THE USE OF GLORIA LONG-RANGE SIDESCAN SONAR FOR DEEP-OCEAN MAPPING

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ABSTRACT

The Institute of Oceanographic Sciences' sidescan sonar GLORIA has been used for many years to aid bathymetric, physiographic and lithologic mapping of the deep ocean floor. The major advantages of the system are high tow-speed (up to 10 knots) and wide swath (up to 60 km), providing a rapid surveying capability. GLORIA does not measure depth directly, though depth can sometimes be inferred from shadow lengths. More often, GLORIA data are used to guide the manual contouring of widely spaced soundings. Contour maps thus produced are a great improvement over those made conventionally. While not quite as accurate or detailed as those produced by SEABEAM, they still provide a great deal of information on detailed depth, morphology and physiography that cannot be obtained from a conventional bathymetric survey, and do so with survey rates of ten to fifteen times that of SEABEAM. Recent advances in digital recording and image processing allow improved accuracy and presentation of the data, mainly by the application of slant-range correction and user-controlled time-varied gain. The latter can be selected interactively to match best the features under study. We are now experimenting with various ways of combining sidescan and bathymetric data in the same digital image.

OCEAN SURVEYING

There are very few deep ocean surveying techniques which permit the bathymetric mapper to see the shape and extent of the features he is trying to contour before he even puts pen to paper: sidescan sonar is one. At the Institute of Oceanographic Sciences (IOS), a long-range sidescan sonar has been developed that will insonify the seafloor over a double-sided swath up to 60 km wide at a speed of 10 knots. Originally developed for scientific purposes (Laughton, 1981), GLORIA (Geological Long Range Inclined Asdic) has shown its potential as a survey tool, producing results from which bathymetric, morphologic and potential resource maps may be produced (EEZ-SCAN Staff, 1986).

GLORIA Mark II (Somers et al., 1978) looks to both sides at once. It consists of a neutrally buoyant torpedo-shaped vehicle towed 40-50 m deep and 300-400 m behind the survey ship. The vehicle houses the dual sidescan transducer arrays which operate at frequencies around 6.2 and 6.8 kHz. Maximum range depends on the sound velocity profile and water depth, and in deep water can be up to 30 km. More information about the present system and past surveys can be found in Laughton (1981) and Somers & Searle (1984).

<u>Shipboard sonograph processing</u>

Signals are recorded onto magnetic tape, which are then replayed to produce a photographic hard copy. During replay a correction for "slant range distortion" is applied. This distortion arises because the images are produced by recording the travel-time of sound not along a horizontal surface but along the diagonal path from near-surface instrument to deep sea-bed. This makes the cross-track scale non-linear and distorts seafloor features. For 5-km-deep water the apparent displacement is about 2 km at 5 km range, but falls to 0.6 km at 20 km. The distortion is calculated and applied digitally assuming straight rays and a horizontal seafloor whose depth is given by the ship s echosounder. Any departures from these assumptions have small effects compared with errors in navigation.

