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AN IMPROVED PORTRAYAL OF THE FLOOR OF THE ARCTIC OCEAN, BASED ON A GRID DERIVED FROM GEBCO BATHYMETRIC CONTOURS

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Abstract

Digital descriptions of sea floor relief and land topography in the Arctic are useful for scientific and illustrative purposes, however existing public-domain data sets, such as the ETOPO5 grid and extracts from the GEBCO Digital Atlas, don't lend themselves particularly well to visualization and other processes that work best with uniformly-spaced data. A technique has been developed for converting isobaths from the GEBCO Digital Atlas into a uniform 5 km X 5 km grid of depth values. At the same time, the land component of ETOPO5 has been re-sampled at a similar grid spacing. When combined, these two grid sets yield convincing shaded relief portrayals of the Arctic region. The methodologies described here are not restricted to the Arctic, but may be applied with minor modification to other regions as well.

INTRODUCTION

The portrayal of shaded relief is a useful technique for visualizing and interpreting bathymetry, topography, and other continuous surfaces (such as gravity and magnetic fields) that are most often defined as Z values at the X and Y mesh points of regular grids. In general, a shaded relief image offers a better representation of surface shape and texture than does a standard contour map, because of its ability to portray information in the intervals between isolines. This has obvious benefits not only when analyzing and correlating the surface characteristics of one or more

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parameters, but also when searching for errors or flaws in the data base which manifest themselves as breaks or discontinuities in the surface.

For cartographers and geoscientists alike, the availability of public domain data sets in computer readable form has led to substantial progress in the visualization and analysis of surface relief in both continental and oceanic areas. In particular, two data sets hold significant potential for portraying such information in regional settings: the ETOPO5 description of global land and seafloor relief in grid form (National Oceanographic and Atmospheric Administration, 1988), and a set of contour lines for the world ocean, digitized from the General Bathymetric Chart of the Oceans (GEBCO; JONES *et al*, 1994).

For certain applications, e.g. the regional portrayal of shaded relief in the Arctic, the usefulness of either of these two data sets is limited by one or more shortcomings: the construction of the ETOPO5 grid gives rise to unrealistic and unattractive portrayals of the floor of the Arctic Ocean, whereas the GEBCO contours come in a form that is not directly amenable to the production of shaded relief plots, nor do they contain relief information on land. However if the ETOPO5 and GEBCO data sets are combined with due regard for their inherent limitations, their best features can be retained to produce an acceptable description of the land and sea area in the Arctic.

THE ETOPO5 GRID OF GLOBAL SURFACE RELIEF

ETOPO5 defines elevations and depths at 5-minute intervals of latitude and longitude. Details of its construction and of its constituent data sets have not been publicly documented, however due to its ready availability, this data set has found widespread favour with investigators and mapmakers who need to express, to model, or to visualize generalized relief at global or regional scales.

In its regularly distributed form, ETOPO5 is afflicted with several spatial inhomogeneities in the polar regions; the north-south intervals between grid points remain constant, but the east-west intervals diminish ultimately to zero on account of meridional convergence towards the North and South Poles (Fig. 1). These inhomogeneities can lead to noticeable artifacts in the visualization of ETOPO5, particularly in shaded relief representations; this is well demonstrated by the radial striations emanating from the Pole in Figure 2, which portrays ETOPO5 in the Arctic Ocean with simulated illumination from the upper lefthand corner of the illustration.

A NEW GRID CONFIGURATION

To circumvent the visualization problem described above, we decided to seek a grid configuration that was more amenable to the presentation and processing of bathymetry in the Arctic Ocean. After some investigation, we devised a master configuration that consisted of a square-celled Cartesian grid constructed on a Polar Stereographic projection; the origin of the grid was situated at the North Pole, and its

