Report no. changed (Mar 2006): SM-282-UU

SACLANTCEN MEMORANDUM
serial no.: SM-282

SACLANT UNDERSEA RESEARCH CENTRE

MEMORANDUM

High-resolution characterization of shallow-water sea bottom:

Need and methodology for a ground-truth reference database

M.D. Max, L. Gualdesi and F. de Strobel

December 1994

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(excluding Covers
and Data Sheet)

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The content of this document pertains to work performed under Project 12 of the SACLANTCEN Programme of Work. The document has been approved for release by The Director, SACLANTCEN.

Issued by:
Underwater Research Division

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Executive Summary:

A methodology for identifying and recovering high-resolution sea-bottom environmental data has been developed by oceanographic and seafloor scientists at SACLANTCEN working directly with nearby Italian Navy MCM personnel. There was an immediate need to improve, expand, and quantify seafloor attribute information, and provide a dataset of scientific quality. Our approach, based on diver observation, sampling, and measurement, has proved useful in that an acceptable quality of data has been collected by a number of observers having a wide spectrum of educational backgrounds and underwater experience. Dived site information is intended to provide hard, quantitative descriptions and to be merged with larger bottom-descriptive datasets obtained by more rapid, larger area survey.

This report presents the results of this interactive work and the methodology for this new level of detail of seafloor description. The methodology, when modified for other areas, could prove to be a model for other detailed sea floor characterizations.

Determining the high-resolution character of near-seabed oceanography, depositional environment, *in situ* sediment physical properties and composition (including gas), and geotechnical properties in shallow water is necessary to meet recent Navy concerns in littoral operations. For example, for any small object near, at, or within the seabed to be located, the physical properties of the background natural environment and their patterns must be characterized in greater detail. Environmental description must be on a smaller scale, for individual features, than any potential search object. This requires natural element recording on a scale of centimetres or tens of centimetres, and definition of the areas within which descriptions hold true.

A diver's tablet for recording specific qualitative and quantitative high- resolution sea bottom information has been designed and tested. Systematization of observation and recording of measurements of a number of common seafloor features allows the numerical descriptions to be treated as data. This data can be used to produce statistical seafloor descriptions for seafloor areas. Mapping and statistical information is being inter-linked using commercially available geographical information system (GIS), spreadsheet, and relational database software. This information can provide ground-truth for calibrating acoustic and other remote sensing instruments.

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Abstract: A systematic approach to underwater observation of high-resolution seabed features has been developed. These include: morphology caused by current, wave, and biological factors and certain engineering geological factors such as compaction (penetration) and shear-strength character. Particular attention is paid to recording any seabed element that would constitute a discrete acoustic reflector and areas of strong acoustic scattering, such as would be characteristic for seagrass meadows. An underwater recording tablet is proposed and its use described. The information is recorded in such a way that it is amenable for encorporation into spreadsheets and relational databases that can be linked to digital maps.

Keywords: environment ∘ GIS ∘ high resolution ∘ sea-bottom morphology database

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Introduction

1.1. THE DEVELOPING NEED FOR HIGH-RESOLUTION SEA-BOTTOM INFORMATION

Large area surveys of shallow water sea bottom, like the deep sea bottom, have been studied mainly through remote sensing techniques such as multibeam bathymetric mapping, reflection seismics, and side-scan sonar surveying. Cameras, and one-atmosphere diving vessels have provided a small proportion of information from the deep sea. Determining physical properties at underwater sites by mechanical apparatus lowered from ships requires a high level technical and operational capability, in addition to acquiring and maintaining the expensive equipment designed for making these tests. These operations have mainly been carried out at special and restricted sites, such as hydrothermal vents on oceanic ridge systems and in sediment movement studies.

Databases and seafloor characterization derived through largely acoustic techniques render highly particular images of the seafloor at whatever frequencies, processing, and outputs are normal for each type or model of equipment. When one set of acoustic-derived information is compared with another it is a type of ground-truthing, generally leading to a comparison of one acoustic 'image' with another. Real observational measurements are necessary, however, for providing ground-truth for calibrating remote systems.

Scientific diving in shallow-water areas has provided a great deal of seabed information, particularly for sites where high-resolution description (tenths of metres or less) is necessary. Diving and direct observational and measurement techniques have been used instead of remote techniques primarily because scientific diving is a safe, relatively inexpensive, and a proven method for obtaining this type and scale of information. In addition, some data of sea-bottom properties can be obtained only directly. Direct observation is also important where quantitative geotechnical data are needed. These cannot be determined unequivocally by advanced, sophisticated remote sensing means available today.

The most high resolution commercial surveys have been done preliminary to pipeline, cable, and engineering installation. Both regional geology and high resolution data recording have been carried out for geotechnical surveys, mariculture, and sedimentological fields. Experience gained in these survey and research efforts is adapted here with the aim of producing a high resolution seafloor database optimized for sea-bottom classification.

Shallow-water regions offer both problems and opportunities. Complexities are mainly a problem when they are not understood. In particular, shallow water commonly exhibits a wide variety of geological bottom materials whose predominant type and mode of deposition can change over short distances. Sub-bottom materials also can be complexly distributed and highly variable. This complexity of materials and their disposition often results in strong variations of sea-bottom acoustic and mechanical response. The existence and distribution of these shallow-water bottom materials is the primary reason why characterization of shallow-water areas must be geologically and morphologically based in order to develop adequate physical models.

Deep and shallow-water geoenvironments differ strongly. Some of the main variations occur in: Bathymetric expression, rock types, age, geological history, disposition with respect to continents, water depth, geophysical properties, and human activities. Probably the most important contrast between the geological histories of deep and shallow water, however, has been the periodic drying of virtually all continental shelves. In fact, usually only the latest (younger than about 10,000 years) sediments on continental shelves world-wide, are truly of full marine character. Whereas deep water sediments have accumulated as the result of a continuous process of marine sedimentation, continental shelves that dry have developed properties of dry land sediment and rock that are not found in deep ocean sediments. Many important shallow-water areas, such as the southwest approaches to the British Isles (SWAP), have sea-bottom properties of temporarily flooded land that may only be coated with a discontinuous veneer of marine sediment. Both subareal and marine research and descriptive techniques are necessary to understand large areas of shallow-water seafloor.

The occurrence and disposition of continental shelf rocks and sediments are the result of normal geological and oceanographic processes acting over time. The sediments are, in fact, a record of this activity. Thus, knowledge of the regional and local geology allows for extrapolation of point or line environmental data over broader shelf areas and provides a predictive perspective often absent from more purely mathematical and physical sciences. Knowledge of where certain environmental attributes occur, and are likely to occur, can be combined with both empirical and experimental information that constrain the impact of each environmental element.

Shallow-water bottom is often strongly dynamic, swept by strong currents and different water masses and both close to terrigenous sediment supply and the source of most clastic carbonate sediments. In addition, the three-dimensional morphology of many bottom forms, such as sandwaves, dunes, wash-outs, terraces, levees, sediment fans, etc., are actively forming and moving under the influence of dynamic currents. In these areas, mapping of individual features is inappropriate for all but the most short-term interests. However, mapping of the *areas* where particular features and combinations of features of interest occur is possible. Morphological terranes can be defined in which the statistical properties of roughness, relief, bottom type, asymmetry of acoustic and other response, etc., can be characterized. These statistical datasets retain their numerical descriptiveness despite the normal changes taking place with each sub-region or morpho-terrane.

The physical complexity of shallow-water sea bottoms is an inescapable fact. There are potential major advantages to operating in a complex rather than in an environmentally more benign area, however, once the complexities are known and modeled. Environmental attributes within shallow water offer immense opportunities for the future, once they can be understood, statistically described, and factored into applications.

1.2. THE HIGH-RESOLUTION DATA NICHE

Detailed sea-bottom observations and measurements are not intended to stand alone, although when used intensively in small areas, they can provide unique information for specific applications. These direct observations and measurements are primarily meant to be part of larger shallow-water databases. Their main purpose is to provide control points within a larger dataset. The sea-bottom descriptions are also meant to extend to characterization of areas, defined by mapping using direct and indirect methods, rather than to reflect only the situation at each site. In fact, the descriptions are meant to be an average description of an area, rather than an over-specific reference. The size of areas and the statistical variants will vary.

The observational techniques drawn on here are not new, having been used for geotechnical and scientific investigations. But this methodology, while it will produce information valuable to other disciplines, is intended primarily for Navy applications. The data recording system is configured so that it can be easily altered for different languages without affecting interchangability of data records.

Areas in which this high-resolution observational and measurement work is carried out will almost certainly be limited in extent and site intesity. There is no requirement foreseen for continuing high-resolution observational operations of a purely scientific character, unconnected to other sea-bottom characterization activity. It is anticipated that virtually all operations associated with gaining the high-resolution information, with the possible exception of training, will focus entirely upon characterisation of already selected areas.

