauna is generally composed of crustaceans, fish and a variety of other taxa. The middle depth fauna is dominated by fish, while echinoderms are the major component of the deeper fauna.

These results are consistent with the findings of Haedrich, Rowe and Polloni (1975) and Grassle et al., (1975). The higher nutrients of the shelf and upper slope allow this region to support a greater variety of trophic types. Fish and crustaceans are large mobile predators and scavengers, while some of the other shelf fauna are filter feeders. The deeper slope environment has a lower sedimentation rate and is characterized by a predominance of deposit feeding echinoderms.

The trend of replacement of faunal constituents with depth is best seen in slope areas, such as is shown in Fig. C2 for the slope south of Baltimore Canyon. The relative proportion

of the major taxa are presented for 50-meter depth intervals. ALVIN dive 765 covered depths ranging from 200 to 450 meters. Crustaceans, such as a species of *Munida* and *Cancer borealis*, dominated the fauna from 200 to 300 meters. The quill worm *Hyalinoecia artifex* was the dominant species seen between 300 to 450 meters. This species appears to have a rather patchy distribution and is found in exceedingly high abundances (300-400 individuals/100 m^2) where it occurs. ALVIN dive 767 covered a depth range of 850 to 1250 meters in the same area. At all depths within this range fish comprise the majority of the epifauna seen. The most abundant of these was the deep-sea eel *Synaphobranchus kaupi* frequently seen hovering just above the bottom. The main crustacean in this region was the deep-sea red crab *Geryon quinquedens* with most of them seen as mating pairs. ALVIN dive 766 covered the depth range from 1550 to 1800 meters. Throughout this dive the predominant animal was the ophiurid *Ophiomusium lymani*.

Figure C3 shows the dominant faunal constituents seen on ALVIN dive 807 covering the depth range from 1000 to 1350 meters on the slope north of Norfolk Canyon. Again fish accounted for the majority of the fauna seen. The dominant crustacean found between 1000 to 1050 meters was *Geryon quinquedens* which burrowed extensively in the consolidated clay bottom as evidenced by numerous large excavations. A species of the solitary cup coral *Flabellum* was seen in high concentrations in the 1300 to 1350

meter depth interval.

The general trend of gradual replacement of crustaceans and fish by echinoderms with increasing depth is somewhat obscured in canyons. This is probably the result of greater environmental heterogeneity in canyons due to more substrate variability. Additionally, canyons have been identified as nutrient enriched environments (Rowe, 1971; Haedrich, Rowe and Polloni, 1975). The environmental heterogeneity and increased nutrient flux would allow canyons to support a greater variety of species and trophic types. As a result canyons tended to have higher concentrations of corals. A notable exception to this was Hudson Canyon which was predominated by fish and crustaceans, and followed the more general trend seen on the slope. This may well be due to the scarcity of outcrop within its axis.

Norfolk Canyon is the only Mid-Atlantic canyon in which there is deeper dive coverage. Figure C4 shows the major faunal components seen during dive transects in the axis of this canyon. Dive 808 covered the depth range from 1050 to 1250 meters. All depths within this dive were dominated by the quill worm *Hyalinoecia artifex*. The corals which comprised a minor component of the fauna were the solitary horn coral *Desmophyllum cristagalli* and a white gorgonian *Acanthogorgia armata*, both of which require a hard substrate. Dive 809 covered the axis from 1200 to 1550 meters. A variety of trophic types were

found in this interval. *Geryon quinquedens* dominated the first 50-meter depth interval. A species of the burrowing cerianthid anemone dominated from 1250 to 1450 meters, fish dominated from 1500 to 1550 meters, while two soft corals *Anthomastus grandiflorus* and a species of *Pennatula* dominated the last interval. During dive 810 deeper in the canyon axis the same two soft corals, *A. grandiflorus* and *Pennatula* sp., dominated between 2150 and 2350 meters.

The trend is also obscured in the northern canyons. Fig. C5 shows the results of faunal observations made from three ALVIN dives in Oceanographer Canyon. One dive covered the west wall between 650 to 1550 meters while the other two dives covered the canyon axis between 1450 and 1900 meters. The canyon wall consists of a variety of different substrates and no single taxa or trophic type predominates. *Geryon quinquedens* is common in the shallower part as well as a species of the large starfish *Porania*. Two gorgonians *Acanthogorgia armata* and *Paramuricea borealis*, and an octocoral *Anthomastus agassizi*, which are restricted to hard substrates, are also common in this area. One very unique feature of this region is the presence of extensive coral rubble formed by dead and broken pieces of the colonial scleractinian *Lophelia prolifera*. This rubble provides a very heterogeneous substrate for a variety of attached taxa. Below 1150 meters fish and shrimp dominate the fauna. The fauna in

the axis of Oceanographer Canyon is dominated by *Hyalinoecia artifex* and fish from 1450 to 1550 meters, while between 1550 to 1600 meters it is dominated by *Desmophyllum cristagalli*, a solitary coral restricted to hard substrates. Deeper in the canyon axis the fauna is dominated by the ophiurid *Ophiomusium lymani* and a species of the burrowing cerianthid anemone.

Figure C6 shows the major faunal components seen during three dives in Heezen Canyon. The wall of this canyon is mostly composed of a silty substrate and areas of consolidated clay outcrops. It is not nearly as heterogeneous as the wall of Oceanographer Canyon. Two corals, the gorgonian *Acanella arbuscula* and the octocoral *Anthomastus grandiflorus*, both of which are found of soft substrates, dominate the shallower part of the wall (850 to 1050 m). Deeper several echinoderms, an *Ophiocantha* sp., *Ophiomusium lymani* and the urchin *Phormosoma placenta* dominate the fauna. The gorgonian *Paramuricea borealis* was common between 1450 to 1500 meters. In the axis *Hyalinoecia artifex* dominated the fauna between 1150 to 1500 meters. The corals seen were *Anthomastus agassizi* and *Desmophyllum cristagalli*, both restricted to hard substrates. From 1500 to 1550 meters *D. cristagalli* dominated the fauna, whereas deeper *Ophiomusium lymani* was dominant.

The fauna on the wall of Corsair Canyon was heavily dominated by coral (Fig. C7). These were all corals restricted to soft substrates. The delicate bush-like gorgonian *Acanella*

arbuscula was a prominent constituent of the fauna between 600 to 800 meters. From 800 to 1000 meters the fauna was dominated by the corals *Anthomastus grandiflorus* and a species of *Pennatula*. The wall of Corsair Canyon, as well as that of Heezen Canyon, is not nearly as heterogeneous in terms of substrate variability as that of Oceanographer Canyon. Thus, particular species tend to dominate the taxa, whereas the fauna on the wall of Oceanographer Canyon is composed of a much more complex assemblage of a variety of taxa and trophic types.

The canyon fauna on the whole tends to follow the trend of increasing importance of echinoderms with depth. The middle depth zone from 650 to approximately 1400 meters is dominated by corals and a variety of other taxa, whereas on the slope it is dominated by fish. This difference could well be due to the greater variety of substrate types and higher nutrient flux available in canyon habitats.

Several other notable exceptions to this trend were also seen. During most of the shallow water DIAPHUS dives a delicate white sea pen (unidentified at this time) was seen. The percent of echinoderms in one dive at the head of Lydonia Canyon is anomalously high. This reflects the large number of individuals of the burrowing ophiuroid *Amphilimna olivacea* seen during that dive. The dive transcript stated that the submersible stayed in one place for a longer time than usual and the ophiuroids started coming out of their burrows. Thus, because

of their burrowing habit they could be an important constituent of the shelf fauna that would be overlooked in photographic surveys.

Two exceptions in the deeper part of the study area were one dive at the Deep Water Dumpsite #106 and one dive in the deep axis of Hudson Canyon. The fauna seen on dive 666 at DWD-106 was dominated by a small unidentified sea pen. A major component of the fauna seen on dive 594 in the axis of Hudson Canyon was a large white galatheid crab *Munidopsis rostrata* which was seen only on hard substrates.

Community Analysis and Depth Zonation

The results of the principal components analysis yielded some broad faunal trends that could be related to depth and substrate variability. However, extreme care must be taken in interpretation of this data. The obvious problem with this sort of survey is that samples tend to be concentrated in areas that were not randomly chosen, hence this raises the question of how representative they are of the study area as a whole. This factor is compounded by the problem of species recognition from photographs. Thus, patterns seen may or may not be real in terms of species distribution if two closely related species could not be discerned on the basis of gross morphology.

The data was first run with all dominant taxa included in the data matrix. This analysis resulted in 73% of the variation in the entire sample set being explained by 10 species or species

assemblages. The first four end-members of the analysis were monospecific, meaning that the numerically dominant species tended to be independently distributed. In a biological sense this basically means that these species are being controlled by different variables, and do not form a tight interactive assemblage of organisms. The pattern that does emerge is one of gradual replacement of species over depth intervals.

However, three major faunal zones superimposed on several minor ones were identified by the rotated principal components analysis. The shelf and upper slope (100-350 m) samples can be mainly explained by the presence of four species. The middle slope (800-1300 m) samples were dominated by fish, while the deeper slope (>1500 m) samples were dominated by three species. The samples from the canyons, on the whole, tend to be composed of a more complex mixture of species, with each species or pair of species being rather independent of the others. Also there are non-consistent variations of assemblages with depth on the canyon walls, which tend to indicate a very patchy distribution.

Two of the dominant taxa, fish and a species of sponge, were then excluded from the second run; the rationale being that these taxa were very dominant and had not been separated into distinct species, thus, these taxa were omitted for the next analysis to ascertain whether they might be obscuring fine scale variation in some of the other components. The first three end-members of this run were monospecific, again meaning

that the distribution of the dominant taxa are probably being controlled by different parameters. Sixty-eight percent of the sample variance could be accounted for by the first 10 end-members, while 35% of the variance was explained by the first three species.

The first ten end-members (species or species groupings) are identified in Table IV. Five of these are monospecific, meaning their distribution is independent of all other species in this sample set. Four of the factors are dispecific, being composed of two species whose distributions are similar and hence may be controlled by similar parameters. The other factor was composed of three species whose distributions were similar.

When these ten end-members are listed against depth three major faunal zones are discernable (Table V). However, there are minor replacements within the zones with increasing depth. The shallow samples (100-350 m) are composed of two of these end-members: the monospecific white sea pen (9) which is independently distributed, and the *Cerianthus borealis*, *Cancer borealis* and *Munida valida* assemblage (4). The distributions of these three species tend to coincide, indicating that they may be largely controlled by similar parameters. The middle zone (600-1600 m) is composed of a combination of several end-member groups (2, 3, 5, 6, 7, 8 and 10), both mono and dispecific. This means that there is no recognizable cohesive

grouping of organisms (i. e. a community) within this zone. However, one or two of these factors tend to dominate this zone within a given area. The deeper zone ($\geq$ 1500 m) is largely composed of two independent end-members, the monospecific *Ophiomusium lymani* (1) and the cerianthid anemone and *Echinus affinis* grouping (7).

These results are not surprising when one views the geographic extent of the survey and the variety of habitats found within the study area. The shelf edge and upper slope environment is fairly uniform consisting of a sandy substrate with shell fragments and occasional coral rubble. On close study of the depth distribution of the four major taxa in the shallow samples, a slight emergence of peak densities with increasing latitude is noted (Fig. D1). The white sea pen shows a slightly different depth distribution, when compared to the other three taxa. It shows peak densities at 150-200 meters in the northern canyons and at 200-250 meters in the southern canyons, while *Cerianthus borealis* has a peak density at 150-200 meters in the northern canyons with a secondary peak at 250-300 meters. In the south its density peaks at 250-300 meters. *Munida valida* has peak densities between 150-200 meters and *Cancer borealis* peaks between 250-300 meters. Thus, the white sea pen is probably responding to a slightly different environmental parameter when compared to the other three dominant species found in these samples. Whether the slight pattern of emergence with increasing

latitude is in response to substrate availability or a variety of other factors cannot be determined at this time.

The fauna of the middle zone (600-1600 m) is much more complex. This zone, also, includes the greatest habitat variability seen throughout the survey. The fauna of the depths between 800-1300 meters generally consists of two end-member groups, shrimp (2) and the red crab *Geryon quinquedens* and the witch flounder *Glyptocephalus cynoglossus* (5). Figure D2 shows the depth distribution of *Geryon quinquedens*, which was found in the depth range of 300-1600 meters within our study area. In the south peak densities were encountered at 1200-1250 meters where this crab extensively excavated the semi-consolidated clay of the slope. Peak densities in the north were found at 800-850 meters on the wall of Oceanographer Canyon. The depth range of *G. quinquedens* overlaps with the lower range of the jonah crab *Cancer borealis*, but it was never encountered in as high a density.

Another faunal component of this middle zone is the quill worm *Hyalinoecia artifex* (3), which when it occurred was present in such high densities that it obscured the contribution of any of the other taxa within that sample. It has been pointed out by Grassle et al., (1975) that the taxonomy of *Hyalinoecia* is quite complex, and thus, it is likely that more than one species of this polychaete does exist within the study area.

The urchin *Phormosoma placenta* (10) is also found within the middle depth zone. Like *Hyalinoecia* this species tends to be numerically dominant in the fauna areas where it is seen. Both of these species tend to have a very patchy distribution, characterized by high dominance in several of the samples and absence in the other samples.

The dominant taxa at these depths are similar to those found by Haedrich, Rowe and Polloni (1975) in the middle zone (393-1095 m) of their trawl study on the slope south of New England. *Geryon quinquedens*, *Glyptocephalus cynogossus* and *Hyalinoecia artifex* were among the seven top ranking species in this depth interval. Surprisingly, *Hyalinoecia* was absent from the canyon in their study, whereas in the present survey three out of five occurrences were in canyons.

The notable exceptions to the general species found within this middle depth zone are the faunas of the walls of Heezen and Corsair Canyons. The fauna of the upper wall of Heezen Canyon (850-1100 m) is dominated by two corals *Anthomastus grandiflorus* and *Pennatula* sp. (6). These corals are not independently distributed and almost always occur together. Both are restricted to soft substrates. This assemblage is also found on the wall of Corsair Canyon (750-950 m), at 1450 meters in Oceanographer Canyon, and deeper in the axis of Norfolk Canyon (1500-1600 m and 2150-2350 m). The fauna of the wall of Corsair Canyon is mainly composed of two dispecific end-members, the

Anthomastus grandiflorus and *Pennatula* sp. assemblage (6) and two other corals *Acanella arbuscula* and a sea pen that may be *Distichoptilum gracile* (assemblage 8). Both assemblages are restricted to soft substrates. *Acanella arbuscula* is also seen at 2300 m DWD-106 and from 1750 to 1900 meters south of Norfolk Canyon. *Anthomastus grandiflorus*, *Pennatula* sp. and *Acanella arbuscula* all show a general pattern of emergence with increasing latitudes (Figs. D3 and 4). Without more detailed information on the fine scale substrate and current regimes, it is impossible to determine what factors are controlling the distribution of these corals.

The fauna of the deeper portion of the study area (1600 m) is dominated by two end-member assemblages, the ophiurid *Ophiomusium lymani* (1) and the urchin *Echinus affinis* and a cerianthid anemone (7). These two end-members are independently distributed. Qualitative observations made during the photographic review note that although all three of these species occur in the same area, when *Ophiomusium lymani* was particularly abundant the other two were not. Conversely, where the cerianthid anemone was locally abundant *O. lymani* was not. *O. lymani* is found at depth ranging from 1100 to 2500 meters, with peak abundances near 1800 m. This ophiuroid was frequently seen at the base of sea pens and gorgonian colonies. It is not known if the ophiuriod is merely responding to

structural heterogeneity or whether there is a beneficial association between the two. The burrowing cerianthid is found at depths ranging from 600 to 3200 meters, with peak abundances at approximately 1800 meters. It is also likely that more than one species of cerianthid occurs within the study area, however, this could not be discernable from the photographs. *Echinus affinis* is found between 1400 to 3000 meters within the study area, with peak densities at 1800 meters in the northern region and somewhat deeper in the south. However, the coverage is too sparse to determine the full extent of its depth distribution.

Corals

Corals (primarily alcyonarians) were seen at all depths throughout the study area. Figure E1 shows the depths where corals were seen during individual dives, as well as the availability of hard substrates. These corals include a wide variety of types, sizes and growth forms. Both scleractinians (hard corals) and alcyonarians (soft corals) were seen. The scleractinians range from delicate solitary cup corals to large branching colonies. The alcyonarians range from small nondescript sea pens to massive branching colonies several meters in height. The following is a brief description of most of the dominant or more striking corals seen during the survey.

Scleractinians:

Damosmilia lymani is a pale-orange fairly delicate solitary coral that reproduces by longitudinal splitting. Its reported geographic distribution is from Massachusetts to Florida at depths ranging from 48 to 366 m. In this study it was observed on the continental shelf between Baltimore and Hudson Canyons and on the shelf near the head of Hudson Canyon. When it occurred *D. lymani* was found in extremely high density, probably as a result of its reproductive mode, with dead individuals forming a considerable mat of coral rubble on the surface. This coral is found on soft substrates.

Desmophyllum cristagalli is a pale-pink large horn-shaped solitary coral always found attached to hard substratum. This species was found only in canyons where outcrops provided a suitable habitat. Its geographic distribution is from Nova Scotia to Brazil at depths ranging from 155 to 1939 meters. During this survey *D. cristagalli* was observed attached to outcrops at depths ranging from 1000 to 1900 meters. It frequently occurred in dense concentrations on underhangs, with a downward facing orientation which probably protects the polyp from sediment loading..

Flabellum alabastrum is a large salmon-colored solitary cup coral. It is found on soft substrates from Georges Bank to Cape Hatteras at depths from 400 to 1200 m. In the study area

it was found in both canyons and on the slope from 600 to 2500 m. Many of the individuals seen were probably *F. alabastrum* however, some of the deeper ones may well have been *F. angularis* or *F. moseleyi*.

Lophelia prolifera is a large pale-pink anastomosing colonial hard coral that frequently forms deep-sea coral banks (Stetson, Squires and Pratt, 1962). Its geographic distribution is from Nova Scotia to Brazil at depths ranging from 95 to 1000 meters. *Lophelia* banks have best been studied on the Blake Plateau where they closely follow the 800 meter isobath (Steve Cairn, pers. comm.). A dense stand of *Lophelia* was observed in Oceanographer Canyon at 1100 meters. However, extensive *Lophelia* rubble was also found on the wall of that canyon at depths ranging from 700 to 1300 meters.

Alcyonarians:

Paragorgia arborea was the most spectacular soft coral seen within the study area. It is a massive red branching colony with large polyps and is restricted to hard substrates. It was seen in Norfolk Canyon between 400 and 600 m and in Oceanographer Canyon between 900 and 1100 m. *P. arborea* has also been reported from Baltimore Canyon (specimen at the Smithsonian) and the northeast tip of Georges Bank in a region known to local fishermen as the trees, where it apparently provides a rich habitat for commercial fish species.

Anthomastus grandiflorus is a bright-red low growing octocoral restricted to soft substrates. This species was found throughout the study area occurring at highest densities in the canyons. In the northern canyons it was found at depths ranging from 700 to 1500 meters, whereas in the southern canyons it was found from 1500 to 2200 meters (Fig. D3). *A. grandiflorus* was frequently seen in areas where species of *Pennatula* were also common.