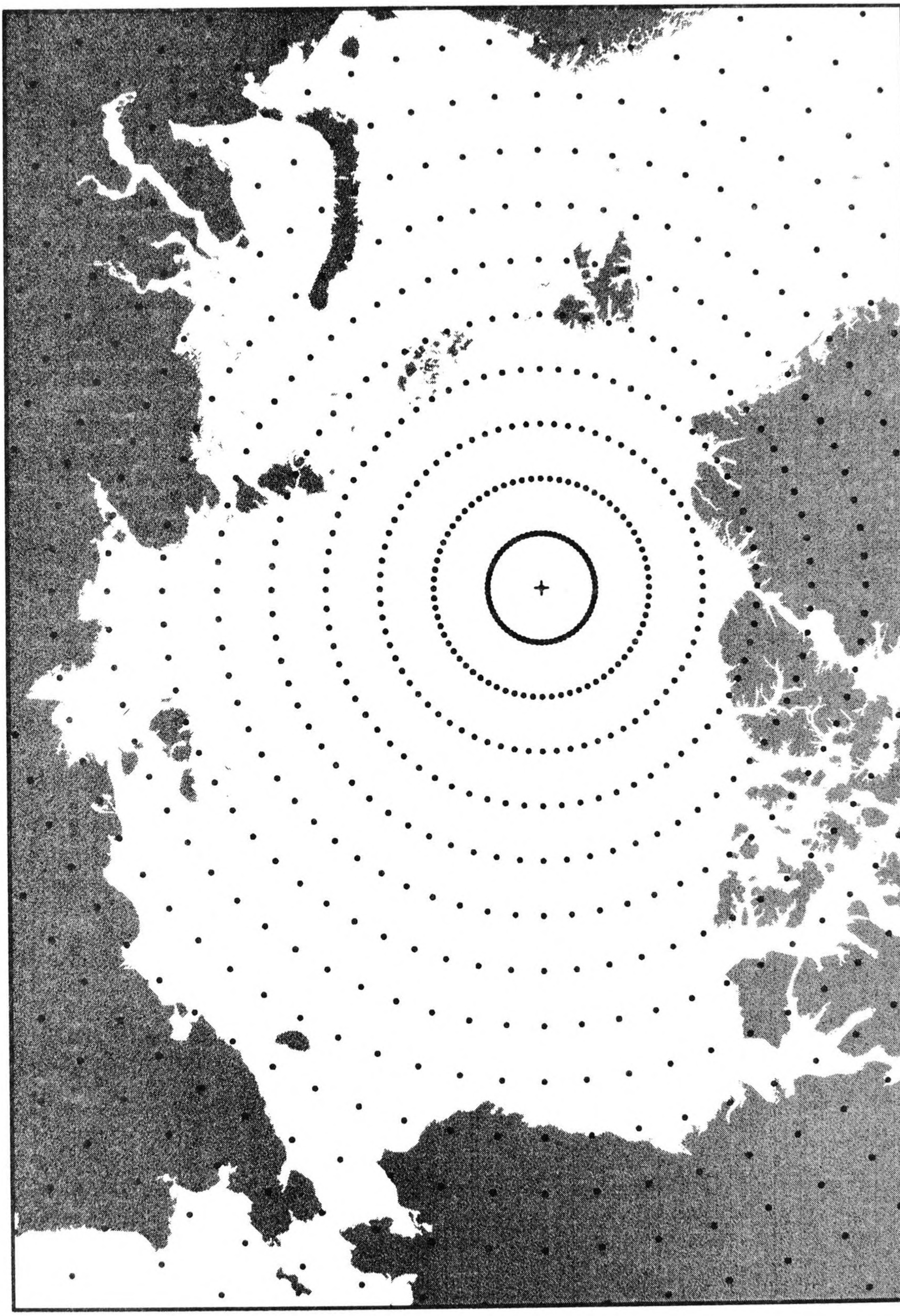

FIG. 1.- Generalized configuration of the ETOPO5 grid in the Arctic. The standard ETOPO5 grid defines topography and bathymetry at intervals of 12 points per degree of latitude and longitude. For clarity, this figure only illustrates every 24th point in the north-south direction, and every 60th point in the east-west direction. Inhomogeneities in the spacing of grid points are obvious throughout the map area, due to the pronounced east-west convergence of grid points with decreasing distance to the North Pole.

