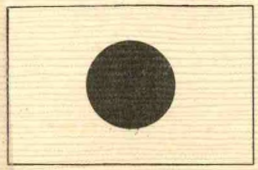


Proceedings of the 11th Meeting of the

United States-Japan Cooperative Program in Natural Resources (UJNR)

Panel on

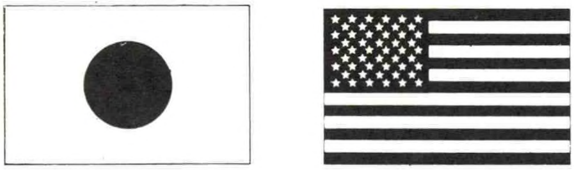
Diving Physiology and Technology

Hakone, Shizuoka

September 26–27, 1991

Japan Marine Science and Technology Center

National Oceanic and Atmospheric Administration



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Science and Technology Agency
Japan Marine Science and Technology Center
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JAPAN

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WELCOME ADDRESS

SHINICHI ISHII

CHAIRPERSON OF JAPAN PANEL

I was appointed executive director of JAMSTEC on April 9, 1991. Sinultaneously, I was privileged to serve as Japanese chairperson of the UJNR panel on Diving Physiolog and Technology. As successor to Mr. Mayama, I would like to do my best to further the cause that the Charter of this Panel sets forth, thus helping scientific exchange overall between the United States and Japan.

I am very pleased to hear that this will be the 11th time that the Panel meets and that each past meeting saw more activity than did the one just before. It is my neal honor that I can serve as the Japanes chairperson this time of this long-standing and successful Panel. With Dr. Busch's consent, this yesr's meeting will be adopting a new topic-oriented committee style to reflect the rapidly growing activity particularly in deep sea research. I look forward to most active discussions and exchange of views taking place in each committee. I hope that this Panel being convened here at Hakone, One of Japan's best scenic spots, will prove a menorable occasion for everyone attending. Representing all JAMSTEC staff serving as the Panel's secretariat, I would like to express my sincere appreciation to Mr. Gregory E. Stone of NOAA for his invaluable assistance rendered during all stages of preparation for this meeting.
Our appreciation also goes to Dr. Busch who was instrumental in making his sojourn at JAMSTEC possible. Now I hereby announce the opening of the 11th meeting of the UJNR UJNR Panel on Diving Physiology and Technology.

Thank you.

OVERVIEW BY U. S. CHAIRPERSON

WILLIAM BUSCH

CHAIRPERSON OF U. S. PANEL

First of all, I would like to thank our gracious hosts, the Japanese delegation. This has been a very productive and successful meeting largely because of careful preparation and planning. It has also been wonderful to have the meeting in such a beautiful location. Along with the many Japanese participants who worked on this meeting, I owe special thanks to NOAA scientist Mr. Gregory Stone who has been working in Japan for the past two years to strengthen the activities of this Panel.

For the first time, we have divided the Panel meeting into two groups. One dealing with Diving Physiology and the other with Deep Sea Science. This was a good step and is a natural evolution in our Panel's activities. Some 30 years ago, when our Panel was formed, most undersea activity was conducted by humans working in a hyperbaric environment. Today, we still have a very large group of people working underwater in a hyperbaric environment, but we also now have many new one-atmosphere or unmanned underwater systems that enable researchers to work at much greater depths for longer periods of time. Thus, we have accommodated this expansion in undersea ability with the deep sea science group.

The deep sea science group heard from leading scientists in the U.S. and Japan on pressing undersea science topics. A superb summary and very clear direction for was provided for future activity. This was very successful.

Once again, the Diving Physiology group provided one of the best summaries in the world on hyperbaric research and activity. We heard many report of work from this past year and exciting expectations for future work. This was also very successful.

This years meeting has carried on in the very special spirit of the UJNR group and has fostered and will continue to foster cooperative research and activity. Thank you all for doing such a fine job.

Thank you.

The 11th Joint Meeting of UJNR/MRECC Panel on Diving Physiology and Technology

Sep. 26, 27, 1991, Hakone, Japan

AGENDA

26 September, 1991

09:00 - 09:45 1. Opening of the Meeting (A-room)

(1) S. Ishii, Chairperson of Japanese Panel

(2) W. S. Busch, Chairperson of U.S. Panel

2. Election of Chairperson and Co-chairperson

3. Recommendation of Vice-chairpersons

(1) S. Ishii

(2) W. S. Busch

4. Adoption of the Agenda

5. Opening Remarks

① D. Duane

② S. Earle

6. Notice from secretariat

Hyperbaric group (A-room)	Deep sea science group (B-room)
SESSION 1	SESSION 1
10:00-10:15 1. I. NISHI Breath by breath mass spectrometric continuous respiratory gas analysis from hyperbaric chamber. —Menthodological appoach for advance study on hyperbaric physiology—	10:00-10:20 1. D. DUANE Developing a plan for the future.
10:15-10:30 2. M. NODERA Spinal DCS in rats after He-O_2 chamber dives.	10:20-10:40 2. C. KATO Deep-sea microbiological research at the Japan Marine Science and Technology center.

10:40-11:00 Coffee Break

Hyperbaric group (A-room)	Deep sea science group (B-room)
11:00-11:15 3. Y. GOTOH Experience of using multiple techniques in the ultrasonic bubble detection.	11:00-11:20 3. L. P. MADIN Use of submersibles for research on deepwater zooplankton.
11:15-11:30 4. K. KOBAYASHI Comparison of bubble appearance between air and nitrox chamber dives.	11:20-11:40 4. T. HAMAMOTO Characterization of an amylaze from a psychrotrophic vibrio isolated from deep Sea mud Sample.
11:30-11:45 5. R. ARAKI Enhancement by intravenous fluorocarbon infusion of alveolar inert gas elimination in rats after hyperbaric exposures.	11:40-12:00 5. W. WAKEFIELD The application of marine technology to research needs in deep-sea biology for the coming decade.
11:45-12:00 6. T. NAKAI Automatic bubble detection system of gas bubbles generated in blood streams by linear predictive analysis method.	

12:00-13:00 Lunch

Hyperbaric group (A-room)

SESSION 2

13:00-13:15
7. M. KITANO
Histopathological analysis of dysbaric osteonecrosis experimentally induced in sheep.

13:15-13:30
8. Y. C. LIN
Determination of interspecies $T_{1/2}$ for the formulation of decompression tables (UDT-300)

13:30-13:45
9. M. KAWASHIMA
Decompression sickness and dive profiles.

13:45-14:00
10. C. E. LEHNER
Dive profiles control the risk of dysbaric osteonecrosis:validation in Japanese diving fishermen and sheep.

14:00-14:15
11. S. YAMAZAKI
Safety management of repetitive no-decompression diving profiles using a Scuba Data Service & Safety Diving System (SDS).

14:15-14:30
12. D. CHANDLER
The utility of diving memory recorders for diving research.

14:30-14:45
13. Y. MANO
Recent diving profile of shellfish divers at Ariake Sea.

14:45-15:00
14. P. B. BENNETT
DAN, sports diving accidents and deaths in the USA.

Deep sea science group (B-room)

SESSION 2

13:00-13:20
6. T. OKUTANI
Marine biological wealth brought by the submersibles. —— New light to molluscan systematics as an example——

13:20-13:40
7. D. L. STEIN
Deep nekton: Prospects for future studies using undersea vehicles.

13:40-14:00
8. S. EARLE
Results of Shinkai 6500 dive & deep sea science & technology needs.

14:00-14:20
9. Y. UEDA
A seabottom observation project in sagami bay by the hydrographic department of Japan.

14:20-14:40
10. M. YUASA
Submarine pumice volcano in the IZU-OGASAWARA ARC
—— a submersible study of the myojin knoll.

14:40-15:00
11. J. LUPTON
Deep submersible and rov needs for mid-ocean ridge research.

15:00-15:20 Coffee Break

15:20-15:35

15. S. ISHIGAMI
Neuropsychological assessment for saturation divers.

15:35-15:50

16. Y. S. PARK
Renal response to head-out water immersion in Korean women divers.

15:50-16:05

17. K. SHIRAKI
Heart rate responses to breath-hold dives in Japanese male funado divers.

16:05-16:20

18. S. K. HONG
Natural diving patterns of Korean and Japanese breath-hold divers(AMA)

15:20-15:40

12. K. KISHIMOTO
In-situ measurement and observation of hydrothermal activity. A feasibility study of new usage of submersible

15:40-16:00

13. P. A. RONA
Frontier of seafloor hydrothermal research.

16:00-16:20

14. S. R. HAMMOND
Establishing a seafloor observatory: NOAA VENTS Program's longterm seafloor and hydrothermal monitoring experiments.

16:20-16:40

15. G. H. BILLY
U. S. NAVY deep submergence program deep

16:40-17:00

16. S. YAMAMOTO
ONR activities

18:00-20:00 Reception by Japanese side

Hyperbaric group (A-room)	Deep sea science group (B-room)
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11:45-12:00 6. T. NAKAI Automatic bubble detection system of gas bubbles generated in blood streams by linear predictive analysis method.	

12:00-13:00 Lunch

11:20-11:40 Informal discussion time

11:40-12:00 Final Discussion and Summing-up of Meeting
(A-room)

12:00-13:00 Lunch

13:00-18:00 Informal discussion time

18:00-20:00 Reception by U.S. side

CHARTER OF THE UJNR PANEL ON DIVING PHYSIOLOGY AND TECHNOLOGY

Objectives:

1) Encourage, develop, and implement the exchange-between the United States and Japan-of undersea science and technology (including data, other information, facilities, state-of-the-art equipment, and personnel) in the areas of diving physiology and technology.

2) Develop close and meaningful scientific, governmental, industrial, and personal ties among scientists, engineers, and administrators from the two countries.

3) Conduct joint undersea and diving-related research and development missions and hyperbaric physiological projects using undersea technology. Resources to be used include such facilities and techniques as hyperbaric chamber complexes, SCUBA and tethered diving systems (both air and mixed gas), manned submersibles, diving support vessels, habitats, and unmanned undersea vehicles.

4) Implement administrative mechanisms, systems, and procedures to conduct and achieve to panel's joint efforts.

Topics and Subject Areas of Interest include;

1) Hyperbaric and diving related medicine
2) Hyperbaric, diving, and thermal physiology
3) Diver performance
4) Diving technology
5) Application of diving technology and diving physiology (including use of related undersea facilities) to the oceanographic and marine sciences.
6) Manned and unmanned undersea vehicles and research
7) Application and implementation of research results
8) Environmental Hazards affecting divers.

CHARTER OF THE UJNR PANEL ON DIVING PHYSIOLOGY AND TECHNOLOGY

Cooperative Activities:

1) Develop joint undersea and hyperbaric research programs
2) Exchange of scientists and engineers.
3) Share scientific and technological data and information.
4) Conduct official joint panel meetings approximately every 2 years, alternating meeting locations between the United States and Japan.
5) Publish joint informational documents and publications.
6) Establish and maintain person-to-person contacts among scientists, engineers, and administrators of the respective countries.

Panel Membership:

1) Members of the panel and employees of either the U.S. or Japanese Governments or national government-affiliated organizations

2) Advisors shall be selected from appropriate disciplines representing either industry, academia, or research organizations to insure that the panel has the latest state-of-the-art advice and experience available.

Detailed Regulations:

1) To implement this charter, appropriate detailed regulations and policies of both the United States and Japanese governments must be followed.

2) This panel will only administer and manage joint US-Japan undersea related activities. All activities will conform and comply with the diving safety regulations, procedures and diving classification requirements of each country.

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TECHNICAL PRESENTATION

(Hyperbaric Group)

Breath by Breath Mass Spectrometric Continuous Respiratory Gas Analysis from Hyperbaric Chamber

— Methodological Approach for Advance Study on Hyperbaric Physiology —

I. Nishi, *H. Oiwa, *K. Okonogi, *A. Hashimoto, H. Ishii and G. Tomizawa

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Mass Spectrometric respiratory gas analysis is evaluated to achieve the advanced physiological analysis on respiration, circulation and metabolism.

Employing direct sampling from the hyperbaric chamber, this method was successfully applied to the study on hyperbaric physiology. Several methods newly developed were also successfully applied with a intention of attaining structural analysis of aerobic process and heat balance in hyperbaric environment.

1. Primary measurement

Primary measurement consists of breath by breath continuous and simultaneous measurement of respiratory gas concentrations, flow, and temperature. Respiratory gas analysis including water vapour was attained with sufficient precision and response up to 36 ATA (to be scheduled up to 42 ATA in this autumn). Continuous respiratory gas sampling from hyperbaric simulation chamber and the related correction processing of the primary mass spectrometric output were the most essential.

2. Methods developed for advanced physiological analysis

(1) Structural estimation of aerobic capacity.

Simultaneous measurement of ventilation, perfusion, gas exchange and their mutual coworking derivatives was proved to be successfully applied to make a structural analysis of aerobic gas transport and estimation of physiological work capacity in the hyperbaric environment.

(2) Compartment analysis of body heat balance.

Metabolic heat production, body heat storage, respiratory heat loss, body surface heat loss and kinetic work energy were simultaneously and continuously measured in conjunction with respiration and circulation.

With all the measurements, the more structural analysis of physiological respons and the more accurate estimation of work capacity and adaptation to the hyperbaric environment were considered. In this report, the principles and the technical descriptions on these methods will be given.

SPINAL DCS IN RATS AFTER He-O2 CHAMBER DIVES

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ABSTRACT

Twenty-four male Wistar strain rats weighing 190 - 260 g were exposed to He-O2 (20.5% O2) atmospheres of 7 ATA for 45 to 90 min and then decompressed to 1 ATA at a rate of 20 m/min in a small hyperbaric chamber. Ten min after surfacing, they were taken out from the chamber to examine the manifestations of decompression sickness (DCS). Nine rats died before the manifestations. Eleven of survived 15 rats showed difficulty in walking owning to the paralysis of hind legs. Another group of 24 rats were subjected to air dive using the same profile. In this case, 8 rats died before the manifestations, while survived 16 rats had no DCS manifestations.

These results suggest that the risk of spinal DCS is higher in He-O2 dive at deep depth for relatively short period than that in air dive.

INTRODUCTION

Many physiological changes have been reported in animal models with decompression sickness (DCS) following air dive.

Helium-oxygen mixture (heliox) has been used at depth greater than 50 meters, instead of air (Edmonds et. al., 1981). However, there are few reports about the effects of decompression on small animals in heliox diving. We examined the characteristics of DCS of small animals which were exposed to high heliox pressure.

METHODS

Male Wistar strain rats weighing 260-350 g were exposed to heliox (He-79.5%, O2-20.5%) atmospheres of 7 ATA for 45, 60, or 90 min in a small hyperbaric chamber. Then they were decompressed to 1 ATA at a rate of 20 m / min.

Ten min after surfacing, they were taken off from a hyperbaric chamber, to examine the manifestation of DCS. Twenty min after surfacing, survived animals of them were anesthetized with sodium pentobarvital (60 mg/kg, i.p.), and abdominal incision was made to observe the appearance of bubbles in posterior vena cava.

Those observations were carried out until 60 min after surfacing. Bubbles were observed under a microscope (Nikon TMD-photo). The pictures were recorded by microscopic high speed VTR system (nac, MHS-200) at a rate of 200 frames/ sec for detailed analysis. Eight rats were exposed in each exposure times (45, 60 and 90 min). The similar experiments using air were also carried out to compare with the results of heliox diving.

RESULTS

Table 1 shows the results obtained in 48 rats. Nine of 24 rats (37.5%) in the heliox group and 8 of 24 rats (32%) in air group died after surfacing. On the other hand, no DCS symptoms were seen in all of survived rats after air dive. However, 11 of 15 survived rats in heliox group showed difficulty in walking owning to paralysis of hind legs (Table 2). They dragged low part of the body, and walked by only behind legs (Figure 1). They also did not die during the experiment. But all of survived rats in air group walked normally.

Table 1. Mortality of rats after surfacing following exposure to high pressure

Group	Exposure Time (min)	Number of Rats	Number of fatal rats (%)
He/O_2	45	8	2 (25)
	60	8	3 (37.5)
	90	8	4 (50)
(Total)		24	9 (37.5)
Air	45	8	2 (25)
	60	8	1 (12.5)
	90	8	5 (62.5)
(Total)		24	8 (32)

Table 2. Occurrence of DCS symptoms (paralysis) in survived rats

Group	Exposure Time (min)	Paralysis / Survived Rats
He/O_2	45	4/6
	60	4/5
	90	3/4
(Total)		11/15 (73.3%)
Air	45	0/6
	60	0/7
	90	0/3
(Total)		0/16 (0%)

Figure 1. Paralysis of hind legs (heliox group)

Twenty min after surfacing, posterior vena cava was observed under a microscope to examine formation of intravenous bubbles. In heliox group, bubbles were seen in 14 of 15 survived rats. These bubbles disappeared within 60 min after surfacing in 7 cases (Figure 2). On the other hand, in air group, bubbles were seen in 7 of 16 survived rats. However, in most cases of air group, bubbles did not reduce their size, and did not disappear with elapsed time (Table 3).

Table 3. The appearance of bubbles in vena cava of survived rats

Group	Bubbles	
	30 min after Surfacing	60 min after Surfacing
He/O_2	14/15	7/15
Air	8/16	7/16

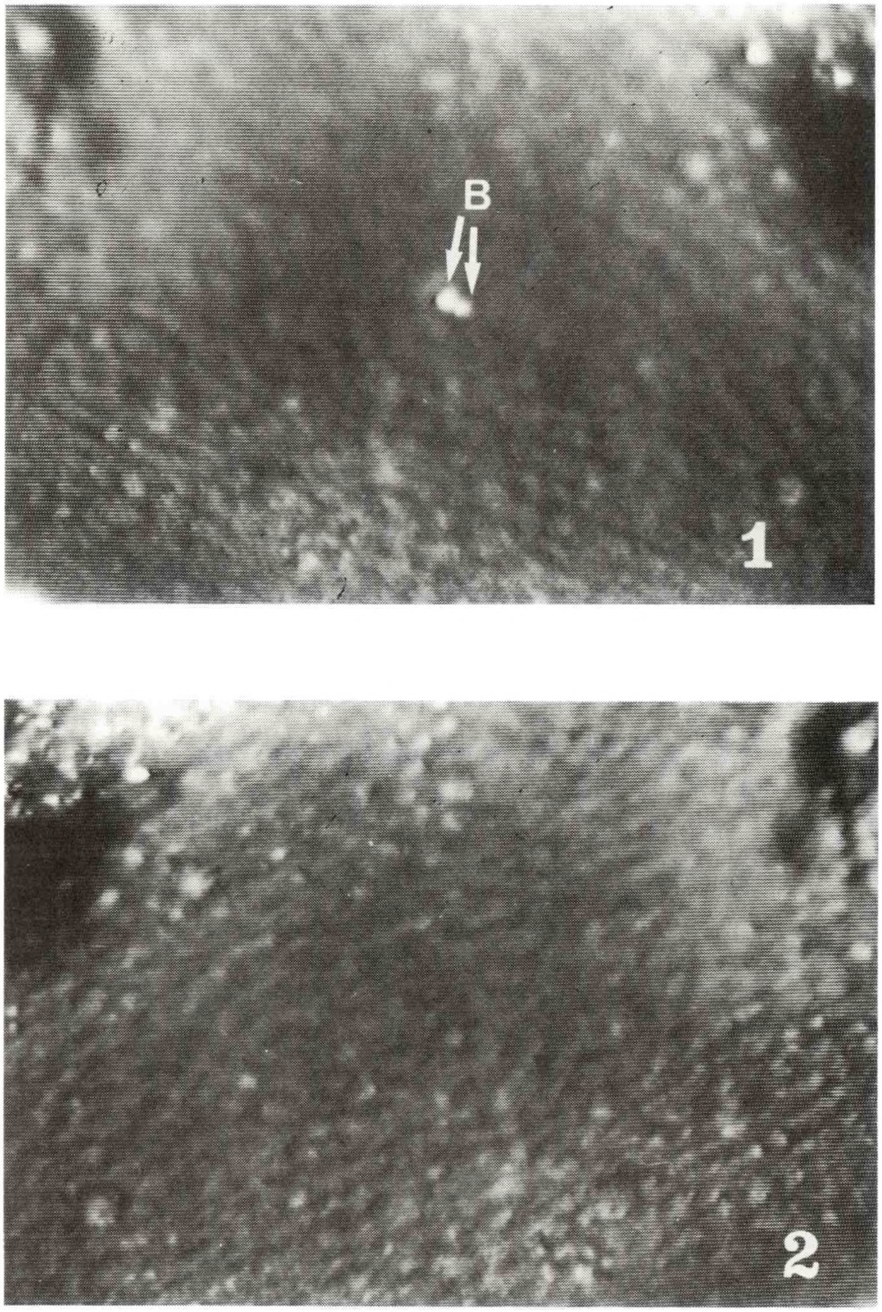

Figure 2. Appearance of bubbles in vena cava (heliox group)
1 : 30 min after surfacing. B : Bubble.
2 : 60 min after surfacing.

DISCUSSION

In this experiments, there was no significant differences in mortality of DCS between heliox and air (heliox-37.5%, air- 32%). Nevertheless no DCS symptoms were seen in all survived rats in air group, paralysis of hind legs were done in 73.3% of survived rats in heliox group. These results suggest that the risk of spinal DCS is higher in heliox dive at deep depth for relatively short period than that in air dive.

On the other hand, the rate of bubble appearance immediately after surfacing in heliox group was higher than that in air group. Furthermore helium bubbles easily disappeared with elapsed time. These phenomena will be explained by the difference of solubility and gas exchange rate in tissues between helium and nitrogen (Wienke 1991). Helium will be absorbed quickly in tissue and reach to higher saturation rate within short exposure at high pressure than nitrogen. Accordingly heliox exposure will higher risk of bubble formation in tissue after surfacing. On the other hand, helium will be quickly eliminated from tissues and reached to lower saturation rate. Accordingly helium in bubbles due to rapid decompression will diffuse to out side quickly and bubbles will disappear soon.

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EXPERIENCE OF USING MULTIPLE TECHNIQUES IN THE ULTRASONIC BUBBLE DETECTION

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We have examining detection of intravascular bubbles of divers using a precordial ultrasonic Doppler bubble detector (continuous wave type, model 1032G and 1058H, IAPM, USA) in relation to the appraisal of DCS risk. We have, however, sometimes found difficulties in confirming the appearance of bubbles owing to Doppler signals which might be derived from the movement of valves of right heart or the movement of heart itself. The signals were very similar to bubble signals. In the last two years we obtained the different types of ultrasonic equipments : a transcranial Doppler ultrasonic device (pulsed wave type, model TC2-64B, EME, Germany) and a two-dimensional ultrasonic system (model SSD-870, Aloka, Japan). We have examined bubbles of divers using these equipments as well as the CW Doppler equipment after the surfacings of experimental chamber dives. Aloka SSD-870 can show the ultrasonic images of heart in B and M mode at the same time or B mode image and Doppler signals on CRT with sounds simultaneously. We monitored the bubbles with Aloka SSD-870 using a trans-cutaneous sector probe. Furthermore in some cases we did them using a trans-esophageal probe. We also monitored bubbles in subclavian veins and vena cava inferior using pulsed Doppler equipment and bubbles in pulmonary artery with CW precordial Doppler equipment. From our experience of using multiple techniques in the ultrasonic bubble detection, the following results were obtained;

1. Bubbles in vein were monitored easily with transcranial Doppler device (TC2-64B), especially after squeezing forearm. However, a false positive signals which might be caused from the movement of lung appeared in a subject before diving. Therefore, peripheral Doppler detection is not always suitable to distinguish the bubble signals.
2. The bubble signals are recognized as bright short lines or bright spots on both B-mode image and M-mode recording, moving irregularly in heart chambers.
3. Combination of ultrasonic techniques such as Doppler detection, B-mode image and M-mode recording will be increase the detectability of bubbles.

COMPARISON OF BUBBLE APPEARANCE BETWEEN AIR AND NITROX CHAMBER DIVES

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Venous gas emboli (VGE) were examined in a series of oxygen enriched nitrox (60 N2/ 40 O2) dives and of air dives to compare the risk of decompression sickness (DCS) between them. Eight volunteer divers carried out air and nitrox chamber dives of 20 m/60 min, 30 m/60 min and 38 m/30 min. Three of 8 divers entered in the chamber at each dives. Decompressions were done according to the schedules in the Japanese Ministry of Labor Tables (JML-2) in case of air dives, while they were done according to the schedules in Norweigian nitrox tables in case of nitrox dives. Decompression times are much shorter in nitrox diving than those in air diving at same depth for same bottom time. VGE of grade I appeared in 2 divers after surfacing of 20 m air dives. VGE appeared in all divers except for one nitrox diver after surfacing of both air and nitrox dive at 30 m deep, while skin bends occurred in 3 air divers. In case of 38 m diving, VGE appeared in all divers, skin bends occurred in 3 air divers but done in 1 nitrox diver. These results suggest that nitrox dive with suitable decompression schedule will reduce the risk of DCS as well as decompression obligation.

[INTRODUCTION]

Oxygen-enriched nitrox diving has been carried out to shorter decompression time as well as to reduce the risk of decompression sickness. However there have been few studies which evaluate the above mentioned matters. We carried out a series of nitrox chamber dives as well as a series of air chamber dives to examine the usefulness of nitrox diving.

[METHODS]

Subjects

Eight male commercial divers served as subjects for this study (Table 1). They joined in this experiment voluntarily.

Table 1. Physical status of the subjects.

Subject	Age	Heigt(cm)	Weight(kg)
A	22	179	75
B	22	166	68
C	20	168	54
D	28	167	74
D	24	168	65
E	35	172	77
F	43	166	65
G	39	168	70

Dives

The combinations of depth and bottom time were one hour at 20 meters and 30 meters respectively, and 30 minutes at 38 meters. Bottom times included compression times. We decided these combination considering actual working time and oxygen toxicity. Decompression schedules were taken from Japanese tables for air diving and from Norwegian Navy tables for nitrox diving (Table 2). The component of nitrox was 40% oxygen and 60% nitrogen. Prior to these experiments subjects breathed pure oxygen for 30 minutes at 18 meters in the chamber to examine oxygen tolerance.

Three subjects entered to the chamber in each dive. They were compressed with air at the rate of 10 meter per minutes. In case of nitrox dives, they breathed nitrogen-oxygen mixture via the built-in breathing system (BIBS). They had exercise for 10 minutes at the bottom pressure using a bicycle ergometer at the work rate of 300 kpm per minutes.

Ultrasonic Examination

After surfacing from the dives of subjects, bubbles were examined by ultrasonic methods using a continuous wave Doppler detector (1032H;IAPM), a pulse Doppler instrument (Trans cranial Doppler; EME Inc.) and a portable two-dimensional imaging system (Convex liner scan;Aloka Inc.).

Table 2. Dive profiles of air and nitrox chamber dive experiments.

Breathing Gas Media	Subject	Depth (meter)	EAD (meter)	Bottom Time (min)	Decomp. Table (meter/min)	Dec. Stops 6 m	3 m	Total Ascent (min)
Air	A、B、C	20	—	60	18-20/60	—	9	11
Nitrox	A、B、C	20	13.2	60	15 /60	—	—	2
Air	D、E、F	30	—	60	28-30/60	16	16	36
Nitrox	D、G、H	30	20.9	60	21 /60	5	5	10
Air	A、B、C	38	—	30	36-38/30	—	22	27
Nitrox	A、B、C	38	27.1	30	30 /30	5	5	10

Bubble signals were scored M.P.Spencer's classification in case of precordial Doppler detection, while F.Eda's classification in case of two-dimensional detection (Table 3).

Table 3. Bubble grades for two-dimensional detection of bubbles.

Grade	Description
Zero	No bubble seen
1	Occaisionally bubble seen
2	Steady flow of a few bubbles
3	Steady flow of many bubbles but countable
4	Bubble fill ventricle and uncountable

[RESULTS]

20m/60min Dives

Bubbles were found in the subjects B and C, who carried out air dive. However, no bubble found in nitrox dive. No bends appeared in air dive as well as nitrox dive (Fig. 1). Total decompression time was 11 min in air dive while only 2 min in

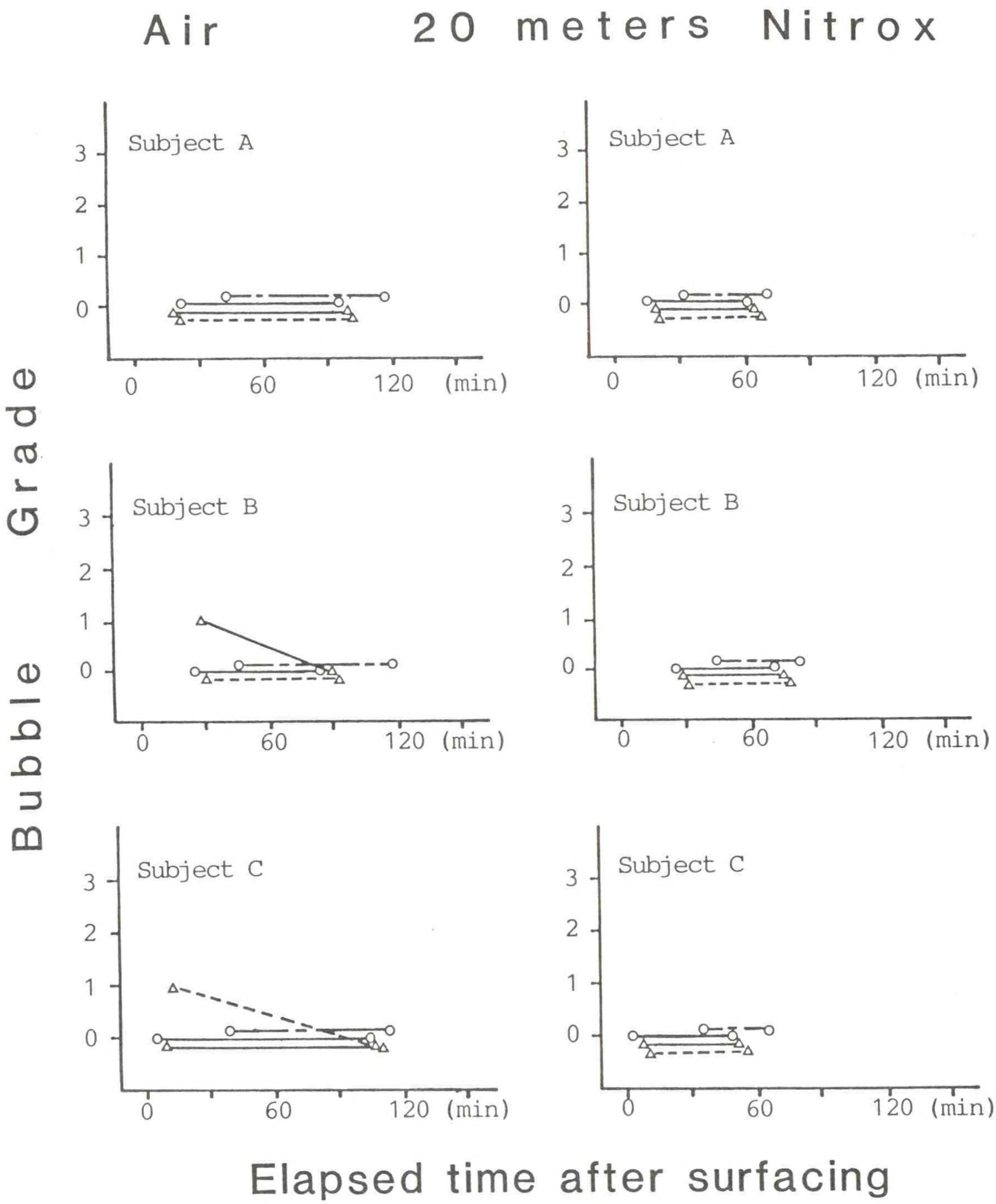

Fig. 1. The appearance of bubble in the subjects after the surfacing from 20m/60min air diving and nitrox diving. Left three graphs show the outcome of bubble detections in air dive. Right graphs are the outcome in nitrox dive. (o—o :Precordial Doppler, o---o :Two-dimensional echo, △—△ : Right subclavian vein, △--△ :Left subclavian vein)

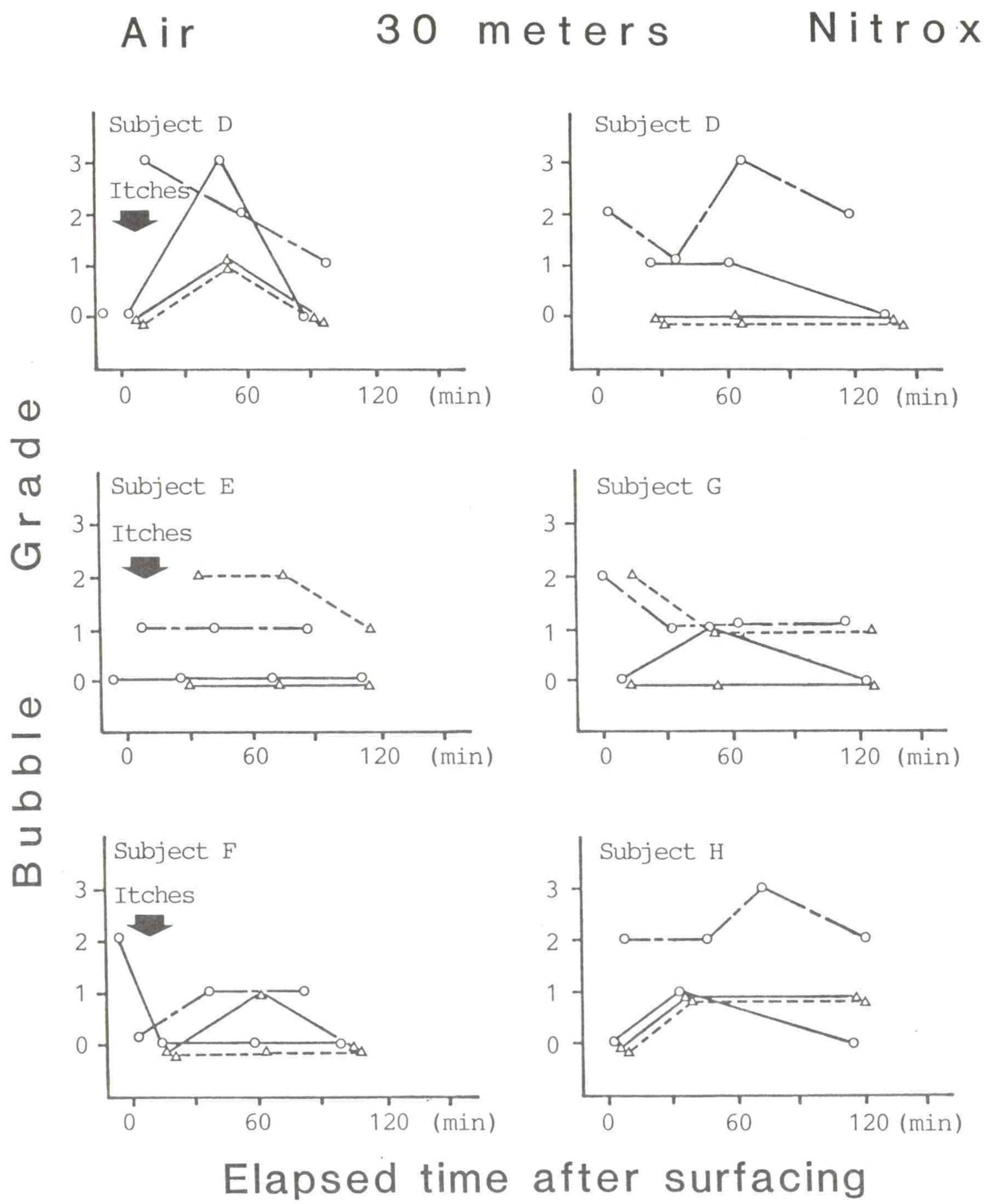

Fig. 2. The appearance of bubbles in the subjects after the surfacing from 30m/60min air dive and nitrox dive. (o—o :Precordial Doppler, o---o :Two-dimensional echo, △—△ : Right subclavian vein, △--△ :Left subclavian vein)

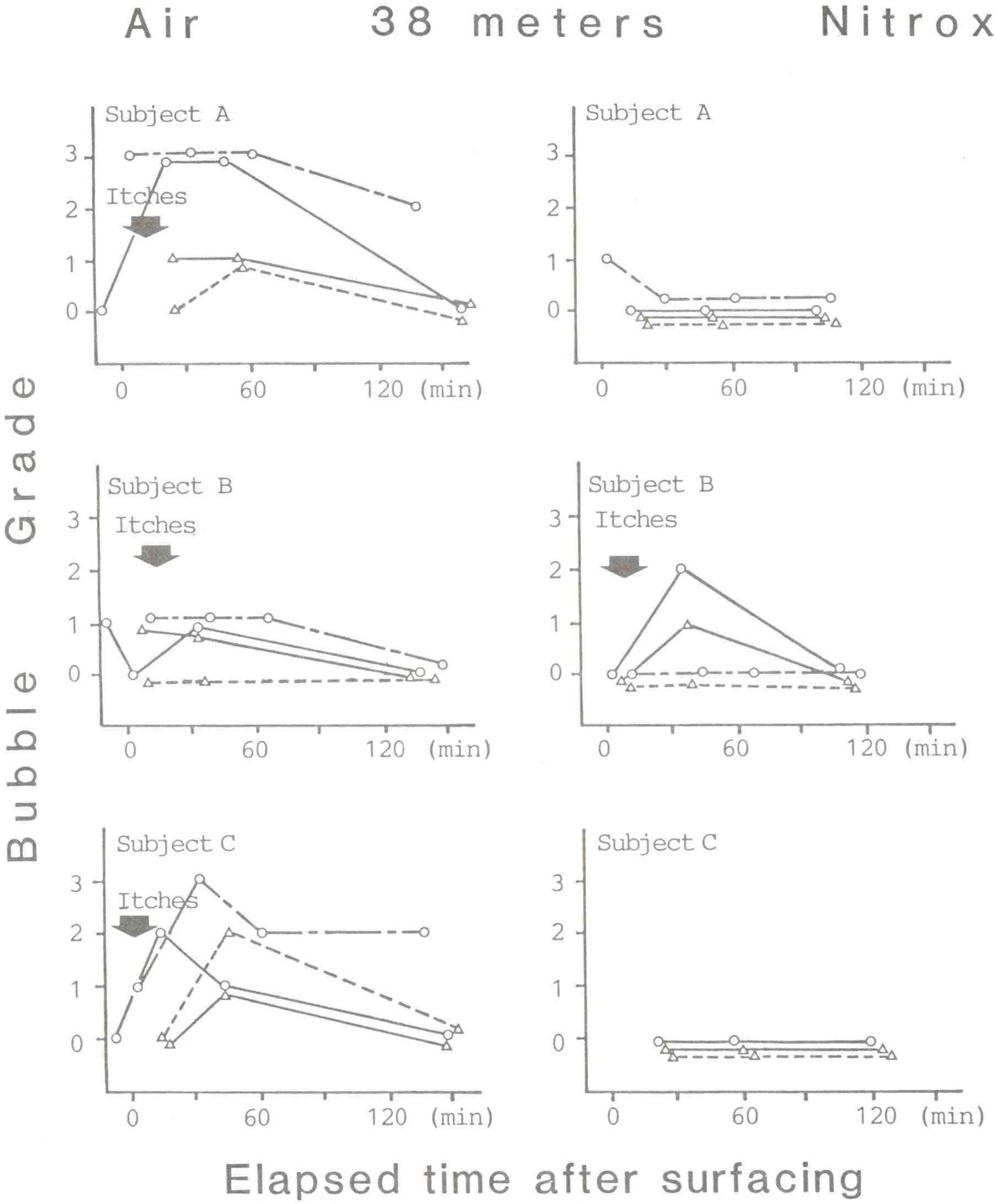

Fig. 3. The appearance of bubbles in the subjects after the surfacing from 38m/30min air dive and nitrox dive. (o—o :Precordial Doppler, o--o :Two-dimensional echo, △—△ : Right subclavian vein, △-△ :Left subclavian vein)

nitrox dive. Although bubble appeared in two subjects in air dive, no bubble was detected in nitrox dive.