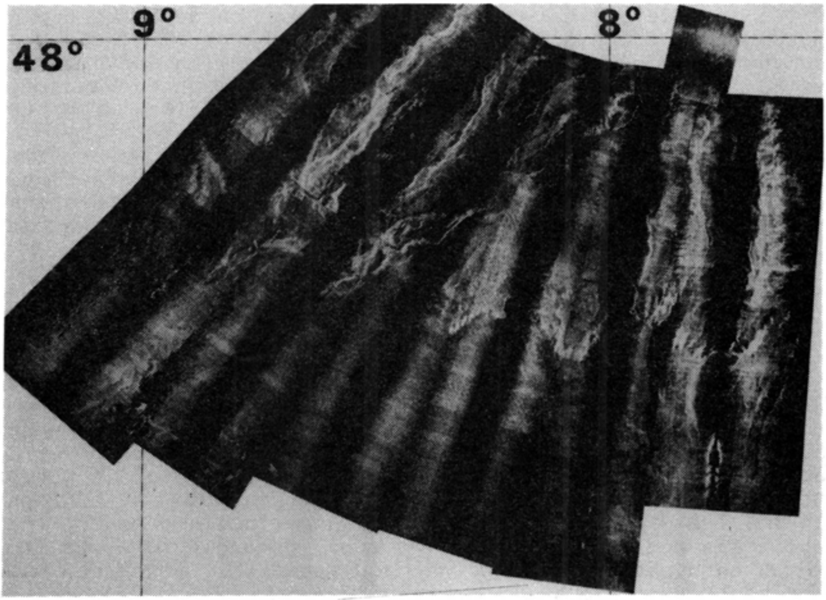

Figure 1. GLORIA sonograph mosaic over Meriadzek Terrace, northern Bay of Biscay continental margin (after Kenyon & Hunter (1985). Sonographs have been slant-range corrected but are otherwise unprocessed.

The photograph is then "anamorphosed" to correct for variations in ship's speed. Such variations result in a variable ratio of along-track to across-track scales. Until very recently the effect was corrected at sea by rephotographing the images through a special camera in which both object and film moved at speeds selected to give the required amount of stretch, though now this correction is also applied digitally during tape replay by replication of scan lines a variable number of times depending on ship's speed. For an average ship speed of 8 knots a stretch factor of about 3 is required. Finally the resulting photographic negative is printed to the required scale (usually between 1:200,000 and 1:500,000).

The sonographs are mounted along a plot of the ship's track and a mosaic is built up (e.g. Figure 1). In general features can be correlated between adjacent tracks, but errors can result from the varying viewing direction and because of navigational inaccuracies. Navigation is usually by Transit satellite, Loran-C or Pulse-8. Earlier errors due to slant-range distortion have now been eliminated.

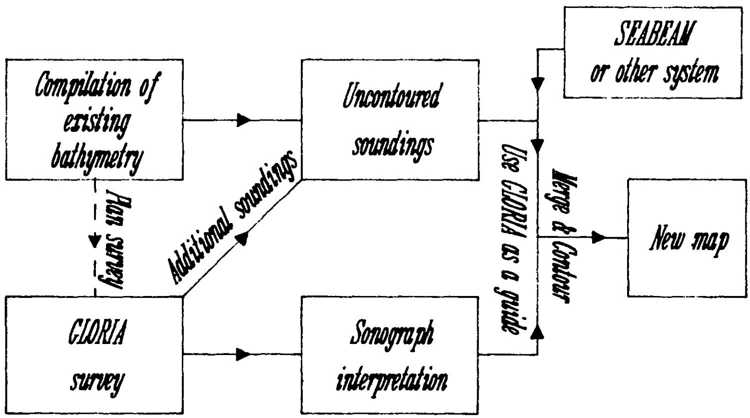

Figure 2. Procedure for creating a bathymetric map using GLORIA data.

Sonograph interpretation for mapping purposes

We illustrate the mapping procedure (Figure 2) with reference to an area on the continental margin west of Land's End (Figure 1). Before the start of the GLORIA survey an initial compilation of the proposed study area is usually made, and based on this the directions and spacing of the track lines are planned. In Figure 1 the tracks fan out almost perpendicular to the continental slope, owing to the increase in range as the depth increases.

The sonograph image is a map of different levels of acoustic backscattering from the seafloor. Signals are produced not only by topographic features but also by the variety of bottom deposits often found on areas of little or no relief (e.g. Kidd et al., 1985). Basalt flows and rocky terrain produce high levels of backscattering, whilst smooth mud produces very little.