Although this report is in part a justification for the use of divers to contribute information to a wider database, its main aims are to

1. Detail the developing need for an observational high-resolution database
2. Delineate the factors affecting the collection and application of information
3. Describe a methodology and the techniques for recovering systematized information, and
4. Describe in a handbook form the technique of making the observations.

2

Observation of shallow-water sea bottom

Sea bottom in shallow water is amenable to observation using both diving and low-cost, non-acoustic remote sensing means that are not used in the deep oceans because of operational and physical difficulties and their consequent high cost. Specialized observational procedures suited to shallow water have been developed over the last thirty years and are widely used within the shallow-water scientific community (Flemming and Max, 1988). Whereas survey techniques employed in deep water characteristically resolve only gross and macro-scale morphological elements, the accessibility of shallow-water areas allows for high resolution bottom characterization on the scale of metres, centimetres, or less. Direct observations and direct measurements are commonly carried out at the same site by a team. Three main elements control the nature and form of high-resolution information:

1. *Identification of the purpose for assembling a database and its user base.* What information is needed, and for what purposes? It is envisaged that the primary uses of this dataset will be for specific research and applications. Description of all bottom features and properties necessary for a wide variety of scientific and non-Navy applications, the obtaining of which might indicate a major and unsustainable research effort, is not required. However, the data is intended to be of scientific quality and interchangeable with scientific research institutions as well as between NATO countries.

2. *Systematic description of seafloor using direct and remote visual observations.* Can observations be systematized and combined as a dataset to give them usefulness? This can be achieved through organization of the naturally occurring physical properties and morphological sea-bottom elements into their natural categories with minimization of variables. To facilitate the initial observation and recording, an underwater tablet has been developed that allows a wide variety of scientists and divers to make observations and numerical measurements *in situ* through choice selection, orientation and numerical entries, and specific descriptions.

3. *Geographical and numerical relationships within sites, between sites, and with external data.* Quantitative and semi-quantitative representation of the small-scale seafloor character can be compared within the dataset and directly related with other information. The observational data is intended to consist of primary, system-independent information. In addition, some of the numerical data can be processed to produce higher level numerical data, such as roughness.

2.1. SYSTEMATIC DESCRIPTION OF THE SEA BOTTOM

Characterization of high-resolution features of the bottom has proven difficult, especially for the non-specialist, because there is a wide variation in the way individuals can describe the same or similar seafloors. On the other hand, specialists can observe and construct an intensely detailed dataset that may suit their scientific applications, which is almost incapable of integration into other applications. Without a system that constrains information recording, which gives the information its character as data, even the same individual can describe the same seafloor differently, from time to time.

Describing the sea bottom depends on a number of factors including: the state of the current, visibility, light and color of light, physical difficulties involved in making the observations, and immediately preceding site observations and training. Individuals' observations are strongly dependent on their education and experience, in addition to their anticipation of the purpose for which the observations are being made. For instance, a trained sedimentologist and a hard-rock geologist will observe from fundamentally different viewpoints. Without doubt, however, technically aware divers can be trained to make observations according to a well laid-out system when the main attributes to be recorded are clearly laid out (Masterson et al., 1987). At the same time, the systematization restricts what a specialist observer might record.

The best answer to producing uniform site observations is through the use of data recording sheets where the observer must pick from only a limited number of choices for the most relevant bottom character. This forces observers to use a uniform descriptive terminology and produces numerical data that can be tabulated. It is important in designing the observational tablet to allow for:

1. The purpose(s) for which the data is being acquired.
2. Operational concerns.
3. Importance of features likely to be encountered.
4. Significant variations within each set of features.
5. Systematizing observations.
6. Restricting observations.
7. Different observer capabilities.
8. Database-friendly observations.
9. Easy data handling from recording to database production.
10. Flexibility of the database and directness of its application.

2.1.1. The purpose(s) for which the data is being acquired; Toward a NATO standard high resolution shallow-water database

Seabed information has long been collected for engineering applications, usually for platforms, pipelines, or for constructing engineering facilities such as harbors and moorings. In addition, high resolution collection of seabed information, including geological, engineering, and biological features have been made for shellfish mariculture. The particular need for collecting the information strongly affects the manner in which the data are collected, as well as the type of information. All direct seafloor observation has to be highly focused, organized, and carried out, in order to produce a usable product with minimum cost and effort in the shortest time. It is common for continental shelf maps to incorporate high-resolution information in larger data sets (Max, 1982).

This observational dataset, and the resultant database that can be based on it, are designed to aid Navy and NATO activities in shallow water. This data recording scheme (Fig. 1) is intended to be used by a wide variety of divers in order to produce a standard set of data that will numerically characterize the high resolution details of the seabed. This data is collected in a manner that allows for direct reading into a digital database format, allowing area and parameter sorting and selection. In addition, the data recording tablet has been designed so that records can be quickly interpreted in numerical form, regardless of the language of the observer or the language inscribed on the data tablet because the data entries will be in the same position on all tablets.

2.1.2. Operational concerns

This mainly involves training to use the recording scheme and the actual operation of planning, organization, transit, and multiple diving. ROV and AUV data collection, for deeper areas, is also possible, but requires the design and operation of new equipment, whereas diver observation and recording can be implemented in divable depths immediately. The number of sites observed in any time period and the number and relative skill of observers must also be taken into consideration (Max, 1982). Support and procedures will vary considerably depending on conditions such as the availability of platforms, weather and sea conditions, training levels and experience of the staff, equipment available, and other factors affecting site and project scientific diving (Flemming and Max, 1988). The degree of difficulty imposed by dive conditions and physical factors such as water temperature also can affect observations.

It is important that both scientific quality and safety be emphasized in operations, which should be governed by Codes of Practice (De Strobel and Colantoni, 1984; Flemming and Max, in press) and procedures suitable for conditions and staff.

It is common practice to use trained scientific observers and non-scientists on working scientific diving. This is because dive teams can partition the effort into the two clearly definable responsibilities of observer (scientist) and helper.

Mapping the sea bottom is best conducted by a team rather than by individual divers or a crowd (more than two). One team member is mainly responsible for safety (rope handler, higher level of fitness, carries equipment, etc.) and sampling (equipment handling) while the other is primarily responsible for recording observations. By conducting a highly organized dive, bottom time can be limited and an increased number of sites can be surveyed and sampled.

2.1.3. Importance of features likely to be encountered

The scale of features and their physical properties must be recorded at sufficiently high resolution to allow identification of unnatural or man-made objects against the seafloor background. In the case of relatively large objects on the scale of tens of metres, resolution of seafloor attributes can be more coarse grained. Features as small as a few centimetres may be important, as well as their disposition, orientation, scale, and form variations. For instance, coarse gravel patches on a silty bottom strongly affect acoustic response. Although mapping of each and every small feature in its three-dimensional form is clearly impossible, it is possible to identify areas of seafloor by particular features or combinations of features. Often, individual areas in which complicated morphologies persist can be surprisingly large and the geoenvironmental model relatively straight-forward.

Sonar backscatter and seismic response (terrane) prediction charts are a useful aid to characterizing sea bottom. However, at higher frequencies, it is likely that fully azimuthal and grazing angle bottom character will be needed to construct relevant databases. Because it is not known precisely how future systems will integrate acoustic response with their geoenvironmental information, the recording of sea bottom information should be purely observational and as system-independent as possible. It should be based only on an accurate morphological, statistical, and measured physical property/geotechnical characterization.

Bottom features likely to be encountered include; gross bottom types and form of variation (gravel, sand, mud, etc.), mounds, depressions and pockmarks, scars and drag marks, rippling, and biological activity, importantly, the various 'sea grasses', such as *Posidonia*, that form thick mats in shallow water, especially in the Mediterranean littoral. Isolated features that might cause a high background 'noise' are also noted where possible, although in the case of large features such as rock pinnacles, these are better mapped as individual objects.

2.1.4. Significant variations within each set of features

There is in nature often almost a continuous variation in size and expression of some naturally occurring sea bed features. However, it is usually possible to describe bottoms as being mainly of one type, with often a sub-type of that attribute also present. Although the scale of features varies on a world-wide basis, within any particular seafloor area affected by the same depositional conditions, the scale of features is commonly similar. Thus, it is consistent with the concept of defining areas of the seafloor where similar features have a common expression and scale, to make and record *in situ* observations and apply them as characteristic types within related geographical areas.

