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Bruun memorial lectures, 1989

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Impact of new technology on marine scientific research

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Preface

Presented during the Fifteenth Session of the Assembly of the Intergovernmental Oceanographic Commission, this series of lectures is dedicated to the memory of the noted Danish oceanographer and first chairman of the Commission, Dr. Anton Frederick Bruun. The "Bruun Memorial Lectures" were established in accordance with IOC Resolution VI-19 in which the Commission proposed that important intersessional developments be summarized by speakers in the fields of solid earth studies; physical and chemical oceanography and meteorology, and marine biology. The Commission further requested Unesco to arrange for publication of the lectures and it was subsequently decided to include them in the "IOC Technical Series".

Anton Bruun was born on 14 December 1901, the first son of a farmer; however, a severe attack of polio in his childhood led him to follow an academic, rather than an agrarian career.

In 1926 Bruun received a PhD in zoology, having several years earlier already started working for the Danish Fishery Research Institute. This association took him on cruises in the North Atlantic where he learned from such distinguished scientists as Johannes Schmidt, C.G. Johannes Petersen and Th. Mortensen.

Of even more importance to his later activities was his participation in the Dana Expedition's circumnavigation of the world in 1928-1930, during which time he acquired further knowledge of animal life of the sea, general oceanography and techniques in oceanic research.

In the following years Bruun devoted most of his time to studies of animals from the rich Dana collections and to the publication of his treatise on the flying fishes in the Atlantic. In 1938 he was named curator of the Zoological Museum of the University of Copenhagen and later also acted as lecturer in oceanology.

From 1945 to 1946 he was the leader of the Atlantide Expedition to the shelf areas of West Africa. This was followed by his eminent leadership of the Galathea Expedition in 1950-1952, which concentrated on the benthic fauna below 3,000m and undertook the first exploration of the deep-sea trenches, revealing a special fauna to which he gave the name "hadal".

The last decade of Bruun's life was devoted to international oceanography. He was actively involved in the establishment of bodies such as the Scientific Committee on Oceanic Research (SCOR), the International Advisory Committee on Marine Sciences (IACOMS), the International Association for Biological Oceanography (IABO) and the Intergovernmental Oceanographc Commission (IOC); he was elected first Chairman of the Commission in 1961.

His untimely death a few months later, on 13 December 1961, put an end to many hopes and aspirations, but Anton Bruun will be remembered for his inspiring influence on fellow oceanographers and his scientific contribution to the knowledge of the sea which he loved so much.

Contents

Opening Statement

Prof. Manuel M. Murillo, First Vice-Chairman IOC

Distinguidos Delegados,

Me complace sobremanera abrir este Punto de la Agenda correspondiente a las conferencias en memoria del Dr. Anton Bruun de Dinamarca, primer presidente en la Comisión Oceanográfica Intergubernamental, quien falleció el 13 de diciembre de 1961. Esta serie de conferencias Anton Bruun se realizan cada dos años en ocasión de la reunión de la Asamblea de la Comisión Oceanográfica. Tal como ha sido costumbre, un resumen/texto de las conferencias será distribuido y después publicado como un documento especial de la Comisión.

En esta ocasión el tema alrededor del cual giran las Conferencias Anton Bruun, es la aplicación de tecnologías avanzadas para la investigación de Océanos.

Tres distinguidos científicos han sido invitados para hacer estas presentaciones. El Dr. Bernard Grandvaux de Francia, Sir Anthony Laughton de Inglaterra y el Dr. D. James Baker de los Estados Unidos. El orden de presentación de las conferencias es el que he mencionado.

Voy ahora a hacer un breve resumen del Dr. Bernard Grandvaux:

El Dr. Grandvaux es Sub-director de Ingeniería y Tecnología del IFREMER, (Instituto Francés de Investigaciones para la Exploración del Mar). La carrera científica del Dr. Grandvaux comenzó con su graduación como Ingeniero en el Instituto Nacional Politécnico de Grenoble, Francia en 1961. Luego se desempeñó como Ingeniero de Estudios de Investigación y Jefe del Departamento de Acústica Submarina de la Marina Francesa entre 1961 y 1975.

Seguidamente, fue designado Jefe de los Servicios Técnicos de la Base Oceanográfica del Mediterráneo del CNEXO (Centro Nacional para la Exploración de los Océanos) entre el 1976 y 1982.

Seguidamente, ocupó la Dirección Técnica de la Sociedad Francesa de Trabajos en Alta Mar entre 1982 y 1983 donde ocupa el puesto de Sub-director en Ingeniería y Tecnología de IFREMER desde 1983 hasta la fecha.

El Dr. Bernard Grandvaux hará una presentación sobre la utilización de sumersibles y Vehículos Teleoperados a Control Remoto al Servicio de la Investigación Oceanográfica.

Es con gran placer, que invito al Dr. Grandvaux, a iniciar su presentación.

1. Submersibles et véhicules télécommandés au service de la recherche océanologique

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Summary

Submersibles and Remotely Operated Vehicles at the Service of Oceanologic Research

One of the main aims of IFREMER, a public body, is to offer to the national scientific community the facilities of the heavy equipment which it requires for oceanographic research.

Within this framework, and based on more than 20 years experience, its teams have developed and operated a whole range of first class submersibles, remotely operated vehicles, equipment and tools for exploitation and intervention in deep seas.

This presentation is aimed at describing their main components and commenting on contributions made to discoveries and recent scientific oceanographic activities.

As can be seen, these vehicles were often used in international cruises in which some of the most well-known scientific teams participated.

Je voudrais tout d'abord vous remercier de m'avoir invité à vous présenter cette conférence lors de la journée inaugurale de votre Assemblée. Je mesure l'honneur qui m'est fait et j'y répond par le plus vif plaisir, d'autant plus que le sujet que je dois vous présenter aujourd'hui est celui auquel j'ai consacré les quinze dernières années de ma carrière professionelle.

Donc, je vais vous présenter - et j'espère répondre à votre attente - cet exposé sur l'utilisation des submersibles et des véhicules sous-marins téléopérés pour la recherche océanologique. Pour ce faire, je vais revenir un petit peu en arrière au cours de la décennie 1950. Au cours de la décennie 1950 sur une idée du Professeur Auguste Piccard, on assista à une amicale mais non moins vive compétition entre le BATHISCAPHE Trieste qui avait été développé en Italie puis ensuite repris par la marine des Etats Unis et le BATHISCAPHE Archimède (figure 1) qui avait été développé par la marine française. Ces deux BATHISCAPHES se livraient donc à une petite course au record, si je puis dire, et c'est ainsi que le 22 janvier 1960 le BATHISCAPHE Trieste plongeait à 10 916 mètres dans l'Océan Pacifique, suivi deux ans après d'une plongée de l'Archimède à 9 545 mètres - cela s'est passé le 26 juillet 1962. Ces deux exploits marquaient

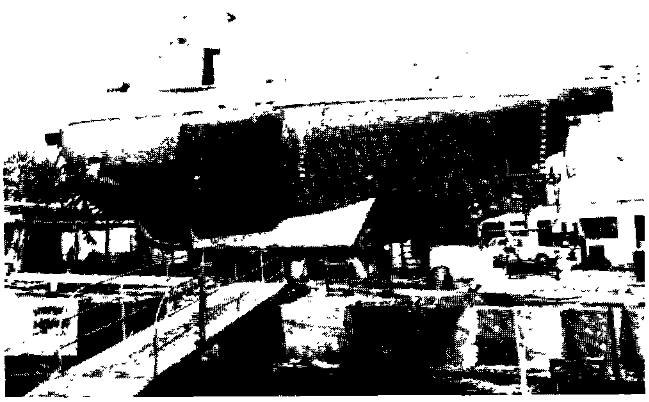

Figure 1

le début d'une nouvelle aventure qui était l'utilisation de ces véhicules sous-marins pour l'exploration scientifique des océans, mais aussi pour l'exploitation industrielle de leurs ressources. Si vous le voulez bien, c'est au premier aspect scientifique que je consacrerai mon exposé d'aujourd'hui, et pour ce faire j'adopterai comme fil d'Ariane l'ordre séquentiel avec lequel il est désormais classique d'effectuer les campagnes de reconnaissance géomorphologique.

Le point de départ de toutes ces campagnes, et avant même de faire intervenir les véhicules sous-marins, c'est le relevé bathymétrique - relevé bathymétrique, qui vous est bien entendu familier à tous et donc vous savez qu'il est maintenant effectué par les techniques des sondeurs multifaisceaux dont le premier équipement civil fut installé en 1977 sur le navire océanographique français le JEAN CHARCOT, mais qui est maintenant très répandu et qui est vraiment l'équipement de base de toutes recherches océanographiques. Donc, après que l'on ait effectué un relevé bathymétrique systématique avec ces sondeurs multifaisceaux, dont je vous rappelle qu'ils permettent d'établir des cartes avec des courbes de niveau espacées de 5 à 10 mètres environ, mais dont la bathymétrie relève d'une valeur moyenne sur des surfaces qui peuvent atteindre plusieurs centaines de mètres de diamètre. On a donc là des relevés qui même s'il sont déjà assez précis, sont en fait encore très loin de donner aux géologues tous les paramètres, toutes les données qu'ils demandent.

On va passer aux véhicules sous-marins qui permettent des degrés d'investigation à résolution croissante. On commençera (figure 2) par les systèmes d'imagerie acoustique. Sur cette figure vous voyez représenté le schéma d'un système d'imagerie acoustique

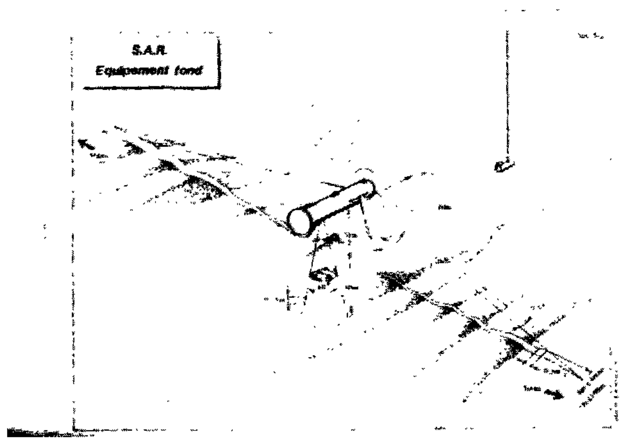

Figure 2

qui utilise deux capteurs principaux, l'un est le sonar lattéral, l'autre le sondeur penétrateur. Le sonar lattéral est un outil qui est désormais familier aux océanographes et qui permet une photographie acoustique un petit peu comme on fait la photographie aérienne des surfaces terrestres. Cet équipement va nous permettre une photographie acoustique des fonds marins et en lui associant un sondeur pénétrateur on pourra avoir également une connaissance des premiers mètres du substratum. La figure 3 montre un exemple de système

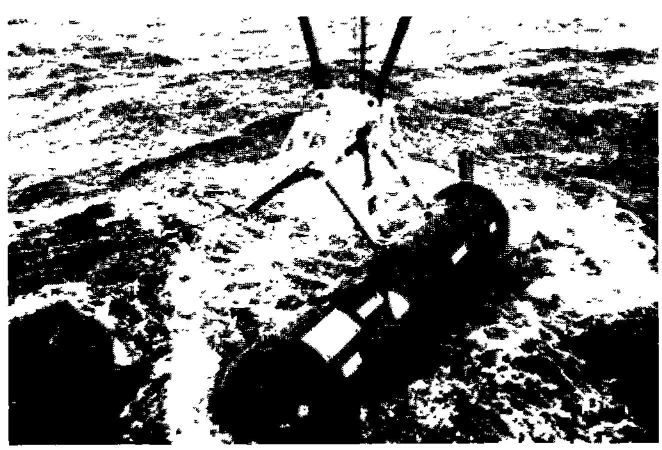

Figure 3

sonar latéral, il s'agit du système SAR (Système Acoustique Remorqué) qui est opéré par l'IFREMER au bénéfice de la communauté scientifique. C'est un gros poisson qui fait environ quatre mètres de long et qui est remorqué par les plus grandes profondeurs à une altitude de quelques dizaines de mètres au dessus du fond. Ce gros poisson porte de part et d'autre les antennes du sonar latéral qui va servir à l'imagerie. Sur la figure 4 vous voyez au milieu dans la partie noire un petit rectangle bordé de couleur, ce sont les antennes du sonar latéral d'imagerie. Ces sonars latéraux permettent une résolution qui est de l'ordre de quelques mètres, c'est à dire qu'on va être capable de saisir sur le fond de la mer des détails dont les dimensions seront de quelques mètres

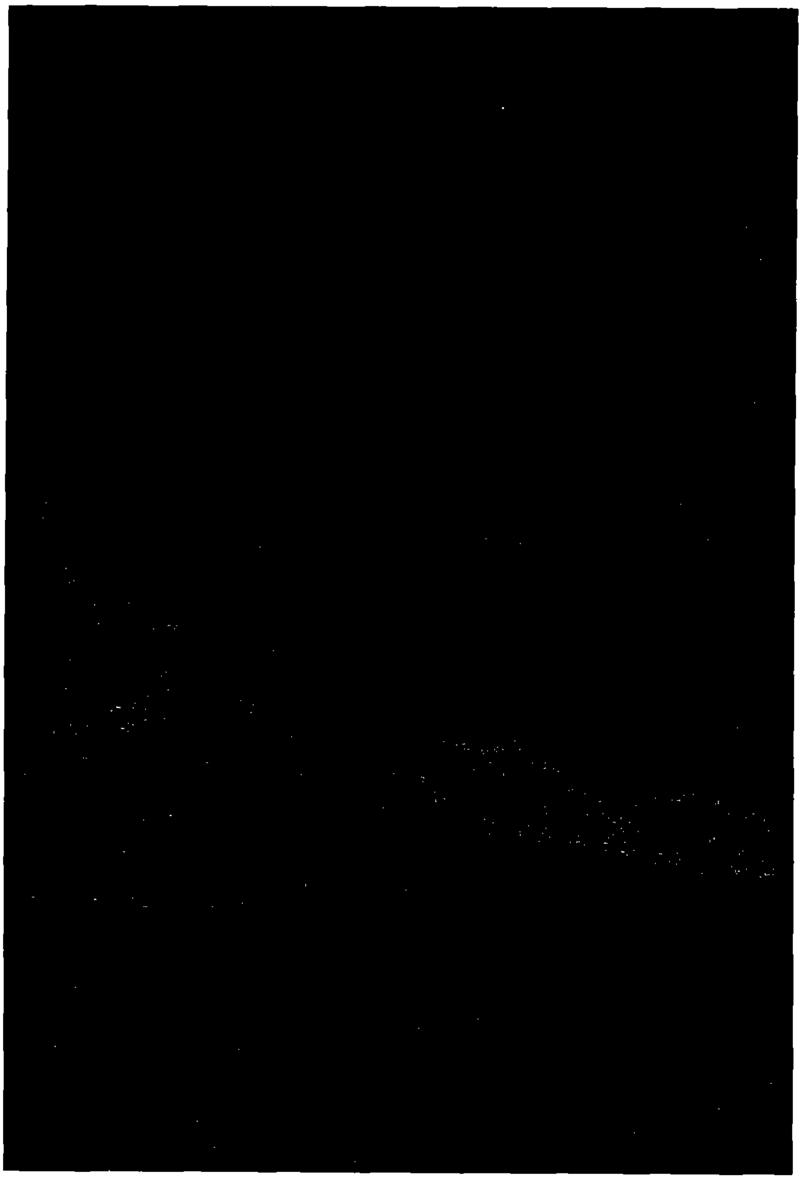

Figure 4

Figure 5

et le taux de couverture, c'est à dire, les surfaces que l'on pourra couvrir chaque jour avec un tel système remorqué à une vitesse d'un ou deux noeuds derrière le navire, de l'ordre de quelques kilomètres carrés par jour. Qui dit imagerie très précise dit faisceaux sonar extrêmements étroits et nécessité d'une très grande stabilité de navigation du poisson. Pour ce faire le poisson est découplé des mouvements de pilonnement ou des mouvements de lacet du navire par l'intermédiaire d'un lest. Avec cet appareil on peut relever des photographies acoustiques dont vous voyez un exemple sur la figure 5 qui est une sorte de canyon sous-marin - vous voyez une photo qui s'apparente un petit peu - comme je vous le disais - à une photographie aérienne. Une difficulté cependant, c'est une difficulté d'interpretation; le sonar latéral travaille en éclairage rasant, si je puis dire, du fond de la mer et par conséquent l'imagerie s'obtient par un phenomène d'ombre et sur ces images les parties blanches que vous pouvez observer sont en fait les ombres portées par les reliefs sous-marins. Cela necéssite une très grande habitude des scientifiques pour interpréter ces images, qui sont néanmoins extrêmement riches d'information. Voilà un autre exemple (figure 6) de relief sous-marin relevé avec un sonar latéral. La dimension d'une telle image, sa largeur dans le sens vertical sur la photo est