Anthomastus agassizi is a bright red mushroom-shaped octo coral restricted to hard substrates. It was found from Corsair Canyon to Hudson Canyon at depths ranging from 750 to 1800 meters. *A. agassizi* was not seen in Norfolk Canyon even though adequate substrates and depth ranges were reviewed. A similar coral (*Trachythela rudis* ?) was seen in Oceanographer and Heezen Canyons. Its growth form and habit is very similar to *A. agassizi* but its coloration is brilliant purple as opposed to red..

Paramuricea borealis is a large yellow irregularly branching gorgonian restricted to hard substrates. It was found from Corsair Canyon to as far south as DWD 106 at depths ranging from 700 to 2200 m. Again as with *A. agassizi* it was not found in Norfolk Canyon despite coverage of suitable substrates and depth range. This species is known to occur in a variety of colors ranging from white to yellow to pink and to purple. Some colonies seen on the Reykjanes Ridge, in fact,

had two colors occurring within the same colony (unpublished photographs). Frequently five to six individuals of the ophiuroid *Asteronyx loveni* were seen coiled in the branches of a *P. borealis* colony.

Pennatula is a large purple plume-like sea pen restricted to soft substrates. This sea pen was found throughout the study area, but it appeared in high concentrations only in the canyons. As with *Anthomastus grandiflorus* it was found at shallow depths in the northern canyons (600 to 1500 m.) and deeper in the southern canyons (1500-2400 m). Again, a pattern of emergence is indicated but the geographic coverage is too sparse to warrent a conclusive generalization. Three species of *Pennatula*, *P. aculeata*, *P. grandis* and *P. borealis*, are found in the study area. However, the taxonomic differences between the three species are not gross enough to be readily discerned in photographs. Hence, we identified all pennatulids seen under *Pennatula* sp. It is likely that most of the northern and southern pennatulids seen are *P. aculeata* since this species is quite common and has been collected throughout the study area.

Acanella arbuscula is a pale-pink finely branched bush-like coral usually restricted to soft substrates. It is known to occur all along the eastern sea coast at depths ranging from 425 to 2875 m. In the study area its depth range was from 600 to 1300 meters in the north and 1500 to 2000 meters in the

south. The growth habit of the northern form was denser than that of the southern form. This difference may indicate that more than one species of *Acanella* exists within the study area. However, the slightly different growth forms might also be the result of habitat differences, such as current velocity and nutrient availability. The southern and northern forms may, in fact, be the same species or closely allied species.

Acanthogorgia armata is a fluffy white to pink soft coral restricted to hard substrates. Approximately four polyps branch off from the main axis at any given level giving the colony a very delicate bushy appearance. This coral was found throughout the canyons in the study area at depth ranging from 600 to 2500 meters. A stouter yellow gorgonian with large polyps was frequently found directly next to an *A. armata* colony. At present the species identification of this coral or whether there is an association between it and *A. armata* is not known.

Eunephthya fruticosa is a translucent white gorgonian with branches and polyps radiating out from a central axis. This species presented a major problem in species identification, because preserved specimens of *E. fruticosa* are opaque grey and broccoli shaped. It was found in the southern region of the study area at depths ranging from 2300 to 3100 meters. A similar but shorter and denser coral was seen in Corsair and Heezen Canyons between the depths of 600 to 1200 meters. This

coral is probably *E. florida,* which is known to be common in that area.

Anthoptilum grandiflorum is a large fluffy plum colored whip with polyps extending along its entire axis. Eleven individuals of *A. grandiflorum* were seen within the study area at depths ranging from 800 to 2200 meters.

Balticina finnmarchia is a pale slender whip with polyps arranged in oblique rows along its axis. Six individuals of this species were seen in the northern region of the study area between the depths of 900-2200 meters.

Virgularia mirabilis is a stiff pen with compact polyps on each side of the main axis. Seven specimens of this sea pen were seen on the slope between Baltimore and Norfolk Canyons at depths from 1500 to 1800 m. Each pen seen had an associated ophiurid coiled around its central axis

White sea pen was similar to a very fine *Pennatula.* It was found in great densities on the shallow water dives throughout the study area at depths ranging from 100 to 300 meters. At this time its species identification is not known.

White stalked pen is a short stiff sea pen with large polyps coming out from the central axis. This pen was found throughout the study area at depths ranging from 1300 to 1800 m. A similar pen was also seen at comparable depths in the Hatteras Canyon region. At this time a species identification for this organism has not been determined.

White feather is a fluffy white plume coral found in the northern canyons between the depths of 850 to 1200 meters. No species identification has been made at this time.

Throughout the dives small short non-descript sea pens were observed at all depths within the study area. Without voucher specimens identification of these pens cannot be made.

Distribution of corals:

A number of coral species were seen fairly consistently throughout the study area. Positions of their known occurrences are mapped on Fig. E2. It can be seen that coral species requiring soft substrates have a much broader distribution than those restricted to hard substrates. Sea pens (not identified to species level) are found throughout the study area.

Acanella arbuscula, *Pennatula* sp. and *Flabellum alabastrum* were found on the deeper part of the continental slope south of Norfolk Canyon. In the axis of Norfolk Canyon the coral population is dominated by *Flabellum alabastrum*, *Pennatula* sp. and *Anthomastus grandiflorus* on the soft substrates, with occasional occurrences of *Acanthogorgia armata* and *Desmophyllum cristagalli* where outcrops were exposed. Deeper at the mouth of the canyon *Eunephthya fruticosa* was seen along with the soft substrate corals. On the slope just south of Baltimore Canyon *Acanella arbuscula*, *Pennatula* sp. and *Flabellum alabastrum* were seen.

White fluffy sea pens were the only corals found in the

heads of Carteret and Toms Canyons. Deeper at Deep Water Dumpsite #106 populations of *Eunephthya fruticosa, Pennatula* sp. and *Anthomastus grandiflorus* were seen. An outcrop in this area provided the necessary substrate for *Paramuricea borealis, Acanthogorgia armata, Desmophyllum cristagalli* and *Anthomastus agassizi.*

Only sea pens were found in the main part of Hudson Canyon. *Eunephthya fruticosa* and sea pens were found in the deeper portion of this canyon. Corals observed in a number of dives on the deep continental slope near Alvin Canyon include *Acanella arbuscula, Flabellum alabastrum, Acanthogorgia armata, Paramuricea borealis* and sea pens.

The shallow water dives in the head of Veatch Canyon again revealed high concentration of the white sea pen. Numerous corals were seen in several photo transects in Oceanographer Canyon. *Paramuricea borealis, Desmophyllum cristagalli, Anthomastus agassizi* and *Acanthogorgia armata* were found on boulders or outcrops, while *Acanella arbuscula* and *Flabellum alabastrum* were found on the soft substrates in this canyon.

Sea pens were seen in the head of Lydonia Canyon, while *Paramuricea borealis, Anthomastus agassizi* and *Desmophyllum cristagalli* were seen in selected slides of some early dives in this canyon.

A number of dives in Heezen Canyon revealed many corals. *Pennatula* sp., *Anthomastus grandiflorus* and *Acanella arbuscula* were found on soft substrates within this canyon,

while *Paramuricea borealis*, *Desmophyllum cristagalli* and *Anthomastus agassizi* were seen on outcrops.

Corals were also abundant in Corsair Canyon. *Anthomastus agassizi*, *Acanthogorgia armata*, *Paramuricea borealis* and *Desmophyllum cristagalli* were seen on outcrops in this canyon, while *Pennatula* sp., *Acanella arbuscula* and *Flabellum alabastrum* were seen on soft substrates.

Corals that were rarely encountered during the survey are mapped on Fig. E3. The most striking of these is *Paragorgia arborea* which was seen on several pictures obtained from a dive in the shallow part of Norfolk Canyon. This species was also seen in selected slides and a film from Oceanographer Canyon. Three whips *Virgularia mirabilis*, *Acanthoptilum grandiflorum* and *Balticina finnmarchia* were seen in the study area, as well as species of *Umbellula* and *Radicepes*. *Dasmosmilia lymani* was found on the continental shelf between Wilmington and Hudson Canyons. A coral that we called blue bush was found in Heezen and Corsair Canyons. This may be a species of *Eunephthya* but without voucher specimens this is impossible to determine.

A detailed mapping of the corals is possible for those dives where we have accurate dive track information.

The locations of dominant coral species seen during dives 808, 809, and 810 in Norfolk Canyon are mapped in Fig. E-4. *Acanthogorgia armata*, *Desmophyllum cristagalli* and

Flabellum alabastrum are present on outcrops shallower than 1200 meters. During dive 809 sea pens, *Pennatula* sp. and *Anthomastus grandiflorus* are found on the soft substrate. Dive 810 was the deepest dive in this area and many individuals of *Pennatula* sp. and *Anthomastus grandiflorus* were seen, while *Flabellum alabastrum* and *Eunephthya fruticosa* were less common. Except for *E. fruticosa* these corals are restricted to soft substrates.

Figure E-5 is a map of the corals occurring between Baltimore and Hudson Canyons. It shows the location of corals seen in the heads of Toms and Carteret Canyons as well as those seen at DWD-106. As was previously mentioned, the white sea pen and other undifferentiated sea pens were seen in the shallow region. *Eunephthya fruticosa, Anthomastus agassizi, Paramuricea borealis, Pennatula* sp. and *Acanthogorgia armata* occurred at approximately 2250 and 2500 meters depth in this area.

The location of coral populations seen on the continental slope near Alvin Canyon is shown in Fig. E-6. *Acanella arbuscula, Anthomastus agassizi, Paramuricea borealis, Flabellum alabastrum* and sea pens were found in this area of mixed substrates.

Dives in Oceanographer Canyon (Fig. E-7) covered the canyon axis and west wall, revealing a pattern of coral distribution that is somewhat different from that seen farther north in Heezen

Canyon. *Desmophyllum cristagalli, Anthomastus agassizi* and *Paramuricea borealis* were found in the axis of the canyon while *P. borealis, Acanthogorgia armata* and *A. agassizi* occurred on cobbles and glacial erratics on the canyon wall. Some individuals of *Acanella arbuscula* were seen on the soft substrate of the canyon wall.

The dives in Heezen Canyon (Figure E-8) provide good comparative coverage in both the canyon axis and on the canyon wall. Corals restricted to hard substrates, such as *Desmophyllum cristagalli, Anthomastus agassizi* and *Paramuricea borealis* were seen on outcrops in the canyon axis, while *Pennatula* sp., *Acanella arbuscula* and *Flabellum alabastrum* were seen in the soft substrate of the canyon floor. On the canyon wall soft substrate species such as *Acanella arbuscula, Pennatula* sp., *Anthomastus grandiflorus* and *Flabellum alabastrum* were seen.

Numerous corals were seen during dive 781 in Corsair Canyon near the northern limit of the study area. This dive provides coverage of a transect from the axis up the canyon wall. *Acanella arbuscula, Pennatula* sp., *Anthomastus grandiflorus* and *Flabellum alabastrum* were seen on the soft substrates, while *Paramuricea borealis* and *Anthomastus agassizi* were restricted to occasional outcrops.

Coral Communities

The most striking result of a rotated principal components analysis on the corals in the data matrix is that the coral

assemblages exhibit very little cohesive structure. The general category of sea pens was again excluded from this analysis because of the problems with species recognition discussed in the preceding section. Eighty-six percent of the variance within the data matrix can be explained by the first 10 end-members (Table VI). Seven of these end-members are monospecific, while three are dispecific. The general interpretation of the results of this analysis is that the distributions of most of these deep-sea corals are being controlled by different parameters. This trend was also found in the community analysis of the total fauna, namely a shallow zone dominated by one species and a general tendency of some species to become shallower with increasing latitude. This pattern of emergence cannot be explained without a rigorous examination of the factors that control the distribution of these organisms.

Study of some of the 10 end-members elucidates several of these factors. End-member 4 is composed of two species, the octocoral *Anthomastus agassizi* and the gorgonian *Parmuricea borealis* both of which are restricted to hard substrates. They are dominant deeper in the northern canyons, but are not found in the southern canyons even though suitable substrate (outcrops) does occur at comparable depths in Norfolk Canyon. *Acanthogorgia armata* (8) and *Desmophyllum cristagalli* (9) are also restricted to hard substrates. In Norfolk Canyon both of these species co-occur on the same outcrops. In the

northern canyons *Acanthogorgia armata* is most prevalent on the glacial erratics occurring on the wall of Oceanographer Canyon, while *Desmophyllum cristagalli* is restricted to the underhangs of the more massive outcrops found in the axes of all three northern canyons (Table VII). These four species do have at least one thing in common, the fact that they are restricted to hard substrates and are therefore found only in canyon areas. However, without more detailed information on some of the other factors, such as current activity, the specifics of these overlapping but discontinuous distributions cannot be interpreted.

Anthomastus grandiflorus and *Pennatula* sp. (6) and *Acanella arbuscula* (3) are restricted to soft substrates. Their distributions have been discussed in detail in the community analysis of the total fauna. *Flabellum alabastrum* (5) and *Distichoptilim gracile* (1) are both found on soft substrates and are present throughout the deeper part of the study area. It should be mentioned that the distribution of both of these species may, in fact, be composites of more than one species. Both are rather small making detailed identification from photographs, on species characteristics, impossible. One interesting assemblage is composed of *Eunephthya fruticosa* and *Pennatula* sp. (10). This assemblage is restricted to the deeper parts of Hudson and Norfolk Canyons. Abundant populations of large individuals of *Eunephthya fruticosa* were found

only in the deeper part of Hudson Canyon.

In general the corals in our study area do not occur as discrete communities, but rather tend to co-exist in some regions and not in others. The corals found on hard substrates are restricted to canyons where outcrops and boulders provide suitable habitats. Several of the coral species whose distributions are similar within our study area are recognized as members of dispecific assemblages. It might be inferred that the habitat requirements of these species are quite similar. Closer examination of the coral populations found on the northern canyon wall dives indicate that canyons offer a variety of habitats. Seven species of corals are dominant between 650 and 1550 meters on the wall of Oceanographer Canyon, three monospecific and two dispecific assemblages. The depth interval between 650 to 950 meters is dominated by *Acanthogorgia armata* (8) which is found on numerous glacial erratics and coral rubble. Between 950 and 1350 meters *Acanella arbuscula* (3), *Anthomastus agassizi* and *Paramuricea borealis* (4) predominate. *Acanella arbuscula* is found on the soft substrate, while the other two corals are restricted to the glacial erratics, outcrops and coral rubble occurring in this area. Slightly deeper *Pennatula* sp. and *Anthomastus grandiflorus* are found on the soft substrate. The surface sediments on the wall of Corsair Canyon are mostly composed of silt and consolidated clay. The corals here are dominated by species requiring

soft substrates. The same is true for the wall of Heezen Canyon, with the exception of the deeper part. Here outcrops occur and the coral fauna is dominated by *Paramuricea borealis* and *Anthomastus agassizi*. A closer examination of the canyon walls might yield distinct assemblages, but at this time the data is not extensive enough to warrent this type of analysis.

Faunal Similarity

The faunal similarity analysis yielded somewhat ambiguous results. The percent of faunal overlap between depth intervals was frequently amplified or decreased by patchy distribution of the organisms and by substrate variability. For example, faunal similarities between adjacent 50 m depth intervals was fairly low in shallow water (100-300 m). It ranged from 0% to 50% but was frequently as low as 10%. This phenomena is probably a reflection of the rather restricted depth zones of many of the species found in the shelf faunal province. This situation is further complicated by the fact that a large geographic area is contained within a depth interval and thus that depth interval is more likely to include a variety of gradational substrate types. Percent faunal similarity was somewhat higher, frequently from 50% to 80%, between adjacent dives within a depth interval. However, there was a marked difference between the fauna of the southern area when compared with that of the northern area (0% to 30%).

The southern shelf province is dominated by *Munida valida* and the white sea pen, while the northern province showed much greater variability. This province was dominated by the white sea pen, a small pink amphipod, a shrimp, and the ophiurid *Amphilimna olivacea*. A pueblo community as defined by Warme et al (1978) was seen at a depth of 250 meters in Carteret Canyon. Dominant taxa were *Cancer borealis*, occasional lobsters, and fish. A similar pueblo community was seen at a depth of 150 meters in Veatch Canyon.

Between the depths of 300 to 500 meters on the slope south of Baltimore Canyon faunal similarity was extremely high between adjacent 50 meter depth intervals (80% to 90%). These high values were due to the overwhelming presence of *Hyalinoecia artifex*. This quill worm has a patchy distribution and is extremely abundant where it occurs. It thus tends to obliterate any trend found in the other fauna. Percentage similarity, between adjacent 50 meter depth intervals, was also uniformly high between 850 to 1300 meters (50-80%). This high degree of overlap was due to the dominance of the fish found throughout this zone. Percentage similarity was again high between adjacent 50 meter depth intervals in the 1550 to 1800 meter range (70%-90%). This was due to the presence of one dominant species, *Ophiomusium lymani* throughout this range. Faunal similarities between dives in the depth range of 1700 to 1900 meters are also uniformly high (70% to 80%), being due to the

ubiquitous presence of *Ophiomusium lymani*.

However, at intermediate depths comparisons between slope and canyon fauna yield a low percentage faunal similarity (10% to 20%). The amount of species overlap between adjacent depth intervals in a canyon is exceedingly variable (3% to 90%). These results again point to the fact that canyons provide rather unique habitats for their faunal constituents. The high degree of environmental heterogeneity found on canyon walls provides opportunities for the coexistence of a large variety of different epifaunal species and trophic types. The slope, on the other hand, does not provide as heterogeneous an environment and therefore has similar fauna over wider latitudinal and depth ranges.

Faunal Associations

Several types of faunal associations were observed during this survey. However, probably many more faunal associations exist between the animals which are not apparent in photographs. Examples of this might be the reported association between a small shrimp and the coral *Paragorgia arborea* or the association between cleaner shrimp and fish in pueblo communities. This is, additionally, complicated by the fact that associations are usually manifested behaviorally, which can be determined only by direct visual observation over a period of time.

One common association observed was that of the ophiurid

Asteronyx loveni and corals. Most instances of this association were probably not discernable on photographs, due to the fact that *Asteronyx* is frequently tightly coiled within the inner branches of gorgonian colonies. Additionally, in relation to the association between the coral *Acanella arbuscula* and *Asteronyx loveni* the coloration of the two is similar enough to prevent recognition of the ophiurid. This association appears to be obligatory because no individuals of *Asteronyx* were ever found alone.

Another association noted during this survey was the co-occurrence of *Ophiomusium lymani* with several gorgonians. This ophiurid was frequently found at the base of the coral. Whether or not this relationship is obligatory is not known. *Ophiomusium lymani* may merely be responding to structural heterogeneity in its environment. However, frequently as many as four were found at the base of the gorgonians. Another association was observed between *Collosendeis colossea* and *Paramuricea borealis*. Individuals of this pycnogonid were frequently seen climbing on the coral colonies. Whether this indicated instances of predation, a cleaning association, or were mere coincidence is not known.

An association that was noted during the shallow water dives of this survey was that of the large burrowing anemone *Cerianthus borealis* and small individuals of the jonah crab *Cancer borealis*. These jonah crabs were frequently found around the base of the anemone tubes. Additionally small fish exhibited a similar

relationship with this anemone. It is possible that juvenile fish and crabs utilize the base of the anemone for protection.