2.1.5. Systematizing observations

Virtually every observer has his own way of describing a sea bottom. Early attempts to verbally describe seafloor character resulted in large written documents, which were usually indigestible and unapplyable, unless drastically simplified, even where there was only a single observer. Where more than one observer was involved, the descriptions were often inconsistent and highly variable, thus difficult to compile. These difficulties were not necessarily because the observers were incompetent observers and describers of seafloor. It was because the different backgrounds of the different observers, their experience, and the observational conditions at each site and at each time could vary and strongly affect perception.

Systematization of observations is the answer to the problems of seafloor observation. Selection of the parameters to be observed and careful definition of the allowable variables forces all observers to choose the 'best fit' for their observations. Where these observations are not absolutely correct or incomplete, they do not usually vary significantly from those which have been perfectly achieved. Masterson et al. (1987) found that systematized surveys have resulted in usable datasets, even where there is great variation in the capabilities of observers.

2.1.6. Restricting observations

The aim of data recording is not to record the absolute size and all variation at a site, but to pick the best fit. By reducing the number of choices, enumeration of observations is possible. In restricting the observation set, care must be given to the attributes and the range of variables likely to be encountered. It is not possible to design a data recording scheme without some knowledge about the environment, and this means that a pilot literature study, and a working knowledge of the bottom-environmental conditions is usually a requirement to designing a successful survey. It is also important not to focus solely on purely academic concerns, except where these features bear strongly on the validity and usefulness of the final dataset.

2.1.7. Different observer capabilities

The only prerequisite for an observer in a well organized bottom-survey program is that they should be technically competent and aware, have the features to be observed and the choices made clear to them in a training program, and have an interest in making the observations. Strong motivation is important to the quality of the observations. A non-specialist cannot design a bottom attribute recording scheme, and should not be expected to do so. Once a scheme exists, however, a non-expert observer should be fully capable of taking part in making observations. The differences in education and experience of observers, are minimized in a suitably organized recording scheme and differences in the capabilities of participants has proved to be less important in practice than it might seem in theory.

2.1.8. Database-friendly observations

Systematization of data allows enumeration, which allows the information to be placed in a database for multiple and relational sorting, and processing, and integration with other data. Because modern spreadsheets and databases allow a broad range of formats and complex retrieval, handling, output, and graphical display of information, technical aspects of computerization are less of an impediment than they were only a few years ago.

2.1.9. Easy data handling from recording to database production

Data handling must be secure and simple. If requirements to copy or transcribe information are made part of the operation, they can cause failure of the operation itself. Therefore, a single site hard-copy of the actual underwater data record sheets, of an adequate size to allow for easy transcription, yet small enough to handle and copy on A4 format, provides a good solution for primary data recording. In our system, the data record sheets themselves fit into a frame over the data-recording template (Fig. 1), whose form can be maintained while other languages are substituted. This allows for multi-language use. Raw data recorded in one language can be enumerated into a dataset operated in another language, without loss of information or confusion. Entry of data from these sheets to a digital database can be made at any time, and the data shared in hard copy between different users who have established different digital systems or data file structures for dealing with the data. The dive sheets provide an archived, hard-copy record.

2.1.10. Flexibility of the database and directness of its application

A database can have a number of expressions. Firstly, the information should be realizable in a geographical and relational manner suited to a geographical information system (GIS) format. GIS systems are now operating on virtually all computer hardware and translation of files from one system to another is normal. Therefore, the choice of GIS system is not restricted by the type or amount of data held for digital map visualization. Currently, the GIS MapGrafix, operating on a Macintosh, is implemented at SACLANTCEN, and appears capable of handling the high resolution bottom complexities.

The numerical data derived from physical property analysis are best held in a database, either in file format or in a relational matrix. Both types of database may be necessary for different purposes, and preliminary experience with synthetic datasets has shown that both types can be interfaced via graphical data selection successfully with the GIS.

If any programming is undertaken, it must be no higher than the macro standard within a commercial application. This will ensure that if the data recording system and the data derived from it are used by a number of operators, interchange of data between users can be maintained.

2.2. QUANTITATIVE SEA-BOTTOM DESCRIPTION

Two different types of quantitative information can be gained for any sea-bottom site.

1. Morphological and other descriptions and *in situ* measurements. These can only be obtained at the observation site and probably comprise the most valuable data.
2. Laboratory determined physical properties. These are determined in a laboratory, which may be either on board ship, or on land.

Both types of information are necessary in order to adequately describe small-scale features and physical properties on the sea bottom. Permanent records of observations can include photographs, videos, and remote sensing records captured and stored in a wide variety of forms.

2.2.1. *In situ seafloor and water description and measurement.*

Morphology of a surface is its shape or texture described in a quantitative or semi-quantitative manner, which can be modeled graphically. Commonly, a variety of high resolution sedimentological, biological, and man-introduced features are found over discrete areas of the seafloor. Although individual areas may appear complex or confused, these areas can usually be modeled in terms of their dominant morphological character. Even on the small scale, areas of various charactor often have relatively sharp margins.

Morphology is derived only partly from bathymetry. Bathymetry is an often gross representation of sea-bottom depths. Morphology is an environmental model of a geographically indexed statistical and graphical expression. In many areas where a bathymetric data set might show a relatively simple sloping or flat bathymetric surface, a morphological model can represent seafloor roughness, composition, and the asymmetrical disposition of the various morphological elements and physical properties.

Qualitative sediment composition From a purely observational standpoint, the detailed composition of sediment is a principal descriptor. In addition, the high resolution variation in sediment composition (grain size of clastic sediment) is usually intimately related to the development of high resolution roughness. For instance, the sediment type commonly found in ripple dunes is usually quite different from the sediment in ripple troughs; it can be either coarse or fine depending on local depositional history and environmental conditions.

All sediment is naturally occurring unconsolidated particulate material lying on the seafloor, which has not been significantly compacted or cemented. Qualitative observations as to general sediment type can be logged *in situ* with little difficulty. Quantitative laboratory analysis of sediment samples, can be carried out. However, it has been found that the qualitative observations alone are often adequate for many purposes.

Slope and seafloor orientation This is another first order morphological descriptor of seafloor. Seafloor, within the visibility of most dives, may be almost flat appearing, but local slopes often can be measured.

Mechanical properties; penetration, shear strength These must be measured, wherever possible, *in situ* on the seafloor to minimize alteration introduced by the sampling and extraction process. For the purpose of this database, all rock, unless it is strongly altered by weathering and secondary processes that have caused significant reduction of mechanical strength, can be treated mechanically as the same material. Thus the type of rock present is less important than it would be in a purely geological evaluation of the seafloor. Penetration testing, shear strength testing and sampling for the presence of gas can all be carried out by a diver *in situ*.

Ripples and other current features Ripples and other current features such as sediment ribbons and patches often dominate the high-resolution sediment surface. Current features are important because they are intimately related to sediment composition and cause asymmetry of high-resolution roughness. For the purpose of these observations, the word 'ripple' is used to denote all longitudinal roughness elements whether they are ripples, waves, or ribbons (formed along current trend rather than at an angle to current). This allows the orientation of morphological elements to be characterized in an azimuthal framework without the need to draw on specialist observational requirements. Where possible, the type of longitudinal element also can be identified.

Rock and rock roughness This is also a primary seafloor descriptor on large areas of many shallow-water areas. For the purposes of observation, rock is considered to be any thoroughly compacted, cemented, or more lithified material. Often, there is only a thin, discontinuous veneer of sediment on an eroded rock bottom. In this case the morphological character of the rock surface, because of its high acoustic reflectance, is extremely important.

Seaweed cover is usually associated with rock or a very course, rocky bottom where the seaweed can anchor.

Weathering effects in rock Rock surfaces are commonly weathered, in some cases to many metres depth. However, the most a diver will usually be able to ascertain is whether the immediate rock surface is strongly weathered. Cm thick crusts of soft, recrystallized rock are common on some marine exposures and fracturing or cracking can also occur. The presence of both these secondary attributes are potentially important because they strongly alter the normal acoustic or seismic character of the rock mass.

Color This is an important secondary observational parameter that is usually directly related to sediment and rock composition and disposition. Surface and subsurface color can vary strongly, depending on the nature of biological activity and oxygenation. Color normally does not change rapidly in a sample saturated with its accompanying bottom seawater after sampling, expecially when contained in a sealed core barrel. Color in the laboratory is normally determined using natural sunlight according to widely used international color schemes for sediment and rock color such as Munsell (1990). Fine variations in color can be identified under laboratory conditions. Underwater, however, only general color can be determined with confidence. Sunlight underwater varies with depth and water transparency, as well as with the time of day and other natural factors that virtually rule out repeatability of fine-variation underwater color identification.