30m/60min Dives

Bubbles were found in all subjects in the both dives. All of air divers suffered from mild skin bends. However, nitrox divers had no symptoms (Fig. 2). Total decompression time was 36 min in air dive, while 10 min in nitrox dive. Nitrox dive reduced 72% of decompression time in air.

38m/30min Dives

Bubble grades of the subjects were higher in air dive than those in nitrox dive except for subject B in nitrox dive. Furthermore, skin bends appeared in three subjects in air dive while in one in nitrox dive (Fig.3). Total decompression time was 27 min in air dive, while 10 min in nitrox dive. Nitrox dive reduced 63% of decompression time in air. The bubble grades and skin bends rate in air dive were higher than those in nitrox dive.

These results suggest that appropriate use of oxygen-enriched nitrox is effective in reducing decompression time as well as lowering decompression risk.

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ENHANCEMENT BY INTRAVENOUS FLUOROCARBON INFUSION OF ALVEOLAR INERT GAS ELIMINATION IN RATS AFTER HYPERBARIC EXPOSURES

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INTRODUCTION

Perfluorocarbon emulsions (PFCE) have proved to be valuable carriers of respiratory gases (O_2 and CO_2). The solubility of N_2 is also more than 20 times higher in pure perfluorochemicals than in plasma (Table 1). Because of these favorable properties of PFCE, several investigators have examined protective effect of intravenous PFCE infusion against DCS in rats after hyperbaric exposures (Lutz and Herrmann, 1984; Spiess et al., 1988; Lynch et al., 1989), and found that treatment with PFCE significantly reduced mortality and prolonged survival time of the animals. The detailed mechanism of protection from DCS with PFCE is, however, still uncertain. Conducted by these findings, we examined effect of PFCE infusion on alveolar N_2 elimination in rats after hyperbaric exposures.

Table 1. Comparison of solubility coefficients of respiratory gases in typical perfluorochemicals and plasma (Lutz and Herrmann, 1984).

Solubility Coefficients (ml/l at 1 ATA, 37°C)

Compound	Gas		
	OXYGEN	CARBON DIOXIDE	NITROGEN
FDC	454.0	1530.0	284.0
FTPA	455.0	1660.0	357.0
Plasma	21.4	513.0	11.7

FDC: perfluorodecalin
FTPA: perfluorotripropylamine

EXPERIMENTAL PROCEDURES

Male albino rats of Wistar strain weighing 230 - 290 g were used. The animals were anesthetized with pentobarbital-Na (50 mg/kg i.p.) and immobilized with pancuronium-Br (0.5 mg/kg i.p.), and then artificially ventilated at a rate of 480 ml/kg/min. The animals were then exposed to 6 ATA for 30 min, followed by rapid decompression. Ten min after surfacing, the experimental and control groups (n = 5) received 20 ml of PFCE (Fluosol DA-35, Green Cross Co., Japan) and vehicle solution at a rate of 2 ml/min via femoral veins, respectively. Precise composition of the exhaled gas was continuously measured with a medical mass spectrometer (Medspect II, Chemetron, U.S.A.). Fig. 1 summarizes experimental setup used in this study.

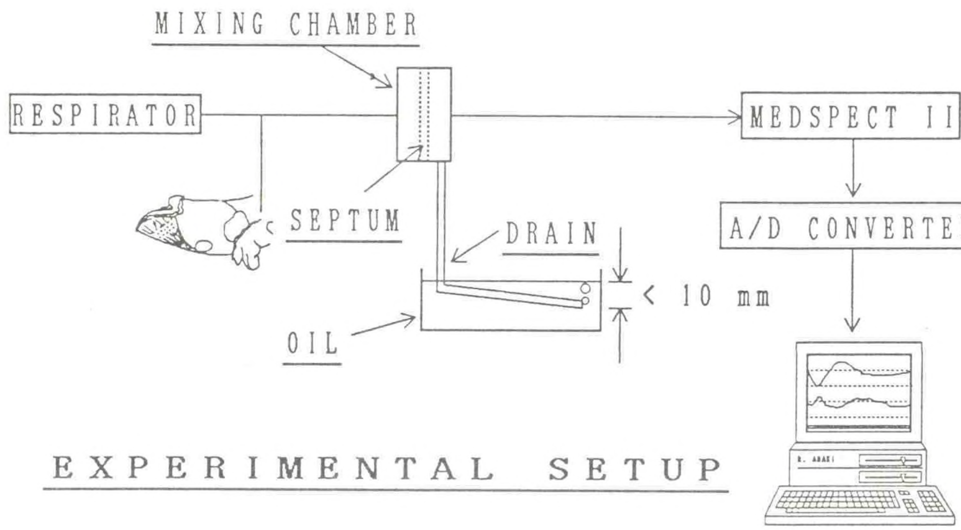

Fig. 1 Experimental setup used in this study. The Exhaled gases were introduced into a medical mass spectrometer via a small mixing chamber. The output signal of the medical mass spectrometer was digitized with 16 bit accuracy, then analyzed with a computer.

RESULTS AND DISCUSSION

Figs. 2 and 3 show effects of PFCE- and vehicle- infusions on N_2 and O_2 content in the exhaled gases after hyperbaric exposures. Infusion of PFCE caused increase in N_2 content in the exhaled gas, while decrease in N_2 content was observed in the control. This decrease might be explained by blood dilution. Student's t-test revealed a statistically significant difference in rate of alveolar N_2 elimination in PFCE-treated and control groups ($p < 0.01$). On the other hand, there was no statistically significant difference between PO_2 in the exhaled gas in PFCE-treated and control animals (Fig. 3). From these results, we concluded that protective effect of PFCE against experimental DCS is not attributable to PFCE-enhanced oxygen supply but, at least in part, due to PFCE-enhanced alveolar N_2 elimination.

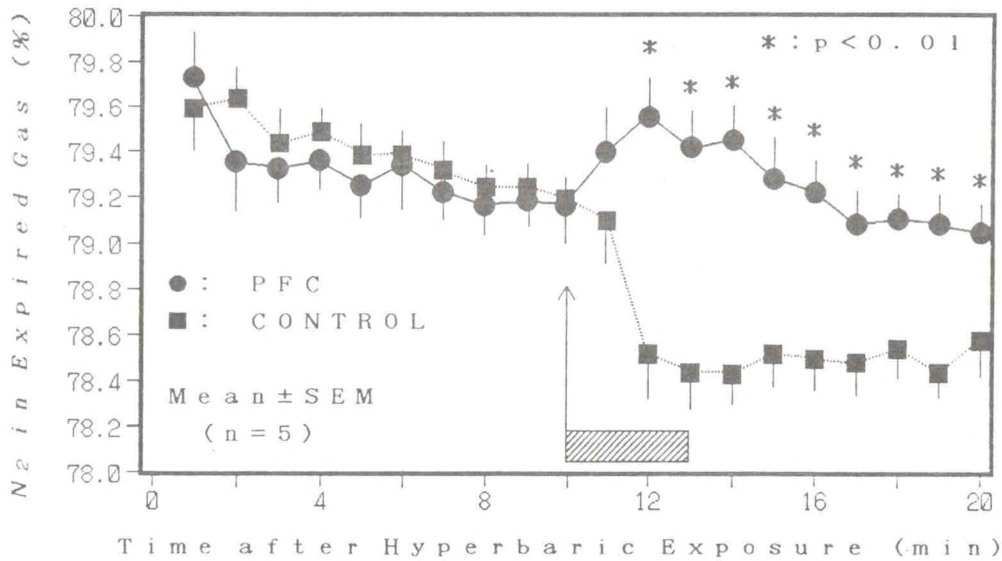

Fig. 2 Effect of intravenous PFCE infusion on N_2 elimination in rats after hyperbaric exposures. Since the animals were artificially ventilated at a constant rate, increase in N_2 content in the expired gas corresponded to increase in alveolar N_2 elimination.

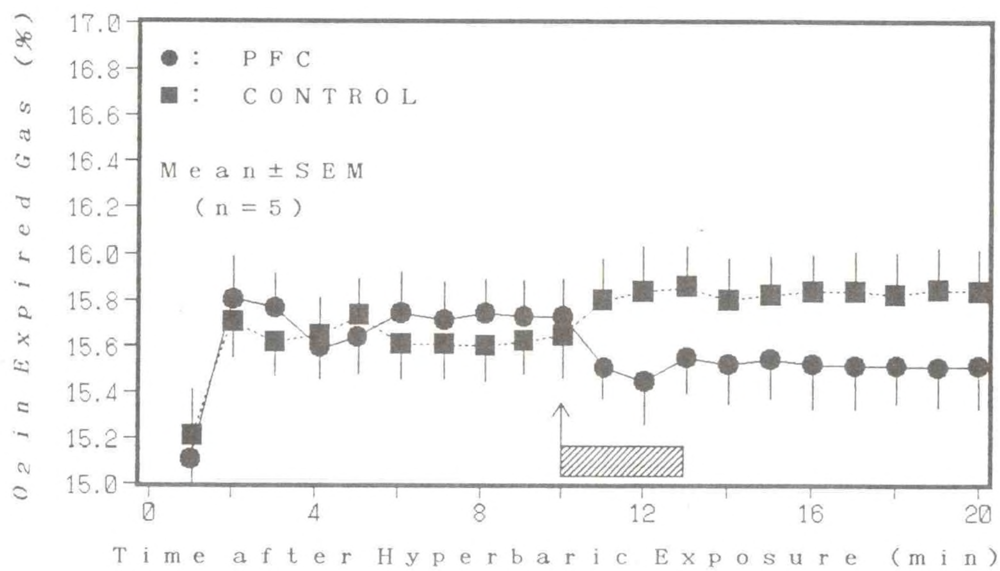

Fig. 3 Effect of intravenous PFCE infusion on O_2 uptake in rats after hyperbaric exposures. Since there were no statistically significant differences in O_2 content in exhaled gases of PFCE-treated and control groups, PFCE infusion did not increase O_2 supply.

SUMMARY

To examine the mechanism of protective effect of PFCE against DCS, we measured precise composition of exhaled gases in rats after hyperbaric exposures with and without infusion of PFCE. Intravenous infusion of PFCE (20 ml/kg) caused statistically significant increase in alveolar nitrogen elimination in rats after hyperbaric exposures, while no statistically significant increase in oxygen uptake was observed. Our results demonstrated that protective effect of PFCs on experimental DCS (Lutz and Herrmann, 1984; Spiess et al., 1988; Lynch et al., 1989) can be explained in part by enhancement of alveolar nitrogen washout.

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Automatic Bubble Detection System of Gas Bubbles Generated in Blood Streams by Linear Predictive Analysis Method

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Abstract

This paper describes an algorithm and a hardware implementation of automatic bubble detection system using digital processing of Doppler signal. The discussions are made on the subjects as follows:

The acoustic features of bubble signal in ultrasonic Doppler sound;

The algorithm of digital signal processing for automatic bubble detection;

The outline of Hardware implementation;

Result of performance test.

1. Introduction

Gas bubbles formed in the tissues and blood stream of a diver in the process of decompression may often induce a functional disorder called decompression sickness. An ultrasonic device has been prevalently used to detect such bubbles[1,2,3]. This device projects an ultrasonic beam into the pulmonary artery from the surface of the chest and detects the frequency shift caused by Doppler effect in the reflected sound. If there are bubbles, it sounds like a whip or chirp.

Although the bubble sound can aurally be listened for, it is not easy to count the number of bubbles appeared in a given number of heart cycles or a time interval. We have developed a computerized system called ABD system to detect the bubbles[4]. The automatic bubble detection system consists of a conventional ultra-sound Doppler signal sensing unit and a digital signal processing unit. A personal computer(FM16β-FD2) is used for system control and data I/O and display. A few numbers of semiconductor devices including a large scale integrated semiconductor circuit called DSP are used for high speed numerical operations. One of the uniqueness in author's ABD system that distinguishes from the other computer assisted systems[5], is that the authors have exhaustively applied the linear predictive signal analysis (LPC) method for the analysis and the feature extraction of bubble sound in the Doppler signal.

2. Characteristics of bubble sound in Doppler signal

Degree of the bubble generation is classified into five rating scales by Spencer as follows:

Grade 0: no bubble

Grade 1: occasional bubbles

Grade 2: more than one-half of heart cycles have bubbles and less than one-half of them are detected in groups

Grade 3: every heart cycle has bubbles but heart cycle is heard

Grade 4: too many bubbles to distinguish heart cycle

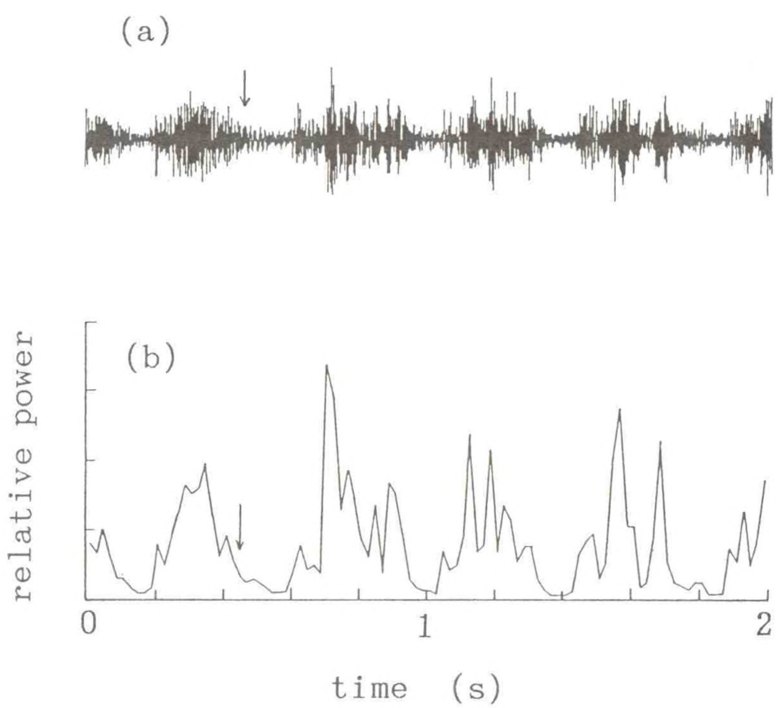

Fig. 1 (a) Waveform and (b) its power envelope of Doppler sound. The mark ↓ indicates the location of bubble.

The symptoms of decompression sickness often arise at the grade 2. Therefore, we should detect the bubbles within the grade 1 or 2.

Fig. 1 shows an example of waveform of Doppler sound at the grade 1. Fig. 1(a) is the waveform and (b) is its power as a function of time. The location of bubble occurrence is indicated by an arrow mark. From this figure one can see that the large powers are derived from not the bubble but the heart sounds. This means that the key of bubble detection is not in the power but in the other physical characters of Doppler sound.

Fig. 2 shows a power spectrum of Doppler sound including a bubble sound. Spectral peak located at 1.1kHz is due to a gas

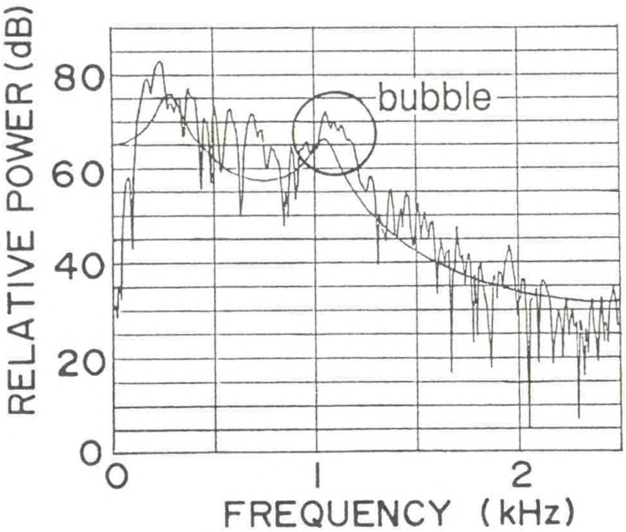

Fig. 2 Power spectrum of Doppler sound when a bubble occurs. LPC spectrum is superimposed on FFT spectrum.

bubble in the blood stream at particular velocity corresponding to the frequency modulation of 1.1 kHz in supersonic sound. Relatively sharp peak is produced because the reflection coefficient of gas is larger than that of other materials in blood.

For description of the features of such a spectrum shape, it is very effective to apply the linear predictive analysis method, LPC method, that is extensively used in speech technology for analysis, synthesis, and coding.

Fig. 3 shows several successive frames of linear prediction spectra (LPC spectra) of Doppler signal including bubble sound in three dimensional displays. Almost all frames have two spectral

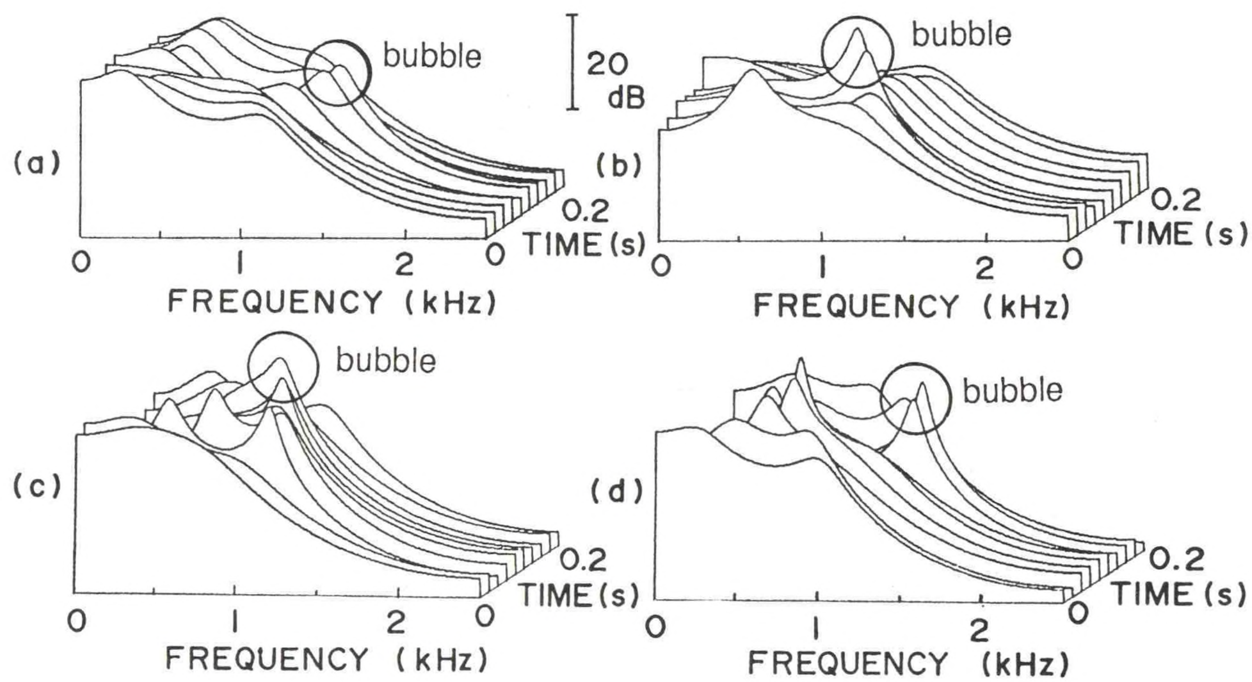

Fig. 3 Three dimensional illustration of LPC spectra in various bubble rating scales.
(a) grade 1, (b) grade 2, (c) grade 3, (d) grade 4

peaks at approximately 500Hz and 1kHz. And, a few frames show somewhat sharper peaks near 1kHz, which is an evidence of bubble sounds. One can remark that the grade becomes higher, the peak grows sharper and its frequency goes down a little lower.

Fig. 4 shows a distribution of the spectral peak frequencies (LPC poles) and their bandwidths. In the data of bubble rating grade 0, there are no poles of frequency higher than 1kHz and bandwidth narrower than 400Hz. The number of such poles in-

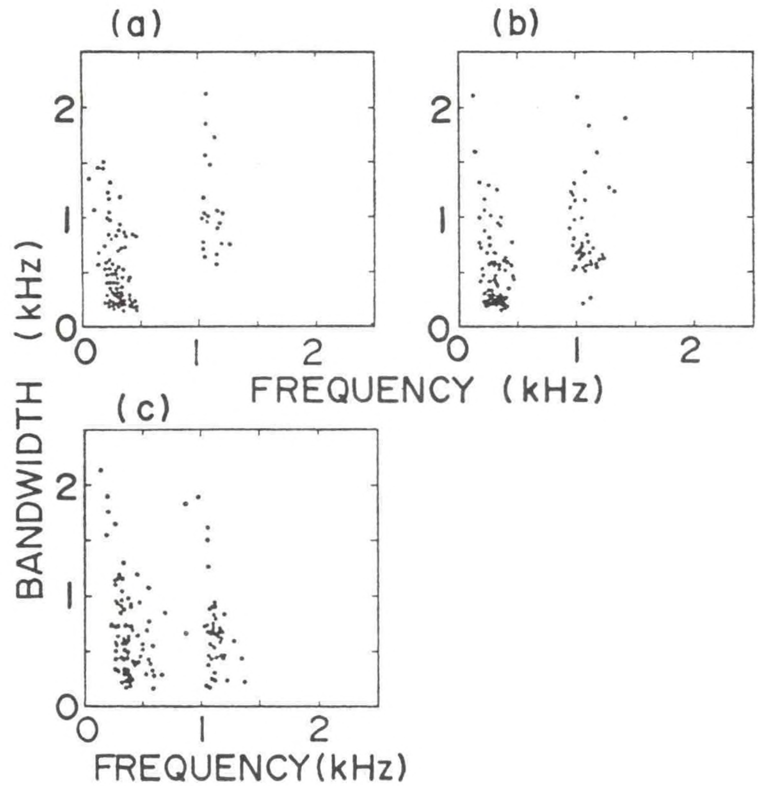

Fig. 4 Distributions of pole frequencies and their bandwidths of LPC spectra for 2 seconds interval of Doppler sound in grades 0, 1 and 2.
(a) grade 0, (b) grade 1, (c) grade 2

creases if the grade becomes up.

From Fig.s 3 and 4, one can see that the bubble sound has the LPC pole whose frequency is located around 1kHz and with relatively narrow bandwidth. This feature is used in our bubble detection process to decide if a particular sound segment is bubble sound or not.

3. Reduction of heart beat sounds in Doppler signal

As seen in Fig. 1, there are big heart beat sounds that may mask the bubble sound. To detect the bubble sound, we should reject or reduce the heart beat sounds in advance.

The velocity of blood flow is fairly periodically changing with the period of heart beat. Therefore, the waveform of Doppler sound caused by such a periodical blood flow is quite predictable, and the resulting prediction error called "residual signal" of the linear prediction analysis must be small. On the contrary, the bubble sounds are not predictable because they occur at random and abruptly. Accordingly, the residual signals of LPC analysis of the bubble sound are inevitably large. This property is used in our bubble detection process.

4. Signal processing algorithm in the ABD system

Whole schematic diagram of the bubble detection process is shown in Fig. 5. The process is composed of a pre-processing stage, a heart sound rejection stage, and a bubble sound detection stage.

The operation at the pre-processing stage is band-pass filtering and sampling of the Doppler signal in the frequency range from 100Hz to 2.4kHz with sampling rate of 5kHz. The first step of the heart sound rejection stage is to calculate the residual signal of third order linear prediction analysis for the Doppler signal. A measurement on the amplitude of the Doppler signal (SUM), and the threshold values of amplitude (TSUM), and the number of frames (LFR) that TSUM exceeds a threshold (TFR) are calculated.

At the heartbeat sound rejection stage, the segments of Doppler signal whose amplitude and time length satisfy certain conditions are discarded as the heart beat sound. The conditions are that the amplitude measure SUM is large enough to exceed the threshold TSUM, and that the number of frames (LFR) having such a large amplitude successively exceeds TFR times.

At the bubble sound detection stage, the waveform of LPC residual of Doppler signal except for the segments of heart beat sound is analyzed.

First, the amplitude (BSUM) and the number of zero-crossing (CROSS) of the residual signals are calculated. If the BSUM and CROSS of any segment of residual signal exceed the threshold

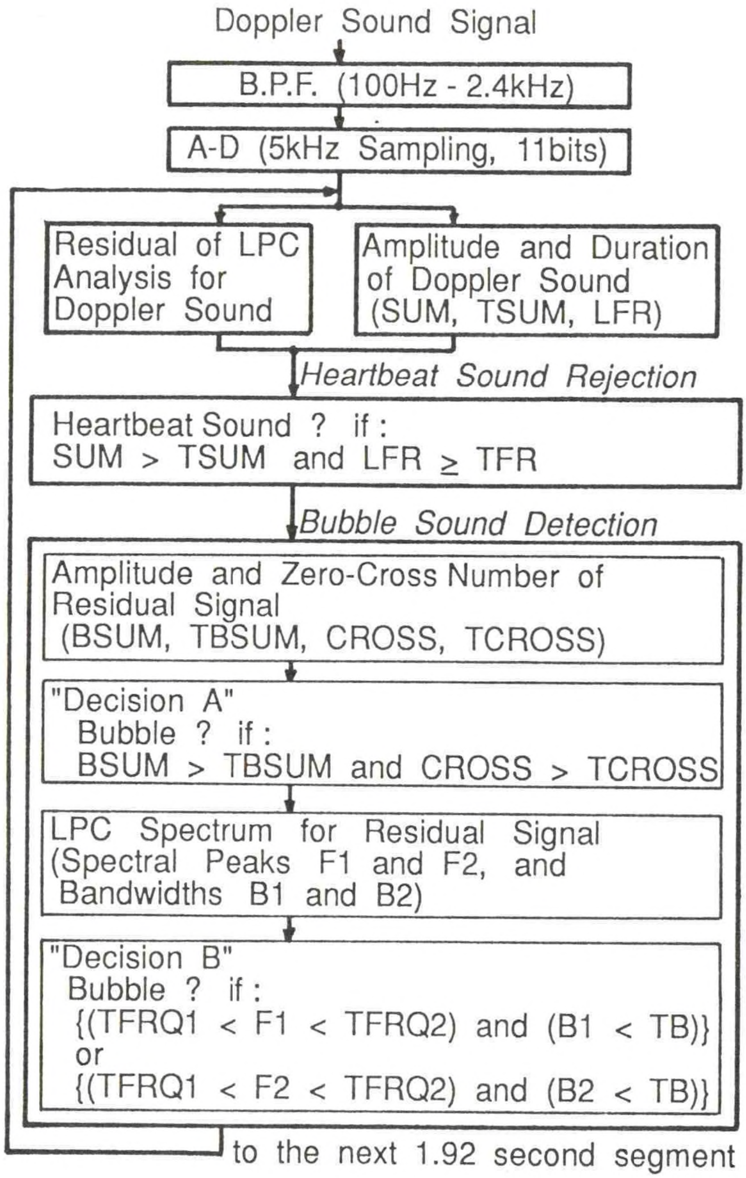

Fig. 5   Flowdiagram of bubble detection procedure.

values TBSUM and TCROSS, respectively, this frame is decided as a bubble candidate at the decision-A.

Next, the linear prediction analysis is applied to the bubble frame candidates, where the order of linear prediction analysis is four in this stage. The resonant frequencies (F_1 and F_2) and bandwidths (B_1 and B_2) of LPC spectrum of the frames are estimated by solving the fourth order polynomial equation derived from the linear predictive analyses. By these frequencies and bandwidths, the segment is judged whether the bubble sound exists in it, at the decision-B.

To illustrate the result of processing at each stage mentioned above, typical waveforms of Doppler signal are shown in Fig. 6.

Fig. 6(a) shows the waveform of Doppler signal. The time length is 1.92 seconds including four heart beats and one bubble sound indicated by an arrow ↓. The 9600 data, corresponding 1.92 seconds of time length shown in this figure are treated as a unit of processing. This signal unit is divided into 96 segments called frames (100 samples per frame). The time length of one frame is 20ms. Fig. 6(b) shows the power defined as a sum of squares of samples in each frame. If more than three successive frames should exceed the threshold TSUM, these frames are regarded as a heart sound. These frames are excluded from the processing hereafter. The segments indicated with symbol ┌┐ in Fig. 6 (b) show the survived parts from the heart beat sound rejection stage.

Fig. 6(c) shows the waveform of residual signal of LPC analy-

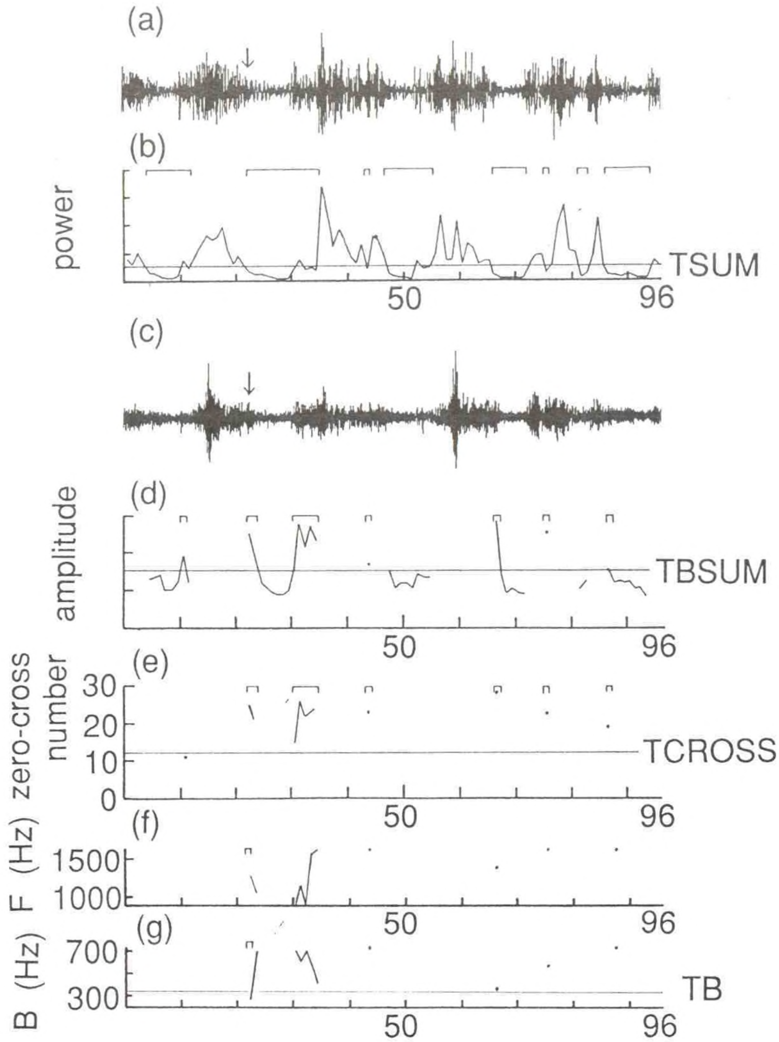

Fig. 6 Typical waveforms at various steps in the bubble detection procedure.

