GOMaP (Global Ocean Mapping Program): *A Proposed International Long-Term Project to Systematically Map the World's Ocean Floors From Beach to Trench.*

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Abstract

At the 1999 Spring American Geophysical Union meeting, the concept of a long-term (20-30 year) international, systematic effort to map the entire world seafloor from beach to trench (GOMaP = Global Ocean Mapping Program) was first presented to the earth science community. A Forum article followed in Eos (P. Vogt, W-Y. Jung, and D. Nagel, Eos, AGU, v. 81, p.254, 258) in June 2000. About 40 experts and stakeholders, representing mostly US government, academia and industry, assembled in Bay St. Louis, MS 12-14 June 2000, endorsing GOMaP as important and technically feasible with current technology and existing vessels (Meetings Report, Eos, v. 81, p.498, 2000; NRL Tech Memo, in preparation).

The goal of GOMaP would be to map the ocean floors with at least 100 percent coverage sidescan and swath bathymetry and perform whatever other data collection could be carried out simultaneously (e.g., subbottom profiling, magnetics, gravity, physical oceanography and meteorology). Minimum standards for data accuracy, pixel navigation, and resolution would need to be established before GOMaP is launched.

Spatial resolutions for GOMaP sidescan sonar imagery should be 200 m or better in the deep sea. This is comparable to what has been achieved by the Shuttle Imaging Radar over the terrestrial earth, the MAGELLAN radar mapping of Venus, the MARS GLOBAL SURVEYOR and other probes on Mars, and the GALILEO mission to the moons of Jupiter. The spatial resolution for swath bathymetry is slightly less than for sidescan. Both bathymetry and sidescan resolutions improve sharply with decreasing water depths, particularly for the 10 percent of the world ocean less than 500 m deep. The decrease of swath width with water depth implies that over 600 ship years are required to map waters 25-500 m deep, compared to just approximately 200 ship years for the deep ocean (500 m and greater). Better pixel navigation accuracy suggests hull-mounted systems (9-16 kHz for deep water, and 30 kHz or higher for shelf waters) may be superior to towed systems, although improvements in towed system navigation instrumentation may mitigate this difference in the future. Seafloor mapping with air-deployed hyperspectral and laser bathymetric scanning may be required to replace or supplement shipborne mapping in clear waters less than 50 m deep.

At the GOMaP workshop, the following areas were proposed as candidate "pilot" GOMaP areas: 1) The Gulf of Mexico [Good opportunities to utilize US Gulf Coast assets and to demonstrate international cooperation]; 2) The Juan de Fuca plate [A nearly complete "ocean floor in miniature," a chance for US-Canadian cooperation and to support the NEPTUNE project]; 3) an area in the Southern Ocean with exceptional scientific interest but with very sparse data coverage; 4) the EEZ of a willing, small coastal state, as a demonstration; and 5) the Black Sea [A great opportunity for international cooperation and geological and archeological significance].

Introduction

The end of the 20th century was a period of exciting mapping projects in our solar system. Unfortunately, the century closed with Earth being one of the most poorly mapped objects in the solar system. As demonstrated by Figure 1, much of the world's ocean bottoms have not been surveyed.

At the 1999 Spring American Geophysical Union meeting, the concept of a long-term (20-30 year) international, systematic effort to map the entire world seafloor from beach to trench (GOMaP = Global Ocean Mapping Program) was first proposed to the Earth science community. A Forum article followed in Eos (P. Vogt, W-Y. Jung, and D. Nagel, Eos, AGU, v. 81, p.254, 258) in June 2000. About 40 experts and stakeholders, representing mostly US government, academia and industry, as well as representatives from Canada and the United Kingdom, assembled in Bay St. Louis, MS 12-14 June 2000. This group endorsed GOMaP as important and technically feasible with current technology and existing vessels (Meetings Report, Eos, v. 81, p.498, 2000).