Biological presence, 'seagrass' fields and patches 'Seagrass', which is a general name for marine plants similar to coarse terrestrial grasses, often form knolls and large meadows in shallow water. They are particularly common on limy substrate such as shelly sands and where water is particularly clear and unpolluted. Seagrasses are found in both Mediterranean and Atlantic shallow-water areas. *Posidonia* is probably the most common type in the Mediterranean. Usually found adjacent to coasts, it can extend many kilometers offshore and is also found on isolated banks.

It often stands in dense blankets up to 40 cm high that can be in constant movement, driven both by currents and wave activity. It is responsible for considerably aerating the marine sediment in which it is rooted, and for exsolving gas into the sediment and water as part of its photochemical life processes. Gas bubbles can also be common, fixed to the plant surfaces by surface tension. In addition, plant surfaces can also be encrusted with calcareous algae and small shelly organisms.

Mounds, biological activity Many seafloors, especially those below normal wave base that are composed of muds and silts, have surfaces whose morphological textures are determined largely by biological activity. It is common for some marine burrowing organisms such as worms and shellfish to throw up mounds on the seafloor around their habitats. These mounds can often be 10–40 cm high, and they can cover up to 75% of some seafloors. Where current activity is weak, mounds can persist for long periods, even after the death of the biological community that formed them. There are often also associated seasonal and shallow gas generation effects.

Depressions, pockmarks Where gas and fluid seeps are common, pockmarks and shallow depressions can form the dominant seafloor texture. Usually pockmarks are on the order of 5 m across, which makes their overall shape difficult for a diver to judge. However, the uneven, curved ridges and slope breaks associated with pockmark rims are quite distinct from ripple dune current features. Confirmation of pockmark extent rests with a good side-scan sonar record.

Scars Some areas of continental shelf and slope are scarred by the marks of trawling and anchor drag over more than 95% of the seafloor area (Max and Michelozzi, in preparation). Their presence is important for a number of reasons. Firstly, the scar forms a wall or two walls to the scar depression, and there is often a spoil train thrown up to one side. These scars form unnatural facets in what would often be a flat natural seafloor. Whatever the natural morphological character might have been, scaring strongly alters its high-resolution morphology along with the acoustic reflection character. Secondly, where a scar occurs, sediment is compacted and dewatered, causing higher acoustic velocities and higher reflectances, as well as greater resistance to object penetration because of a higher strength.

Dumps Continental shelves contain areas where material has been dumped on purpose or by accident. Where this material is of a strongly different character to the natural seafloor on which it occurs, its presence defines a definite seafloor type for the purposes of this database. Sometimes, where highly reflective dumped objects occur, even single occurrences are worthy of note.

Water movement Water can be characterized both by observations and measurements. Bottom currents can be measured and estimated by a variety of means and no single method is preferred here. Dyes, Secchi discs, actual movement over distance, and other methods can all be used to find current speed and direction.

Water visibility, transparency and turbidity These can be both measured or estimated. Both methods are valid.

Transparency describes the ability of visible light to pass through water. Light transmission is impeded by the presence of particles and natural dyes, which can absorb light either in a wholesale manner, which simply dims the light, or a frequency dependent manner, which can strongly 'color' the water. Light is commonly absorbed and impeded by water-dispersed particles which are large enough to reflect or scatter light, giving the water a cloudy or turbid appearance. Turbidity is attributable to the presence of any particles greater than one nanometre (1 nm = 1/1,000,000 mm) irrespective of their chemical nature.

Water transparency is most variable in coastal waters where salt water incompletely mixes with fresh water and its high sediment and natural dye load. In addition, coastal waters often contain a high proportion of fine sediment introduced by aeolean (wind) processes. Where visibility is low, it is important to know whether particulate material or some other reason is the cause.

Direct photoelectric measurement of turbidity is normally carried out both in laboratory and *in situ* conditions. The data is expressed in terms of Formazin units, an international standard measure and technical standard, that allows direct comparison of these measurements in this database with water turbidity measured elsewhere. For semi-quantitative purposes, and to calibrate the ocean area visibility, site measurements of Formazin units can be compared with Secchi disc measurements.

It is common to use the simple, yet effective Secchi disc to measure water visibility. This device was introduced as long ago as 1865 and consists of a metal disc 20 cm in diameter, painted in alternately white and black quadrants. It is suspended on a line and lowered into the water or swum horizontally by a dive team. The depth or distance at which it disappears provides a measure of water transparency. Results obtained by a number of scientific divers have been found to vary by no more than 0.5 m. Clean coastal seawater can commonly have visibilities on the order of 30 metres or greater.

Both transparency and turbidity change dynamically in shallow and littoral waters, especially under conditions of periodic storms which cause re-suspension of bottom particles. These parameters are thus less likely to be characteristic of the water mass over a long period of time as are some of the other parameters, such as salinity.

It is intended that in addition to any transparency and turbidity measurements made on the bottom that the surface team will make Secchi disc measurements on the sea surface.

2.2.2. Other parameters that can be measured in situ.

Conductivity or salinity Salinity is a measure of salt content of a water. It is reported as grams of salts per thousand grams of water, that is, as parts per thousand by weight ('X. w/w'). Salinity measurements provide a convenient method for monitoring the mixing of freshwater with seawater, and can be related directly to water density, which is directly related to the speed of sound in water. Salinity is easily measured directly *in situ*.

Dissolved oxygen Oxygen is only sparingly soluble water, that is, the highest concentrations (mass per unit volume) found in waters are very low compared with many other chemicals commonly found in sea water. For instance, clean sea water at 15°C contains only about 8.1 milligrams of dissolved oxygen per litre. When water is enriched with organic matter such as sewage or run-off from agricultural areas, a great variety of oxygen-consuming microorganisms rapidly multiply in response to the newly available nutrients and dissolved oxygen levels decrease. In deeper and restricted waters, for instance the Black Sea or harbors with restricted access, and in other poorly oxygenated regions, oxygen depletion is even more marked than in normal littoral conditions.

Dissolved oxygen levels are reported as concentrations in terms of 'tension', which is often loosely referred to as partial pressure. This expresses the oxygen pressure as a percentage of total pressure, which changes with water depth. This has the effect of normalizing the oxygen values so that they can be directly compared regardless of water depth. The tables employ the pressure unit 'torr' (1.0000 torr = 1.3332 mbar). When water is potentially in equilibrium with the atmosphere there is no net transfer of oxygen between the water and the atmosphere and the oxygen tension lies in the range 155 to 160 torr. Thus, dividing any of the tabulated values by 158 torr yields a good approximation of the degree of oxygen saturation. If this fraction is less than 1 the water is said to be undersaturated, if greater than 1, it is supersaturated.

Other gases Oxygen deficiency in sea bottom sediment can important. When biodegradable particles accumulate on the seafloor or in an estuary or bay, the rate of oxygen uptake by the waste-consuming microorganisms may well greatly exceed the rate at which oxygen enters the sediment from the water. In this case the sediments become completely depleted of oxygen and the oxygen-consuming ('aerobic') microorganisms become dormant or die and the oxygen-hating ('anaerobic') bacteria begin to multiply, taking over the biodegration process. Some of these bacteria produce hydrogen sulfide, a toxic gas with a characteristic rotten-egg odor. This gas reacts with traces of metals in the sediments and water and gives it a characteristic gray to black appearance. Other anaerobic bacteria release nitrogen, an inert, colorless and tasteless gas, and methane, which can act as a food stock for microorganisms in the benthic boundary layer. When these anaerobic gases are produced in quantity in the uppermost sediments, gas bubbles can coalesce, forming pock marks as they escape the sediment layer and causing lumps of sediment to become detached.

Gases other than oxygen can be analyzed from gas samples collected directly or *in situ*. No analyses other than *in situ* oxygen is planned, but provision for further analyses can be made from gas, water, or sediment samples.

Samples; suspended solids It may be necessary to take water samples to determine the precise nature of water coloring or turbidity.

'Suspended solids' is the term for water-dispersed material which can be removed through the normal process of settling. Much of the material introduced to water by natural and human processes is very small in particle size and is often of low density; it commonly remains in the form of suspended solids. There is almost always a direct relationship between transparency and suspended solids. However, in highly turbulent (vigorously moving) waters, for instance in near shore littoral conditions during stormy weather, a considerable fraction of the suspended solids can consist of resuspended particles that will settle out relatively rapidly when water turbulence diminishes.

Provision is made for recording the taking of water samples, although this will rarely be carried out. Details of analyses will be reported in the database, following laboratory analysis.

2.2.3. Laboratory determined physical properties

Determination of physical properties of sediment samples must be carried out in a laboratory. This activity can be associated with, or be remote from the sampling sites. Where suitable cores are available, sound velocity measurements should be carried out before the cores are opened for analysis of physical properties, and as soon after their recovery as possible.

