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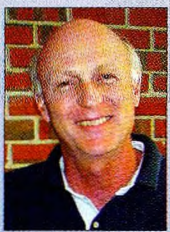

Analysis of Data Relevant to Establishing Outer Limits of a Continental Shelf under Law of the Sea Article 76

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Coastal states may extend the limits of their juridically defined continental shelf beyond 200 nautical miles from their baselines under the provisions set forth in Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS). In a preparatory desktop study, the University of New Hampshire's Center for Coastal and Ocean Mapping/Joint Hydrographic Center analysed existing U.S. bathymetric and geophysical data holdings, identified data adequacy, and survey requirements to prepare a U.S. claim beyond the Exclusive Economical Zone (EEZ). In this paper we describe the methodology for our desktop study with particular emphasis on how we assembled and evaluated the existing data around the shelf areas of the United States, and estimated where additional surveys may be required.

Introduction

Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS) provides the opportunity, under certain circumstances, for States Parties to UNCLOS to establish outer limits of their continental shelf beyond their current 200 nautical mile limits. Such an exten-

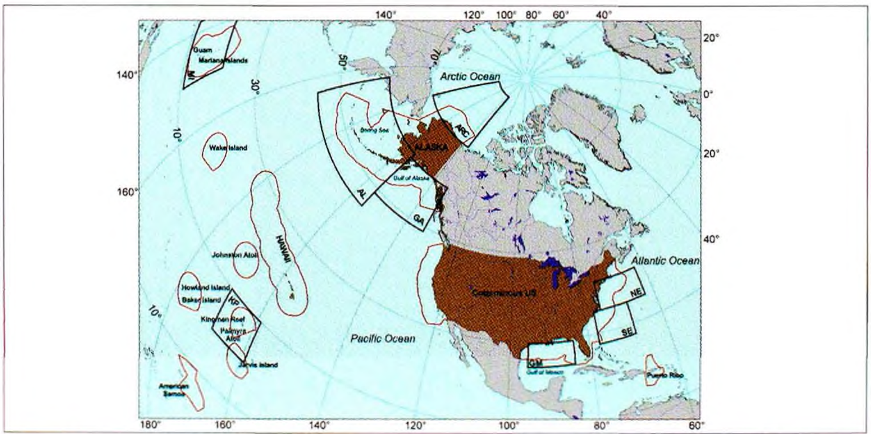


Figure 1: Coterminous United States of America (U.S.) and trust territories that were the focus for this study. The red line denotes the current U.S. Exclusive Economic Zone (EEZ). The black boxes represent those areas selected for more detailed studies based on an identified potential for an extended claim under the provisions of UNCLOS Article 76 (see text)

sion of jurisdiction over the seabed and subsoil requires that the state prepare its case for a claim, a process that involves the construction of a set of limit lines set forth in Article 76 [United Nations, 1993]. These limit lines are based on the depth and shape of the seafloor as well as the thickness of the underlying sediments. Therefore, it is necessary to analyse bathymetric, geologic and geophysical data of the seafloor areas where a potential exists for an extended claim under Article 76. In order to avoid unnecessary data collection, desktop studies that evaluate existing available data should be among the first steps in any nations' preparation for a claim.

In preparation for a potential U.S. claim, the University of New Hampshire's Center for Coastal and Ocean Mapping/ Joint Hydrographic Center was directed by the U.S. Congress, and funded by the National Oceanic and Atmospheric Administration (NOAA) to investigate U.S. bathymetric and geophysical data holdings in relevant areas and to evaluate the extent and cost of additional surveys required to complement these data holdings so that they might be used, with full confidence, for substantiating a U.S. claim under Article 76. The first phase of this task was carried out in collaboration with NOAA's National Geophysical Data Center (NGDC), the U.S. Geological Survey (USGS), and several consultants during the course of 6 months. Our effort was **not** designed to establish a U.S. claim, but rather, to explore the relevance and quality of existing data holdings in regions where there might be potential for an extended claim.

This paper describes the approach we developed for our desktop study, particularly with respect to assembling and evaluating existing bathymetric, geologic and geophysical data around the shelf areas of the United States as well as estimating where additional data acquisition is required (Figure 1). The complete results from our desktop analysis are summarised in a report [Mayer et al., 2002] and an atlas consisting of 40 maps [Jakobsson et al., 2002] submitted to the U.S. Congress and available at http://www.ccom.unh.edu/unclos/index.htm.

Article 76: Overview and Implementation

In order to understand the type and coverage of bathymetric, geologic and geophysical data

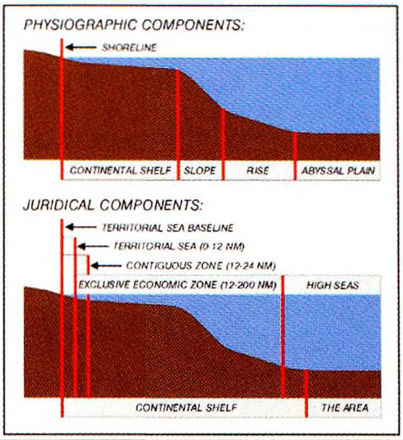


Figure 2: Physiographic (top) and juridical (bottom) definitions of the continental margin as presented in UNCLOS Article 76 [Modified from Macnab and Haworth, 2001]. Using physiographic nomenclature, the three components of the continental margin consist of the continental shelf, slope and rise, forming a transition zone between land and the abyssal plain. The juridical nomenclature of UNCLOS defines components that pertain to the seabed and the superadjacent waters: the territorial sea, the Exclusive Economic Zone, and high seas. UNCLOS also defines juridical components that pertain only to the seabed: the continental shelf and the Area. Note that the juridical continental shelf and the physiographic continental shelf are quite different

required, and the type of analyses needed to extend a claim, it is necessary to have a basic understanding of the main contents of UNCLOS Article 76 and its implementation [see: United Nations, 1993; 1999]. The first criterion for determining whether or not under any circumstances a coastal state can extend the outer limit of its continental shelf beyond the 200 nautical mile limit of the EEZ is to determine if a natural prolongation of the continental shelf exists. This is referred to as the 'test of appurtenance'. It should be pointed out that the 'Continental Shelf' as defined in Article 76 refers to a juridical proclamation and not to the classical geological definition of a shelf [see: Macnab and Haworth, 2001] (Figure 2). Neither Article 76 nor the Commission of experts established to oversee the process (The Commission on the Limits of the Continental Shelf, CLCS) provides a precise definition of what constitutes a natural prolongation of a state's continental shelf. The determination must be based on a general knowledge and interpretation of the bathymetry and

	Base Feature	Derived Feature	Line Type	Claim Line
1	The coastal state's territorial baseline	350 nmi geodetic distance from the territorial baseline	Most Seaward -> 'Cut Off Line'	Most Seaward -> 'Formula Line'
2	The 2500 m isobath	100 nmi geodetic distance from the 2500 m isobath		
3	The 'foot of the slope'	60 nmi geodetic distance seaward from the foot of the slope	Most Landward -> 'Outer Limit'	
4	The thickness of the sediment seaward the foot of the slope	The outer limit of points where the thickness of sediment is 1 per cent of the distance between that limit and the foot of the slope		

Table 1: Article 76 main features that need to be determined

nature of the seafloor in a region. For example, if a coastal state has a narrow physiographic shelf bounded by a seaward subduction zone (which clearly indicates the transition from continental to oceanic crust) there is, under most circumstances, no natural prolongation of the continental shelf. In those areas where there is some evidence (broad shelves or other extended plateaus and/or thick sediment sections) that suggests a natural prolongation of the continental shelf according to Article 76, further study is required.