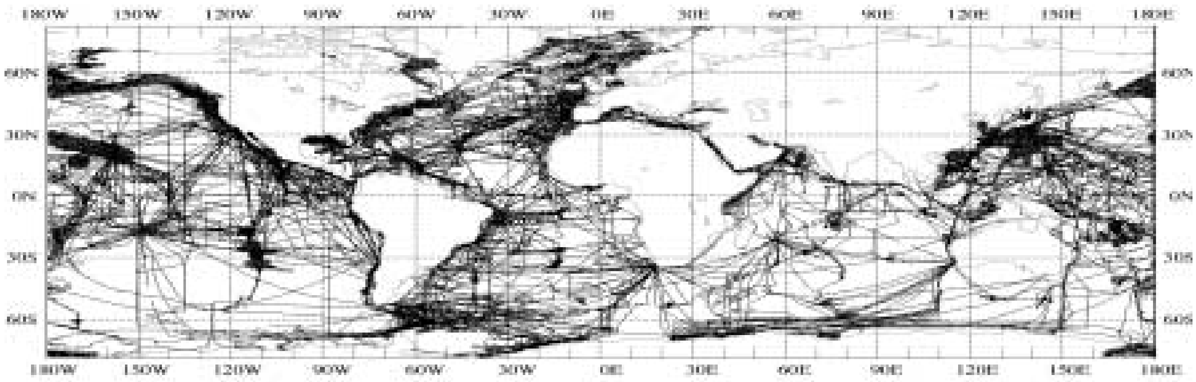

Figure 1. Inhomogeneous world seafloor database: Ship tracks for 1980-1999 period, courtesy of the National Geophysical Data Center. Tracks for surveys using sidescan sonar and/or swath bathymetry are a small subset of tracks shown here. Note: Actual width of tracks is much smaller than shown in this figure.

This presentation will summarize the efforts to define the GOMaP, set standards, establish a loose organizational structure for information and data sharing, and discuss the issues involved in estimating the effort required to undertake and accomplish such a large task.

The strategic goal of GOMaP is to systematically map the world ocean floor with at least 100 percent coverage of sidescan imagery and swath bathymetry and to perform whatever other data collection that can be carried out simultaneously. Minimum standards for data accuracy, pixel navigation, and resolution will need to be established before GOMaP is launched.

Why a GOMaP?

It should be easy to argue that detailed maps of the Earth's topography are at least, in the short term, as important to those who inhabit the Earth as maps of extraterrestrial bodies. Can any direct benefit, other than an intellectual exercise, be gained by doing so? We believe so. For example, precise knowledge of the seafloor topography would have direct benefits for improved assessments of geologic resources, finfish and shellfish habitat mapping, geologic risk assessments (for example, submarine landslides, earthquake fault activity, tsunamis, and submarine volcanism), navigation hazards, and bottom boundary conditions for dynamic oceanographic and meteorological models that are used in the prediction of long-term global change.

What are the technical issues?

Just what does it mean to completely map the world's ocean floor? A good example of 100 percent swath coverage can be shown by the data collected during a Naval Research Laboratory survey in part of the extinct Aegir Ridge rift valley and its adjacent rift mountain summits (Figure 2A). These data, resolving features with wavelengths of approximately 200 m, and the corresponding side-scan sonar image (Figure 2B), resolving wavelengths on the order of 10-20 m, capture the topography and sediment characteristics of the debris flows and turbidites that have spilled onto the rift valley. The Navy GEOSAT and ERS-1 microwave altimetric mapping programs allowed us to estimate the bathymetry from the gravity field (Figure 2C) on a global scale at full wavelengths of 20,000-30,000 m (Sandwell and Smith, 1997). To illustrate the magnitude of the proposed effort, the region illustrated in Figure 2A-C is less than 1/3000 percent of the total ocean floor. Figure 2D is the Clementine solar-illuminated image of part of the Schroedinger lunar crater, with an area of the same dimensions as in images A-C. The central swath (20-40 m pixel resolution) is comparable in resolution to a 12-kHz ocean-floor sidescan image at a 500-1000 m depth range, while outer areas of the image have spatial resolution comparable to that of 12-kHz sonar in the deep (~7 km) ocean.