Results of analyses for physical properties fall into two general groupings;

1. those properties that do not change owing to sampling and handling and directly represent seafloor. Grain size, color, chemical composition of particles, and stratigraphy, which is the vertical and lateral variation of the other invariant physical properties, are the same in samples and cores as they are on the seafloor, given that they have not been mixed or suffered particle loss.
2. those properties which are altered in the process of sampling and handling.

A number of important physical properties may be expected to vary between ambient *in situ* conditions and the laboratory. This is because bottom-environmental conditions are not maintained. The primary reason why these changes occur in the samples is that dissolved gas exsolves as pressure decreases during recovery from the sea-bottom to the surface. This drives fluid and gas migration and has the potential to cause small-scale changes virtually throughout sediment micro-fabric. Porosity, water content, and density, are all likely to be substantially altered from their sea-bottom state. Thus these measured properties must be regarded as reflecting, but not absolutely representing, the *in situ* properties in the seafloor. Color, water chemistry, and gas content will also vary.

Both grab and shallow coring samples are commonly acquired by SACLANTCEN on a year-round basis using standard techniques and handling procedures. Analyses are carried out using a number of recognized techniques (Tonarelli et al., 1993):

Grain size Grain size analysis requires three separate sub-analyses:

- The first sub-analysis is the pipette method, which mainly determines clay content. It calculates the fall of the particles in accordance with Stoke's Law. The sample first is sieved and then dampened with a dispersing solution and the mixture passed through a fine sieve (62.5 microns, phi 4.0). The suspension is then passed through a pipette. After 5 days of settling in a standard fluid, the phi 11, 12, and 13 size fractions (fine and very fine clay) are determined.
- The second sub-analysis is carried out using a sedigraph, which uses analyzed soft x-ray emission to detect relative particle size amounts. This instrument also uses Stoke's Law and the settling rate of the particles in a standard fluid to determine size fraction percentages. With this method the size fractions from 0.8 to 70 microns (silt and medium to coarse clay) are determined.
- The third sub-analysis uses sieving techniques to determine the coarser fraction. Sieves conform to the ASTM E11 US standard within a mechanical multi-axis sieving machine. The portion of the sample remaining after the initial sieving (above phi 4.0 fine sand to gravel) is stack vibrosieved. A sieve for every quarter phi from phi 4.0 to -2 and a sieve for every phi from −2 to −4 separates the fractions, which are then weighed.

The data from the three separate sub-analyses are tabulated within a spreadsheet and the data is numerically analyzed. Results can be presented in a number of ways:

1. Particle size in phi or fraction of phi, which is a specially defined metric size fraction definition
2. Weight in grams corresponding to phi data
3. Percentage of the raw numerical values
4. Cumulative percentage of the sediment in terms of phi size.

In addition, calculation of statistical moments are made using 7 phi units corresponding to size (i.e., 5%, 11%, 25%, etc.). The Folk values for: mean, standard deviation, skewness or asymmetry, kurtosis and normalized kurtosis and the Inman values. Median, mean, standard deviation, standard deviation, kurtosis, skewness 1 and skewness 2 are also calculated within a spreadsheet.

Calcium carbonate A Dietrich Frühling calcimeter, similar to those used in commercial activities such as cement factories, is commonly used. It operates on a gasometric technique that allows for rapid analysis and accuracy of ±1.0%.

Porosity Porosity is the ratio of the volume of water compared to the total volume of wet sediment. The volume of water evaporated from a sample is measured by weighing, before and after drying. The total wet volume of the sediment is obtained using a stereo-pycnometer to an accuracy of ±1.0%.

Water content Water content is the weight of water expressed as a percentage of the weight of the dry material. The accuracy of this measurement depends on the drying process. It has been found that keeping the samples in an oven for 48 hours at 105°C evaporates the water irrespective of prior treatment (so long as the sample was not previously dried). Water content accuracy is usually 2.0% or better.

Wet density The wet density is the weight per unit volume of the sediment mass saturated to 100% with interstitial water. It is assumed that the saturation of the sample is 100% when analyzed which is valid only when the core has not been drained. The wet unit weight is usually given with a maximum error of 1%.

Void ratio The void ratio is the ratio between the volume of the voids and that of the solid particles. The accuracy of the measurement is a relative error of 7%.

Dry density The density of the solid particles is the ratio between the weight and volume of a dried sample. This value is given with a maximum error of 6%.

Density ratio This is the ratio between wet density and specific weight of bottom water (as recovered and preserved in the core barrel).

Stratigraphy Stratigraphy is determined from cores. It is a graphical representation of sediment character with depth, that is not determined *in situ*, but only after the core has been recovered. Recording the stratigraphy is the primary way in which the immediate sub-bottom is described at each site. Stratigraphy offers a shallow sub-surface, or three-dimensional component to bottom observation. The character of continuity of stratigraphic changes between a number of sites allows estimation of lateral continuity of the uppermost bottom sediment outside of the sampling area. The first order elements of stratigraphy are determined by visual inspection of the macroscopic properties immediately following core recovery and quantitized following laboratory analysis.

2.2.4. Records of observations

Written data record of observations The primary record of sea-bottom character is held on waterproof data recording sheets. The variety of information can be expanded or varied to suit the purpose of collecting the data, the particular variations of any specific shallow-water area, or operational and training considerations. Other record types are photographs, side-scan sonar, multibeam bathymetry, and less commonly used remote sensing apparatus. These materials are stored separate from the database.

Photographs Macroscopic coarse material such as shells, shell fragments, pebbles, etc., taken from cores, may be photographed in the laboratory, as well as *in situ* photos of the seafloor. These should be noted immediately when taken, with film number, location, etc., entered in the permanent record sheet as soon as possible.

Video Underwater video can now be taken during most operations and is very useful in deeper shelf areas. Camera locations should be entered in the GIS database along with core and grab sample locations and all track information, with video copying facilities provided for archiving all video from particular sites or natural laboratories in a systematic, recoverable fashion.

Digital records All site information should be geographically referenced.

2.2.5. Qualitative or inferred sea-bottom information

Side-scan sonar, reflection and refraction seismics, special acoustic bottom classifiers and other special sonars, and remote systems that test for specific physical properties, all return information of sea-bottom character. It is not intended to discuss the precise relationship between any of these systems and the high resolution information that can be gained from direct observation because this discussion would be long and specific to each of these systems. When the direct observations and acoustic system response are combined, however, many features in the acoustic record that were inferred should be relateable to real bottom features.

The real value of any sea-bottom information, be it derived from acoustic, direct observation or other means, is when it can be related to other information such as that derived from remote-sensing instruments. Because the scale of the areas of interest in shallow-water seafloor are now becoming much finer than before, a high resolution database is fundamental to interpretation of remotely-acquired data.

3

Systematized data recording

3.1. INTRODUCTION

A systematized data recording system for high-resolution shallow-water bottom features has been devised that allows integration of a wide variety of observations. This systematization forces observers to record their information in such a way that it can be compiled into a single enumerated dataset. The system provides a hard copy record for each site that can be shared by simple copying, and archived at more than one site. Once enumerated, the data can be treated statistically as well as graphically. Provincing of bottoms based on a variety of parameters, can thus be made to provide map output suitable for particular demands. The basis of the recording system is a tablet on which the basic observations are made on a transparent overlay.

It is not necessary to record all parameter sets; only those that dominantly describe the bottom. In fact, it is unlikely that all data topics included on the tablet will be considered on most dives. However, in order to maintain interchangeability of the data sheets, it is necessary that all data tablets have the same selection categories. To facilitate observation and data quality, it is envisaged that templates may be inserted beneath the data recording sheet which will block the attributes which are not to be recorded. Blocking view of unnecessary data makes the observational process easier and the data more reliable. With training and familiarity, observers should make more decisions faster and more reliably.

1. *Choice selection.* For many of the descriptors, only a limited number of choices are offered in each category. The observer must select the best choice in each category, even though he/she might regard the situation to be marginal between two choices. With a large enough dataset, randomness will introduce a statistical balance.

2. *Orientation and numerical entries.* Although the presence and type of features can be denoted through choice selection, enumeration allows for detailed statistical treatment. In the case of orientation, the same compass rose symbol has been used in all cases. On these compass roses, the linear trend of features can be entered as a simple line, with enumeration of, for instance water velocity and dip of surfaces shown as numbers near an arrowhead. For height and width or spacing of features, space is provided for each numerical entry, which should be rounded up to the nearest whole cm or m for simplicity.

3. *Specific descriptions.* In only a few cases will specific descriptions of any features be necessary; space is provided at the appropriate places.