Figure 6

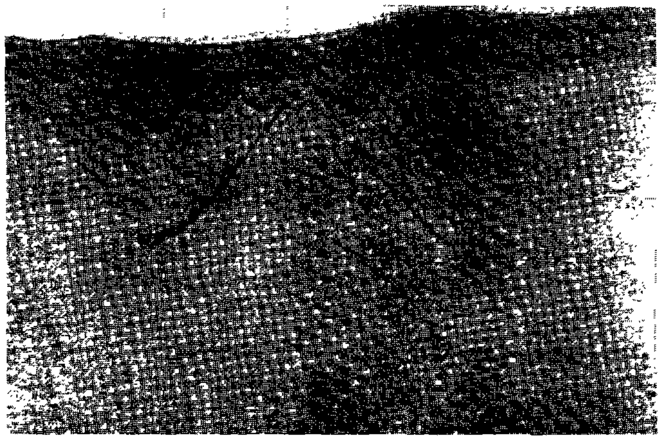

Figure 7

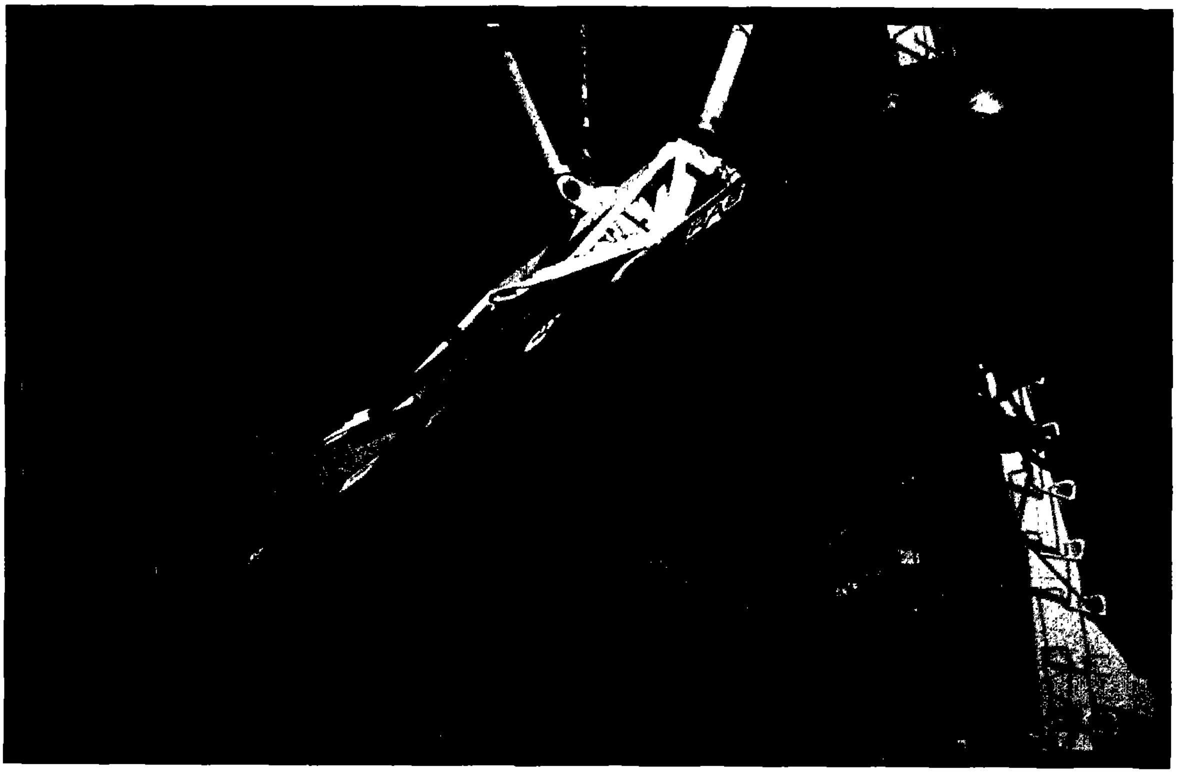

Figure 8

en gros de 1500 mètres et les plus petits reliefs que l'on peut distinguer sont de l'ordre d'un mètre à quelques mètres.

Je vous disais que le sonar latéral était associé à un sondeur pénétrateur et paralèllement à la photographie aérienne du relief, on peut, à l'aide de ce sondeur pénétrateur, avoir une bonne connaissance du substratum. Sur la figure 7, la pronfondeur de pénétration est de l'ordre de 70 mètres et la résolution, c'est à dire la finesse avec laquelle on peut déterminer les couches du substratum, est de l'ordre de 70 cm. Bien entendu, un tel équipement s'il est capable d'observer le relief sous-marin peut être utilisé aussi pour de la recherche d'objets et vous avez sur la figure 8 l'image acoustique d'une épave sous-marine qui est traitée par un traitement fausse-couleur et là encore, vous pouvez distinguer de façon très fine la silhouette d'un navire et la partie vert clair qui est à la partie supérieure du navire est l'ombre portée du bâteau sur le fond de la mer,un petit peu comme ce que vous pourriez observer avec une photographie sous éclairage rasant.

Après la bathymétrie faite par sondeur multifaisceaux, voilà le deuxième stade de reconnaissance géomorphologique qui est l'imagerie acoustique dont je vous rappelle qu'elle a des résolutions de quelques mètres avec des taux de couverture de quelques kilomètres carrés par jour.

Si l'on veut poursuivre l'investigation encore plus finement et avant de faire intervenir les submersibles habités qui sont des engins à grande capacité d'investigation mais aussi relativement couteux on va faire intervenir une autre catégorie de système qui sont les engins téléopérés, engins qui vont donner une capacité d'observation avec une résolution encore plus grande que l'imagerie acoustique mais, bien entendu, avec une couverture plus faible. La figure 9 présente un exemple de véhicule téléopéré qui s'appelle L'EPAULARD - c'est un véhicule libre télécommandé par onde acoustique, c'est à dire qu'il n'est pas relié au navire par un cable de liaison. Il est entièrement

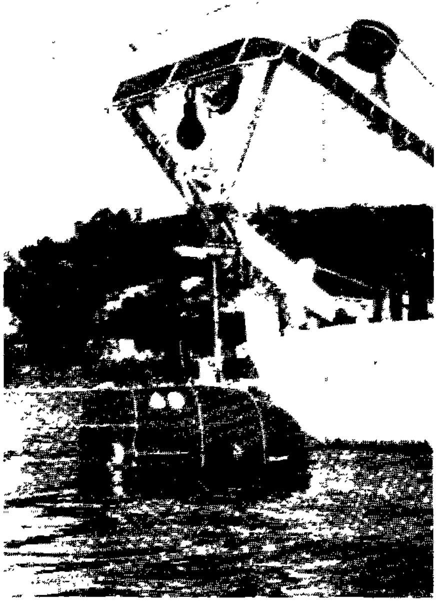

Figure 9

téléopéré et télécommandé depuis le navire. Ce véhicule a été conçu à la fin des années soixante-dix et mis en service au début des années quatre-vingts pour la reconnaissance fine des champs de nodules polymétalliques dans l'océan Pacifique. Sa profondeur maximale d'intervention est de 6000 mètres; son autonomie en distance au cours d'une plongée est d'environ 25 kilomètres et son cycle de travail est conçu pour faire deux plongées par jour. Les capteurs qu'il porte sont de deux sortes: d'abord une caméra photographique à haute résolution qui fait des images d'environ cinq mètres sur cinq, et ensuite des capteurs acoustiques, des sondeurs à ultrasons qui permettent la mesure du micro-relief. Pourquoi la conjugaison de ces deux informations? Lorsque l'on s'intéresse aux champs de nodules au niveau d'exploration, il est intéressant, bien entendu, de mesurer la densité de répartition des nodules au mètre carré, mais il est aussi très important dans l'hypothèse où l'on voudrait un jour les ramasser de connaître de façon très fine les reliefs sur lesquels ils se trouvent.

Sur la figure 10 on observe relevés dans l'océan Pacifique à une profondeur d'environ 5000 mètres, des champs de nodules polymétalliques qui recouvrent les vastes zones de l'océan Pacifique. Au cours d'une plongée l'engin est capable de faire 6000 photos et d'assurer de cette façon une couverture photographique continue du fond de la mer et de la répartition des

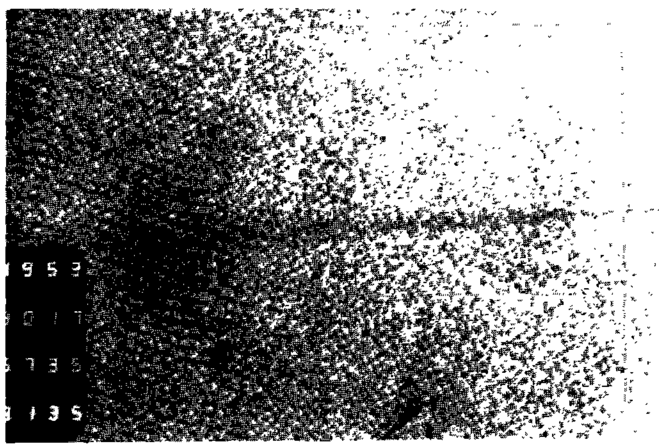

Figure 10

nodules. Un autre aspect d'un champ de nodules polymétalliques où on a, contrairement à la précédente, une répartition tout à fait hétérogène apparaît sur la figure 11. Dans l'hypothèse d'un ramassage de nodules et aussi pour étudier la teneur de ces nodules polymétalliques dans les différents matériaux qu'il contiennent, il est important d'en prélever quelques échantillons, et un véhicule téléopéré tel que celui-ci a été conçu, lui aussi, pour une profondeur de 6000m. et il est capable de ramasser quelques centaines de kilos de nodules et de les rammener à bord de son navire support aux fins d'analyses.

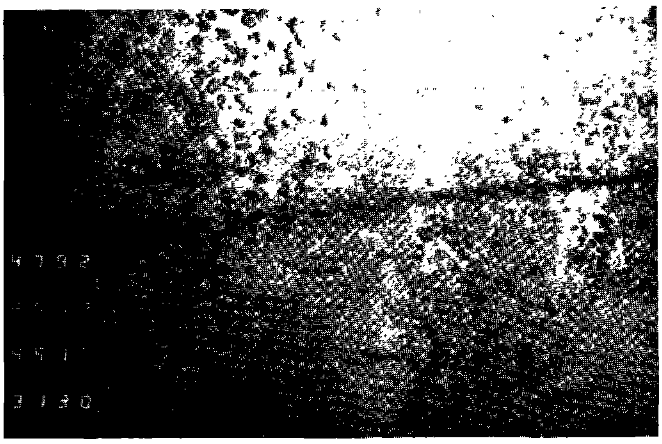

Figure 11

Nous avons vu jusqu'à maintenant trois échelons successifs d'investigation, le relevé bathymétrique, l'imagerie acoustique avec des résolutions de quelques mètres, la photographie ou la vidéo avec des engins téléopérés qui eux ont une résolution de quelques millimètres ou quelques centimètres. Maintenant on va pouvoir faire intervenir les submersibles habités qui, au dela des capacités de mesure qu'ont les véhicules précédents, offriront aux scientifiques une réelle capacité d'intervention, de mise en oeuvre d'équipement et d'outillage, de prélèvement, etc. La figure 12 montre un premier véhicule sous-marin qui est un submersible

Figure 12

pouvant transporter trois hommes jusqu'à la profondeur de 3000m. Ce submersible est opéré par l'IFREMER depuis une quinzaine d'années et il a déjà effectué plus de mille plongées jusqu'à 3000m. de profondeur. Il a été très largement utilisé pour les campagnes d'investigation scientifique dont je vais vous présenter quelques exemples et quelques résultats.

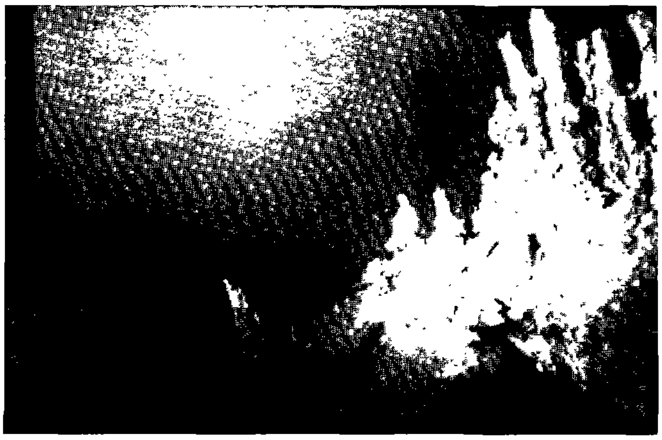

Figure 13

La figure 13 présente une autre vue de ce sous-marin en train de prendre la plongée et dont vous pouvez voir une partie des équipements utilisés; à la partie supérieure vous avez un sonar à haute résolution qui permet un examen du relief et un repérage du submersible par rapport à ce relief et dans la partie inférieure des équipements de prise de vues. Ce submersible a été utilisé pour des interventions sur les sources hydrothermales. Les océanographes que vous êtes connaissent tous la découverte de l'hydrothermalisme sous-marin, découverte qui a été faite au cours de la décennie 1970 et qui encore maintenant intéresse beaucoup la communauté scientifique. A l'aide d'un submersible tel que celui-ci on peut procéder à l'investigation très détaillée de ces sources hydrothermales. La photographie reproduite dans la figure 14 qui est prise à près de 3000m de profondeur vous montre un site de cheminées hydrothermales,

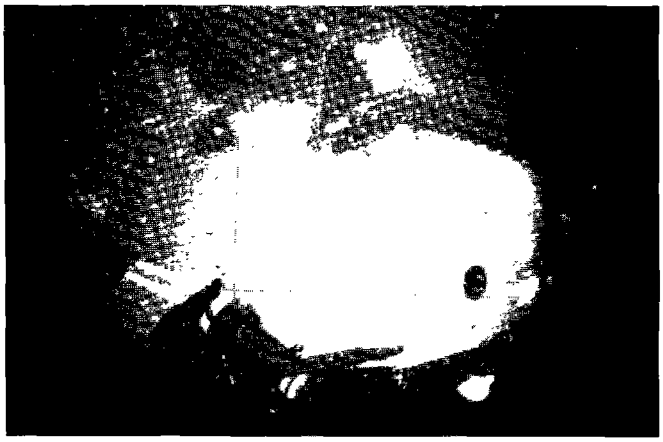

Figure 14

celles-ci sont inactives, elles sont mortes, et ont été observées dans l'océan Pacifique. Une autre prise de vue - figure 15 - obtenue par le submersible, montre une cheminée hydrothermale active. C'est un geyser sous-marin qui est constitué d'un nuage d'eau très chaude aux environs de 300C°, eau qui est chargée de particules métalliques et en particulier de sulfures métalliques et dont vous pouvez voir la couleur significative au niveau des dépôts sur la cheminée - cette couleur jaune qui est très caractéristique de ces dépôts métalliques.

Un autre exemple d'investigation avec des submersibles, ce sont des investigations sur les zones volcaniques, vous avez sur la figure 16 un paysage dit de lave en oreiller, des "pillow lava" observés sur ces zones volcaniques; ce sont des roches basaltiques. La figure 17 présente un exemple du bras télémanipulateur du submersible à l'extremité duquel est fixé une sonde qui permet le prélèvement de ces sources chaudes aux fins d'analyses. Cette photo est également prise lors d'une intervention à 3000m de profondeur. Au voisinage de ces sites hydrothermaux, on a pu constater l'existence d'une faune extrêmement riche et tout à fait spectaculaire présentant des couleurs extrêmement vives, ce qui est tout à fait curieux de constater dans des profondeurs océaniques aussi grandes.

Ces submersibles peuvent être utilisés à autre chose que la science et, en particulier, de nombreuses opérations de récupération des épaves ou d'objets sont largement facilitées par ces sous-marins. Beaucoup plus récent dans son développement et avec une capacité d'intervention plus grande, le submersible NAUTILE qui a été développé au début des années 80 et mis en service en 1985 en coopération avec la marine française, capable d'amener trois hommes à la profondeur de 6000m. Sa capacité de travail est très largement accrue par rapport au submersible précédent, en particulier à l'aide des bras télémanipulateurs extrêmement puissants dont il dispose sur sa partie avant. La figure 18 montre le submersible NAUTILE lors d'une prise de plongée. Vous pouvez observer sur la partie basse les conteneurs contenant les batteries d'accumulateurs qui fournissent l'énergie nécessaire au sous-marin pendant sa plongée et à la

Figure 15

Figure 16

Figure 17

partie avant les deux bras manipulateurs qui permettent des efforts de l'ordre de 100 kg. Deux bras manipulateurs, un bras manipulateur dextre qui a 7 degrès de liberté et un bras manipulateur dit de préhension plus simple à 5 degrès de liberté qui permet au sous-marin de s'accrocher sur une structure ou sur des objets pendant que le second bras travaille. Vous savez qu'on aime bien la plaisanterie, nous les français, et en particulier que la France est renommée pour la qualité de ces vins, et nous avons symboliquement baptisé ce submersible en lui faisant ouvrir une bouteille de Bordeaux à l'aide de ces bras manipulateurs pour en démontrer ainsi la dextérité. Sur la figure 19 on peut observer la partie avant du sous-marin avec un ensemble d'équipements scientifiques qui ont été installés en vue d'une campagne. Vous pouvez observer en particulier ces cylindres brillants qui sont des caméras

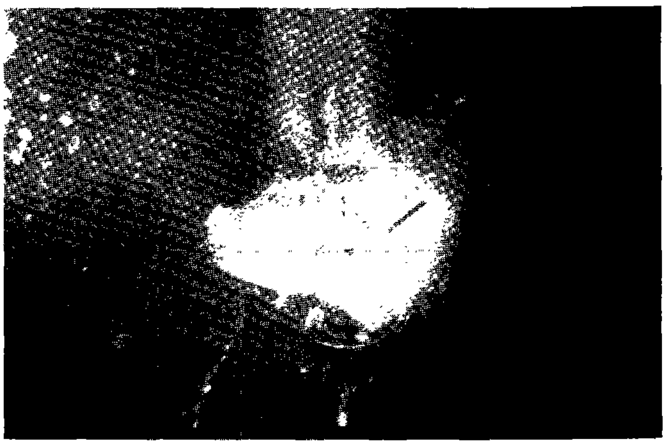

Figure 18

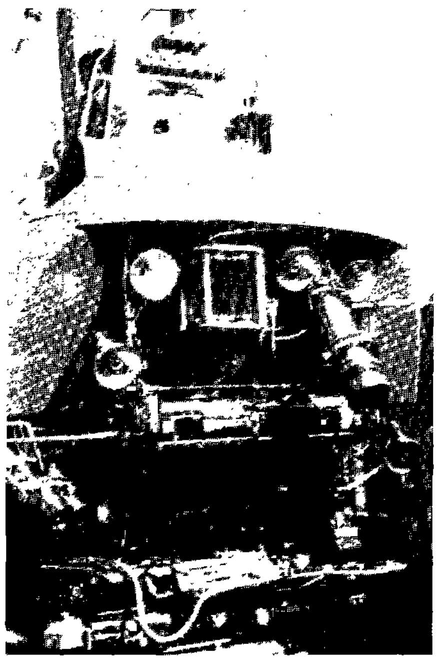

Figure 19

photographiques ou des caméras de prise de vue vidéo, les projecteurs qui servent tout à la fois au pilotage du sous-marin et à la vidéo parce que, bien entendu, aux grandes profondeurs l'obscurité est totale, et les flashes qui servent à faciliter la prise de vue. Vous avez à la partie centrale un équipement de prélèvement sur le fond de la mer. En ce qui concerne les sources hydrothermales l'utilisation d'une bouteille de prélèvement permet de récupérer ces eaux chaudes chargées de particules métalliques indépendament de toute pollution extérieure, ou de tout rinçage extérieure par l'eau de mer afin de les remonter en surface et d'en assurer l'analyse la plus correcte possible.