CONCLUSIONS

On the whole the analysis of the submersible photographs identified submarine canyons as providing rather unique habitats for their faunal constituents. They provide a variety of substrate types, and are implicated as being areas of increased current activity and nutrient enrichment. Our analysis supports the evidence that suggests the existence of three major faunal provinces on the continental margin. The shelf and shelf-break area is dominated by crustaceans and fish. While fish dominate the upper portion of the slope and echinoderms dominate the lower slope. This trend was somewhat obscured within canyons, attesting to the greater environmental heterogeneity afforded by canyons. The canyon fauna is unique in that it is frequently composed of high percentages of sessile organisms such as corals and sponges. At intermediate depths filter-feeding corals tend to dominate the faunal assemblage. Another finding was that canyon epifauna was generally more abundant than slope epifauna at comparable depths.

Within these three major depth zones gradual faunal replacement with increasing depth was observed. Shallow water species tended to have narrower depth ranges than deep water species. These ranges may be determined by the availability of

suitable substrates rather than by temperature variability or barometric pressure. Another trend noted was that of the gradual emergence of some species with increasing latitude. This again may be related to substrate availability. This conclusion is somewhat tenuous due to the lack of correlative substrate characteristics and environmental parameters of the areas viewed.

The nutrient rich shelf supports a variety of trophic types. However, the fauna is dominated by carnivores and scavengers (crabs and fish). The upper slope which tends to be rather homogeneous with regard to substrate is also relatively nutrient rich. The fauna here again is dominated by carnivores and scavengers namely, the red crab *Geryon quinquedens* and fish. The lower slope is slightly more heterogeneous in terms of substrate availability and is rather nutrient poor. This region is dominated by deposit-feeding echinoderms. This pattern is somewhat changed on the walls of canyons. Here the fauna is frequently dominated by sessile filter feeding organisms, namely corals and sponges. The presence of filter-feeders in canyons and not on the slope may be explained by the postulated nutrient enrichment of canyons and availability of hard substrates.

In general, no discrete cohesive faunal assemblages were identified by the community analysis. Rather the results indicate that most of the dominant species in the study area are independently distributed. This is concluded from the fact that most

end-members of the factor analysis were monospecific. Intensive study of a more restricted geographic area might reveal cohesive localized communities, but when viewed over a wide geographic area such relationships are obscured. In effect, this means that the factors controlling the distribution of the species are slightly different such that each species cues in to slightly different specific environmental parameters. At this time the limited information, such as can be discerned from a study of photographs, does not allow elucidation of these differences. Hopefully the controlled sampling of the field program will enable determination of some of the factors responsible for the variations seen in the data set.

ANTICIPATED ENVIRONMENTAL IMPACT OF OCS RESOURCE DEVELOPMENT

Assessments of the possible environmental impact of OCS resource development, at this point, would be exceedingly premature. The inadequate historical data base does not permit a detailed evaluation of the environmental parameters that may be responsible for many of the variations seen in the distribution of the epifauna. The lack of correlative fine scale environmental data hampers interpolation of results from one area to another. Hopefully, by correlating fine scale salinity, temperature and substrate characteristics with the abundance and distribution of epifauna, in

the field program, some of the important environmental parameters can be elucidated.

The results have identified canyons as unique habitats, particularly for corals and other filter-feeding organisms. It should be noted that these organisms can be considered as potential environmental "indicators". As filter-feeders they are directly tied to water column characteristics for their nutrients. Thus, any development of resources on the OCS that alters the characteristics of the water (i. e. drilling increasing the amount of suspended particles or oil spills decreasing the primary productivity) could potentially increase coral mortality. Once coral communities, in a specific area, have been located and identified they can be revisited and used as "indicators" of environmental disturbance.

SUMMARY

For the historical coral report all available submersible dives on the mid and north Atlantic continental margin were reviewed. Particular emphasis was placed on the canyons found within this area. The depths studied ranged from 100 to 3200 meters.

1. Corals were found at all depths within the study area. Particularly high concentrations and more diverse assemblages were found in the northern canyons. Several of the species

exhibited emergence with increasing latitude while others did not.

2. Three major depth zones were identified. The shelf and shelf-break region was dominated by crustaceans and fish. The upper slope was dominated by fish, while the lower slope was characterized by high concentrations of echinoderms. Individual species had more restricted depth ranges within these zones. Gradual faunal replacement with depth was observed.

3. No discrete faunal assemblages were identified. Community analysis indicated that the distributions of the dominant taxa were independent. This implies that the factors controlling each of these organisms are slightly different.

4. Faunal densities were highest on the shelf and at the slope-continental rise boundary. In general higher faunal densities were noted in the canyons than on the slope. This supports the hypothesis that canyons are areas of nutrient enrichment.

5. Canyon walls were identified as unique habitats. They provide a variety of substrate types which in turn determines the distribution of various taxa. Sessile species that require hard substrates were restricted to canyon areas. Canyons also support a greater variety of trophic types than does the adjacent slope.

6. Several types of faunal associations were noted. The most obvious was the occurrence of the ophiurid *Asteronyx loveni* in gorgonian colonies. This ophiurid was always seen tightly coiled in the branches of several species of coral. Another association was that of *Ophiomusium lymani* frequently occurring at the base of coral colonies. Another type of association

observed involves the anemone *Cerianthus borealis*. Small individuals of *Cancer borealis* and fish were frequently found at the base of this anemone. Possibly these juveniles utilize the anemone for protection.

7. The results of this study do indicate that canyons are unique habitats. However, the inadequacies of the historical data base do not permit adequate assessment of the factors controlling the distribution of the faunal constituents. Hence, it would be extremely tentative to attempt to interpolate the results to assessing environmental impact. Hopefully, the field program will enable elucidation of some of these factors.

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information on the dives. Thanks also go to George Keller of Oregon State University for sending us his film and dive tracks from early submersible work in Hudson Canyon. Richard A. Cooper and Joseph Uzmann of NMFS at Woods Hole very kindly provided us with a review of some of the dominant fauna seen in their survey of the canyons. We owe special thanks to the WHOI Deep Submergence Group, particularly Jack Donnelly who provided us with the logs of ALVIN dives.

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Figure A-1.

Map of submersible dives and camera lowerings along the Mid and North Atlantic Continental margin reviewed for the historical data survey.

● Quantitative Data

○ Camera lowerings

☆ NMFS and Qualitative Data

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Map

Figure B-1.

Histogram of the total faunal density standardized to the number of individuals per $100m^2$ for 50 meter depth intervals.

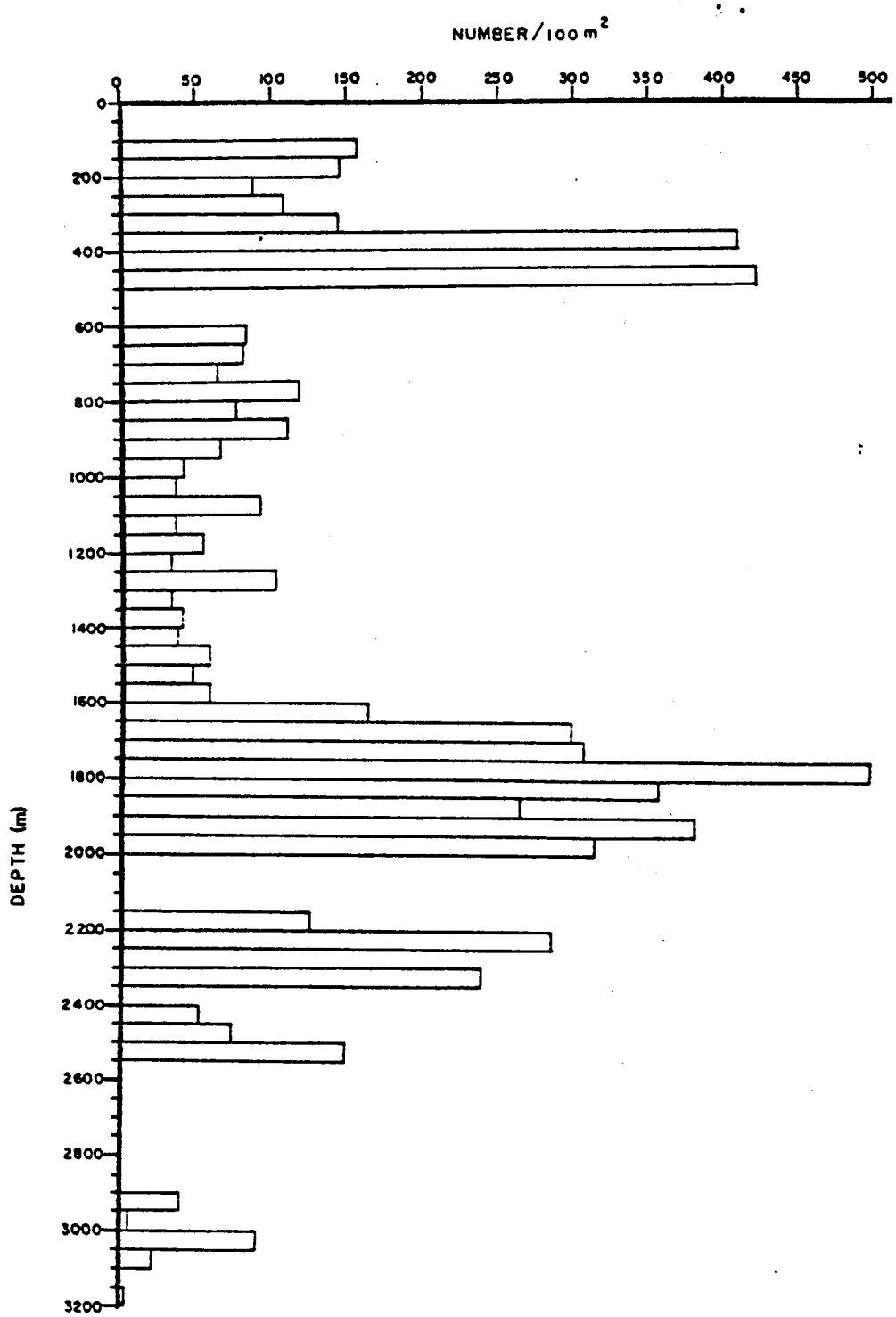

NUMBER/100 m²
0
50
100
150
200
250
300
350
400
450
500
DEPTH (m)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200

Figure B-2.

Histogram of the total faunal density in canyons versus slope standardized to the number of individuals per $100m^2$ for 50 meter depth intervals.

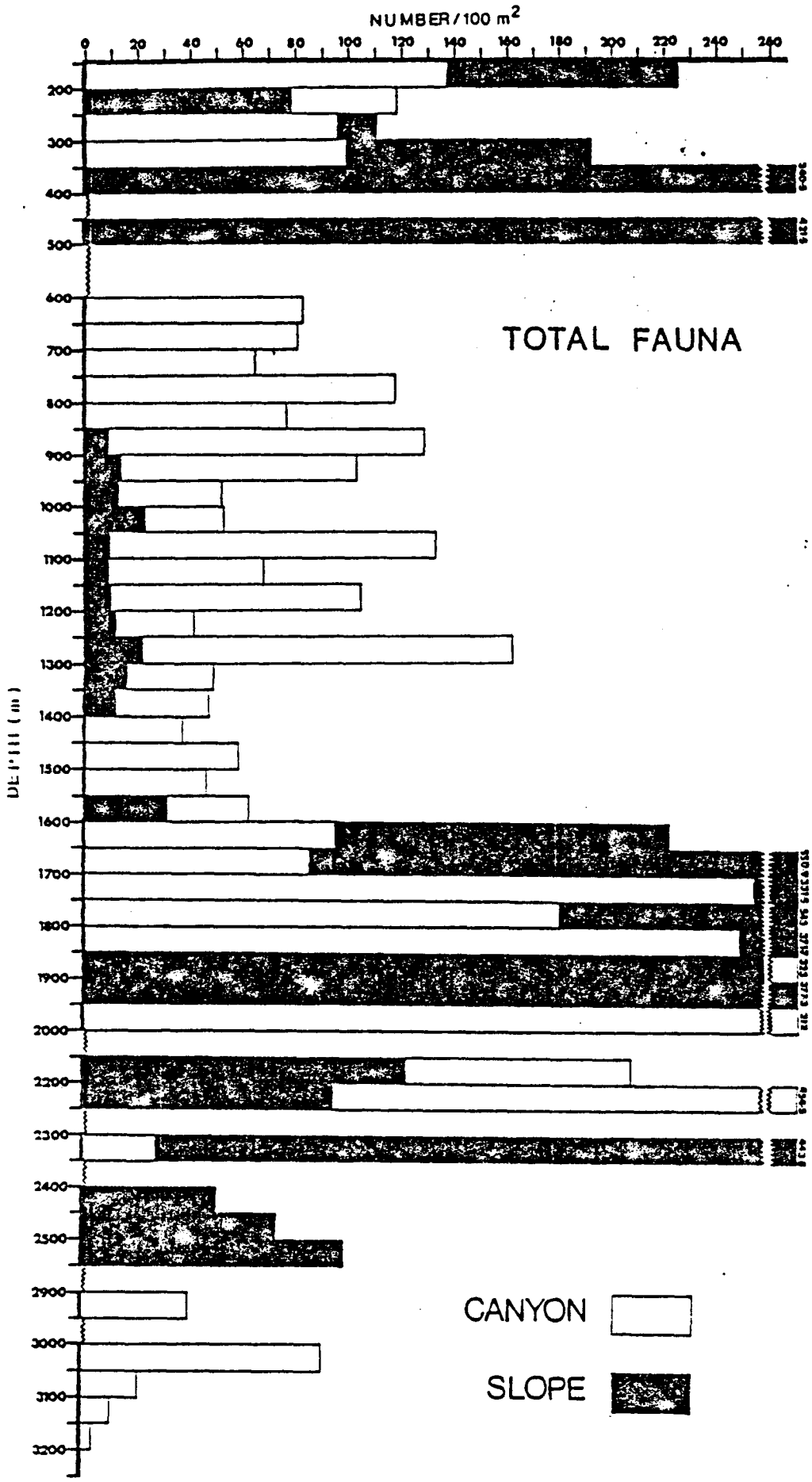
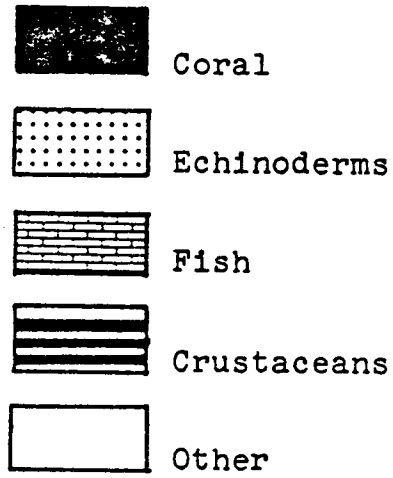

NUMBER/100 m²
0
20
40
60
80
100
120
140
160
180
200
220
240
260
DEPTH (m)
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2200
2300
2400
2500
2900
3000
3100
3200
TOTAL FAUNA
CANYON
SLOPE

Figure C-1.

Map showing the relative percentages of major faunal groups for each dive.



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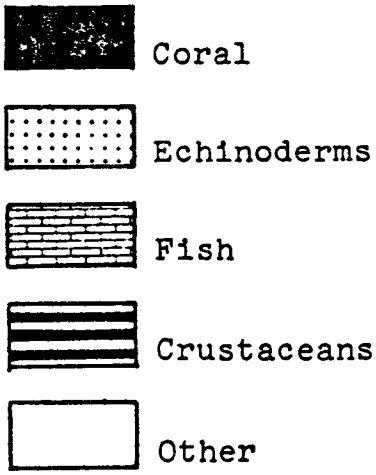
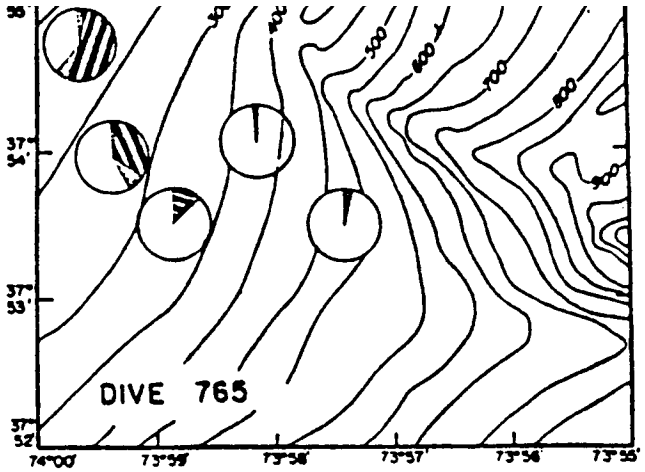
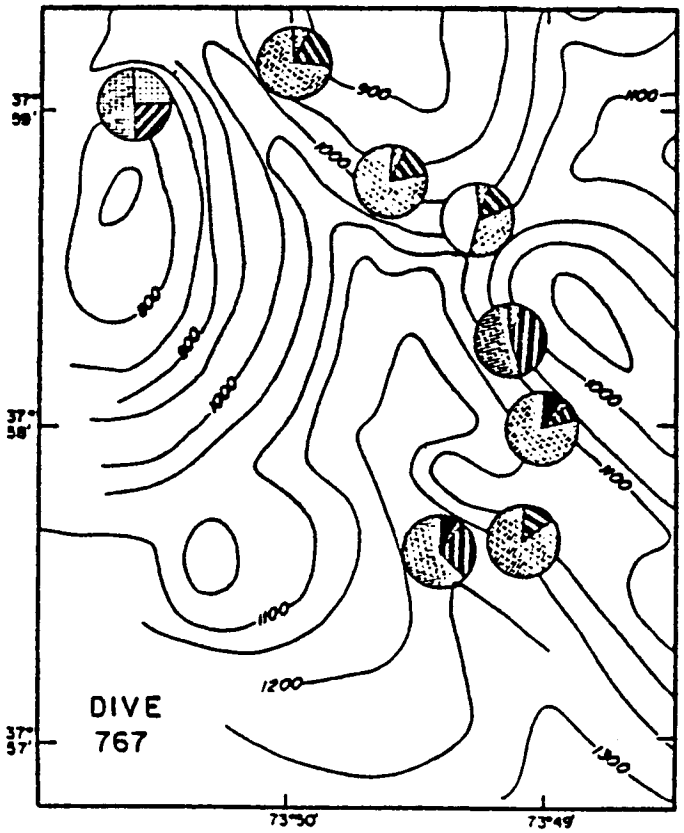
Map

Figure C-2.

Map showing the relative percentages of major faunal groups on the continental slope south of Baltimore Canyon for 50 meter depth intervals.