Once a natural prolongation of the shelf is established, a claim is made through the application of a series of formula and cut off lines described in UNCLOS Article 76 (see Table 1 and Figure 3). To derive these, three classes of geoscientific information must be analysed: 1) the shape of the seabed; 2) the depth of water, and; 3) the thickness of the underlying sedimentary material. A full description of the implementation process can be found in the Scientific and Technical Guidelines of the CLCS [United Nations, 1999], and a discussion regarding the hydrographic requirements in Monahan and Wells [2002].

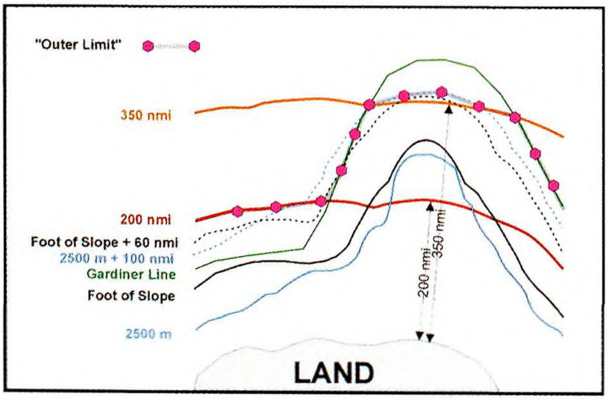


Figure 3: Article 76 main features and their combinations that need to be determined and the combination of them in order to derive the 'Outer Limit'. This illustration is not to scale [Modified after Smith and Taft, 2000]

Outline of Approach and General Methodology

In order to evaluate the content and condition of existing relevant data holdings in all areas where the U.S. may have a potential claim for an extended continental shelf beyond the present 200 nautical mile limit, a general work plan and approach was developed (Figure 4). The individual steps in this plan are described below.

Identify All Major Sources of Data

Gathering of all existing data available within and outside the U.S. EEZ was a significant task given the large area and long survey history; complete analysis of all this data would be an overwhelming task. In order to limit the scope of the study we initially used a series of regional and global data compilations to identify those areas that could be eliminated from further studies, i.e., areas that do not pass the 'test of appurtenance'. This elimination was based on estimates of the Article 76 components for which the following fundamental information is required:

1. Territorial baselines (Current EEZ, baseline points, country limits etc)
2. Bathymetry (to provide a general idea of the position of the foot of the continen-

tal slope (FOS) and the position of the 2,500-m contour)
3. Sediment thickness

Additional data, like gravity or magnetics, may also be useful in preparing a claim if questions about the nature of the crust (oceanic or continental) are posed. These data would also play an important role in cases where it would be more advantageous to establish the FOS by means known as 'evidence to the contrary' [See CLCS: United Nations, 1999].

Baseline data were mainly provided by NOAA's National Ocean Service (NOS) whereas bathymetric and sediment thickness data came from available regional/global data compilations, of which we identified the following to be particularly useful:

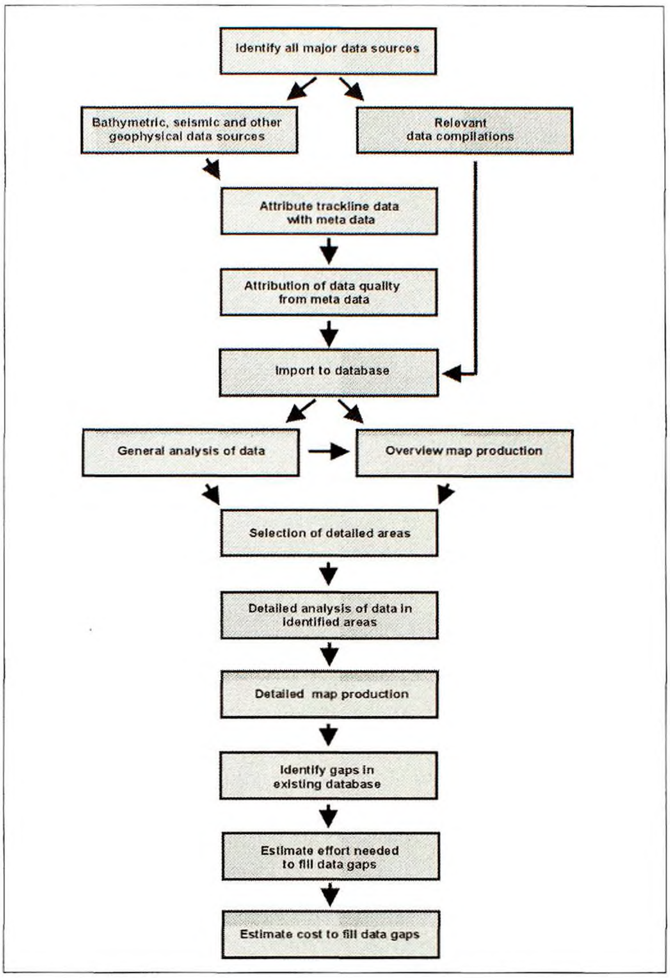


Figure 4: Flowchart illustrating the general work plan and approach designed for the evaluation of content and condition of existing relevant data holdings in all areas where the U.S. may have a potential claim for extension of the continental shelf beyond the present 200 nautical mile limit

1. ETOPO5 – a 5-minute latitude/longitude (approximately 5 mile) digital global grid of seafloor and land elevations. This bathymetry is based strictly on single beam sonar data collected over many years [NOAA, 1988]

2. ETOPO2 – a newly released gridded digital dataset of ocean depth and land elevation with 2-minute latitude/longitude grid spacing. This data set is based on a seafloor compilation between latitudes 64° N and 72° S from Smith and Sandwell [1997]. Their compilation is derived from satellite altimetry observations combined with quality-assured shipboard echo-sounding measurements. The seafloor compilation south of 72° S is from the US Naval Oceanographic Office's (NAVOCEANO) Digital Bathymetric Data Base Variable Resolution (DBDBV), version 4.1, gridded at 5 minute spacing, and in some regions from the older DBDB5 that also was used in ETOPO5. The Arctic region north of 64° N, ETOPO2 consists of a sub-sampled version of the International Bathymetric Chart of the Arctic Ocean (IBCAO) Version 1 (see below). ETOPO2 is available through NGDC [NGDC, 2002a]