La figure 20 montre un autre exemple de la capacité d'intervention d'un tel sous-marin: il s'agit là d'une navette de diagraphie. Vous savez que les scientifiques

Figure 20

procèdent très souvent à des forages des fonds sous-marins pour en déterminer la nature géologique et pour étudier des phénomènes de comportement thermique par exemple. Lorsque l'on a éxécuté un forage géologique et que l'on veut repénétrer dans le trou de forage quelques mois ou quelques années après, on est normalement obligé de faire réintervenir un navire de forage qui va procéder à ce qu'on appelle une opération de ré-entrée. La mobilisation d'un navire de forage coûte très cher. Aussi est-il intéressant de pouvoir faire ré-entrer de l'instrumentation scientifique à l'intérieur des puits de forage sans avoir à mobiliser un navire foreur. L'équipement que vous observez sur cette image est une navette de diagraphie, c'est à dire; un système qui permet de déscendre dans le trou de forage des capteurs permettant de mesurer par exemple les températures, des flux de chaleur, et cet équipement peut être mis en oeuvre par le submersible NAUTILE. Autre exemple de la capacité d'intervention (figure 21) de ces submersibles c'est la mesure des caractéristiques des sols sur les champs de nodules polymétalliques: le submersible NAUTILE à l'aide de son bras manipulateur que vous voyez à la partie supérieure met en oeuvre un

Figure 21

scissomètre qui permet de mesurer les caractéristiques de cisaillement des sols sous-marins, et, par conséquent, de bien en connaître la structure en vue encore de la mise en oeuvre du système de ramassage. L'une des limitations, cependant, à la capacité de travail de ces submersibles est que leur charge utile et leur volume utile sont limités. Un sous-marin comme le NAUTILE a une charge utile d'environ 200 kg., et si l'on veut au cours d'une plongée mettre en oeuvre plusieurs outillages ou effectuer de nombreux prélèvements, on va très vite être limité par cette charge utile. On fait alors appel à un concept de navette satellite; c'est à dire que l'on va larguer sur le fond de la mer à proximité du lieu du plongée du sous-marin une navette porte-outils telle que celle que vous voyez sur la figure 22 et dans laquelle vous avez des tiroirs et bien rangés dans les tiroirs un certain nombre d'outils. Le sous-marin s'approchera de cette navette, viendra prélever dans un

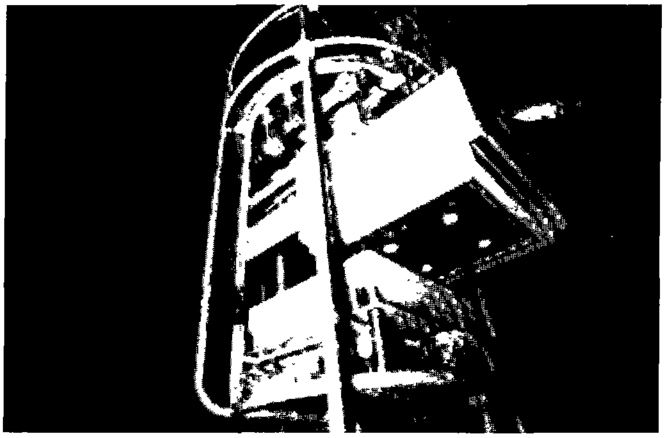

Figure 22

tiroir un outil, va se connecter sur cet outil, établir les liaisons électriques ou hydrauliques qui sont nécessaires pour la mise en oeuvre de l'outil, aller accomplir son travail, ramener l'outil dans la navette, saisir un autre outil à la place et recommencer ainsi de suite pour effectuer tous les travaux au cours d'une même plongée. Vous reconnaissez là des techniques qui sont aussi utilisées dans le domaine spatial ou l'on utilise aussi ce concept de navette porte-outils.

Toujours à l'aide d'un submersible (figure 23), et ceci s'est passé au cours de la campagne KAIKO en 1985, cette campagne franco-japonaise dont l'objectif était d'étudier la seismologie au large des côtes japonaises, vous voyez sur cette photographie la mise en oeuvre d'un appareil qui est à la partie supérieure droite de la photo il s'agit d'un inclinomètre permettant de mesurer

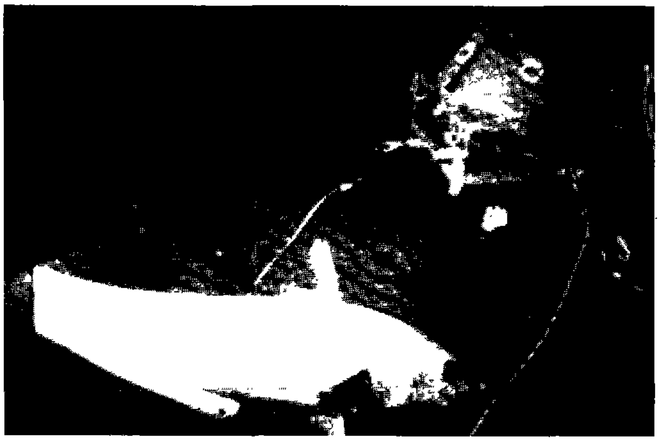

Figure 23

les moindres variations d'inclinaison des sols dans les zones de subduction que l'on suppose être génératrices de séismes. Vous observez que ce travail se fait sous l'oeil très attentif d'un magnifique poisson. Ce submersible a été utilisée pour autre chose que pour la science, bien que l'on puisse estimer que la recherche des épaves archéologiques ou historiques fait aussi partie de la recherche scientifique, et vous avez probablement entendu parler des campagnes d'intervention sur l'épave du TITANIC, eh bien vous avez reproduite dans la figure 24 une photographie de la proue du TITANIC

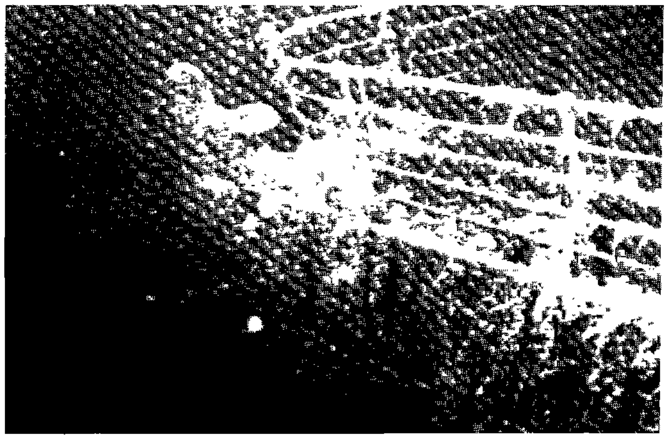

Figure 24

obtenue à la profondeur de 4000m. par le submersible NAUTILE.

Un autre problème que l'on trouve dans la mise en oeuvre de ces submersibles c'est le fait qu'il y a des hommes à bord, et par conséquent, l'on doit penser à la sécurité des hommes. Il y a des sites et des lieux sous-marins qui pourraient être dangéreux pour le sous-marin, soit parce qu'ils sont difficilement accessibles, soit parce que le sous-marin risquerait d'y rester coincé comme lors d'une intervention sur une épave ou lors d'une intervention dans une grotte sous-marine. Pour permettre aux sous-marins de poursuivre ces investigations dans des lieux pas très hospitaliers pour lui, on a dôté le sous-marin d'un petit robot auxilliaire (figure 25) qui est télécommandé à partir du sous-marin et ce petit robot va pouvoir s'éloigner du sous-marin jusqu'à une distance de quelques dizaines de mètres et pénétrer lui dans des endroits qui seraient inaccessibles au sous-marin, soit pour des questions de dimensions, soit pour des questions de sécurité. Ce petit robot sous-marin est installé un petit peu comme un petit kangarou dans le ventre de sa mère à la partie avant de sous-marin NAUTILE.

Figure 25

Voilà donc un tour assez rapide, mais néanmoins assez exhaustif des capacités d'investigation et d'intervention des véhicules sous-marins, qu'ils soient habités ou non, au bénéfice de la recherche océanologique ou de tous autres travaux sous-marins.

Pour terminer, le dernier né, si je puis dire, de ces véhicules qui a une vocation peut être plus industrielle mais qui néanmoins pourra être utilisé pour la recherche scientifique parce qu'il doit avoir une capacité d'intervention très grande, mais dans des profondeurs plus modestes: il s'agit du sous-marin SAGA (figure 26), un très gros sous-marin qui peut plonger jusqu'à la profondeur de 600m. et mettre en oeuvre des plongeurs jusqu'à une profondeur de 450m. On a là un outil qui est plus industriel que scientifique, mais qui néanmoins, possède une très grosse capacité d'intervention.

Me voici au terme de cet exposé sur l'éventail des moyens submersibles et véhicules télécommandés que je souhaitrais vous présenter. Je vous remercie pour l'attention que vous m'avez prêté.

Figure 26

Prof. Manuel M. Murillo

Continuamos con nuestra Sesión de conferencias conmemorativas Anton Bruun. Tengo el honor de presentar a Uds a Sir Anthony Laughton, nacido en Londres en Abril de 1927, graduado en física en la Universidad de Cambridge en 1951. En el misma Universidad obtuvo el Doctorado en Geofísica. Sus estudios doctorales versaron sobre la compactación de los sedimentos, efectos y sus propriedades físicas. En 1952, Sir Anthony ingresó al Observatorio Geofísico Lamont en Nueva York, y se incorporó al Instituto Nacional de Oceanografía hoy conocido como Laboratorio Deacon, Instituto de Ciencias Oceanográficas. Las investigaciones de Sir Anthony han versado sobre los siguientes temas: el desarrollo de la fotografía de los fondos oceánicos en el Reino Unido; la evolución geológica del Atlántico y del Océano Indico, con énfasis en el Golfo de Aden y el Mar Rojo; le preparación de mapas batimétricos del Atlántico Norte y del Océano Indico Noroccidental. Ha participado en el planeamiento y ha sido investigador en la Expedición Internacional del Océano Indico y en el Proyecto de perforación de los fondos profundos. Ha participado en el estudio de la morfología del océano profundo mediante el sistema de sonar de amplio espectro, long-range sonar system, GLORIA, para entender la tectónica de las cordilleras oceánicas. Sir Anthony ha participado y dirigido muchas expediciones oceanográficas. Desarrolló el programa de investigación del Instituto de Ciencias Oceanográficas para asesorar al Gobierno sobre aspectos técnicos y de seguridad relativos a la descarga de desechos radioactivos en los sedimentos oceánicos. Ha asesorado a la Oficina de Asuntos Exteriores del Reino Unido sobre aspectos técnicos; en ocasión de la Conferencia de las Naciones Unidas sobre el Derecho del Mar. En el presente, se desempenaña Sir Anthony como Presidente del Comité Director del Programa GEBCO de la COI-OHI, responsable de los mapas batimétricos globales y del Comité de Asuntos Internacionales de la Comisión Británica de Coordinación para las Ciencias y las Tecnologías Marinas. Ha sido Presidente de la Sociedad "Challenger" para las ciencias marinas. Dentro de los reconocimientos recibidos por su labor científica, se cuentan los siguientes: la medalla de plata de la Real Sociedad de Artes en 1958; la incorporación a la Real Sociedad en 1980; la medalla de oro Principe Alberto de Mónaco en oceanografía en 1980; la medalla de los Fundadores de la Real Sociedad Geográfica en 1987; la medalla Murchinson de la Sociedad Geológica de Londres.

Le gusta mucho la música, la vela y el jardinage.

Sir Anthony va a hacer una presentación sobre la forma de los fondos oceánicos.

2. The Shape of the Ocean Floor

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Summary

The shape of the ocean floor refers to features varying in size from sand ripples to ocean basins. The shapes of features tell scientists about their origin and about the processes in the ocean. Thus sand ripples indicate a high energy environment, deep sea channels indicate confined density flows, calderas on seamounts indicate volcanism, and midocean ridges, with their offsetting fracture zones, reveal the movement of tectonic plates.

But the shape of the seabed is also needed by engineers for laying cables and the construction of seabed installations, by seamen for navigation, by the navy for submarine operations and for acoustic characteristation, by fishermen for locating upwelling nutrients, by mineral prospectors to locate and exploit seabed resources and by lawyers to determine the boundaries of national jurisdiction.

Different technologies are required to observe the features over a size spectrum of ten decades. At one end, direct observation from submersibles, underwater photography and television have long been used, supported by sampling and laboratory measurements.

At the other end, contoured charts of ocean basins or parts of them, derived from the compilation of soundings from many ships, have been used for more than a hundred years, although they have always been constrained by the relative paucity of data points. The global chart series, GEBCO, jointly sponsored by IOC and IHO has evolved during this century with increasingly detailed and accurate bathymetric charts and is now moving to the age of the electronic chart.

Until the last decade or two, bathymetric charts of the deep ocean, even when the surveys have had closely spaced lines and good navigation, have been limited in resolution of bottom features by the water depth and by the wide beam angle of echosounders.

Now it has become possible to examine features in the size range between those observed by visual or photographic means and those mapped by conventional survey using multibeam swath echosounding techniques, long range side scan-sonar, such as GLORIA, operating from near the surface, and near bottom high resolution sonar operated from deep towed or autonomous vehicles. These techniques have revealed new processes at work in the ocean and have provided valuable new data for geologists and oceanographers.

The GLORIA system has enabled the huge new areas of the sea bottom, now being claimed as Exclusive Economic Zones by coastal states and which could amount to nearly forty percent of the area of the oceans, to be rapidly and cheaply surveyed in reconnaissance mode in order to pinpoint areas of economic interest for subsequent detailed examination.

The wealth of new high resolution data from the new technology combined with the high accuracy navigation becoming available makes heavy demands on the processing and presentation of the results and their accessibility to the end user. Computer technology and geographical information systems will need to be exploited to the full.

In 1540 the explorer Cardenas was fighting his way through the wild west in the United States when suddenly before him he saw the Grand Canyon opening up as a huge gash in the surface of the earth, 18 miles wide, 150 miles long and a mile deep. This must have prompted in his mind numerous questions. How was this huge chasm on a high plateau created, why is it there and what had cut it?

The explorer on land takes it for granted that he can view the landscape that unfolds before him as he rounds a bend or tops a ridge. The geologist mapping new terrain can see the mountains, the scarps, the sediment plains and the rivers.

But the explorer of the ocean floor is not so fortunate; all he can see from his ship are the waves, the sky, the sea surface. In shallow water he can see the bottom if sunlight is penetrating and the water is clear; in deeper water he can lower a camera and take a photograph of the sea bed. What he will probably see is mud disturbed by burrowing benthic organisms. His view is limited to a matter of a few metres or few tens of metres.

So the oceanographer, if he wishes to see more, has to reject light and use sound. I shall talk this afternoon about the use of both light and sound in looking at the shape of the ocean floor.

What do I mean by the shape of the ocean floor? The shape can refer to sizes ranging from sand grains and pebbles of the order of millimetres or centimetres. It can refer to rock outcrops and sandwaves of one to a hundred metres or so, it can include faults, canyons, volcanos ranging in size from a hundred metres to a hundred kilometres or it can refer to ocean basins and mountain ranges where sizes range from a hundred to ten thousand kilometres. Ten orders of magnitude are covered by this word 'shape'. Knowledge of the shapes in each of these size ranges tells us something about the geology of the ocean floor, about the influence of the ocean floor on currents, on dispersion of pollutants, on sound propagation, on biological activity and the processes that are taking place on the ocean floor.

In practical terms we use the shape of the ocean floor for navigation and have done for generations, even for millenia. Fishermen know where there are banks, they know where there are upwelling currents bringing nutrients and navigators know where there are shoals. We use it to guide sea-bed engineering, such as cable laying and sea-bed installations. In warfare and in defence the shape of the sea bed is critical in determining sound propagation, and the operation of submarines. We use the shape of the ocean floor to discover and exploit resources and we use it to determine national boundaries under the United Nations Law of the Sea Convention. You will all be aware of the problems of defining the base of the continental shelf in the Convention - that critical line from which other key boundaries can be drawn.

In this talk I will deal only briefly with the small end of the size spectrum since the techniques of underwater photography, television and direct observation from submersibles are well established. I will dwell rather longer on the larger scale since the preparation of bathymetric charts is an important IOC activity and is now moving into a new phase exploiting computer technology. But I want principally to concentrate on the newer techniques of swath mapping and side-scan sonar that have more recently filled the centre part of this spectrum of sizes.