DIVE 765
37° 54'
37° 53'
37° 52'
74°00'
73°59'
73°58'
73°57'
73°56'
73°55'
500
600
700
800
900


DIVE 767
37° 59'
37° 58'
37° 57'
73°50'
73°49'
900
1000
1100
1200
1300

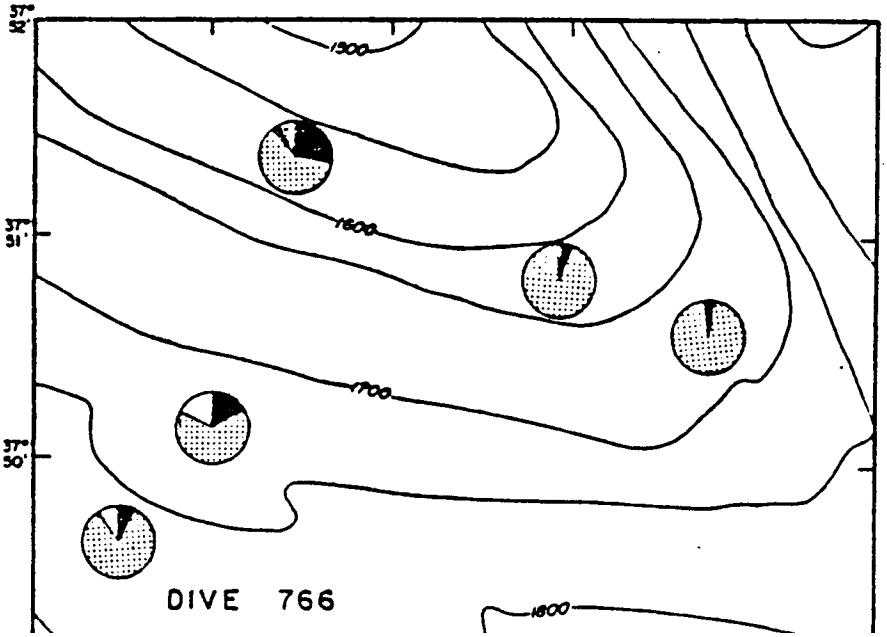
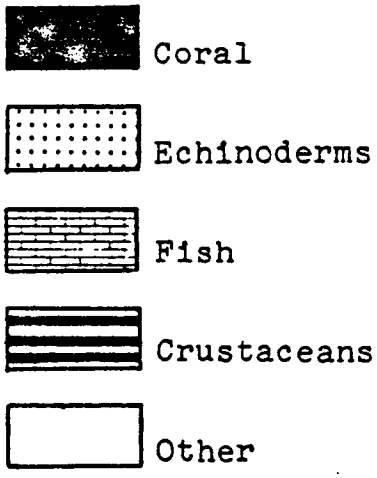

DIVE 766
37° 52'
37° 51'
37° 50'
1500
1600
1700
1800

Figure C-3.

Map showing the relative percentages of major faunal groups on the continental slope north of Norfolk Canyon for 50 meter depth intervals.



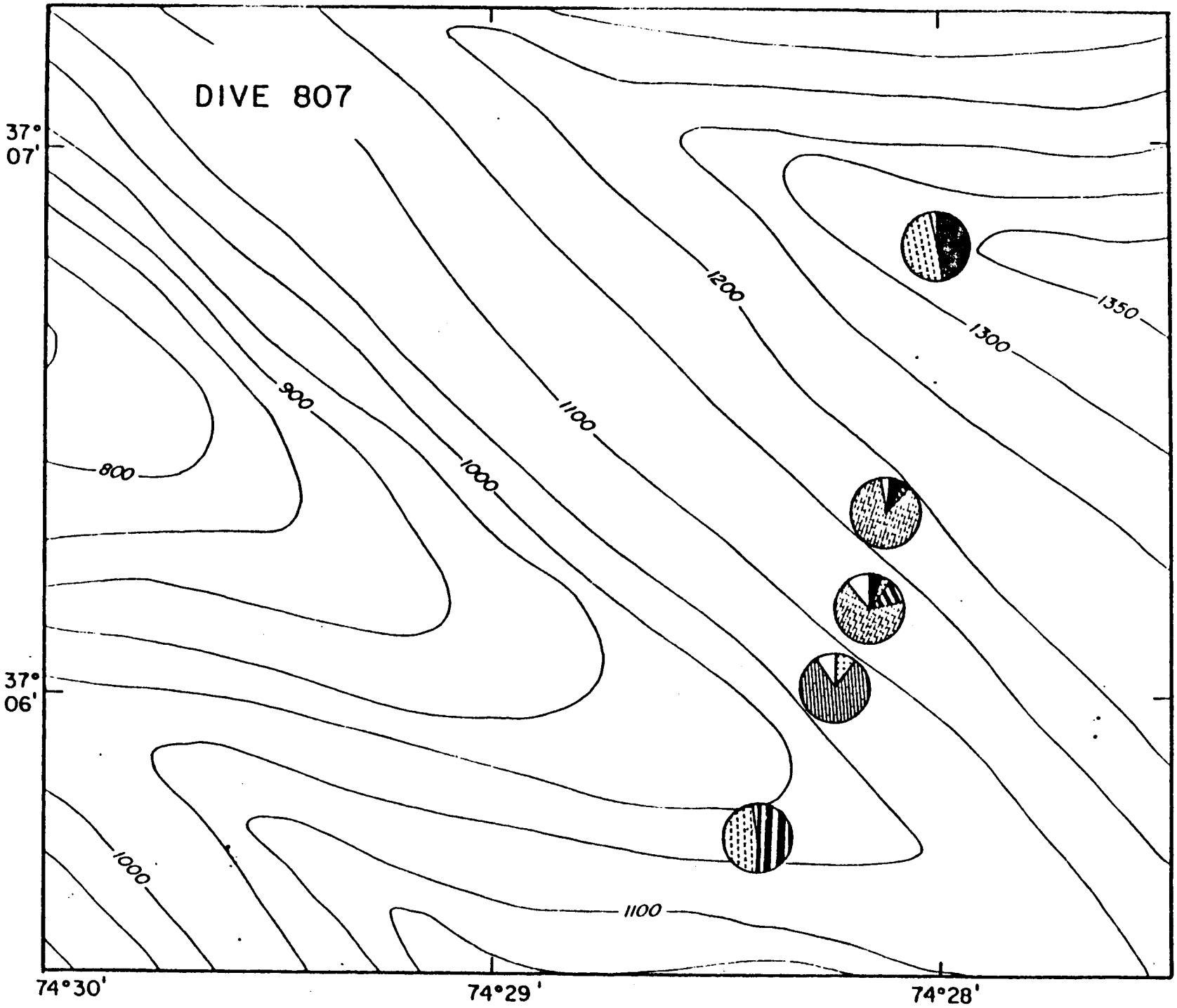
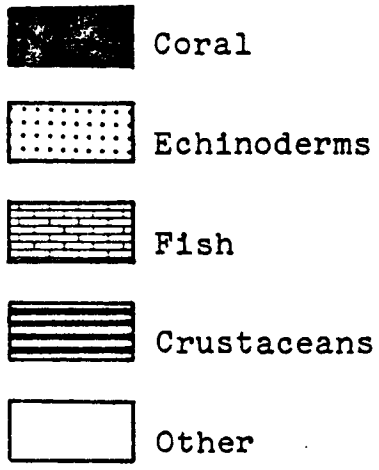
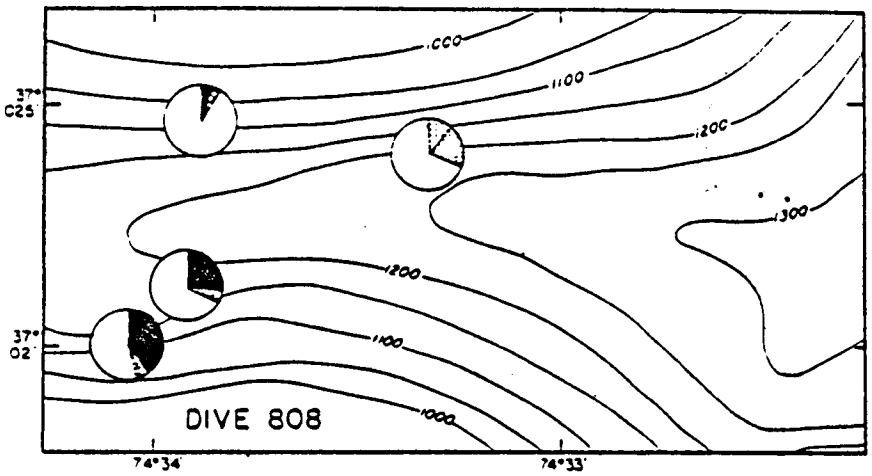
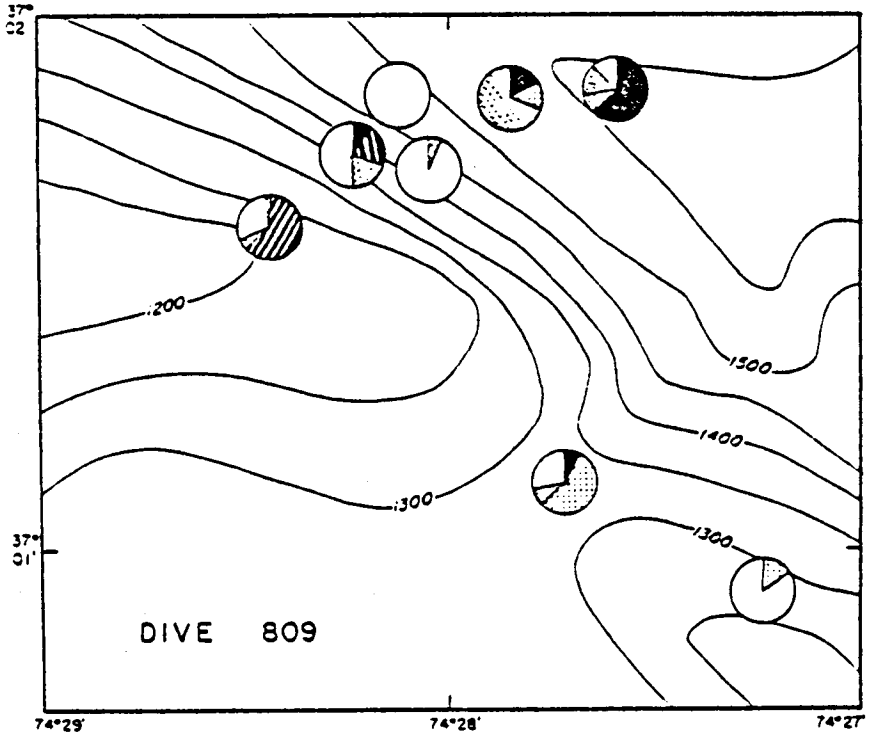

DIVE 807
37°
07'
37°
06'
74°30'
74°29'
74°28'
800
900
1000
1100
1200
1300
1350
1000
1100

Figure C-4.

Map showing the relative percentages of major faunal groups in Norfolk Canyon for 50 meter depth intervals.




1000
1100
1200
1300
1200
1100
1000
37°
02'
37°
02'
DIVE 808
74°34'
74°33'


37°
02
1200
1300
1400
1500
1300
37°
01'
DIVE 809
74°29'
74°28'
74°27'

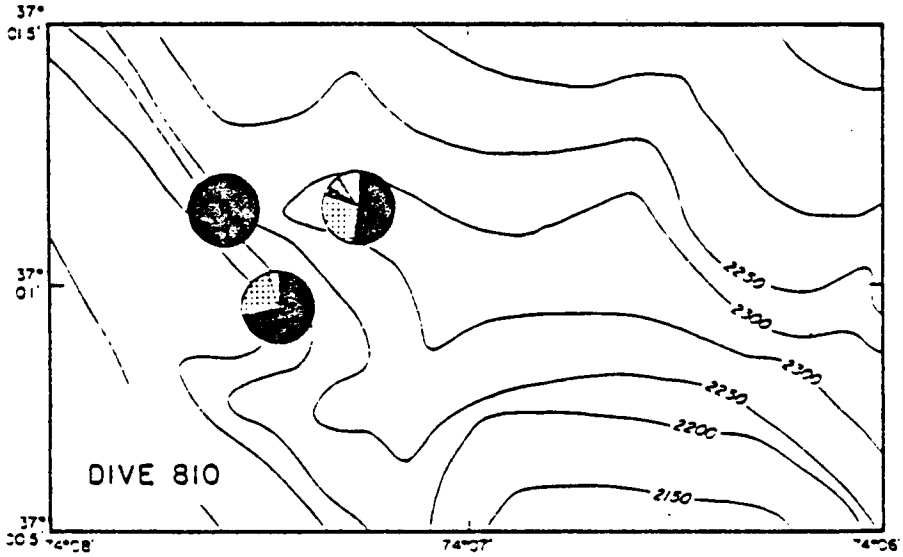
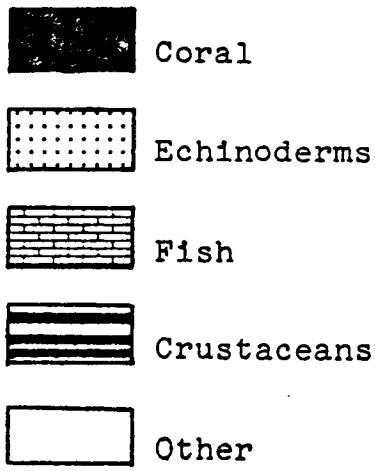

37°
01.5'
37°
01'
2250
2300
2350
2250
2200
2150
DIVE 810
74°07'

Figure C-5.

Map showing the relative percentages of major faunal groups in Oceanographer Canyon for 50 meter depth intervals (ALVIN dives 779, 784 and 785).



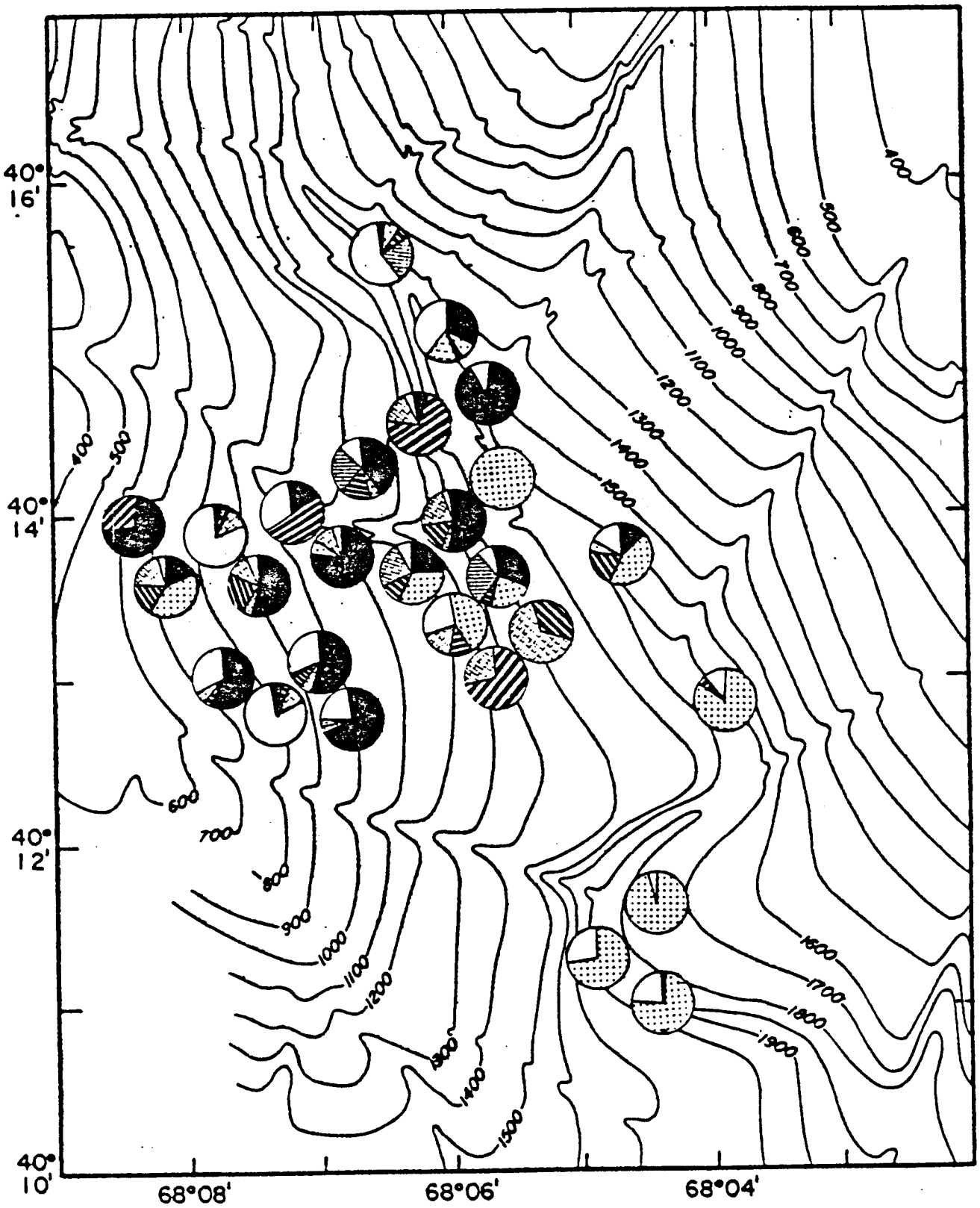
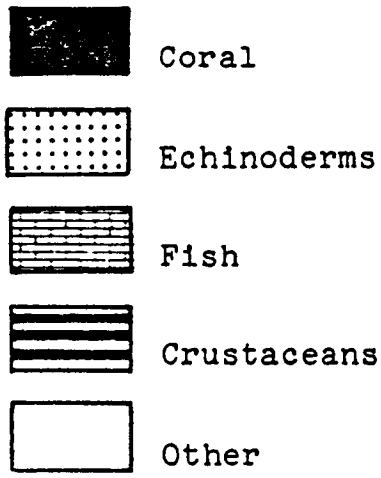

40° 16'
40° 14'
40° 12'
40° 10'
68°08'
68°06'
68°04'
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900

Figure C-6.

Map showing the relative percentages of major faunal groups in Heezen Canyon for 50 meter depth intervals (ALVIN dives 780, 782 and 783).