Extra space on the tablet is available for making written entries, but this is not encouraged because the observations are likely to be highly qualitative and thus unusable in relation to the other data in a systematic fashion. Practice has shown that most of these extra observations are likely to be of little value to the dataset. Because of the extra bottom time that is required to enter handwritten descriptions, there will be an impact upon the number of dives, the dive schedule, and operational efficiency if observers persist in making lengthy descriptions apart from the systematized schedule. However, it is recognized that occasionally the observer will wish to record an observation which is not provided for in the data set.

It is suggested that SACLANTCEN be the repository for at least copies of these original data sheets and the clearing house for the high resolution observational database within NATO.

3.2. THE FRAME

The frame holding the information recording tablets is enscribed with measurement enumeration that allow small distances and angles to be measured. Longer distances require multiple tablet lengths or a marked line of from 5–10 m. One side of the frame is marked in linear measurements in centimetres and the other is marked in angular measurements in degrees. A combined compass and inclinometer, such as used by field geologists, can be mounted on the frame for ease of use and security.

The frame holds data-record sheets firmly in position over either side of the tablet. The frame also has a robust handle. The exterior size of the frame that contains information is also smaller than A4, for easy copying, although the overall exterior size of the frame is slightly greater than A4. Practice has shown that this is the maximum size for a data record sheet that can be handled with confidence under difficult diving conditions.

Frames can be implemented in a variety of manners to suit the type of bottom and diving conditions. No seabottom information is recorded on the frame, although information relevant to the dive (time, depth, dive profile, etc.) may be. Logging of dive character is also made on the frame. It is not intended to archive dive information in the database, except where it pertains to sea bottom or water column features such as current shear zones.

3.3. THE TABLET

The observational tablet consists of a two-sided plastic tablet with characterization of both naturally occurring and human activity. Initially it was envisaged that the faces would be engraved, but it was found to be cheaper and more expedient to have weatherproof printed plastic gummed labels produced. Each tablet is configured for describing the average and variable properties of a single bottom type. Thus, if multiple bottom types in a complex area are anticipated, for instance on a section that will pass from a sandy through a gravelly area and onto a steeply shelving rocky seacoast, a number of tablets should be taken under water. Each area can thus be described with respect to the others, with boundaries mapped either by reference to depth or directly by other means (signal to surface).

One side of the tablet contains observational parameters mainly concerned with describing rock and sediment character, particularly current features (Fig. 1a). The other side contains observational parameters pertaining to biological, sediment disruption, water, and human activity. All parameter sets are recorded in three main manners (Fig. 1b). Figures 1a and 1b are near original size so that they can be xeroxed and used directly. Both sides should be enlarged to 26 cm in width before use to ensure that all data records will have the same spatial relationship from one institute to another. Full size plastic labels are also directly from SACLANTCEN.

Information is intended to be recorded on overlays of two sheets of matt mylar, cut to fit in a standard position over the inscribed template. Thus, no data transfer from the recording tablet to a master sheet is necessary. Requiring transfer of information within the course of data acquisition has proven to lead to operational problems and loss of data and is thus undesirable.

After each site observation, the data sheets are archived by the person-in-charge, with additional information added from surface observations, and new blank sheets are inserted for another site observation. Thus a primary hard-copy of each site observation is maintained. Data exchange can be made by circulation of copies of original data sheets, or subsequently, following data reduction and quality control. The data record tablet is smaller than both A4, the standard European paper size and the North American US Letter size to facilitate observation, handling, and transfer of information in the North Atlantic and Mediterranean region. Multi-site identification parameters on each sheet of the site set guarantee the uniqueness of each set of observations and allow for subsequent computer searching of the database.

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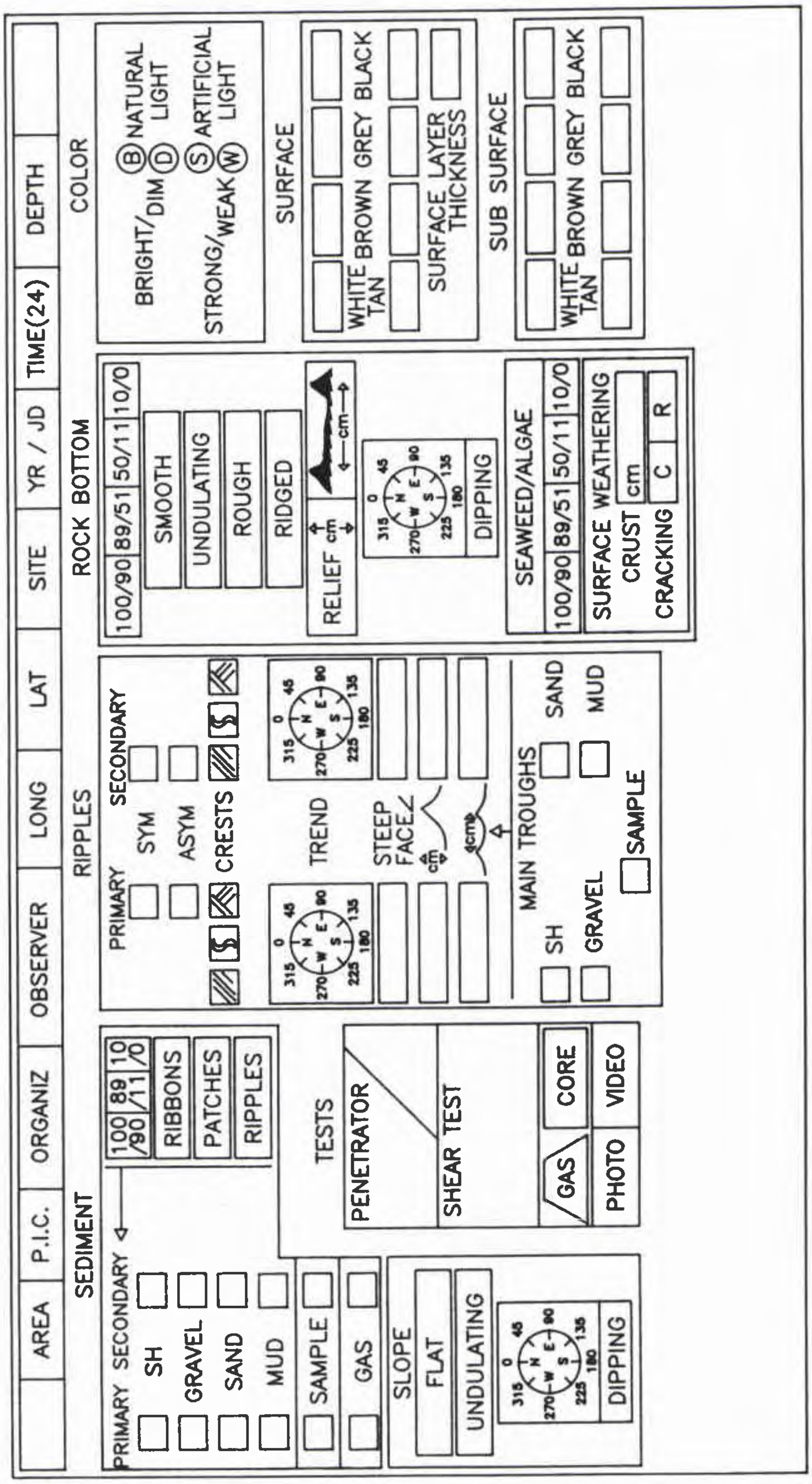

Figure 1a *Natural environment side of the tablet. Note: Only desired observatons need to be made.*