Photography

You have already seen this morning many underwater photographs and the capabilities of direct observation. M. Grandvaux has taken you through the development of submersibles and some of the near bottom instrumentation. Even with the limited range available by the propagation of light under water, much can and has been revealed about important geological processes. Ripple marks at a depth of 2000m, where only a few decades ago the conceived wisdom was that the ocean depths were still, show currents strong enough to move sediments. Fissures on the mid-ocean ridges show the tension near the spreading centre resulting from the tectonic forces operating with sea floor spreading. Lava pillars, left behind as pools of lava from volcanos on the sea bed are drained, are decorated with ridges indicating the various stands of the draining lava pool.

These sorts of analyses of underwater photographs show some of the very detailed mechanisms at the small scale that are going on and are only a few examples of a wide variety of processes, revealed by underwater photographs that have been taken of the sea bed, which match the processes that operate on land.

What are the new directions for underwater photography? Stereo photography and photogrammetry enable quantitative three dimensional measurements to be made. Time sequences, from cinephotography at the one extreme, to time lapse photography at the other, show the processes in action. For example, time lapse photography over several months has shown that, after the spring bloom occurs in the north-east Atlantic, phytoplankton debris very rapidly reaches the ocean bottom, fills the small depressions in the sediment and is thereafter scavenged by benthic fauna. Pulsed laser photography using time-gated receivers is another new technique to get over the difficulties of cloudy water - the backscattering arising from suspended particles - which is such a problem in energetic coastal environments.

Charting

Let me move now to the very large end of the size scale; the charting of the ocean floor. Ocean charts grew out of the needs of mariners. Early navigators found their way around by experience passed down by generations of seafarers, recognizing salient features of the coast. But, by the end of the Middle Ages, around 1200, written guides and charts appeared and the compass came into common use. The early charts were made in the Eastern Mediterranean and rapidly multiplied as exploration and discovery increased. Depths on charts first appeared in the sixteenth century as aids to navigation.

From such humble beginnings charts of the ocean bed, and later contour charts, started to evolve. Although the first contour charts appeared at the end of the seventeenth century, the first oceanic contour charts did not really emerge until the nineteenth century when there were sufficient rope or wire soundings to construct bathymetric charts. By 1854 Matthew Fontaine Maury contoured the north Atlantic, the classic chart produced on the basis of 200 soundings only. An updated version was published in his 'Physical Geography of the Sea' in 1861 (Fig.1). The mid-Atlantic ridge at that time was called 'Middle Ground' and at the top of this chart it is called 'Telegraphic Plateau' reflecting the interest of the telegraph companies in the ocean sections when

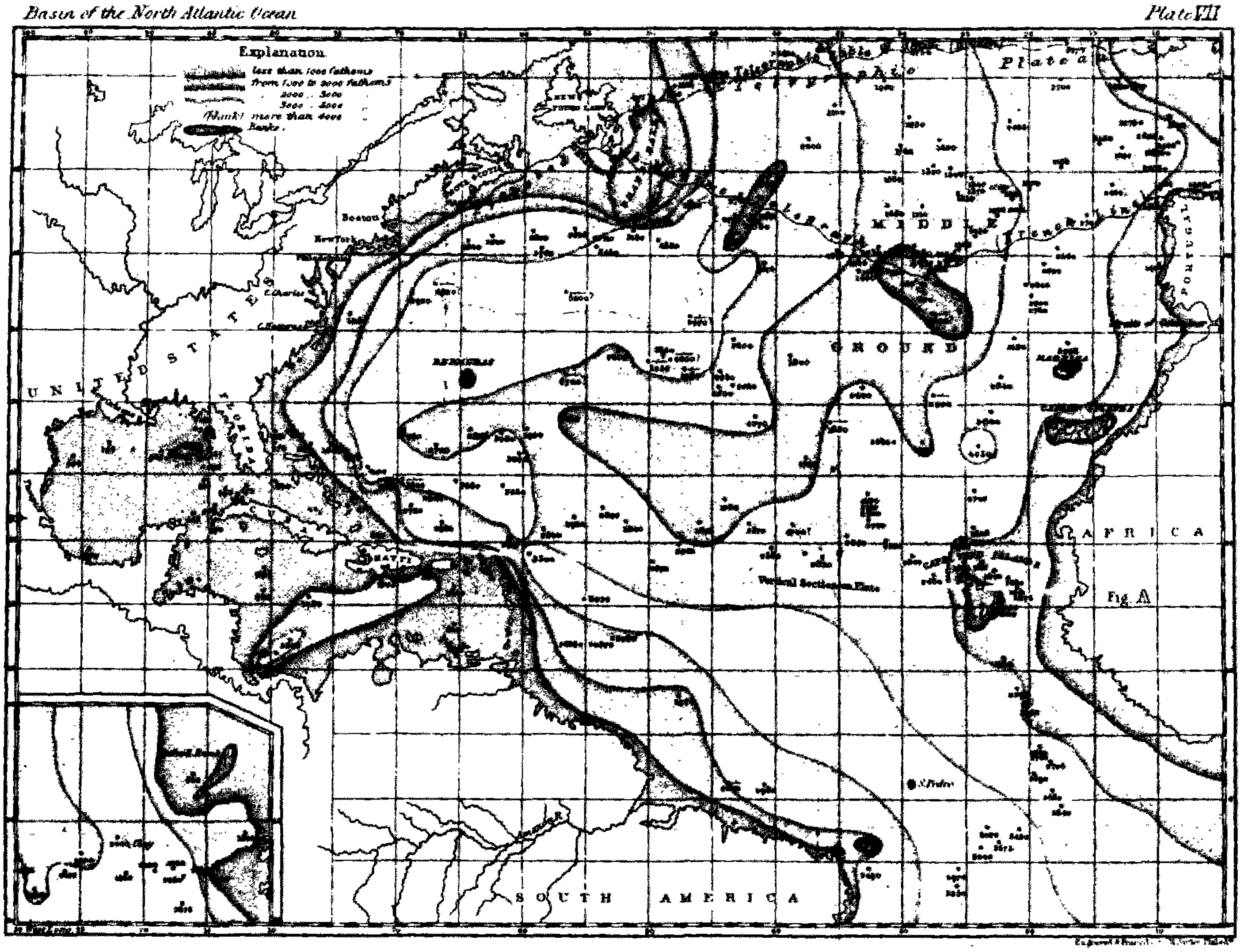


Figure 1 Contour chart of the basin of the North Atlantic Ocean published by M.F. Maury in 1861 in 'Physical Geography of the Sea'. This was one of the earliest contour charts of a whole ocean basin.

laying their cables. Another classic chart of the Atlantic, arising from the Challenger Expedition, showed the continuity of the mid-Atlantic ridge established not from soundings alone, but from the temperature of the water in the oceanic basins either side of the ridge; the differences in the temperature of bottom water gave convincing evidence of the continuity of the ridge isolating the basins.

As more and more soundings were taken at the end of the nineteenth century a group of oceanographers which included Professor Krummel from Germany, Sir John Murray of the famous

Challenger Expedition from the UK, and Prince Albert I of Monaco, put a proposal to the Eighth International Geographical Congress to bring together all the soundings that had been taken in the world, to plot them on a standard scale and to produce standard contour charts of the whole globe. The proposal was accepted. The project was generously financed by Prince Albert I of Monaco and his office in Monaco produced the first edition of GEBCO (the General Bathymetric Chart of the Oceans) in a matter of seven months - a complete edition of some twenty separate sheets. This was a tremendous landmark for ocean mapping.

It was soon clear that new editions had to follow; as more data became available, so the second, third and fourth editions followed during the next decades, prepared in later years by the Institut Géographie National for the International Hydrographic Organization. By 1921 echosounding had started to replace the wire soundings and suddenly there was a huge increase in available soundings. The data set was enhanced once again, after the Second World War, in the nineteen fifties and sixties, by the tremendous explosion of activity in oceanography, and by the increasing number of deep ocean echo-sounders carried by ships. With this activity came new insights into geological processes in the deep ocean and the revolutionary concepts of plate tectonics. At about this time the fourth edition of GEBCO was running into financial difficulties; people did not like the product so they did not buy the sheets. It was not useful to mariners, the defence community were developing their own classified contour charts and the charts took no cognisance of the new knowledge of deep ocean geological processes.

In 1970 IOC produced its first long-term expanded programme of oceanic research - LEPOR - and in this document high priority was given to the preparation of ocean bathymetric charts. This led, in turn, to a series of workshops, and to SCOR setting up Working Group 41 to look at the morphology of the ocean floor. The recommendations that came from SCOR WG41 resulted in the creation of a joint IOC/IHO Guiding Committee for GEBCO, IOC bringing the necessary additional scientific input. The fourth edition of GEBCO was scrapped and a new fifth edition started which had the qualities which oceanographers and others were by now beginning to demand. The outcome was the publication in 1984 of the fifth edition of GEBCO (Fig.2), to new scientific and cartographic specifications. I must here give credit to the enormous and generous contributions made by the Canadian government in funding the preparation and publication of these charts.

What was new about the GEBCO fifth edition? We brought in scientific co-ordinators into the preparation of the contours of these charts to interpret the data that was being produced by oceanographers and by hydrographic departments and was being collected by the IHO, designated as the world data centre for bathymetry. We insisted that each chart, before it was published, was scientifically reviewed, just as scientific papers are refereed and reviewed. We insisted that the control for the contours should be shown on the face of the chart, so that you could see what was interpolated guess-work and what was based on sounding lines. We limited the actual numbers of the soundings that appeared on the chart to critical points such as the tops of sea mounts and the bottoms of valleys.

The data base on which the GEBCO project depends is held by the IHO and is supplied by the network of volunteering hydrographic organizations contributing to it in agreed areas of national responsibility. The success of this project depends on the co-operation of all countries and all laboratories in providing the sounding data which they take during their cruises or during their hydrographic operations to bring them to the central database at a high specified standard.

Where do we go next with our ocean mapping programme? The GEBCO Guiding Committee has been exercising a lot of thought about this, as there are many things that are changing in mapping circles. Firstly we believe it essential to digitize the entire fifth edition so that at least the contours can be played out, using computer graphics, in the form that they are found on the contour charts in the fifth edition. This process is about half complete thanks to the help of the Institut Géographie National in Paris and the International Gravity Bureau in Toulouse. But the production of vectors delineating the contours is not, we believe, sufficient. We want to move onwards from that into generating digital terrain models where each square (pixel) of the ocean floor has a defined depth, either measured or interpolated (Fig.3). We are well aware of the work that the Department of the Navy and NOAA have done in the United States with this sort of approach. Their charts are produced from a digital database DBDB5 where every five minutes of latitude and longitude is characterized by a depth. Automatic contouring, hill shading and oblique projections can be displayed, and the depth distributions can be treated statistically. But the difficulty with DBDB5 is that we have no precise knowledge of data on which the contours are based. The data sources are shrouded in a certain amount of mystery for fairly obvious reasons. We are proposing, with the GEBCO database, to be able to have at least as good a database as this. This raises all kinds of problems about how you arrive at a depth in a five minute square when you have no sounding lines near it. There are many computer techniques to interpolate

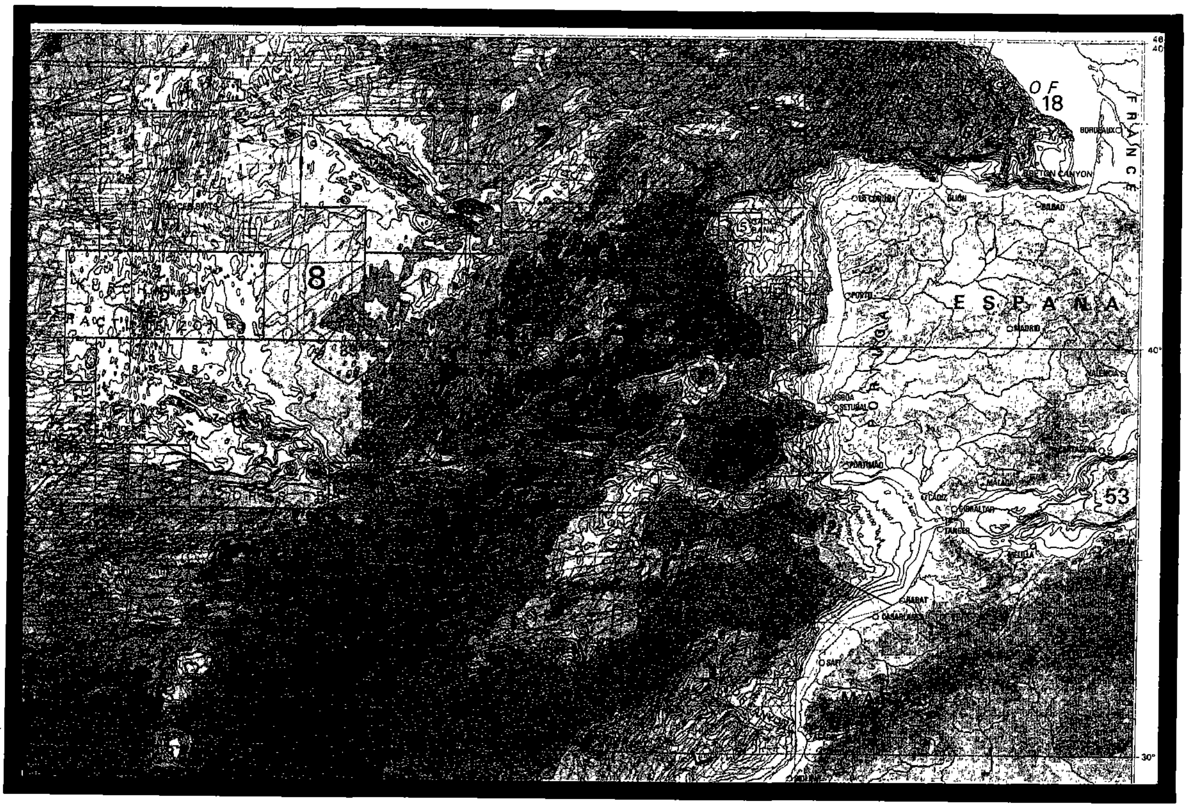


Figure 2 Part of the North Atlantic Chart (5.08) of the 5th Edition of GEBCO published in 1982. (Courtesy Canadian Hydrographic Service).

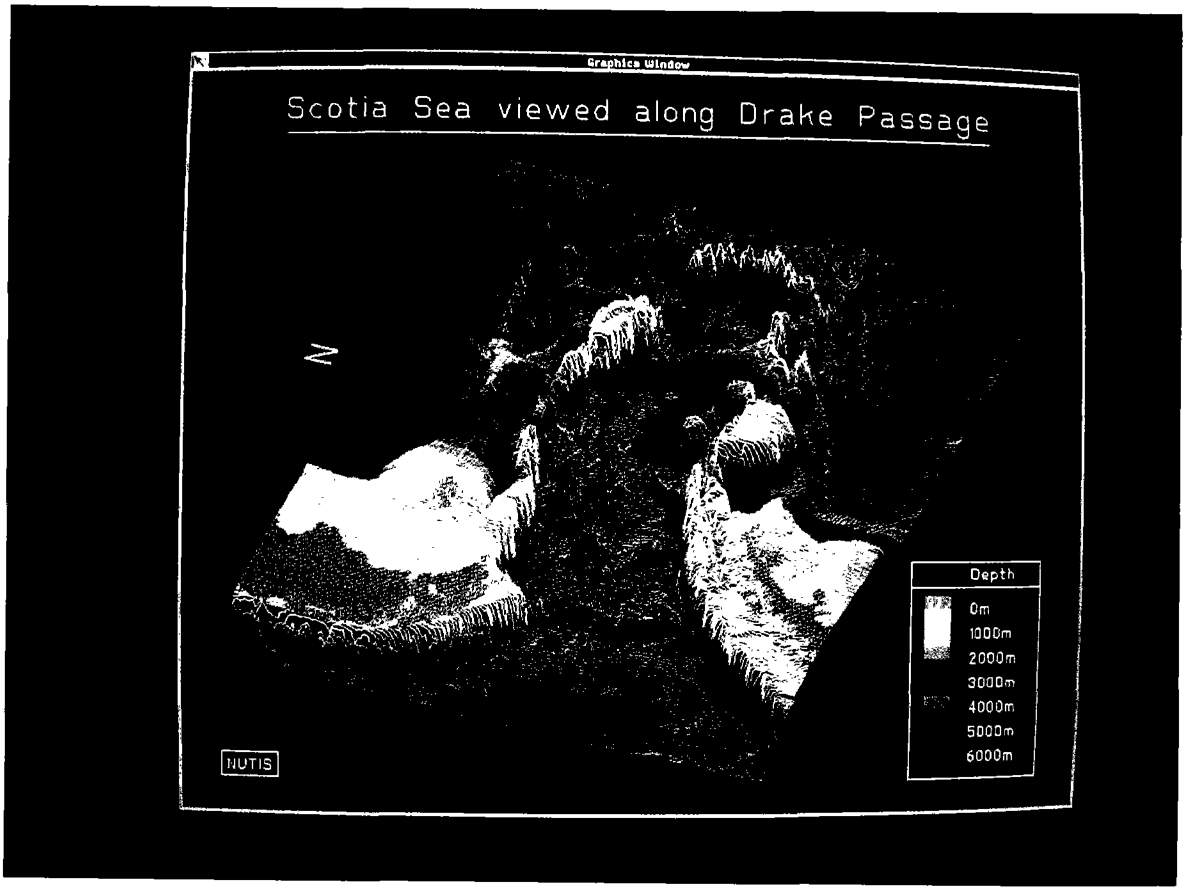


Figure 3 Digitization of the contours of the 5th edition of GEBCO and subsequent generation of digital terrain models enables the GEBCO data set to be manipulated to give different views of the topography. (Courtesy NERC Unit of Thematic Information Services).

between sounding lines in order to guess (because it is not much more than that) the depth in an intermediate position. Various techniques of interpolation are being explored by a variety of centres around the world.