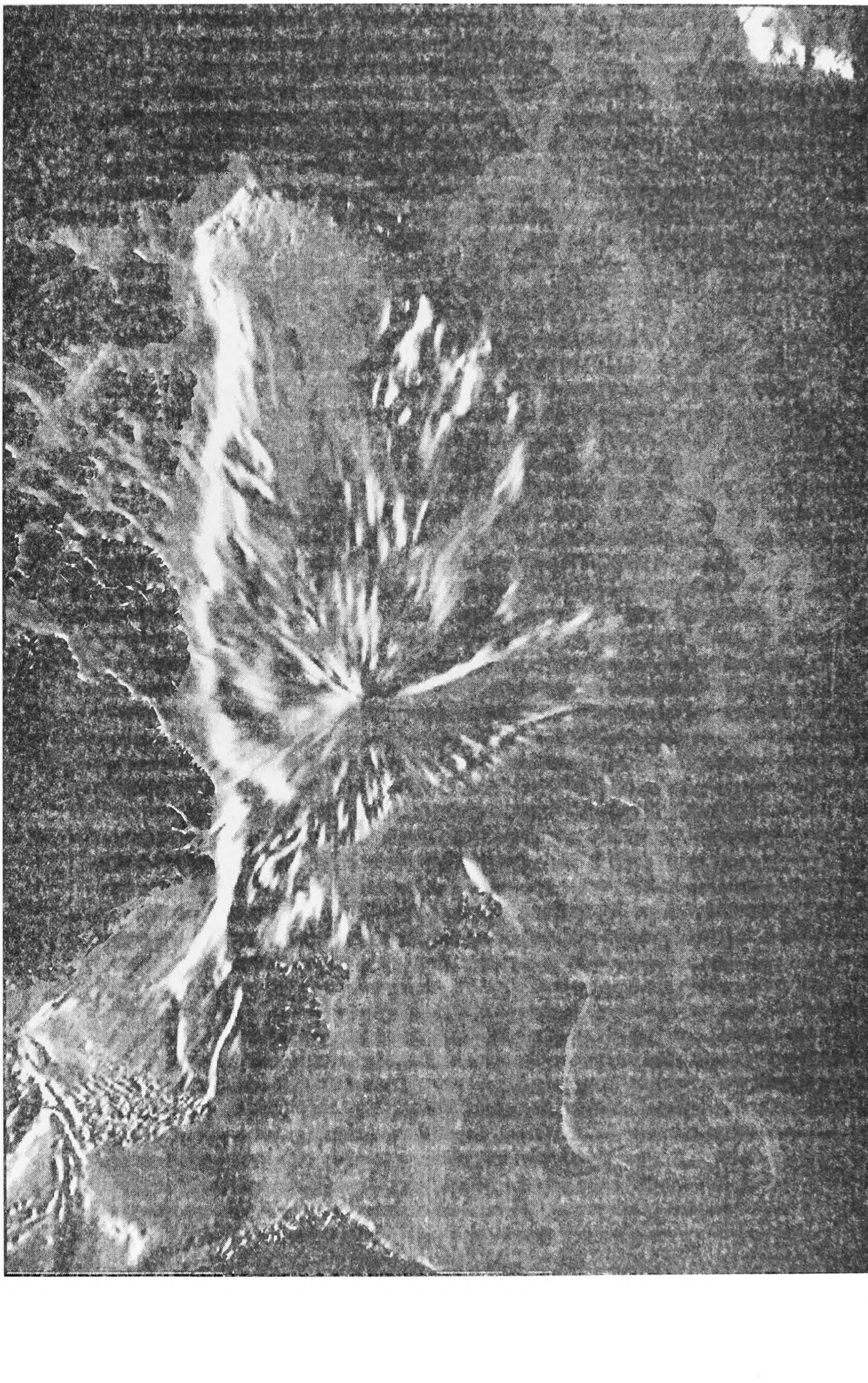

FIG. 2.- Shaded relief portrayal of the floor of the Arctic Ocean created from the ETOPO5 global relief grid, which defines topography and bathymetry at intervals of 5 minutes of latitude by 5 minutes of longitude (Fig. 1 illustrates the layout of the grid configuration). Simulated illumination is from the upper lefthand corner of the image. Striations emanating radially from the North Pole are artifacts caused by the pronounced east-west convergence of data points in the vicinity of the Pole.

y-axis was oriented along the Greenwich Meridian (Fig. 3). Although the primary focus of the project was to develop a better representation of the bathymetry in the Arctic Ocean, for the sake of consistency with adjacent marine areas, we made the master grid large enough to extend south of 64°N.

Figure 4 portrays a generalized distribution of master grid points within the Arctic Ocean. A constant interval of 5 km in the X and Y directions was selected in order to achieve a grid of manageable proportions, but which retained a uniform resolving power over the map area that compared very favourably with that of the ETOPO5 grid.

THE GEBCO MAP SERIES

In the Fifth and current Edition, the General Bathymetric Chart of the Oceans (GEBCO International Hydrographic Organization, 1997) consists of 18 separate map sheets. Maps for the Arctic and Antarctic regions are constructed on a Polar Stereographic projection at a scale of 1:6 million; the remaining 16 maps are constructed on a Mercator projection at a scale of 1:10 million. For depths that exceed 100 m, contours are portrayed at intervals of 100 m or multiples thereof. On any given map sheet, the magnitude of these intervals is selected on an area-by-area basis to suit local densities of sounding observations or the slope of the sea floor.

We chose to base the contents of the new Arctic bathymetric grid on the information shown in GEBCO Sheet 5.17 (Canadian Hydrographic Service, 1979) which portrays depths north of 64°N. We picked Sheet 5.17 because:

(a) it is widely circulated and it is the closest thing that exists to a standard chart of the region;

(b) the principles and techniques of its construction are well documented (IHO/IOC/CHS, 1984); and

(c) sounding control is illustrated by means of overprinted ship's tracks that indicate the locations of bathymetric profiles that were used to develop the contour lines.

GRIDDING THE GEBCO CONTOURS

On the original GEBCO maps, depth contours were drawn manually, however, they have since been converted to digital form for distribution in the GEBCO Digital Atlas (GDA; Jones *et al.*, 1994). In the GDA, contour line segments are defined and stored as variable-length strings of points whose locations are defined by geographic (latitude and longitude) coordinates; each line segment is headed by a record that defines among other things the depth of that particular string, as well as the number of points in the string. The spacing between points varies.