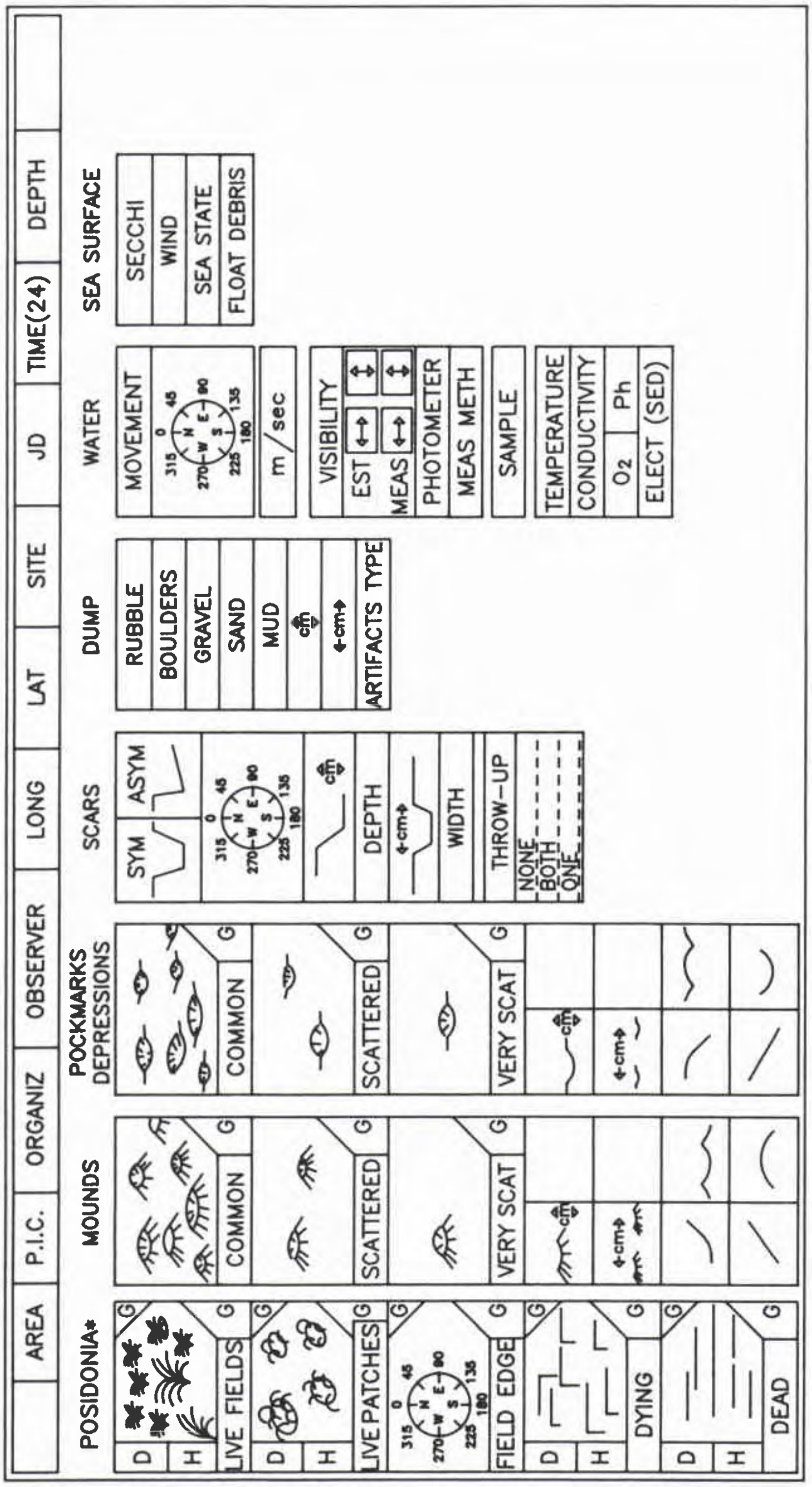

Figure 1b *Human activity and water column information side of the tablet. Note: Only desired observatons need to be made.*

3.4. OBSERVATIONS

Related observations are grouped so that like attributes are logged in a sequence. On both sides of the tablet the observer is intended to begin with the left-hand column and pass successively to the right.

Within each observational group, the natural flow of observation is from top to bottom, so that once the bottom of a column is reached, the next to the right can be begun at its top. On both sides, the most important entries are to the left. If only the left hand pertinent columns has been completed, for instance in the case of a dive being aborted, the data may still be worth archiving. Enough measurement of features is included to allow for sufficient statistical description although for some bottoms, additional detail may be available.

It is not intended that all choices, entry locations, or even columns should be filled in. The bottom may have no rock, *Posidonia*, mounds, ripples or scars. Absence of an observational group can simply be shown by a diagonal line through the entire box or the column title, to indicate that observations were not neglected.

Some observations can be entered before or after the dive by the dive officer, including the whole of the identity strip at the top of each sheet, and the surface conditions. It is the responsibility of the diving officer or his designate to insure the completion of entries, not the lead diver, who is primarily responsible for the observations under water.

3.4.1. The identity strip

The identity strip is common to both sheets and need only be filled in completely on one side, with the other filled in enough to insure that the sheets from any site can be matched if they become separated. Two blocks can be filled in with undesignated entries, if desired.

AREA	Formal project area or a named project/area; if specific to a particular institute/organization this should also be named to denote the source for inquiries. If used to denote a particular water body such as an estuary, etc., description should be self-explanatory.
P.I.C.	Person-in-Charge. Anyone who is in charge of the operational data recovery effort. He/she must be on-site. Most often this will be the Chief Scientist or the Diving Officer.
ORGANIZ	This refers to the organization(s) responsible for the collection of the information. May be multiple entries or a project name.
OBSERVER	This is the chief underwater observer.
LONG	Longitude, expressed in degrees/decimal.

LAT	Latitude, expressed in degrees/decimal.
SITE	Local area and number.
JD	Julian Day. If only month/day/year are known enter spelling out month.
TIME(24)	Time (hr:min) on a 24 hour clock.
DEPTH	Bottom depth(s) at site where observations/samples were taken. Dive depth recorded in dive profile information elsewhere

3.4.2. Side 1 – Natural sediment and rock bottom character

SEDIMENT Most bottom sediments vary, but commonly, bottom sediment can be divided into two main components, for instance where sand ribbons are present on a gravel bottom. A third and more components rarely may be present, but as it will usually comprise a very small portion of bottom sediment, no provision is made for its logging here. This can be sampled separately, if necessary.

PRIMARY refers to the main type, in areal extent, while SECONDARY refers to the main type of other sediment present, if any. Many bottoms will have no significant secondary sediments.

SH indicates shell hash, a sand formed from uneven grains of broken shells and calcareous algae; other sediment types are self explanatory. RIBBONS, PATCHES, or RIPPLES describe the main form. Where the observer is unsure, enter ripples (which includes sand waves). SAMPLE denotes the taking of a sample and GAS denotes the presence of gas freely rising from the sediment or when it is prodded gently.

Within the vision of a dive observer, most sediment covered seafloors will appear FLAT or UNDULATING. Where it is DIPPING, or sloping, the orientation of the surface can be marked by a strike line showing the orientation of a horizontal line on the seafloor, with dip shown by an arrowhead in the downslope direction with slope in degrees.

TESTS Certain quantitive measurements and other tests can be made *in situ* on the seafloor using small, hand-operated equipment. PENETRATOR refers to a penetration test carried out using a standard apparatus modified for diver use. SHEAR TEST refers to numeric values determined using a vane-shear instrument.

GAS indicates a sample of gas, and CORE indicates that a short core, as opposed to a grab sample, was taken from the seafloor. PHOTO and VIDEO indicate that either of these records were made. Their numbering and archiving must be made following return to the operational center.

RIPPLES Rippled bottoms (including sand waves) are very common in shallow water. Often, a larger set is present along with a smaller set, whose trend is often at high angles to the larger set. Ridge trends within a single set can often be complex. The larger ripples or dunes PRIMARY are usually the result of a storm or intermittent strong water movement and are often stable over considerable periods of time. The smaller set SECONDARY tends to reflect shorter term features, and less strong water movement. SYM denotes a *symmetrical* profile shape while ASM denotes an *asymmetrical* profile with one slope markedly steeper than the other. The steep slope on an asymmetrical ripple shows the direction in which current is moving. CRESTS allows three choices for the general form of the linear trend of the ridges, whole orientation and asymmetrical steep face. STEEP FACE $<$ is the slope angle of the steep face. Boxes for recording both height and crest spacing are provided. Commonly sediment in the trough is different than in the ripples. Where this is the case, the character of the ripple floor should be denoted. SAMPLE indicates that a grab sample of this material has been taken.

ROCK BOTTOM Denotes the presence of rock. Where sediment and rock are present, both columns should be filled in. Numbers are in percentages indicating approximate area that is rock covered. Form descriptors are self explanatory. RELIEF and approximate distance between rock ridges should be denoted, as well as the orientation of ridges, where they are present, using a strike line and a dip arrow where the flat surface is dipping. Rock can often be seaweed/algae covered and the approximate cover over the rock may be important. Where the rock surface is weathered there is often a soft CRUST, which is usually no more than a few cm thick, and CRACKING can either be common (C) or rare (R).

COLOR The color of a bottom can indicate a recent sediment fall or other long term depositional conditions. NATURAL or ARTIFICIAL may prevail, and this will strongly influence the apparent color.

3.4.2. Side 2 – Biological, human activity, and water properties.

POSIDONIA* refers generally to all seagrass, since in the Mediterranean it is mainly this species. This column could be titled with the names of other sea grasses. LIVE FIELDS, LIVE PATCHES, DYING and DEAD refer to the relative abundance and manner of growth. Where water has recently become polluted, seagrass often dies. D in upper left of each box is a count that indicates density of individual stalks in an average 10 cm square, H is the average measured height reached above the seafloor. G in lower right of each box indicates the presence of gas released from the seafloor with gentle prodding, and G in upper right indicates visible gas released surface tension capture when the grass when is shaken gently. Orientation of a field edge can be shown on the standard compass rose, although this trend may have no importance away from the immediate site of observation.