So what are we going to do for the sixth edition of GEBCO? Is it going to be a series of paper charts like the existing one or are we moving towards a computer data base? We would like to see the sixth edition of GEBCO to be the GEBCO Digital Atlas (GDA) comprising a world digital bathymetry contour database, together with supplementary files containing ship tracks, geographical names, world coastline, etc. It would initially be based on the digitized fifth edition, using computer technology to update significant areas when adequate new data is made available. We would not of course abandon paper charts, as we are well aware that there are many countries, and many laboratories who do not have the facilities of taking a CD-ROM or other form of computer output and playing it out on to a hard copy to generate their own charts. We hope therefore that we would run two systems in parallel in the course of the sixth edition.

There are various problems facing GEBCO in this area. How do we include the new sorts of datasets that are coming through saturation surveys, such as those done with multibeam swath systems? How do we integrate the side-scan sonar surveys I'll be talking about later? How do we use the information that comes from the satellite observation of the sea surface by radar altimetry showing the gravity field at the surface of the ocean, but which also reflects the gravitational attractions of the topography underlying it? These are some of the problems which we are currently grappling with and we shall hope to solve in the next decade.

Swath mapping and sonar

Let me now move on to the intermediate scales, smaller than can be handled by conventional mapping, larger than you can see from photography and the use of light. I am talking here of the fractured fabric of mid-ocean ridges, of the patterned texture of massive sediment deposits, of the detailed topography of overlapping volcanic chains and of the meandering sea bottom channels. These require spatial resolution of metres to tens of kilometres.

Two approaches have been used over the last decade or two to fill in this spectrum. One approach is the multibeam swath mapping technique from the surface. Sound pulses are transmitted in narrow beams fanning out either side of the ship. Echoes are received, are corrected for the slant range and give the depths of the ocean on a section across the track. As the ship steams at normal cruising speed the system generates contours of the sea floor along a swath approximately equal in depth to the sea. With this technique you see finer detail than is given by a conventional single beam echo-sounder, and you build up three-dimensional information by the precise correlation of some 20 or 40 narrow beams.

Although swath mapping was initially developed for the US Navy, and has been extensively used for classified surveys, the system has been available commercially for many years and has shown its value to geosciences in the detailed topographic charts in support of studies of sea floor spreading processes, subduction dynamics and sedimentation as well as providing the detailed site surveys for ocean drilling.

Being a digital system, the output data can be displayed in many ways, besides contours, such as topographic sections (Fig.4), and oblique views with variable vertical exaggeration and hill shading.

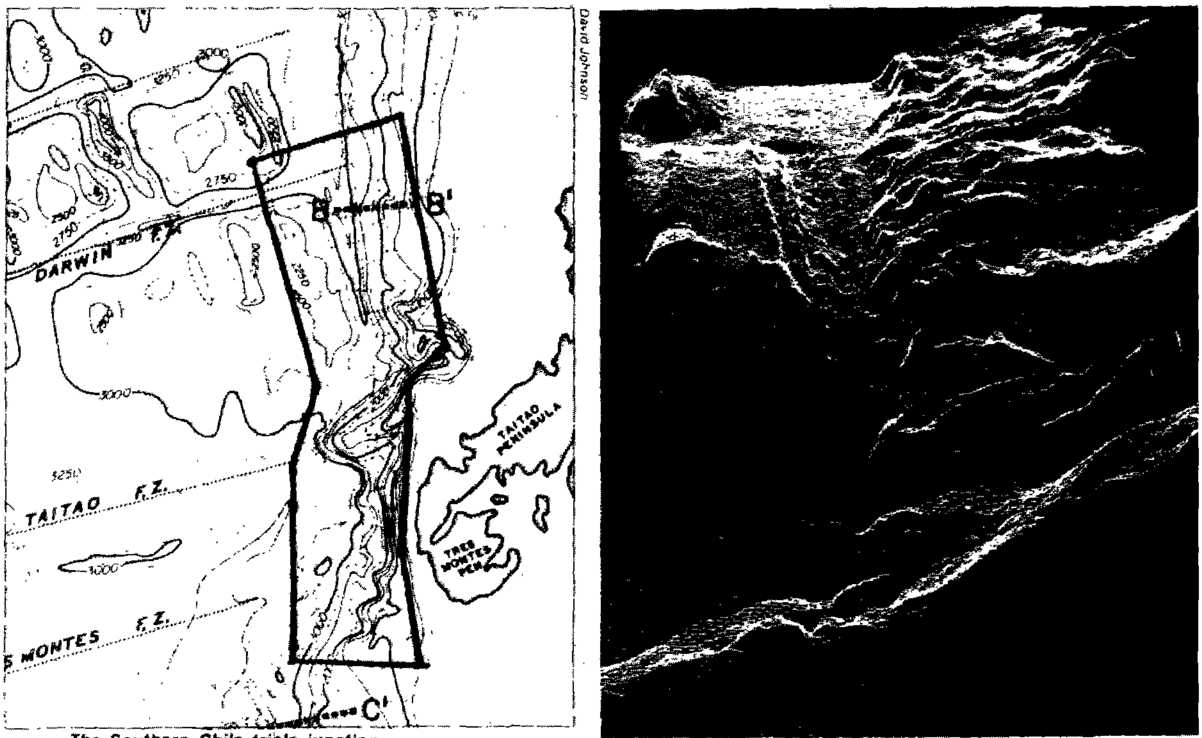
However, the system is expensive to install and to operate and makes big demands on computing. Compared to long range sonar, which I will discuss next, the rate of data acquisition is relatively slow, the swath width being limited approximately to the water depth i.e., some 5 kms. in deep water.

Side-scan sonar provides you with a different sort of information from multibeam swath sounding. It will give you the amplitude of the reflected signals at oblique incidence. It will give you the texture of the bottom and it will give you shadows, but it does not, however, give you the depth. The far ranges of side-scan sonar are very insensitive to depth variation because of the obliquity. With side-scan you can cover a much greater width, but you lose the information on the depth.

The early side-scan sonars for sea-bed geology were derived from naval submarine sonar and were limited to a range of about one or two kilometres on the continental shelf. To obtain the same resolution in the deep ocean, the system has to be mounted on a vehicle towed near the bottom, as in Deeptow and Seamark in the USA, SAR in France and TOBI in the UK. The cable and the towing problems are however very restrictive. Some attempts have been made to mount a short range sonar on untethered autonomous vehicles but there are problems of data storage or telemetry.

At the Institute of Oceanographic Sciences in the UK, we believed in the early 1960s that we could reproduce the characteristics of the successful short range side-sonar by scaling it up to be operated in the deep ocean but from near the surface. The resulting system was called GLORIA (Geological LOng Range Inclined Asdic).

In order to preserve the geometry of side-scan, the range had to go up to 20-30 kms: in order to get this range, the frequency had to be reduced to 6.5 kHz: in order to preserve the narrow beam at these low frequencies, the transmitting and receiving array had to be long and the vehicle large: and in order to



The Southern Chile triple junction region, with R/V CONRAD's track map.

SeaBeam image of the collision.

Figure 5 The long range side scan sonar vehicle, GLORIA, in its launching gentry on RRS Discovery. For launching this gantry is moved to be nearly vertical and the yellow vehicle streamed out to a depth of about 70 metres 400 metres astern of the ship. (Courtesy IOSDL).

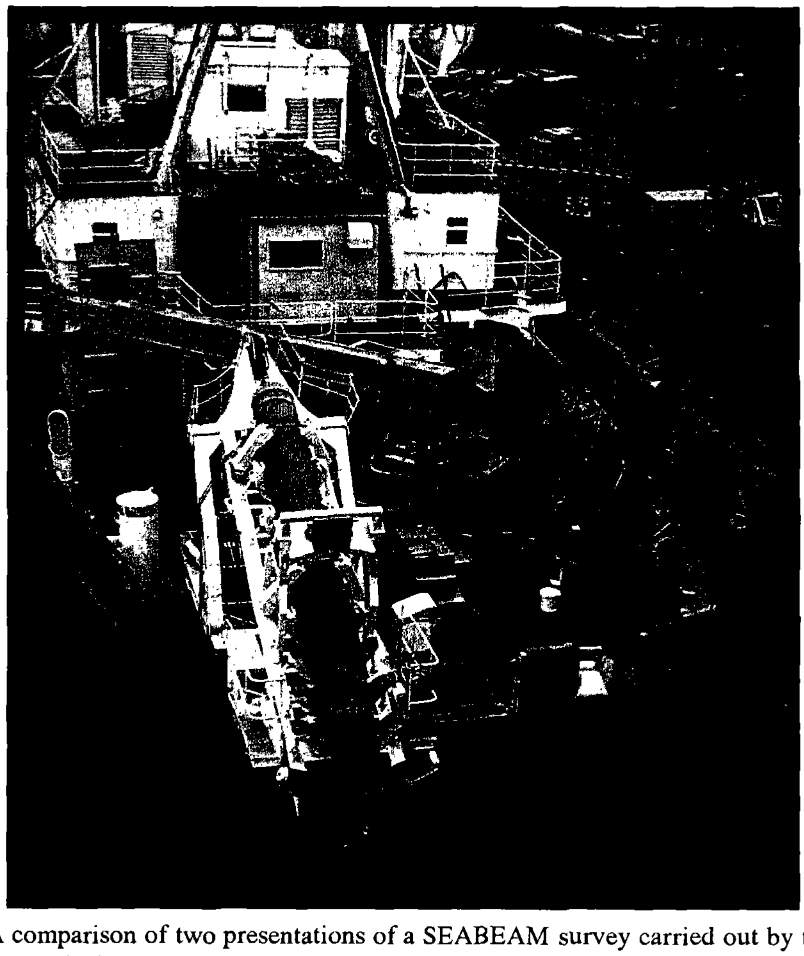


Figure 4 A comparison of two presentations of a SEABEAM survey carried out by the Lamont-Doherty Geological Observatory over the junction between the East Pacific Rise Spreading Centre and the Peru Trench. The SEABEAM survey within the box on the left is presented as stacked profiles on the right. (Courtesy Lamont-Doherty Geological Observatory).

get the sound power into the ocean the vehicle had to be in or below the thermocline.

So GLORIA is a vehicle (Fig.5) towed at a depth of about 70 metres, or maybe somewhat shallower, on 400 metres of cable. It is neutrally buoyant, and sends out sound in both directions from transducers inclined at 30° to the horizontal (Fig.6). It covers a swath width of about 60 kilometres, and the surveying speed is about 9 or 10 knots. It is suitable for depths of anything between about 200 and 10,000 metres and can cover an area of something like 10,000 square kilometres a day.

The GLORIA survey technique has been used over a very wide variety of terrains from the continental margins, dissected with submarine canyons and scarred with huge slumps, to the newly created oceanic crust at the mid-ocean ridges where the topography is dominated by the volcanism and tectonism associated with plate creation. The shape and texture of the sea floor pictorially represented in the sonographs has been interpreted by the geologists to give the details of the geological processes operating on the sea floor.

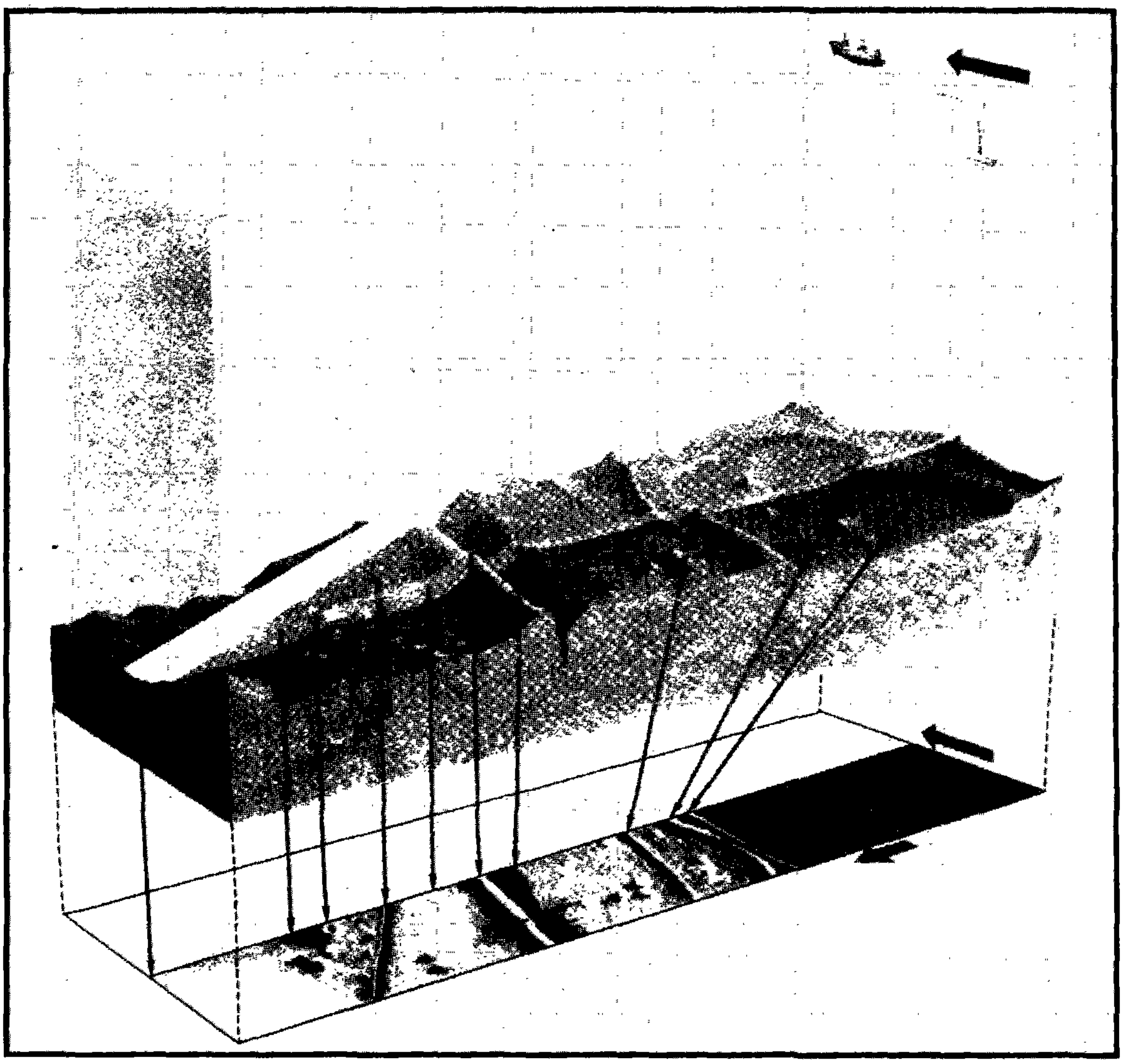


Figure 6 The GLORIA side scan system insonifies the ocean floor out to 30 kilometres both sides of the ships track in water depths up to 6 kilometres. The sonographs are subsequently corrected for slant range distortion and other errors. (Courtesy IOSDL).

A sonar mosaic survey of a section of the Mid-Atlantic Ridge was made in 1973 as part of the concentrated French, American and British study of ocean ridge formation (the FAMOUS project). This showed a texture of ridges and valleys paralleling the spreading axis and offset by fracture zones. Analysis of the shadows showed that the ridges were asymmetrical, the steep scarp facing the axis. These were normal faults resulting from periodic collapse into the progressively depleted magma chamber from which the lavas ejected.

The pattern of this tectonic fabric has been used in the much more complex regions where several spreading centres meet, in order to unravel the kinematics of the plate movements. In a survey of the Easter Microplate and its boundaries in the south east Pacific, the survey mosaic showed a swirl of

Figure 7 A mosaic of GLORIA sonographs of the Easter Microplate in the SE Pacific. The boundary of the plate is delineated by heavy lines. Dark areas indicate high backscatter from younger, rough, unsedimented sea floor. Light areas are older, smoother and covered by several metres of sediment. (Courtesy IOSDL).

lineations with regions of highly contrasting back scattering indicating the amount of sedimentation over crust of different ages (Fig.7). The complex lineations and the age data from sedimentation have enabled the evolution of this small piece of oceanic crust to be precisely determined (Fig.8). The tectonic patterns arise from the interaction of the propagating ridge systems resulting in the whole microplate having been rotated clockwise by 15 degrees every million years.

In the great sedimented ocean basins, GLORIA surveys have come up with surprises. The existence of deep ocean channels linked to canyons carrying sediment down to the continental slope have long been known. But it was not until GLORIA surveys were made that it was realized that these were highly sinuous meandering channels carrying high density water and spilling their sediment load over the edge as levees on the meanders (Fig.9). These have the same characteristics as the river systems on low gradient land, with oxbow lakes, cutoff meanders and discarded channels. On the Amazon deep sea cone and on the Indus cone, the channels have been traced for thousands of kilometres and the sequences of activity and decay have been worked out.

The problems addressed by GLORIA surveys have not only been scientific. Following the declaration of an Exclusive Economic Zone in 1983, the US Geological Survey wanted a rapid yet comprehensive survey of their newly acquired territory totalling some 10 million square kilometres. GLORIA was the tool chosen for this and the first survey in 1984 off the Californian and Oregon coasts out to 200 nm (1 million square kilometres) took just 95 days. The survey, together with the subsequent ones which are continuing today, was designed to assess the resources of the EEZ so that these can be later exploited by industry. The output is a series of Atlases showing the GLORIA sonograph mosaics and their interpretation, backed up by other underway geophysical data.

