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

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The concept of a long-term (20-30 year) systematic, international effort to map the entire world seafloor from beach to trench (GOMaP = Global Ocean Mapping Program) has been developing at a series of informal and formal meetings over the last 2 years. The goal of GOMaP is to systematically map the ocean floors with at least 100 per cent coverage sidescan and swath bathymetry, and to 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 have been recommended.
Spatial resolutions for GOMaP sidescan sonar imagery should be 100 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. Although spatial resolution for swath bathymetry is slightly less than for sidescan, the resolution of both systems improves sharply with decreasing water depths, particularly for the 10 per cent 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 and techniques 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.

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 suggested by Figure 1, much of the world's ocean bottoms has not been surveyed.

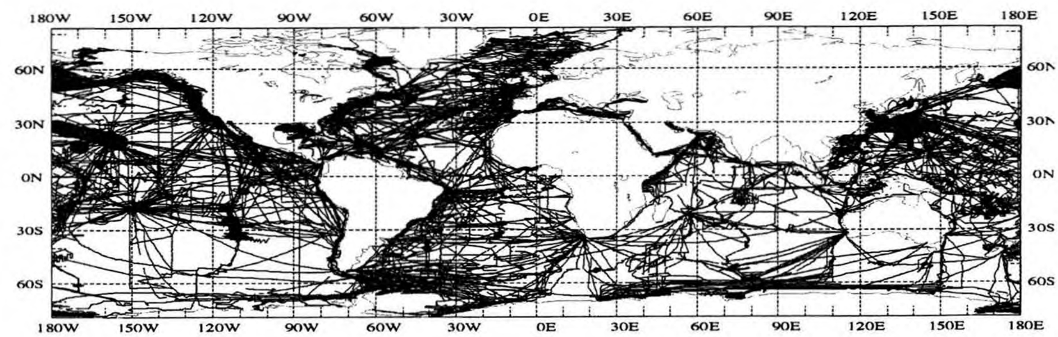

Figure 1: Inhomogeneous world seafloor database: Ship tracks for 1980-1999 period, courtesy of the National Geophysical Data Centre. Tracks for surveys using sidescan sonar and/or swath bathymetry are a small subset of tracks shown here. Note: Actual width of swaths is much narrower than line widths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

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).

We will summarise the efforts to define the GOMaP, set standards, establish a loose organisational 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 per cent 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 from GOMaP? We are certain of it. For example, precise knowledge of the seafloor topography would have direct benefits for improved assessments of geologic resources, finfish and shellfish habitats, 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 annual, decadal, and 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 per cent 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 in the Norwegian Sea (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 mor-

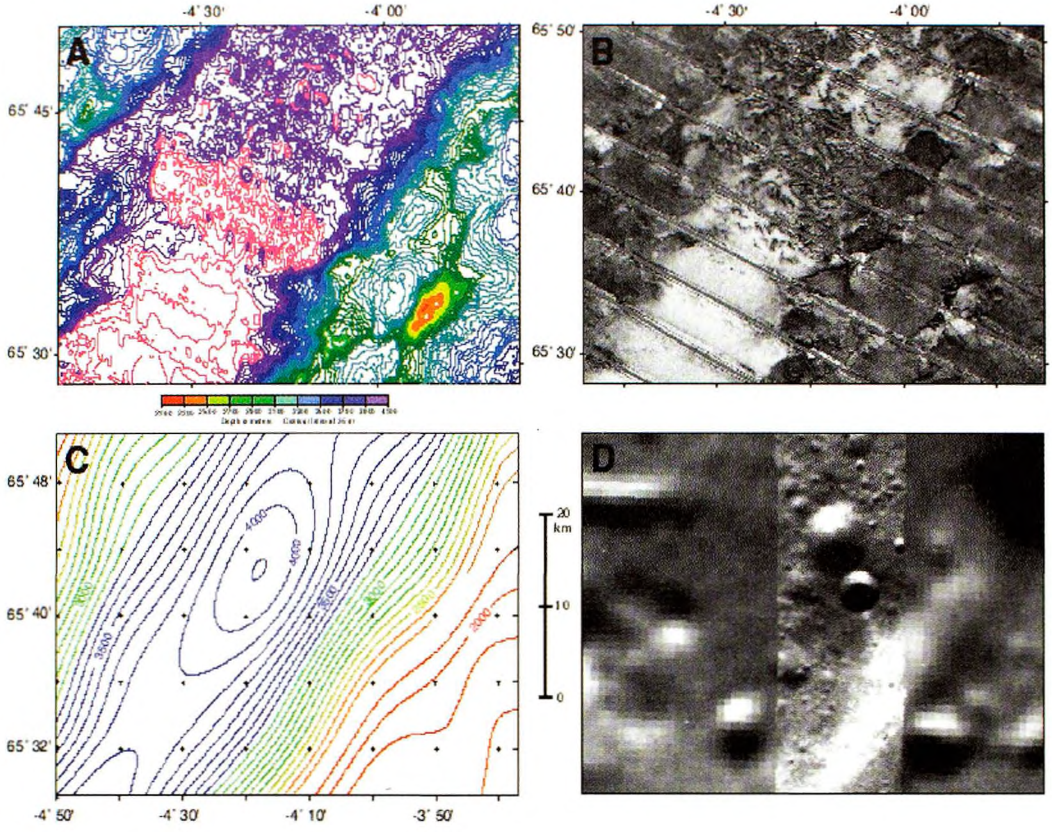

Figure 2:

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)

phology of the rift valley walls and rift mountains, as well as the topography and sediment characteristics of the debris flows and turbidites that have spilled onto the rift valley. The Navy's GEOSAT and ERS-1 microwave altimetric mapping missions allowed predictions of bathymetry from the gravity field (Figure 2C) on a global scale, but at full wavelengths no better than 20,000-30,000 m (Sandwell and Smith, 1997). To illustrate the magnitude of the proposed GOMaP effort, the region illustrated in Figure 2A-C is less than 1/3000 per cent 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 per cent of the world ocean less than 500 m deep. The decrease of swath width with water depth leads one to 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). 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 be 100 m or better in most locations except in the very deep sea, where they 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 very small portion of the ocean bottom (Figure 3).

Christian deMoustier of Scripps Institution of Oceanography (Personal Communication, 2000) proposed that bathymetric 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 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 for many years because of the logistics involved.)

Depth accuracy of individual soundings must be less than 0.2 per cent of the sonar's altitude above the bottom. All depths must be reported as true depths (implying 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 10m. 3D measurements using GPS should have 1-m elevation accuracy. In 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 Organisation 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 'organisation' should, working with appropriate international bodies (International Hydrographic Organisation, for example), establish standard protocols for survey design in addition to specifications for instrument calibration, data processing, and quality control. For a typical deep-ocean region that spans the edge of the continental shelf, slope, rise, and ocean basin, one can imagine a schematic of existing seafloor mapping tracklines. One could opt to use a 'Cartesian' survey pattern or a hybrid 'Cartesian/slope-parallel' pattern. The advantage of the pure Cartesian pattern is its ease in planning and execution. Its disadvantage is that it is not optimal in spatial coverage and requires constant sound velocity updates in the shallower areas. (Sound speed regimes change 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, executes optimally in shelf and shallow regions, and does not 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 per cent) 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 complete the deep-water portion, if fully funded. Mapping the shallowest 10 per cent 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. The US and other space-capable nations 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 and tsunamis to threats 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 will not be here to see the Earth's solid surface mapped to the accuracy that we now have achieved for many of the other bodies in our solar system. However, this is no reason not to begin! Our generation needs to plan, influence policy and funding organisations, and implement a programme 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 utilise US Gulf Coast assets, and to demonstrate international co-operation]; 2) The Juan de Fuca plate [A nearly complete 'ocean floor in miniature,' a chance for US-Canadian co-operation, 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 co-operation and geological and archaeological significance.].

Who Should Be Players?

The next step in the political process is to engage the international organisations who have a vested interest in the long-term success of a project with GOMaP goals; the International Hydrographic Organisation (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 organisations can and must facilitate international co-ordination 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.