MOUNDS Where biological activity from burrowing animals is high, mounds are often thrown up. They can be COMMON, SCATTERED, or VERY SCATTERED. Because their size and shape are highly variable, this is a qualitative selection only. Average height and distance between mounds, as well as slope and overall form, can be denoted by best fit.

POCKMARKS/DEPRESSIONS The seafloor is often pitted from fluid and gas release. These features are like inverse mounds, and can be described by a similar terminology, and measurements.

SCARS Anchor and trawl scars are common on many shallow-water areas; in some cases, the seafloor has no naturally occurring morphology, being entirely scarred. Scars can be symmetrical SYM, or asymmetrical ASYM, and their general trend can be noted, as well as their general DEPTH and WIDTH. THROW-UP refers to ploughed-up seafloor, which may be thrown up on one or both sides of the scar. Directions should be used for all relationships, not 'right' and 'left'.

DUMP Often, material has been purposely or accidentally dumped on the seafloor. The type, general size (more than one can be selected as necessary) and height and width of the largest material should be shown. If the dumped material is identifiable, such as 'oil barrel', it should be noted.

WATER Water characteristics, such as bottom CURRENT and direction, and VISIBILITY, either estimated EST or measured MEAS, can be noted. Where it has been measured, the measurement method should be noted. Measurements and sampling will less commonly be made, but provision is made for recording a measurement.

PHOTOMETER for water transparency or translucency, TEMPERATURE, CONDUCTIVITY or salinity, oxygen and pH measurements can be made, along with a resistivity measurement of the uppermost sediment.

SEA SURFACE The primary measurement to be made at the sea surface is of visibility, using a SECCHI disc. WIND and SEA STATE should also be noted. If significant floating debris is observed it should be identified (e.g., trees, barrels, etc.) and noted.

3.5. ARCHIVING AND USE OF THE INFORMATION

The precise nature of the digital application of the high-resolution shallow-water information is not discussed here. Our main purpose is to demonstrate the need for high resolution, real seafloor data and its and its recording in a useable form.

It is intended that the observational bottom environmental data will be encapsulated on commercial software packages running on inexpensive micro-computers, such as Macintosh and IBM-compatibles. This reduces the need to have costly support to allow the information to be used. Where necessary, the information can be transferred to larger databases in UNIX-based workstations or mainframe computers. A spreadsheet or common database format ensures compatibility at the file level for data transfer. Accessibility of the information in a digital manner will enhance its use.

The observational data is archived at SACLANTCEN on Macintosh personal computers, DOS/Windows PCs and, more recently, on an Apple Power PC concurrently running the GIS under the Macintosh OS and a native 601 softwindows. Positions are geo-referenced in the MacGrafix Geographical Information System, which is compatible at the file transfer level with other commonly used GISs. It is envisaged that imminent developments in personal computing will allow for wide-spread use of the environmental dataset without particular concern for the operating system or the specific spreadsheets being used.

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Appendix A
Logged dive characteristics

Note: No figures are shown to match these descriptions, which are included in this appendix to indicate the level of dive information regarded as appropriate. Figures can be obtained by writing to 'Diving Officer, SACLANTCEN'.

Two fill-in graphics are present on the frame for recording dive profile and time. These simplify the task of keeping these records by divers and its transcription by the diving officer immediately following each dive. These are not part of the bottom data observations, but are necessary for good diving practice, regardless of the decompression computers used by the divers.

A normal site or 'square dive' profile should be used to describe dives. There should be a time box for (a) leaving the surface; (b) arrival at bottom D deepest occupied depth of site; (c) time of leaving bottom; (d) time of resurfacing. Almost all site occupations for the purposes of this data survey will be this type of dive working from the base of a shot line (Flemming and Max, in press). Total time underwater should be checked with the surface diving officer to ensure that times match. If times are not close, compare all watches and resubmerge for precautionary or recompression stop(s). Good square dive recording allows for safe multiple repetitive diving. Decompression computers may be less safe for multiple, intensive repetitive diving.

Line surveys, either swimming or with a DPV should include total time underwater and the deepest depth reached, regardless of how long that depth was maintained.

Decompression diving is not recommended, but if it is used, both divers should be regarded as having finished their diving day upon surfacing from a decompression dive.

A mandatory precautionary stop is to be included in all time underwater, but not logged as dive time for table purposes, except where tables or practice requires.

It is the responsibility of the diving officer to immediately check with the surfaced divers to confirm dive time and dive profile and maintain firm control of the diving within the planned table schedules.

Making multiple variable profile dives using a decompression computer (DC) is not recommended, although it is recognized that a correctly operating DC calibrated to a modern nitrogen absorption algorithm can safely prolong a single dive beyond the time indicated using square dive methodology.

The personnel of dive groups should not be changed during the course of a repetitive dive schedule.

A set of rules should be promulgated specifying practices and procedures, with reference to existing Codes of Practice, and specific tables should be recognized for use. The written operational rules should be as short as necessary, with referenced documents providing guidance, in order to simplify planning and administrative procedure.

Appendix B

Requirements for diver carried, multi-parametric quantitative measurement device

Precise measurement of a number of sea bottom (geotechnical) and lower volume (oceanographic) measurements are necessary to provide parameters in which acoustic and other Navy equipment can be optimized. New equipment can also be designed that can have the narrow focus, high-resolution attributes allowed by precise knowledge of the range of environmental parameters. Modern technology has allowed all of the measurements necessary to be made using sensors and probes, usually lowered from ships and boats, but occasionally carried by divers. No currently existing commercial equipment optimized for both the full range of measurements necessary and underwater handling, currently exists. Therefore, this appendix seeks to define the purpose and operational character necessary for this equipment, to facilitate its design and production. The measuring device should be optimized for both operational convenience and ease and accuracy of data recovery. Examples of information to be recorded are:

1. Salinity
2. Temperature
3. Conductivity
4. Pressure
5. Gas partial pressures

Because a wide range of underwater conditions is anticipated, it is necessary to design for the worst case, that of strong currents and low visibility. In all more favorable conditions, both accuracy and ease of data recording will be enhanced. But no matter how unfavorable bottom-observation conditions may be (and they are often difficult to predict in detail), the site occupation will have the potential to recover useful measurements without impeding safety.

1. Measure and record A primary requirement is that the device must be able to accurately measure and record all measurements so that transcription can take place on the surface after the dive if conditions on the bottom are demanding.

2. Physical character

- Size – The device must be small and easily carried in a bag.
- Weight – The device should be slightly positively buoyant with an invariant buoyancy character (not changing with depth).
- Shape – The device should be hydrodynamic and non-lift inducing. It will usually be operated facing into current. It should be capable of resting in a stable position on the bottom with the read-out facing up while not held.
- Robustness – The device must be sufficiently robust to take rough handling, but there has to be a trade-off between robustness and size/weight, the device may have to be made less robust than an engineer might prefer.

3. Operation One handed operation is preferred. This facilitates safety in demanding conditions. A pistol-grip handle with a thumb switch and a measurement trigger in the absence of automatic reading allow for best control. The handle should be on the natural up-facing side.

4. Illumination The dial should preferably be an illuminated, large digital read-out. Illumination should be capable of being switched off (most of the time). Standard commercial D-cell internal batteries should be used to guarantee replacement at remote sites. A number of test runs should be carried out early on to determine battery life and actual power consumption. It should not be necessary to break the seal on the sensor container to change batteries.

5. Operating conditions The working depth will normally be shallower than 55 m. 100 m design depth should be sufficient.

6. Design level Existing commercial sensors and read-outs should be used and manual handling should be planned for to minimize cost. Remotely-operated versions of this parametric counter can be implemented at a later state if the demand for surveys using this equipment demands.

Report no. changed (Mar 2006): SM-282-UU

Security Classification NATO UNCLASSIFIED		*Project No.* 12
Document Serial No. SM-282	*Date of Issue* December 1994	*Total Pages* 40 pp.

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Title

High-resolution characterization of shallow-water sea bottom:

Need and methodology for a ground-truth reference database

Abstract

A systematic approach to underwater observation of high-resolution seabed features has been developed. These include: morphology caused by current, wave, and biological factors and certain engineering geological factors such as compaction (penetration) and shear-strength character. Particular attention is paid to recording any seabed element that would constitute a discrete acoustic reflector and areas of strong acoustic scattering, such as would be characteristic for seagrass meadows. An underwater recording tablet is proposed and its use described. The information is recorded in such a way that it is amenable for encorporation into spreadsheets and relational databases that can be linked to digital maps.

Keywords

environment, GIS, high resolution, sea-bottom morphology database

Issuing Organization

North Atlantic Treaty Organization
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Report no. changed (Mar 2006): SM-282-UU

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