What are these resources? The survey off the west coast revealed some two hundred volcanoes that were not previously known in this region even though

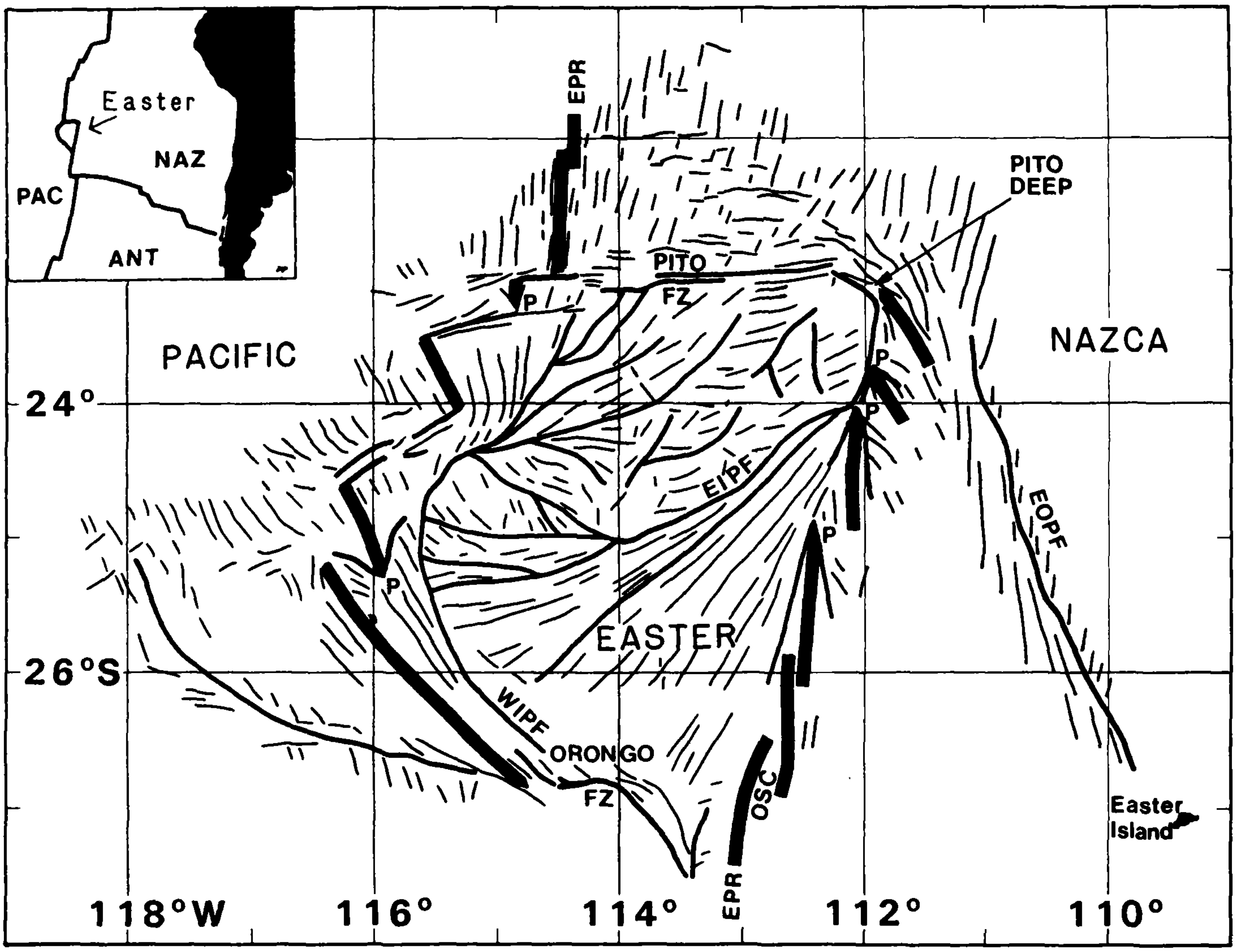


Figure 8 A simplified tectonic interpretation of the Easter Microplate mosaic. Heavy lines show plate boundaries, median lines indicate pseudofaults and other discontinuities, light lines denote the faulting fabric associated with spreading. (Courtesy IOSDL).

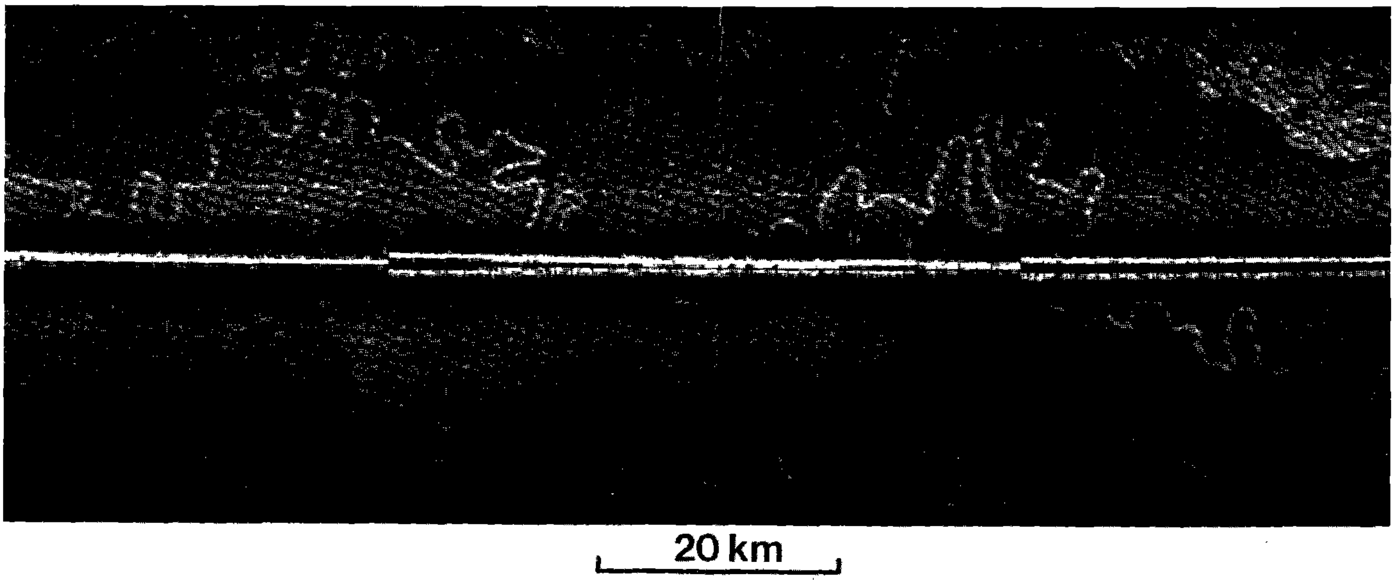


Figure 9 A GLORIA sonograph of a meandering submarine channel on the Indus Cone. (Courtesy IOSDL).

this was close to a very active oceanographic country. The economic importance of submarine volcanoes is that many of them are encrusted with manganese and within the depth range of about one to two thousand metres these manganese encrustations are rich in cobalt, about two per cent in some cases, and hence economically viable as a resource once recovery techniques are developed.

From the survey mosaics one can locate spreading centres and hence look for hydrothermal vents which might give rise to hydrothermal mineral accumulations. One can learn about the stability of the continental slope from the recognition of the scars of underwater slumps. Slope instability can put at risk the exploitation of oil on the continental margin. One can say something about the sediment accumulations and the mechanism whereby those sediments have come into place and, hence, something about the hydrocarbon potential of the deep ocean sediments which might, in time, become economic to exploit. Submarine topography is related to fisheries activities and off the coast of New Zealand, I believe, a thriving fisheries industry has been recently developed in relation to some quite deep topographic features. And, last but not least, it can contribute to the determination of national boundaries under the UN Law of the Sea Convention, which are in some cases closely related to submarine topography.

Swath bathymetry and side-scan sonar complement one another in the determination of the shape of the sea floor at the intermediate scale. Both can be operated at varying ranges and varying frequencies to give finer or coarser detail.

Conclusion

I have shown that we have many different sorts of data that are available at a wide range of scales to integrate into the whole concept of sea floor shape. How can we bring these together?

At the Institute of Oceanographic Sciences we have made some experiments combining the detailed depth information obtained by multibeam echo sounder surveys with the textural information given by side scan sonar (Fig.10). The topography obtained from the multibeam data can be presented as an oblique view comparable to that seen by the sonar insonification. The sonographs can then be superimposed on the topography to give the texture. Research into the combination of different data sets using the methods of GIS is now active in many countries.

These techniques are now being extensively exploited in aerial and satellite imagery using the image processing and manipulation power of modern computers. Visual and radar imagery can be combined into digital terrain models from land measurements to give a data base from which synthetic images of the land surface can be generated.

Under the sea, the inherent errors and lack of resolution arising from the use of sound make such integration more difficult. However I have a vision of a future when most parts of the ocean floor have been surveyed in adequate detail, and when every pixel, of say one kilometre square, can be characterized by a depth, by a reflectivity viewed at a number of different azimuths and with a range of frequencies, and by the geological nature of the bottom. As the data available increases, so the resolution can be improved.

From such a data base, stored perhaps on a CD-ROM, we should be able, at the touch of a button on a desk top computer, to generate views of the ocean floor at whatever scale we choose and from whatever direction.

At present these images of the shape of the ocean floor are carried in the minds of the specialists, people who are skilled in the interpretation of echosounding records, who pore over sonographs and photographs and who agonize over the construction of contour charts.

The images should in future be available to all non-specialists who want to visualize the ocean floor so that they can have the advantages of even the most casual observer on land.

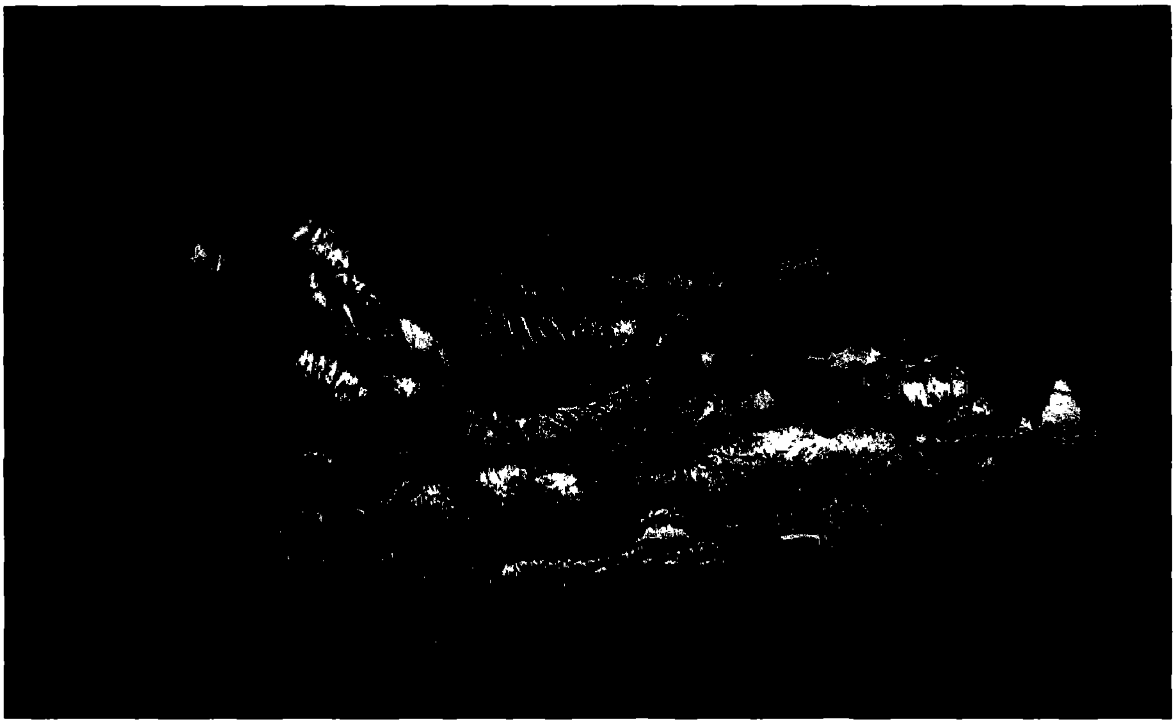


Figure 10 Three-dimensional view of the Indian Ocean triple junction by a superposition of GLORIA data (displayed as colour intensity) on SEABEAM generated topography. The area measures 100 by 100 kilometres. (Courtesy IOSDL).

Prof. Manuel M. Murillo

El tercer conferencista invitado es el Dr. James Baker. El Dr. Baker es presidente de la Unión de Instituciones Oceanográficas con sede en Washington, un consorcio de Instituciones Académicas de los Estados Unidos que es responsable de la administración del programa internacional de perforación en los Océanos.

El Dr. Baker es miembro del Comité Científico Conjunto del Programa de Investigación del Clima Mundial y es Co-director del Grupo Científico; Co-ordinador del experimento sobre la Circulación Océanica Mundial.

El Dr. Baker, también es Miembro de la Asociación Americana para el Avance de las Ciencias: (la triple AS) y es Presidente Interino de la Sociedad Oceanográfica. Entre sus contribuciones científicas se citan artículos sobre la circulación oceánica, la interacción oceano-atmosféra y la aplicación de instrumentos y mediciones con satélites.

Ha participado el Dr. Baker activamente, en la formulación de planes y en el desarrollo de macroprogramas oceánicos. Antes de incorporarse a la Unión de Instituciones Oceanográficas, el Dr. Baker fue decano de la Facultad de Ciencias Oceánicas y Pesquería de la Universidad de Washington en Seattle. Es graduado en física de la Universidad de Cornell y realizó sus primeros estudios en la Universidad de Standford.

La conferencia que presentará el Dr. Baker versa sobre "Observaciones de los cambios en el Océano Mundial: Una vista desde el espacio".

3. Observing change in the Global Ocean: the view from space

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Summary

Today we are on the verge of a new vision of Earth, ready to achieve an understanding of problems of major societal interest: weather and climate prediction, biogeochemical cycles, waste disposal, and the distribution of resources. To do this, we need global measurements and modeling of the physical, chemical, and biological processes responsible for Earth's global evolution and global environmental change. New space technology, new techniques for directly sampling the earth, and new supercomputers for quantitative models have given us the capability to probe the complex interactive processes of the earth. This talk focuses on some of the new technology, some of the new results that have been achieved, and the status of such systems for future programmes aimed at understanding global change such as the World Climate Research Programme and the International Geosphere-Biosphere Programme.

Introduction

Today we are gathered to celebrate the opening of the Fifteenth Session of the Intergovernmental Oceanographic Commission, and to honour Anton Bruun, the Danish oceanographer who was renowned for his pioneering expeditions. Today is also the fourth of July, the national day of the United States. Anton Bruun was a key figure in the founding of the IOC, and he worked closely with his colleagues in the United States as well as elsewhere. I will begin my talk by noting some connections among all of these.

Anton Bruun was a biological oceanographer with special interest in global problems. One of these was the navigation of eels that spawn in the open ocean and then for some mysterious reason know exactly where to go to find fresh water to live. He also believed in sea monsters, thinking that they were the grown-up progeny of the eel larvae that he had found with many more vertebrae than normal.

One of the purposes of the Galathea expedition was to search for such creatures, even in the very deep trenches. Although no sea monsters were found, the expedition did bring back an enormous variety of new biological specimens. Moreover, they discovered for the first time living material, bacteria, on the floor of the deep trenches, and brought back pebbles from the deep floor of the Philippine Trench, giving geologists new information about processes there.

In 1962 the US presidential yacht that had served for Harry Truman and Dwight Eisenhower (by the way, the US no longer has such yachts) was renamed the R.V. ANTON BRUUN and converted to a research vessel for participation in the Indian Ocean Expedition. The ship had a distinguished history of accomplishment then, reflecting her namesake.

Anton Bruun's career and the man himself symbolized much of the excitement of oceanography - new ideas, global scope, and new discoveries. Today oceanography is much the same: we have new techniques that are leading to better understanding of how the ocean works. The Galathea expedition was one of the last of the global expeditions aimed at many purposes that helped to outline oceanography on a global scale. It set the stage for a focus on process studies that occupied the 1960s and 1970s. Today we are seeing another global focus, this time from the point of view of how the earth works as a system, with interconnections between physics, chemistry, biology, and geology.

The IOC Assembly comes at the time of another key anniversary: the 200th anniversary of the beginning of the French Revolution in 1789. The revolutionaries had a scientific bent and proposed the adoption of the metric system. Despite the fact that France adopted the system officially in 1795, other nations were slow to abandon their customary measures for the metric system, despite its advantages. Those of us from the backward part of the English-speaking world still use inches, feet, yards, miles and fractions in eighths, sixteenths, and thirty-seconds know the value of the new system. During the same year, 1789, the French chemist Lavoisier published his elementary treatise on chemistry, which firmly established the oxygen theory, new chemical nomenclature, and the law of conservation of mass. But given his later fate, it is not clear that Professor Lavoisier would have supported all of the aspects of the revolution.

In the nineteenth century, the French coined the term Industrial Revolution as an analogy to their own political revolution for the period from the 1740s to the 1780s when new inventions led to rapid techniques for manufacturing items from cloth to steel. This was the introduction of technology in the modern sense of the word: the direct application of science to machines. For example, the improvement in steam engines was based on the science of gases that had been developed in the seventeenth century.

Today we are also in the midst of another, scientific, revolution in the earth sciences that is based on technology. New techniques for measuring and computing are giving us an understanding of how the earth works, and how its parts are interconnected. At the same time, there is an increasing public awareness of the importance of the environment to the health of humankind. A better ability to predict change is emerging. Of particular interest to the nations of the world gathered here as part of the Intergovernmental Oceanographic Commission, itself a legacy of Anton Bruun, is the rapidly growing understanding of the ocean and how it works as part of global change. For this lecture, I would like to focus on new satellite technology in this context.