The spatial resolution for swath bathymetry is slightly less than for sidescan. Bathymetry and sidescan resolutions improve sharply with decreasing water depths, particularly for the 10 percent of the world ocean less than 500 m deep. The decrease of swath width with water depth (Figure 3) leads one to

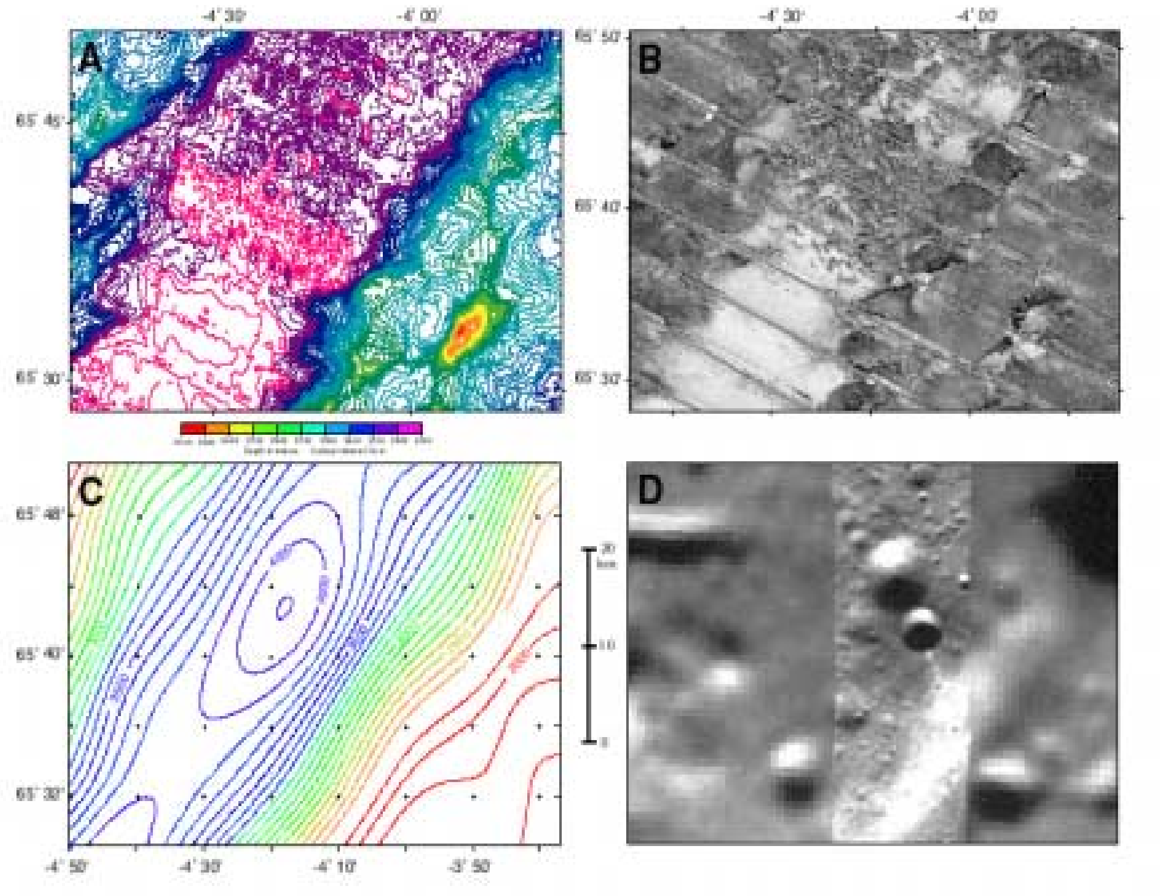

Figure 2. A) 16-KHz multibeam (HYDROSWEEP) bathymetry for part of the extinct Aegir Ridge rift valley, Norway Basin (NRL data). B)11-12 kHz SeaMARC II sidescan sonar image of same area. Darker shades indicate stronger returns (NRL data). C) ERS-1/GEOSAT-derived predicted bathymetry for same area (Sandwell and Smith, 1997). D) *Clementine* solar-illuminated image of part of Schroedinger lunar crater, with area of same dimensions as in images A-C. The central swath (20-40 m pixel resolution) is comparable in resolution to a 12-kHz ocean-floor sidescan image at 500-1000 m depth range, while outer areas of the image have spatial resolution comparable to that of 12-kHz sonar in the deep (~7 km) ocean. (P. Vogt, W-Y. Jung, and D. Nagel, Eos, AGU, v. 81, p. 258)