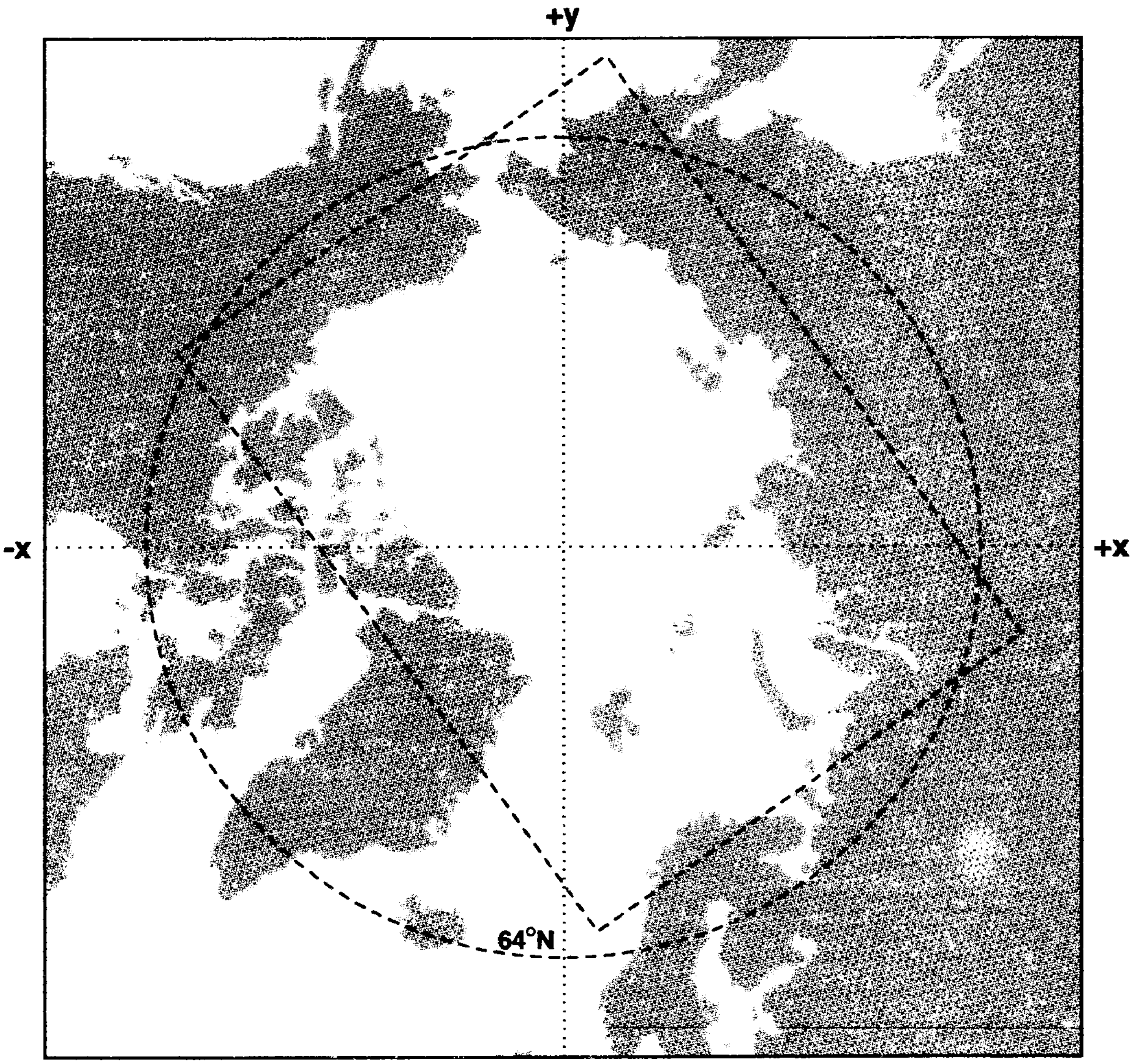

FIG. 3.- The square perimeter outlines the area covered by a master grid configuration that was designed specifically for polar data sets. Grid points are spaced regularly at intervals of 5 km by 5 km on a polar stereographic projection. The origin of the master grid is situated at the North Pole, and its y-axis coincides with the Greenwich Meridian. The oblique rectangle in the middle of the image outlines the area portrayed in Figures 1, 2, 4, 5 and 7.

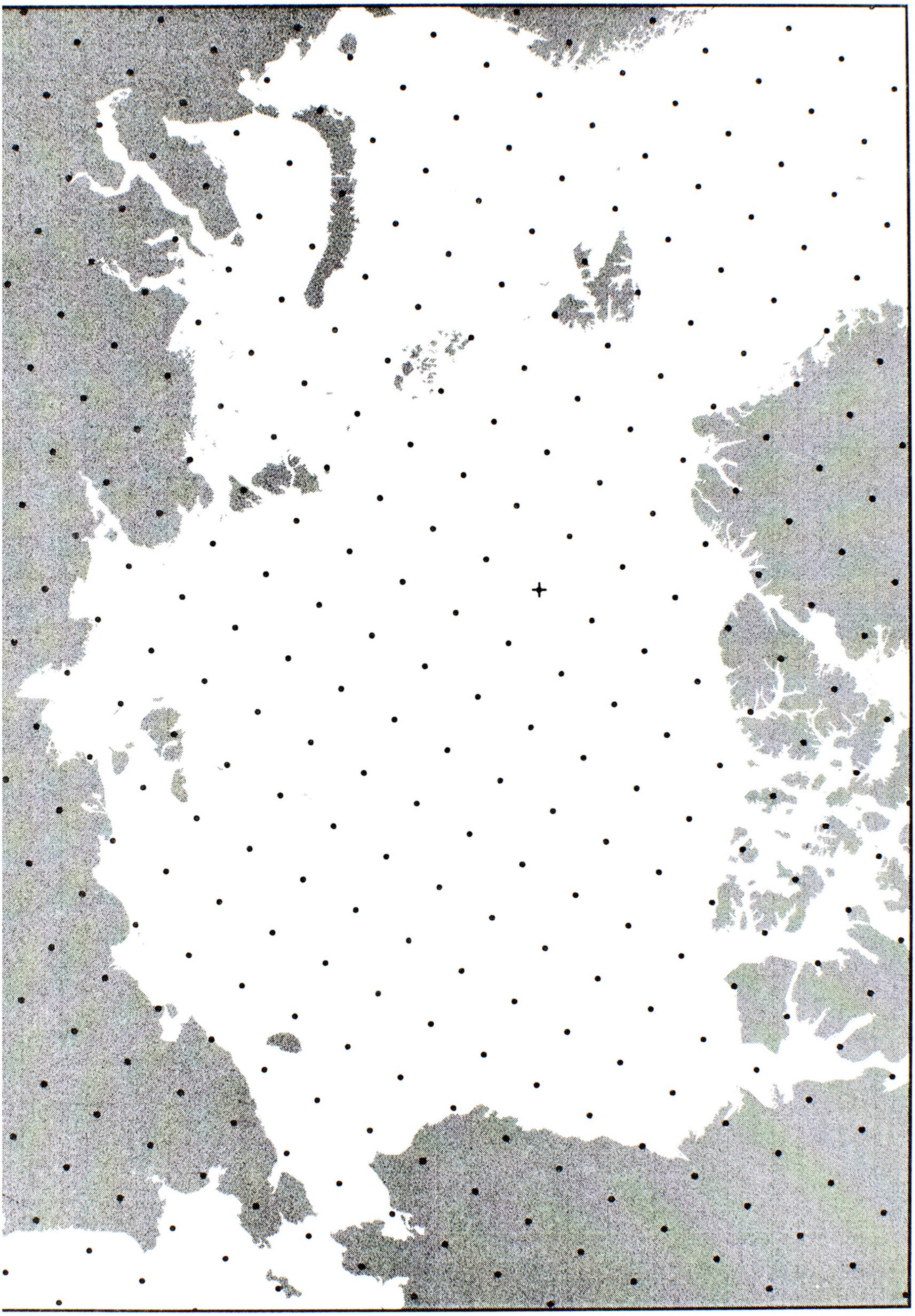

FIG. 4.- Generalized configuration of a rectangular grid which was designed expressly to facilitate the visualization and processing of Arctic bathymetric data. The origin of the grid is at the North Pole (location indicated with a cross), and its major axis coincides with the Greenwich Meridian (see also Fig. 3). Grid points are uniformly spaced at intervals of 5 km in the X and Y directions throughout the map area. For clarity, this figure only illustrates every 50th point in either direction.