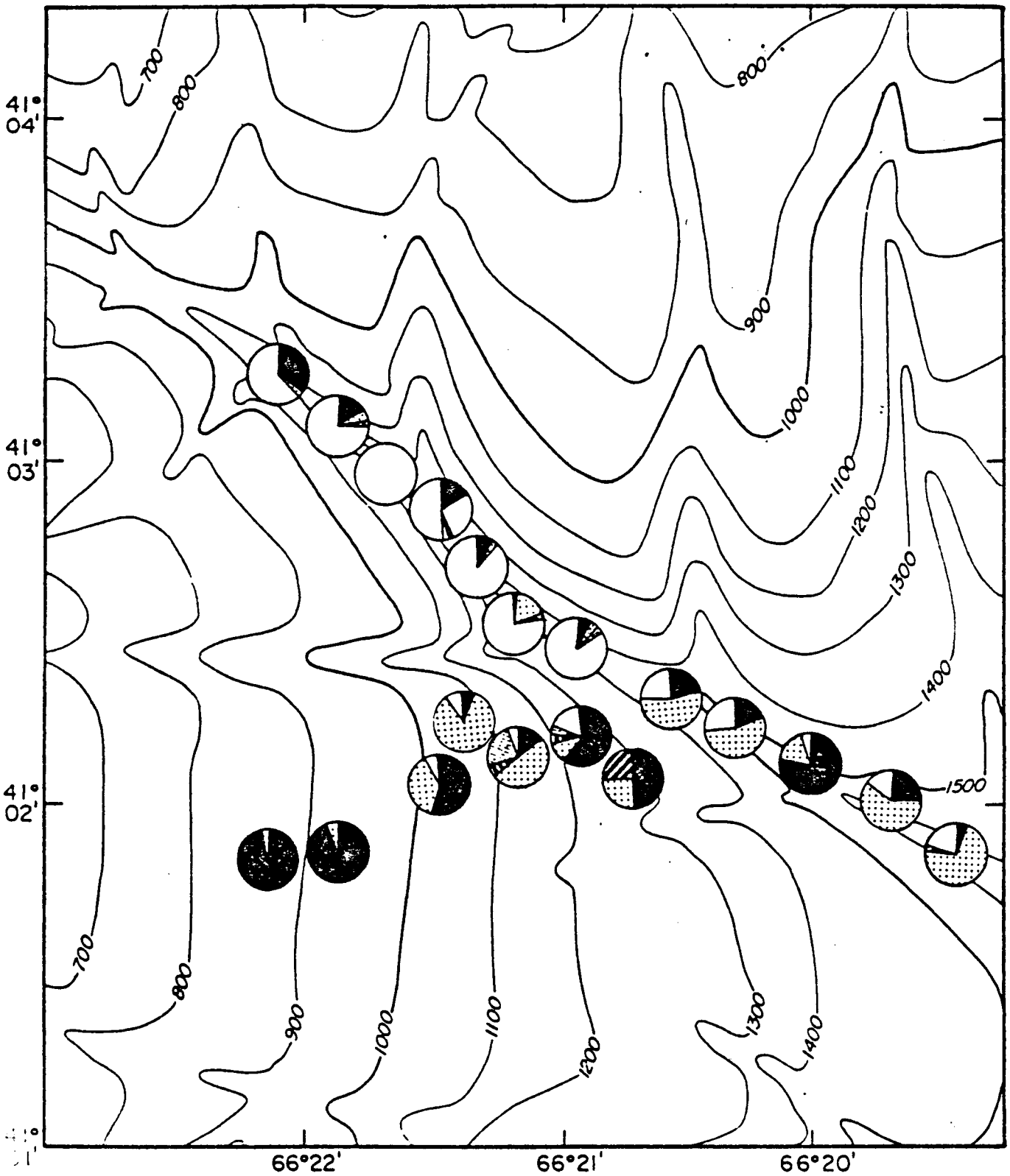
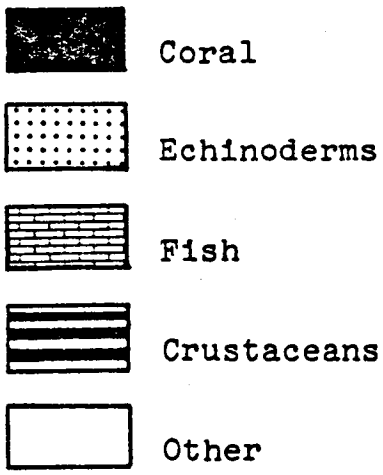

41° 04'
41° 03'
41° 02'
66°22'
66°21'
66°20'
700
800
900
1000
1100
1200
1300
1400
1500

Figure C-7.

Map showing the relative percentages of major faunal groups in Corsair Canyon for 50 meter depth intervals (ALVIN dive 781).



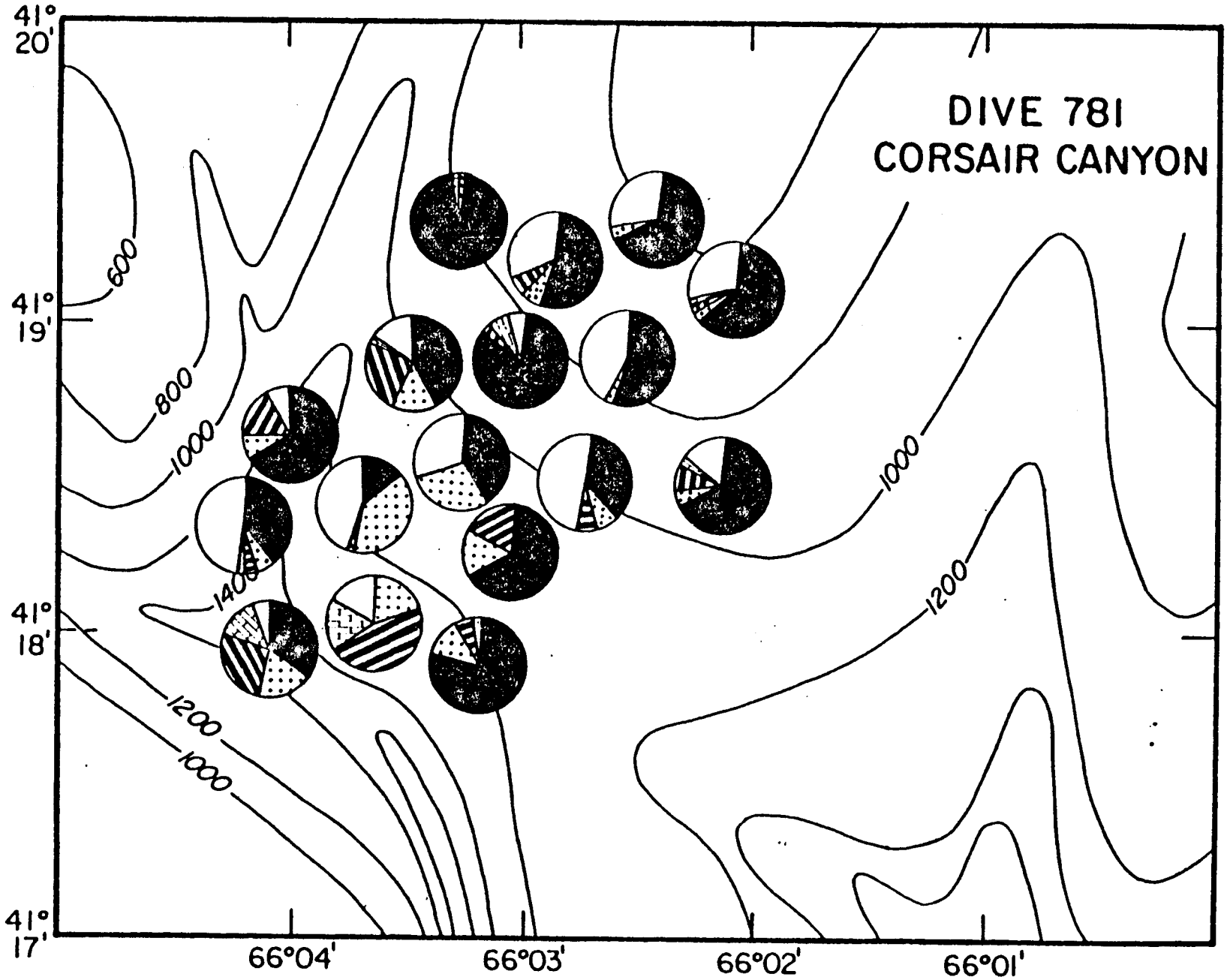

DIVE 781
CORSAIR CANYON
41° 20'
41° 19'
41° 18'
41° 17'
66°04'
66°03'
66°02'
66°01'
600
800
1000
1400
1200
1000
1000
1200

Figure D-1.

Histograms showing the depth distribution of the dominant shallow water species in number of individuals per $100m^2$ for 50 meter depth intervals.

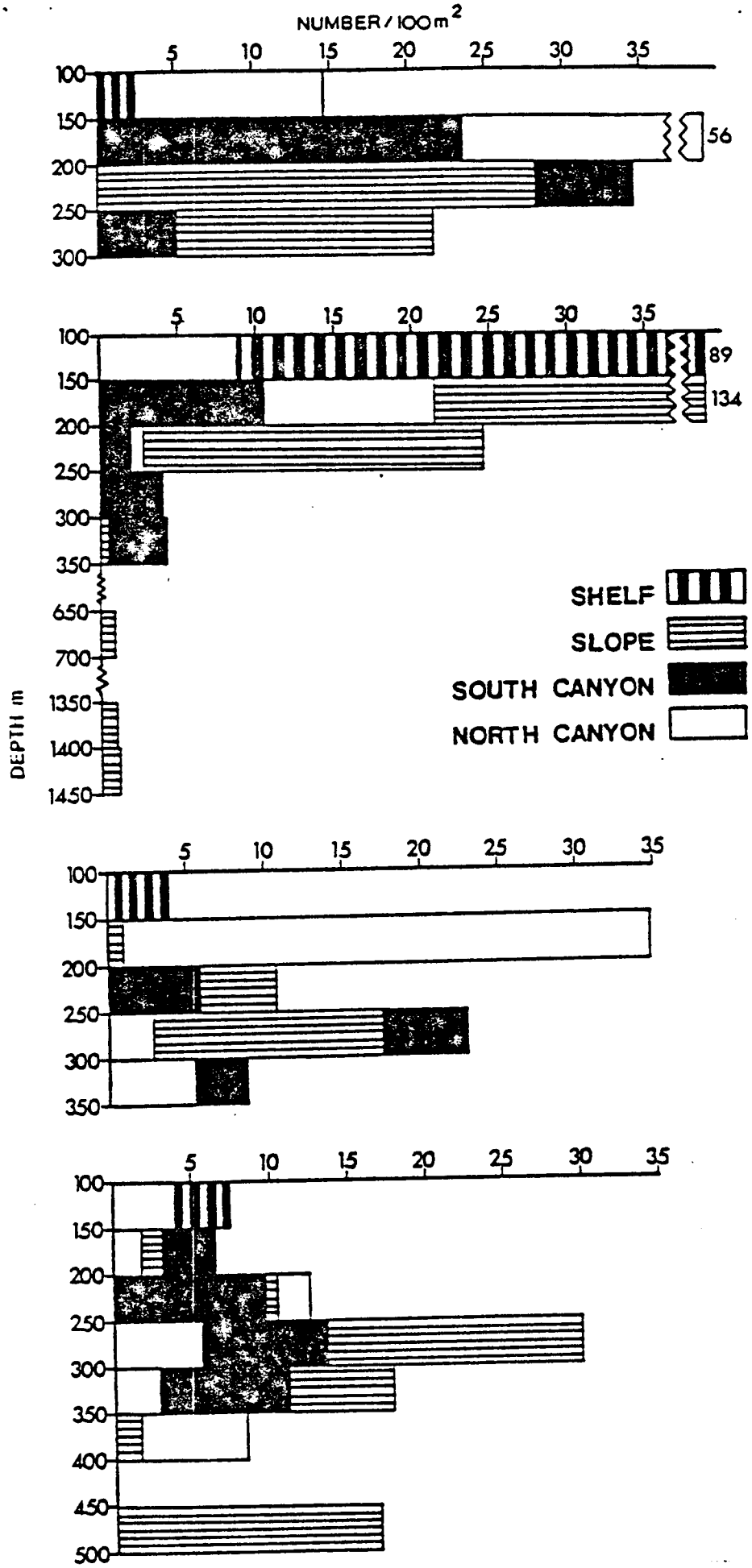

NUMBER / 100m²
5 10 15 20 25 30 35
100 150 200 250 300
56
White sea pen
5 10 15 20 25 30 35
100 150 200 250 300 350 650 700 1350 1400 1450
89
134
Munida valida
SHELF
SLOPE
SOUTH CANYON
NORTH CANYON
DEPTH m
5 10 15 20 25 30 35
100 150 200 250 300 350
Cerianthus borealis
5 10 15 20 25 30 35
100 150 200 250 300 350 400 450 500
Cancer borealis

Figure D-2.

Histogram showing the depth distribution of *Cancer borealis* and *Geryon quinquedens* in number of individuals per $100m^2$ for 50 meter depth intervals.

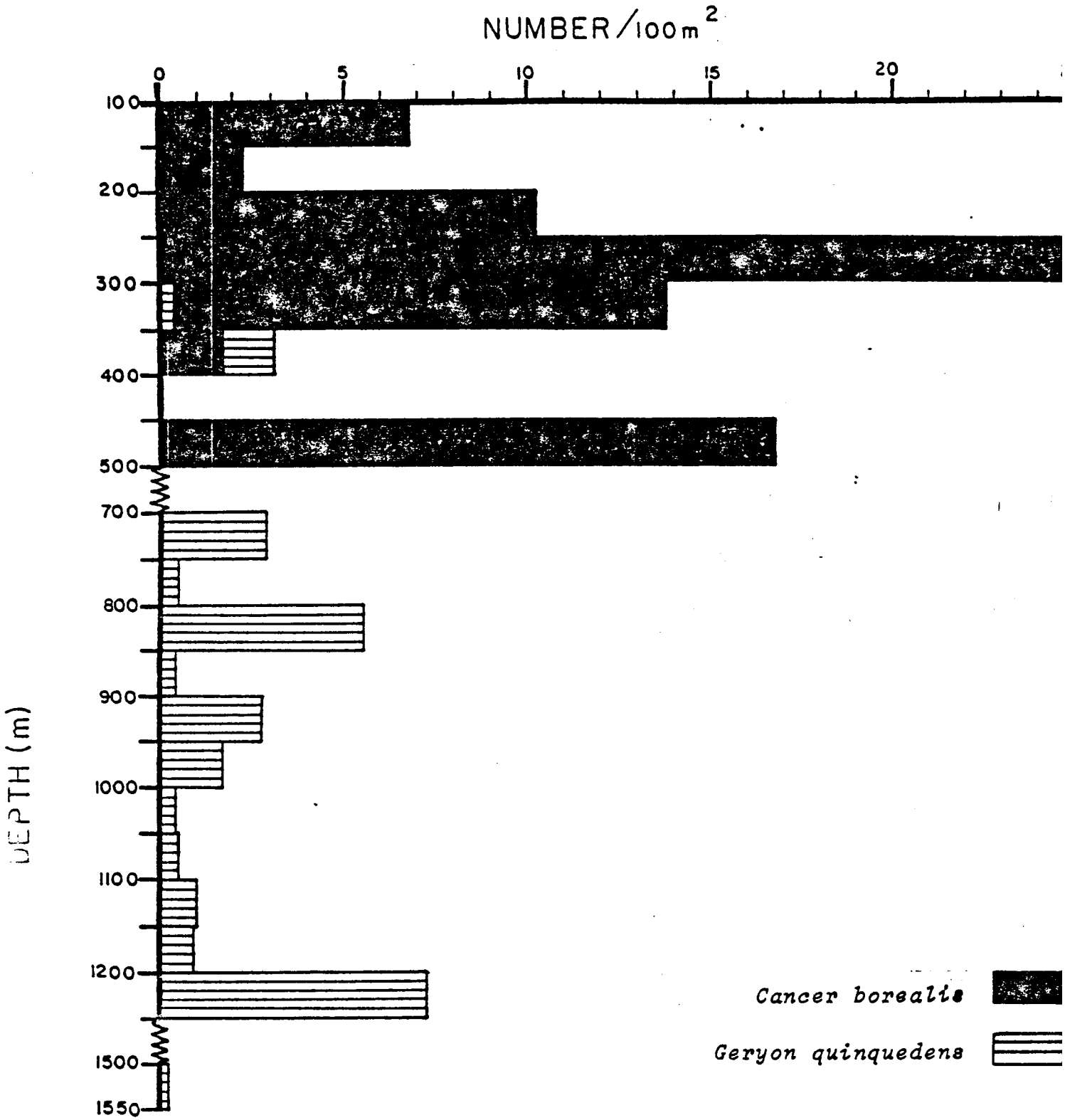

NUMBER/100m²
0
5
10
15
20
DEPTH (m)
100
200
300
400
500
700
800
900
1000
1100
1200
1500
1550
Cancer borealis
Geryon quinquedens

Figure D-3.

Histogram showing the depth distribution of *Anthomastus grandiflorus* and *Pennatula* sp. in number of individuals per $100m^2$ for 50 meter depth intervals.

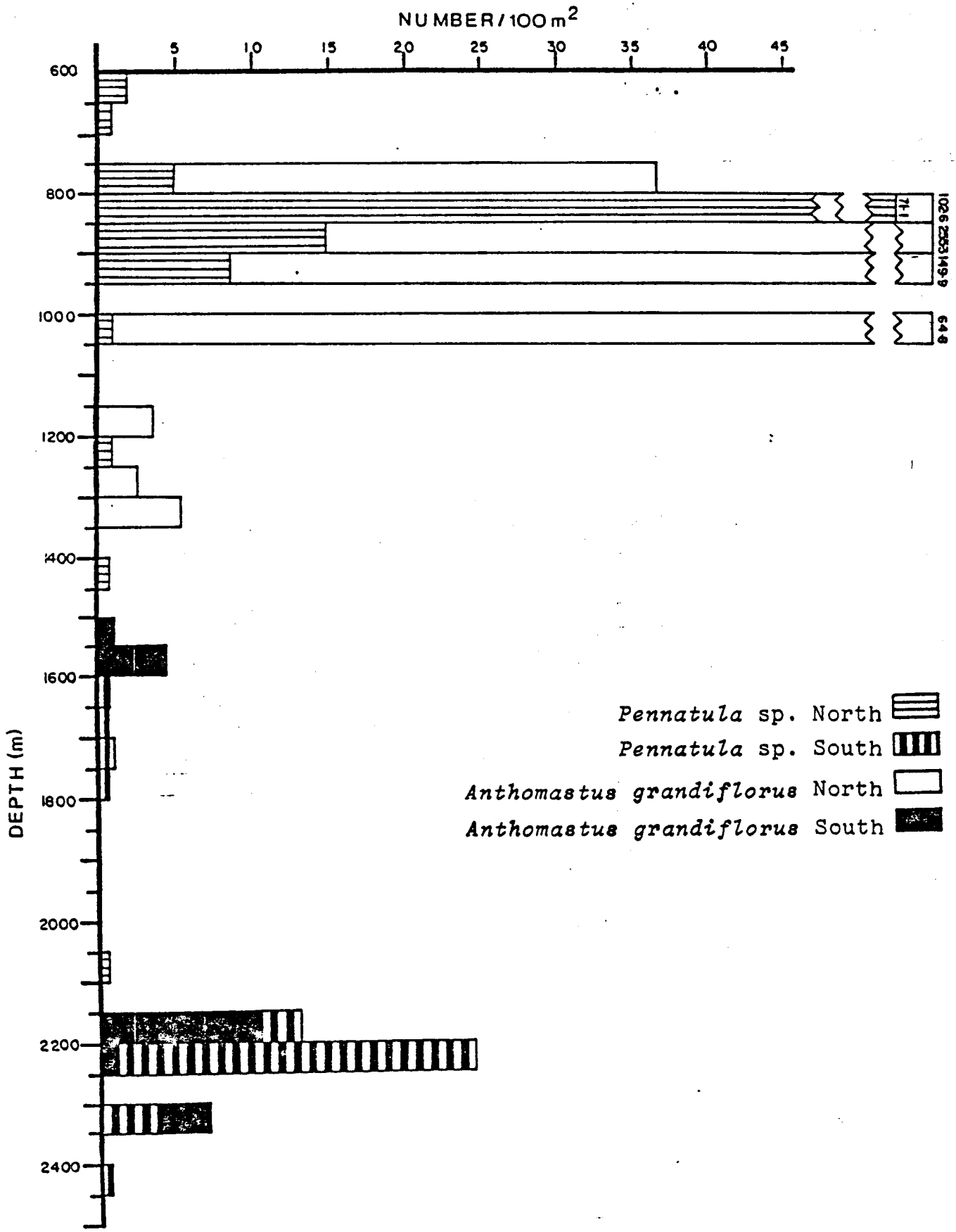

NUMBER/100m²
5
10
15
20
25
30
35
40
45
DEPTH (m)
600
800
1000
1200
1400
1600
1800
2000
2200
2400
1026
2253
1499
649
Pennatula sp. North
Pennatula sp. South
Anthomastus grandiflorus North
Anthomastus grandiflorus South

Figure D-4.

Histogram showing the depth distribution of *Acanella arbuscula* in number of individuals per $100m^2$ for 50 meter depth intervals.