(a) and (c) show the original Doppler sound and its LPC residual, respectively. Time length of the segment is 1.92 second. The mark ↓ indicates the location of bubble detected aurally and visual inspection by an expert.

(b) shows the power envelope of the original Doppler sound in (a). The mark ┌┐ indicates the subsegment of bubble candidate that exceeded the thresholds TSUM.

(d) and (e) show the amplitude and zero-crossing number of residual signal of the subsegments except heartbeat sounds. The mark ┌┐ indicates the subsegments of bubble candidate that exceed the thresholds TBSUM and TCROSS at the Decision-A.

(f) and (g) show the pole frequency Fi and its bandwidth Bi of the LPC spectrum of bubble candidates, where i=2 in this particular example. The mark ┌┐ indicates the frames exceeding the threshold TB at this stage.

sis of the waveform of Fig. 6(a). The amplitude (BSUM) and zero-crossing number (CROSS) of the residual signal except of heart beat sounds are shown in Fig. 6 (d) and (e), respectively.

At the decision-A stage, the frames whose amplitude BSUM is larger than the threshold TBSUM and the zero-crossing number CROSS is larger than the threshold TCROSS are regarded as the bubble candidates. The residual signal of bubble candidate is further processed by fourth order linear predictive spectrum analysis method. In this stage, the spectral peaks F_1, F_2 and the bandwidths B_1, B_2 are calculated as shown in Fig. 6(f) and (g).

At the decision-B stage, it is examined if either spectral peak F_1 or F_2 is located between two thresholds TFRQ1 and TFRQ2, and that the bandwidth of the spectral peak is narrower than a threshold TB. If either one of the spectral peaks F_1 and F_2 is located between the thresholds and its bandwidth is narrower than the threshold, the frame is finally judged as the bubble signal.

At the point indicated with an arrow mark ↓ in Fig. 6(f), the bubble sound is detected.

5. Hardware implementation.

The system consists of a personal computer Fujitsu FM16β-FD2, DSP hardware emulator Fujitsu FDSP KIT-8764, and 32 kilo words external random access memories. Fig. 7 shows the block diagram of the system.

Table 1 shows the average processing time length at each stage. Total processing time per one segment is about 183 milliseconds. The most time consuming process is the stage of bubble detection-B. It is approximately 105 (6.9+25.9+72.7=105.5) milliseconds.

Doppler sound data on the personal computer are loaded on the external memories when a segment is processed. Since the length of the program of process exceeds the capacity of program memory unit in the emulator Fujitsu FDSP KIT-8764, the program has to be reloaded on the emulator's program memory when any segment is processed. Therefore, the total execution time per one segment is about 1 second, which can be easily reduced, if necessary, by increasing the memory capacity of emulator.

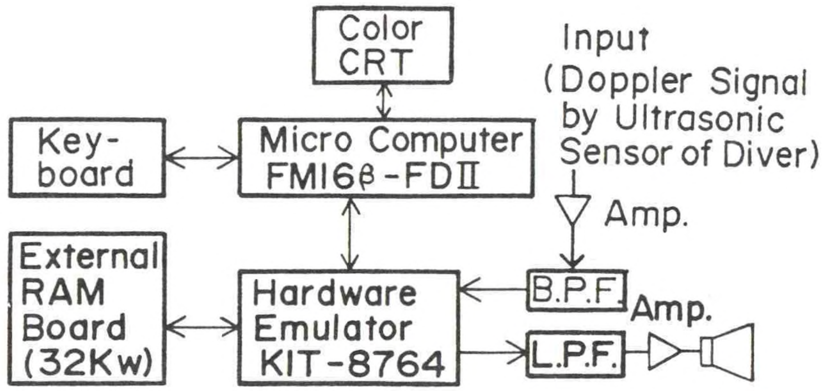

Fig. 7 Block diagram of the automatic bubble detection system (ABD system).

Table 1 Number of arithmetic operation and time length of processing per one segment.

stage	number of frame	process	number of mul. and add.	calcu. type	processing time(ms)
heartbeat sound rejection	96	power	11100	F	8.5
residual	96	auto-correlation	38400	D	34.1
		residual	15020	F	22.7
bubble detection A	50	BSUM	5000	F	4.8
	30	zero-crossing	4200	F	7.9
bubble detection B	20	windowing	15000	F	6.9
		auto-correlation	30600	F	25.9
		poles	3200	FL	72.7
				Total	183.5

F: 16bit fixed point calcu., D: 32bit fixed point calcu.
FL: floating point calcu.

Table 2 Results of a demonstration tape analyzed by ABD system.

grade	data length F	data length T(s)	H	B	frequencies of bubbles B/min.	frequencies of bubbles B/H
0	1344	22.68	33	2	5	0.06
1	2208	44.16	57	22	23	0.39
2	2784	55.68	75	111	120	1.48
3	2784	55.68	75	139	150	1.85
4	1056	21.12	27	43	122	1.59

F: number of frames, T: processed time
H: number of heartbeats, B: number of bubbles

6. Result of performance test

Table 2 shows a result of performance test. Data of Doppler signal is a demonstration tape for bubble rating scale. The data length of grade 0 is time length T=22.68 seconds that correspond to the number of frames F= 1344 frames. The number of heart beats H of this data is 33. The number of detected bubbles B is 2. Therefore, the ratio of bubble number to heart beats B/H is 0.06, and the bubble occurrence rate per minute B/min is 5.

In the grade 1 and 3, the numbers of detected bubble per heart beat(B/H) are 0.39 and 1.85, respectively. They are quite reasonable values as their grades.

In the grade 2, B/H is 1.48 and is larger than that of grade 2 by Spencer.

In the grade 4, B/H is 1.59 and is less than that of grade 3 by Spencer. In this case, the bubble sounds were so large that they were erroneously rejected as a part of heart sound at the heart sound rejection stage. However, this may not be a serious misjudgment because the ability to detect the bubbles in lower grades without missing is more crucial than to detect the bubbles in higher grades accurately. From the point of view of safety allowance of misjudgment, the over estimation of bubble number is better than the under estimation in the grades 0, 1, and 2. In this sense, the judgment by the ABD system is adequate for detecting the bubbles in lower grades.

7. Conclusion

In this paper, the authors have introduced an automatic bubble detection system based on a digital processing of ultrasound Doppler signal. To detect the bubble sound buried in the noises due to the reflection from other materials than gas bubbles in blood stream, several physical features of bubble sound were extracted and processed by quite complicated decision processes. The features include the power and duration of Doppler signal, the amplitude, the zero-crossing frequency, and the spectral peak frequencies and bandwidths of the residual signal of LPC analysis. The all processes were implemented in a hardware digital system using DSP and a personal computer. This system works in quasi real time, for example, a segment of signal of length 1.92 seconds are processed in about 1 second. A performance test has shown the acceptable results that bubbles in lower grades are detected quite precisely although the number of bubbles in higher grades are under estimated.

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The authors indebted to professor Seki of Kanagawa university, and Dr. Mouri of JAMSTEC for encouragement toward the research of bubble detection. The authors also express their thanks to Messrs. Watanabe and Kimura for their contributions

in their graduate course studies.

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HISTOPATHOLOGICAL ANALYSIS OF DYSBARIC OSTEONECROSIS EXPERIMENTALLY INDUCED IN SHEEP

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ABSTRACT

Sheep were subjected to a series of 0.5, 1, 2, and 4 hour-hyperbaric exposures over a 2.5 year period to simulate recreational and commercial diving. Sheep were euthanized 16 months after the last hyperbaric exposure. Roentgenographic examination of the sheep long bones revealed dysbaric osteonecrosis (DON) lesions, but these DON lesions were milder than those induced in sheep with similar 24 hour-hyperbaric exposures in the previous study. Femurs from two mature female sheep with dysbaric osteonecrosis (DON) were examined for histopathological changes. A histopathological evaluation performed on undecalcified sections of femur showed widespread fatty marrow necrosis in association with a proliferation of granulation tissue, calcification, and ossification around the necrotic foci. Endosteal new bone formation also occurred. In DON, both tissue calcification and ossification appear closely linked to fat cell necrosis.

INTRODUCTION

Dysbaric osteonecrosis (DON) is a form of nontraumatic bone necrosis prevalent in caisson and tunnel workers (Davidson[1]), and in Japanese diving fishermen (Kawashima[2]). DON can often disable a diver, and the disease represents an important public health problem, especially among professional divers. DON has now been experimentally induced in sheep (Lehner et al.[3]). With an experimental model of DON, we can study the development of this condition and recommend diving procedures designed to avoid DON.

We previously induced DON in the long bones of sheep with repetitive 24-hour hyperbaric exposures (Lehner et al.[3]) For this series of experiments, we assessed whether DON could be induced with hyperbaric exposures of shorter duration.

HYPERBARIC EXPOSURE AND BONE PREPARATION

Experimental procedures that induced DON in sheep were conducted at the University of Wisconsin-Madison. Two, 2-year-old, crossbred female sheep (#227 , 92 kg; and #249 , 108 kg) underwent a series of 29 - 30 hyperbaric exposures of 0.5 to 4 hour duration over a 2.5 year period. Decompression to surface pressure was at a rate equivalent to about 10 meters of sea water pressure (MSW)/min. Persistent limb lifting, a sign of limb bends, was often observed in the sheep after their hyperbaric exposures. Signs of limb lifting and non-weight bearing in sheep sometimes lasted up to 8 days. Signs of mild chokes in sheep were also commonly observed. Maximum pressures of the hyperbaric exposures reached 2.7 atmospheres absolute (atm), equivalent to 17 MSW, in the 4 hour exposures and 4.3 atm, 33 MSW, in the brief 0.5 hour exposures (Table 1).

The sheep were killed 16 months after the last hyperbaric exposure and were autopsied. At the time of autopsy, perfusion fixation was performed with 10 % neutral-buffered formalin and contrast media (Barium sulphate : Novapaque and Micropaque) through the heart for systemic fixation and later roentgenographic examination.

The femurs were disarticulated and removed from the sheep cadavers. The heads and shafts of femurs were sampled as indicated in Fig. 1. Two transverse sections were cut from the proximal and distal shaft, each approximately 6 - 7 cm from the proximal and distal ends. The femoral ends were cut into longitudinal sections. Femoral head sections included articular cartilage, subchondral cortical and cancellous bone and marrow. Femoral shaft sections included cortical bone and marrow.

For the contact microradiographic and histopathological examinations, undecalcified sections of bone were prepared at Kagoshima University. Bone blocks (1.5 - 2.0 mm thick) were embedded in polyethylene resin and then each was sectioned using an Exact's cutting machine (BS 3,000) and ground to a 5 micrometer thickness using an Exact's precision grinder (MG 4,000). Bone sections were analyzed by contact microradiography using a Softex's soft X-ray photographic instrument (CSM-2), and the sections were then stained with methylene-blue and basic fuchsin for histological analysis.

FINDINGS OF DON IN SHEEP

Radiological Changes in the Femurs: Prominent medullary opacities were evident in the distal femurs, especially in the right femur of Sheep #227 and in both femurs of Sheep #249. Medullary opacities are evidence of DON development in the long bones of sheep.

Macroscopic Findings: Sectioned bone from the sheep femurs contained fatty marrow necrosis which is a common finding in DON. Fatty marrow necrosis appeared as opaque, shiny yellow-white inclusions in the marrow cavity. The distribution of necrotic foci is schematically illustrated in Figs. 2, 3, 4, and 5. Red marrow was present in some areas of the proximal femoral head. Necrotic foci occurred in the right femur of Sheep #227 (Photo. 1a, b) and in both femurs of Sheep #249.

Histological Findings in Sectioned Bone: In spite of variations in the size of the necrotic foci, the histological findings of marrow necrosis were similar.

Necrotic fatty tissue showed partial liquefaction (Photo. 1b).

Individual necrotic fat cells were interspersed with thin layers of basophilic material suggesting pericellular calcification. The foci of the necrotic fatty tissues were globally enveloped by fibro-osseous tissue. Mononuclear or multinucleated histiocytic cells which contained many fat droplets in their cytoplasm were aggregated in the fibrous layer in which collagenosis had considerably advanced. Ossification took place intermittently around the necrotic foci. The most predominant calcification took place around necrotic fat cells in peripheral areas of the necrotic foci, and these fat cells appeared as "cores" of ossification which showed definitive lamellar structure (Photos. 2, and 3).

Endosteal new bone formation was widespread in the shafts of the four femurs. Endosteal thickening by the new bone formation was more extensive in the femur which also sustained more extensive necrotic changes in the bone marrow tissue (Photo. 1b). Vascular channels in the marrow were collapsed in the necrotic foci, but in viable areas they appeared patent and normal.

The articular cartilage appeared intact (Photo.4). There was no marked necrotic change in the subchondral bone in which bone trabeculae appeared viable, although necrotic foci in the right femurs of Sheep #227 and #249 extended from the shafts into the proximal and distal metaphyses (Photo. 5).

A contact microradiographic survey of the undecalcified thin sections revealed that the necrotic foci were enveloped by a irregularly-shaped band-like membranous and radiopaque layer. This layer was composed of calcified or ossified material. Moreover, individual fat cells in the necrotic foci were also surrounded by radiopaque, calcified tissue (Photo. 6).

DISCUSSION

In the present study, we found evidence of marrow and bone necrosis of DON primarily in the shafts of femurs from both sheep subjected to relatively short hyperbaric exposures from 1/2 to 4 hours duration. A histopathological evaluation performed on undecalcified sections of femur showed fatty marrow necrosis in association with fibrosis, histiocytic aggregation, calcification, and ossification around the necrotic foci. Endosteal new bone formation also occurred. In DON, both tissue calcification and ossification appear to be closely linked to fat cell necrosis. We previously reported this change as the ossification of fat cell ghosts in long bone lesions of DON (Lehner et al.[3]).

The histological changes in sheep DON appear to be essentially identical to those in diver's DON (Kawashima[2], Kitano et al.[4]) , although in divers the prevalence of necrotic foci appears to be almost as high in the femoral heads as in the distal femoral shafts.

The findings in sheep and the prevalence of DON in caisson and tunnel workers and diving fishermen exposed to compressed air suggest a common etiological basis for this disease. We propose that the development of DON typically requires the following conditions : 1) prolonged exposure to compressed air, either in a single long exposure or in extensive repetitive exposures, 2) abundant fatty marrow, and 3) rapid decompression, presumably at a rate that produces large numbers of bubbles in the fatty marrow. Moreover, the development of DON probably involves a bone compartment syndrome. Bubbles may form within fatty marrow of the long bones and elevate intramedullary pressure (Lanphier, Fatty marrow can become a significant reservoir of N_2, because N_2 is about 5 times more soluble in fatty tissues than in non-fatty tissues. Blood flow rates in fatty marrow are low. Fatty marrow represents a "slow" tissue, with slow washin and washout rates of N_2. The marrow cavity surrounded by rigid bone is anatomically represents a semi-closed compartment. In another study, we observed elevated marrow pressures in sheep long bones of symptomatic limbs, with limb lifting after 24-hour hyperbaric exposures (Lanphier et al.[5]). If bubble formation occurs within a compartment, as in the marrow cavity of long bones, a bone compartment syndrome may develop as tissue pressure increases. Then, blood flow and tissue N_2 washout would virtually cease.

Another pathogenic mechanism which may play an important role in DON development is intravascular obstruction. Intravascular N_2 bubbles with bubble embolization can promote blood coagulation (Kawashima et al.[6], Kitano et al.[7]). N_2 bubbles produced by decompression may cause fat cells to rupture and release fat globules into the marrow sinusoids and embolize the marrow vessels (Jones [8]). Fat embolization process activates then blood coagulation (Kitano & Hayashi[9]). Circulatory disruption due to intravascular blood coagulation in association with bubble and fat emboli would contribute to the development and progression of DON. However, we found no definitive evidence to support this pathogenic mechanism in the sheep femurs which were examined. This is likely due to the late autopsy performed 16 months after the last hyperbaric exposure of the sheep.

In summary, we believe that DON results from a form of bone compartment syndrome initiated by bubble formation in the fatty marrow which causes circulatory disruption due to intravascular occlusion or obstruction. Blood coagulation, fat and bubble emboli may also play important roles in DON pathogenesis. Prolonged hyperbaric exposures and extensive repetitive air dives with rapid decompression carry the risk of DON.

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Table 1. Protocol of the DON Sheep Experiments

Animals : Sheep (#227 : 92 kg, #249 : 108 kg)
6 Years Old at Autopsy
Female, Crossbred

Hyperbaric Exposures :

Duration, h	Maximum Pressures, atm abs
0.5	4.31
1	3.80
2	2.38
4	2.68

Compression Rate at 0.7 atm/min
Decompression Rate at 1.1 atm/min

Sheep #227 was subjected to 29 hyperbaric exposures in 2.5 years and euthanized 16 months after the last exposure.

Sheep #249 was subjected to 30 hyperbaric exposures in 2.5 years and euthanized 16 months after the last exposure.

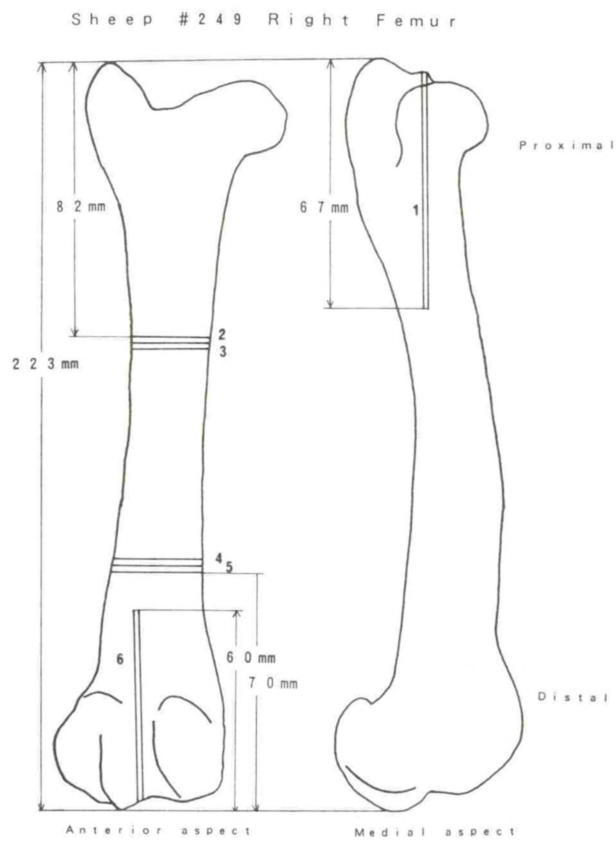

Fig. 1 : Schematic illustration of bone sampling from the femur of sheep #249.

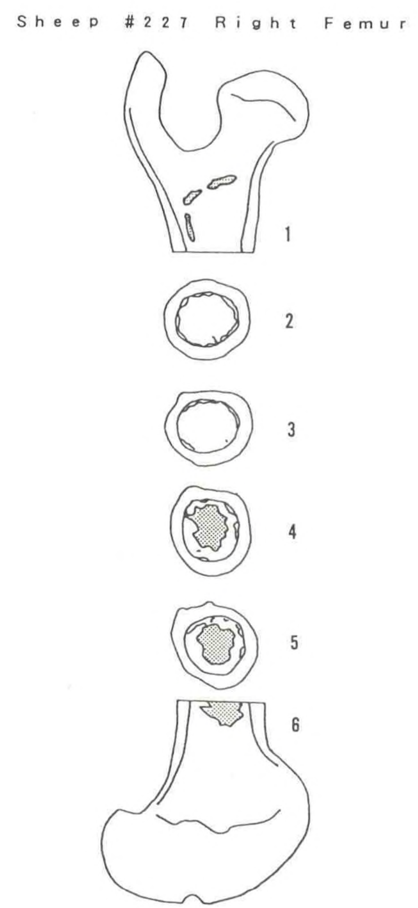

Fig. 2 : Schematic drawing of the distribution of necrotic foci in the right femur of sheep #227. Dotted areas indicate the necrotic foci.

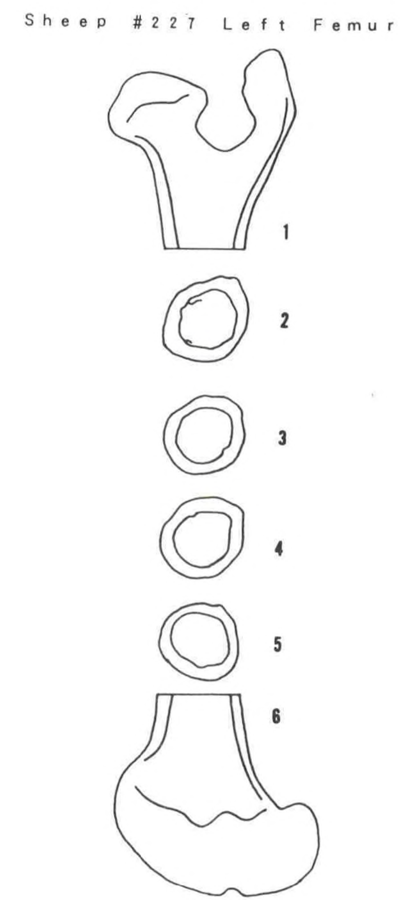

Fig. 3 : Normal left femur of sheep #227, except for a slight, irregular endosteal thickening of the cortical bone.

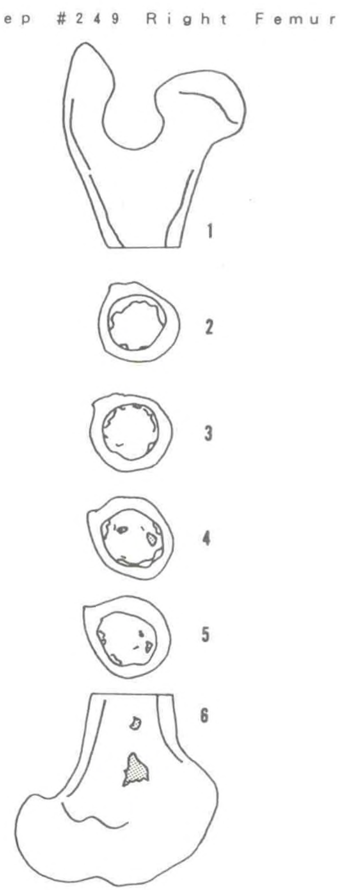

Fig. 4 : Distribution of necrotic foci (dotted areas) in the right femur of sheep #249.

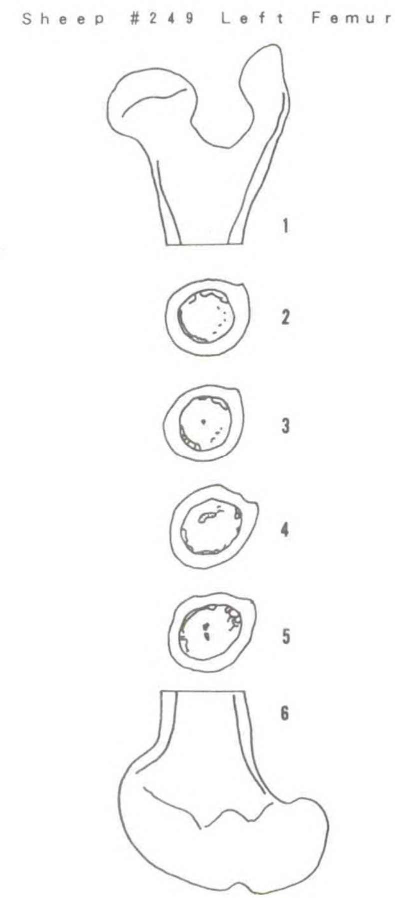

Fig. 5 : Distribution of necrotic foci (dotted areas) in the left femur of sheep #249.

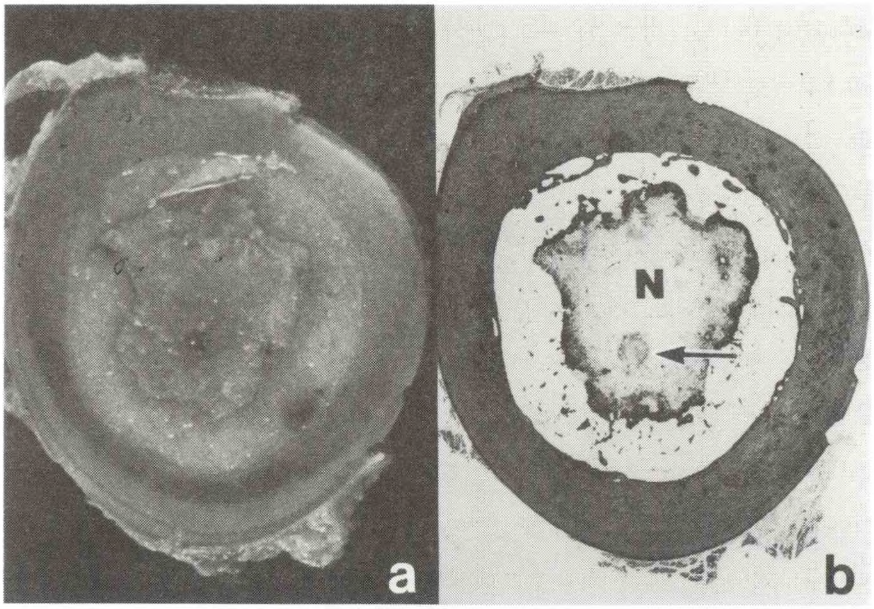

Photo. 1 (a : left) : Transverse section of the distal shaft from the right femur of Sheep #227.
(b: right): Undecalcified histological preparation stained with methylene-blue and basic fuchsin (MBF) of the same material as in Photo. 1a. Focal liquefaction of fat (arrow) occurred in the necrotic focus (N). Endosteal new bone formation was present in the cortical bone. x2.4.

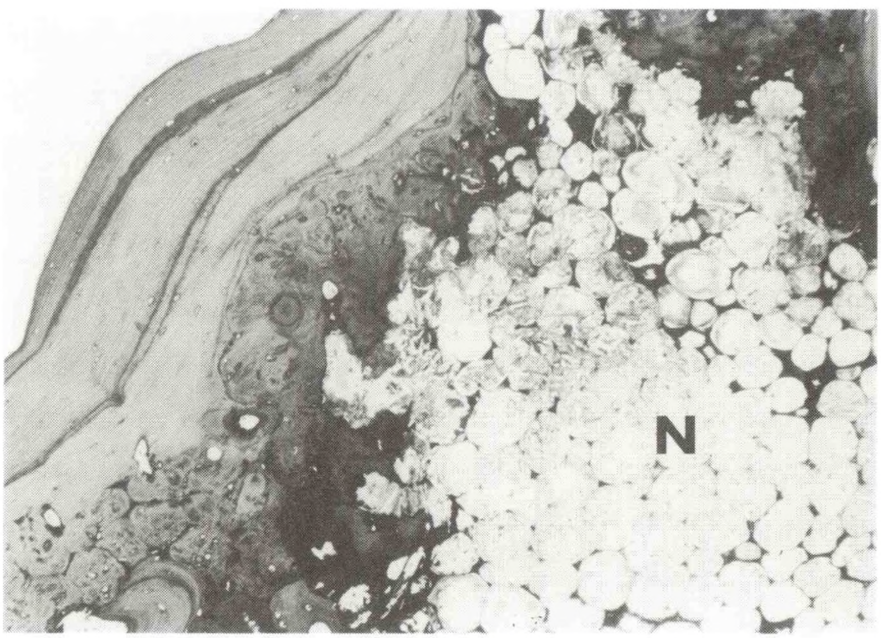

Photo. 2 : Higher magnification of the necrotic focus (N) which appears in Photo. 1b. Necrotic fatty marrow is surrounded by a fibro-osseous layer. Individual necrotic fat cells are enveloped by basophilic material (calcified tissue). MBF, x750.

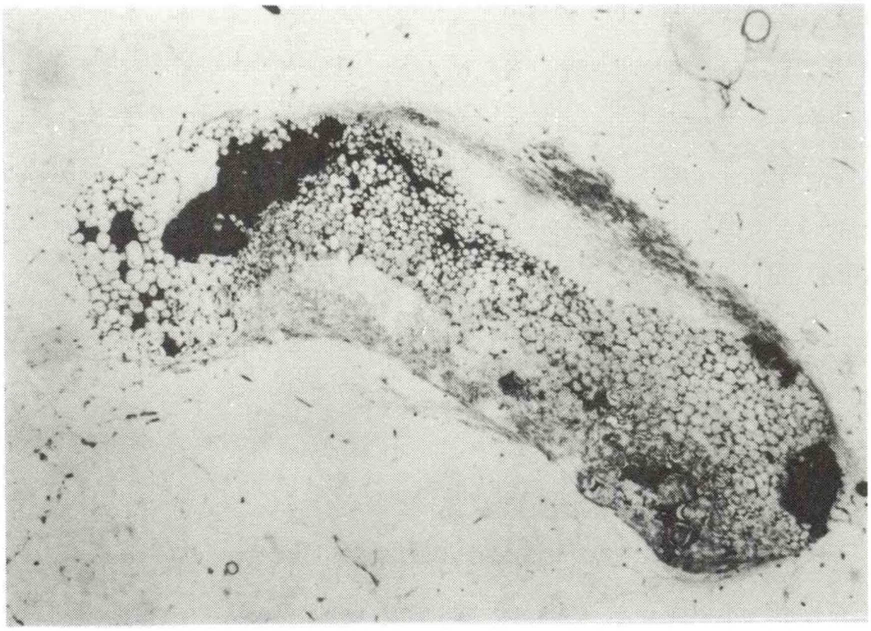

Photo. 3 : A small necrotic focus in the distal shaft of the left femur of Sheep #249. MBF, x150.

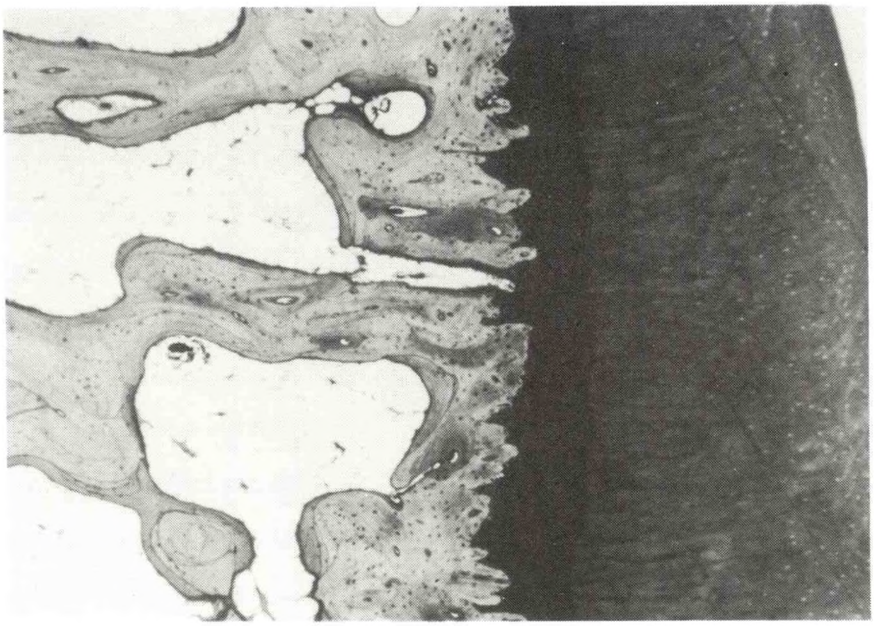

Photo. 4 : Normal appearance of articular cartilage and juxta-articular bone from the proximal head of the right femur of Sheep #227. MBF, x300.

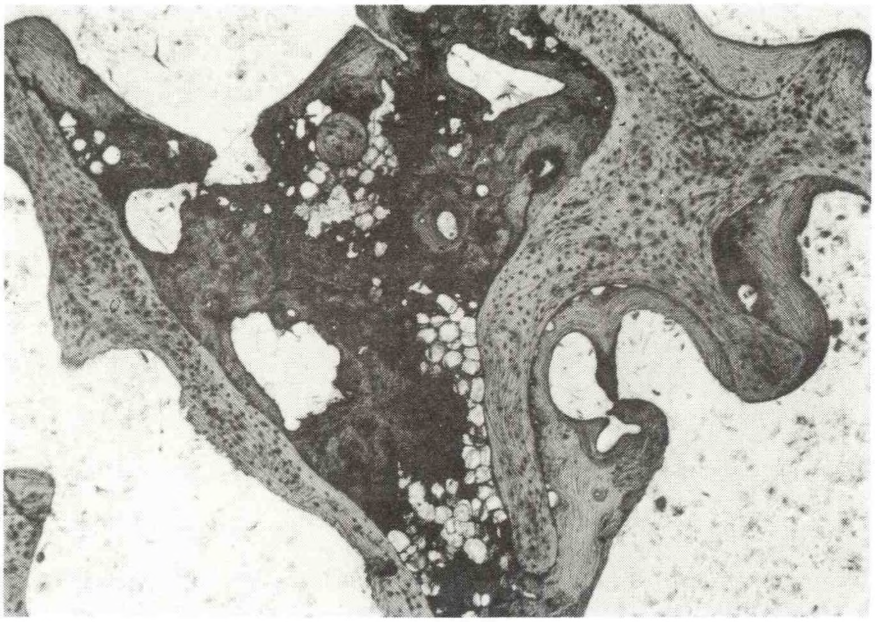

Photo. 5 : A small necrotic focus in the intertrabecular marrow space of the proximal metaphysis in the right femur of Sheep #227. The bone trabeculae appear viable, and appositional new bone formation is conspicuous. MBF, x300.

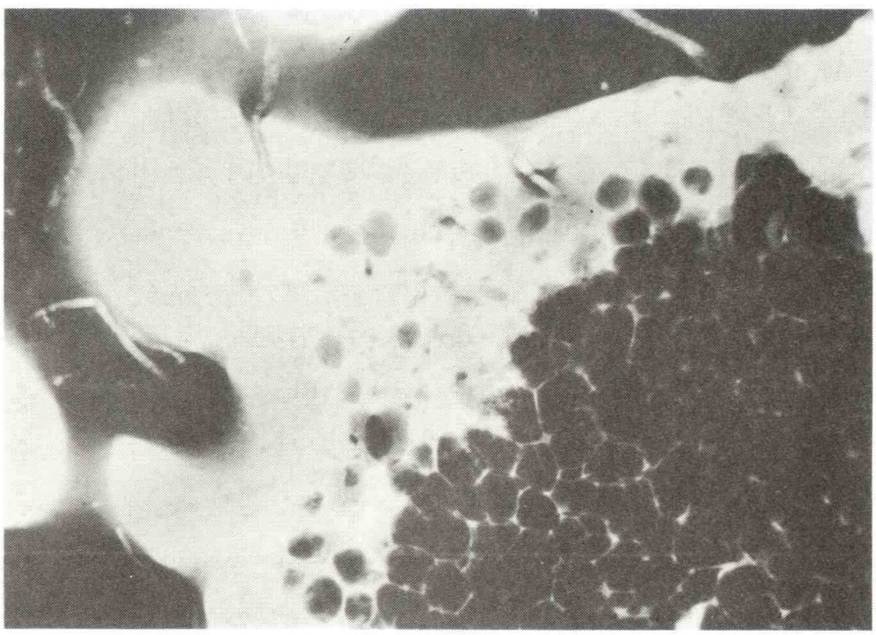

Photo. 6 : A contact microradiograph of the same necrotic focus in Photo. 1. The necrotic focus (N) is surrounded by a radiopaque area (calcified or ossified), and individual necrotic fat cells are also enveloped by radiopaque material. The small blood vessels containing contrast media are radiopaque. x750.