Contours lines inside the master grid area were extracted from the GDA; those for the Arctic Ocean proper are shown in Figure 5. After extraction from the GDA, the contour lines were first converted into strings of discrete points that described ocean depths at positions defined by latitude and longitude coordinates. Prior to gridding, these string segments were subjected to three preparatory procedures illustrated in Figure 6:

(1) geographic coordinates were converted to their X and Y equivalents (in km) within the master grid;

(2) linear interpolation was used to calculate and insert regularly-spaced intermediate points along the contour lines, in order to populate every cell that was crossed by a contour line; and

(3) depth values corresponding to the contour points were binned in 5-km square cells over the entire grid area. Binning consisted of averaging the X, Y and Z coordinates of all points in each bin, and of assigning the averaged Z value to the position defined by the averaged X and Y values.

Gridding was performed with program *surface*, which is distributed as part of the public domain GMT data visualization package (WESSEL and SMITH, 1991). *Surface* approximates the shape of a thin elastic membrane which is under tension and which is constrained to pass through all data point (SMITH and WESSEL, 1990). The operator designates the tension of the membrane by entering a number ranging from 0.0 (no tension) to 1.0 (high tension); for this application, a factor of .99 was specified to apply a high tension to the membrane, thereby minimizing the curvature of its surface between the contour lines.

To check how well the outcome of the gridding procedure reproduced the original input data, synthetic contours were extracted from the new grid, plotted, and then overlaid directly onto GEBCO Sheet 5.17 for a visual comparison. In all instances, the synthetic contours matched the published contours exactly, confirming that the new grid was an accurate replication of the bathymetric information portrayed on the original map.

Figure 7 was prepared with the new grid to illustrate the floor of the Arctic Ocean in shaded relief. A comparison with Figure 2, which was prepared with the standard ETOPO5 grid, indicates a substantial improvement in the quality of visualization; featuring a higher level of detail in the deep ocean basin, this image is also completely free of the radial striations that were produced by meridional convergence in the vicinity of the North Pole.