3. GEBCO Digital Atlas (GDA) – is comprised of digital contours, digitised from the General Bathymetric Chart of the Oceans (GEBCO) bathymetry chart series, released on a CD-ROM [NGDC, 2002b]

4. Coastal Relief Model – gridded bathymetric data sets for selective coastal regions collected by NOAA and provided as gridded digital terrain models with variable sample spacing (depending on region) [NGDC, 2002c]

5. Sediment Thickness Database – a global compilation and interpolation of interpreted seismic data and other sediment thickness compila-

tions presenting a crude estimate of sediment thickness. This is a gridded product with 5 minute grid spacing that is provided by NGDC [NGDC, 2002d]

6. International Bathymetric Chart of the Arctic Ocean (IBCAO) - a gridded bathymetry compilation combined with land elevations from ETOPO 30 for the Arctic region above 64° N. IBCAO provides a polarstereographic grid with 2,500 m cell spacing and a 1-minute latitude/longitude grid for download from NGDC [NGDC, 2002e]. The first version of IBCAO was released in the spring of 2000 [Jakobsson et al., 2000]

7. Sedimentary Thickness Map of the Arctic Ocean – a printed contour sediment thickness map of the Arctic Ocean compiled by Jackson and Oakey [1990] from seismic reflection and refraction data and other sediment compilations

In addition to the territorial baseline data provided by NOAA, the following sources of vector information were used:

1. The World Vector Shoreline (WVS) provided by NIMA (1:250,000 - 1:1,000,000) [NGDC, 2002f]
2. The Digital Chart of the World (DCW) assembled by NIMA

The compiled data sets play an important role in providing general insight into the nature of the bathymetry and sediment thickness in a given region but probably do not have enough detail to substantiate a claim for an extended continental shelf. For those areas where there is potential for an extended claim, the real challenge consisted of identifying 'all available' individual data and determining where more data are required. The data compilations listed above played an important role in this process but the original bathymetric, seismic and other geophysical source data, the sources for the compilations, had to be located and investigated. Fortunately, the U.S. has established, under NOAA, The National Geophysical Data Center (NGDC), an organisation charged with being the central repository for bathymetric and geophysical data sets in the U.S. NGDC provided our main data resource and the starting point for the data collection effort. Unfortunately the NGDC collection is not complete as numerous academic institutions and governmental agencies are lagging behind in delivering their data. Therefore, in order to seek other sources of data we also carried out searches outside NGDC. While every attempt has been made to identify and locate all sources of data available, it is inevitable that there are still some data that have not yet been discovered.
Seismic data present several special challenges. Much of the seismic data in and within the vicinity of the U.S. EEZ were collected by the private sector, and are proprietary in nature and, thus, not readily accessible. Additionally, to use seismic data for the purpose of defining sediment thickness, it is necessary to convert seismic travel times to distances – a process that requires knowledge of the speed of sound in the sediment column. Sound speed information is derived from multichannel seismics, refraction experiments or boreholes and requires the interpretation of a skilled geologist or geophysicist. For these reasons a full understanding of seismic data coverage and quality is a complex task requiring access and specialised expertise, and thus we contracted the search for seismic data to the U.S. Geological Survey (U.S.G.S.) who worked with the Mineral Management Service (MMS).

Attribution of Metadata and Data Quality

While the collection of all available data was clearly the first step in evaluating the need for further data collection, an attempt was also made to understand the quality of the gathered data. A thorough quality analysis requires that the individual datasets be analysed for internal consistency as well as for their relationship to neighbouring data (cross track analysis). This can be done through a range of statistical techniques [e.g. Jung et al., 2002], though when a database is heterogeneous and consists mainly of ship tracklines, as does the one we are working with, it is difficult to evaluate the quality of the data without compiling a bathymetric model. In this case 'compiling' refers to a process including both statistical and manual cleaning, gridding, and subsequent visualisation through rendering [e.g. Macnab et al., 2000]. This is a time-consuming task and given the time constraints for this study (6 months) it was not an option. Instead, our quality assessment was more

Attribute	Comment
SURVEY_ID	Identification to for example field sheets or cruises
NGDC_NUMBER	Specific NGDC assigned record number
SHIP_NAME	Survey ship
INSTITUTION	Source Institution
START_DATE	Survey start date
END_DATE	Survey end date
NAV_INSTRUMENT	Used navigational instrumentation
DATUM_POS_METHOD	Navigational method (e.g. TRANSIT fixes + ship inertial system)
BATHY_INSTRUMENT	Type of bathymetric acquisition system
NAV_CLASS	Navigational class assigned within this present project
NAV_ACCURACY	Navigational accuracy assigned within this present project

Table 2: Example of metadata that was attributed the NGDC trackline bathymetric data during the database loading process. This metadata was retrieved from the NGDC inventory header records

rudimentary, and carried out by using metadata (data describing the data) (Table 2).

The data available to us in various national archives have been collected over at least the last 50 years using a variety of sonar and navigation systems. The accuracy of the determination of many of the key features used for making a claim for an extended shelf under Article 76, will be dependant on the type of sonar and navigation system used [see discussion by Monhan and Wells, 2002]. Given the relatively small uncertainties associated with a sonar's ability to measure depth (typically 10's of metres in the worst cases) compared to the large uncertainties associated with many of the older positioning systems (on the order of km's), it is uncertainty in positioning that will dominate the errors associated with a claim under UNCLOS Article 76. For example, data collected using celestial navigation will have a much higher degree of uncertainty than data collected using the Global Positioning System for navigation. Thus a claim built on GPS-based data will be much more reliable than one based on non-GPS navigated data.

A conversion table was created in which all navigational systems used were grouped by general navigational system classes (Table 3). The classes were subsequently assigned estimated uncertainties. The full conversion table from navigation system to class and uncertainty is documented in Mayer et al., [2002]. We realise that this approach is a gross generalisation of the complex relationship between uncertainty and navigational systems. Furthermore, the accuracy value we have assigned to data sets is the accuracy of a discreet navigation fix. We have not tried to assess the accuracy of data between fixes for several reasons. Foremost among these is that inter-fix accuracy depends on the dead reckoning procedures employed in the survey or cruise and these are not usually documented in the trackline metadata. Also, in most trackline data sets, it is not feasible to distinguish soundings at fix locations from soundings between fixes. In NOAA hydrographic and bathymetric surveys, the accuracy of soundings between fixes is well documented, but with other types of bathymetric data, procedures may vary greatly from cruise to cruise.