DETERMINATION OF INTERSPECIES $T_{1/2}$ FOR THE FORMULATION OF DECOMPRESSION TABLES (UDT300)

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ABSTRACT

Decompression (DC) tables for rats, rabbits, and dogs from 300 m saturation, were constructed by utilizing a pressure-dependent DC threshold, coupled with a stage DC time that avoids cumulative supersaturation. To construct these tables, we utilized one critical pressure equation and a range of $T_{1/2}$ values. The critical pressure equation, $P_1 = aP_2 + b$, allows for calculation of ΔP_{max}, i.e., $P_1 - P_2$ from each saturation pressure, P_1. The time constant, τ ($\tau = T_{1/2}/ln\ 2$) values are used to calculate the rate of DC, the stage DC time (stage DC time in units of τ), and thus also the total DC time. In general form, the equations used are: 1) $\Delta P_{max} = [(a - 1)/a]P_1 + b/a$, 2) DC Rate = $\Delta P_{max}/\tau$, and 3) total DC time = $(M - 1) \times 5\tau + T_{end}$. Where M stands for the number of stages; a and b are respectively, the slope and intercept of the DC threshold equation; and T_{end}, the end stage DC time, equals or is less than 1 stage DC time. The DC rate falls progressively by using a fixed time, 1τ, to effect the pressure change for every stage. Tables are of the same profile for all species when the time parameter is expressed in units of τ. For this reason, we named this group of tables, as well as other tables so constructed, the universal DC tables (UDT). Construction of UDT depends critically on values of $T_{1/2}$. Results so far showed that the shortest $T_{1/2}$'s are 11 min, 59 min, and 86 min for rats (0.3 kg), rabbits (3 kg), and dogs (10 kg), respectively. Based on these results, we derived an interspecies relationship, $T_{1/2} = 26.36W^{0.59}$, and by extrapolation obtained a $T_{1/2}$ of 322 min and calculated a DC table for humans (UDT300H) with a total DC time of 6.77 days from a 300-m heliox saturation dive. The total DC time lies between the two published extremes, 285 h (equivalent to $T_{1/2}$ = 573 min) and 88 h (equivalent to $T_{1/2}$ = 177 min).

INTRODUCTION

The current decompression (DC) procedures for 300 m dive deviate insignificantly from those of the U.S. Navy-Duke experiment in December 1968 requiring 285 h (Summitt et al., 1971). Although a substantially shorter DC time, 88 h as opposed to 285 h, has been published (Buhlmann et al., 1970), the long DC procedure persists. However, neither of these two procedures are trouble free. For example, in the 285-h DC procedure, one of the five subjects complained of pain in the knee, and recompression treatment was instituted. Similarly, one subject required recompression treatment near the end of the 88-h DC procedure. If the abbreviated DC table is as effective as the long one, there is no reason to insist on practicing a seemingly wasteful procedure and to risk divers unnecessarily in a hostile environment. However, before we toss out the long DC procedures and adopt shorter ones, we must be certain not to introduce new problems. Animal experiments screen out potential hazards and pave the way for testing new DC tables in humans.

The calculations of tables according to the universal decompression table (UDT) concept (Lin, 1988; Lin and Shida, 1991) is simple, but it depends heavily on the value of $T_{1/2}$. UDT tables can be calculated for any total DC time by varying the value of $T_{1/2}$. The question remains as to what $T_{1/2}$ value should be used.

The purpose of this experiment was to determine experimentally the value of whole-body $T_{1/2}$ and to establish an interspecies relationship between body weight (W) and $T_{1/2}$, and to systematize interspecies conversion of DC tables.

METHODS

A. CALCULATIONS OF TABLES

Fig. 1 depicts a generic UDT table for DC from 300 m, designated as UDT300X. The table is characterized by large DC steps, which fall progressively with each successive stage, and long stage DC times (5τ). Furthermore, the same table applies to all species if the time is expressed in units of time constant, τ.

Pressure reduction at each stage is calculated according to a threshold equation, $P_1 = aP_2 + b$, which was determined experimentally (Watt and Lin, 1979; Lin, 1981), and this allows us to calculate the pressure threshold (ΔP_{max}, i.e. $P_1 - P_2$) as:

$$\Delta P_{max} = [(a - 1)/a]P_1 + b/a \text{ ---------- } (1)$$

Where P_1 is the saturation pressure and P_2 the reduced pressure, and a and b are respectively the slope and intercept of the DC threshold equation (Watt and Lin, 1979). The rate of pressure reduction from P_1 to P_2 is effected by using 1 unit of τ, thus,

$$\text{DC Rate} = \Delta P_{max}/\tau \text{ ---------- } (2)$$

or, $$\text{DC Rate} = \ln 2 \times \Delta P_{max}/T_{1/2} \text{ ---------- } (2)'$$

Where τ is the time constant for inert gas elimination ($\tau = T_{1/2}/\ln 2$). The rate of DC decreases progressively with each stage as ΔP_{max} falls, but the time used to effect the pressure change remains unchanged at 1 unit of τ. The stage DC time is the same for all except the last stage.

$$\text{Stage DC time} = 5\tau \text{ ---------- } (3)$$

The last stage requires 1 or less than 1 stage DC time, which can be calculated as follow:

$T_{End} = (P_1 - 1)/DC\ Rate$ -- (4)

The total DC time is the sum of stage DC time and T_{End}.

Total DC time = $(M - 1)5\tau + T_{End}$ --- (5)

M is the number of stages. M equals 5 in the case of 300 m saturation dives (Lin, 1988). Therefore, for practical purpose, the total DC time is approximately 21 τ, or 30.3 $T_{1/2}$. The construction of tables according the above formulation depends critically on the value of τ, which is obtained experimentally in this study.

B. SUMMARY OF UDT CALCULATIONS

To construct tables according to the UDT concept, we used the following equations:

1) $P_1 = aP_2 + b$, critical pressure equations
2) $\Delta P_{max} = [(a - 1)/a]P_1 + b/a$, maximum pressure change from P_1, the saturation pressure
3) DC Rate = $\Delta P_{max}/\tau$
4) Stage DC time = 5τ
5) Total DC time $\cong 21\ \tau$ or 30.3 $T_{1/2}$

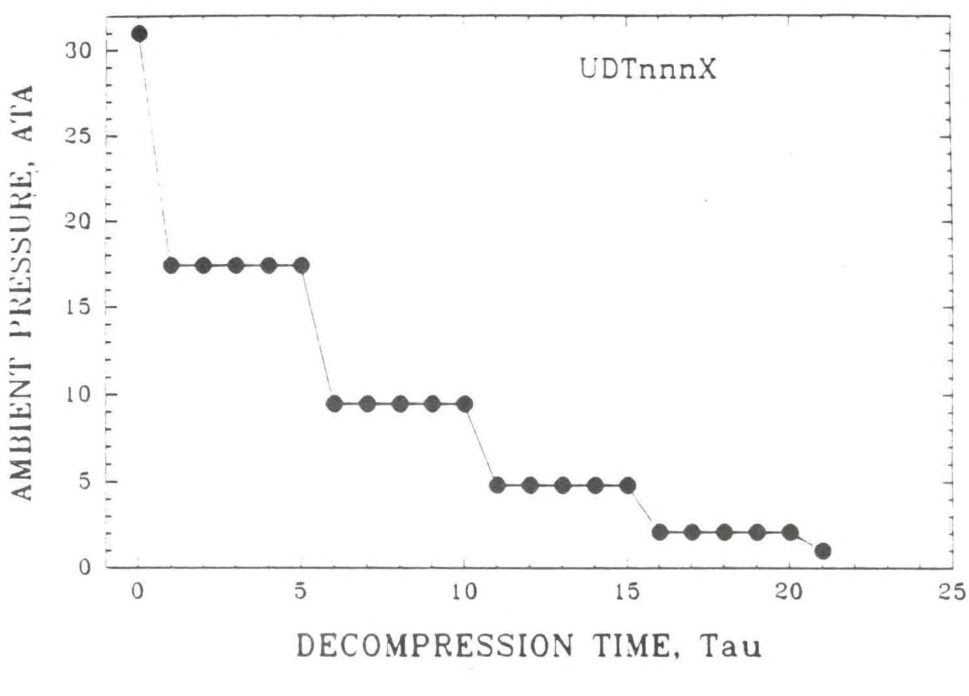

Fig. 1. A generic UDT from 300 m (UDT300X).

C. INTERSPECIES CONVERSION OF TABLES

To systematize the procedure of table conversion between species, we take the following approach:

Firstly, we assume that $T_{1/2}$ rises with body size (W) and falls with cardiac output (Q). Further, a quantitative relationship between Q and W is found in the literature (Juznic and Klensch, 1964). Putting these together, we obtained (Lin, 1988):

$$T_{1/2} = kW^{0.25} \quad \text{------------------------------------} \quad (6)$$

Where $T_{1/2}$ is the half-time in min for overall inert gas elimination, W is the body weight in kg, and k is the proportionality constant.

Secondly, we used human equivalent values of $T_{1/2}$ for animals, according to Eq. 6, to initiate experiment on animals by using human equivalent $T_{1/2}$ values ranging from 40 to 240 min.

Finally, we perform the reverse procedure, by using the experimentally obtained $T_{1/2}$ values from animals to estimate $T_{1/2}$ value for humans. This value is then used to construct DC tables for humans (UDT300H), which will be tested in the future. Although we used the exponent 0.25 to calculate $T_{1/2}$ for animals, the values of k and the exponent for the reverse procedure are determined from the experimental results.

D. ANIMALS

The rats of the Wistar strain, all males, were obtained from a commercial source. Body weight ranged from 228 to 287 g and averaged 255 ± 13 (s.d.) g before compression and 253 ± 13 after the decompression. A total of 82 rats were used (Table 2). Groups of 3-4 rats were housed in wire-cages before placing them in the chamber. Each run consisted of 3 cages. Standard rat chow and water were provided without restriction. Video monitoring and recordings with time code provided continuous surveillance of the behavior of the animals, in addition to direct observations.

Twenty four rabbits of New Zealand white, all male, were used in this study (Table 3). Three individually caged rabbits were placed in the chamber for each compression-decompression cycle. The average body weights were 2.77 ± 0.28 (s.d.) kg before compression and 2.62 ± 0.25 kg after decompression.

Two individually caged beagles were run together in each pressure profile. A total of 14 dogs were used (Table 4). The animal weights did not change over the experimental period lasting between 30 h 40 min and 69 h 10 min. The dog weighed on the average 9.36 ± 0.60 (s.d.) kg before compression and 9.39 ± 0.59 kg after decompression.

E. HYPERBARIC SIMULATOR FOR ANIMALS

Validation of UDT300 tables was carried out at the Japan Marine Science and Technology Center (JAMSTEC) in Yokosuka, Japan. Fig. 2 is a schematic illustration of the JAMSTEC hyperbaric simulator for animals. The simulator is rated for 1,000 m depth and consists of two identical cylindrical chambers (0.6 m i.d. x 2.12 m, each) with a movable central partition. The size and the environmental control capabilities together make the chamber suitable for investigation of a wide variety of problems in animals up to the size of a 20-kg dog. The double-chamber arrangement brings about the possibility of long-term studies. Environmental controls are automated with manual backups. Compression, decompression, temperature and humidity management, deodorizing, CO_2 scrubbing, particulate and bacteria filtering, and air circulation are accomplished automatically according to specific programming. The characteristics of this chamber system have been published elsewhere (Kanda et al., 1979). Temperature is raised continuously during compression with helium to reach 32°C at 300 m depth and lowered gradually to room temperature at the end of decompression. P_{O_2} is maintained at 0.5 Atm, except during initial compression and decompression after reaching 13.9 m whereupon the O_2 is fixed at 21% until surfacing.

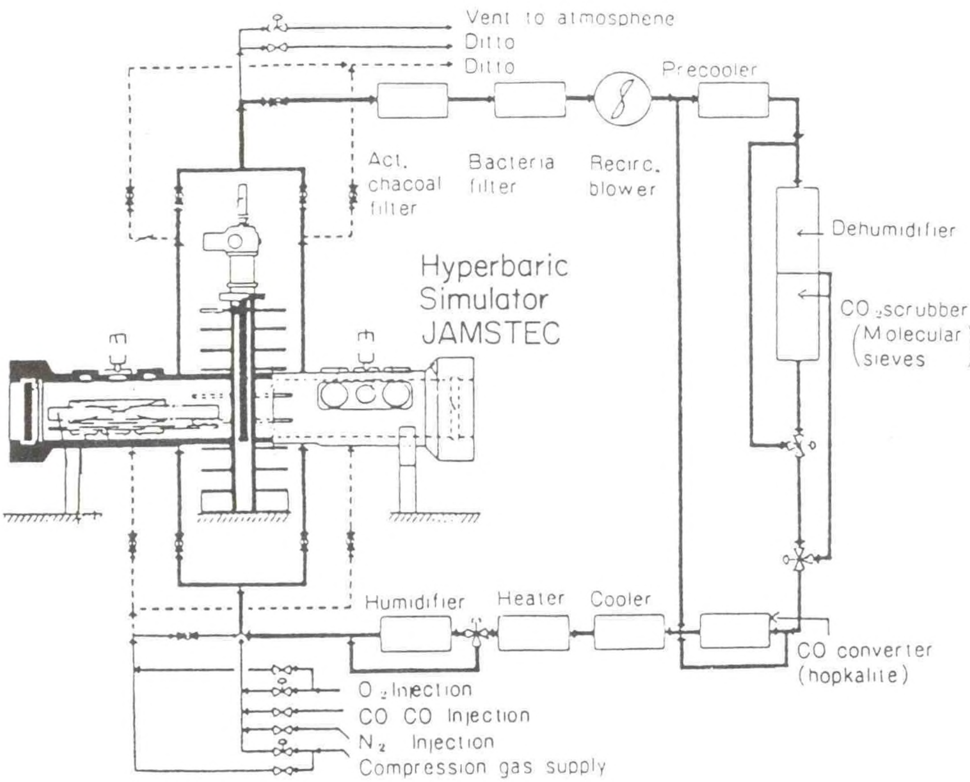

Fig. 2. Animal hyperbaric simulator at the Japan Marine Science and Technology Center (JAMSTEC), Yokosuka, Japan.

F. PRESSURE PROFILE

Compression was carried out at a rate of 150 m/h for 2 h. The saturation pressure, 31 ATA, was maintained for 8 h for the rat, 11 h for the rabbit, and 12 h for the dog. Then the decompression was carried out in the form of UDT300X (Fig. 1), but according to specific $T_{1/2}$ values (Table 1) and stage DC time for specific UDT (Tables 2, 3, and 4).

After the decompression, we examined the animal for signs of DCS, such as impaired righting reflex, tenderness to touch, unusual weight bearing, fast or labored respiration, and abnormal behavioral.

Table 1. Values of $T_{1/2}$ tested and their human equivalent

HUMAN	RAT	RABBIT	DOG
280			172
240	66	117	148
180			111
140			86
120	33	59	74
100		39	
80		29	
40	11	20	

The equivalent $T_{1/2}$ was computed according to $T_{1/2} = kW^{0.25}$, where the body weight (W) is expressed in kg and $T_{1/2}$ in min.

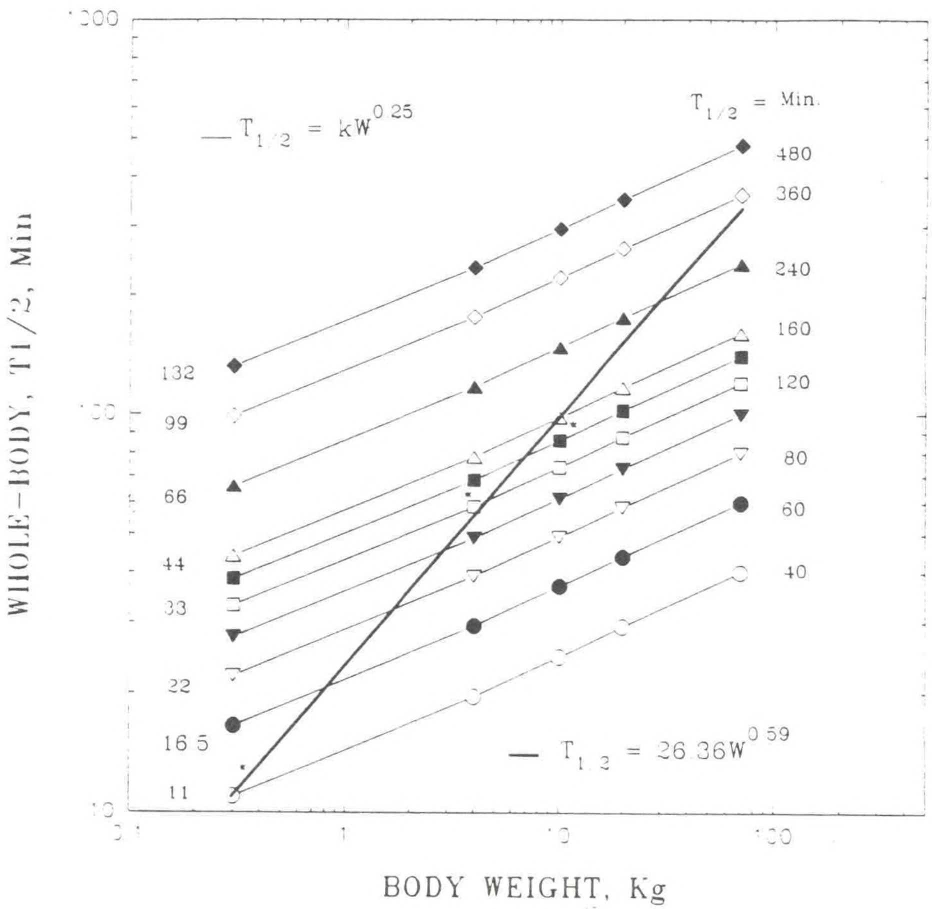

Fig. 3. Interspecies relationships of whole-body $T_{1/2}$ for the elimination of inert gas. The equivalent $T_{1/2}$ for humans (70 kg), dogs (10 kg), rabbits (3 kg), and rats (0.3 kg) are shown with the exponent value set at 0.25. Asterisks indicate experimentally determined shortest $T_{1/2}$ with stage DC time of 5τ, from which a regression equation, $T_{1/2} = 26.36W^{0.59}$ ($r = 0.986$), is dervied (from Tables 2, 3, and 4).

G. THE SHORTEST $T_{1/2}$

For the purpose of this study, any sign of DCS, including death is classified as having DCS regardless of its severity. We determined the shortest $T_{1/2}$ from profiles with stage DC time of 5 τ when all animals in that profile showed no sign of DCS.

H. SHORTEST TOTAL DC TIME

The shortest total DC time was determined from combined reduction in $T_{1/2}$ and shortened stage DC time from 5 to 3 or 1τ.

RESULTS

A. GENERAL OBSERVATIONS

Compression at a rate of 150 m/h produced no observable signs of disturbance to the animals. They eat, drink and sleep as normal. Body weight changes little over the period of experimentation (Tables 2, 3, and 4). EXP. No. in Tables 2, 3, and 4 are assigned before the experiment. Some of them did not appear because the results render them unnecessary, $T_{1/2}$ either too long or too short.

B. MINIMUM $T_{1/2}$

1. Determined from UDT for Rats, UDT300R

Among the 3 $T_{1/2}$ tables with stage DC time of 5τ, we determined that the $T_{1/2}$ of 11 min to be the minimal value for rats weighing 255 g on the average, in which all 10 rats showed no DCS symptoms (Table 2)

Table 2. Test parameters of UDT-300R for rats and its outcome

EXP.	$T_{1/2}$	SDCT		TDCT	Rats	Outcome
	min	τ	h	h		
I	66	5	7.93	33.1	2	No DCS symptoms
II	66	3	4.76	20.3	10	No DCS symptoms
IX	66	1	1.59	7.4	10	No DCS symptoms
III	33	5	3.97	16.4	10	No DCS symptoms
IV	33	3	2.38	10.1	10	No DCS symptoms
V	33	1	0.79	3.7	10	No DCS symptoms
VI	11	5	1.32	5.5	10	No DCS symptoms
VIII	11	3	0.79	3.4	11	1 DCS
VII	11	1	0.27	1.3	9	All DCS

Body weights for 82 rats averaged 255 ± 13 (s.d.) before compression and 253 ± 13 g after decompression; DCS, decompression sickness; SDCT, stage decompression time in units of τ, the time constant for inert gas elimination, or hours (h); and TDCT, total decompression time, in h.

2. Determined from UDT for Rabbits, UDT300B

Among the 3 tables with stage DC time of 5τ and with $T_{1/2}$ values of 20, 29, and 59 min, all animals in the $T_{1/2}$ = 59 min profile showed no DCS symptoms. DCS symptoms appeared with $T_{1/2}$ values shorter than 59 min (Table 3).

Table 3. Tests parameters of UDT300B for rabbits and its outcome

EXP.	$T_{1/2}$	SDCT		TDCT	Rabbit	Outcome
	min	τ	h	h		
III	117	1	2.82	13.2	9	No DCS symptoms
IV	59	5	7.08	29.3	3	No DCS symptoms
V	59	3	4.25	18.0	9	No DCS symptoms
VI	59	1	1.42	6.7	3	1 DCS
XI	39	5	4.67	19.3	6	1 DCS
X	39	3	2.81	11.8	3	1 DCS
VIII	29	5	3.49	14.5	10	5 DCS
IX	29	3	2.09	8.9	3	1 DCS
VII	20	5	2.42	10.0	3	2 DCS

The average body weights for the 52 rabbits were 3.67 ± 0.15 (s.d.) kg before compression and 3.69 ± 0.22 kg after decompression. DCS, decompression sickness; SDCT, staged decompression time in units of τ, the time constant for inert gas elimination, or hours (h); and TDCT, Total decompression time, in h.

3. Determined from UDT for Dogs, UDT300D

Among the 3 tables with stage DC time of 5τ, the shortest $T_{1/2}$ of 86 min caused no DCS symptoms in dogs weighing on the average 9.4 kg (Table 4).

C. EXTRAPOLATION OF $T_{1/2}$ FOR HUMANS, UDT300H

The regression equation derived from the above results is as follow:

$T_{1/2} = 26.36W^{0.59}$ -- (7)

By substituting 70 kg for W, we obtained the shortest $T_{1/2}$ = 322 min (τ =7.74 h) for humans (Fig. 3). This is translated to a total DC time of 162.6 h for humans from a 300 m saturation dive (Fig. 4). This total DC time lies between the published shortest DC time (88 h) and the currently accepted DC time.

Table 4. Tests parameters of UDT300D for dogs and its outcome

EXP.	$T_{1/2}$ min	SDCT τ	SDCT h	TDCT h	Dogs	Outcome
V	172	1	4.13	19.4	2	No DCS symptoms
VII	148	1	3.56	16.6	2	1 DCS
I	111	5	13.34	55.2	2	No DCS symptoms
VIII	86	5	10.33	42.8	2	No DCS symptoms
IX	86	3	6.20	26.2	2	No DCS symptoms
III	74	5	8.90	36.8	2	1 DCS
VI	74	3	5.34	22.5	2	2 DCS

Dogs (14) averaged 9.36 ± 0.60 (s.d.) kg before compression and 9.39 ± 0.59 kg after decompression. DCS, decompression sickness; SDCT, stage DC time in units of τ, the time constant for inert gas elimination, hours (h); and TDCT, total DC time, in h.

D. SHORTEST DECOMPRESSION TIME

The shortest safe total DC time from 300 m saturation dive for the rat was 3.73 h (Exp. V), which was obtained with the profile with $T_{1/2} = 33$ min and a stage DC time of 1τ (Table 2); for the rabbit, 13.2 h (Exp. III) with $T_{1/2} = 117$ min and 1τ (Table 3); and for the dog, was 19.4 h (Exp. V) with $T_{1/2} = 172$ and 1τ (Table 4).

DISCUSSION

Although theories are postulated to guide the timing and staging of pressure reduction, the development of DC tables remains mostly a matter of trial-and-error. The reason is that, in practice, we still lack the ability to make *in vivo* determinations of, or utilize parameters described by theories (Hempleman, 1969; Hills, 1977, Kidd et al., 1971; Schreiver and Kelley, 1967; Vann, 1982; Yount, 1979; Yount and Hoffman, 1986). Equally important is that theories are still incapable of predicting the complexity of direct and indirect biological responses following the formation of bubbles, *in vivo*. For this reason, some combinations of theory and practicality will be essential in devising and revising DC tables. This study concerns testing new DC tables, UDT300R for rats, UDT300B for rabbits, and UDT300D for dogs for a 300 msw saturation dive. Results of these experiments allow us to obtain, by extrapolation, the $T_{1/2}$ for humans and hence the UDT for humans, UDT300H.

Buhlmann and his colleagues (Buhlmann et al., 1970) have demonstrated the feasibility of shortening DC time from 285 h to 88 h from saturation at 300 m depth. Over the years, tables with shorter DC time appeared, although these were not used routinely but as emergency procedures by generous allocation of oxygen (see Table 4 in Lin and Shida, 1991). Since the DC time between the current practice and what is possible differs greatly, ways must be found to bridge them. Furthermore, we believe that the progress in revising DC tables for humans will be painfully slow until a procedure is found to extrapolate animal data to humans. The present study represents one such attempt. Essentially, our approaches are as follows:

Firstly, we used a maximum magnitude of pressure reduction that produces no detectable bubbles (ΔP_{max}) to reduce the ambient pressure from a saturation pressure (P_1) to a lowered pressure (P_2) and hold the pressure at P_2 until the tissues and the ambient pressure reach an equilibrium (i.e., until 5τ has elapsed) before effecting the next pressure change. In the present study, we systematically varied the $T_{1/2}$ values in rats, rabbits, and dogs until the shortest $T_{1/2}$ value was obtained.

Secondly, we utilized the relationship $T_{1/2} = kW^x$ with x = 0.25 as a guide to initiate testing of UDT in rats, rabbits and dogs for the equivalent of human $T_{1/2}$ values between 40 to 280 min. It became apparent that the value of x, 0.25, was too low after testing UDT300B for rabbits. However, this result did not affect the determination of the values of k and x. These values were derived from data obtained in animals (Eq. 7, Fig. 3).

Finally, we obtained the $T_{1/2}$ for humans, 322 min (τ = 464.5 min or 7.74 h), from the k and x values derived from animal data. The human DC table calculated according the UDT concept with this $T_{1/2}$ value lies between the two extremes of DC tables that have been published (Fig. 4).

We have shown that rats, rabbits, and dogs can be decompressed safely according to the table calculated with the UDT concept (Fig. 1), with the minimum values of $T_{1/2}$ determined in this study. Whether the extrapolated $T_{1/2}$ for humans can be used safely awaits validation. However, we strongly believe UDT300H tables can be tested in humans by using the $T_{1/2}$ of 573 min, which bears a total DC time of 285 h, the currently accepted DC time (Fig. 4). Shorter DC times can then be tested to approach $T_{1/2}$ = 322 min, or even $T_{1/2}$ = 177 min, which is equivalent to the shortest published DC time (Buhlmann et al., 1970).

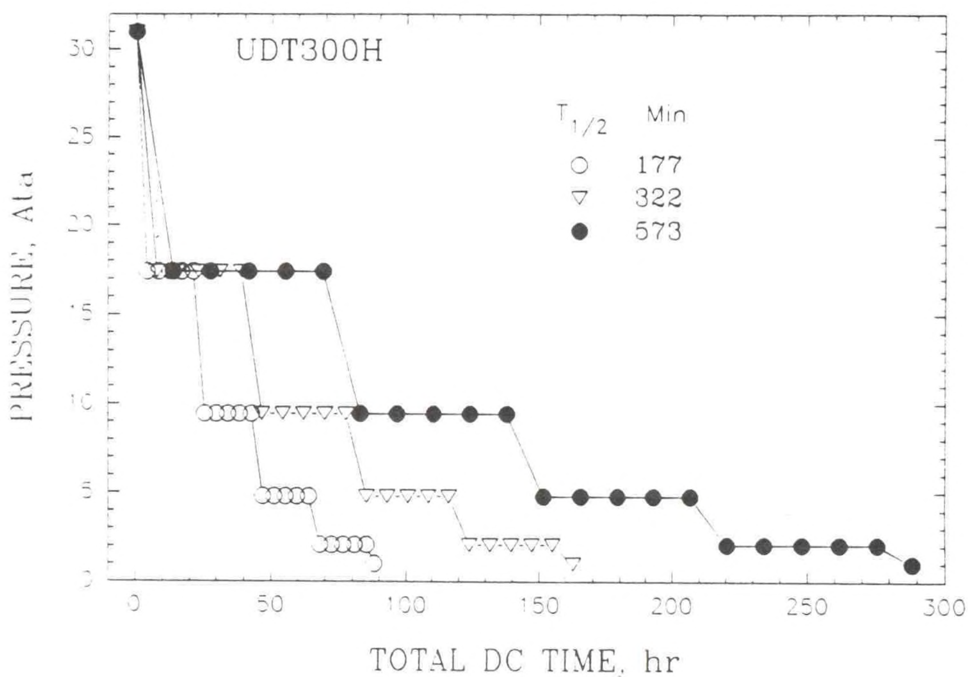

Fig. 4. UDT tables for humans (UDT300H), which are calculated for the two published extremes, and one derived from this study by using $T_{1/2}$ = 322 min.

In this study, we took advantage of the pressure-dependent ΔP. The greater the ΔP, faster the rate of inert gas elimination will be so long as no bubble is present in the circulatory system. In the absence of bubbles, the body store of inert gas decays as a function of time in a monoexponential manner. On the other hand, the presence of bubbles retards inert gas elimination causing obvious asymmetry between the saturation and the desaturation processes (D'Aoust et al., 1976; Thalmann, 1987). For this reason, it is desirable to effect the pressure changes in a manner that causes no bubbles, but is the highest possible ΔP, i.e., ΔP_{max}.

Continuous pressure reductions after the initial pressure reduction is the method of preference for most tables currently in use. However, it may not be in the best interest in terms of gas elimination. With the continuous pressure reduction, supersaturation accumulates causing bubbles to form, thus retarding gas elimination, though DCS symptoms may not appear. The UDT concept suggests that a better way might be to pause pressure reduction until supersaturation diminishes. We suggest a period of 5τ. However, a period of less than 5τ may also suffice. We expect equilibration with the new pressure at a 95% level when a period of 3τ is allocated. Complete equilibration at this level may be assumed when taking into consideration the oxygen window (Behnke, 1951; Yount and Lally, 1980) and the inherent desaturation (Hills, 1966; Rahn, 1961). But, at 1τ, even taking these factors into account the equilibration is less than 70% complete. Why then, 1τ caused no DCS in rats (Table 1, Exp. V), in rabbits (Table 2, Exp. III), and dogs (Table 3, Exp. V) is puzzling. This simpy suggests that the $T_{1/2}$ used was not the shortest possible.

Two studies stand out in the investigation of decompression parameters in a variety of species. Regarding decompression threshold, Flynn and Lambertsen (1971) reported that relative susceptibility to DCS, from saturation or near-saturation exposures on N_2-O_2 mixtures, rises with increasing body weight. Their results were derived by rapid decompression that produces DCS symptoms. They also showed a diminishing species difference with falling ΔP. We expect little species differences in ΔP when a no-bubble or no-symptom criterion is used. On the scaling of DC time, Berghage et al. (1976) proposed the inclusion of minute ventilation per unit body weight as a scaling factor for inert gas uptake, and by using ΔP as a function of body weight essentially as that of Flynn and Lambertsen (1971). No conclusion was drawn for the DC time for various species.

SUMMARY

The UDT-300R tables are constructed by utilizing a pressure dependent decompression threshold, coupled with a staged decompression time that allow tissue inert gas pressure to equilibrate with the lowered ambient pressure before effecting another pressure reduction. To construct tables according to the UDT concept, it requires one critical pressure equation and values of $T_{1/2}$. We obtained, by extrapolation, a $T_{1/2}$ of 322 min for humans, which is equivalent to a total DC time of 6.77 days from a 300-m heliox saturation dive, which lies between the two extremes of published total DC time, 88 and 285 h. The validity of this 6.77-day table according to the UDT concept remains to be tested.

ACKNOWLEDGMENT

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DECOMPRESSION SICKNESS AND DIVE PROFILES

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ABSTRACT

A clinical study analyzed 181 cases of decompression sickness (DCS) in divers who were admitted as patients in the period 1981 to 1991 at Kawashima Orthopedic Hospital. Their average age was 32.5 years old. Methods of diving in this population included helmet 26 (14.4%), scuba

147(81.2%), and hookah 8(4.4%). Classification of decompression sickness cases by most prominent symptoms included limb bends 142(77.6%);spinal cord DCS 16(8.7%);cerebral injury 12 (6.6%);Meniere's 3(1.6%);chokes 9(4.9%) and Puces 1(0.6%). Two divers exhibited multiple symptoms. Latency time(onset time of DCS after surfacing) was 134(77.5%) cases under 30 minutes;17 cases(9.8%) occurred after 30-59 minutes;17 cases(9.8%) occurred between 60-179 minutes;and 3 cases(1.7%) occurred between 180-300 minutes. Ten divers were unable to report their latency times. Treatment outcomes amongst divers were judged as good 175(95.6%);fair 7(3.8%), and failure 1(0.6%). Diving profiles used in the Ariake and Inland Sea in shellfish diving were investigated.

INTRODUCTION

There are many professional diving fishermen in the Kyushu area. The main purpose of their diving is the collection of shellfish,mostly abalone and pen shell,as well as sea urchins. Diving fishermen sustain a high incidence of dysbaric osteonecrosis and DCS. The high prevalence of diving injuries in these divers appears to result from the extraordinarily severe decompression routinely used.

This clinical study was carried out on 181 divers and their dive tables were investigated.

CASE RECORDS

This study constitutes a clinical review of 181 divers admitted for treatment of DCS in the Kawashima Orthopedic

Hospital during a 10-year period from 1981 to 1991. All divers were males except one. Their ages ranged from 17 to 57 years old, and the average age of the divers was 32.5 years old. (Table 1)

The diving equipment used by the diver patients included 26 helmet (14.4%), 147 scuba (81.2%), and 8 hookah (4.4%). Helmets were mainly used for shellfish (Atrina japonica). Scuba and hookah were mainly used to fish for abalone and sea urchins. (Table 2)

Table 3 contains a symptomatologic classification of divers by their most prominent symptom i.e., limb bends in 142 cases (77.6%), spinal cord injury in 16 (8.7%), cerebral injury in 12 (6.6%), Meniere's or vestibular in 3 (1.6%), chokes in 9 (4.9%), and pruritus (Skin) in 1 (0.6%).