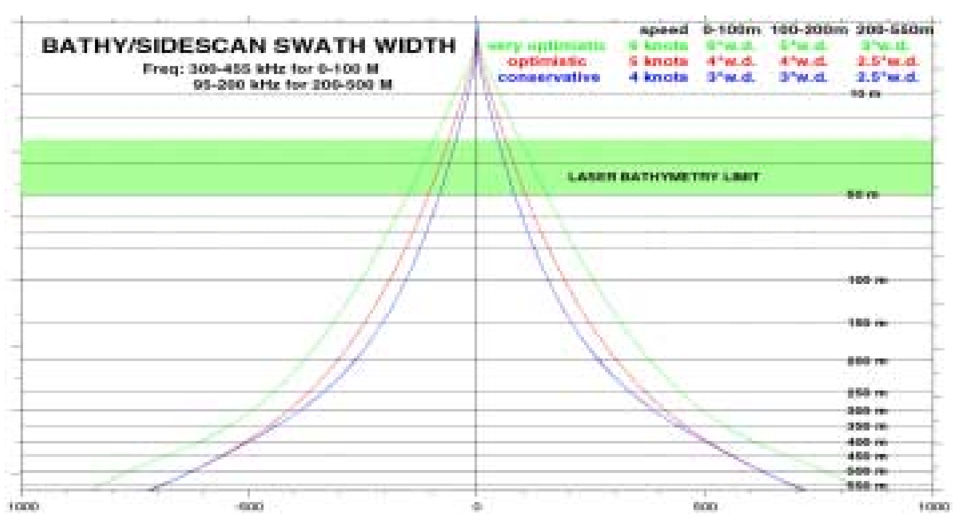

Figure 3. Bathymetric and sidescan swath widths as a function of water depth for typical survey systems, for the shallowest 10% of the world ocean. Vertical (isobath) scale is based on the hypsometry and is therefore non-linear.

estimate that over 600 ship years are required to map waters 25-500 m deep, compared to approximately 200-250 ship years for the deep ocean (500 m and greater). Figure 4 shows an estimate of survey kilometers for varying water depths needed for a global survey using a hull-mounted system and Figure 5 is for a typical towed system. Better pixel navigation accuracy suggests hull-mounted systems (9-16 kHz for deep water, and 30 kHz or higher for shelf waters) may be superior to towed systems but require dedicated ships, while towed systems may be operated from a variety of vessels. Seafloor mapping with air-deployed hyperspectral and laser bathymetric scanning may be required to replace or supplement shipborne and hydrographic survey launch mapping in clear waters less than 50 m deep.

Spatial resolutions for GOMaP multibeam sonar bathymetry and imagery would everywhere be 100 m or better in most locations except in the very deep sea, where it would approach 200 m. This is comparable to what has been achieved by the Shuttle Imaging Radar over the terrestrial earth, the MAGELLAN radar mapping of Venus, the MARS GLOBAL SURVEYOR and other probes on Mars, and the GALILEO mission to the moons of Jupiter. Presently co-registered multibeam (swath) bathymetric and sidescan data exist for only a relatively small portion of the ocean bottom (Figure 6).

Christian deMoustier of Scripps Institution of Oceanography (Personal Communication, 2000) proposed that bathymetry data and co-registered calibrated acoustic backscatter amplitude data should be collected at a horizontal spatial resolution sufficient to produce geographic grids with the following cell size vs. depth range:

	Grid Cell Size	
Depth Range	Bathymetry	Imagery
0-200 m	20 m	1 m
200-4000 m	100 m	2-5 m
4000-11,000 m	200 m	5-10 m

(Note: In most cases, 10-20 soundings per grid node will be needed to obtain reliable geostatistics during the bathymetry gridding process. Other data to be collected include those required for swath bathymetry (sound speed