To determine the accuracy values for individual systems and system classes we referred, wherever possible, to authoritative reference material ['Bowditch' Defense Mapping Agency, 1984;

Unknown	10,000 m
Celestial	10,000 m
Piloting	2,000 m
OMEGA	7,300 m
Loran A	1,200 m
Loran C	500 m
TRANSIT	500 m
GPS	100 m
Starfix	50 m
Survey	50 m
DGPS	20 m
GPS Code	20 m

Table 3: For each data set, we identified, where possible, the navigation system or systems employed. We divided these systems into several classes. Each class was assigned an estimated accuracy value, the radius of a circle of 95 per cent error probability, and each dataset was assigned to one of the classes

National Imagery and Mapping Agency, 1995; 'Dutton's': Maloney, 1985; 'The Hydrographic Manual': U.S. Dept. of Commerce, 1942, 1960, 1976; Ingham, 1984]. When no authoritative reference was available, accuracy values are based on the professional consensus of JHC/CCOM and NGDC experts.
Many cruises employed multiple positioning sensors. Assigned accuracy was generally based on the lowest accuracy of the systems employed. In some cases, particularly during the later period of the transition from TRANSIT (the Navy Navigation Satellite System) to the Global Positioning System, a more accurate system was judged to have improved the less accurate system to a degree sufficient to assign the more accurate value. Where no positioning system metadata existed, the accuracy was labelled as unknown and assigned the default worst possible case value.

Import into the Database

One of the main challenges of the project was to design (create a schema) and populate a database in which all collected data could be stored with associated metadata for rapid retrieval and analysis. The main database chosen for this purpose was the newly released Oracle 9i database. This database was chosen because it provided:

1. Efficient data bulk loading capabilities through scripting
2. Efficient access to all data through a GIS interface
3. Rapid retrieval and querying of spatial data due to indexing (Quad- and R-Tree)

Each of the lines (tracklines), polygons (survey polygons) and point features (e.g. spot soundings) were associated with a set of attributes created from the metadata as described above. A simple data model was chosen whereby each feature was stored as an Oracle defined geometry (SDO_GEOMETRY) directly with its attributes in a Table-design (Figure 5). The data attribution was done using Perl-scripting for reformatting in order to put the data in a format suitable for Oracle 9i database population through SQL-Loader. Data reformatting and entry went very smoothly resulting in a database of 39,861 tracklines from various ship cruises, 6,037 bathymetry survey polygons (polygons enclosing surveys), and several million soundings ready for instantaneous access, sorting, and analyses. The Oracle database was linked to a Geographic Information System (GIS). We used Intergraph's GeoMedia Professional GIS package, which allowed maps to be created from any combination of data sets stored in the database. Further details of the data reformatting, the Oracle database and the Intergraph GIS are presented in Mayer et al., [2002].

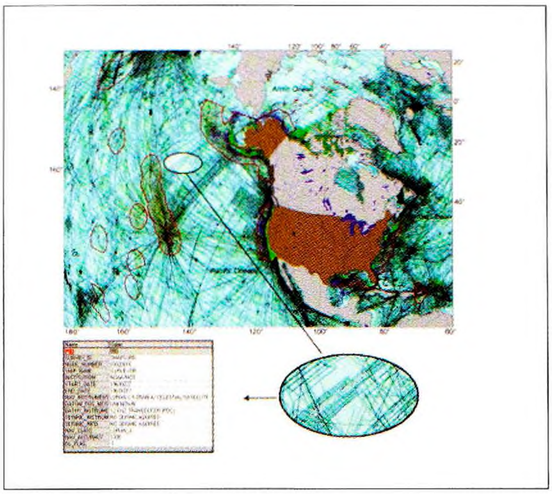


Figure 5: Example of overview maps produced using Geomedia Professional and the Oracle 9i database. This example shows trackline surveys and spot soundings colored by source (NGDC, MMS, USGS, NIMA and Other sources). The text box show metadata information from the database readily available for each trackline survey simply by clicking on the survey. (The displayed map is in the Lambert Equal Area Projection)

General Analysis of Data and Overview Map Production

Once all data and metadata had been entered into the database and made available to our GIS system, the analytical process could begin. In preparation for later analysis a series of overview maps were generated showing the location of all available bathymetric data (Figure 5), the location of all available seismic data, as well as overview plots showing where NOAA detailed survey data and multibeam sonar data were available [see Mayer et al., 2002 and Jakobsson et al., 2002].
The first step in the analysis was to identify those areas surrounding the U.S. where there is potential

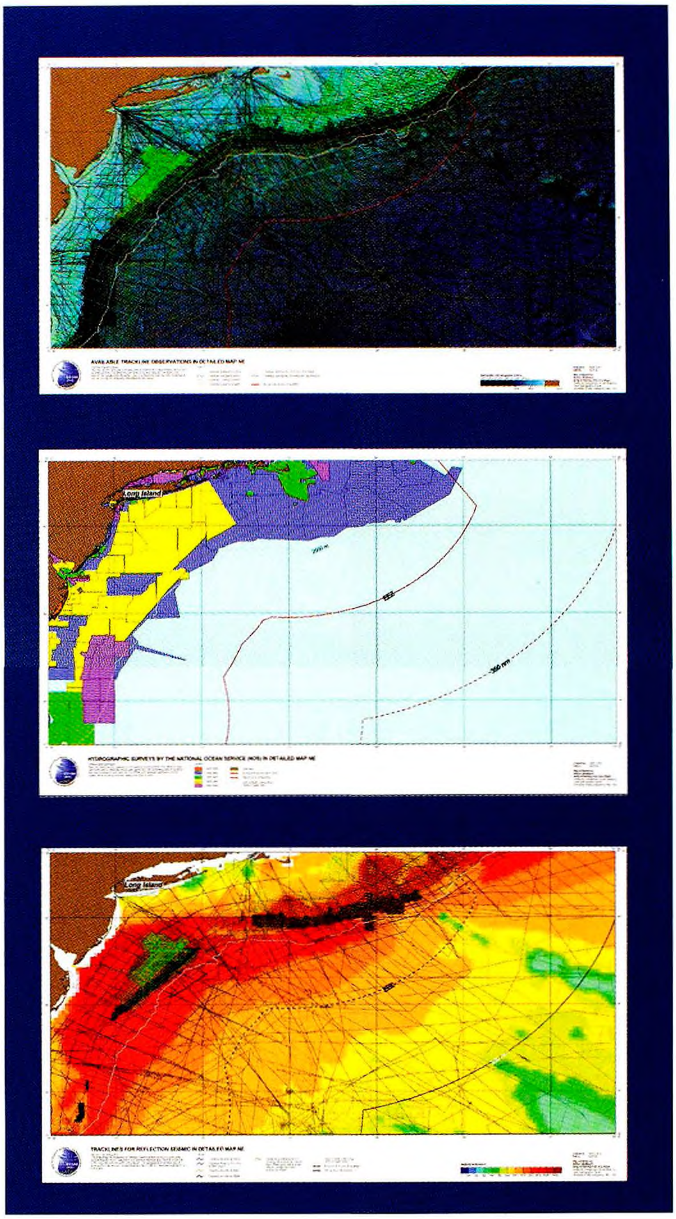


Figure 6: Detailed maps of area NE (see Figure 1) showing various combinations of all available trackline data in the area. The maps are shown in reduced scale from Jakobsson et al. [2002]. A: Tracklines color coded by source and overlain on a shaded relief representing ETOPO2; B: Available high-density NOS data in the NE area; C: Distribution of seismic reflection profile data overlain on sediment thickness information from NGDC