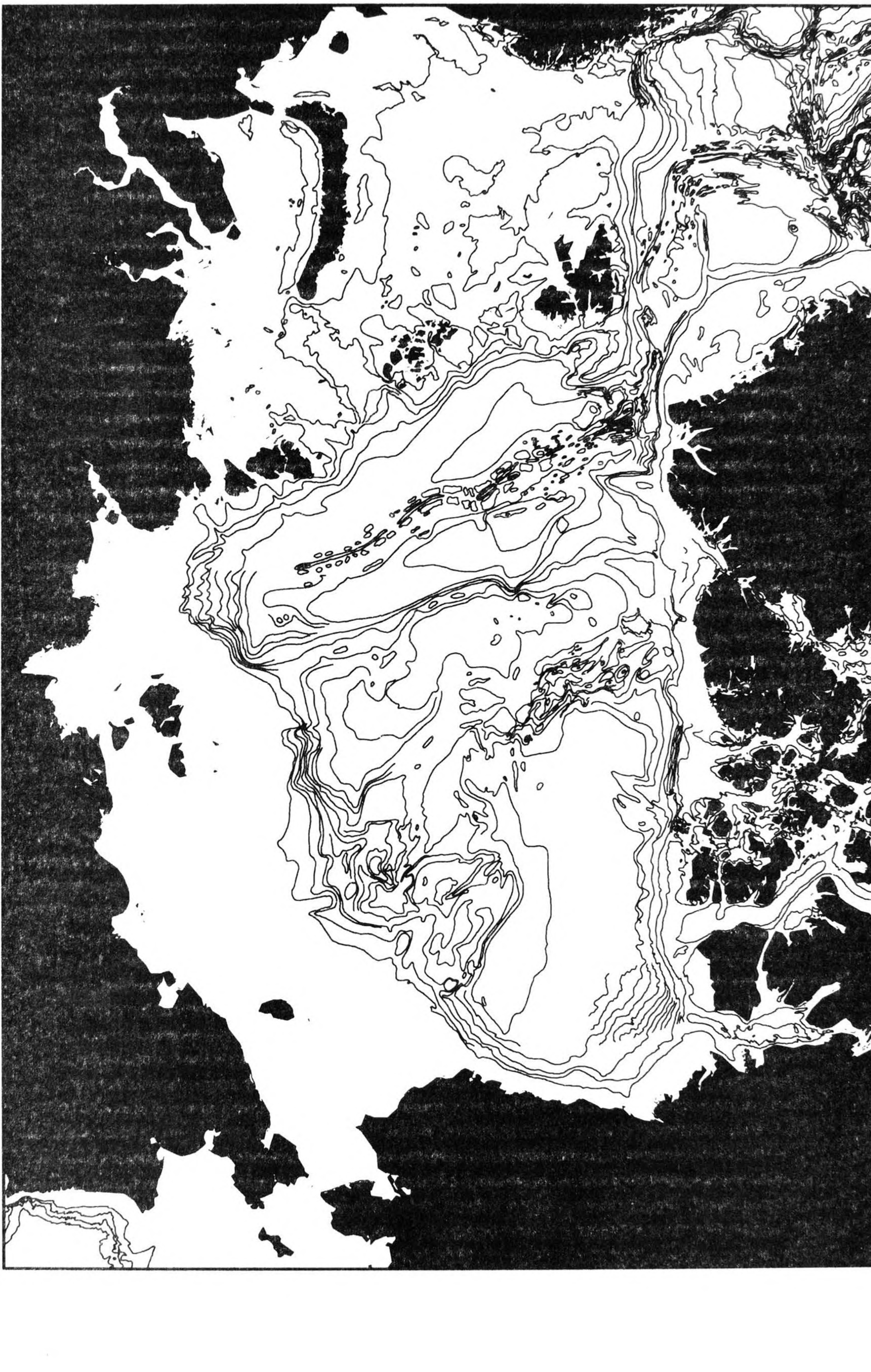

FIG. 5.- Arctic bathymetric contours extracted from the GEBCO Digital Atlas (GDA). Drawn originally by hand for the Fifth Edition of the General Bathymetric Chart of the Oceans, these contours were digitized recently and placed into public circulation in a computer-readable form. For clarity, this figure does not illustrate all the information north of 64°N that was extracted from the GDA for the purposes of this study; contours are shown at 200-metre intervals only, while areas such as Baffin Bay, the Canadian Arctic Archipelago, and the Norwegian-Greenland Sea, are only partially or not shown.

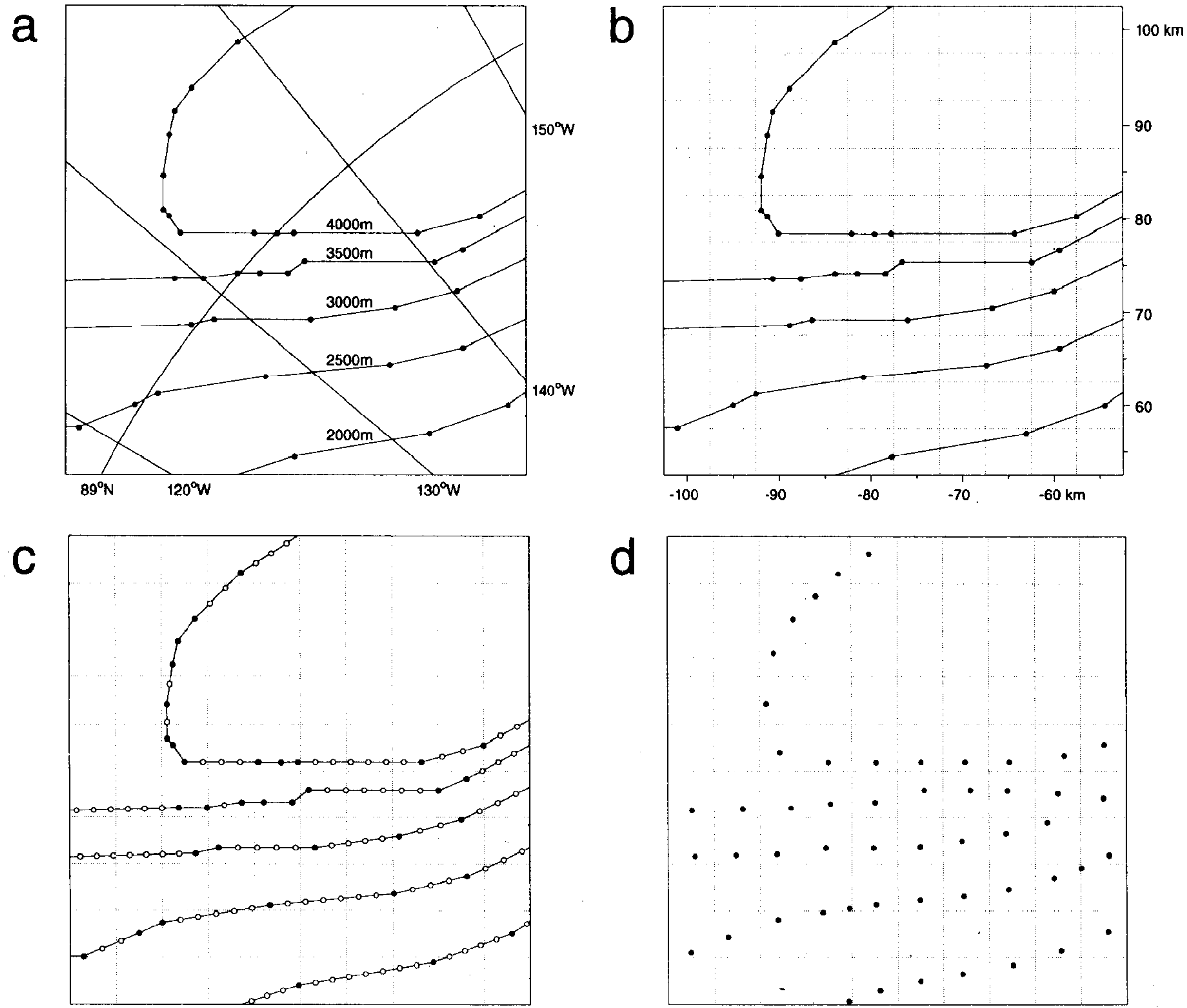

FIG. 6.- Showing how contour information extracted from the GEBCO Digital Atlas (GDA) is processed prior to gridding. (a) Sample of GDA data near the North Pole, plotted on a Polar Stereographic projection; the black dots are points that define the shape of the depth contours between 2000 and 4000 m. (b) Same data with geographic coordinates converted to km and plotted on a Cartesian coordinate system with origin at the North Pole. The dotted lines represent the boundaries of the 5 km grid cells. (c) By a process of linear interpolation, intermediate points have been inserted along the contour segments in order to populate every cell that is crossed by a contour line. (d) Original and interpolated points have been binned by averaging the X, Y and depth values of all points within each cell.