Analysis of the site of limb bends showed that the most frequently involved sites were the shoulder (40.4%), knee (27.7%), and elbow (20.7%). (Table 4)

DCS latency (reported time of symptom onset after surfacing) indicates a declining number of divers who reported DCS symptoms as a function of time after surfacing. The reported DCS latencies were: under 30 minutes 134 (77.5%), 30-59 minutes 17 (9.8%), 60-179 minutes 17 (9.8%), and 180-300 minutes 3 (1.7%). (Table 5)

Recompression treatment tables were those of the US Navy and included Tables 5, 6, 5-A and 6-A.

Dive profiles of the treated divers relied largely upon their personal diving experience rather than decompression tables. The investigation of dive profiles used in shellfish diving was conducted in the Ariake Sea and Inland Sea of Japan. Dive profiles were recorded by oral questioning or by automatic dive recorders (Fig. 1).

Table 6 shows the clinical outcomes of recompression therapy. One hundred and seventy five (95.6%) were judged good, 7 (3.8%) were fair, and 1 (0.6%) was a failure. All patients with good results resumed their previous diving work.

Most of the divers did not use any standard dive table, such as the US Navy dive tables. Each of the divers reportedly used their own personal dive table according to their experiences in diving. However,these tables differ according to the time, diving equipment,and diving area.

Karatsu divers used scuba equipment. Their characteristic dive profile was repetitive(Fig.2),and they frequently came to our hospital with limb bends.

Ohura divers usually dive in the Ariake Sea. Their diving profile has changed over recent history. Very long bottom times were characteristic from 1925 to 1955.(Fig 3) Typically a dive day included 8 hours of bottom time at approximately 27 meters depth.

Bottom times decreased to 4 hours during the period from 1957 to 1985.(Fig 4) In order to save the natural resources and to maintain the high price of shellfish bottom times of the diving fishermen have been reduced.

The typical bottom time has been 3 hours since 1985.(Fig 5)

Ohura divers were well known for their high incidence of dysbaric osteonecrosis(60%). Experimentally induced dysbaric osteonecrosis in sheep has been produced by similar pressure profiles.

When Ohura divers dived in the Kunisaki area,they used a different dive profile(Fig 6). The reported bottom time was 6 hours, and they frequently suffered limb bends.They often used a surface decompression chamber,and a surface decompression table is illustrated in Fig. 7. They frequently suffered Type Ⅱ bends,and five cases were autopsied. Many bubbles were observed in the heart and veins of the brain(Figs 8,9).

They attempted to treat themselves according to their own treatment tables.(Fig 10,11)

Recently a dive recorder was used to monitor pressure profiles of Ohura divers in the Inland Sea. Long bottom times and repetitive diving are charactaristic(Fig 12).

CONCLUSION

Diving fishermen with DCS represented 181 cases treated in the Kawashima Orthopedic Hospital,and a clinical analysis was conducted. The high incidence of decompression sickness appears to be caused by their severe diving profiles. Long bottom times and repetitive diving appear to be factors in these DCS cases.

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Age Distribution

Age	Male	Female	Total
0～ 9	0	0	0
10～19	4	0	4
20～29	64	1	65
30～39	77	0	77
40～49	30	0	30
50～59	5	0	5
60～	0	0	0
Total	180	1	181

Average
32.5 years
(17～
57 years)

Table 1

Method of Diving

Method	Cases	(%)
HELMET	26	14.4
SCUBA	147	81.2
HOOKAH	8	4.4
Total	181	100.0

Table 2

Decompression Sickness

Type	Cases	(%)
Bends	142	77.6
Spinal Injury	16	8.7
Cerebral Injury	12	6.6
Ménière's	3	1.6
Chokes	9	4.9
Puces	1	0.6
Total	183	100.0

Table 3

Sites of Bends

Sites	Right	Left	Both	Total
Shoulder	34	38	14	86
Elbow	14	23	7	44
Wrist	2	2	0	4
Low back	1	1	6	8
Hip	5	4	0	9
Knee	28	11	20	59
Ankle	2	1	0	3
Total	86	80	47	213

Table 4

L a t e n c y

Time (minute)	Under 30	30～59	60～179	180～300	After 360	Total
Bends	109	15	15	3	0	142
Spinal	13	1	2	0	0	16
Cerebral	5	1	0	0	1	7
Ménière's	2	0	0	0	0	2
Chokes	4	0	0	0	1	5
Puces	1	0	0	0	0	1
Total	134	17	17	3	2	173
(%)	(77.5)	(9.8)	(9.8)	(1.7)	(1.2)	(100.0)

Table 5

Clinical Outcome

	Average Time	Good	Fair	Failure	Total
Bends	3.2	140	2	0	142
Spinal Cord Injury	21.5	12	3	1	16
Cerebral Injury	24.4	10	2	0	12
Menieres	9.7	3	0	0	3
Chokes	6.0	9	0	0	9
Puces	1.0	1	0	0	1
Total	6.4	175	7	1	183
(%)		(95.6)	(3.8)	(0.6)	(100.0)

Table 6

Fig. 1 Investigation in Ariake Sea

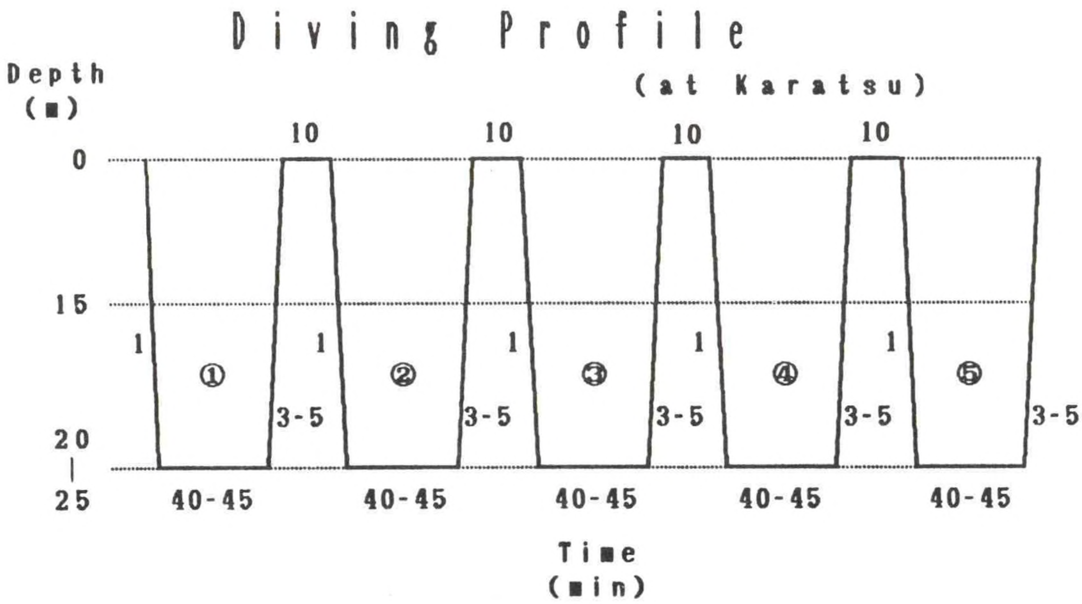

Diving Profile
(at Karatsu)
Depth
(m)
0
15
20
|
25
10
10
10
10
1
1
1
1
1
①
②
③
④
⑤
3-5
3-5
3-5
3-5
3-5
40-45
40-45
40-45
40-45
40-45
Time
(min)

Fig. 2

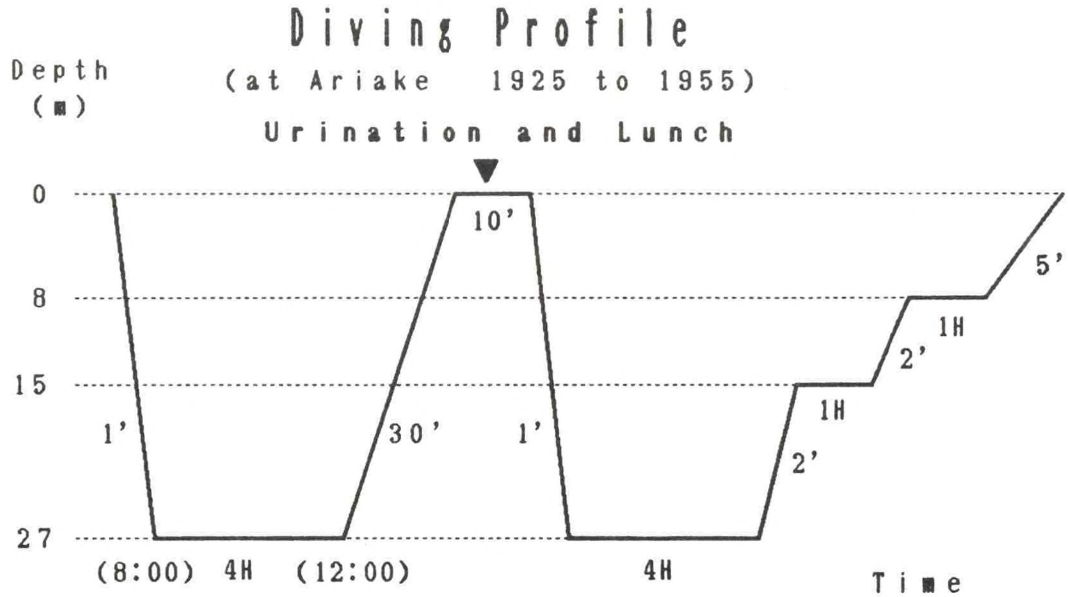

Diving Profile
(at Ariake 1925 to 1955)
Depth
(m)
Urination and Lunch
0
8
15
27
1'
10'
30'
1'
2'
1H
2'
1H
5'
(8:00)
4H
(12:00)
4H
Time

Fig. 3

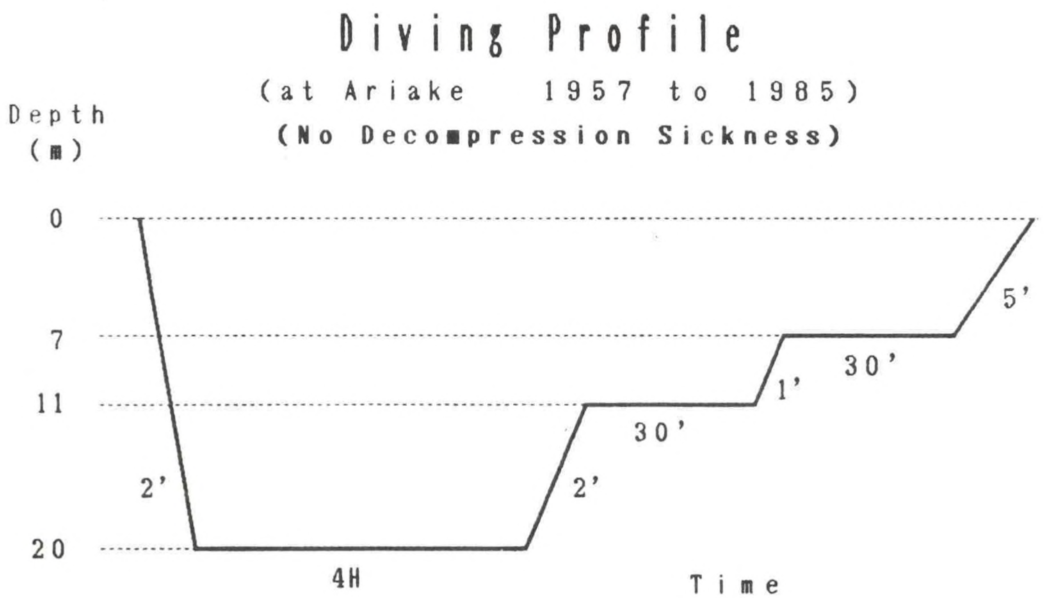
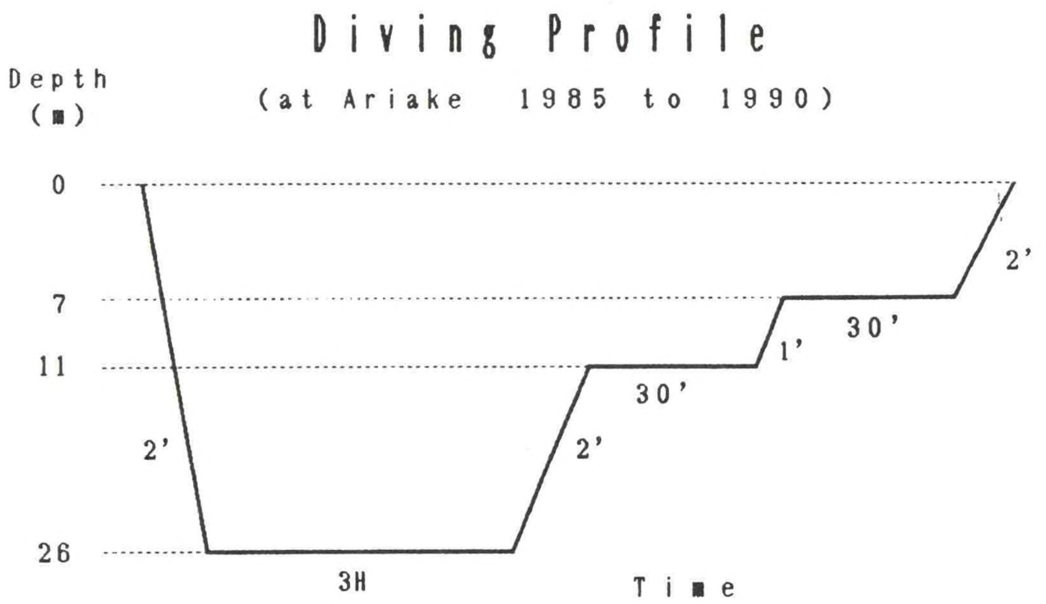
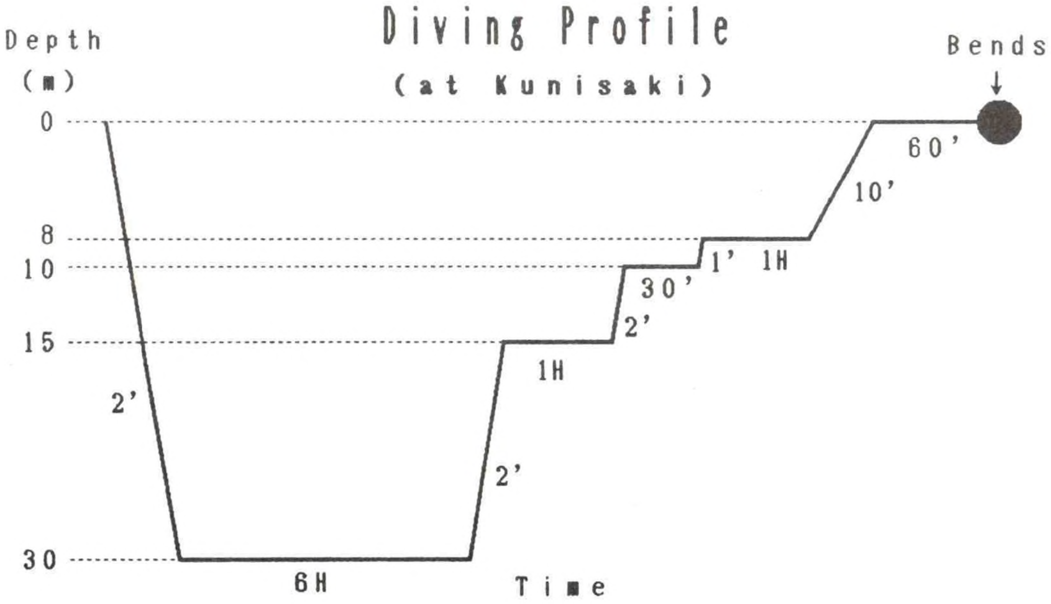

Diving Profile
(at Ariake 1957 to 1985)
(No Decompression Sickness)
Depth
(m)
0
7
11
20
2'
4H
2'
30'
1'
30'
5'
Time

Fig. 4



Diving Profile
Depth
(m)
(at Ariake 1985 to 1990)
0
7
11
26
2'
3H
2'
30'
1'
30'
2'
Time

Fig. 5



Diving Profile
(at Kunisaki)
Depth
(m)
0
8
10
15
30
Bends
60'
10'
1' 1H
30'
2'
1H
2'
2'
6H
Time

Fig. 6

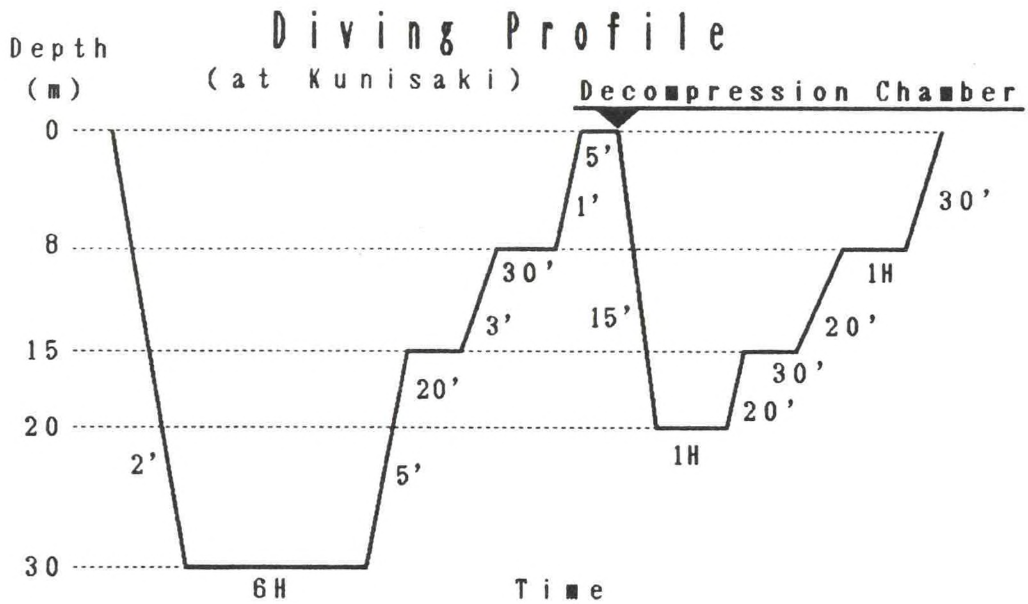

Diving Profile
(at Kunisaki)
Depth
(m)
Decompression Chamber
0
8
15
20
30
2'
6H
5'
20'
3'
30'
1'
5'
15'
1H
20'
30'
20'
1H
30'
Time

Fig. 7

F i g . 8 Bubbles in the heart of an autopsy case

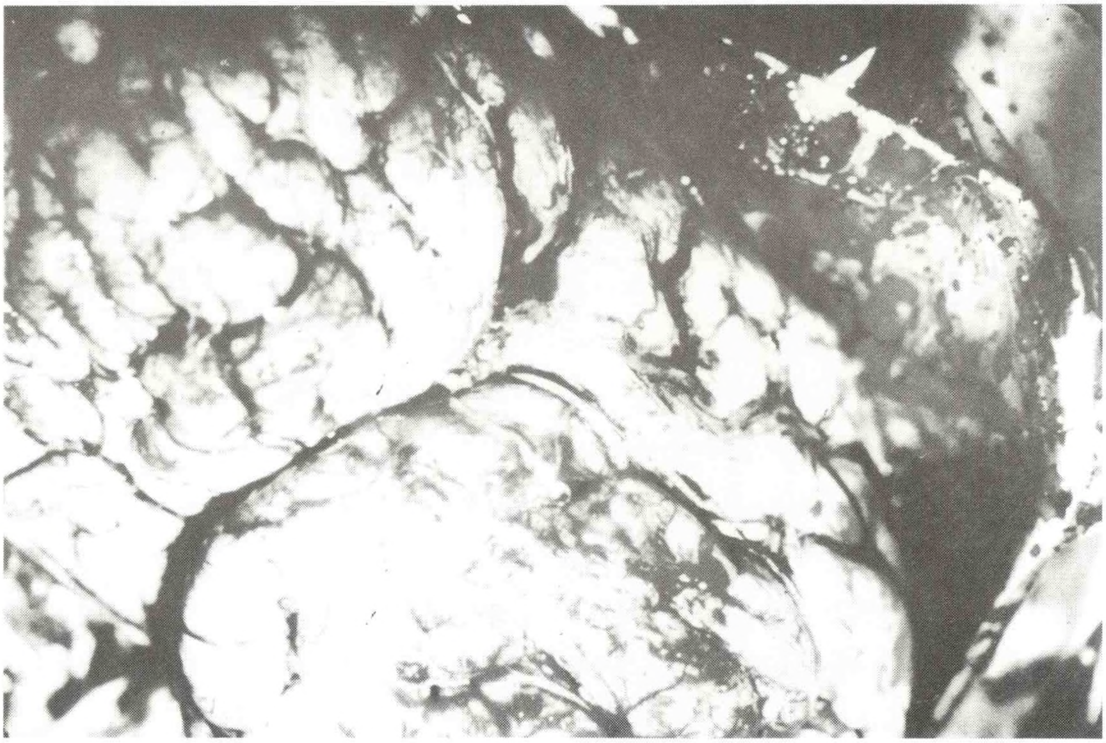
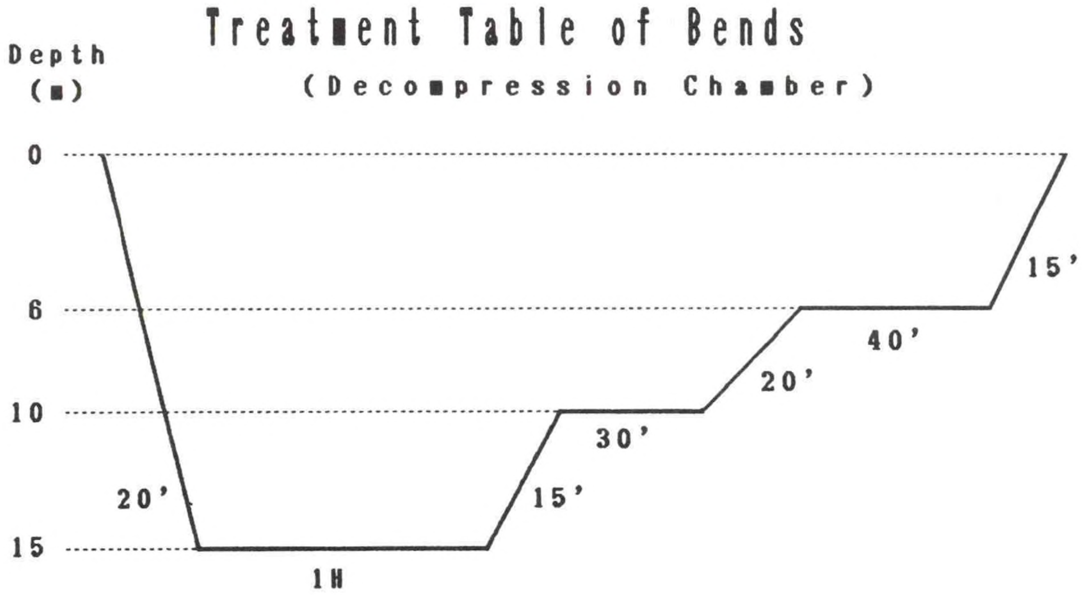


Fig. 9 Bubbles in the veins of the brain in an autopsy case



Treatment Table of Bends
(Decompression Chamber)
Depth
(m)
0
6
10
15
20'
1H
15'
30'
20'
40'
15'

Fig. 10

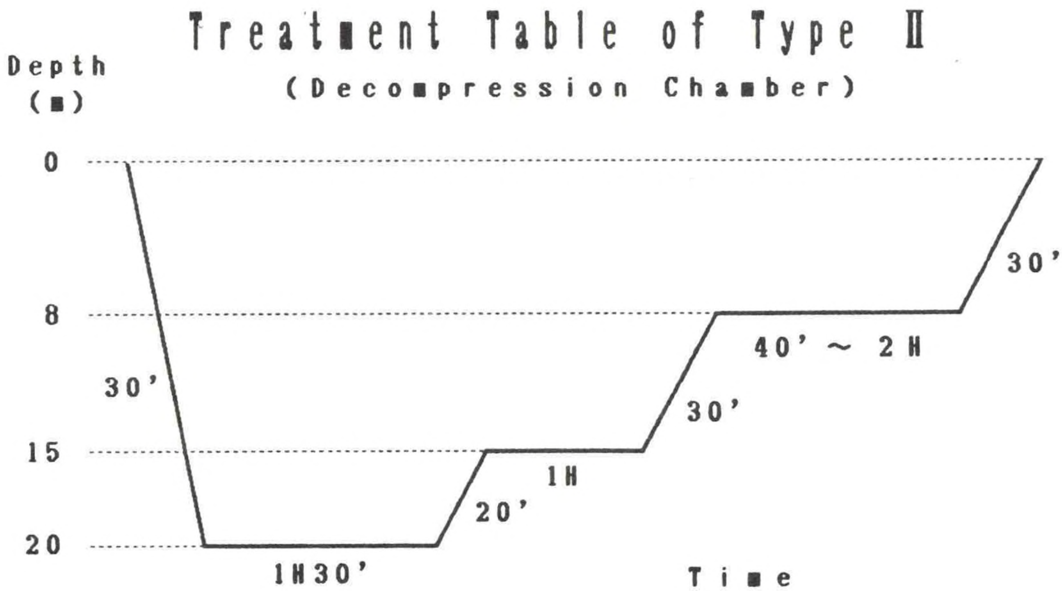

Treatment Table of Type II
(Decompression Chamber)
Depth
(m)
0
8
15
20
30'
1H30'
20'
1H
30'
40' ～ 2H
30'
Time

Fig. 11

Diving Record in Inland Sea

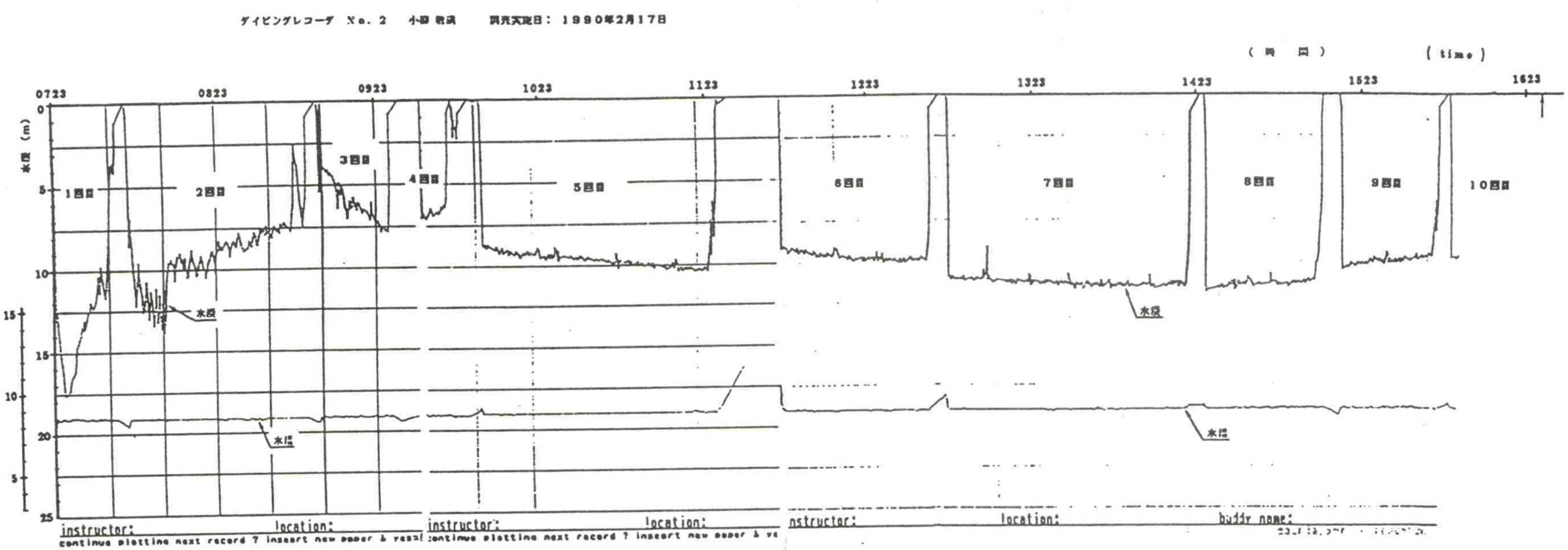


Fig. 12

DIVE PROFILES CONTROL THE RISK OF DYSBARIC OSTEONECROSIS: VALIDATION IN JAPANESE DIVING FISHERMEN AND SHEEP

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ABSTRACT

Dysbaric osteonecrosis (DON) is a potentially disabling form of bone necrosis associated with hyperbaric exposure. Prolonged exposure of humans to hyperbaric conditions, as occurs with tunnel workers and diving fishermen breathing compressed air, often induces DON with lesions prevalent in the long bones. In sheep, short to intermediate duration hyperbaric exposures (1/2 to 4 h) produced comparatively mild DON. Prolonged hyperbaric exposures of 24-h duration produced more severe DON with widespread ischemic necrosis of the fatty marrow in sheep long bones. Subchondral bone necrosis, which can lead to a disabling juxta-articular collapse in the ends of long bones, also occurred. Both short and long duration hyperbaric exposures produced the major forms of decompression sickness in sheep. Limb bends were most frequent after 24-h hyperbaric exposures. DON and the form of limb bends with deep pain may both be manifestations of increased intramedullary pressure caused by N_2 bubble formation in the fatty marrow of long bones. In our view, increased intramedullary pressure causes ischemia in the marrow cavity and, if sustained, a bone compartment syndrome and DON. Experimental induction of DON in sheep points to a strong causal association between the duration of dives and the prevalence of DON. Short hyperbaric exposures appear to carry a low risk of DON, while the closely-spaced repetitive or prolonged dives which have become increasingly common among recreational and scientific divers carry a higher risk of DON.

INTRODUCTION

Dysbaric osteonecrosis (DON) is a disabling form of ischemic bone necrosis which can result after hyperbaric exposure of those individuals engaged in helmet or scuba diving or tunnel work in compressed air. DON is most prevalent among tunnel workers and diving fishermen exposed to compressed air, and DON represents an important public health problem for these populations. DON etiology and manifestations have been extensively reviewed by Davidson (1976, 1989), McCallum and Harrison (1982), and Walder (1990).

DON usually occurs in the long bones and can be permanently disabling when juxta-articular lesions cause the painful collapse of the articular surface in the affected bone (McCallum and Harrison, 1982). DON lesions in the joint regions of the long bones are often painful, but even extensive DON lesions in long bone shafts characteristically remain asymptomatic.

Although the underlying pathogenesis of DON remains controversial (Walder, 1990), prolonged hyperbaric exposure is widely accepted as the most important etiological factor in the disease. In this context, the high frequency of decompression sickness (DCS), especially limb bends after prolonged hyperbaric exposure, is strongly correlated in those populations with a correspondingly high prevalence of DON.

In the 4,000 to 6,000 current Japanese diving fishermen who use compressed air, the DON incidence is greater than 50% (Amako et al., 1974), and Wade et al. (1978) reported a similarly high incidence in Hawaiian coral divers. In the United States, the commercial scallop divers in Maine and abalone divers in California who use hookah rigs may also face a high risk of developing DON.

DON has been reported in only a few recreational divers. Recreational diving practices have typically involved only a few dives per day, and those dives have been comparatively brief in duration and with mild decompression. In contrast, tunnel workers and commercial diving fishermen, especially those in Japan and Hawaii, have sustained a high incidence of DCS and DON. Hyperbaric exposures in these populations tend to be prolonged and with severe decompression.

Although the prevalence of DON among recreational divers is very low, multi-level, repetitive diving practices with dive computers may increase the overall incidence of DON (Lehner, 1992). Such dive practices can involve cumulative hyperbaric exposures similar to those associated with a high prevalence of DON. Dive tables have never been tested with DON as an outcome, and the risk of developing DON from repetitive dive profiles remains uncertain. However, the sheep model of DON (Lanphier and Lehner, 1990) and epidemiological patterns of DON in humans offer us clues about the risk of developing DON from various hyperbaric exposures.

In this study, the authors report DON findings from a reliable animal model of DON, observations about Japanese diving practices which validate the sheep model, potential risk factors in DON, and the pathophysiological basis for the use of therapeutic recompression to prevent the development of DON.

JAPANESE SHELLFISH DIVING

Japanese diving fishermen in southern Japan use small, motor-powered boats in their shellfish diving operations. Some shellfish dive boats carry a small recompression chamber, which permits surface decompression, so the diver can avoid long in-water decompression under cold conditions. Typically, a shellfish diving operation involves two people, a diver and his tender who assists the diver with the hookah air rig and helmet diving suit. Sea urchins are gathered at shallow depths, and pen shells (*Atrina* sp.) are collected at greater depths, between 10 to 30 m. The on-board tender is the one who usually shucks the adductor muscle from the *Atrina*.

The highly-prized adductor muscles of the pen shell are quickly transported to major fish markets where they command a high price and are often sold to sushi bars. A Japanese diving fisherman may earn as much as $80,000 per year during the shellfish season, so his risk of developing DCS and DON may be partly balanced by the financial return. Financial incentives to shellfish divers in the United States are reportedly similar to those in Japan.

Shellfish divers conduct rigorous dives in pursuit of the *Atrina*. An example of a severe repetitive dive profile and surface decompression that typifies Tairagi shellfish diving is represented in Fig. 1. This pressure profile was recorded by an automatic dive recorder worn by a young, male diver who dived the waters off the island of Kyushu.