for a claim for an extended continental shelf under Article 76 (and eliminate areas where there is no potential). This step is the 'test of appurtenance' described by the Commission of the Limits of the Continental Shelf in which subjective decisions must be made (particularly with respect to the demonstration of the 'natural prolongation' of the land territory). To establish whether or not a region had potential for an existing claim, we went through the procedure of deriving the Article 76 components (see Table 1) using Caris LOTS. The results were exported from Caris in order to make them available in Geomedia Professional for map production and analysis in conjunction with the remaining data stored in databases. The limits derived using Caris LOTS were based on the bathymetry from ETOPO2 and IBCAO, the compiled sediment thickness data from NGDC and a gridded version of the Arctic sediment thickness map by Jackson and Oakey [1990] (Courtesy of Ron Macnab), the existing territorial baselines, and the official 200 nautical mile EEZ limits (see Section 4.1 for references). We produced a rough estimate of the foot of the slope using the Caris LOTS tool

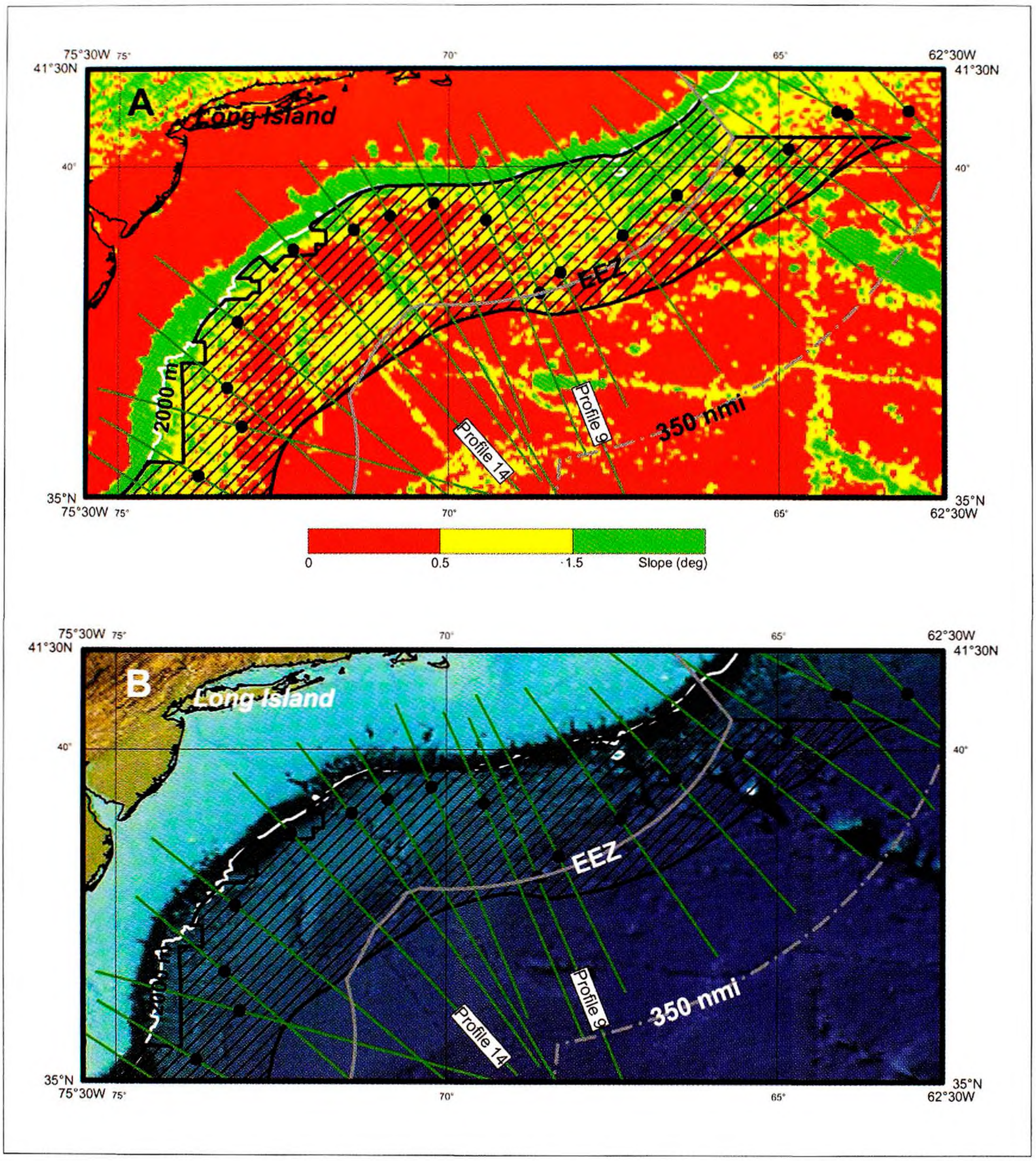
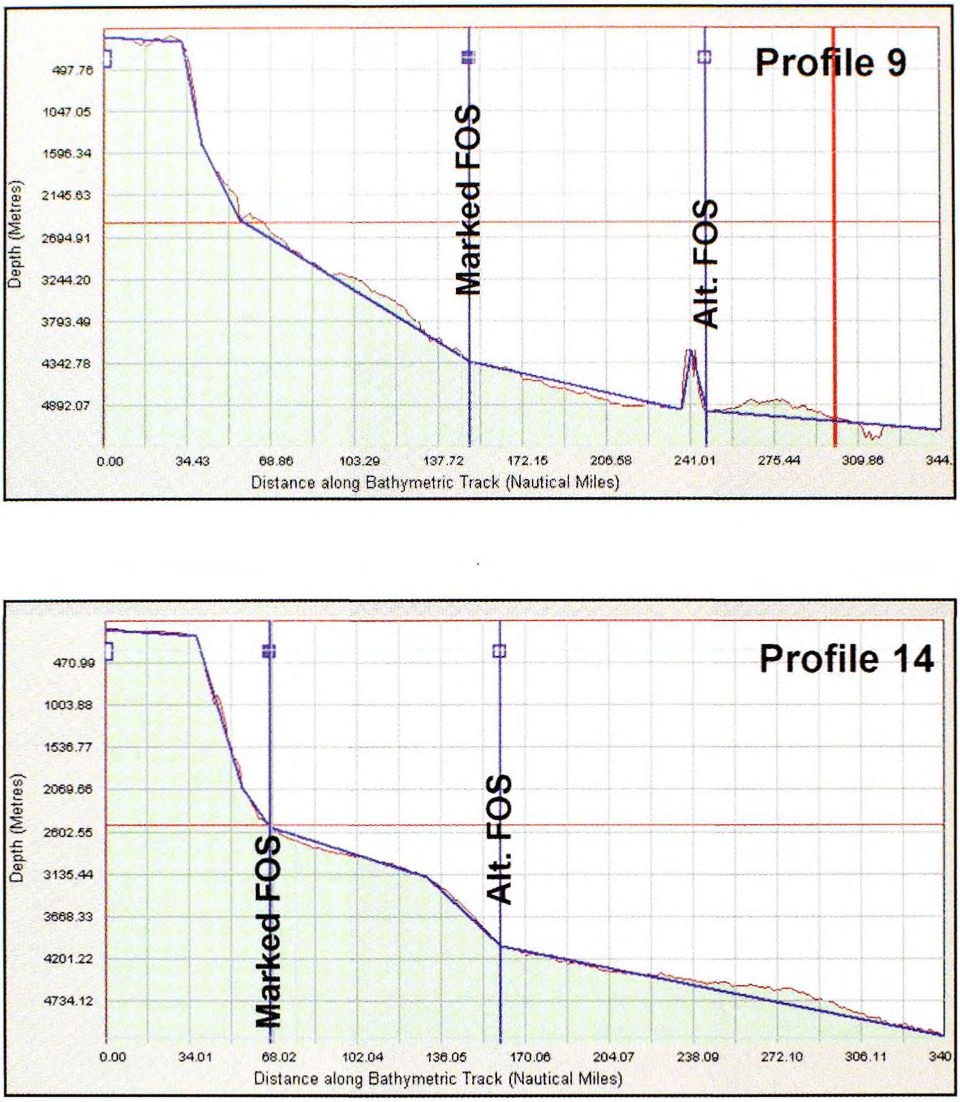


