ABSTRACT
Multibeam swath sonar systems and highly accurate positioning systems have made it possible to rapidly collect large amounts of quality bathymetric data in the Exclusive Economic Zone (EEZ). Processing and production techniques for potential products are described.

INTRODUCTION
On March 10, 1983, President Ronald Reagan through official proclamation, established a new frontier known as the Exclusive Economic Zone (EEZ). The EEZ is an area of sovereignty that extends from the coastline 200 nautical miles seaward from the United States and all of its possessions. To better understand this vast new undersea frontier, systematic exploration must begin if we are to utilize and manage the area in a prudent manner. It is the intent of this paper to discuss bathymetric data collection in the EEZ by multibeam sonar swath technologies and its applications for mapping products.

BATHYMETRIC HISTORY
In the beginning of the 1900's, Prince Albert of Monaco, sponsored several prominent scientists of the day to produce a chart series called "General Bathymetric Chart of the Oceans (GEBCO)". The series, scaled at 1:10,000,000, was composed of 16 sheets on a Mercator projection along with 8 sheets in gnomonic projection. Sounding data for the project was obtained from British Admiralty Charts with supporting data from vessels laying cable. The first series contained approximately 18,000 selected sounding values. Upon completion of the project in 1904, GEBCO member, Professor Thoulet uttered these words:

"Here then is everything which is known today about the relief of the ocean floor. For many years to come, mariners, telegraphists, engineers, oceanographers, and scientists will continue their soundings, for now we must proceed to fill in the details; no point will escape our investigation. The incessant and untiring efforts of succeeding generations are the glory of mankind. In one century - in ten centuries - this is the chart our great-great nephews will be using, perfected but not changed." (3)

The first echo sounders were developed in the 1920's, making it possible to discern the ocean floor and collect large amounts of bathymetric data without weighted lines. Improvements were made over the next twenty years to create continuous sounding and recording devices. The period from 1940 through 1960 saw increased military mapping and data collection with advances in the sonar products. Narrow beam sonar developed in the 1960's, gave scientists precise soundings in rough and sloping terrain. At the same time, the first multibeam sonar system, Sonar Array Sounding System (SASS), was developed for the U.S. Navy. During the first seventy years of this century not only did the quantity of data increase, but its collection accuracy was also greatly improved. Mislocations of up to fifteen miles in the era from 1900 to 1930, were reduced to less than one-half mile in the 1970's by using satellite calibration. Today, three multibeam sonar systems are utilized by the National Oceanic and Atmospheric Administration (NOAA) to collect highly accurate bathymetric data.

DATA COLLECTION SYSTEMS
The method of acquiring bathymetric data in the EEZ is through the utilization of multibeam sonar swath technologies (see table 1 and figure 1). The overall
process is quite complex, taking numerous intricate details into account. A more thorough discussion may be found in Farr (3). In general, these systems send active sonar signals through a transducer at defined times, and receive the returning signals with a hydrophone array. Raw soundings are collected for each beam, and stored on magnetic medium on a real time basis. During this process, complementary velocity, navigation, orientation, and positioning information is also being recorded. Through this method accurate depth profiles and location parameters can be determined.

### TABLE 1

| System            | Bathymetric Swath Survey System (BSSS) | Seabeam |
|-------------------|---------------------------------------|---------|
| Signal Frequency  | 36 kHz                                | 12 kHz  |
| Beams/angles      | 22 x 5°                               | 16 x 2 2/3° |
| Swath width       | 2.5 x depth                           | .75 x depth |
| Resolution        | .10 depth                              | .05 depth |
| Operational depth range | 3-650 m                   | 50-11,000 m |

### FIGURE 1

**SONAR BEAM GEOMETRY**

SHIPBOARD DATA PROCESSING

Onboard each of the multibeam survey vessels, data collection and processing is an ongoing endeavor. Each data segment collected must meet quality assurance standards. Once all raw soundings segments have been collected for a given survey, additional processing is required to digest the massive amount of data and allow representation on a reasonable scaling. Several methodologies have been developed to accomplished this task, one of which is through a post-processing program known as the combined offline program (COP). COP is used to vertically filter and reduce the number of data points. Soundings not meeting the selection limits for the given systems are rejected. The remaining data points are amassed into a sounding matrix for final selection based on the following procedure:

1. Determining plottable unit area (PUA) based on the parameters of survey collection. (see figure 2)
2. One minimum (shallowest) value is identified for each PUA. (see figure 3)
3. One maximum (deepest) value is identified for each PUA. (see figure 3)
4. Each minimum/maximum value from the PUA must pass the following tests:
   I. Within 25% of mean for nearest 8 points.
   II. Difference between sounding value and mean of nearest 14 neighbors must be within 1.8 times the standard deviation. If either one of these tests fail, the value is set to zero and the PUA is re-searched for the appropriate value.
5. The paired values remaining are resolved to full accuracy in depth and location by using available correction and calibration information.
6. The values are recorded on magnetic tape for future sounding and/or contour plot analysis.

PROJECT OFFICE DATA PROCESSING

The bathymetric data collected during each research vessel's survey is sent to the EEZ Project Office in Rockville, Maryland. At the project office the survey soundings are processed in the following manner :

1. Appropriate sounding and support parameters are extracted from the magnetic tape and stored on magnetic disk.
2. A commercial contouring package, Contour Plotting System (CPS-1) developed by Radian Corporation is used to:
   I. Transform the data points into the Universal Transverse Mercator projection.
   II. Create a fixed grid of 250 meters from the transformed points.
   III. Produce a 1:50,000-scale contour plot of each individual field survey based on the values at the grid nodes.