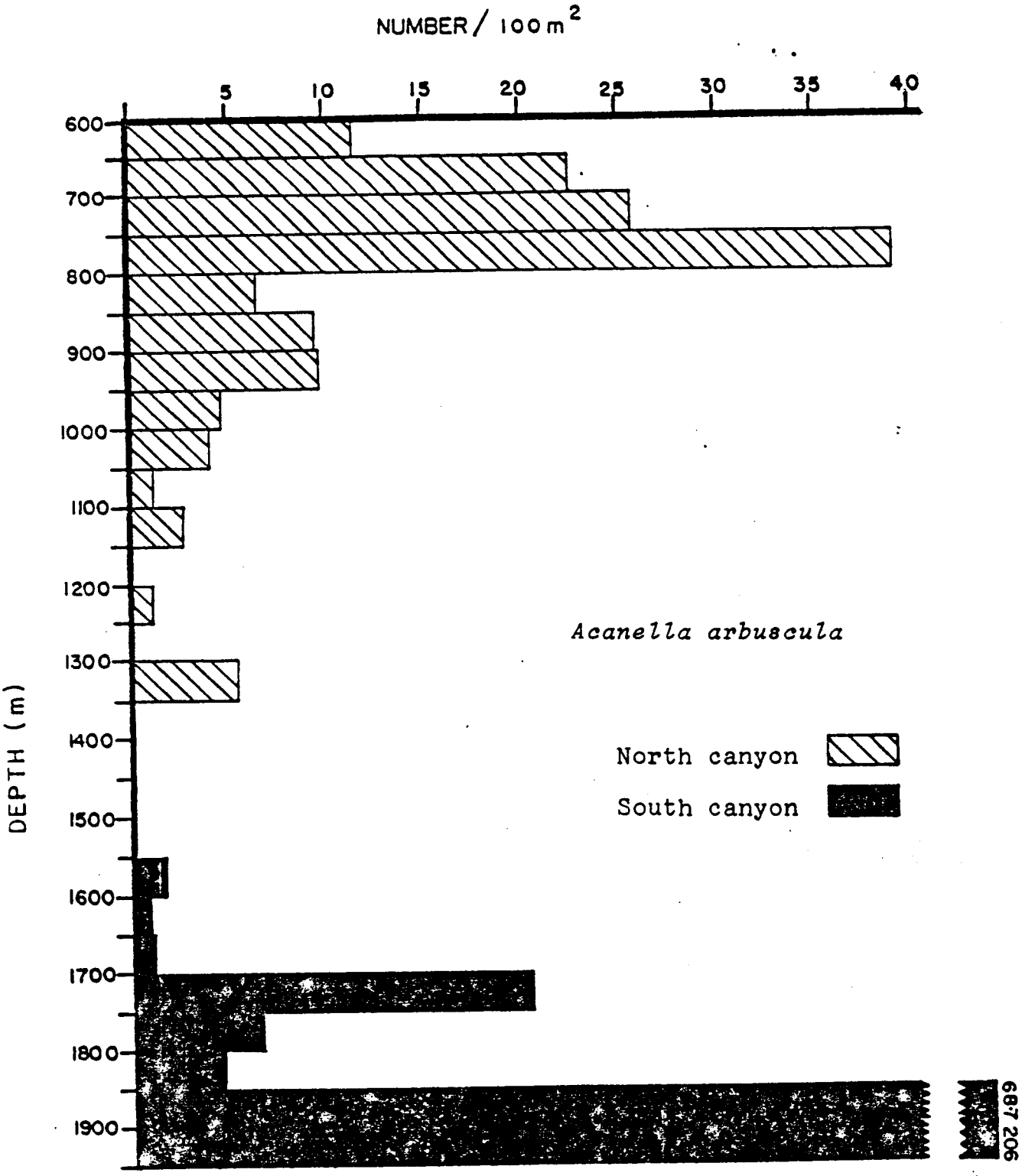
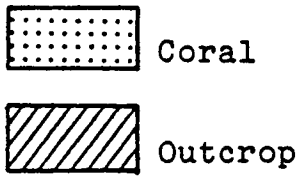

NUMBER / 100 m²
5
10
15
20
25
30
35
40
DEPTH (m)
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
Acanella arbuscula
North canyon
South canyon
687 206

Figure E-1.

Depths at which corals and outcrops were seen in the historical data survey with dives arranged from south to north.



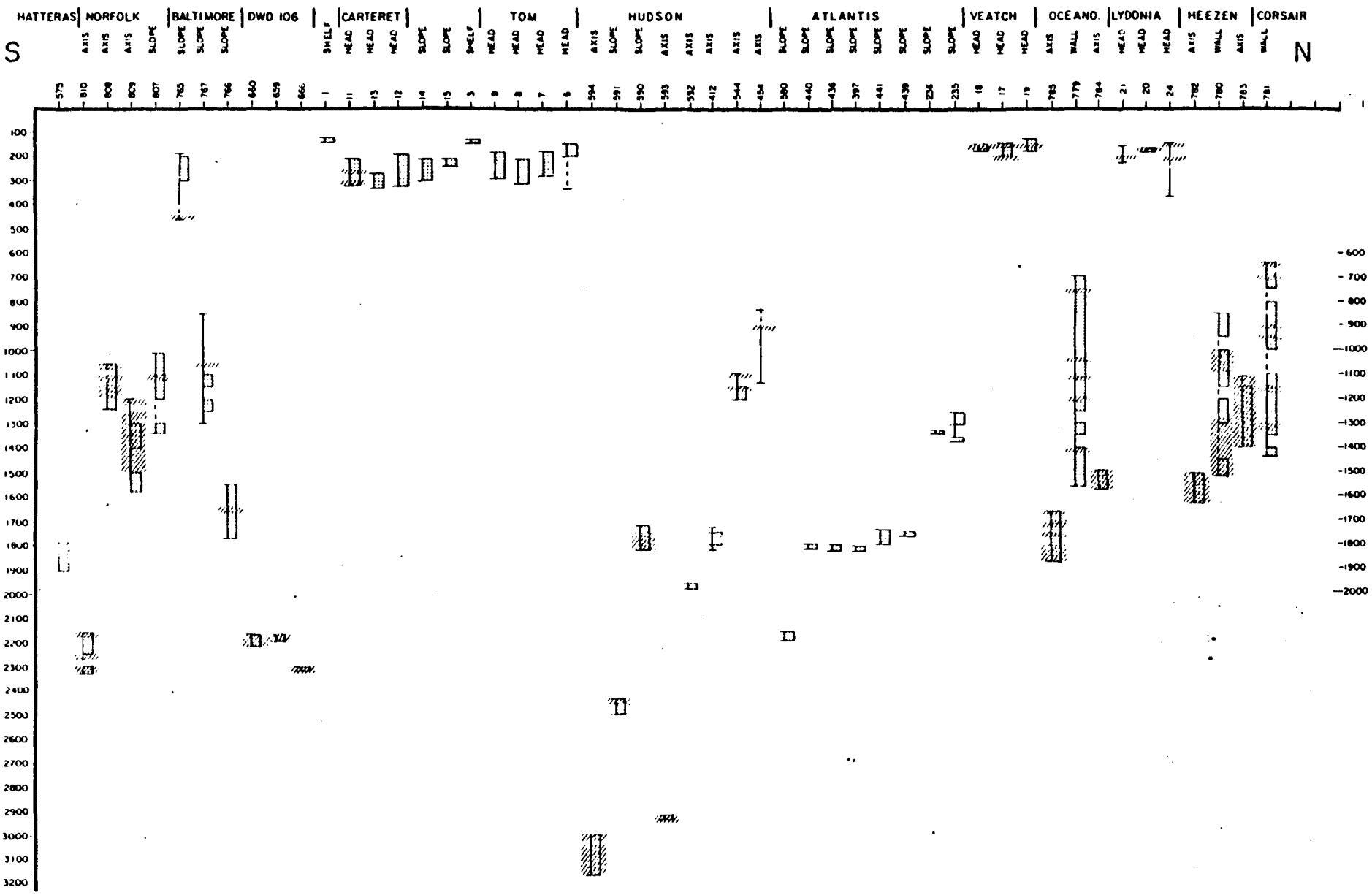

HATTERAS
NORFOLK
BALTIMORE
DWD 106
CARTERET
TOM
HUDSON
ATLANTIS
VEATCH
OCEANO.
LYDONIA
HEEZEN
CORSAIR
S
N

Figure E-2.

Location of the dominant coral species seen in the historical data survey.

- ● *Pennatula* sp.
- ✪ *Eunephthya fruticosa*
- ○ White sea pen
- ★ *Anthomastus grandiflorus*
- ☆ *Anthomastus agassizi*
- ■ *Acanthogorgia armata*
- □ *Paramuricea borealis*
- ◪ *Acanella arbuscula*
- ▲ Sea pen
- ◆ *Desmophyllum cristagalli*
- ◈ *Flabellum* sp.

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map

Figure E-3.

Location of the coral species rarely seen in the historical data survey.

- ● *Umbellula lindahli*
- ○ *Virgulina mirabilis*
- ◒ *Acanthoptilum grandiflorus*
- ◓ *Balticina finmarchica*
- ■ *Paragorgia arborea*
- □ *Radicipes gracilis*
- ⊡ *Chrysogorgia agassizi*
- ◩ *Lepidisis caryophylla*
- ◆ *Trachythela rudis*
- ⊙ *Kophobelemnon stelliferum*
- ☆ White stalked pen
- ▞ White feather
- ◆ Yellow gorgonian
- ⊕ Blue bush
- ★ *Dasmosmilia lymani*

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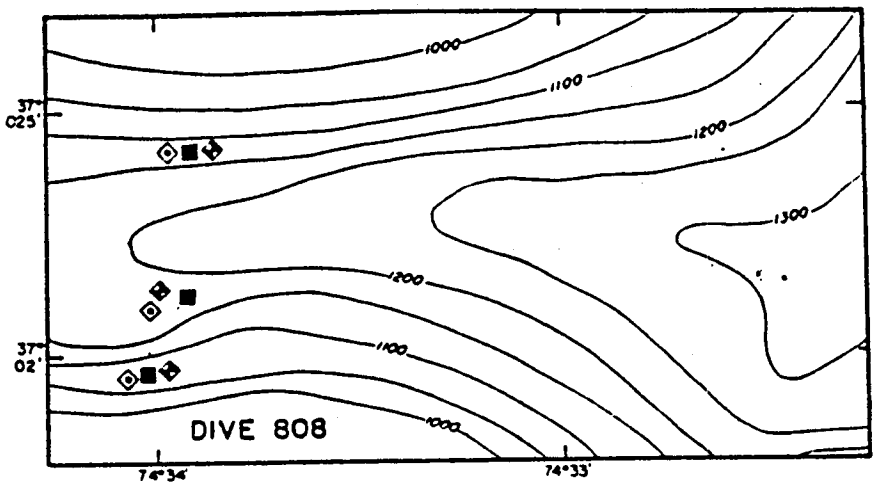
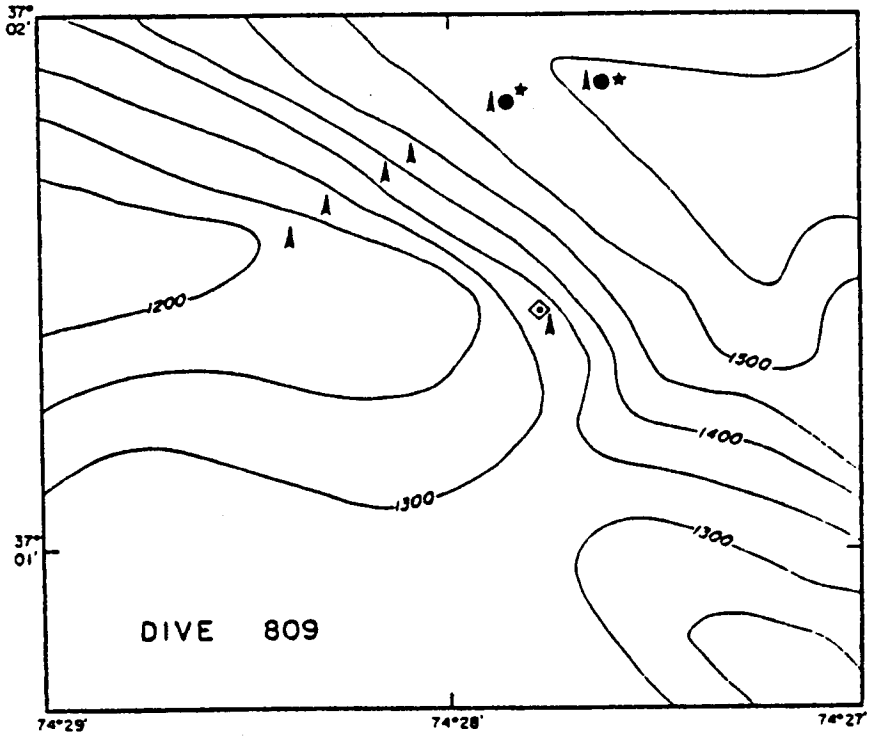
Map

Figure E-4.

Location of coral species in Norfolk Canyon seen in ALVIN dives 808, 809 and 810.

- ● *Pennatula* sp.
- ✪ *Eunephthya fruticosa*
- ★ *Anthomastus grandiflorus*
- ■ *Acanthogorgia armata*
- ▲ Sea pen
- ◆ *Desmophyllum cristagalli*
- ◇ *Flabellum* sp.


1000
1100
1200
1300
1200
1100
1000
37° 02'
37° 02'
DIVE 808
74°34'
74°33'


37° 02'
1200
1300
1400
1300
1300
37° 01'
DIVE 809
74°29'
74°28'
74°27'

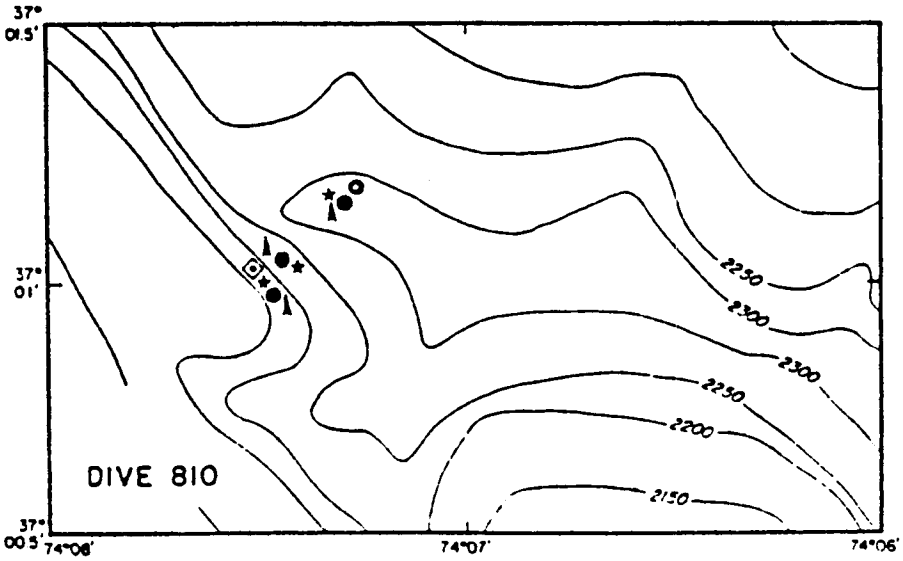

37° 01.5'
2250
2300
2300
2250
2200
2150
37° 01'
DIVE 810
37° 00.5'
74°08'
74°07'
74°06'

Figure E-5.

Location of coral species in Carteret and Toms Canyons, and at DWD #106.

- ● *Pennatula* sp.
- ✪ *Eunephthya fruticosa*
- ☆ *Anthomastus agassizi*
- ★ *Anthomastus grandiflorus*
- □ *Paramuricea borealis*
- ○ White sea pen
- ▲ Sea pen
- ■ *Acanthogorgia armata*
- ◆ *Desmophyllum cristagalli*
- ◇ *Flabellum* sp.

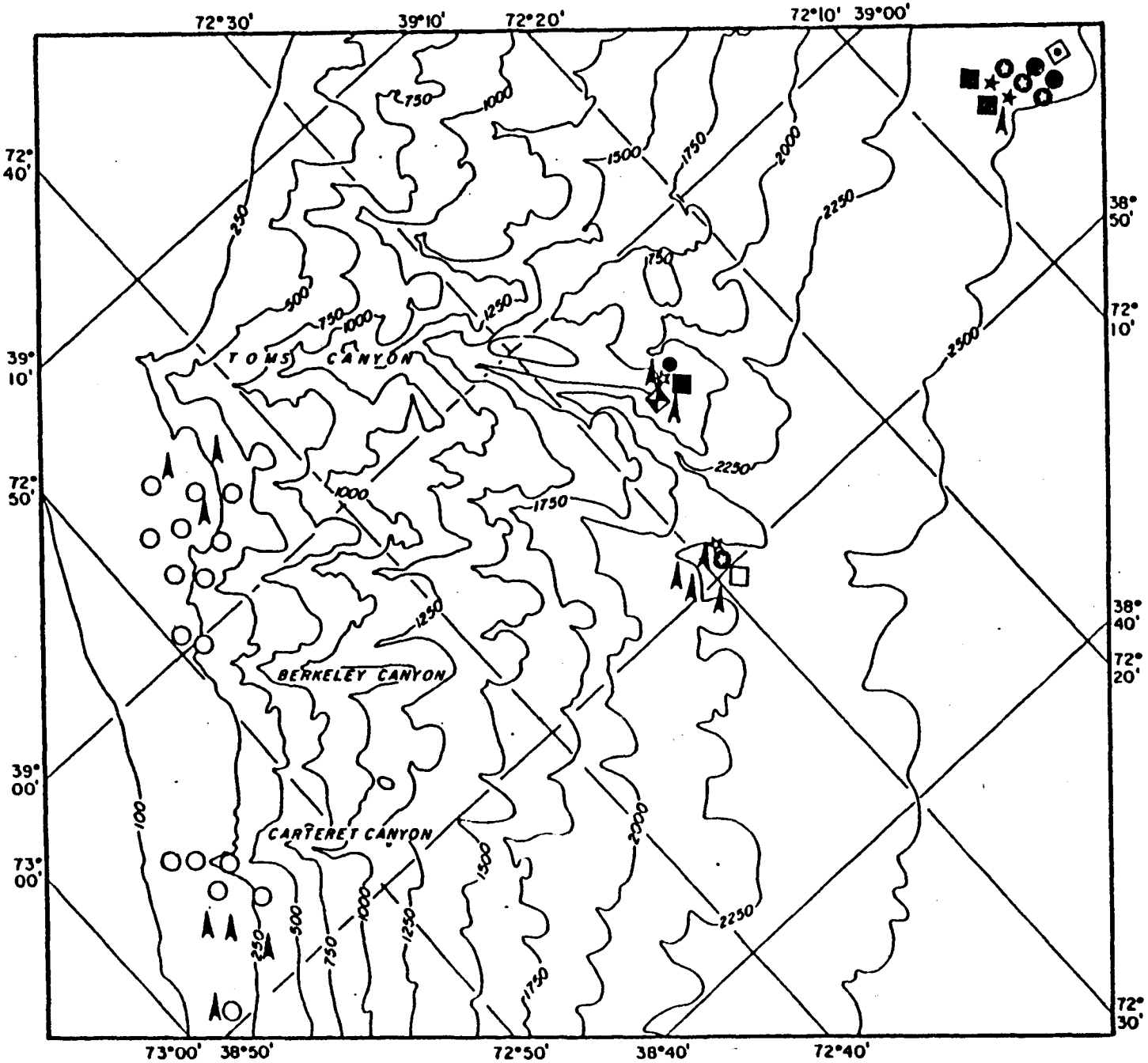

72°30'
39°10'
72°20'
72°10'
39°00'
72° 40'
39° 10'
72° 50'
39° 00'
73° 00'
38° 50'
72° 10'
38° 40'
72° 20'
72° 30'
73°00'
38°50'
72°50'
38°40'
72°40'
TOMS CANYON
BERKELEY CANYON
CARTERET CANYON
100
250
500
750
1000
1250
1500
1750
2000
2250
2500

Figure E-6.