Parallels in History: Satellites and Global Change

To understand the ocean, we must observe it. Observing change in the global ocean requires techniques that can provide a global view. Satellite-borne instrumentation, developed over the past decade, can provide one part of the required view. Although *in-situ* measurements will always be a critical element of any global ocean observing system, measurements from satellites will provide the global synoptic view not available any other way.

It is interesting to note that the career of Anton Bruun parallels the development of satellites and of the growing interest in global change and the role of the ocean. Dr. Bruun was born in 1901, at about the same time that the Swedish chemist Svante Arrenhius warned about the possible global warming caused by carbon dioxide from the burning of fossil fuel. During the years 1928 to 1930, while Bruun was on the Dana Expedition, Konstantin Tsiolkovsky of the Soviet Union proposed the us of artificial earth satellites, and the first "real time" transmission of aerial photographs from aircraft - the first "remote sensing" - was achieved by Robert Goddard of the USA. In 1945 to 1946, Bruun led the Atlantide expedition; in the same year, the first photographs from V-2 rockets were taken.

In the decade of the 1950s international activities were of prime interest to Bruun, and the first large global international programmes were undertaken. Carl Rossby of Sweden suggested that trace chemicals in the atmosphere be measured as a prelude to the International Geophysical Year: this led to the decision in 1955 to begin monitoring at Mauna Loa and in the Antarctic by David Keeling of the United States. During 1956 the oceanographic community was making plans to participate in the IGY and Roger Revelle and Hans Suess recognized that the ocean would not take up as much carbon dioxide as originally thought, warning that "Human beings are now carrying out a large-scale geophysical experiment of a kind that could not have happened in the past, not be repeated in the future. The experiment, if adequately documented may yield a far-reaching insight into processes determining weather and climate". Revelle and Harry Wexler of the US Weather Bureau arranged for funding of the programme that has been so central to our current understanding of long-term climate change.

The IGY also began with the hope of satellite measurements; in 1957, the launch of the Soviet Sputnik opened the space age. By 1960, when Bruun was on the globe-circling Galathea expedition that brought so much new information about the deep sea, the first polar-orbiting meteorological satellites were flying and the first cloud cover photography took place. The first complete view of the earth's weather was achieved in 1965. By 1966, the first geostationary meteorological satellites were in place, by 1972 the first LANDSAT, and by 1978, a dedicated ocean satellite Seasat was providing the first global ocean data.

These technology successes have led to the development of a whole series of operational satellites and proposed new missions that will fly in the 1990s, the next great age of satellite measurements of the earth.

The ocean programmes of the 1970s also led to the realization that the ocean was a key element in global environmental change. Better understanding of the space and time scales of eddies, mixing, and chemical, biological, and air-sea interaction processes was achieved. New technology, both satellite and *in situ*, together with better computers, was used to develop new ideas and to plan a series of new global and regional programmes. Before I turn to these new programmes, I will discuss briefly the technology of satellites.

Ocean from Space: the New Technology

Today, thanks to space agencies around the world, satellite-borne instrumentation is available that can sit well away from earth and give us a snapshot view of the ocean. The instruments can also tell us how the atmosphere drives the ocean with wind, heat, and rainfall and evaporation, and how sea-ice fluctuates. Satellite-borne instruments give us a snapshot, like photography, but with a much broader range of wavelengths from the ultraviolet to the infrared and microwave, so that we get a much better description of ocean processes.

The development of satellites and their instruments depended not only on rocketry and the understanding of orbit mechanics, but also on the development of microelectronics, which allowed miniaturization of instruments and solar cells for power. In that sense satellites paralleled the development of modern instrumentation in oceanography.

Satellites circle the earth in orbits whose period depends on the distance from the earth. These orbits can be close to the earth, typical for a polar-orbiting satellite, or far from the earth, typical for a geostationary satellite. The polar-orbiting satellites are typically about 850 km., above the surface and have a period of about 90 minutes. Geostationary satellites are about 36,000 km., from the earth, and have a period of 24 hours. Orbits in between can be elliptical for special coverage of particular areas.

A special case of the polar orbit is the sun-synchronous orbit: normally the orbit is fixed in space because of conservation of angular momentum. But it is useful to have a measurement with a constant relation to the sun, for example, ocean colour. In that case, we want the orbit itself to rotate to follow the sun as the earth goes around the sun in its orbit. An orbital precession is required, which can be maintained because of the slight gravity perturbations from the earth's non-spherical shape.

Instruments carried by satellites operate in two modes: passive and active. The passive instruments are essentially telescopes that focus and collect radiation that comes from earth in different wavelengths, ranging from ultraviolet to visible to infrared to microwave. Unfortunately, atmospheric absorption cuts out much of the radiation that might otherwise be observed. The visible and near-infrared have relatively high transmission, but the far infrared is mostly opaque due to water vapor absorption. Satellite instruments therefore work at several wavelengths at once: for example, the NOAA

Advanced High Resolution Radiometer uses five spectral bands, each of which gives a different view of the same scene.

The atmosphere in the microwave spectrum from about 1.0 cm., is mostly transparent and is valuable for studying surface features and sea ice: emission of microwaves is very different for water and for ice. Particular absorption regions can be used to detect water vapor and liquid water and various atmospheric constituents.

Active radar involves ending pulses of radiation from the satellite down to the earth and receiving the reflected signal. The reflected signal will have been modified by the surface, and the modifications can be used to determine the features of the surface. The altimeter is probably the simplest of these: it operates by *sending* a pulse directly down to the earth and measuring the time it takes to come back. The time can be turned into distance, and changes in distance are then directly proportional to changes in the ocean surface height.

The scatterometer is more complex: a pulse is sent out at an angle and the reflected signal is received. The frequency shift, time, and shape of the pulse help to determine the characteristics of the surface. Perhaps the most sophisticated of the instruments is the synthetic aperture radar, which uses the motion of the sensor in flight to synthesize a signal from the surface. The size of the synthetic antenna depends on the coherence of the signal, but can be enormous: from a range of 850 km., Seasat mapped the earth with a synthetic aperture radar with a resolution of roughly 25 meters. To have achieved the same resolution with a real array antenna operating at the same wavelength of 24 cm., the antenna would have had to be roughly 8 km., long.

For power, satellites generally use solar cells, although some that require high power use nuclear generators. Data systems vary: some systems collect and store on tape recorders, then later transmit to ground stations. Some collect and send data directly over a region. The total series of operational earth remote sensing satellites now flying is shown in Figure 1: five geostationary and seven polar-orbiting satellites. The data from these satellites are carried and made available through the Global Telecommunications System.

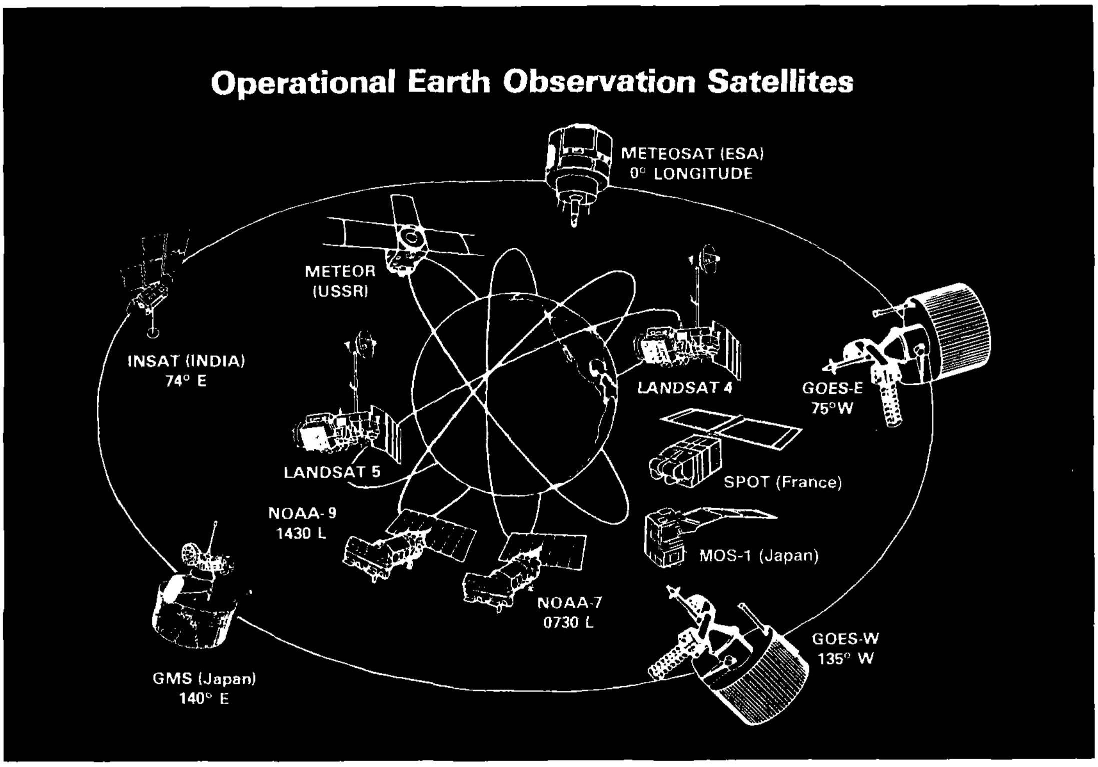

Figure 1. The set of operational earth-observing satellites in place as of 1989. The orbits are not to scale; typical polar orbits are 850 kms. above the earth and geostationary orbits are about 36,000 km. away. (Courtesy of NOAA).

What is possible now: Global and Regional

Today with satellites, we can measure sea surface temperature, waves, currents, surface color, sea ice, shallow and deep bathymetry, and the driving forces of the atmosphere: wind, rainfall, and heat flux. From the initial demonstration of the feasibility of these new satellite techniques, quantitative measurements from satellite-borne instrumentation are now fundamental parts of many new global programmes. The information from these programmes is essential to understand how the ocean works and how it is driven by and affects the atmosphere. Together these new programmes will form the basis for a new understanding of global change and of coastal environmental processes. All of these programmes have as central elements the measurement of ocean processes by satellite-borne instrumentation.

The World Climate Research Programme, together with the SCOR-IOC Committee on Climatic Change and the Ocean has developed the Tropical Ocean and Global Atmosphere (TOGA) Programme which has already given us the first step in the prediction of the El Nino. The World Ocean Circulation Experiment (WOCE) will tell us about ocean currents and how they distribute heat and carbon dioxide. SCOR has developed the Joint Global Ocean Flux Study (JGOFS) programme which is now a core project of ICSU's International Geosphere-Biosphere Programme (IGBP). JGOFS will show us the workings of the carbon cycle and how ocean biology and chemistry are part of global change. IOC is developing a new programme in Coastal and Shelf Seas Dynamics to link these processes to global processes. The WCRP is developing a Global Energy and Water Cycle Experiment to understand water cycles through atmosphere, ocean, and land. There is an on-going programme of satellite and *in situ* measurements of the Earth's radiation budget. New programmes for understanding the interaction of sea ice and climate are being developed.

The El Nino is being studied in TOGA with weather satellites and with sea-level measurements from the US Navy's altimeter satellite. The European Space Agency's ERS-1 satellite will provide valuable wind measurements in the tropics for TOGA. The World Ocean Circulation Experiment depends crucially upon accurate measurements of the ocean surface topography and surface winds which will be provided by ESA's ERS-1 and a new US-French satellite mission TOPEX/POSEIDON. JGOFS will use satellite ocean colour measurements to measure biology in the ocean. The Global Energy and Water Cycle Experiment will use satellites to measure rainfall. New polar programmes will use European and Japanese satellite measurements for sea ice. New coastal programmes will use satellites to measure biology, sediments and pollution.

Sea surface temperature (SST) and ocean colour measurements are important for many of these programmes. Today, SST measurements are routinely provided on regional and global scales from operational satellites. Ocean colour provides information on suspended sediments, the amount of biological material, and even ocean currents. The ocean colour instruments are tuned to the wavelengths that are absorbed by sediments and chlorophyll, and can give accurate data on what is present after correction for what is in the atmosphere. Figure 2 shows how ocean colour data from the satellite-borne Coastal Zone Color Scanner can be used to delineate currents and chlorophyll patterns. It shows the regions of the Gulf Stream and Kuroshio current in 1979. The areas of high productivity are in red and yellow; low productivity areas are in blue and violet.

The data can also be used to produce a global picture of land vegetation patterns and ocean colour which is related to biological productivity. Figure 3 was produced at NASA's Goddard Space Flight Center with data from both NOAA and NASA satellite measurements. The land vegetation data come from the Advanced Very High Resolution Radiometer on the NOAA-7 polar-orbiting satellite during the period between April 1982 and March 1985. The ocean colour data come from the coastal zone colour scanner instrument on NASA's Nimbus-7 satellite during the period between November 1978 and June 1981. 400×10^9 bytes of raw data were used to generate this figure. Although the periods of measurement do not overlap, the general patterns are believed to indicate how vegetation on the earth's surface is distributed. Desert and fertile areas on the continents are immediately evident, with Africa providing a particularly vivid example. Ocean productivity is clearly most active near the coasts, but there is a significant amount along the Equator in the Pacific Ocean. Note also the high productivity in the Greenland Sea.

The same data can be used to produce time series of changing productivity. Figure 4 shows the growth of the North Atlantic bloom in 1979, an area where the first JGOFS experiment took place this past spring.

But in order to understand how the ocean works, we must also know the driving forces. Heat flux, winds, precipitation, and sea ice must also be monitored. Clouds were one of the first parameters to be monitored from satellite; today routine measurements provide cloud type, height, and moisture.

Ice conditions are routinely measured from a number of satellites including the NOAA polar-orbiting satellites, the LANDSAT satellites, the SPOT satellite, and a number of USSR satellites. Clouds, ice conditions, and soundings of the atmosphere are now routinely provided through a number of polar-orbiting satellites operated by the US, the USSR with its METEOR series, and now China with its Wind-Cloud-1 satellite that was launched in September 1988. Microwave measurements that can penetrate through clouds in the polar regions have proven enormously valuable.

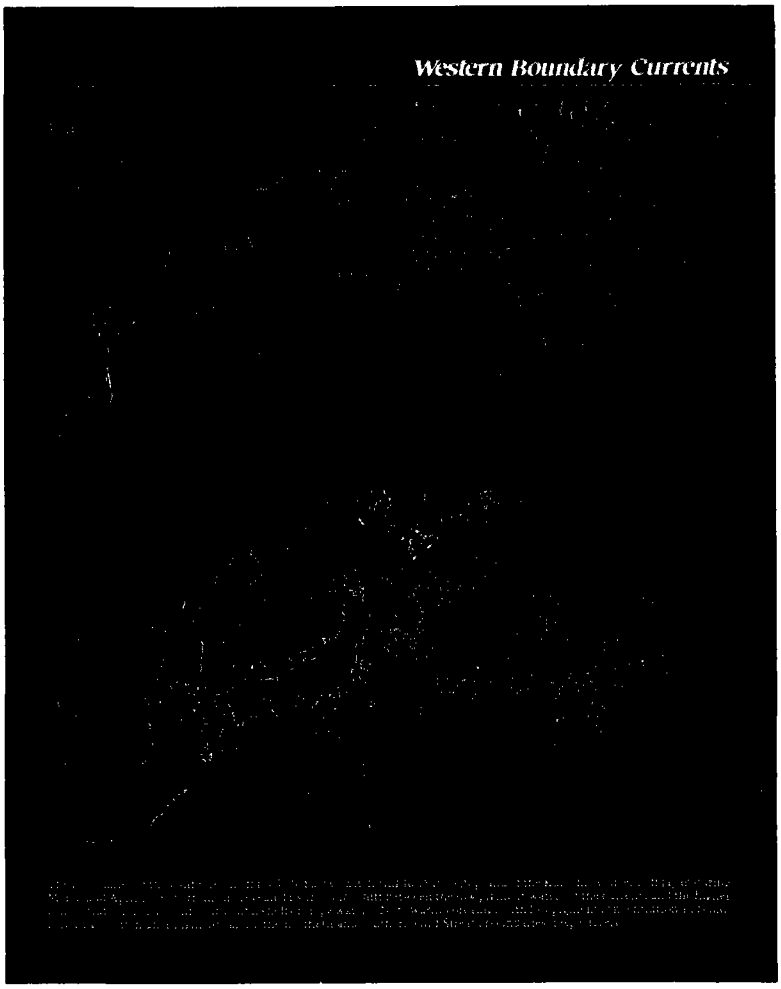

Figure 2. The regions of western boundary currents as observed by the Coastal Zone Color Scanner on the NASA Nimbus-7 satellite. High productivity is denoted by red and yellow; low productivity by blue and violet. (Courtesy of NASA).