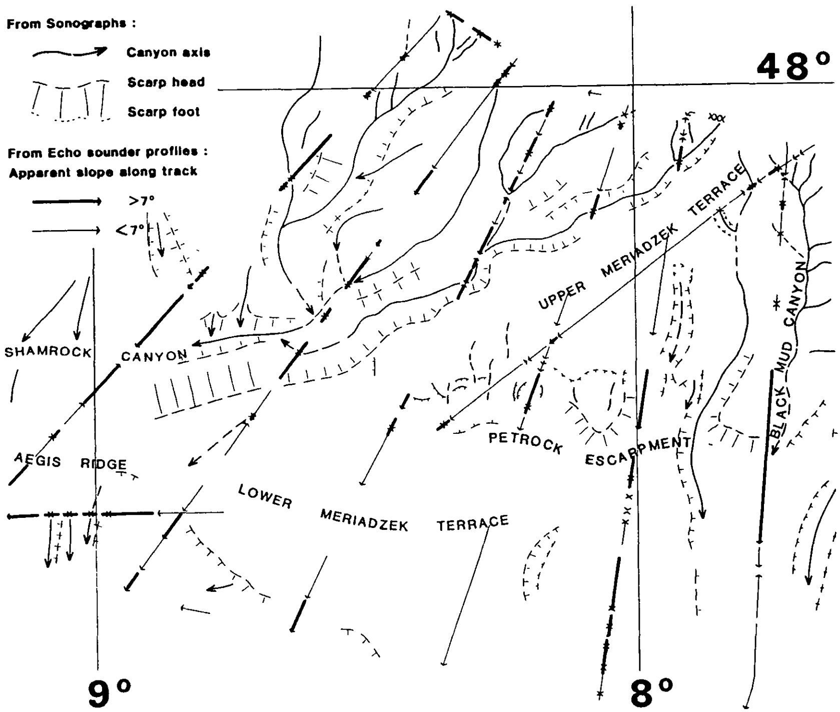

Figure 3. Interpretation of the area of Figure 1 based on echosounder profiles and GLORIA sonographs (after Kenyon & Hunter (1985).

Interpretation of the sonographs is carried out by overlaying the mosaic with a sheet of film and extracting the outlines of the relevant features. To identify the types of features reference is made to echo-sounder and seismic profiles and to any existing maps. Other information such as the seafloor gradients can also be included on the overlay as in Figure 3.

The final stage in the mapping is to merge the compilation of sounding information, supplemented by soundings collected during the GLORIA survey itself, with the interpretation of the sidescan data. Now the contours passing through areas between sounding lines can be interpolated with far more confidence than has been hitherto possible, resulting in more accurate maps such as that presented in Figure 4.

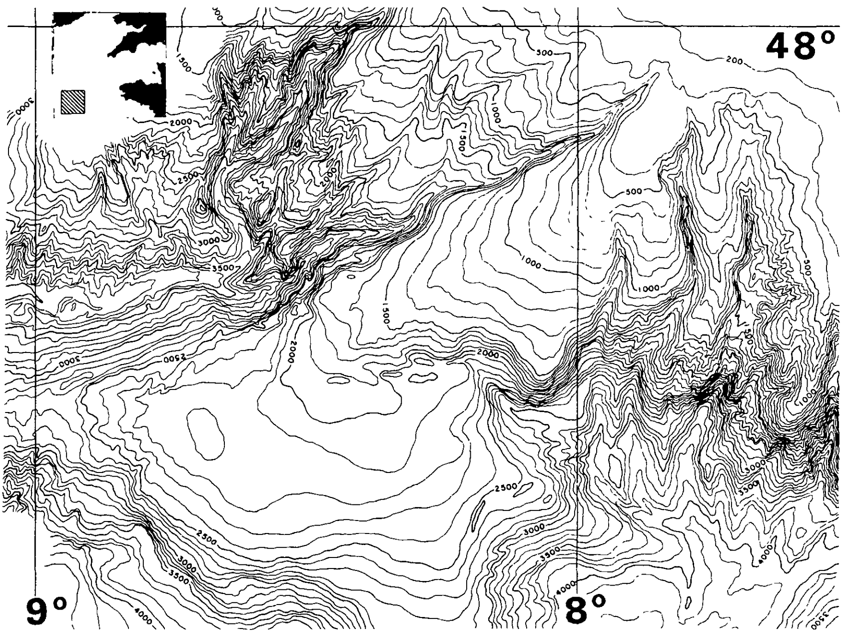

Figure 4. Bathymetric map, contoured in metres, of area shown in Figures 1 and 3 (after Kenyon & Hunter (1985).