Location of coral species on the continental slope near Alvin Canyon.

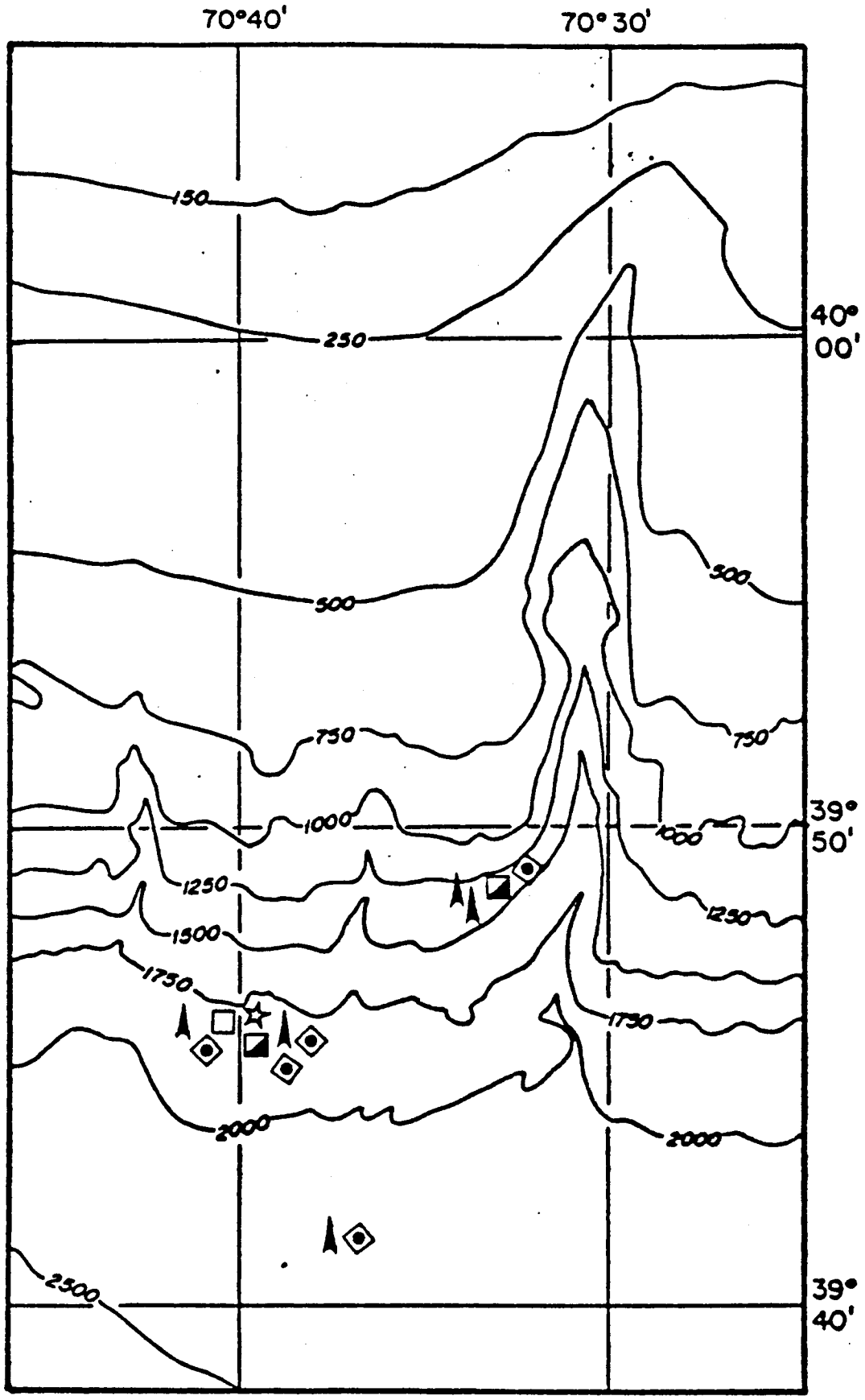
☆ *Anthomastus agassizi*

□ *Paramuricea borealis*

◪ *Acanella arbuscula*

◈ *Flabellum* sp.

⮝ Sea pen



ALVIN CANYON

Figure E-7.

Location of coral species in Oceanographer Canyon seen in ALVIN dives 779, 784 and 785.

☆ *Anthomastus agassizi*

★ *Anthomastus grandiflorus*

■ *Acanthogorgia armata*

□ *Paramuricea borealis*

◪ *Acanella arbuscula*

◆ *Desmophyllum cristagalli*

◉ *Flabellum* sp.

▲ Sea pen

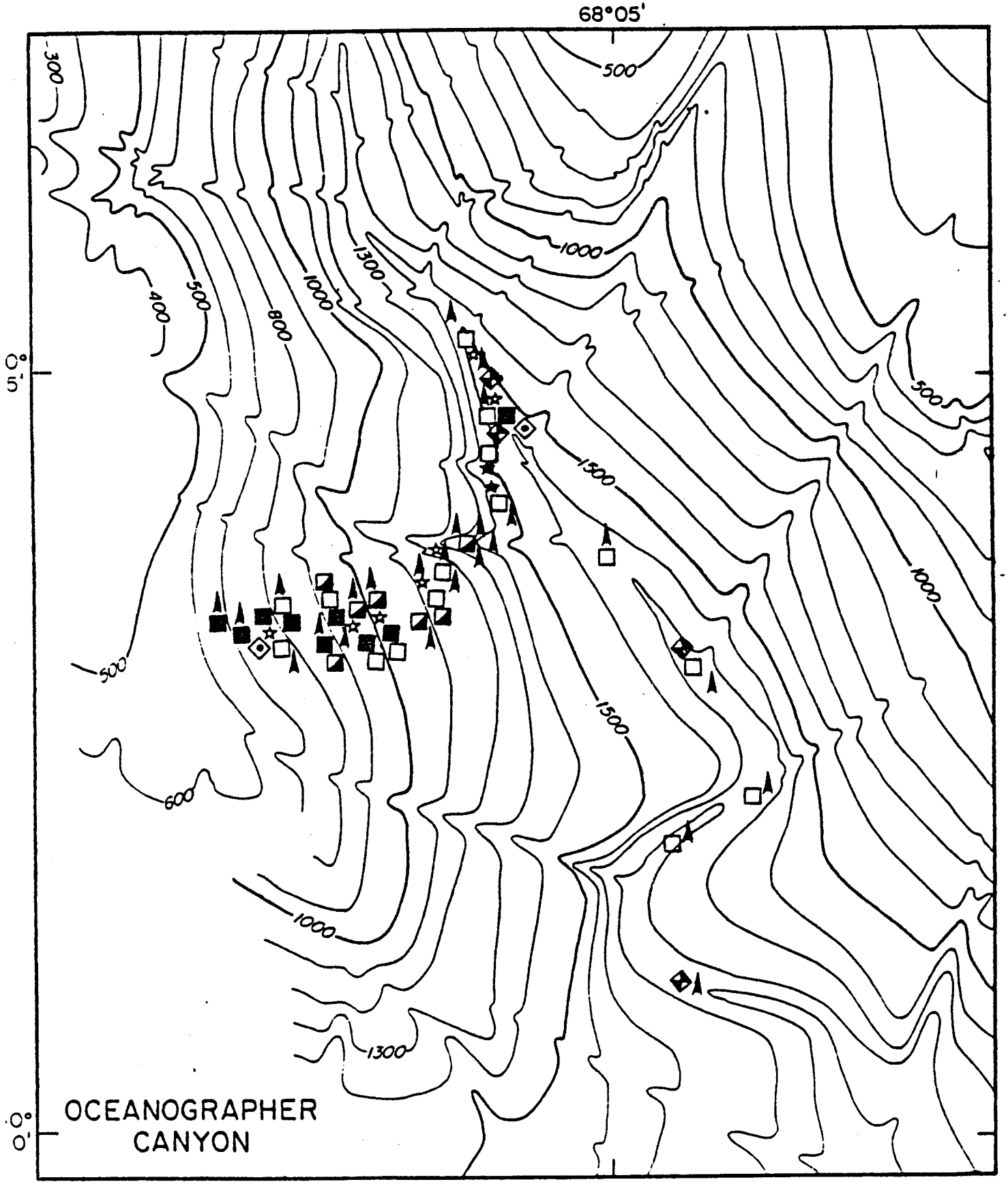

68°05'
0°
5'
0°
0'
300
500
400
500
800
1000
1300
1000
1500
500
1000
1500
500
600
1000
1300
OCEANOGRAPHER
CANYON

Figure E-8.

Location of coral species in Heezen Canyon seen in ALVIN dives 780, 782 and 783.

● *Pennatula* sp.

☆ *Anthomastus agassizi*

★ *Anthomastus grandiflorus*

□ *Paramuricea borealis*

◪ *Acanella arbuscula*

◆ *Desmophyllum cristagalli*

◈ *Flabellum* sp.

▲ Sea pen

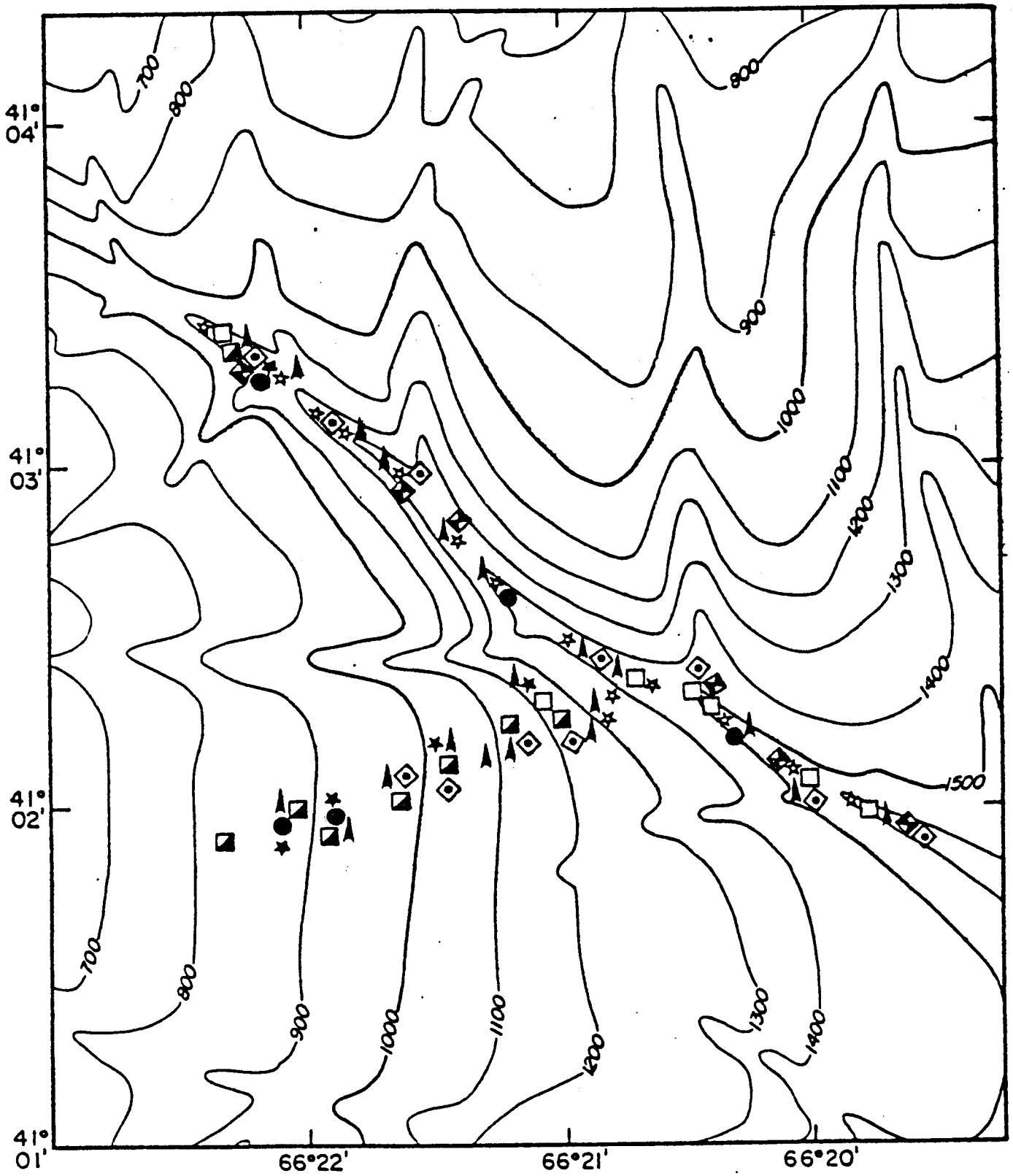

41°
04'
41°
03'
41°
02'
41°
01'
66°22'
66°21'
66°20'
700
800
900
1000
1100
1200
1300
1400
1500

Figure E-9.

Location of coral species in Corsair Canyon seen in ALVIN dive 781.

● *Pennatula* sp.

☆ *Anthomastus agassizi*

★ *Anthomastus grandiflorus*

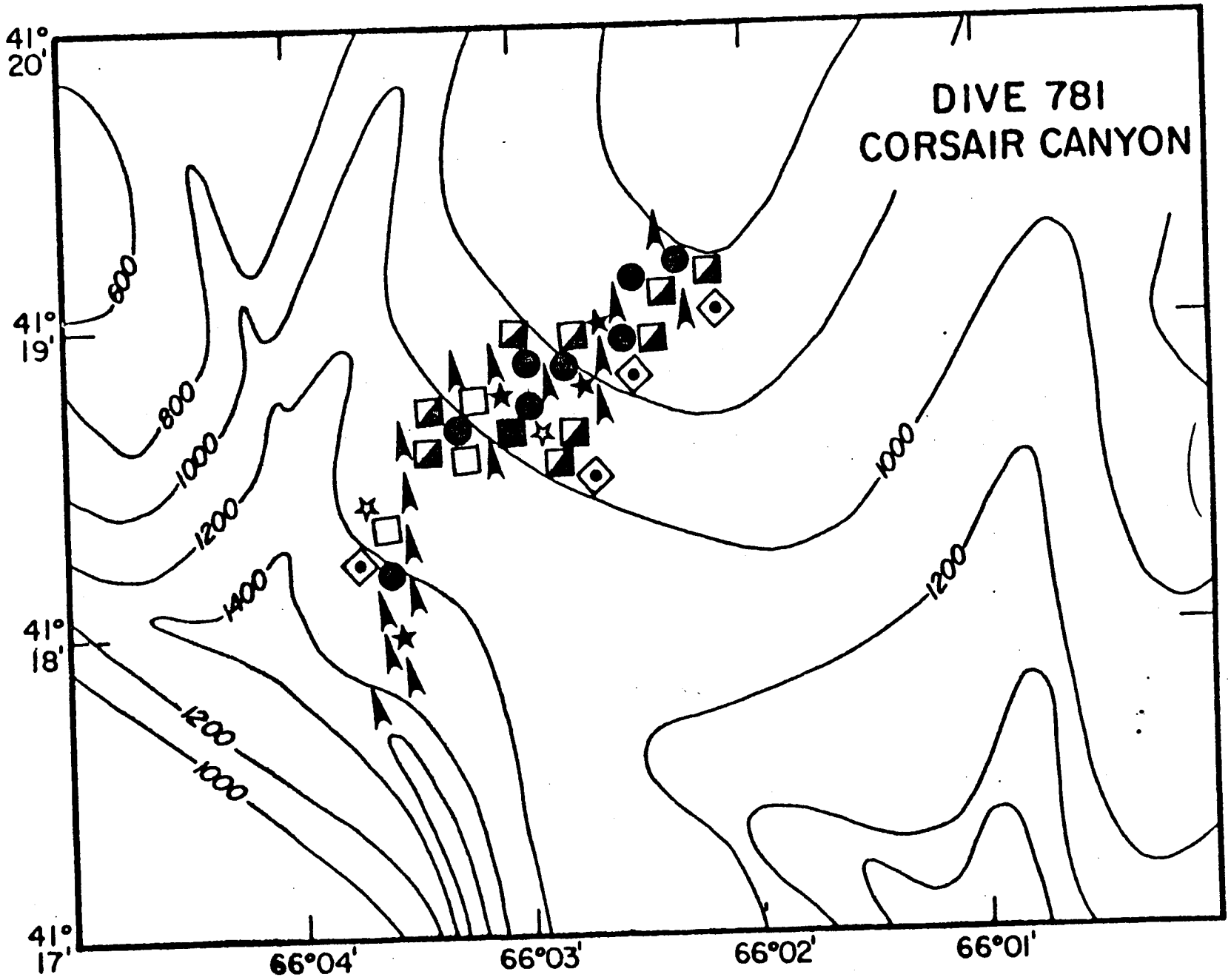
■ *Acanthogorgia armata*

□ *Paramuricea borealis*

◪ *Acanella arbuscula*

◈ *Flabellum* sp.

▲ Sea pen


DIVE 781
CORSAIR CANYON
41° 20'
41° 19'
41° 18'
41° 17'
66°04'
66°03'
66°02'
66°01'
600
800
1000
1200
1400
1200
1000
1000
1200

dives, the rest were ALVIN dives.