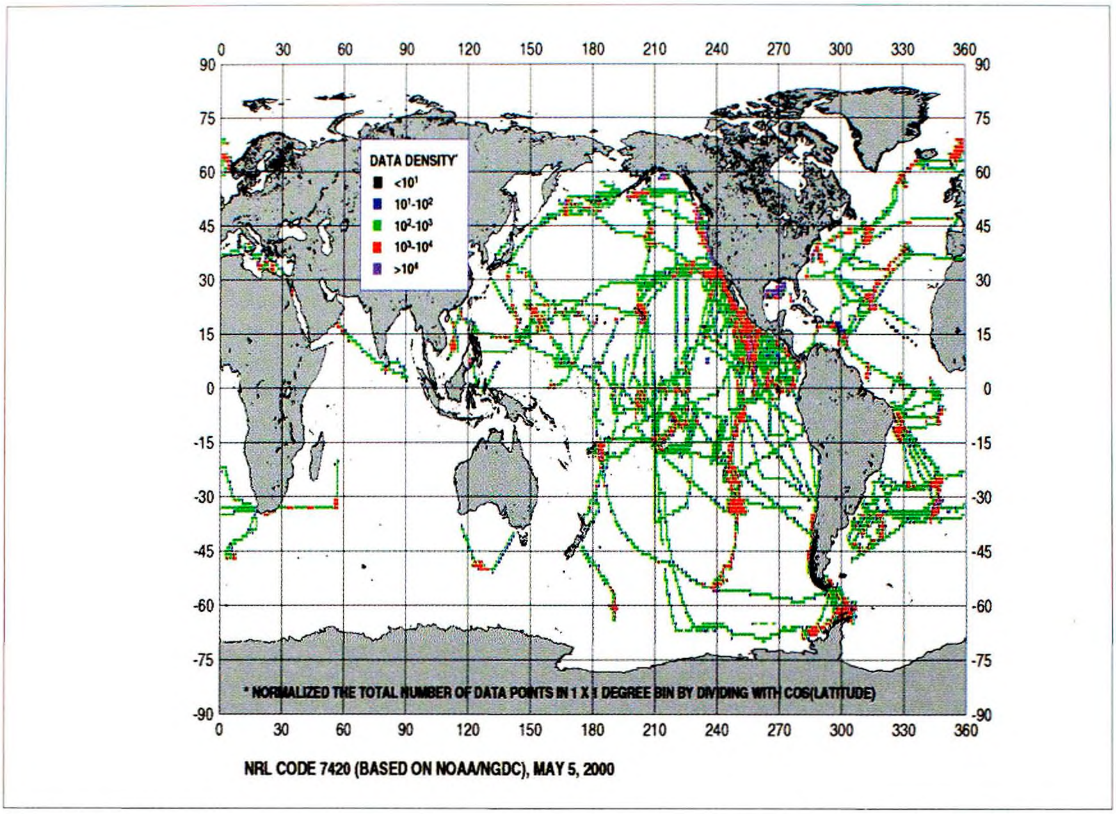

Figure 3: Current multibeam bathymetry tracks and data density from holdings at the National Geophysical Data Center. Data density is the number of soundings per 1 degree latitude x 1 degree longitude cell, corrected for the decrease of cell area with increasing latitude

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Biographies

Dr. Michael Carron graduated from the US Naval Academy in 1968 with a BS in Oceanography. During his active duty time he served as a navigator for a naval amphibious squadron, as Staff Riverine Patrol Officer for Commander Naval Forces Vietnam, and a Special Weapons Officer at Yorktown Naval Weapons Station. In 1999 he retired as a Captain in the Naval Reserves and Commanding Officer of the Naval

Oceanography Command Headquarters Unit, Stennis Space Center, MS. He holds both an MA and Ph.D. in Marine Science from the College of William and Mary in Williamsburg, VA and an MA in National Security and Strategic Studies from the Naval War College. He began work at the Naval Oceanographic Office in 1980. During his time with the Office he has held various positions including Head of the Physical Oceanography Branch, stationed in Naples, Italy as representative to the Mediterranean Fleet, and since 1996 is the Naval Oceanographic Office Chief Scientist and Director of the Scientific Technology Staff. He holds an appointment as Adjunct Professor in the Institute for Joint Warfare Analysis at the Naval Postgraduate School. Professional activities include: Membership in both US and International Steering Committees of the Global Ocean Data Assimilation Experiment, member of IOC/IHO GEBCO Subcommittee on Digital Bathymetry and GEBCO Strategic Planning Committee, and is coordinator for the construction of the GEBCO Worldwide Gridded Bathymetry.
Dr. Carron has recently accepted a position as Senior Principal Scientist in the Littoral Anti-Submarine Department of the NATO SACLANT Undersea Research Center in La Spezia, Italy.

Peter Vogt received his BS (geophysics major) at the California Institute of Technology in 1961. After spending a year at the University of Innsbruck, Austria as a Fulbright Fellow, Vogt did his graduate work at the University of Wisconsin, Madison (MA in Oceanography, 1965; PhD in Oceanography, 1968). The MA research dealt with seafloor basalt magnetization and magnetic anomalies, and the PhD work comprised a geophysical reconnaissance of the Arctic Basin and Norwegian-Barents Sea. Vogt was employed at the US Naval Oceanographic Office (1968-1975), and since then has worked as a marine geophysicist (plate tectonics, oceanic crustal magnetization, seafloor sediment dynamics, and other topics) at the Naval Research Laboratory. With his coworkers, he has researched marine geology and geophysics in nearly all the oceans, and has spent over three years total on a great variety of research vessels, acting as co-Chief Scientist for example on the Glomar Challenger and on the Mstslav Keldysh (and MIR submersibles). A Fellow of the Geological Society of America, Vogt has authored or co-authored about 150 technical publications, with over 4000 literature citations. He was awarded an Honorary Doctorate from the University of Bergen (Norway) and made a Fellow of the Norwegian Academy of Science in 2000. Vogt is fluent in German and Norwegian, with a fair knowledge of Russian and Spanish.

Born in South Korea, Jung came to the USA in 1977 after he finished college (BS in oceanography, 1973) and graduate school (MS in marine geology, 1976) at Seoul National University. Jung then switched to study marine geophysics in 1978 at Lamont-Doherty Earth Observatory of Columbia University, receiving an MS degree in 1981. He received his PhD (dissertation title: 'Free-air gravity and geoid anomalies of the North Atlantic Ocean and their tectonic implications') from Texas A&M University in 1985. After spending a year as research scientist at TAMU, Jung was awarded an NRC Research Associateship at the US Naval Research Laboratory in 1987. He was later hired by NRL's Marine Physics Branch. Jung's primary research area involves inversion/numerical modeling techniques related to geopotential field anomalies (gravity and magnetics), and more recently to gas hydrate stability under the ocean floors.