The GLORIA data here reveal a more complex pattern to the distribution of the canyons than could be determined by echo-sounder alone. Multibeam scanning systems such as SEABEAM produce high-resolution maps which would also reveal the same pattern, but would take around ten times as long to cover the same amount of ground. However, a combination of the GLORIA coverage of an area with even a few SEABEAM passage tracks to give information on the contour complexities can produce an accurate map of a large area in a fairly short time.

An idea of the quality of GLORIA-aided mapping can be obtained by comparing figure 3 of Hey et al. (1980), produced conventionally, with figure 6 of Searle & Hey

(1983), which was contoured from conventional soundings but guided by an 18-hour GLORIA survey, and figure 6 of Hey et al. (1986) over the same area produced from a two-week SEABEAM survey.

POST-CRUISE IMAGE PROCESSING

Sidescan sonar images normally suffer from two types of distortion: geometric and intensity distortion. The geometric distortion comprises the slant-range distortion and the anamorphic distortion which have already been discussed and are now routinely corrected during data acquisition.

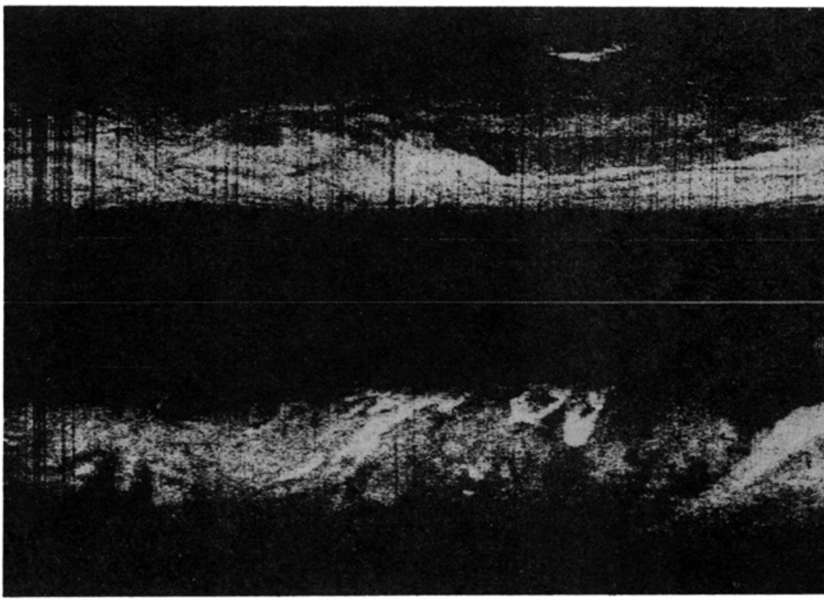

Figure 5. Single GLORIA image from the Saharan Slide study area, northwest African continental rise. Image has been photographically anamorphosed but is otherwise unprocessed. Image area is 50x60 km; ship´s track runs horizontally along centre (port beam to the top). Straight lines parallel to track are bottom echoes from vertically beneath the sonar.

Intensity distortions

Even after the image has been geometrically corrected, it is usually seen that recorded intensities are greatest at mid-range (about 10 km horizontal range) and fall off at greater and lesser ranges (Figures 5, 6). This has the

effect of producing very uneven levels of illumination and contrast, which may obscure important features and also make very difficult the publication of mosaicked images. We can now correct for this effect during post-processing, and hope soon to be able to apply the corrections during data acquisition.
The intensity distortion arises from several different effects, of which the most important are the sonar beam shape (i.e. the variation in sensitivity with direction), the geometric spreading of the beam (inverse square law loss modified by any focussing or defocussing due to refraction), physical attenuation of sound in the water, and effects of changing angle of incidence. All except the first of these are monotonic variations, and a very approximate correction for them is applied during data acquisition by a hard-wired time varied gain. Even so, there is a rapid fall-off in intensity beyond 15-20 km.