AREA	DIVE	LATITUDE(N)	LONGITUDE(W)	MIN. DEPTH (m)	MAX. DEPTH (m)	REPOSITORY
Corsair Canyon	781	41°18'	66°04'	630	1400	L-DGO
Heezen Canyon	783	41°03'	66°22'	1110	1400	L-DGO
	780	41°02'	66°21'	848	1519	L-DGO
	782	41°02'	66°20'	1510	1630	L-DGO
Lydonia Canyon	24	40°29.32'	67°41.32'	152	366	Slater
	20	40°25.2'	67°39.1'	170	180	Slater
	21	40°24.57'	67°42.72'	160	230	Slater
Oceanographer Canyon	784	40°15'	68°06'	1495	1572	L-DGO
	779	40°13'	68°06'	697	1560	L-DGO
	785	40°12'	68°04'	1730	1860	L-DGO
Veatch Canyon	19	40°00.65'	67°37.93'	130	180	Slater
	17	40°00.53'	69°37.48'	150	200	Slater
	18	40°00.27'	69°37.40'	150	180	Slater
Slope Near Atlantis Canyon	235	39°47'	70°32'	1265	1365	WHOI
	236	39°47'	70°32'	1330	1330	WHOI
	439	39°46'	70°40'	1755	1755	WHOI
	436	39°46'	70°40'	1805	1825	WHOI
	440	39°46'	70°40'	1795	1795	WHOI
	441	39°46'	70°40'	1745	1800	WHOI
	397	39°46'	70°41'	1820	1820	WHOI
	580	39°40'	70°37'	2165	2200	WHOI

TABLE I, continued

AREA	DIVE	LATITUDE(N)	LONGITUDE(W)	MIN. DEPTH (m)	MAX. DEPTH (m)	REPOSITORY
Hudson Canyon	454	39°27.5'	72°13.1'	835	1130	Keller
	544	39°26.5'	72°11.0'	1095	1205	WHOI
	412	39°19.6'	72°02.3'	1730	1820	Keller
	592	39°10.2'	71°55.6'	1965	1985	WHOI
	593	39°01.2'	71°18.2'	2925	2925	WHOI
	594	38°51.9'	71°11.0'	2995	3165	WHOI
Tom's Canyon	6	39°03.26'	72°46.5'	155	336	Slater
	7	39°02.89'	72°45.13'	190	280	Slater
	8	39°02.33'	72°46.64'	210	310	Slater
	9	39°01.87'	72°47.55'	180	290	Slater
Slope	15	38°58.96'	72°49.32'	210	240	Slater
	14	38°57.17'	72°51.09'	210	300	Slater
Carteret Canyon	12	38°55.27'	72°54.82'	190	320	Slater
	13	38°54.67'	72°53.16'	270	330	Slater
	11	38°54.41'	72°54.44'	210	320	Slater
	3	38°50.3'	72°53.2'	135	135	Slater
	1	38°50'	72°54'	120	120	Slater
	590	38°56.5	72°26.5	1765	1833	WHOI
	591	38°54.8'	72°05.7'	2445	2507	WHOI
DWD 106	666	38°50'	72°29'	2305	2305	WHOI
	659	38°50'	72°31'	2175	2195	WHOI
	660	38°49.8'	72°31.1'	2175	2215	WHOI

AREA	DIVE	LATITUDE(N)	LONGITUDE(W)	MIN. DEPTH (m)	MAX. DEPTH (m)	REPOSITORY
Slope Near Baltimore Canyon	766	37°59.1'	73°45.2'	1550	1769	NOAA
	767	37°57.2'	73°48.5'	850	1299	NOAA
	765	37°51.9'	73°57.5'	190	459	NOAA
Norfolk Canyon	807	37°06.5'	74°27.2'	1011	1338	NOAA
	809	37°02.2'	74°27.2'	1201	1577	NOAA
	808	37°02.1'	74°33'	1052	1239	NOAA
	810	37°01.2'	74°07.5'	2160	2330	NOAA
Cape Hatteras	575	36°43.9'	74°19'	1785	1905	WHOI

TABLE II: ALVIN dives reviewed but not analyzed, due to inaccessibility of slide or poor picture quality, with location and maximum depth.

AREA	DIVE	LATITUDE(N)	LONGITUDE(W)	MAX. DEPTH (m)	REPOSITORY
Corsair Canyon	216	41°16'	66°01'	5283 ft.	WHOI
Lydonia Canyon	274	40°17'	67°40'	1660	WHOI
	275	40°25'	67°40'	590	WHOI
Oceanographer Canyon	207	40°16'	68°07'	5049 ft.	WHOI
	208	40°15'	68°06'	4923 ft.	WHOI
	835	40°21.1'	68°08.2'	690	NMFS
	836	40°17.7'	68°07.4'	1295	NMFS
	837	40°27.4'	68°07.4'	354	NMFS
	838	40°11.1'	68°04.7'	1800	NMFS
	839	40°25'	68°08.5'	516	NMFS
	840	40°28.8'	68°08.9'	946	NMFS
Slope	211	40°09'	68°17'	4010 ft.	WHOI
Slope Near Alvin Canyon	437	39°46'	70°40'	1815	WHOI
	438	39°46'	70°40'	1820	WHOI
Hudson Canyon	416	39°39.5'	72°28.0'	204	Keller
	451	39°38.5'	72°26.4'	307	Keller
	409	39°34.5'	72°25'	409	Keller
	413	39°34.5'	72°25'	481	Keller
	450	39°34.5'	72°25'	510	Keller
	455	39°32.4'	72°24.5'	570	Keller

TABLE II, continued

AREA	DIVE	LATITUDE(N)	LONGITUDE(W)	MAX. DEPTH (m)	REPOSITORY
Hudson Canyon	410	39°31'	72°21'	688	Keller
	414	39°29.5'	72°18'	844	Keller
	415	39°25.0'	72°09.5'	1439	Keller
	595	38°46.4'	71°09.8'	3264	WHOI
DWD-106	587	38°50'	72°33.9'	2148	WHOI
	665	39°49.7'	72°31.1'	2200	WHOI
Washington Canyon	811	37°22.5'	74°25'	1041	NOAA
Norfolk Canyon	574	37°03.3'	74°38.4'	656	WHOI

TABLE III: Camera lowerings reviewed with location and maximum depth.

AREA	DIVE	LATITUDE(N)	LONGITUDE(W)	MAX. DEPTH (m)	REPOSITORY
Shelf	Bear 281	40°12'	71°13.5'	295 ft.	WHOI
Hydrographer Canyon	A-260	40°06'	69°01'	400 fms	WHOI
Slope	A-260	39°56'	69°22'	400 fms	WHOI
	RC19/7	39°52'	71°39'	308	L-DGO
	V22/162	39°52'	69°35'	1331	L-DGO
	RC19/16	39°44	71°41'	833	L-DGO
	Yama 3	39°42'	71°04'	1055 fms	WHOI
	RC19/6	39°41'	71°31'	1384	L-DGO
	V18/312	39°40'	69°55'	2006	L-DGO
Hudson Canyon	RC19/13	39°36'	72°25'	367	L-DGO
	RC19/12	39°30'	72°21'	663	L-DGO
	V21/139	39°30'	72°18'	774	L-DGO
	V31/101	39°30'	72°18'	833	L-DGO
	V32/5	39°30'	72°16'	608	L-DGO
Slope	V32/7	39°30'	72°05'	385	L-DGO
	RC19/5	39°23'	71°19'	2462	L-DGO
Hudson Canyon	V21/138	39°20'	72°07'	1626	L-DGO
	V32/8	39°19'	72°06'	1907	L-DGO
	RC19/4	39°17'	71°59'	1963	L-DGO
	V20/206	39°17'	71°47'	1923	L-DGO
	RC19/3	39°12'	72°02'	1274	L-DGO
Slope	RC19/18	39°09'	72°29'	516	L-DGO

TABLE III, continued

AREA	DIVE	LATITUDE(N)	LONGITUDE(W)	MAX. DEPTH (m)	REPOSITORY
Hudson Canyon	RC18/56	39°05'	71°43'	2448	L-DGO
	RC19/17	39°05'	71°42'	2262	L-DGO
Slope	RC19/2	39°01'	71°51'	2285	L-DGO
Hendrickson	RC19/11	39°01'	72°26'	1421	L-DGO
Carteret Canyon	V32/1	39°00'	72°46'	531	L-DGO
Slope	RC19/1	38°33'	71°40	2785	L-DGO
	RC11/195	38°19.5'	70°59	3181	L-DGO
	RC18/55	37°56'	72°37'	2854	L-DGO
	RC19/31	37°37'	73°17'	2597	L-DGO
	RC10/138	37°21'	72°13'	3492	L-DGO
	RC10/137	37°02'	72°30'	3162	L-DGO

Table IV: First ten end-members of the total fauna (excluding fish and sea pens) and the percent of sample variance explained by them.

Factor	Species	Variance	Cummulative Variance
1	*Ophiomusium lymani*	17.05	17.05
2	Shrimp	8.39	25.44
3	*Hyalinoecia artifex*	9.38	34.82
4	*Cerianthus borealis* *Cancer borealis* *Munida valida*	5.05	39.87
5	*Geryon quinquedens* Flounder	5.81	45.68
6	*Anthomastus grandiflorus* *Pennatula* sp.	4.68	50.36
7	Cerianthid anemone *Echinus affinis*	5.40	55.76
8	*Distichoptilum gracile* *Acanella arbuscula*	4.35	60.11
9	White sea pen	4.76	64.87
10	*Phormosoma placenta*	3.51	68.38

TABLE V. Results of rotated principle components analysis of the total fauna listed against depth arranged from south to north. Numbers denote primary assemblages found in the dive at that depth.

DIVE-DEPTH	575	810	808	809	807	765	747	766	660	659	666	11	13	12	14	15	9	8	7	6	594	591	590	593	592	412	584	458	586	440	436	397	441	439	236	235	18	17	19	785	779	784	21	20	24	782	780	783	781
100																																					4.9													
150																				9																														
200						4									9	9	9	9	9																												4			
250						4							4		4.9		4	4	4																											2			
300						3						4	4					4																																
350						3																																												
400																																																		
450						3																																												
600																																																		8
650																																																		8
700																																								5.2										8
750																																								5									8.6
800																												2												5									6
850							2																					5																			6		6
900							5.2																					2																			6		8.6
950							2.5																				5	5													2							6		8
1000					5		3.5																																											8.2
1050			3		5		2																														10				2									1.8
1100			3		5		2.5																														10				10.2									1.8
1150			3		2.5																																10				2							10.1		8.2
1200			3	5			2																														10	10			2								3	1.8
1250				7			5.2																																		7							8.7	3	8
1300				7																																					6		3					6.1	3	8
1350				7																																							31						3	6.8
1400				7																																													3	2
1450																							1																	1.7									3	2.1
1500				8																			1.7			1				1			1		1					7.1							1		3	
1550				6				1															1								1.7	1								1							1			
1600								1																																1							1			
1650								1																																1										
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2200								7.1														7.1																												
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Table VI: The first ten end-members of a rotated principal components analysis of the corals in the study area.

Factor	Species	Variance	Cummulative Variance
1	*Distichoptilum gracile*	18.94	18.94
2	White sea pen	12.12	31.06
3	*Acanella arbuscula*	10.74	41.80
4	*Anthomastus agassizi* *Paramuricea borealis*	9.62	51.42
5	*Flabellum* sp.	9.20	60.63
6	*Anthomastus grandiflorus* *Pennatula* sp.	7.02	67.64
7	Whip	6.27	73.91
8	*Acanthogorgia armata*	6.50	80.41
9	*Desmophyllum cristagalli*	3.80	84.21
10	*Eunephthya fruticosa* *Pennatula* sp.	2.11	86.32

TABLE VII. Results of rotated principle components analysis of corals listed against depth arranged from south to north. Numbers denote primary assemblages found in the dive at that depth.

DIVE-DEPTH	575	810	808	809	807	765	767	766	660	659	666	11	13	12	14	15	9	8	7	6	594	591	590	593	592	412	548	454	580	440	436	397	441	439	236	235	18	17	19	785	779	784	21	20	24	782	780	783	781
100																																							2										
150																				2																	2	2	2					7					
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750																																									88									3,6
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850																																									8						6			10,6
900																																									8,3						6			3,6
950																																									8									3
1000																																									8						6			3
1050			8																																						3						3,1			3,1
1100			9,8		5		5																																		8,3									1
1150			8,9		5																																				7,8						1	8,8		1,8
1200							5																			1															7,8						6		8	1
1250							5																																										8	1
1300				5	5																															5					3								8	6,1
1350																																			5,3														8	
1400																																				1					1								8	6
1450																																									6						8	9,8		
1500				6																																						8,9				9				
1550				6				1,3																																		9,8				9				
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1700								1,1														1																		1,8					1,8					
1750	3							10,1														1				1				1			5,8	5						1,8					1,8					
1800	3																					1									5	5								1,8									
1850	3																																							1										
1900	3																																																	
1950																									1																									
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2100																													7																					
2150		8,10							1	1																																								
2200		10,6							1																																									
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APPENDIX I

Data sheets used for collection of data during the historical survey.

USERS GUIDE FOR DATA INPUT SHEET A

The following is a description of the data input catagories for the basic dive identification data sheet. Verbal information is recorded in numerical code form in order to ease computer handling and interfacing with analytical and interpretive programs. All numerical codes are listed on the data input sheet.

Note: This information need be recorded only once for each dive. All input is right rectified in the spaces provided unless otherwise noted.

1. Dive number: Use the number given the dive by the submersible group sponsoring the dive. Four digits are allowed.

2. Latitude: Six digits are allowed. Minutes are reported to one decimal place if possible. The decimal point must be recorded (i.e. 67°55.4 = 6755.4)

3. Longitude: Seven digits are allowed. Record as for latitude.

4. Date: This refers to the data of the dive. Six digits are allowed. Use zeros to fill spaces. (i.e. December 7, 1971 = 120771).

5. General area: This is the area of the dive being studied. T code list gives the two digit numeric code for most of the major features in the study area. Any other verbal location informatio may be added to the list and codified as it is needed.

6. Photo archive: This catagory indicates where the slides or film is kept. This information is given a one digit numeric code which is listed on the data input sheet.

7. Photo record: This catagory indicates the type of photo reco available (i.e. color slide, B/W, etc.) This information is codified into one digit numbers in the code listing.

8. Submersible: This is a one digit number indicating the submersible used for the photo transect. The numeric codes are list on the data sheet.

9. Observer: This indicates the person collecting data from the photographs. Two digits are allowed, one for each observer. The observer codes are listed on the data sheet.

DATA SHEET A

IDENTIFICATION DATA - record once per dive

DIVE NUMBER

LATITUDE

LONGITUDE

DATE

GENERAL AREA

PHOTO ARCHIVE

PHOTO RECORD

OBSERVER(s)

AREA CODES

Alvin Canyon	--01
Atlantis Canyon	--02
Baltimore Canyon	--03
Georges Bank	--04
Hatteras Canyon	--05
Heezen Canyon	--06
Hudson Canyon	--07
Lydonia Canyon	--08
Norfolk Canyon	--09
Oceanographer Canyon	--10
Veatch Canyon	--11
Washington Canyon	--12
Wilmington Canyon	--13
Continental Slope	--14
Dump Site	--15

PHOTO ARCHIVE CODES

LDGO	--1
EPA	--2
WHOI	--3
NMFS	--4
NOAA	--5
Colorado	--6

PHOTO RECORD CODES

Color Slide	--1
Color Film Strip	--2
B/W Film Strip	--3
Hand Held	--4

OBSERVER CODES

Hecker	--1
Blechschmidt	--2
Gibson	--3
Woodroffe	--4

USERS GUIDE FOR DATA INPUT SHEET B

The following is a description of the data input catagories for the historical coral data. Verbal information is recorded in numerical code form as for Data Sheet A. All numerical codes are listed in Code Table B.

Note: This information must be recorded for each photograph examined. All input is right rectified in the spaces provided unless otherwise noted. Abundance data should be recorded using a red pen to allow easy reading of the data sheet.

1. Dive number: Same as for data sheet A.

2. Photo number: This is a sequential number of the slide or photograph starting with 001 for the first photograph of the dive. Three digits are allowed for this identification.

3. Depth: Depth in meters at the site of the photograph. If only one depth value is recorded in the dive record use this valu

4. Area: The area of the bottom represented in the photograph - or the area which has been counted. This is recorded in meters squared with respect to the Canadian Grid. If the Canadian Grid is not applicable (i.e. on a steep slope or outcrop) approximate the area being counted. Two digits are allowed for this value.

5. Substrate: This represents the general character of the substrate. Substrate types are codified on the attached Code Table B. Two digits are allowed for this catagory.

6. Comments A and B: These are general comments about the substrate, biota, etc. Two comments catagories are allowed here (Comments A and Comments B) for flexibility. (i.e. if both ripple marks and biotic associations are noted in one photograph they may both be recorded). This verbal information is codified in Code Table B with two digits for each comment. This single code listing is used for both Comments A and Comments B catagorie

7. Same: This catagory is checked if the photograph is the same as previous photographs. In such cases, only the dive number and slide number need be recorded. This check will automatically tell the keypuncher to duplicate the previous data card.

8. Taxa: The most commonly found taxa are listed on the data sheet. Each taxon is assigned a three digit code number. Two digits are allowed next to each code number for abundance data. If no specimens of a particular taxon are found no record need be made. Open spaces are available on the right hand side of the data sheet for rarer taxa. These are listed with their assigned code number in Code Table B. Only those taxa which are present in a photograph need be recorded or listed. If taxa are found which are not listed in the code table, they may be added to the listing and given a three digit code number. These code numbers should be unique and sequential in order to avoid confusion.

CODE TABLE B

Substrate codes

Mud	01
Sand	02
Gravel	03
Cobbles	04
Boulders	05
Outcrop	06
Consolidated clay	10
Talus	11

Comment codes

Ripples	01
Scour	02
Overhang	03
Associations	04
Dead ?	05
Tracks	06
Garbage	07
Coral rubble	08
Shell hash	09

COMMON TAXA

Urchin	001
Echinus affinis	002
Echinus alexandri	003
Hygrosoma petersi	004
Phormosoma placenta	005
Ophiuroid	006
Ophiomusium lymani	007
Amphilimna olivacea	008
Ophiocantha sp.	009
Asteroid	010
Astropecten americanus	011
Porcellanaster caeruleus	012
Euphronides sp.	014
Paelopatides sp.	015
Lithodes agassizi	017
Cancer borealis	018
Geryon quinquedens	019
Munida valida	020
Parapagurus sp.	021
Polychaete	022
Hyalinoecia artifex	023
Sponge	024
Hyalonema sp.	025
Anemone	027
Cerianthidae	028
Actinauge longicornis	029
Actinoscyphia saginata	030
Colossendeis colossea	032
Alcyonarian	033
Anthomastus agassizi	035
Anthomastus grandiflorus	036
Pennatula sp.	038
Paramuricea borealis	039
Eunephthya sp.	040
Acanella arbuscula	050
Scleractinian	042
Desmophyllum cristagalli	043
Flabellum alabastrum	044
Lophelia prolifera	045
"Sea pens"	047
"Golf balls"	048
Fish	049
Burrows	051

SELDOM SEEN SPECIES

Ophiuroid	006
Ophiomusium armigerum	052
Asteronyx loveni	054
Ophianax sp.	128
Asteroid	010
Freyella sp. A	056
Freyella sp. B	057
Solaster benedicti	059
Dytaster grandis	060
Plutonaster intermedius	061
Pseudoarchaster pareli	062
Porania sp.	063
Zoroaster fulgens	123
Henricia sp.	131
Stalked crinoid	119
Holothurian	013
Mesothuria lactea	064
Peniagone sp.	116
Lemon cucumber	124
Anemone	027
Bolocera tubiae	066
Cerianthus borealis	112
Anemone A	068
Anemone B	069
Anemone C	070
Anemone E	106
Crustacean	016
Acanthocarpus alexandri	071
Homarus americanus	072
Munidopsis rostrata	073
Bathynectes superba	110
Pink galatheid crab	122
Pink shrimp-like crab	130
Shrimp	113
Sponge	024
Lettuce sponge	076
Alcyonarian	033
Lepidisis caryophyllia	077
Chrysogorgia agassizi	082
Radicipes gracilis	083
Kophobelemnon stelliferum	084
Distichoptilum gracile	087
Virgularia mirabilis	089
Anthoptilum grandiflorum	090
Balticina finnmarchica	091
Acanthogorgia armata	114
Trachythela rudis	129
Whip	104
Pink column	117
White stalked pen	118
White feather	126
Yellow gorgonian	127
White sea pen	132
Blue bush	133
Scleractinian	042
Dasmosmilia lymani	096
Flabellum angularis	099
Octopus	102
Squid	103
Flounder	105
Skate	107
Ray	115
Stalked thing	109
White hydroid	111
Crowned polychaete	120
Gastropod	121
Brissopsis sp.	125