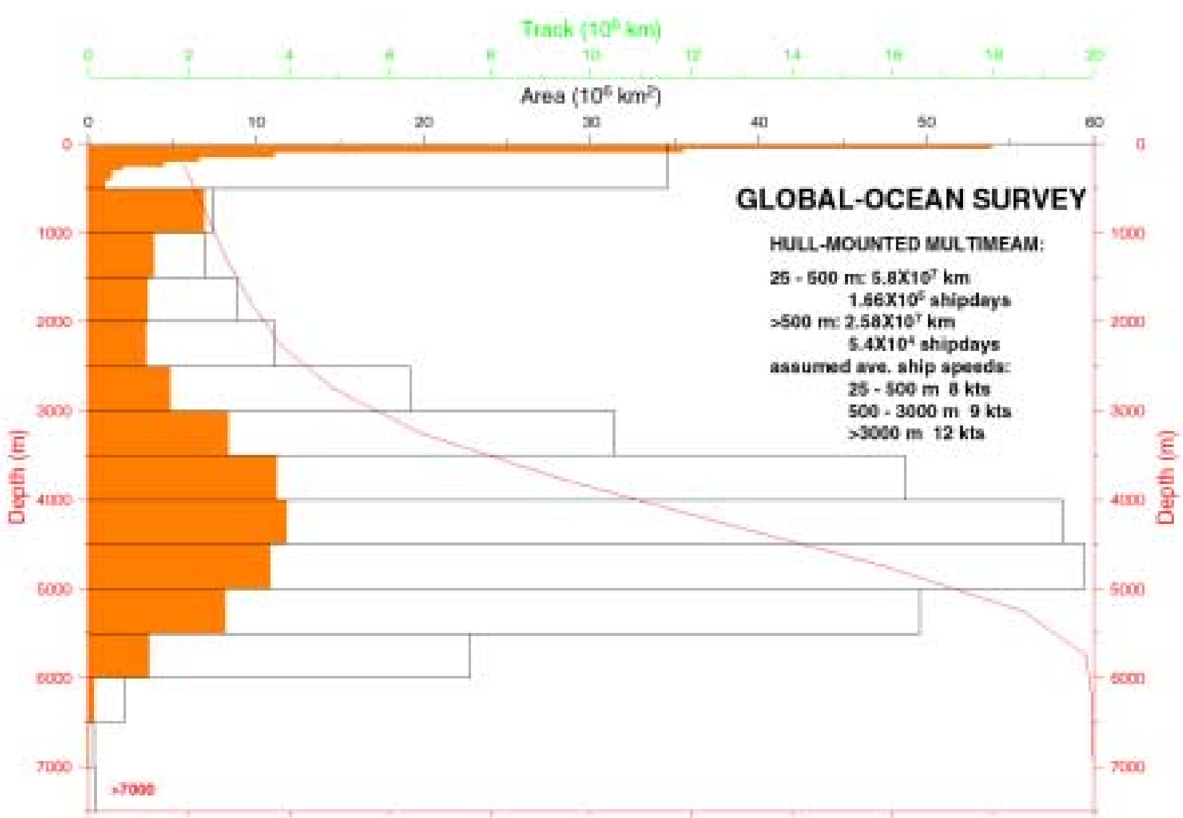

Figure 4. Histogram of track kilometers needed to produce a global ocean survey using typical hull-mounted multibeam survey systems and computations of ship days required for shallow (25-500 m) and deep (>500 m) surveys.

profile, sound speed at the acoustic arrays, attitude and navigation data) along with underway measurements of gravity, magnetics, acoustic subbottom profiling, sea surface temperature and salinity, and acoustic doppler current profiles. Occasionally, in very remote and uncharted areas, it may be desirable to stop the ship and take a sediment core or dredge the bottom for rocks. This would ensure that a few bottom samples are available in places that are unlikely to be revisited because of the logistics involved.)

Depth accuracy of individual soundings must be less than 0.2 percent of the sonar's altitude above the bottom. All depths must be reported as true depths (implies correction for tides, harmonic mean sound speed, and ship's dynamic draught or sonar dynamic depth).