The diver's hyperbaric exposures consisted of four decompressions, including three dives and a surface decompression in a recompression chamber aboard the fishing boat. A brief "scouting" dive to somewhat more than 15 m for 58 min bottom time was followed by a brief surface interval and a second dive of 309 min to almost 16 m. Considerable "missed" decompression time, based on a U.S. Navy air table model, is represented by the hatched areas in Fig. 1. When the diver reached the surface after the second dive, staged decompression would require 44 min at 6 m and 148 min at 3 m to minimize DCS risk. Instead, the diver conducted a no-stop ascent. In the third and final dive, the diver remained on the bottom at 16 m for 92 min and then conducted a no-stop ascent to surface followed by a 32 min surface decompression in pressure chamber aboard the fishing boat. The cumulative time spent under compressed air was

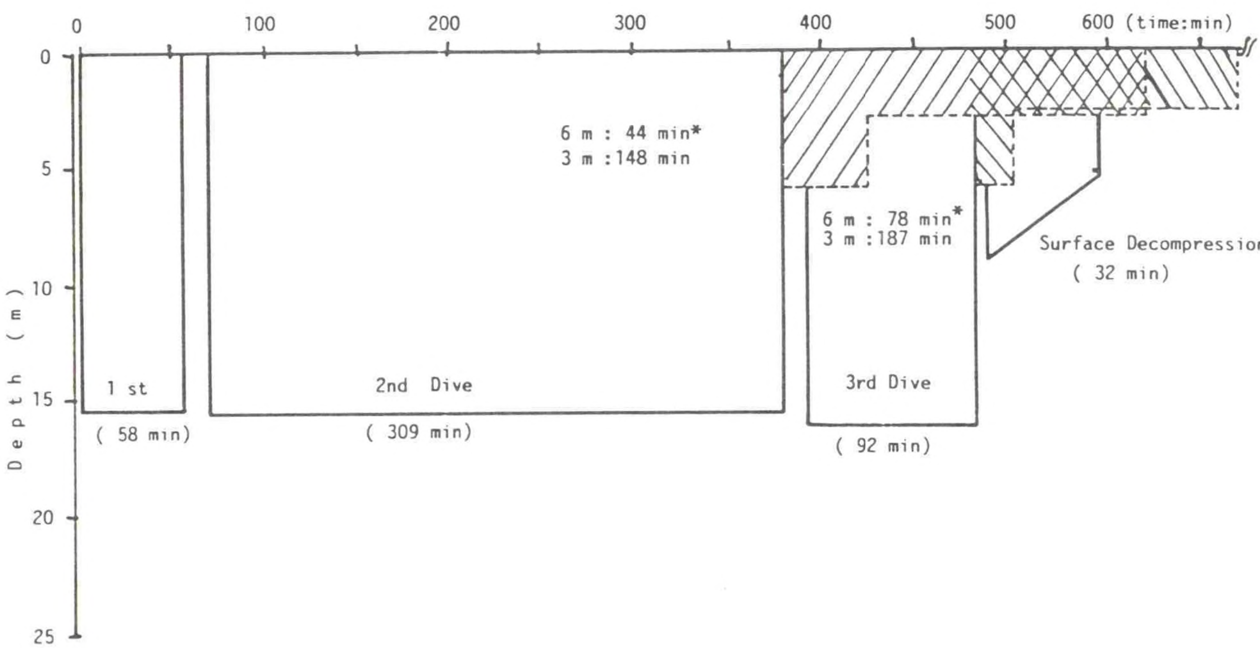

Fig. 1. Dive profile and surface decompression of a Japanese shellfish diver. "Missed" decompression times are represented by hatched areas.

slightly more than eight hours. Additional decompression time was again missed in the third dive and later surface decompression procedure.

This repetitive hyperbaric exposure fortunately went uneventfully for the diver, without any reported clinical symptoms of DCS. However, such hyperbaric exposures are associated with a high incidence of DCS as reported by Kawashima et al. in these proceedings, with many serious cases (Kitano and Hayashi, 1981), and a high prevalence of DON (Amako et al., 1974).

PREVALENCE OF DYSBARIC OSTEONECROSIS

The prevalence of DON varies widely depending on the type of pressure exposure and physical factors of the individual, particularly obesity (Behnke, 1970). Tunnel and caisson workers with prolonged exposures to compressed air, typically greater than six hours and decompressed from high pressures, often have sustained a comparatively high incidence of DCS, mostly limb bends, and DON (Golding et al., 1960; Jones, 1985a; Kindwall, 1975; McCallum et al., 1966). With the more careful use of exposure times and pressure, such high rates of injury have been reduced (Jones and Behnke, 1978). This pattern of a high DON prevalence among many tunnel and caisson workers, especially in the past when decompression procedures were inadequate, is in contrast to the vast numbers of recreational scuba divers routinely exposed to compressed air and who will never experience DCS and DON.

Recreational, scientific and U.S. Navy divers have a low incidence of DON with relatively few verified cases (Jones, 1985a). Short-duration hyperbaric exposures predominate among these divers, although multi-level, repetitive diving by recreational divers, especially among those who use dive computers, has recently changed this diving pattern. Closely-spaced repetitive diving, with its cumulative hyperbaric exposure, increases the risk of DON (Lehner, 1992). Examples of severe repetitive diving, as illustrated by the Japanese shellfish diver's profile, suggest a significant risk of DON. Presumably divers conducting prolonged or saturation dives carry a potentially greater risk of DON than those divers who rarely, if ever, undergo deep, prolonged dives (DCS Central Registry and Radiological Panel, 1981).

Prompt recompression therapy for limb bends, particularly in those patients who describe a deep, medullary pain (Nashimoto and Lanphier, 1991), may be a key element in reducing the risk of DON in diving. Commercial divers in the Gulf of Mexico who breathe compressed air also reportedly have a low DON incidence, and the low DON incidence in this population may be a result of the immediate recompression treatment of those divers who report even mild clinical symptoms of DCS. Under this enlightened policy, divers who receive recompression treatment suffer no financial penalty which would otherwise reduce the frequency of therapeutic recompression in limb bends cases. Indeed, prompt recompression of patients with limb bends may prevent the development of DON.

SHEEP MODEL OF DYSBARIC OSTEONECROSIS

Mature sheep have been used in our laboratory, located in the Biotron at the University of Wisconsin, as human surrogates to test for the risk of DCS and DON from various hyperbaric exposures (Lanphier and Lehner, 1990). Most sheep in these experiments weighed between 80 to 100 kg, comparable to a diver's body weight. We consider body mass of an animal model to be important in scaling physiological responses (Schmidt-Nielsen, 1984) to changes in ambient pressure, because blood flow rates and the other factors which influence inert gas washin and washout rates scale to body mass.

Hyperbaric exposures which simulated diving were tested over a range of durations, from 1/2 to 24 hours, and over a range of pressures from 5.2 to 2.1 atm abs, with the greater pressures in hyperbaric exposures of short duration. All simulated dives have been "square dives," with rapid compression to maximum pressure and no-stop decompression at a rate somewhat less than 1.8 atm/min (< 60 feet of sea water pressure/min).

The most severe DON lesions in sheep were produced in simulated dives of 24-h duration (Lanphier and Lehner, 1990), although DCS incidence was similar across a spectrum of dive durations of 1/2, 1, 2, 4 and 24 h. Hyperbaric exposures of 1/2 to 4-h duration produced relatively mild DON lesions. Sheep marrow and bone lesions reported by Kitano et al., at this meeting, represent DON lesions from these comparatively brief hyperbaric exposures. Lesions of greater severity were produced in sheep by 24-h hyperbaric exposures to 2.5 - 2.8 atm abs, equivalent to approximately 15 to 19 meters of sea water (MSW). These pressures are similar to the maximum pressures illustrated in the diving fisherman profile (Fig. 1).

DON lesions in sheep usually occur in the shafts of the long bones and the fused metacarpals and metatarsals. These bones contain fatty marrow. Bone with fatty marrow is predisposed to DON (Walder, 1991), and for this reason, fatty marrow, with its high N_2 solubility, is strongly implicated in the development of DON. Other bones in the skeleton, typically with more red marrow than yellow, fatty marrow, usually escape DON. DON in sheep appears in roentgenographic films as regions of increased opacities within the marrow and endosteal thickening of cortical bone. Shaft lesions, which normally remain asymptomatic, are the most common form of DON in humans (Davidson, 1976) and in sheep. When DON lesions occur in the ends of the long bones, the ends often collapse and render the DON victim permanently disabled. Pathological findings of such clinical outcomes in divers have been reported by Kawashima et al. (1977, 1978).

In the sheep experiments, a clinically important finding was the induction of subchondral bone necrosis in the joint regions of sheep which underwent twelve to thirteen 24-h hyperbaric exposures. Widespread loss of osteocytes in juxta-articular bone points to osteonecrosis. Necrotic bone in the joint regions often undergoes repair which involves re-vascularization and a structural weakening of the bone which lies beneath the joint cartilage. As the bone remodeling continues, weight bearing can fracture the weakened subchondral bone and collapse the articular surface, permanently disabling the individual.

A histological evaluation of experimentally-induced DON in sheep which underwent relatively brief hyperbaric exposures was reported by Kitano et al. in these proceedings. One of the important histopathological findings of DON in sheep was the progressive calcification of dead fat cells in the marrow. Dead fat cells were replaced by bone, and this calcification process can be evaluated by the non-invasive diagnostic techniques of magnetic resonance imaging (Mitchell et al., 1989), bone scans (Cross, 1991; Gregg, 1989; Galasko, 1989) and x-ray filming. Infarcted fatty marrow, the calcification of dead fat cells, and endosteal new bone formation were prominent findings of sheep DON.

PATHOGENESIS OF DYSBARIC OSTEONECROSIS

In our view, a bone compartment syndrome (Mubarak and Hargens, 1981) which involves bubble formation triggered by decompression appears to be the most likely important pathogenic mechanism responsible for DON (Fig. 2). As the diver breathes compressed air, dissolved N_2 is transported in the diver's blood to the tissues, including bone and fatty marrow of the long bones. A prolonged hyperbaric exposure or repetitive exposures are usually required for bone and fatty marrow to load with sufficient dissolved N_2 to form injurious bubbles upon rapid decompression. In the long bones, the marrow cavity and surrounding cortical bone represent a compartment which contains fatty marrow. Fatty marrow is viewed as a key factor in the development of DON because of the high solubility of N_2 in fat. With rapid decompression, bubbles which form in the marrow occupy space and elevate tissue pressure so that blood flow to the marrow and bone slows or ceases. The ischemia resulting from a sustained bone compartment syndrome results in marrow and bone necrosis (Ficat and Arlet, 1982).

When a diver's breathing gas is compressed air, the role of N_2 solubility in fatty marrow is essential in the development of DON. N_2 is about five times more soluble in fat than in H_2O. H_2

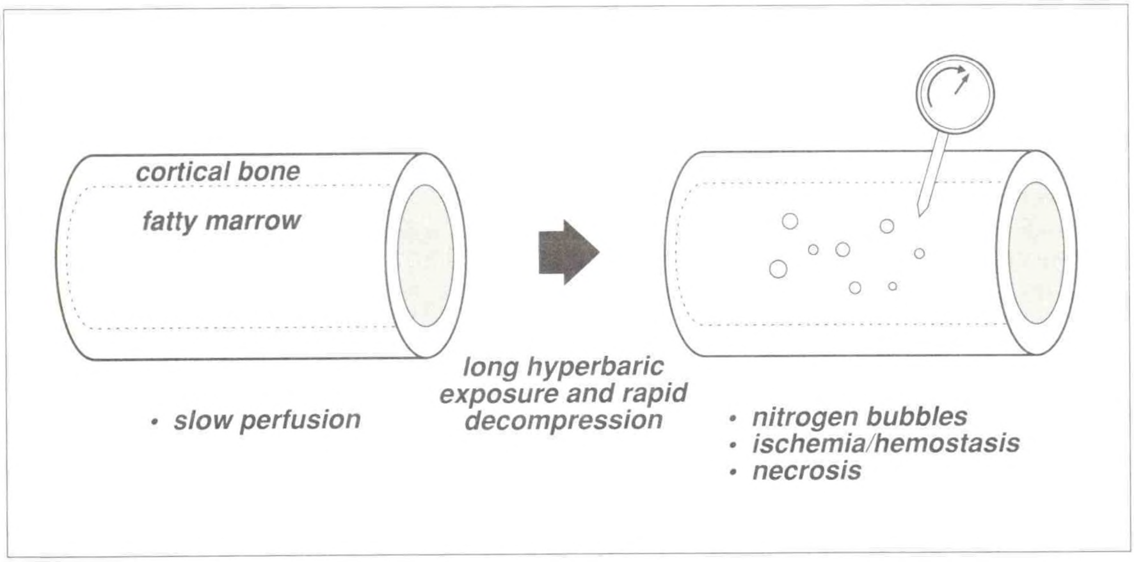

Fig. 2. Proposed bone compartment syndrome in dysbaric osteonecrosis.

and He are both less soluble than N_2 in fat or oil, with H_2 solubility in fat lying between that of N_2 and He (Weathersby and Homer, 1980). On this basis, hydrox (H_2-O_2) diving carries a higher risk of DON than heliox (He-O_2) diving.

Other pathogenic factors may also play important roles in the development of DON in the long bones. These factors include blood sludging and hemostasis with intravascular blood coagulation, mechanical injury to endothelial tissue and other cellular structures, fat emboli (Jones, 1985b), fat cell swelling under hyperoxic conditions (Walder, 1990, 1991), and re-perfusion injury. All of these factors may contribute to the development of DON associated with hyperbaric exposure, but a discussion of these factors lies beyond the scope of this report.

BONE SCAN AND X-RAY FINDINGS OF SHEEP DON

Recent bone scans of DON-affected sheep offered indirect evidence for a bone compartment syndrome in the development of DON. Bone scans provide a measure of bone blood flow based on the rate with which ^{99m}Tc-methylene diphosphonate (Tc-MDP), a gamma-emitting radionuclide, is incorporated into new bone after its intravenous administration. Normal bone undergoes constant remodeling and has a high affinity for Tc-MDP. Where a low blood flow to bone occurs, less Tc-MDP is incorporated into the bone, and an ischemic region will appear as a "cold spot" in a bone scan. We would expect a "cold spot" to occur in a bone compartment syndrome during the early developmental stages of DON, within minutes to a few days after decompression.

"Cold spots," indicating a bone compartment syndrome, were found in decompressed sheep two days after hyperbaric exposure. These "cold spots" later converted into "hot spots." Where a high rate of blood flow to injured bone occurs, the lesion will appear as a "hot spot" in a bone scan. We expect a "hot spot" to occur in the intermediate stages of DON during the repair process when the injured bone undergoes re-vascularization accompanied by rapid remodeling and new bone formation.

Bone scans of those limbs affected by "late limping," a sign of persistent limb bends and a probable indication of a bone compartment syndrome, showed "hot spots" when examined four weeks after the "late limping" episode. It appears that early ischemic regions converted from "cold spots" into "hot spots." An example from an early experiment illustrates the usual appearance of DON lesions in sheep. A mature female sheep (#1828), which weighed 82 kg, underwent five 24-hour hyperbaric exposures at pressures, which ranged from 2.20 to 2.40 atm abs (12 to 14 MSW), over a one-month period. Relatively-mild but sustained "late limping" was frequently seen in this sheep after hyperbaric exposure. Twenty-seven days after the first hyperbaric exposure and two days after the fifth hyperbaric exposure, the left forelimb was scanned. Increased Tc-MDP activity in the distal radius (left bone) appeared to be a probable "hot spot," but the metacarpal (right bone) remained quiescent (Fig. 3). Ninety-five days after the first hyperbaric exposure, the midshaft region of the metacarpal presented with a definite "hot spot." This "hot spot" indicated an active DON lesion. The metacarpal lesion at this site was later confirmed by gross sectioning at necropsy 180 days after the first hyperbaric exposure.

Roentgenographic filming of the tibia from the same sheep (#1828) before and 175 days after hyperbaric exposure revealed a prominent thickening of endosteum along the inner wall of the cortical bone, and there were marrow opacities in the distal end of the bone (Fig. 4). Both the endosteal thickening and marrow opacities observed with this x-ray film indicate new bone formation and tissue calcification. These DON lesions were also confirmed at necropsy.

THE POTENTIAL RISK OF DYSBARIC OSTEONECROSIS

The sheep studies indicate how pressure profiles influence the incidence and the degree of severity of DON. Short to intermediate hyperbaric exposures, up to 4-h in duration, produced DCS in the sheep, principally limb bends. However, these hyperbaric exposures also induced comparatively mild DON lesions. Prolonged, 24-hour hyperbaric exposures, which produced many cases of mild but persistent limb bends in sheep, induced moderate to severe DON lesions, including subchondral bone necrosis. While DON lesions in the shaft of a bone may never cause clinical problems themselves, occasional cases of histiocytic malignancy have been reported to be associated with earlier marrow infarcts in human DON (Kitano et al.,1984; Mirra et al., 1974). The strength of the positive association between DON and bone malignancies remains uncertain.

Epidemiological patterns of DON prevalence and the nature of hyperbaric exposure, especially those of various divers and tunnel workers in compressed air, suggest the strong influence of pressure and duration of hyperbaric exposure on the risk of developing DON. In a graph of hyperbaric exposure duration and pressure, which assumes rapid decompression, potential DON risk increases with greater pressure and longer duration of hyperbaric exposure across a spectrum of hyperbaric exposures (Fig. 5). For example, we estimate a low risk of DON after 24-hour hyperbaric exposures with rapid decompression from pressures less than 2 atm abs. We also estimate a moderate DON risk after 24-hour hyperbaric exposures with rapid decompression from pressures of 2.0 to 2.2 atm abs and a high DON risk at pressures above 2.2 atm abs for 24 hours. As duration time shortens, DON risk will decrease for hyperbaric exposures with the same maximum pressure.

Estimates of DON risk involve a high level of uncertainty, and this uncertainty increases with hyperbaric exposures of

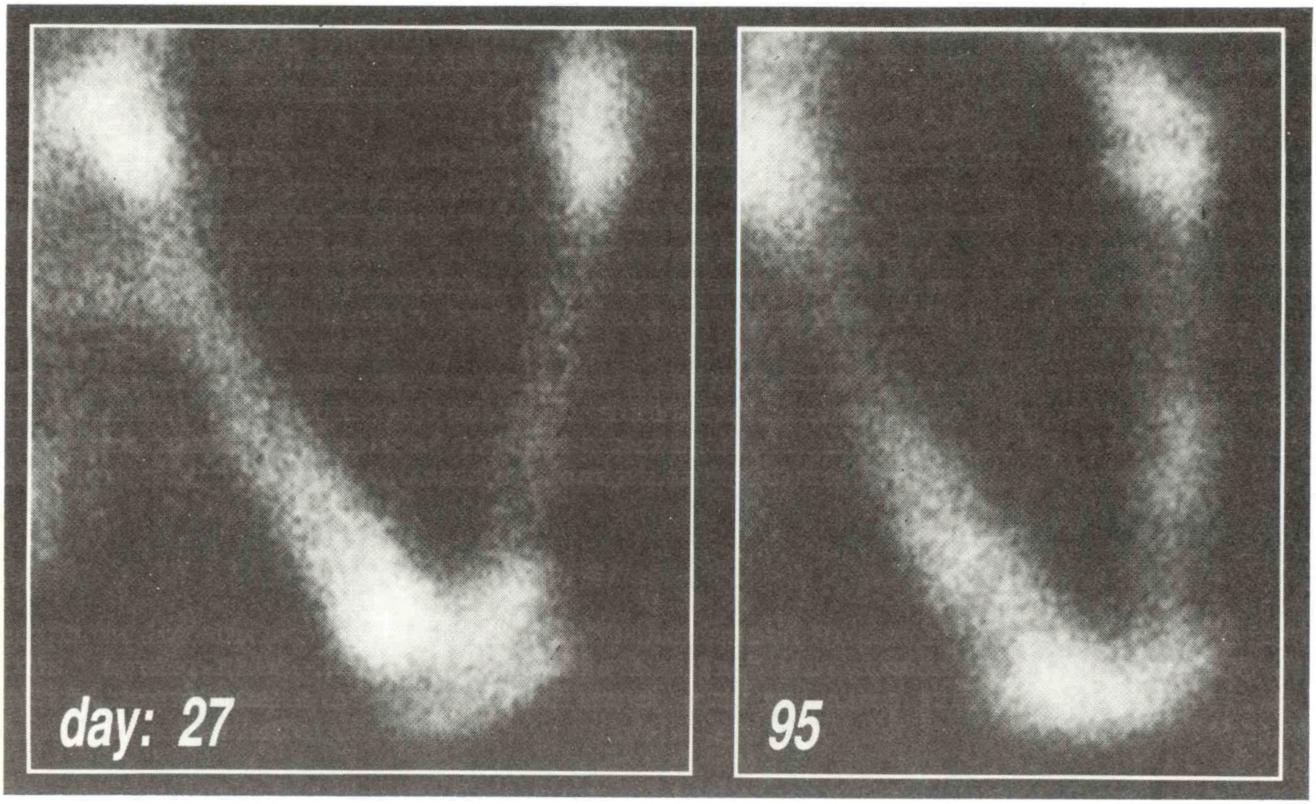

Fig. 3. Successive bone scans of a sheep radius and metacarpal (right) with a "hot spot" indicating a dysbaric osteonecrosis lesion 95 days after the first hyperbaric exposure (Sheep 1828).

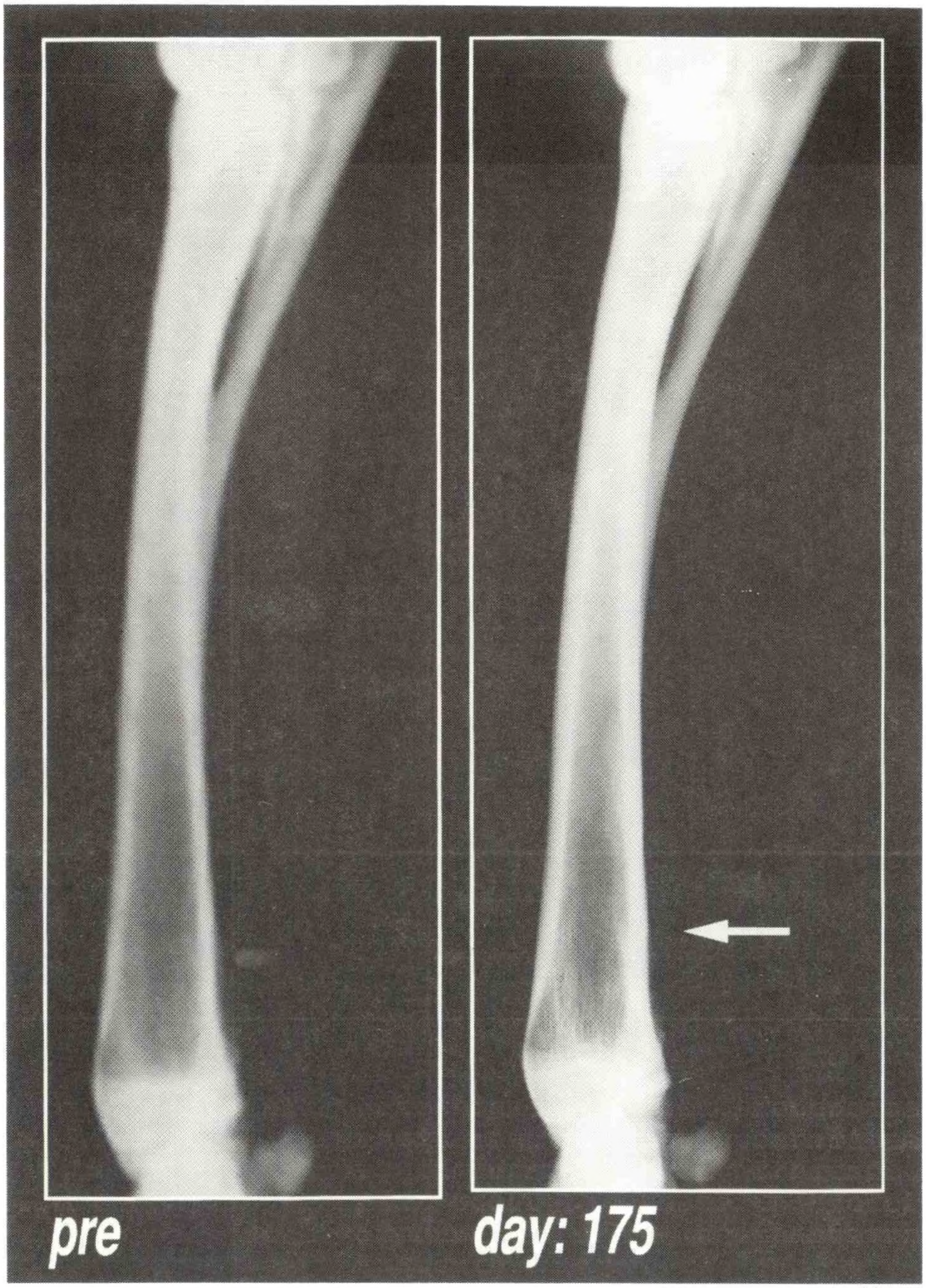

Fig. 4. Roentgenographic films of a sheep tibia before and 175 days after first hyperbaric exposure (Sheep 1828). Endosteal thickening (arrow) and medullary opacities from marrow calcification are prominent indications of dysbaric osteonecrosis in sheep.

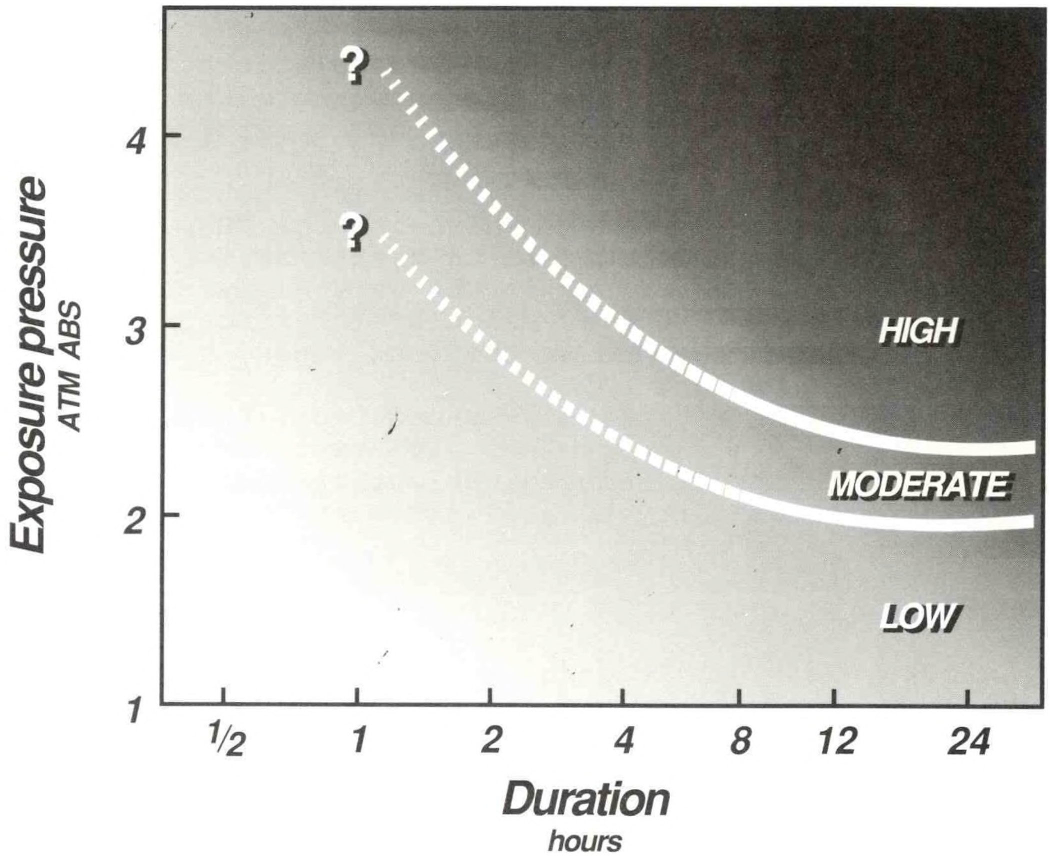

Fig. 5. Potential dysbaric osteonecrosis (DON) risk estimated for the hyperbaric exposure with rapid decompression of humans. Estimated risk of DON is based on the prevalence of DON in humans and in sheep after hyperbaric exposure.

shorter duration. Nevertheless, estimated DON risk is based on empirical data from human and sheep outcomes after hyperbaric exposures, mostly at long times.

CONCLUSIONS

Some patterns in the etiology and pathogenesis of DON are well-known; others have only recently emerged.

- We know that DON is prevalent in some populations of diving fishermen and in those caisson and tunnel workers who use minimal decompression times; in both groups, prolonged hyperbaric exposure is a common factor.
- We hypothesize that marrow bubble formation upon decompression causes a bone compartment syndrome which induces DON.
- We believe that prompt recompression treatment for limb bends may be a key preventive treatment in the very early stages of DON. In our view, prompt recompression treatment can decrease bubble size and tissue pressure in the long bones, relieve deep limb bends pain, and prevent DON.
- We view prolonged dives, closely-spaced repetitive dives, tunnel and caisson work in compressed air, extra-vehicular activities of astronauts at reduced ambient pressure, and habitat saturation exposures as carrying a significant DON risk.

ACKNOWLEDGMENTS

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FIGURES

Fig. 1. Dive profile and surface decompression of a Japanese shellfish diver. "Missed" decompression times are represented by hatched areas.

Fig. 2. Proposed bone compartment syndrome in dysbaric osteonecrosis.

Fig. 3. Successive bone scans of a sheep radius and metacarpal (right) with a "hot spot" indicating a dysbaric osteonecrosis lesion 95 days after the first hyperbaric exposure (Sheep 1828).

Fig. 4. Roentgenographic films of a sheep tibia before and 175 days after first hyperbaric exposure (Sheep 1828). Endosteal thickening (arrow) and medullary opacities from marrow calcification are prominent indications of dysbaric osteonecrosis in sheep.

Fig. 5. Potential dysbaric osteonecrosis (DON) risk estimated for the hyperbaric exposure with rapid decompression of humans. Estimated risk of DON is based on the prevalence of DON in humans and in sheep after hyperbaric exposure.

SAFETY MANAGEMENT OF REPETITIVE NO-DECOMPRESSION DIVING PROFILES USING A SCUBA DATA SERVICE & SAFETY DIVING SYSTEMS (SDS).

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ABSTRACT

A SDS based on U.S. Navy Air Decompression Tables has been developed to enhance military and recreational scuba diver's safety. The SDS consists of five main components; diaphragm strain gauge depth sensor, thermistor to monitor water temperature, 4 bit one-chip micro-computer, external data-ROM and RAM, and Liquid Crystal Display (LCD). Analogue signals from the depth sensor and thermistor are sampled twice per second and sent to an AD converter in the micro-computer. Data of depth, water temperature and sequential time are displayed on LCD through a bi-directional input-output port every second. The PROM (6 K bytes) is used to store system software and the PRAM (256 bytes) is used as a work area. The decompression tables, used for reference, are stored in the external data-ROM (8 K bytes). The dive data is processed by CPU and recorded in the external data-RAM (2 K bytes) every minute. This information is displayed on LCD. The external data-RAM can record dive data for approximately 450 minutes (10 to 20 diving profiles). The recorded dive data can be transferred to another computer for database storage and analysis through a Light Emitting Diode (LED) which converts an optical signal to an electrical signal. For the last two years, SDS has been tested during Underwater Explosive Ordnance Disposal (EOD) operations which use strictly controlled, repetitive, no-decompression schedules. We are planning to improve the SDS for use in complex multi-level and repetitive diving profiles.

INTRODUCTION

Since dive computers follow a diver's exact profile, they need to be more conservative than standard decompression tables. Dive computers allow the diver in multi-level dives to spend time at intermediate shallower depths with no increase in decompression obligation.

Furthermore, by more accurately recording the surface interval and time at depth, the dive computer can more efficiently calculate the appropriate decompression obligation for repetitive diving.

We have developed a dive recorder Model SD-11 (Dive computer) using U.S. Navy Standard Air Decompression Tables, which can record dive profiles, including repetitive diving, over a 24 hour period, and can process data in an external unit to manage and control time-depth log records.

We have reviewed SD-11, to see if it can be used to control the safety of EOD (Underwater Explosive Ordnance Disposal) diving, characterized by no-stop repetitive diving at intermediate depths.

We would also like to report on some improvements now in progress.

METHOD

COMPOSITION OF SD-11

Composition of the dive recorder SD-11 is shown in Figure 1. The underwater depth sensor #101 uses a diaphragm type strain gauge (pressure sensor). The water temperature sensor #103 is a thermistor that uses a temperature dependent resistance changing element.

Analogue signals from these sensors are converted into digital signals by an AD convertor #111 located in the 1-chip micro-computer #110, and transmitted to CPU #113. Sequential time is generated by the timer #116. Information from the operation switches #107 and #108 is transferred to the CPU via input port #112.

These input signals are processed by the program stored in a PROM (Program Read Only Memory) #114 and transmitted through a bi-directional input-output port to a Liquid Crystal Display (LCD) #140. PRAM (Program Random Access Memory) #115 is used to store data provisionally in the working area. U.S. Navy Air Decompression Tables are stored in an external data ROM #120. All information is stored every minute in the external data RAM #130. The external data RAM has sufficient capacity to store all data for 450 minutes.

If any dangerous situation is detected during a dive, then the indication on the LCD will flicker and cause, via the output port #118, the ceramic buzzer #160 to give warning sounds to the diver.

After the end of a dive, all data stored in the external data RAM will be transmitted via the output port to an outside Light Emitting Diode (LED) #170 for transfer to a personal computer.

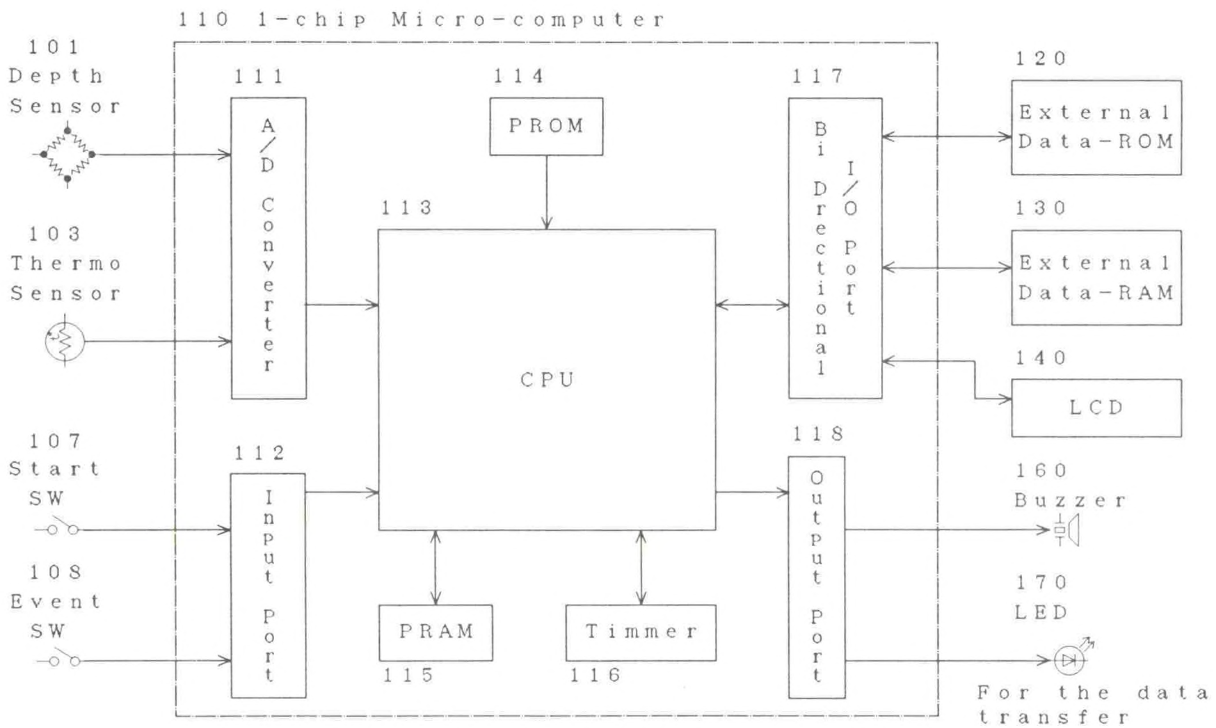


Figure 1. Composition of SD-11.

COMPUTATIONAL DECOMPRESSION TABLE

SD-11 uses U.S. Navy Standard Air Decompression Tables which are the most broadly used schedules in the world. The dive's depth and time, including ascent rate, are tracked so that realtime decompression tables can be calculated. SD-11 can calculate and track data to a maximum depth of 57 msw and a diving time beyond the range indicated in the decompression tables. SD-11 calculates and selects data for the decompression table every second during a dive.