The beam directivity is not at present corrected for. The beam has a null response between the main lobe and the first sidelobe, and this typically falls at a horizontal range of about 2 km. Although the first sidelobe illuminates the seafloor vertically beneath the ship, there is an effective "blind zone" on unprocessed images that is some 4-5 km wide. Post-cruise processing can materially enhance the data by reducing the width of this zone and by extending the effective outer limit of the beam.

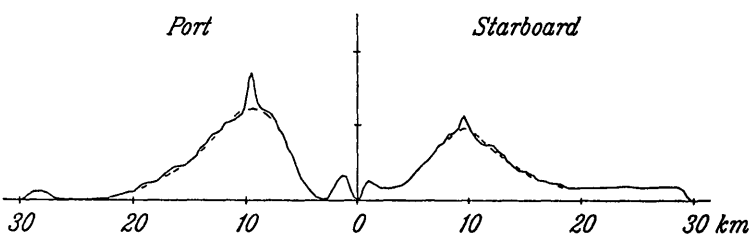

Figure 6. Observed profile of intensity in a GLORIA swath from the Madeira Abyssal Plain, eastern North Atlantic (continuous line). Ordinate is in arbitrary units. Profile produced by averaging 33 pixels along track and 17 pixels across track. Broken line shows the smoothed version used for correcting other images.

We do this by first empirically estimating the effective sonar response, i.e. the average intensity as a function of range. This can be done either by averaging a large number of line scans (the equivalent of several hours of surveying) over a variable area, or by averaging a relatively small number over a restricted area where the seafloor response is very uniform. The US Geological Survey has used the former method to correct its very variable data from a large survey off the US west coast (EEZ-SCAN Staff, 1986), while we have used the latter method over the Saharan Sediment Slide in the eastern North Atlantic (Searle & Kidd, 1984; Kidd *et al*., 1985; Figure 6).

In Figure 6 the spikes near zero range represent the first bottom echo from the seabed directly beneath the ship, and those at 10 km represent the second bottom reflection. Note that the beam pattern is rather asymmetric (owing to the use of slightly different frequencies and unmatched electronics on the two sides), and that in spite of the averaging the profiles are still not completely smooth. A final smoothing was applied by hand (broken line in Figure 6), and zero-level elements were replaced by small non-zero ones, to provide a "standard profile". The images from the Saharan Slide area were then corrected by dividing each image scan by the standard profile, to produce images with a broadly uniform level of illumination (Figure 7).

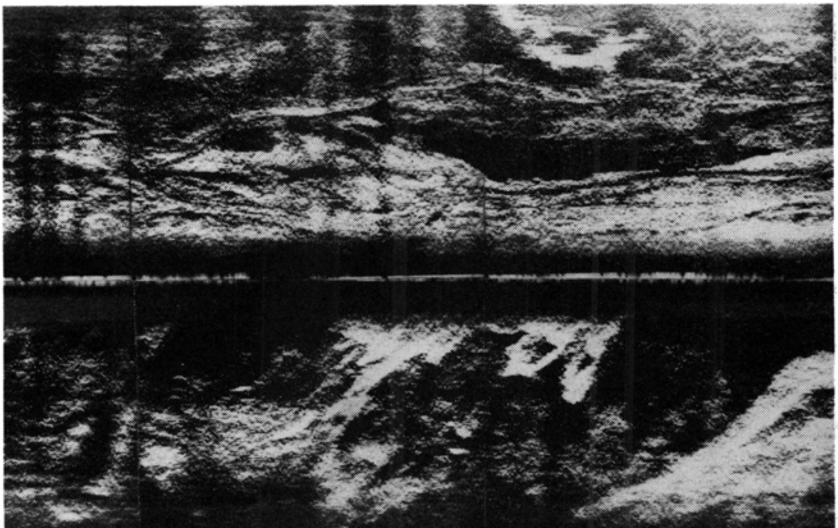

Figure 7. Processed version of image shown in Figure 5, after corrections for slant range distortion, intensity distortion and destriping.

The process also enhances low-level signals near minimum and maximum range, extending the effective minimum range from about 4 to 3 km and the maximum from 15 to 20 km.