In deep water, the 2D-RMS horizontal positioning accuracy must be at least 10 m. 3D measurements using GPS should have 1-m elevation accuracy. In

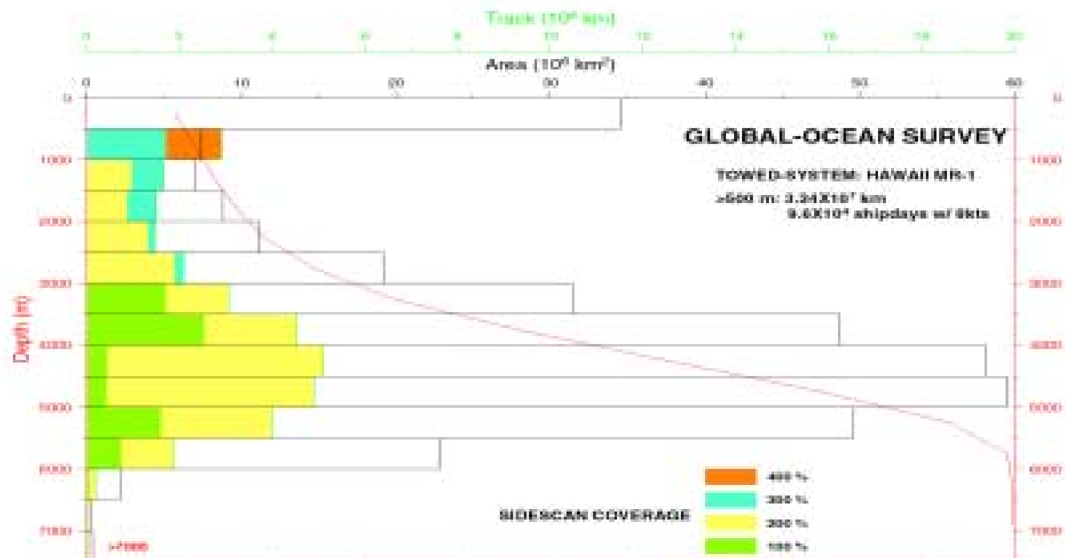

Figure 5. Histogram of track kilometers needed to produce a global ocean survey using typical towed multibeam or sidescan survey systems and computations of ship days required for shallow (25-500 m) and deep (>500 m) surveys.

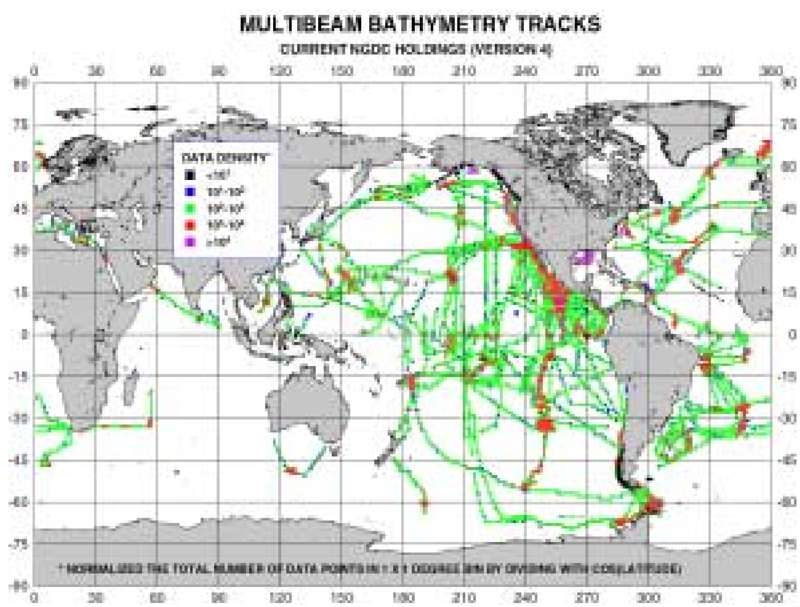

Figure 6. Current multibeam bathymetry tracks and data density from holdings at the National Geophysical Data Center. Data density is the number of soundings per 1 degree latitude x 1 degree longitude cell, corrected for the decrease of cell area with increasing latitude.

shallow water low-end Real Time Kinematic 3D position accuracy standards of 10 cm in x, y, and z should be met. (These would be similar to an International Hydrographic Organization Order 1 survey defined in IHO Special Publication 44.)

Data processing and cleaning standards have yet to be defined for the GOMaP, but ongoing discussions are being held. In particular, the minimum number of soundings per grid node and gridding techniques must be specified. All sonar systems must meet the accuracy standards described above and verify their compliance by running a patch test at the beginning and end of each survey.