DATA STORAGE SYSTEM

Figure 2 shows the external view of the system. #1 is the dive recorder (Model SD-11) which is brought underwater by a diver, #2 is an optic-electric convertor unit that converts optical signals to electrical signals, and #3 is a computer to process the data.

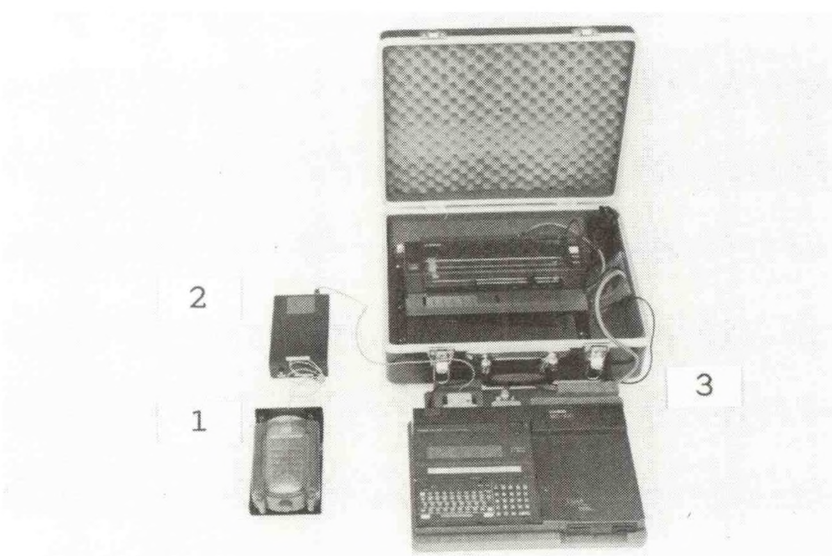


Figure 2. External view of the system.

The profile data is permanently recorded on disk or other recording media. Each profile is recorded under the diver's identification number and subdivided according to date of dive and start time for each dive, as shown in Figure 3.

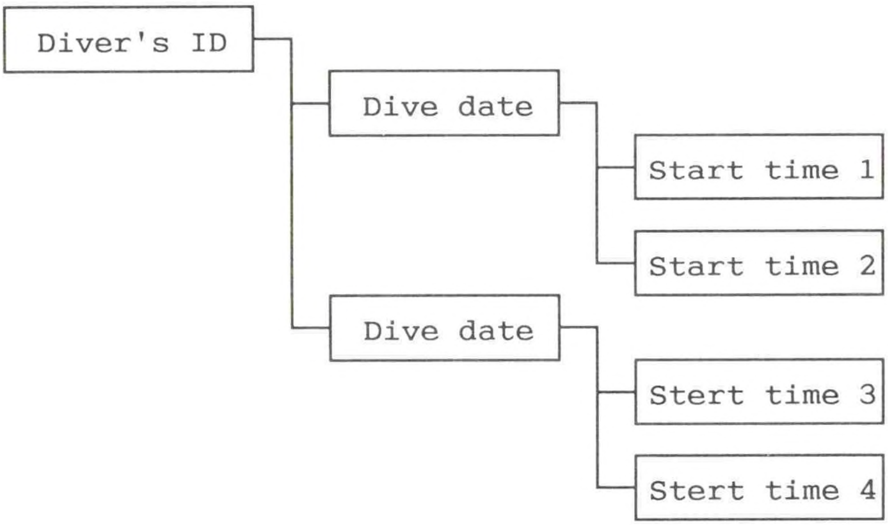


Figure 3. Subdivision of SDS record data.

APPLICATIONS FOR EOD DIVING OPERATIONS.

The SD-11 was used to record diving patterns of EOD diving during MINEX (Mine Sweeper Exercise) performed by the Maritime Self Defence Force in June, 1990, and in February and June, 1991. Average working depth was 41.4 msw in Mutsu Bay of Aomori Prefecture (June of 1990 and 1991) and 17.6 msw in Seto Inland Sea offshore of Yamaguchi Prefecture (Feburary of 1991).

The underwater breathing apparatus used by EOD divers is a Semi-closed Circuit self-contained type (Model ASD-2) using oxygen enriched nitrox breathing medium (N_2-O_2 mixed gas). The no-decompression diving limit is, therefore, greater than that for diving on air. The no-decompression limits at each depth are shown in Table 1.

Table 1. No decompression limits for semi-closed circuit self-contained underwater breathing apparatus.

Actual depth	Mixed gas (O_2 Consumption=1.3L/min)		
	Orifice - 1 O_2/N_2=60/40 4L/min	Orifice - 2 O_2/N_2=40/60 8L/min	Orifice - 3 O_2/N_2=33/67 12L/min
3[m]	- [min]	- [min]	- [min]
6	-	-	-
9	-	-	-
12	-	200 (-)	200 (-)
15	-	200 (-)	100 (-)
18	200 (20)	100 (20)	60 (20)
21	100 (20)	60 (20)	50 (20)
24	60 (20)	50 (20)	40 (20)
27		40 (20)	30 (20)
30		30 (20)	30 (20)
33		25 (20)	25 (20)
36		20 (20)	20 (15)
39		15 (15)	15 (10)
42		10 (10)	10 (10)
45			10 (10)
48			5 (5)
51			5 (5)
54			5 (5)

Note: (n) is the no-decompression limits for repetitive diving.

RESULTS AND REVIEWS

DIVE RECORDER SD-11

Figure 4 shows diving information displayed by SD-11 while diving.

#1 indicates present time; #2 bottom time; #3 maximum depth; #4 current depth; #5 water temperature; #6 maximum depth limit possible to dive; #7 maximum time limit possible to dive at the maximum depth; #8 decompression depth and time; and #9 warnings on ascent rate, battery life, and permission to fly.

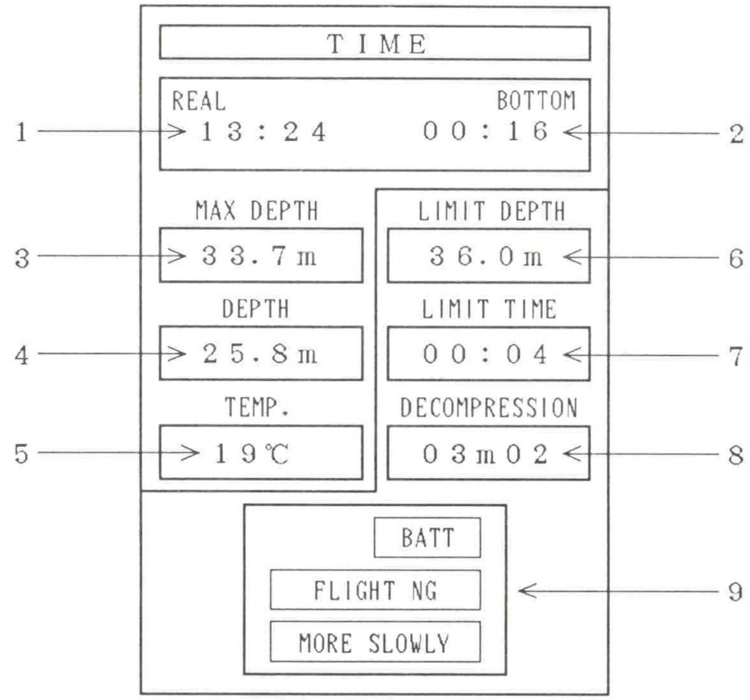


Figure 4. Display data of SD-11 (while diving).

SDS SYSTEM

An example of actual data processed by a personal computer is shown in Figure 5.

Descent and ascent patterns, as well as each change in depth of 1 msw is displayed. Decompression at 3 msw is also shown in correspondence with motion of the diver. Maximum depth is shown as 36.7 ± 0.1 msw.

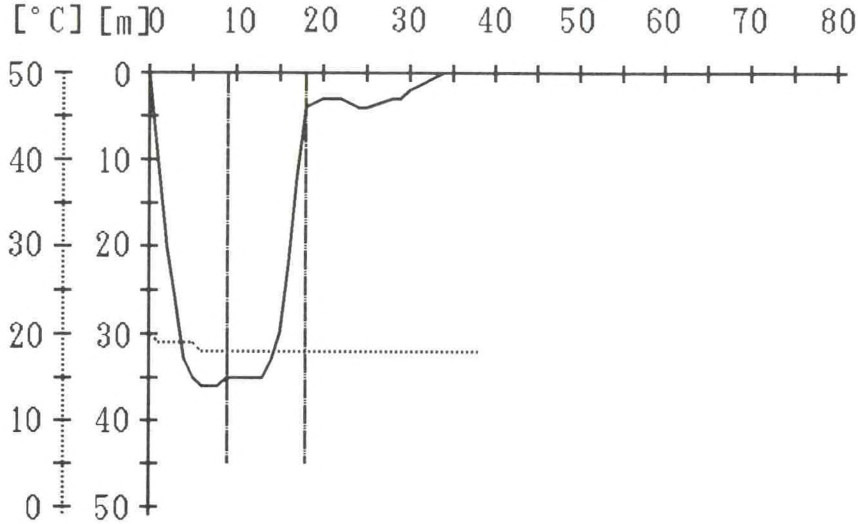
As indicated on the display, the entry time, the exit time and the decompression start time are shown as 11:57, 12:24 and 12:14 respectively.

Maximun and minimum temperatures while diving are shown in Celsius with an error of ± 1 degree.

S D S

Safety Diving System & Scuba Data Service.

1.SDS-ID: TEST1 2.Date: MAY[05]/25 3.Point: Osezaki



4.Interval time: 01:00 5.Maximum depth. : 36.7 [m]

6.Entry time: 11:57 7.Average depth. : 19.9 [m]

8.Exit time: 12:24 9.Tempe.(Max/Min): 20/18 [°C]

10.Bottom time: 00:17 11.[OL] or not[--]: [--]

12.NLOT.------ : 12:05 13.DST.---------- : 12:14

NLOT.=No decomp.Limite Over Time. DST.=Decomp. Start Time.

Figure 5. SDS Dive Log (computer processed data).

SAFETY MANAGEMENT IN EOD DIVING

SD-11 data obtained from EOD is shown in Table 2. It shows bottom time vs depth for 464 EOD dives as recorded by the SD-11.

Table 3 shows the repetitive diving pattern of EOD in the Seto Inland Sea. It shows the range and average depth, bottom time, and surface interval time for 184 dives.

Table 2 The number of EOD dives.

Bottom Time [min]	Depth [m]										
	15	18	21	30	33	36	39	42	45	48	Total
2	-	12	-	-	4	2	6	28	22	-	74
3	-	23	2	2	-	6	10	58	64	8	173
4	-	49	7	-	-	-	4	20	14	-	94
5	2	23	4	-	-	-	2	4	16	6	57
6	-	20	4	-	-	2	-	2	-	-	28
7	-	6	-	-	-	-	-	-	-	-	6
8	-	6	1	-	-	-	-	-	-	-	7
9	-	6	5	-	-	-	-	-	-	-	11
10	-	-	2	-	-	-	-	-	-	-	2
11	-	-	1	-	-	-	-	-	-	-	1
12	-	4	-	-	-	-	-	-	-	-	4
14	3	-	-	-	-	-	-	-	-	-	3
18	-	2	-	-	-	-	-	-	-	-	2
19	-	-	2	-	-	-	-	-	-	-	2
Total	5	151	28	2	4	10	22	112	116	14	464

Table 3. Repetitive diving pattern in Seto Inland Sea.

	1-st Dive	2-nd Dive	3-rd Dive	4-th Dive	5-th Dive
Number of Samples	86	64	25	8	1
Average Depth[m] MIN-MAX	17.26 15 - 19	17.75 15 - 21	17.72 15 - 20	17.5 16 - 18	18.0
Average Bottom Time[min] MIN-MAX	6'05" 2' - 18'	5'06" 2' - 19'	4'40" 2' - 11"	4'00" 2' - 6'	4'00"
Average Interval Time[min] MIN-MAX	286 22-565	126 13-564	140 48-261	20	

The maximum number of dives made in a 24 hour period was 5. The data from this repetitive dive was processed by a Casio pocket computer Model PB-1000 and the dive profile obtained is shown in Figure 6.

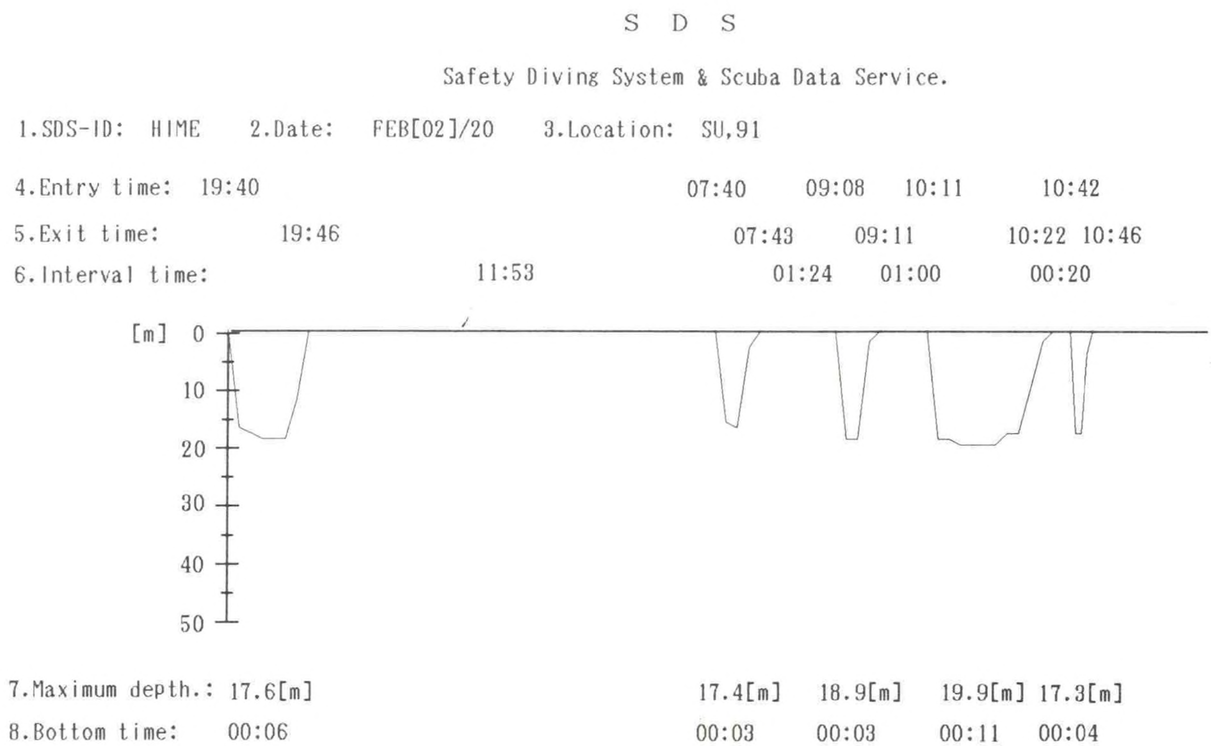


Figure 6. Diving profile of EOD diving in Seto Inland Sea.

The entry time, exit time, surface interval time, maximum depth and bottom time are recorded.

REVIEWS

At the 10th UJNR meeting, R.W. Hamilton reported on a Dive Computer Workshop conducted by the American Academy of Underwater Science.

He made suggestions on the effectiveness and applications of dive computers. A summary of manufacturer's proposals for future models was presented. Recommendations for the next generation of dive computers included;

The ability to use enriched air nitrox and oxygen decompression.

Recording of dive profiles, and capability to download to a computer.

Must not shut off (or discontinue decompression calculation) during a dive, even if diver violates.

The ability to adjust the conservatism of the computational model.

A common decompression algorithm (generally agreed on as desirable, but regarded by most as not a practical goal).

EOD dive profiles proved to be the most appropriate for evaluating future dive computer models.

The SD-11 model uses U.S. Navy Standard Air Decompression Tables, thus it cannot be applied to oxygen enriched nitrox decompression used by the SCA (Semi-closed Circuit self-contained underwater breathing Apparatus) in EOD diving. However, almost all cases of repetitive diving have fallen within the no-decompression limit as calculated by equivalent air depths. Among a few cases, diving after the third repetitive dive required some decompression at 3 msw. However, even oxygen enriched nitrox may require the same decompression as air diving at a depth greater than 42 msw.

The external data RAM has a capacity of about 450 minutes. This is sufficient for repetitive diving for 2 - 20 minutes at a depth of 15 - 48 msw, and allows the dive profile and decompression requirements for a 24 hour period to be evaluated.

EFFORTS AT PRESENT

It has been shown that EOD dive profiles consist primarily of "square" dives. We have finished an improved prototype model that may be used in "multi-level" diving. The algorithm used in the prototype is based on U.S. Navy Standard Air Decompression Tables using tissue M values with decompression calculations conducted every one second.

Future plans include improvement so that the model can be used for SCA, and compute decompression calculations for oxygen enriched nitrox diving.

Decompression calculations for SCA using oxygen enriched nitrox cannot be regarded as simple, because nitrogen content in a diver's air is dependent on the oxygen consumption by the diver. We obtained equivalent air depth values with an oxygen consumption of 1.3 liter per minute. If we can measure the oxygen content in the circuit of an underwater breathing apparatus, then an efficient decompression calculation can be computed for repetitive multi-level dives using nitrox.

A target for future development is to find a decompression computation process for oxygen enriched nitrox diving.

SUMMARY

By applying SD-11 to actual EOD dives, we have shown that model SD-11 helps promote diver safety, especially in divers performing repetitive no-decompression dives.

Data from the dive will be stored on the hard disk drive of a personal computer. This data will not only be useful for maintaining the diver's history and evaluating the diver's training, but in determining a treatment schedule for any decompression difficulties that may develop.

The dive recorder SD-11 we developed is an unique dive computer. It is useful as an Automatic Dive Log (ADL) and will contribute greatly to diver's safety. We will continue to develop and improve upon this model.

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THE NAVAL MEDICAL RESEARCH INSTITUTE (UNITED STATES)
TEAMS WITH THE
DEPARTMENT OF HYGIENE, SAITAMA MEDICAL SCHOOL (JAPAN)
TO INVESTIGATE

"THE UTILITY OF DIVING MEMORY RECORDERS FOR DIVING RESEARCH"

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ABSTRACT

In June, 1987, at the "Thirty-sixth Workshop on Decompression in Surface-Based Diving" in Tokyo, Japan, Captain E.T. Flynn, MC, USN and Mr. D.R. Chandler became interested in a Diving Memory Recorder (DMR) developed by the Department of Hygiene, Saitama Medical School in Japan. They arranged for a loan of ten of the devices to determine their utility as a tool for gathering real time data on free swimming U.S. Navy divers.

After receiving superb training by personnel from Saitama Medical School, U.S. Navy investigators from the Naval Medical Research Institute (NMRI) began what evolved into a three year study of the devices. The DMR's were utilized in chamber dives, short and long bounce dives, equipment dives, recreational dives, and during classified operations.

There is no question that DMR's are extremely useful devices for gathering research data on free swimming divers. In the course of the study, investigators found they are also valuable as a debriefing tool for on-scene commanders of diving operations and as an assist during training evolutions. The response in the Fleet was overwhelming approval by commanders and divers alike.

Throughout the study, personnel from the Department of Hygiene, Saitama Medical School, were available for consultation and advice when needed. This study is an excellent example of how international cooperation can mutually benefit participating countries.

INTRODUCTION

The U.S. Navy's diving medical research community has for many years longed for the capability to gather real time data on free swimming divers. The reason is obvious when one interviews a diver after a prolonged multi-depth dive. For example, one might hear,

> "After about three hours of transit on the craft (at unknown but multi-level depths), I was swimming at about 30 feet for about eighty minutes, then surfaced to look around. After about two minutes at the surface, I submerged to about 20 feet and continued at that depth for about fifty minutes to the target area. The target was at 50 feet, I think; so I dove to the target, did my thing, which took about two minutes, and then returned to my pre-determined pick-up point....and, here I am. By the way, Doc, my shoulder hurts. Think I'm bent?"

This rather ludicrous sounding scenario is not only close to the mark, it hits the mark when one considers the data gathering problems investigators experience during field operations with free swimming divers who are engaged in full mission profiles. A device is needed to track our divers so that an accurate database can be established which can be accessed to develop good, and reasonably safe, decompression profiles for multi-level dives.

In June, 1987, Captain E.T. Flynn, MC, USN and Mr. D.R. Chandler attended the "Thirty-sixth Workshop on Decompression in Surface-Based Diving" in Tokyo, Japan. They became much interested in a device presented by Dr.'s I. Nashimoto and Y. Gotoh of the Department of Hygiene, Saitama Medical School, Saitama, Japan. The device was referred to as a "Diving Memory Recorder (DMR)."

The DMR is carried by a diver and will store depth data, every second, in random access memory (RAM) for as long as 16 hours. When the dive(s) is completed the RAM can be downloaded into a computer (laptop or desktop) and stored on disk. The data can then be accessed for study or to print out an exact depth profile.

Upon returning to the United States, Captain Flynn and Mr. Chandler arranged with Saitama Medical School for a loan of ten DMR's to be used by the U.S. Navy. The purpose was to determine the utility of the device in gathering real time data on free swimming divers. Through the mechanism of invitational travel orders, they requested expert assistance in teaching U.S. Navy personnel the intricacies of the DMR operation.

Dr. R. Araki and Mr. K. Kobayashi were kindly given permission to visit the Naval Medical Research Institute for a period of two weeks. During these two weeks, they taught Mr. D. Schoenauer and Mr. P. Karnik the operation of the DMR's; these two then became the U.S. Navy's experts on DMR operation and personally transported them into the field to conduct operational tests.

The Naval Medical Research Institute had the DMR's for almost three years and utilized them in many different dive operations. They were used during short and long bounce dives, equipment dives, recreational dives, and during classified missions. Good care, akin to motherhood, by Mr. Karnik kept the DMR's operational and available when they were needed.

TECHNICAL DESCRIPTION

The DMR's tested by the Naval Medical Research Institute (US) can be described as a cylinder approximately six inches long with a diameter of three and one-half inches. Coupled with a computer (laptop, in this case), one has a system of recording a depth and time profile of a free swimming diver. The DMR's small size caused them to be unobtrusive when worn by U.S. Navy Special Warfare divers.

The following is excerpted from the paper "A Dive Profile Recording System," (Nashimoto, Gotoh, and Kobayashi - 1985)

> "The data on dive profiles are stored in the random access memory (RAM) of the DMR. It can record up to 16 hours of dive profiles. After the final dive, the DMR is connected to a hand-held computer through the interface. The data stored in the RAM are read out and transferred to the hand-held computer...."

To reduce power consumption, electric current to the pressure sensor and its peripheral circuit is supplied only while the A/D converter is processing the signal (5 msec/sec).

The DMR's are equipped with a CMOS 8 bit microprocessor (Z80) CPU, a 1 MHz clock, 8 KB of CMOS ROM, 16 KB of CMOS SRAM, the I/O is RS-232C 1 channel (4800 BPS), the A/D converter has 8 bit resolution with 1 channel and the maximum data points is 10,000. The DMR is powered by a Ni-Cd 1.2V x 4 (rechargeable) battery that is capable of 100 hours. The pressure sensor, one of its most critical parts, is a KPZ-11G, manufactured by Philips. The DMR's tested by the U.S. Navy had a depth limitation of 160 fsw (see Figures 1 and 2).

THE INVESTIGATION

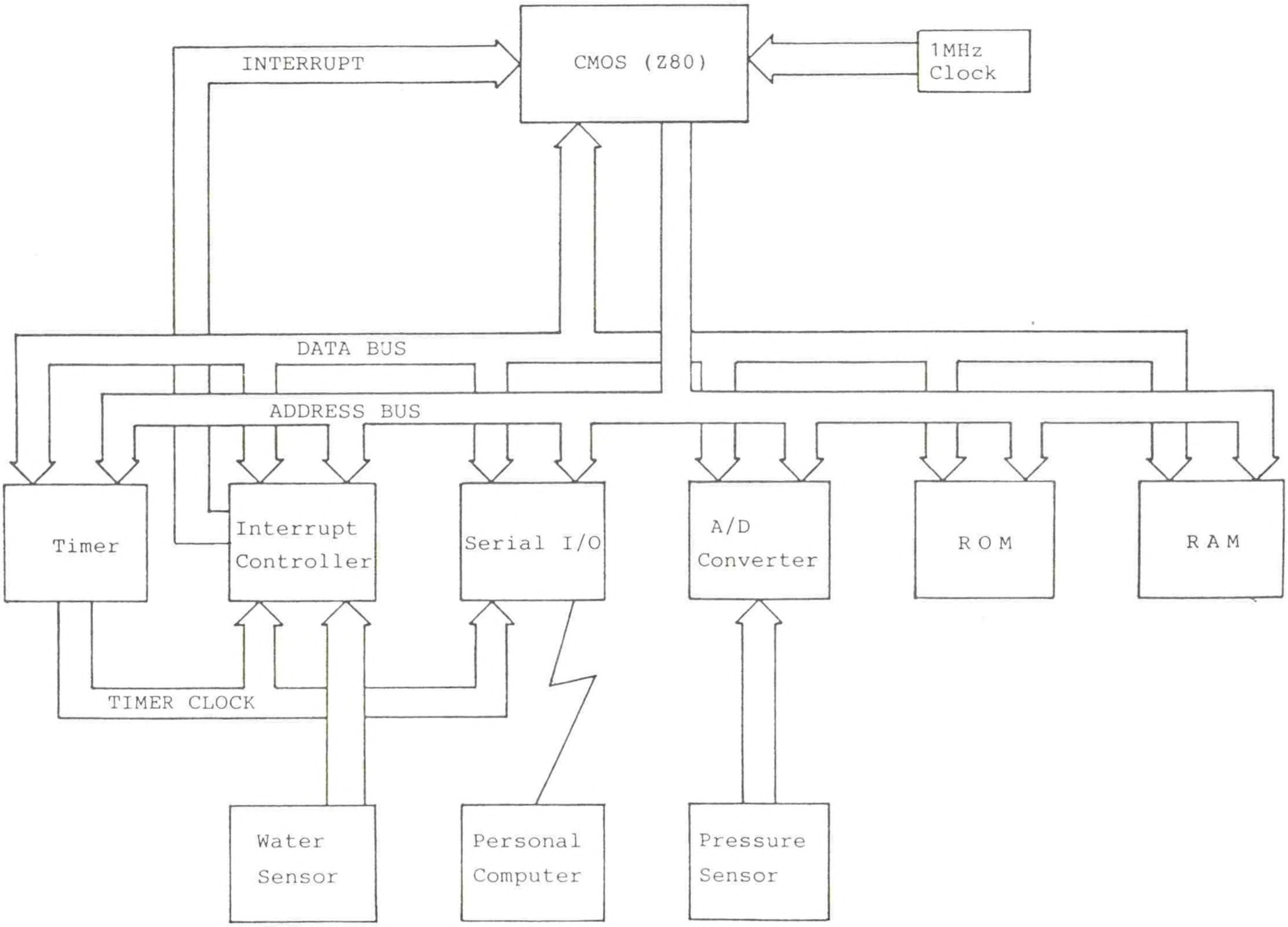
Dr. Araki and Mr. Kobayashi's first tasks upon arriving at the Naval Medical Research Institute was to recalibrate the DMR's to 1 fsw vice 1 msw per bit, translate the Japanese software into English, and teach U.S. Navy representatives how to care for and operate the devices. Their work was superb, to say the least.

Armed with the knowledge gleaned from two weeks of training, Mr. Schoenauer took the DMR's on a classified operation with U.S.

Figure 1 Specification of the DMR

CPU:	CMOS 8 bit Microprocessor (Z80)
Clock:	1 MHz
ROM:	CMOS ROM (8 KB)
RAM:	CMOS SRAM (16 KB)
I/O:	RS-232C 1 channel (4800 BPS)
A/D Converter:	8 bit resolution, 1 channel
Max. data point:	10000 points
Battery:	Ni-Cd 1.2V x 4 (Rechargeable), 100 hrs
pressure sensor:	KPZ-11G (manufactured by Philips)
Max. Depth:	160 FSW

Figure 2 Block Diagram of the DMR



Navy Special Warfare divers where he was given full cooperation by the on-scene commander.

Fully charged DMR's were prepared for each dive by clearing memory and synchronizing the internal clock with the clock on the host computer (in this case, a laptop). This was done shortly before each dive and performed by connecting individual DMR's to the laptop and running the menu driven control software. The interface outlet on the DMR's were then capped to make them watertight. The DMR was attached to the diver's weightbelt where it remained until the diver returned from the mission.

Each DMR was equipped with a water activated sensor, thus when a diver entered the water the DMR began recording time and depth data once each second. To conserve available computer memory space, the depth of each second is compared with the depth of the previous second and if there has been no change, the new depth is not written into memory.

When a diver leaves the water, the water activated sensor reads the activity and turns off the device. If the diver reenters the water, the DMR will record the new data as a new dive. The new data is stored in memory after the data from the previous dive, vis-a-vis recording over the previous data.

During this study, the DMR was downloaded into a laptop computer at the conclusion of each dive following menu driven software and stored on disk in a file created by the user. The software also provided graphic display of the data in sixty minute segments (ten minute enlarged segment if needed) for immediate review. This latter feature was of particular value to the on-scene commander(s). The accurate profile of where the diver had been, with respect to time and depth, left no doubt in the commander's mind as to whether or not the mission had been accomplished as planned.

Once stored in the laptop, the data could be reviewed at any time by simply using the appropriate option on the menu of the control software. The data could also be transferred to any analysis program in the form of ascii characters by converting the coded hexadecimal number representing the A/D converter reading.

RESULTS

Figures 3 and 4 show two different dive operations, each recorded in four sixty minute segments. Thus one must put the four pages together to see the full profile in one view. These are only representative profiles and show the accuracy of recorded data. During the several days of classified operations, Mr. Schoenauer was able to give the on-scene commander immediate feedback as to depth and time each diver was in the water.