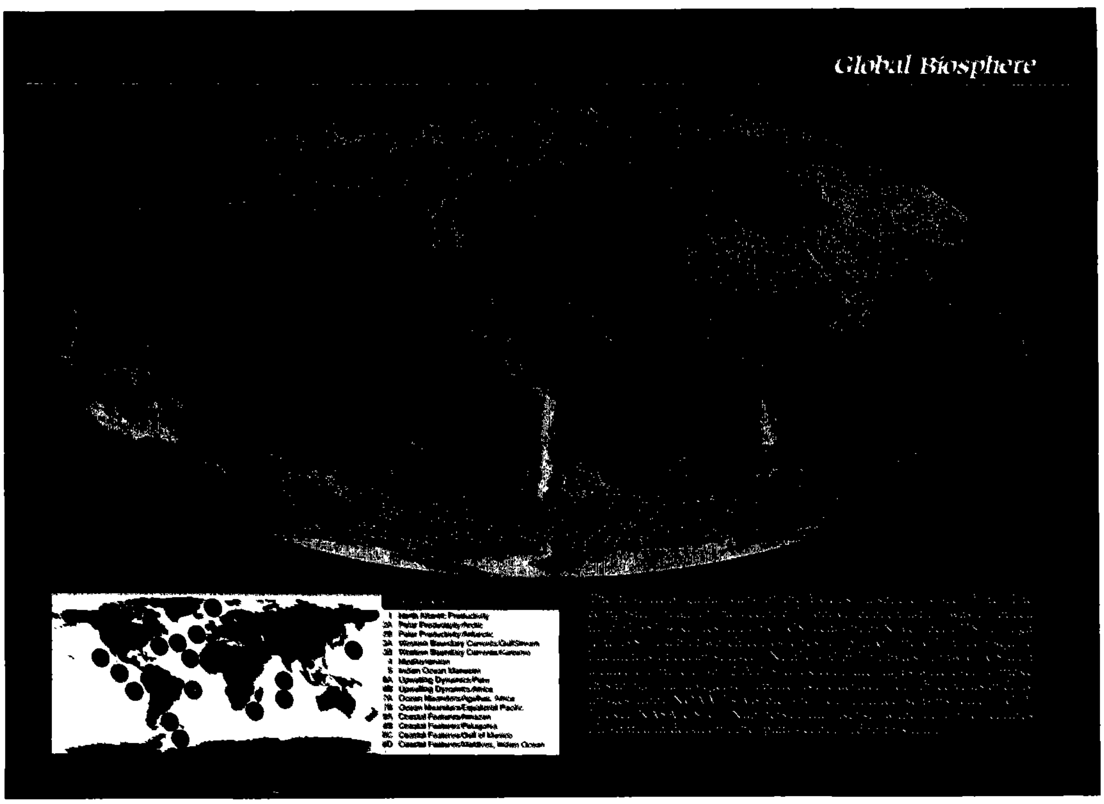

Figure 3. The global biosphere as observed by satellite.

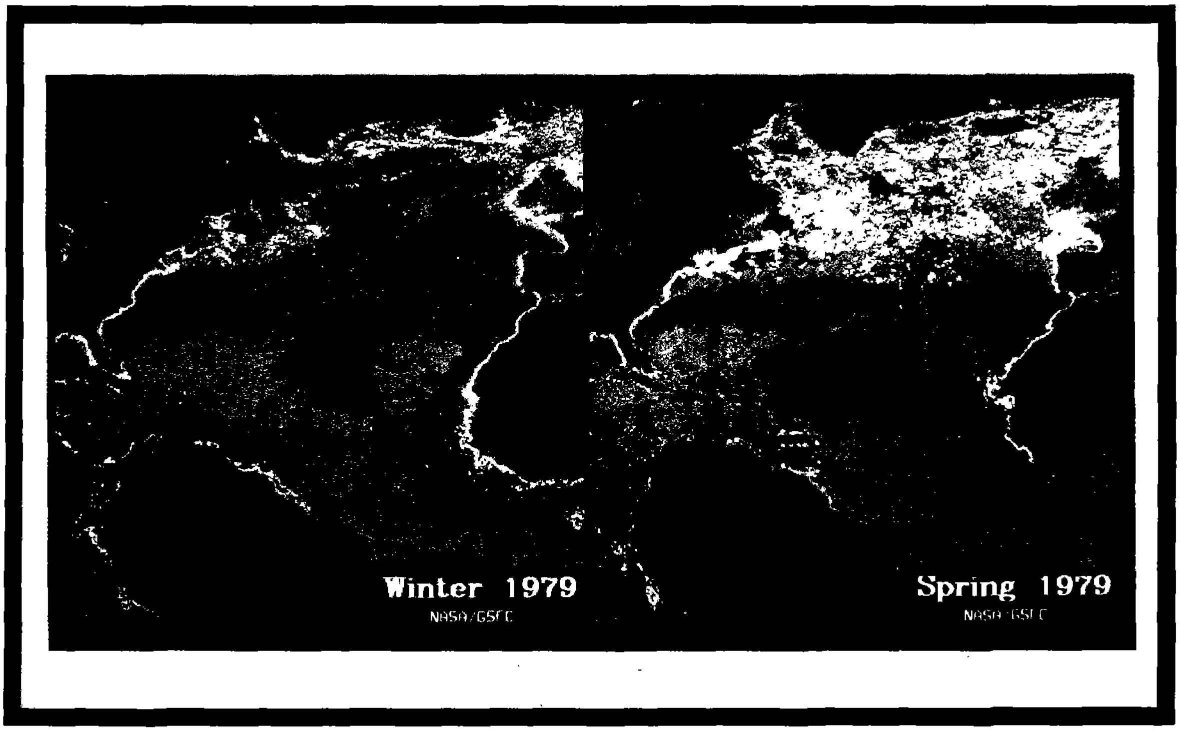

Figure 4. North Atlantic spring plankton bloom observed by the Coastal Zone Color Scanner on the NASA Nimbus-7 satellite. High productivity is denoted by red and yellow; low productivity by blue and violet. (Courtesy of NASA).

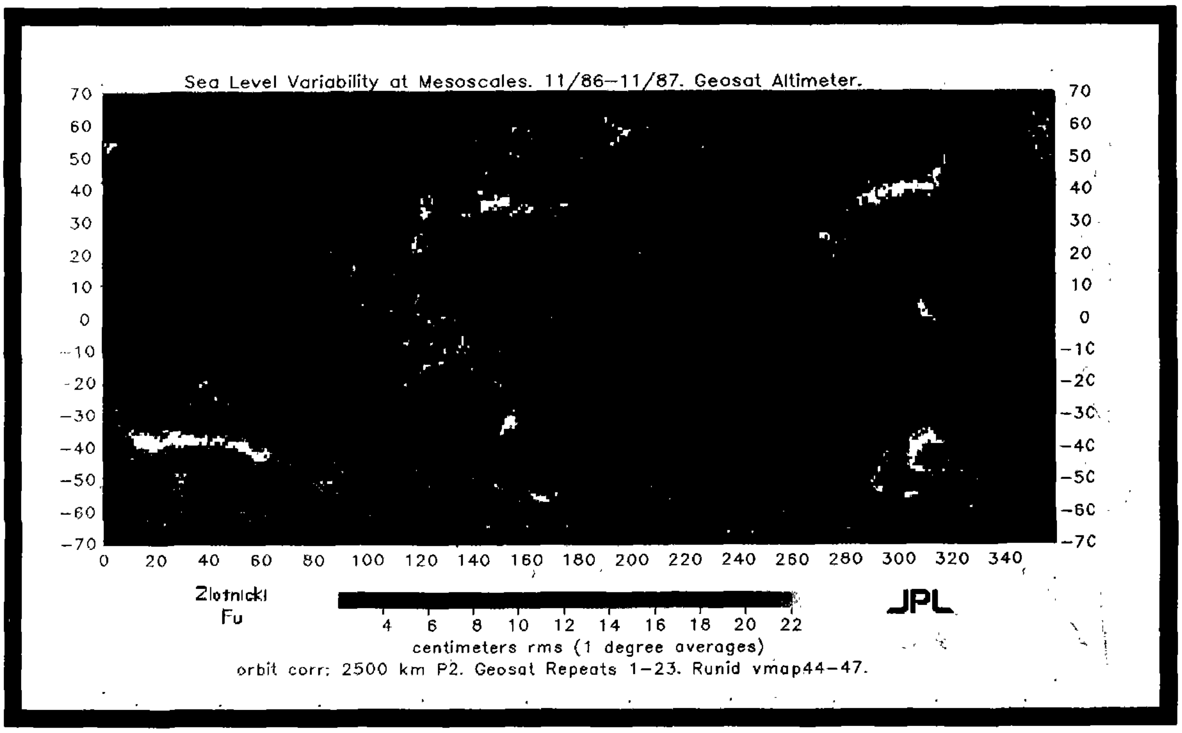

Figure 5. Sea level variability as observed by the US Navy GEOSAT satellite altimeter for 1987.

Active radar satellites began with the flight of instruments on the space shuttle. The SEASAT satellite, although it lasted only three months, provided a suite of data on different kinds of active radar that is still being evaluated. SEASAT demonstrated the possibility of monitoring ocean currents with an altimeter and surface winds with a radar scatterometer.

An altimeter on the US Navy satellite GEOSAT provided data on the earth's gravity field, mesoscale ocean fronts and eddies, surface ocean currents, surface wind speed, wave height, and the edge of the sea ice from 1986 to 1989. Because of this long time series, the resolution of the sea surface is greatly improved over the Seasat data. Figure 5 shows the mesoscale sea level variability from GEOSAT for 1987. The variations of the Kuroshio current, Gulf Stream, and the Antarctic Circumpolar Current are evident.

Perhaps one of the most exciting uses of the GEOSAT data is for monitoring sea level in the Pacific Ocean to detect the onset of an El Nino. The El Nino in late 1986, although not a strong one, was the first such event observed by a satellite altimeter. The satellite data are particularly useful because they provide information from areas where there are no islands with sea-level stations.

Thus the new satellite data are providing basin-wide coverage and resolution not achievable before; they represent an important new way of observing the ocean. Plans are in progress by the US Navy to provide a follow-on altimeter satellite in late 1990. Looking to the future, the data from these altimeter satellites will be valuable not only for direct mapping of ocean processes, but also to help the oceanographic community better use and understand the data from later altimeter missions such as ERS-1 and TOPEX/POSEIDON.

Complementing the ocean measurements by the operational weather satellites and GEOSAT, Japan has successfully launched the Marine Observation Satellite-1 as their first earth observation spacecraft. MOS-1 is an experimental mission planned as the forerunner of a thirteen-year operational programme beginning in the 1990s. Five missions are planned, the first two of which, MOS-1 and MOS-1b, are already approved. The overall emphasis is on ocean observation and on developing the basic technology for global earth observation.

The USSR has launched a series of oceanographic satellites, with the first side-looking radar instrument coming in 1983. KOSMOS 1766 currently operates with a side-looking radar to monitor the polar ice packs for routing of ships in these regions. A new television automatic information system receives and processes data from oceanographic satellites at a centre near Moscow and then transmits ice forecasts directly to ships at sea using geostationary communications satellites.

In 1986, France launched the first of a series of land-sensing satellites which complement the US LANDSAT instruments. LANDSAT has more spectral bands, which extend farther into the infrared, while the French system has superior spatial resolution. With a special Gallic touch, the acronym works both in French and English: Système Pour l'Observation de la Terre or SPOT. The satellite is in a sun-synchronous orbit; its pattern repeats every 26 days.

Other countries are also beginning to enter this field. India has plans for a remote sensing satellite for launch in late 1989 or early 1990, and Brazil and China are developing a joint remote sensing programme.

Satellites offer a unique opportunity for providing location information on earth and for measuring the earth's shape and gravity field (geodesy) to great accuracy. A constellation of satellites, so that one or more is always in view, allows all-weather navigation on land and sea. The Global Positioning System of the US which will eventually consist of 24 satellites in orbit, provides an accuracy of location of less than a metre. As of 1987 there were seven such satellites, called Navstar, in orbit, providing all-weather navigation about 50% of the time for aircraft and ships. The satellites can also be used for geodesy. The Soviet Union also has a constellation of navigation satellites in orbit. There are 24 of the Glonass satellites now flying. Satellites for both systems use nearly circular orbits with an orbital period of 12 hours, and are placed in three different orbital planes separated by 120 degrees for full coverage.

The Decade of the 1990s

The 1990s promise to be the era of ocean satellite measurements. Towards the end of 1990, the European Space Agency will launch the ERS-1, which is expected to be the forerunner of a series of European remote sensing satellites to become operational in the mid-1990s. The ERS-1 payload includes six instruments designed to measure sea surface and cloud top temperature, land and ice radiances, sea state, atmospheric water vapour, surface topography, and surface wind and waves.

About one year later than ERS-1, a second ocean measuring satellite is planned for launch: the joint US-French TOPEX/POSEIDON mission is shown on the next slide. This is a single purpose mission with each element designed specifically to contribute to a precision measurement of the ocean surface topography.

Ocean colour measurements to follow on the Coastal Zone Color Scanner observations are being planned by NASA for an instrument to fly in the early 1990s on a small satellite launched either from a Pegasus or Scout vehicle. The ocean colour sensor is being developed with the support of NASA. It will have eight spectral bands in the visible with special focus on the regions of interest to ocean colour. Another ocean colour and temperature sensor with six channels, based on the design of the instrument used in MOS-1 is being proposed for the Japanese Advanced Earth Observing Satellite (ADEOS) which is scheduled for launch in 1995. The main objective of ADEOS is to develop and operate advanced optical sensors, and to develop and use the new Japanese high data rate Experimental Data Relay and Tracking Satellite.

ADEOS will also carry an Advanced Visible and Near-Infrared Radiometer for high spatial resolution land images. It has been proposed that the ADEOS satellite carry the US scatterometer to measure winds at the surface. The ADEOS flight of the scatterometer will provide the follow-on to ERS-1 for wind measurements.

Two proposed radar satellites are of special interest here: Japan's ERS-1 and Canada's RADARSAT. The Japanese satellite will use newly developed optical sensors and a synthetic aperture radar to observe the land surface. The data will be used to explore non-renewable resources and to monitor land and coastal regions for agriculture, forestry, fisheries, environmental protection, and warning of natural disasters.

Canada's RADARSAT will carry a synthetic aperture radar whose primary use is for ice measurements. It will also be used to measure ocean winds and waves to improve weather and sea-state forecasting, as well as to make fishing, shipping, oil exploration, and off-shore drilling safer and more efficient. It will also be able to detect oil spills.

One of the important parameters for understanding the ocean is rainfall. The freshwater flux into the ocean drives the circulation and determines the salinity of the surface waters. Yet rainfall at sea has proved to be remarkably difficult to measure. Shipboard measurements are few and far between and island measurements tend to be biased because of local weather effects. Satellites offer the best global coverage, but have not been accurate enough yet. Now, with new radar techniques, it appears possible to make such measurements.

The Tropical Rainfall Measuring Mission (TRMM), a joint US-Japan mission, will gauge precipitation in the tropics using both active and passive microwave data together with visible and infrared imagery to derive useful estimates of rainfall amounts and distribution. The mission will fly at a low altitude and in a tropical orbit. The proposed French mission, Bilan Energétique du Système Tropical or BEST, is also aimed at accurate measurements of rainfall. BEST will include radar, laser and radiometer systems also in a low inclination low altitude orbit aimed at sampling diurnal variations.

The Far Future

In the late 1990s, we look to continuation of the operational programmes now in place, to new research missions, and to the deployment of the Earth Observing System on several polar platforms. The Earth Observing System will involve participation by many countries including the US-Japan, and the European Space Agency. The instrument complement includes advanced versions of the various devices flown in the past two decades. Of particular interest to oceanographers will be the high spectral and spatial resolution radiometers. For example, one of these will have a spectral resolution of 64 bands over the visible and near infrared, thus providing detail not achievable before.

The instruments will be aimed at measuring processes in the atmosphere and ocean and on land simultaneously for a better description and understanding of global change. The proposed configuration for a polar platform to carry the instruments is about ten times the size of the existing platforms. A second stage for the Earth Observing System will be new instruments in geostationary orbit.

Towards an Operational Ocean Network for Global and Regional Studies

In the long run, we need to have a global earth observation system that includes ocean measurements made operational the way that weather measurements are made today. We have a World Weather Watch that is driven by the needs of weather forecasting and civil aviation. The ocean customers in the past have been fewer, limited to merchant ships and fisheries vessels. The navies of the world, another customer, tend to collect and use their own data. But now there is a new customer who needs information from both the atmosphere and the ocean. That is the need for observing, understanding, and predicting climate. This new demand for climate information will be an important driver for a global observing system. The World Weather Watch will be augmented and improved, and new ocean observing systems for climate will be developed.

We need to use this new interest to help establish an ocean climate observing system. It will not be an exact analogy to the World Weather Watch, but it will have many similar elements. It will build on the existing sea level, drifting buoy, and XBT programmes now in place, but will of necessity include much more. The new technology of *in situ* measurements now being developed for programmes such as TOGA, WOCE, and JGOFS will contribute to the new system. The satellite technology discussed here will be a key element. And the design of the programme will depend crucially upon what is learned in these new programmes and others about how the ocean works, and where we can best monitor its pulse.

The context is timely. July last month, here in Paris, Dr. Hubert Curien, the French Minister of

Research and Technology, at the request of President Mitterand, hosted a conference on "Planet Earth". The scientists at the conference emphasized the need for a major commitment by nations to long term global earth system monitoring and observations. President Mitterand called upon the countries of the world to enhance their commitment to a programme of international research on global environmental change. He proposed setting up a worldwide system of scientific observatories from satellite systems to many ground based platforms to monitor and observe the earth with international co-operation. He announced that he plans to make the science and policy issues of global environmental change a centerpiece of the July 1989 Economic Summit meeting.

As oceanographers, it is incumbent on us to ensure that long-term observations of the ocean are a fundamental part of such new programmes.

Conclusion

Anton Bruun had a global view of the ocean and was interested in how it and its living systems worked. His career paralleled the development of modern ocean science. Today we are ready to build on that view for a new global observing system. But perhaps it is best to close on a more individual note. Anton Bruun shared with all of us a love for the ocean, and he conveyed this enthusiasm and sparked the interest of all who came in contact with him. It is this interest and enthusiasm that drive a field like oceanography.

Today we have the opportunities for major advances in our field because of new technology. But the application of this technology will depend on how well we use our institutions, resources, and education. These are all issues that will be of importance in the next three weeks here at the Assembly. I hope that we can work on these in the spirit of Anton Bruun.