The resulting plot is carefully reviewed for anomalous sounding values and overall completeness. This is done by evaluating real-time plots created onboard ship during the survey with junction data, cross-swath data, 3.5 kHz printed records, and any other pertinent information available. Data points judged to be anomalous are retained in the archive record, but are flagged with a negative value which is ignored during plotting routines. The final map compilation and a descriptive report are provided to the project manager for acceptance. Approved field surveys can then be merged into larger map areas at 1:100,000 scales.
APPLICATIONS

Up to the present, traditional bathymetric maps and the offshore portions of nautical charts have been compiled using a combination of charting surveys in regular patterns of lines and trackline data. Minimum line spacing prescribable for National Ocean Service surveys along open coasts and offshore are shown in Table 2. The offshore trackline spacing can be as sparse as 35km.

With the advent of digital information from the multibeam sonar systems coupled with accurate positioning systems, it is now possible to rapidly acquire total coverage of the seafloor by overlapping multibeam swaths. The result is a suite of products much greater in detail and accuracy than anything previously compiled. Previously, a 1:100,000 scale bathymetric map covering about 1,350 square nautical miles would have been compiled using five to ten thousand data points. Now, typically one-half million points can be used for the compilation and that represents only about two percent of the observed data.

The raw data reduction software, originally used to select minimum and maximum values in a PUA, can now be used in the construction of offshore nautical chart products. The EEZ Project Office is presently committed to surveys in water depths greater than 150 meters. However, some investigations of shoals and major traffic lane approaches are conducted using the multibeam system. Since nautical charts require conservative depth values for safe passage, testing is underway to determine the value of exclusive minimum data sounding applications. That is, the shoal sounding data set is contoured resulting in a conservative depiction whereas contours constructed from both minimum and maximum values would tend to be less seaward (see figure 4). Preliminary results have shown that the incorporation of the inshore EEZ contour data to be reasonably close to contours originally compiled through professional interpretation of the denser inshore line data.

Other applications such as bathymetric fishing maps will provide better topographic details for deep draggers working to 1,000 meters and deeper. The additional detail will help reduce the possibility of nets becoming entangled and detached on underwater obstructions leading to dangerous free floating capture. Geologists, working in a variety of settings, may find the increased detail useful in locating mineral and geothermal resources, or predicting movement of the earth crust.

FIGURE 4  CONTOUR PROFILE USING EXCLUSIVE MINIMUM VALUES VERSUS EXCLUSIVE MAXIMUM VALUES
TABLE 2

Line Sounding Spacing on Open Coasts

- 200 m in depths less than 20 fathoms
- 400 m in depths 20 to 30 fathoms
- 800 m in depths 30 to 110 fathoms

Line Sounding Spacing for Offshore Surveys

- 1600 m in depths 110 to 500 fathoms
- 3200 m in depths 500 to 1500 fathoms
- 8000 m in depths greater than 1500 fathoms

(Data source: Hydrographic Manual (9))

CONCLUSIONS

At the turn of the nineteenth century, approximately 18,000 soundings were used to represent the relief of the ocean floor. Today, research vessels in the EEZ can collect 18,000 raw data soundings in less than 1 hour. With the dense digital data available from the multibeam sonar swath technology, future map products can be constructed with higher accuracy, and be easily manipulated into a variety of products at differing levels of detail and scale. It will take great vision and judgement to utilize the vast area known as the EEZ in a prudent manner. Only through organized collection, analysis and comprehension of detailed scientific data can important decisions be in the best interest of the present generation and our posterity.

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REFERENCES

1. CREWS, N. L., "Bathymetric Mapping of the Exclusive Economic Zone Using Modern Swath Technology", Technical Paper, 46th Annual Meeting ACSM, March 1986.

2. COHEN, P. M., "Observations on a Sea Map", International Hydrographic Review, Monaco LVIII(1), January 1981.

3. FARR, H. K., "Multibeam Bathymetric Sonar: Seabeam and Hydrochart", Marine Geodesy, Vol. 4, Number 2, 1980.

4. KAPOOR, D. C., "Technical Note: General Bathymetric Chart of the Oceans", Marine Geodesy, Vol. 5, Number 1, 1981, pp. 73-80.

5. KRUSE, W. A. and SCHMieder, R. W., "High Resolution Images of EEZ Data: Cordell Bank, California", Proceedings: 3rd Working Symposium on Oceanic Data Systems, Scripps Institution of Oceanography, February 4-7, 1986.

6. LOCKWOOD, M. and WHEATON, G. E., "Meso-Scale Mapping of Seafloor Topography Utilizing Swath Mapping Technology - A Description of NOAA's EEZ Mapping Project", Current Practices and New Technology in Ocean Engineering, Vol. 11, 1986.

7. PERRY, R. B., "Mapping the Exclusive Economic Zone", Proceedings: OCEANS 85, November 1985.

8. PRYOR, D. E., "Overview of NOAA's Exclusive Economic Zone Survey Program", Proceedings: OCEANS 85, November 1985.

9. UMBACH, M. J., "Hydrographic Manual Fourth Edition", U. S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, July 4, 1976.