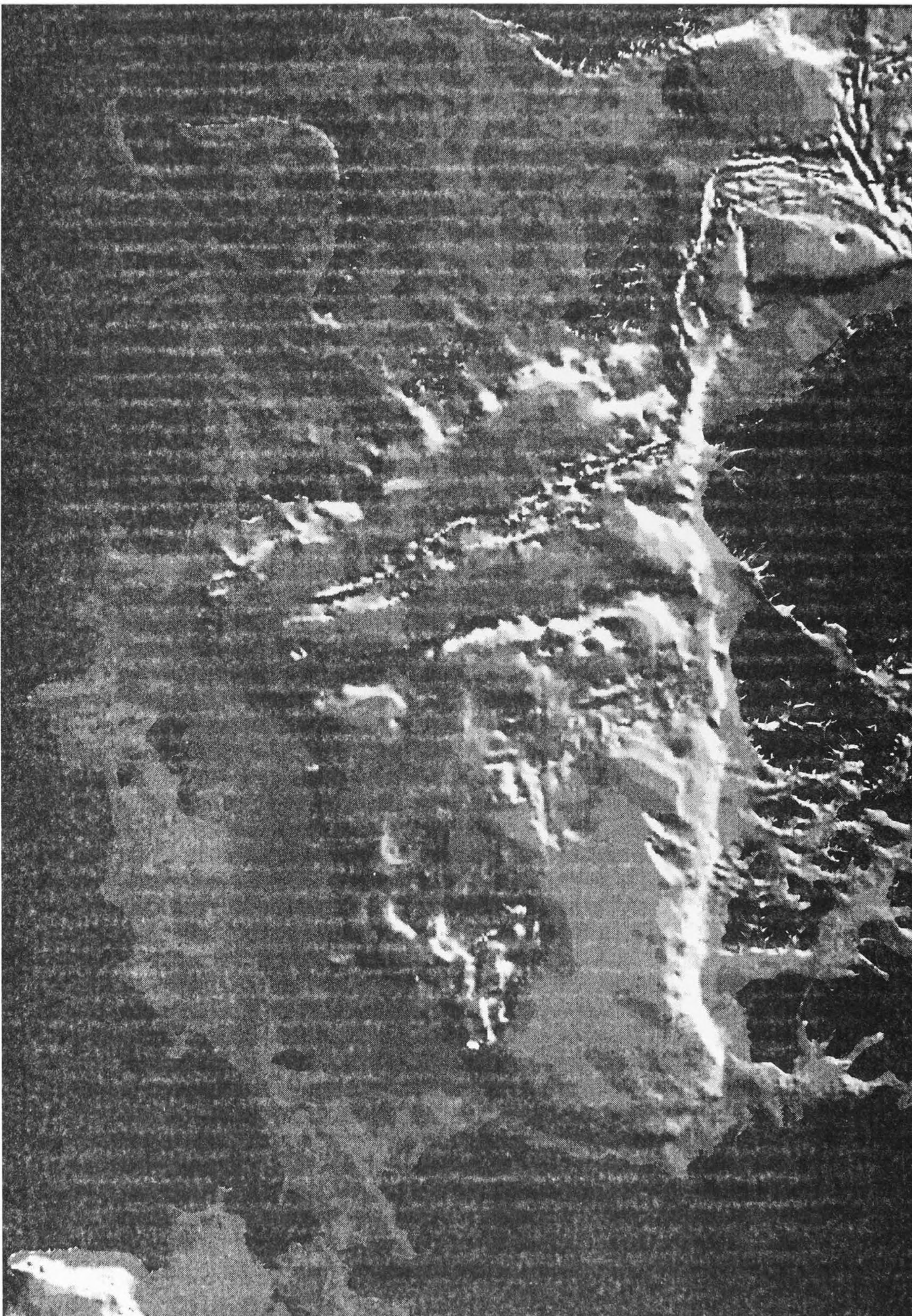

FIG. 7.- Shaded relief portrayal of the floor of the Arctic Ocean created from a Cartesian grid of depth values derived at 5 km intervals from bathymetric contours that have been extracted from the GEBCO Digital Atlas. Simulated illumination is from the upper lefthand corner of the image. The grid was created by means of a minimum curvature technique with variable tension; it contains more detail than a comparable plot of ETOPO5 information, and is free of the radial artifacts that are caused by meridional convergence (see Fig. 2).