Figure 7: A: Slope of seafloor by colour in detailed area NE (Figure 1). Multiple bathymetric profiles were drawn through the area and possible locations of the FOS are marked with black dots. Variation in slope and resulting ambiguity in location of the selected FOS influences the size of the area (hatched) for which detailed bathymetry is required. Note also the 2,000 m depth contour used to define the landward limit of the survey corridor. In the southwest corner, the survey corridor is reduced to start outside the 2,000 m depth contour based on the availability of existing high resolution survey data

B: Bathymetry from ETOPO2 in detailed area NE, drawn bathymetric profiles, and possible locations of the FOS. Labeled profiles are shown in C



C

Figure 7 C: Bathymetric profiles 9 and 14 in detailed study area NE. The locations of these profiles are shown in A and B. The ambiguity in location of the FOS is clearly illustrated. The 'Marked FOS' is the location marked with a dot in A and B. Alternative locations for the FOS are shown in each profile. Note that the vertical exaggeration in the bathymetric profile accentuates gradient changes

and ETOPO2 (see Figure 7c). **We emphasise that this exercise was not designed to establish a U.S. claim but rather to identify regions where there might be potential for an extended claim.** While the data compilations used allow an overview of general bathymetry and sediment thickness; we do not believe they are detailed enough to be used to make a claim under Article 76.

Selection of Detailed Areas

The Article 76 components derived from regional compilation data described above were used to identify areas surrounding U.S. territory for which there may be potential to claim a continental shelf beyond the current 200 nautical mile EEZ limit. We were as liberal as possible so that we would not eliminate any area that may have the slightest potential. We compared our results to a similar analysis done by the Mineral Management Service [Amato et al., 1995; Carpenter et al., 1996] and found our analysis to be in general agreement with theirs though ours encompasses a somewhat larger area. Eight regions were identified for further study, including most of the U.S. east coast, the Gulf of Mexico, the Alaskan margin, the Arctic margin, and the areas around Guam and Palmyra Atoll (Figure 1). A narrow continental shelf and/or lack of thick sedimentary sections eliminated the U.S. west coast, as well as areas around Hawaii, Puerto Rico, Johnston Atoll, American Samoa and Wake Island.

Detailed Analysis of Data in Identified Areas and Detailed Map Production

Detailed maps were generated for each of the identified study areas portraying available data sets and their nature. The maps included: 1- all available trackline data in the area colour coded by source and overlain on a shaded relief representing ETOPO2 (Shown in Figure 6A) or IBCAO bathymetry; 2- all available trackline data colour coded by our estimated navigational fix accuracy; 3- all available trackline data colour coded by source without a shaded relief as a backdrop; 4- the availability of high-density NOS data in the survey area (Shown in Figure 6B) and; 5- the distribution of seismic reflection profile data in the detailed study area overlain on sediment thickness information from NGDC or Jackson and Oakley [Jackson and Oakley, 1990] (Shown in Figure 6C). All of these maps have been assembled in a 21' x 33.5' sized Atlas [Jakobsson et al., 2002] and are available through the CCOM/JHC web site: http://www.ccom.unh.edu.

An analysis was subsequently done of the identified areas to determine which of the features required to make a claim for an extended continental shelf under Article 76 (the 2,500 m isobath, the foot of the slope, or the point where the sediment thickness is 1 per cent of the distance back to the foot of the slope) was the most critical. For those areas where only bathymetric criteria were important, further analysis was restricted to the bathymetry. However, in most cases a claim will be based on a combination of data sets, and in these areas both bathymetric and seismic data will have to be analysed. There may also be areas where bathymetry and sediment thickness will not provide a clear case, or the most advantageous case, for defining the FOS. When these cases arise, additional geological and geophysical data can be examined to determine if a FOS can be established by means of evidence to the contrary.

Identify Adequacy of Existing Database and Define Survey Requirements

This critical step in our analysis involved determining whether the existing database is adequate for making an extended claim under Article 76 and, thus, determining where more data may be needed. Neither UNCLOS Article 76 nor the Scientific and Technical Guidelines of the CLCS explicitly state the data density required for a submission. This leaves the identification of a 'data gap' an inherently subjective decision. The Commission requires 'a full technical description of the bathymetric database' including:

1. Source of the data
2. Sounding survey techniques
3. Geodetic positioning methods and reference system
4. Time and day of the survey
5. Corrections applied to the data for speed of sound in water, calibration and other
6. *A priori* or *posteriori* estimates of random and systematic errors
7. Geodetic reference system
8. Geometric definition of straight, archipelagic, and closing baselines

Cartographic products may include:
1. Two-dimensional depth profiles
2. Three-dimensional depth profiles
3. Charts and maps with contours depiction of normal and straight baselines

Each of these must be accompanied by a detailed description of the methodology used to produce the product; the coastal state may be required to also document the methods of interpolation or approximation used, the density of the measured bathymetric data, and perceptual elements such as map projections, vertical and horizontal scales, etc. The only guideline provided by Article 76 with respect to data density is found in Paragraph 7 which states that: 'The Coastal State shall delineate the outer limit of the continental shelf, where that shelf extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, by straight lines not exceeding 60 nautical miles in length, connecting fixed points, defined by co-ordinates of latitude and longitude'.