Experience so far suggests that different versions of the standard profile are applicable to different geological terrains, probably mainly because the function relating backscattering intensity to angle of incidence is different for different lithologies. Indeed, we are almost certainly losing some of the lithological information in the images by determining the correction empirically, and we are now working on a more objective version of the standard profile.

The last intensity correction is to "de-stripe" the image, i.e. remove any line dropouts. These are recognised by comparison with the average of a number of scans on either side, and replaced by a suitable mean value.

Other processing

The processes described above are carried out on a line-by-line or image-by-image basis. However, once these corrections have been made, it is often desirable to mosaic the individual images together into a large scene. To date that is still done by hand, but we hope soon to develop routine methods for computer mosaicking.

With the advent of digital mosaics there will come the exciting possibility of combining GLORIA images with other types of data. The most useful combination is likely to be sidescan with bathymetry; this could be achieved, for example, by using hue and saturation in a colour image to represent depth, and intensity to represent the sidescan signal. It is also possible to make digitally a perspective view of the shape of the seafloor and to project the sidescan image onto it, so that one sees the image as though pasted onto a relief model. Another possibility is to generate a shaded relief map from detailed bathymetry (e.g. SEABEAM). If the appropriate direction of illumination is used, the result looks rather like a GLORIA sonograph: in fact it represents that part of the sidescan image that arises from topography alone, ignoring any lithological variations. (A good example is the Galapagos "Propagating Rift" in the eastern equatorial Pacific, imaged by GLORIA in Searle & Hey (1983, figures 4 and 5) and as a SEABEAM shaded relief map in Hey et al. (1986, plate 2)). Preliminary experiments with all of these techniques have been carried out and show considerable promise. In principal it should also be possible to subtract the topographic signal from the complete sonar one to obtain the signal due to the lithology alone, but we have not yet attempted that.

REFERENCES

EEZ-SCAN Scientific Staff (1986) Atlas of the Exclusive Economic Zone, Western Conterminous United States. US Geological Survey Miscellaneous Investigations Series I-1792, 152 p., scale 1:500,000, Reston, Virginia, US Geological Survey.

Hey, R.N., Duennebier, F., & Morgan, W.J. (1980) Propagating Rifts on Mid-Ocean Ridges. Journal of Geophysical Research, 85, 3647-3658.

Hey, R.N., Kleinrock, M.C., Miller, S.P., Atwater, T.M., & Searle, R.C. (1986) Sea Beam/Deep-Tow Investigation of an Active Oceanic Propagating Rift Sysytem, Galapagos 95.5° W. Journal of Geophysical Research, 91, 3369-3393.

Kenyon, N.H., & Hunter, P.M. (1985) A long-range sidescan sonar survey of Meriadzek Terrace, Bay of Biscay. Institute of Oceanographic Sciences Report No. 210, 17p., Wormley, UK, Institute of Oceanographic Sciences.

Kidd. R.B., Simm, R.W., & Searle, R.C. (1985) Sonar acoustic facies and sediment distribution on an area of the deep ocean floor. Marine and Petroleum Geology, 2, 210-221.

Laughton, A.S. (1981) The First Decade of GLORIA. Journal of Geophysical Research, 86, 11511-11534.

Searle, R.C., & Hey, R.N. (1983) Gloria Observations of the Propagating Rift at 95.5°W on the Cocos-Nazca Spreading Center. Journal of Geophysical Research,88, 6433-6447.

Searle, R.C., & Kidd, R.B. (1984). GLORIA digital image processing and interpretation of the Saharan Sediment Slide, eastern North Atlantic. EOS, Transactions of the American Geophysical Union, 65, 1082-1083 (abstract).

Somers, M.L., & Searle, R.C. (1984) GLORIA sounds out the seabed. New Scientist, 104, 12-15.

Somers, M.L., Carson, R.M., Revie, J.A., Edge, R.H., Barrow, B.J., & Andrews, A.G. (1978) GLORIA II - An improved long range side-scan sonar. Proceedings of the IEEE/IERE sub-conference on offshore instrumentation and communications, Oceanology International, 1978, Technical session J, 16-24, London, BPS Publications Ltd.