The GOMaP "organization" should, working with appropriate international bodies (International Hydrographic Organization, for example), establish standard protocols for survey design in addition to specifications for instrument calibration, data processing, and quality control. For a typical (stylized) deep-ocean region (Figure 7) that spans the edge of the continental shelf, slope, rise, and ocean basin, one can imagine a schematic of existing seafloor mapping tracklines (Figure 8). One could opt to use a "Cartesian" survey pattern (Figure 9) or a hybrid "Cartesian/slope-parallel" pattern (Figure 10). The advantage of the pure Cartesian pattern is its ease in planning and execution. It's disadvantage is that it is not optimal in spatial coverage and requires constant sound velocity updates in the shallower areas. (Sound speed regime changes faster across shelf isobaths than along isobaths.) The hybrid survey pattern has the advantage in that it is easy to execute in deep-ocean areas, and executes optimally in shelf and shallow regions, and doesn't require sound velocity profile updates as often as cross-isobath surveys. Its disadvantage is that it is more difficult to execute while in the slope-parallel phase.

Is this worth doing if there is no light at the end of the tunnel?

GOMaP will take roughly 225 ship years to complete the portion of the world ocean deeper than 500 m (~90 percent) at a cost of between $8-16 billion, assuming US survey ship rates. There will be political hurdles concerning Economic Exclusion Zones and territorial seas (about one-third of the ocean area). Given the size of the seafloor mapping fleet and competing requirements for these resources, it may take between 20-30 years to just complete the deep- water portion, if fully funded. Mapping the shallowest 10 percent of the world ocean probably offers the greatest practical benefits to mankind, but presents special technical and political problems. We estimate that between 500-600 ship/survey launch years will be needed to complete this daunting task.

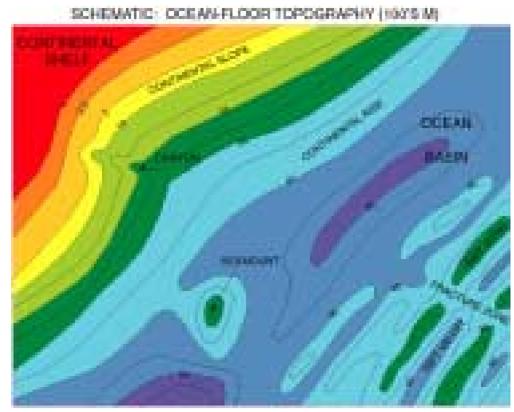

Figure 7. Schematic of typical ocean-floor topography (depths X 100 m)

Figure 8. Schematic of typical existing seafloor mapping track lines. (depths X 100 m)

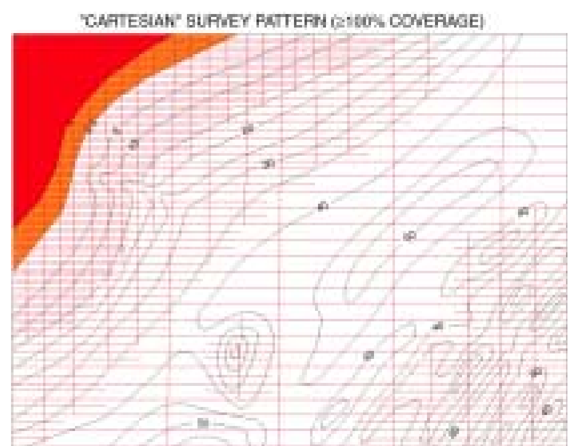

Figure 9. Schematic of typical "Cartesian" survey pattern with 100 percent or greater coverage. (depths X 100 m)

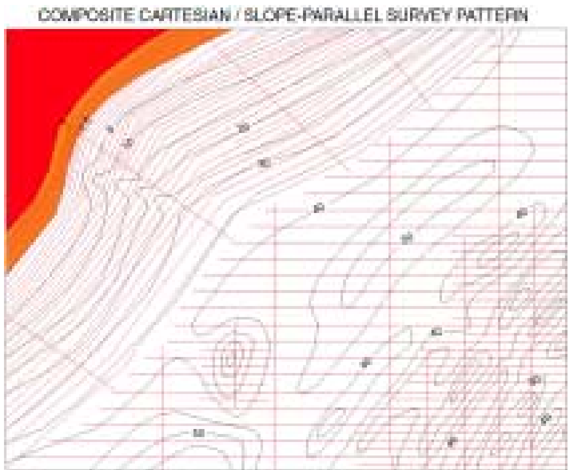

Figure 10. Schematic of typical hybrid "Cartesian/slope-parallel" survey pattern with 100 percent or greater coverage. (depths X 100 m)