Bathymetric Data

Our approach to identifying areas where more data may be required has been very conservative (i.e., if there can be any question, we consider an area to require additional data). For each of the detailed survey areas we examined the density of present data holdings as well as the quality as given by the metadata. Based on data density alone, U.S. bathymetric data holdings may be sufficient for making a claim everywhere except in the Arctic. That is to say, that except for the Arctic, bathymetric data profiles are generally separated by less than 60 nautical miles. However, given the relative quality of much of the older data and the resolution with which the bathymetry can be defined, it is clear that the uncertainty associated with these data sets would make definition of the 2,500 m isobath or particularly the foot of the slope subject to some question. Under the approach to uncertainty determination described by Jakobsson, et al [in press] the random error component alone, estimated from information about navigation- and sounding acquisition system will result in a considerable uncertainty in the location of a bathymetric feature derived from a gridded compilation when the data are sparse [Jakobsson et al., 2001]. While the uncertainty associated with these older data sets may be deemed acceptable by the CLCS, our objective is to establish the basis for an irrefutable and optimal claim. In this light, we have defined regions requiring additional bathymetric data as any region where either multibeam or very dense modern single beam sonar data are not available. We develop this reasoning further in the discussion section. Understanding where more seismic survey work is required (sediment thickness) is far more difficult, as discussed below.

Once the criteria for defining regions where more bathymetric data were required were established, a strategy for estimation of required survey areas was devised. This strategy is based on a general approach of using the best-available compiled bathymetry (ETOPO2) to generate a slope map (the derivative of the bathymetric surface). Based on both the bathymetry and slope map, an isobath was selected from the GEBCO Digital Atlas such that any possible position of the foot of the slope was seaward of this contour (typically the 2,000 m contour). This contour represents the landward limit of the required survey (Figure 7A and B). The seaward limit of the proposed survey was selected based on the ETOPO2 morphology, the derived slope map, and a series of bathymetric cross-sections analysed using Caris LOTS (Figure 7C). The outer survey limit is typically found by analysing the bathymetric cross-sections together with the slope information and accounting for any ambiguity of the location of the FOS. We concluded that any possible definition of the FOS would not be located seaward of where the gradient of the seafloor topography is less than 0.5 degrees. Between these limits we define a survey corridor within which the critical bathymetric features for establishing the limits of the continental shelf under Article 76 (the 2,500 m contour and the foot of the slope) will be found.

Seismic Data

The evaluation of adequacy of the existing seismic data requires that we identify where seismic data exist, and whether or not the sediment thickness can be determined from those data. In our data collection effort, we identified available seismic track lines and loaded those track lines in our database. Much of these data are proprietary industry data held by the U.S. Minerals Management Service (MMS) and are not publicly available in any form other than a track line. The next step would be to analyse these data to determine whether or not they are suitable for a claim under Article 76. This requires that the data be analysed and interpreted by geophysical and geological experts. The scope of this effort is quite large, and the time constraints of our initial study precluded such interpretation. In the United States, the governmental agency charged with this responsibility is the U.S. Geological Survey (USGS). The USGS has begun the process of examining the available seismic data in the areas of interest, and their interpretation will be incorporated into the second phase of our study. The final step in the desktop study is to determine, for those areas of potential claim, where data are inadequate, and what new seismic

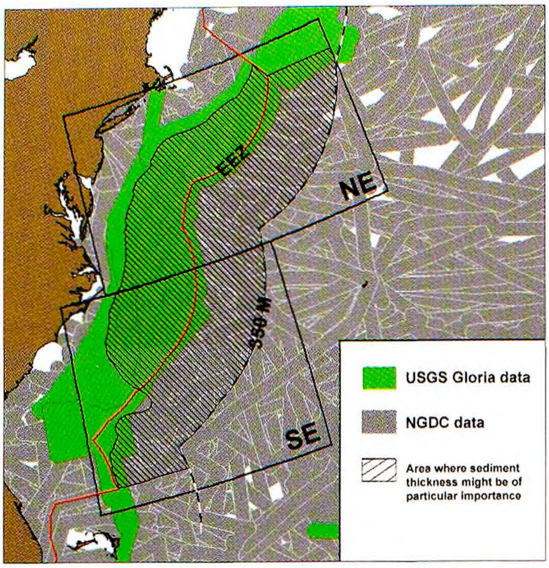


Figure 8: Example showing 15 nautical miles (30 nautical miles wide trackline) buffer zones generated in Geomedia Pro around seismic tracklines from NGDC and the U.S.G.S. Gloria project. This was done to analyse if the line spacing was more than 30 nautical miles

surveying is required. As is the case for bathymetry, the only guideline provided by Article 76 with respect to data density is found in Paragraph 7 which states that: 'The Coastal State shall delineate the outer limit of the continental shelf, where that shelf extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, by straight lines not exceeding 60 nautical miles in length, connecting fixed points, defined by co-ordinates of latitude and longitude'. This paragraph does not explicitly talk about the density of the underlying data, but rather the fact that in constructing a claim the proposed limits must be established at intervals no more than 60 nautical miles apart. In the case of seismic data, however, the 60 nautical mile constraint suggests a reasonable starting point to test for data density. A simple Nyquist criterion calls for sampling at twice the required spatial frequency. Thus as a start for further analyses we define data gaps only as those areas for which a seismic profile crossing the margin does not exist every 30 nautical miles. To do this, we plotted the tracklines on our area of interest maps, and overlaid the lines with a 30 nautical miles -wide swath (Figure 8). Wherever the swaths do not overlap, new data are required. We do not assume that seismic data lines from the FOS to the cutoff are required, only that seismic profiles across the area are sufficiently dense such that gaps no more than 30 nautical miles exist between data. We believe that a sediment thickness model constructed from validated data at this density is sufficient to form the basis for 60 nautical miles -spaced sediment thickness profile lines drawn through the model from the FOS to the cutoff.