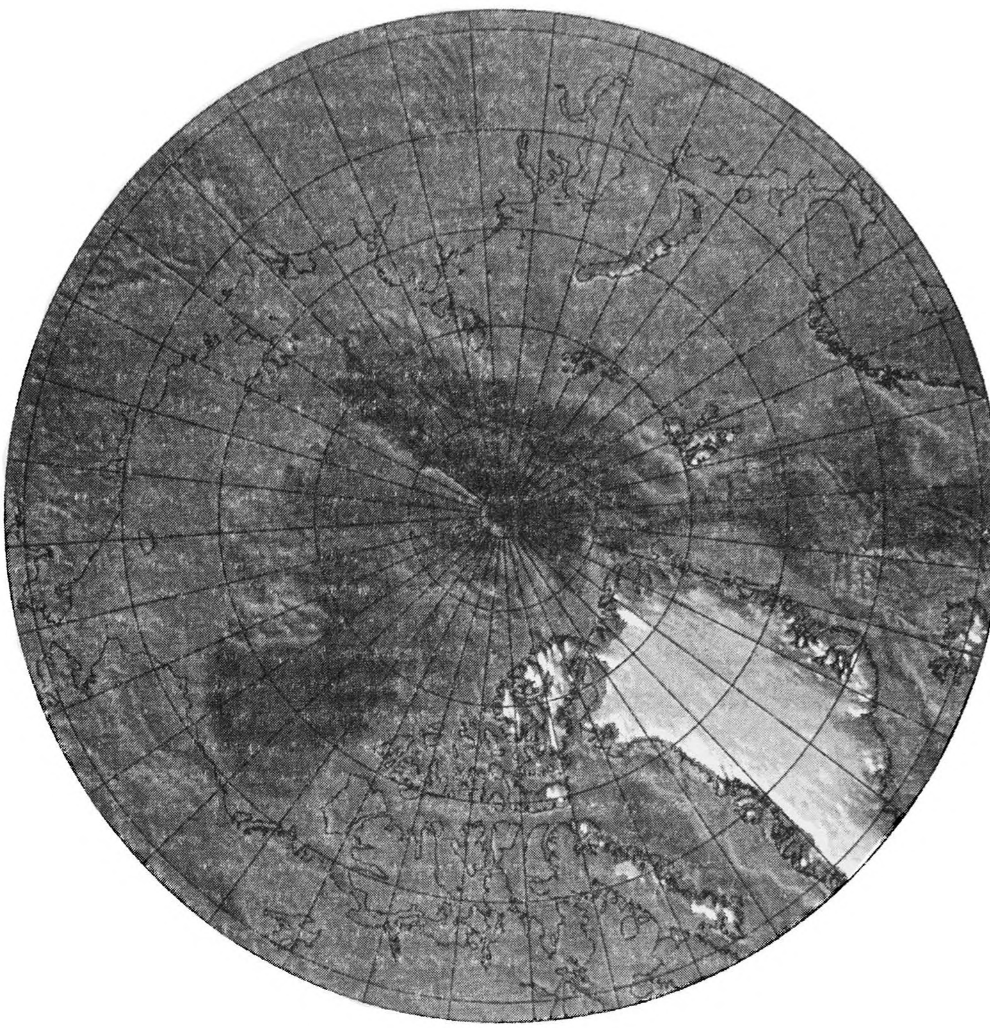

FIG. 8.- Black and white rendition of the new Arctic map, portraying the contents of a composite 5-km grid which combines bathymetric information from the GEBCO Digital Atlas and topographic information from the ETOPO5 global relief data set. The original map shows ocean depths in shades of blue, and land elevations in shades of buff.

AN APPLICATION OF THE NEW BATHYMETRIC GRID

One of the first applications of the new grid was to produce a digital replica of GEBCO Sheet 5.17 that portrayed not only the depth and shaded relief of the sea floor, but also the elevation and shaded relief of all adjacent landmasses north of 64°N. This was achieved by constructing a composite grid that merged the new GEBCO oceanic grid with the land components of ETOPO5; prior to merging, the latter was re-sampled at regular 5 km intervals using the same grid configuration as for bathymetry. In principle, the zero contour level (ZCL) in ETOPO5 is a rendition of the shoreline; to retain this particular contour level in the composite grid, the two constituent grids were actually merged at the 50 m isobath, i.e. the ETOPO5 grid was used to define not only elevations on land, but also nearshore bathymetry to a depth of 50 m.

The resulting composite grid was processed with a suite of in-house display software to create a plot that portrayed depth and shaded relief. This plot was overlain with the World Vector Shoreline (WVS). Intuitively, the WVS should have been a reasonably close match to the ZCL in ETOPO5, however discrepancies of 25 km or more appeared in many locations; in our experience, this is not an unusual occurrence when these two data sets are combined in this fashion. In this instance, we resorted to manual editing of selected ETOPO5 components in order to eliminate some of the more glaring discrepancies between coastlines, but made no further effort to improve the match. This apparent lack of agreement between two important public-domain data sets clearly needs to be addressed in a more rigourous fashion.

The new map was produced in a two-tone colour scheme that replicated the standard GEBCO colour scheme (blue and buff below and above sea level, respectively). Contour lines were not overprinted, however the intervals between colour gradations closely match the contour intervals of Sheet 5.17. Hence depth and elevation ranges are easily read directly from the map, while variable shading conveys a realistic representation of the slope and roughness of the sea bed and the surrounding landmass. A black and white version of the map is shown in Figure 8.

In colour hardcopy form, this map is distributed in two scale: 1 to 6 Million, which is the scale of GEBCO Sheet 5.17, and approximately 1 to 23 Million (Geological Survey of Canada, 1994). In computer-readable form, the map is available as a PostScript plot file for direct output to a colour plotter at any user-defined scale.

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We acknowledge the communal perspective of Walter SMITH and Paul WESSEL, developers of the public-domain GMT software package, particularly the *surface* program that was applied to such good effect in this study. Karl USOW under the direction of Jacob VERHOEF developed other routines that were used at various stages to manipulate and display the data sets described in this report. Walter ROEST and David MONAHAN offered helpful comments and reviewed an early draft of this report.

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