We as a nation have spent tens and probably hundreds of billions of dollars on extraterrestrial exploration, while only spending an order of magnitude less on Earth exploration. While extraterrestrial exploration may be important for the long-term survival of mankind, recent events ranging from major earthquakes to threat of global climate change should make our understanding and ability to accurately model our planet our highest priority in Earth and planetary science. Most of us attending this forum will not be here to see the Earth mapped to the accuracy that we now have achieved for most of the other bodies in our solar system. Our generation needs to plan, influence policy and funding organizations, and implement a program to systematically map, understand, and model the major systems of the earth. GOMaP is our proposal to start the ocean-mapping phase.

How do we start?

The participants at the Bay St. Louis GOMaP Workshop are committed to begin work on this project. The Naval Research Laboratory is establishing a GOMaP web site to facilitate information exchange and discussion. The Naval Oceanographic Office has agreed to host an interim data server. The participants at the Workshop recommended that initially the GOMaP should focus on various pilot areas as a proof of concept: 1) The Gulf of Mexico [Good opportunities to utilize US Gulf Coast assets, and to demonstrate international cooperation]; 2) The Juan de Fuca plate [A nearly complete "ocean floor in miniature," a chance for US-Canadian cooperation, and supporting the NEPTUNE project]; 3) an area in the Southern Ocean with exceptional scientific interest but with very sparse data coverage; 4) the EEZ of a willing, small coastal state, as a demonstration; and 6) the Black Sea [A great opportunity for international cooperation and geological and archeological significance.].

We expect to see proposals submitted to various funding agencies during 2001.

Who should be players?

The next step in the political process is to engage the international organizations who have a vested interest in the long-term success of a project with GOMaP goals; the International Hydrographic Organization (IHO), the UNESCO Intergovernmental Oceanographic Commission (IOC), the Joint Commission on Oceanography and Marine Meteorology, and especially, the IHO/IOC General Bathymetry Chart of the Ocean (GEBCO) committee. These organizations can and must facilitate international coordination and funding.

This project will not succeed just because it needs to be done; it will only happen with the dedicated involvement of those individuals and institutions that have the "know how" and experience with oceanic surveys. We hope that members of the US Hydrographic Society, being just those types of individuals and institutions, will join the present active team in making GOMaP a reality.

Acknowledgements

We thank all the experts and stakeholders who attended the June 2000 GOMaP workshop in Bay St. Louis, especially the speakers. Christian deMoustier and Larry Mayer contributed ideas and information both before and after the workshop, as did R. Martino and C. Andreasen. We also thank GOMaP supporters who could not attend especially Jim Gardner, J. Delaney and A.N. (Sandy) Shor.

The workshop and EOS publications resulted in numerous inquiries from a number of nations. The two NRL authors were supported by ONR—and we particularly thank Vice Admiral Paul Gaffney (then Chief of Naval Research) for his endorsement of the GOMaP and for funding the Bay St. Louis workshop. We also think Rear Admiral Kenneth Barbor (Ret) (now Director, Hydrographic Science Research Center, University of Southern Mississippi) for his insightful welcoming discussion. H. Fleming of NRL management strongly supported the GOMaP planning and workshop. NRL marine geologist Joan Gardner assisted in every phase of the workshop.

References

DeMoustier, C. Personal Communication presented to GOMaP Workshop, June 2000.

International Hydrographic Organization, IHO Standards for Hydrographic Surveys, Special Publication No. 44, 4th Ed., April 1998.

Sandwell, D. T. and W. H. F. Smith, Marine gravity anomaly from Geosat and ERS-1 satellite altimetry, *J. Geophys. Res.* 102, 10,039-10,054, 1997.

Vogt, P., W-Y. Jung, and D. Nagel, *EOS*, AGU, v. 81, p.254, 258, June 6, 2000.

Vogt, P., Meetings Report, *EOS*, AGU, v. 81, p.498, October 24, 2000.