Summary, Discussion and Conclusion

We established a GIS database containing information about bathymetric and geophysical data holdings in areas relevant to a U.S. claim under UNCLOS Article 76, developed an approach for a gross evaluation of the data quality, and estimated where more data might be required to substantiate a U.S claim. Our time constraint of six months forced a number of time saving solutions that will be discussed. In particular, the use of a GIS platform that is able to access directly the established database in real time for analysis and map production was a key. With this approach, database queries can be displayed directly in maps that illustrate the results. It should be emphasised that we made **all** data available for our GIS system, including the derived Article 76 limit lines. This approach also allowed us to rapidly identify the detailed study areas where there is a potential for a claim and, thus, greatly reduce the area for which the available data distribution and quality needed to be scrutinised. The identification was based on the UNCLOS Article 76 limit lines derived from regional compilation data sets. Given the low resolution and large uncertainty associated with these regional compilations, we defined a relatively large 'zone of uncertainty' for the potential location of the Article 76 FOS from the ETOPO2 data. This zone of uncertainty provided initial bounds for the recommendation of the collection of new survey data. Once a zone for potential new survey work was defined, the quality of the available data was addressed from metadata. This route was taken because a thorough quality analysis of bathymetric data requires that the individual datasets be analysed for internal consistency as well as for their relationship to neighbouring data (cross track analysis), and for areas as large as those associated with a potential U.S claim under Article 76, a thorough analysis was simply not feasible given our time constraints. Our approach only provides a gross estimate of data quality, but does allow an estimate of the relative quality associated with the existing data and demonstrates that relatively high levels of uncertainty are to be expected with much of the existing database.

Our desktop study also suggests that where complete coverage of high-resolution multibeam sonar bathymetric data or very dense single beam survey data exist we are able to precisely define the bathymetric components of Article 76, the location of the 2,500 m isobath, and the FOS, and in doing so optimise a potential claim. The reason for this is illustrated with the example in Figure 9A to 9D. Complete high-resolution coverage not only more accurately defines key bathymetric features, but also allows these data to be interactively explored using 3-D visualisation techniques, helping to resolve ambiguities associated with the location of the FOS. With the FOS and 2,500 m contour clearly defined, the strategic selection of line segments used for definition of the boundary can increase significantly the area claimed. Thus where full-coverage multibeam data or very dense single beam data already existed, we removed these regions from our required survey areas.

In many of the areas where an extended claim may be made, such a claim would be made based on the position of the Gardiner Line (the point where the sediment thickness becomes 1 per cent of the distance back to the FOS). While

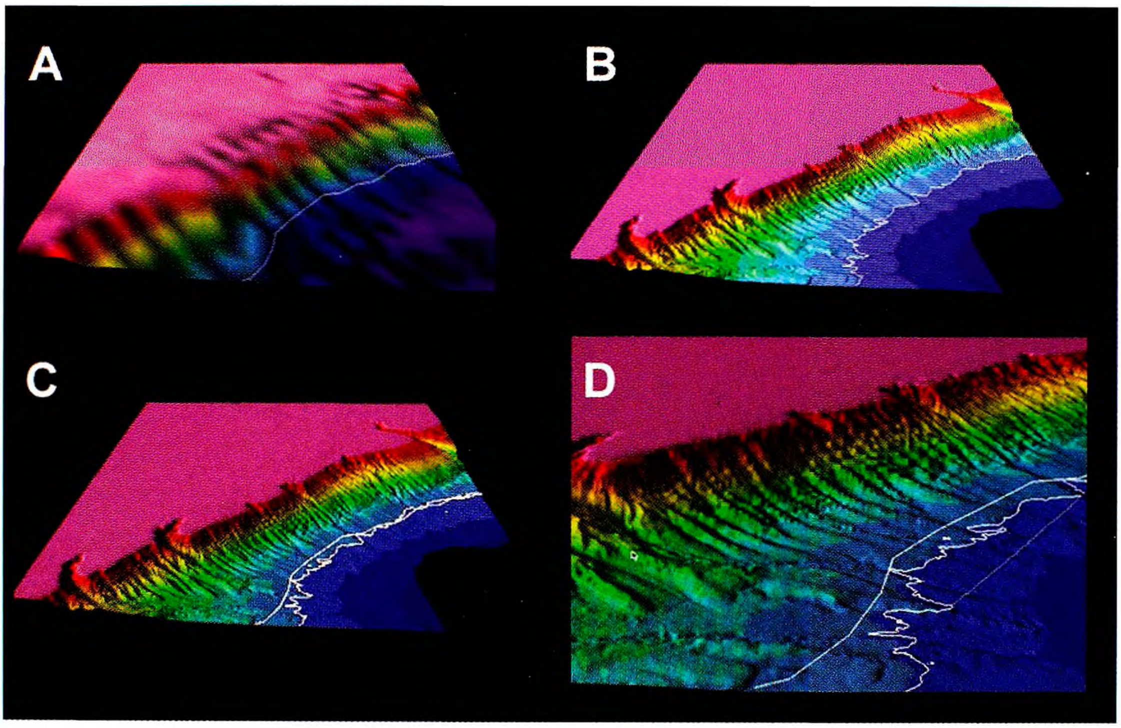


Figure 9: An example of how full-coverage multibeam data can result in a significant extension of a claim beyond the claim that could have been made based on single beam sonar data.

A: A 200 km long by 160 km wide section of the continental margin off New Jersey as depicted from data contained in the ETOPO-5 bathymetric compilation from NGDC (based on single beam soundings). The white line represents the 2,500 m isobath derived from these data.

B: The same piece of seafloor as depicted with multibeam sonar data. The white line represents the 2,500 m isobath as derived from the multibeam data.

C: The contour derived from ETOPO-5 and the contour derived from the multibeam bathymetry superimposed. Note the much greater detail of the 2,500 m contour derived from the multibeam data. Using this detail and the flexibility provided in constructing limit lines provided by UNCLOS Article 76 seaward-facing promontories can be selectively chosen to extend the claim.

D: An example of the ability to extend a claim by selectively choosing bathymetric profile points. In this small example (just a 200 km section of the margin), the claim is extended by 600 km² dense bathymetry is recommended to define the FOS, seismic data will be necessary to define the thickness of the sediment column. To address the density of available seismic data we performed a GIS analysis on the database by applying 15 nautial mile buffer zones around seismic tracklines to identify data gaps larger than 30 nautical miles (Figure 8). Nyquist criterion calls for sampling at twice the required spatial frequency, which is 30 nautical miles and, thus, we assumed that information from a seismic profile is needed every 30 nautical miles. Our analysis shows that, with the exception of the Arctic, existing seismic data, assuming that its quality is good, is of sufficient density to be acceptable for a claim under Article 76. However, we recognise that a further thorough study is necessary to determine whether or not the existing seismic data is adequate for determining the thickness of the sediment column, a necessity for establishing the Gardner line. We would also note that analysis of the bathymetry and seismic data may suggest that a more advantageous location of the FOS might be possible using 'evidence to the contrary'. In this case, the analysis (and possible acquisition) of other types of geophysical data may be useful and beneficial.

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Biographies

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