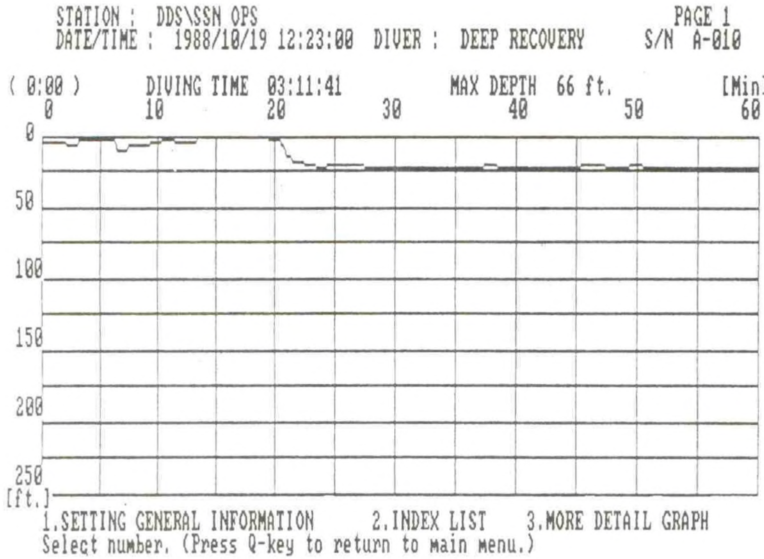


Figure 3 - Page 1

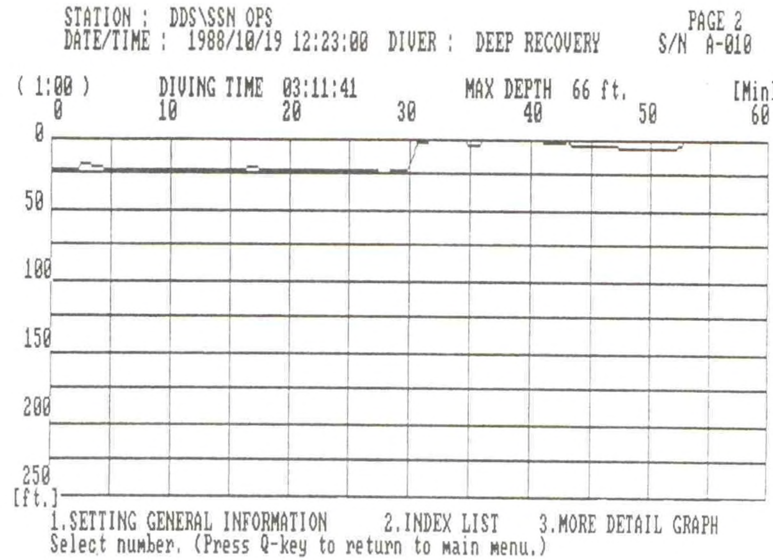


Figure 3 - Page 2

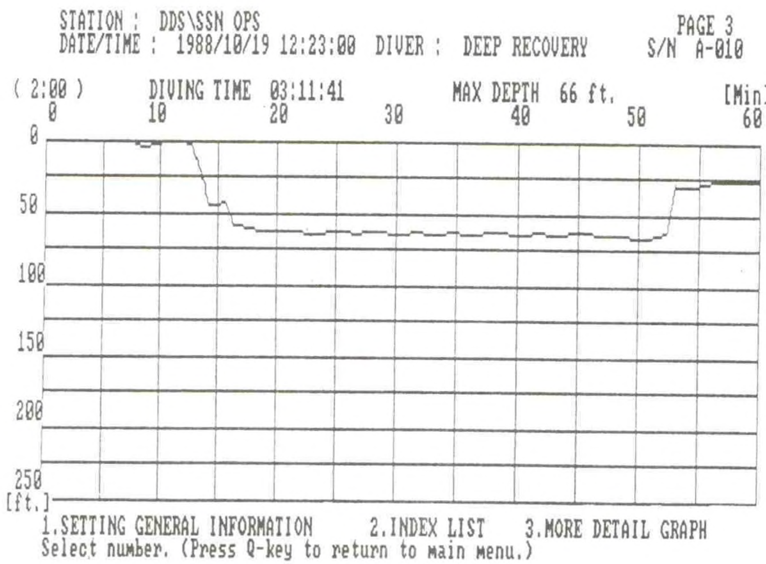


Figure 3 - Page 3

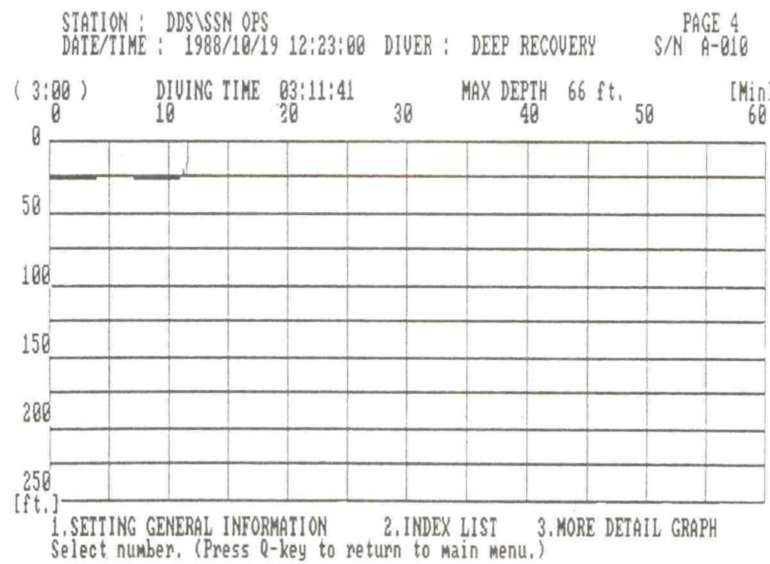


Figure 3 - Page 4

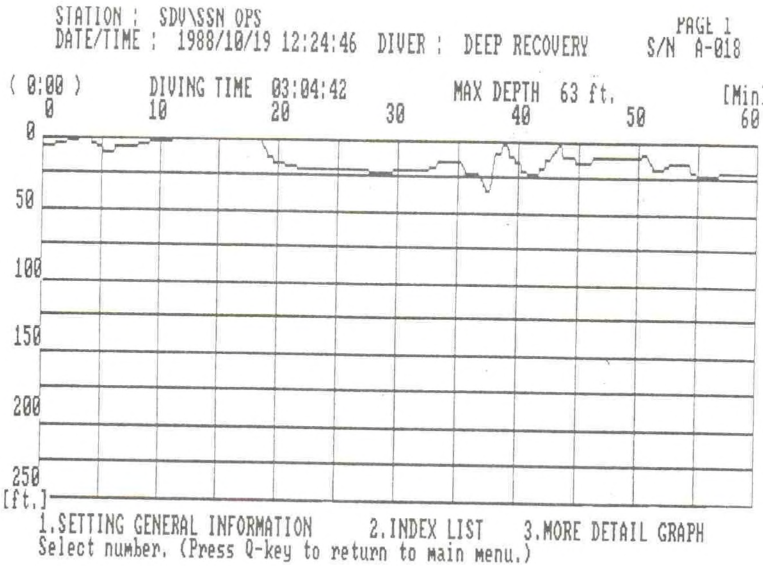


Figure 4 - Page 1

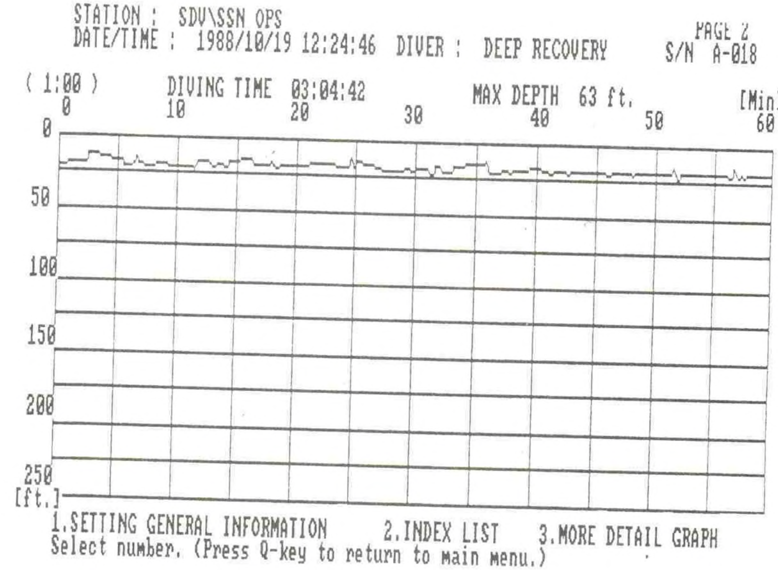


Figure 4 - Page 2

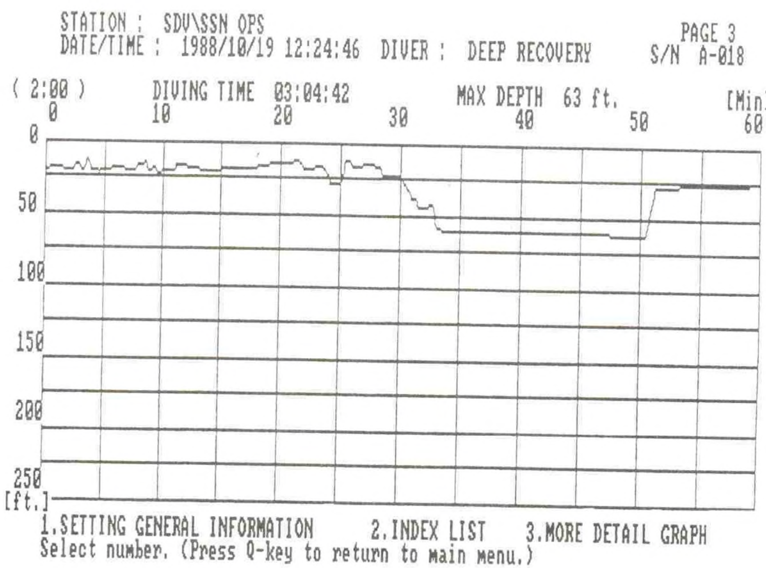


Figure 4 - Page 3

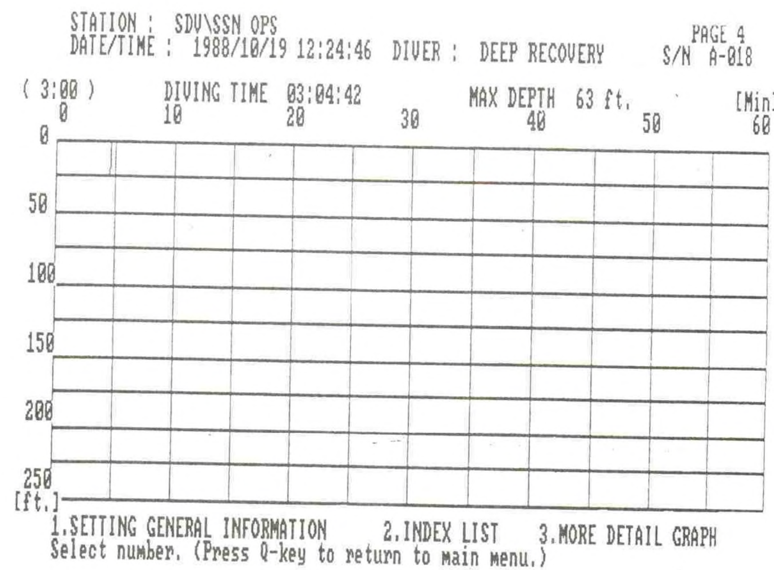


Figure 4 - Page 4

The reaction in the Fleet was unanimously positive from the on-scene commanders as to the high value they would place on such a device should they become SOP for Special Warfare divers. The reaction from the divers was negative at first blush because the last thing they wanted was one more device to carry around; however, by the time the first mission was concluded and they were debriefed, they echoed the on-scene commander's view. During subsequent missions the divers gladly strapped on the DMR's.

The data gathered by the DMR's was later studied at the Naval Medical Research Institute and was instrumental in developing mathematical profiles for decompressing from a multi-level dive. This profile underwent validation in a series of dives at the Navy Experimental Diving Unit. It is expected that the results will be in the form of a revision to the U.S. Navy Diving Manual.

CONCLUSIONS

Because this study was limited to a few chamber dives, a few recreational dives, and two classified operations, the full potential of DMR's was hardly touched. There was enough evidence, however, to convince investigators that DMR's, or like devices, are invaluable tools in gathering real time data from free swimming divers; particularly for research purposes.

As alluded to above, DMR's would be valuable to on-scene commanders of diving operations; whether they employ free swimming divers or surface supported divers. Also, the data from DMR's would be extremely useful to physicians who conduct post-dive examinations and for those who must diagnose decompression sickness.

A new generation of DMR's is needed. Miniaturizing the device to make it less cumbersome, a water temperature readout, and a scale graduated in five feet increments would also be helpful.

SUMMARY

The Naval Medical Research Institute teamed with the Department of Hygiene, Saitama Medical School to investigate the utility of Diving Memory Recorders for diving research. After using the devices during several U.S. Navy diving operations, it was concluded that they are an extremely useful device. So useful, in fact, that the Naval Medical Research Institute has ordered several to be fabricated for use in gathering real time data on free swimming divers. It is envisioned that future generations of DMR's will be widely utilized by U.S. Navy divers both for training evolutions and during full mission operations.

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Recent diving profile of shellfish divers at Ariake sea

Yoshihiro Mano, Masaharu Shibayama (Tokyo Medical & Dental University)
Mahito Kawashima (Kawashima Orthopedic Hospital)
Yasushi Taya, Motohiko Mohri (JAMSTEC)
Charles E. Lehner (University of Wisconsin-Madison)

There has been high incidence of aseptic bone necrosis on shellfish hermet divers at Ariake Sea in Kyushu area, and it is due to their reckless diving profiles, especially their decompression procedure after bottom works. According to this background, we have investigated their actual circumstances by using ADL (Automatic Diving Log) three times during these two years (Feb. 1990, Feb. and March 1991). There were recorded their actual diving profiles of 36 times in February 1990 from 6 divers and of 16 times in 1991 winter seasons from 19 divers, the Doppler sound records from 3 divers in 1990 and 6 divers in 1991, and we could gather questionnaire answers from 83 divers in 1991.

This work shows us that recent diving profile at Ariake Sea has remarkably been improved than the before, however the risk of DCS and bone lesion still remains.

BACKGROUND

Helmet fishermen divrs at Ariake Sea have engaged in catching shellfish called Tairagi since 1920 and the techniquewere introduced from Korea. The Japanese divers had started the work to pick up shellfish from the bottom since 1934 and all divers before the age we re Korean divers. They had taught the diving technique to Japanese, however they had not taken care of decompression procedure to prevent DCS. They must dive deeper to deeper eventually to keep their work in each year. Their diving depth had been 10 to 15 meters in earlier ages but increased in 50 to 60 meters. Type two DCS and bone lesionh ad been recognized in 1960's and especially the incidence of bone lesions became to 60 % in Ariake divers. The fishermen's Union had dicides to decrease their bottom time and limited their working time from 8:00 to 16:00 in 1972. There were no restrictions before 1971. It had been from 9:00 to 13:00 in 1973 and has been changed from 9:00 to 12:00 in 1977. The diving depth has gradually been changed to shallower recently because of preventing the indiscriminate fishing according to the shorter working time.

So, it would be sonsidered that this rsarch results are quite different from the before actual status.

METHODS

There have been near 400 helmet divers engaged in shellfish diving at Ariake Sea and twenty divers were randomly chosen as subjects for this resarch work by the Fishermen's

fore starting this work, many discussions had been repeated with fishermen's
ome chief divers for an agreement. A previous arrangement were set up the
live works to carry data collections smoothly.
iirs on dive history, health check, DCS and so forth were distributed to 100
s and collected 83 from them. The withdrawal of answer were done by the
s Union and analysed at our laboratory.

Diving profiles have been recorded by Adnis Diving Data Recording System (Automatic Dive Log) which has been developed by our laboratory since 1984.
This diving recorder has the property to record both the depth of 10 cm depth difference and water temperature continuously until 960 min (16 hours) from the surface to 99 m depth. This ADL is highly efficient with a good performance (Fig. 1).

Fig. 1.

Photo of ADL

Divers has been equipped a ADL recorder on his waist just before dive work. This ADL can record their diving depth and water temperature continuously for 960 min between the surface and 99 m depth and can describe the diving profile within 10 cm of the defference.

ADL was attached to each diver's waist before diving and collected after their work in each day. The data were analysed in each case and put back to each diver with comments and suggestion for safety diving (Fig. 2).

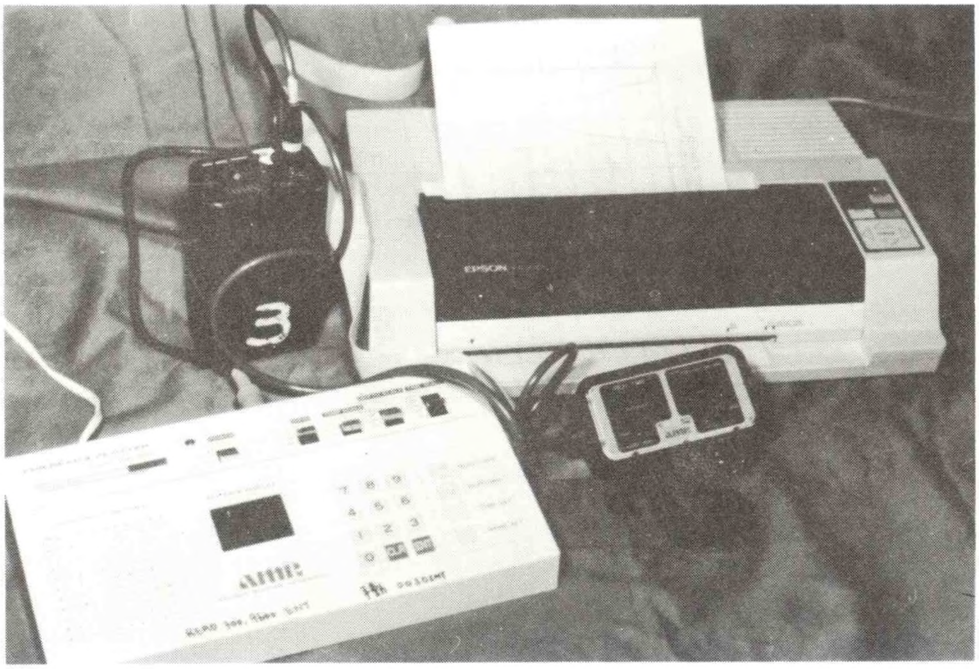

Fig. 2. System of ADL

Black box (number 3) is a diving recorder (the same ADL on Fig. 1), white box under left side is an information adapteor, a small goggles type box is a digital display and the biggest box is a color printer plotter.

RESULTS

There were few shellfish at Ariake Sea in 1990, so they had dived at Setouchi Sea in Hiroshima prefecture. Three divers had been followed in February, 1990 and there had been collected 36 different diving profiles by ADL. At the other area like as Setouchi Sea, there are no restrictions of working time, so Ariake divers had dived from sunrise to sunset. This dive frofile at Setouchi Sea would be a same style in previous years at Ariake Sea before 1971. Fig. 3 is an example of ADL at Setouchi Sea dive work. He is T.K. (32 year old). This profile was taken February 17, 1990. He started to dive at 7:27 and finished his dive work at 16:27. The depth was fortunately shallow within 14 meters, however had to continue his dive for 9 hours. He could have a rest time only twice at 11:00 for 20 min and 13:30 for 45 min. He repeated 8 times in one day and his actual dive time was 478 min but he had no decompression time in every dives because his mean depth was 9 meters.

ダイビングレコーダ No. 4 川下 武則 調査実施日：1990年2月17日

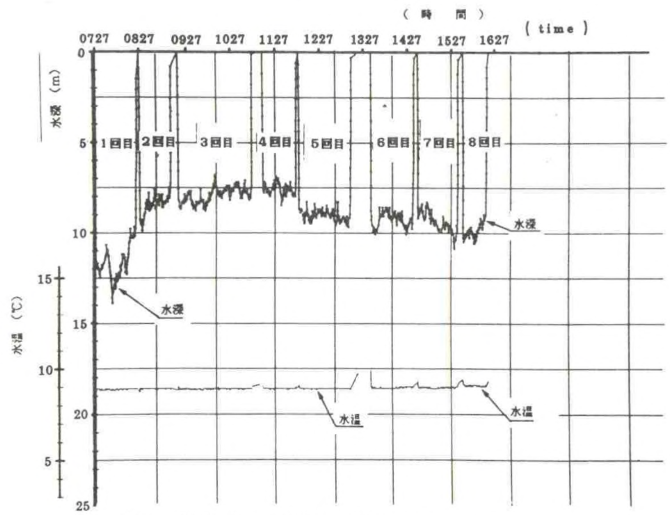

図 4 ダイビングレコーダで記録された潜水プロフィール（ADR：No.4、川下武則）

Fig. 3.

A sample of ADL. He dived eight times on Feb. 17th, 1990. His depth was shallow, so he could keep away from DCS fortunately. Water temperature was 18.7 ℃.

Fig. 4-1 is another case of same day of H.K. (41 years old). He dived at a different deeper point area at Setouchi Sea. He began to dive at 7:55 and finished his fifth dive at 16:04. He dived at 23 meters depthat the third dive for 75 min and he had selfish decompresion time a little bit at 10 meters depth according to his judgment of necessity. His working time was 489 min (8 hours and 9 min). His forth and fifth dives had meaning both of working time and decompresion. He had decided these diving procedures under 10 meters depth during his third dive to prevent DCS. Dive depth had been different in each day and it must dependupon shellfish habitation areas.

ダイビングレコーダ No. 5 橋本 英紀 調査実施日：1990年2月17日

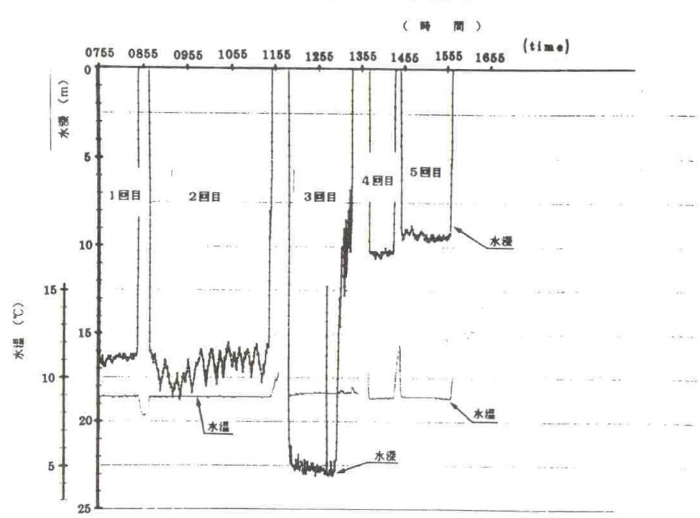

図 5 ダイビングレコーダで記録された潜水プロフィール（ADR：No.5、橋本英紀）

Fig. 4-1.

Another case of the same day. He dived 5 times a day He needed his decompression from his second dive. It was shown on Fig. 4-2.

was another case which had been used deck decompression chamber after his

He worked 8 hours from 7:35 to 15:35. He did his first dive at 16.5 meters 8 min and changed his dive point but at the same depth after 12 min from the

He had never surfaced for 309 min andhe continued his third dive of 90 min in after his second dive. He entered into an inferior deck decomression ig. 6) for surface decompresion but this decompression table was also selfis al, which was shown as forth dive profile on Fig. 5-1.

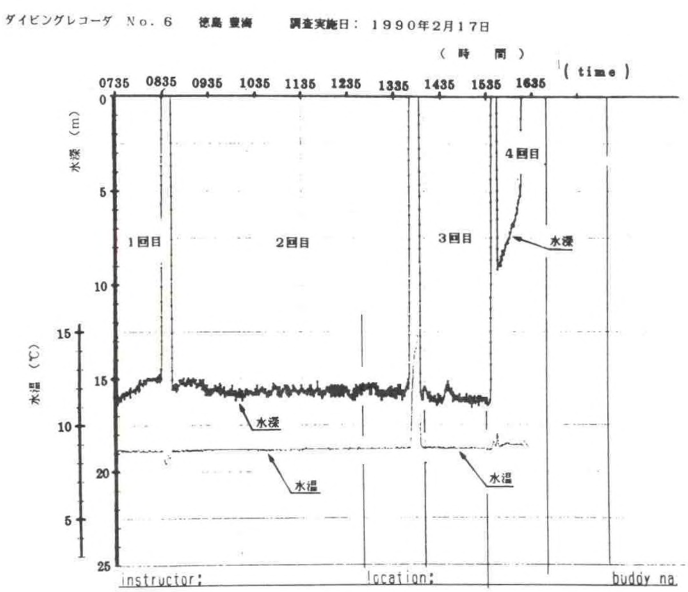

Fig. 5-1.

He dived three times at 16 m depth for 8 hours and used deck decompression chamber after his dive work and this dive profile shows all of them.

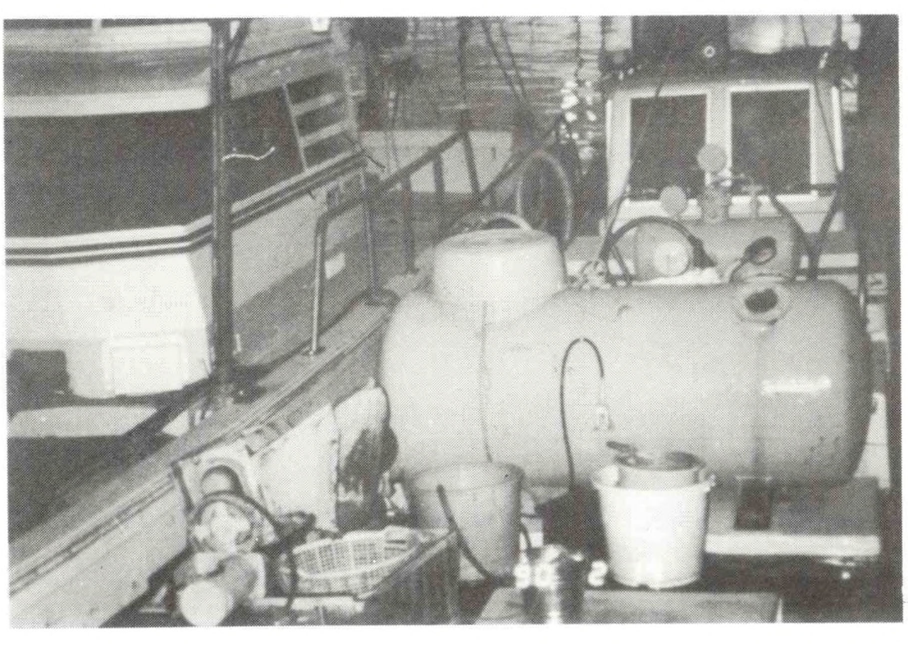

Fig. 6.

A photo of deck decompression chamber in which he had entered. He had learned the technique at Ariake Sea though it was wrong.

Every dive profile except Ariake Sea has similar tendency for shellfish divers, but they must have obeyed the Union's regulation on bottom time of three hours per day since 1977. They can only dive from 9:00 am to noon at Ariake Sea.

Fig. 7 is a case of Ariake Sea area. N.A.(33 years old) started to dive at 9:05 on February 10, 1991. His dive time was 185 min, mean depth was 15.2 meters (maximum was 15.5 m) and sea water temperature was 10.5 ℃. He had only 6 min rest time during the dive and did no ascent time though he needed decompresion of one min. at 6 m and 69 min at 3 m according to USN diving manual.

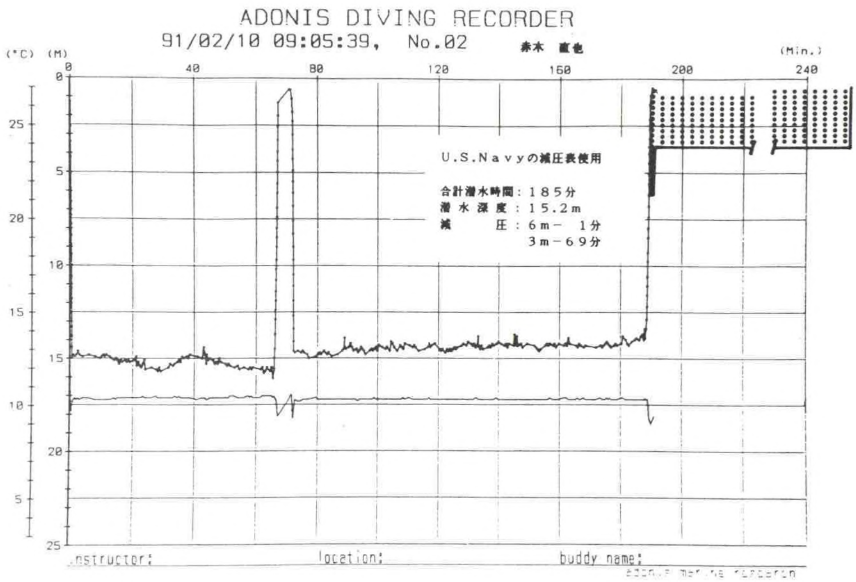

Fig. 7.

This case was Ariake dive profile. It was 3 hours dive by their regulation.

Table 1.

The result of questionaire at Ariake Sea in 1991. They had suffered from bends of 17.4 times on average for these 16.1 years, but only 2.8 for recent 5 year history.

QUESTIONNAIRE OF ARIAKE HELMET DIVERS (88 DIVERS) TOKYO MED. & DENT. UNIV., 1991

	MIN	MAX	MEAN	S.D.
AGE	18	58	35.1	8.12
DIVE DAYS PER YEAR	50	250	94.9	40.06
DIVE TIME PER DAY	1	4	1.5	0.58
DIVING HOURS (MIN)	90	480	195.7	68.95
MAXIMUM DEPTH (M)	10	75	38.3	15.54
MEAN DEPTH (M)	8	30	15.0	3.92
DIVE HISTORY (YEARS)	1	38	16.1	8.40
BENDS HISTORY (TIMES)	0	180	17.4	27.74
TVPE ONE	0	179	16.2	27.03
TYPE TWO	0	10	1.3	1.69
BENDS DURING RECENT 5 YEARS	0	30	2.8	4.83

Questionnair answers on their activity shows on Table one. Most of them have obeyed the rule of bottom time limitation until three hours and the mean time was eventually 195.7 min. The depth has recently become to shallow and the mean was 15.0 meters. But they have experienced their bends history of 17.4 times on average because of their reckless diving history. Their mean diving history was 16.1 years and their recent bends onset during five years was only 2.8 times against 17.4 times during their diving history of 16.1 years (0.56 v.s. 1.32 times/year).

DISCUSSIONS

Diving research works or aseptic bone lesions on Ariake helmet divers have been many times reported by Ohta, Shigetoh, Hayashi, Kawashima, Mano and so forth [1 ~ 5], however their diving profiles had been unclear because of the shortage of ADL, so we have used our original ADL to record the actual diving profiles since 1990. This ADL has been developed in 1984. The property of ADL is to record 10 cm depth difference and the water temperature continuacely until 960 min (16 hours) from the surface to 99 m depth. This record is highly efficient with a good performance [6 ~ 8].

They have been obeyed the rule of three hours diving work per day since 1977 at Ariake Sea , but there are no limitations at other areas like as Setouchi Sea in 1990. Fig. 3 had dived eight times a day from 7:27 to 16:27 for 9 hours except 65 min rest time for eating according to Fig. 3. From Fig. 4, he did five diving a day and had no decompression time during ascent, though he had needed decompression time of 81 min at his second dive and of 120 min at his third dive and so forth acording to the U.S.Navy Diving Manual.

Fig. 4-2. According to Fig. 4-1, we calculated decompression time by USN manual. He must be needed 2 min at 6 m and 79 min at 3 m depth at his second dive and he could not dive more

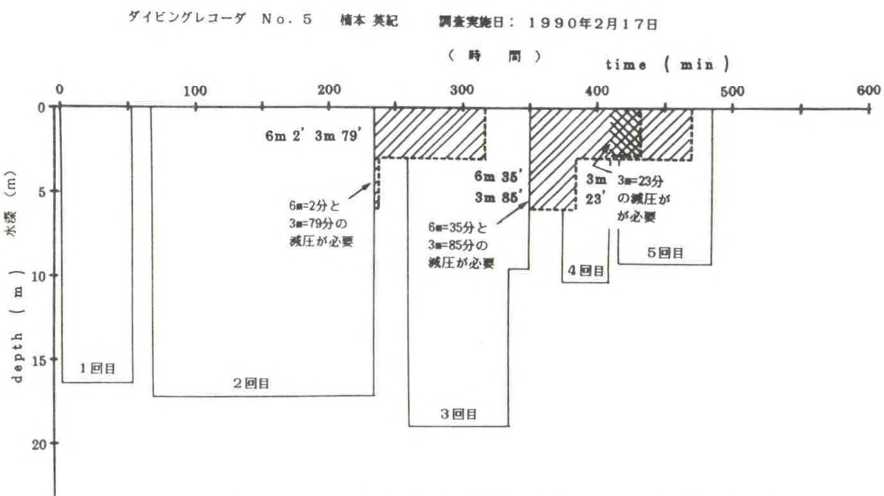

図 11　減圧表（U.S.Navy、標準減圧表）に準じた潜水と平均潜水深度および潜水時間
（ADR：No.5、楠本英紀）

Reckless surface decompression was done at the case of Fig. 5. He dived three times from 7:35 to 15:42 on Feb. 17, 1990. He did his first dive at 16.5 m depth (54 ft) for 58 min and he needed no decompression time. After 12 min of rest time for the transport of the second diving point, he had dived to 16.3 m (53 ft) for 309 min. He had never ascended for these five hours. He had been needed 192 min for decompression after his second dive, but he had no stop during his ascent and dived again after ten min to the same depth for 90 min. He needed 139 min for decompression or regular surface decompression, however he had directly ascended from the bottom and entered into the deck decompression chamber.

Fig. 5-2.

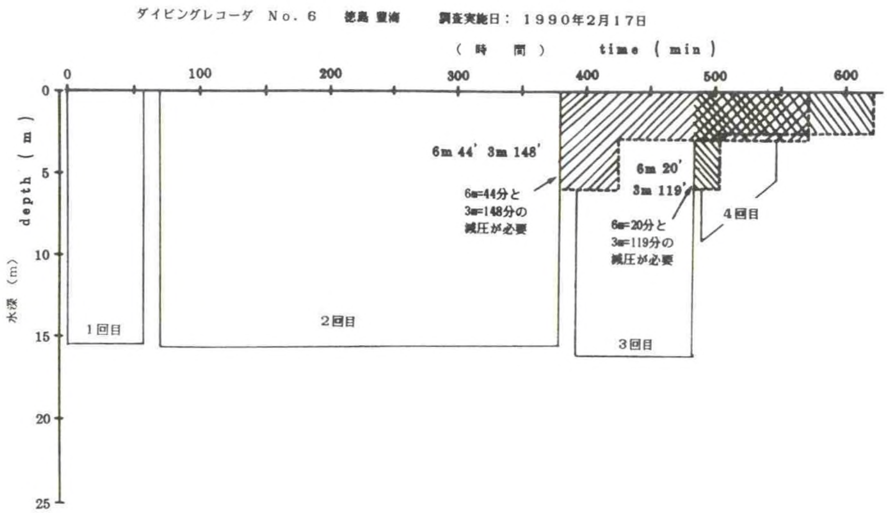

図 13 減圧表（U.S.Navy、標準減圧表）に準じた潜水と平均潜水深度および潜水時間
（ADR：No.6、徳島豊海）

He needed 44 plus 148 min at this 2nd dive and more 20 plus 119 min at his 3rd dive. It was too short and a wrong method of the surface de-compression though he had not been su-ffered from DCS.

This forth schedule in Fig. 5-2 is his selfish surface decompression profile and it is obviously reckless. This style of selfish surface decompression would be the usual style of Ariake shellfish helmet divers in old days. Lots of DCS cases and of aseptic bone necrosis cases are due to these deeper(over 30 m depth) and longer (over 3 hours) bottom work and reckless shorter decompression time.

According to Kawashima et al [3 ~ 5], the diving depth was 30 to 60 m and the bottom time was 3 to 8 hours. Lehner et al [9] have suggesed that prolonged and deeper hyper-baric exposure must increase the incidence of aseptic bone necrosis.

X-Ray examination of fishermen divers at Izu and Sado Islands and Hokkaido have been investigated by Y. Mano et al [10] They have checked 4,205 persons and pointed out 12 cases of Type A, 114 of Type B and 420 of Type C and the number of total persons who have been made the observations on bone lesion were 465 persons. The bone lesion incidence was 11.1 % (420 v.s. 4,205), however Type C cases would not be concerned with diving activity, so the incidence would become to 2.6 % (99 v.s. 4,205). This value is not so high compared with over seas' data. So, the high incidence of bone lesion at Ariake Sea divers is also very special case in Japan.

Our investigation to Ariake Sea divers will be continued and more infromations can be reported in future why they had been suffered from DCS and bone lesions.

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DAN, SPORTS DIVING ACCIDENTS AND DEATHS IN THE USA

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ABSTRACT

DAN started collecting fatalities in recreational diving in 1989 and 114 cases were reported compared to 88 reported by NUADC in 1988. A review of the data will be given including that 104 were males with higher than expected fatalities in the age 20-24 and 50-74 age groups, probably due to training problems and coronary artery disease respectively. Only 92 of the 114 were currently certified and nearly 60% of all deaths occurred in divers who had never made more than 20 dives. Death occurred at depths mostly from the surface to 99 ft.

Diving accidents have been collected by DAN for a number of years. There were 678 diving accident cases reported in 1989 compared to 553 in 1988 or a 23% increase. Of these 289 were male and 102 female age 13-63 (mean 34) and 52% held student basic or open water certification and 45% advanced training. Thirty-three percent (129 of 391) had made only 20 dives or less and 23 divers reported previous spinal or back problems and 6 with asthma. Diagnosis indicated 88 (22.5%) DCS I, 251 (64.5%) DCS II, and 52 (13%) AGE. Some 32% of all injured divers used computers. There was considerable delay to call for assistance and treatment due to lack of recognition of symptoms. This coupled with only about 1/3 divers receiving emergency oxygen first aid resulted in 18% of divers still with residual symptoms 3 months later. The most consistent dive profiles resulting in accidents are repetitive dives at 80 ft. A recent DAN workshop (February 18-19) on the Feasibility of International DAN (IDAN) has led to the formation of DAN Japan, DAN Europe, DAN Australia & New Zealand and DAN South Africa. Their accident and mortality data reveal much the same data. In the future they will send their data also to DAN Center at Duke for a multi-center study.

INTRODUCTION

Scuba diving requires training and certification in order to participate. Like most other recreational sports, there is a risk of personal injury while scuba diving. A special risk exists in scuba diving, however, because the normal ambient environment changes from air to water. Breathing compressed gas at increased partial pressure while in the water may cause decompression sickness (DCS) and arterial gas embolism (AGE). Associated injuries such as barotrauma, marine life injury drowning, and near-drowning are also possible, in addition to complications of underlying disease.

In 1980, an increasing need for a diver assistance service in the United States resulted in the initiation of the Divers Alert Network (DAN). Its mission is to enhance diving safety for recreational scuba divers by:

1. Providing assistance to injured divers, including treatment referral.

2. Collecting statistics on diving casualties to prevent future fatalities and injuries.

3. Providing information to physicians and the general public regarding health issues pertaining to scuba diving.

4. Provide training on diving accident management and utilization of oxygen first aid.

5. Carry out research to improve diver safety.

The Divers Alert Network has advanced along with the increasingly sophisticated dive equipment and multitude of divers' destinations. Wherever divers go through the world, they can now call a single number for assistance or information. DAN now also is able to provide for all in-water accident insurance so that air ambulance and recompression therapy are available.

As the largest diving safety organization in the world, DAN lends its expertise and structural framework to other assistance agencies. In February 1991 DAN hosted the first *International Workshop for Diving Assistance* in Durham, North Carolina to initiate the basis for a global diving safety network or International DAN (IDAN). DAN EUROPE, DAN JAPAN and DAN AUSTRALIA are now a part of IDAN.

DAN accomplishes its safety mission by providing a wide variety of medical and advisory services to recreational divers and physicians:

24 Hour Medical Emergency Hotline (919-694-8111) - DAN maintains a 24 hour emergency service to provide injured divers with medical consultations and referrals. ***This service is free to everyone***. DAN receives over 1,000 emergency calls each year.

Non-Emergency Advisory Line (919-684-2948) - DAN maintains an information hotline to provide answers for commonly asked questions about scuba diving medicine and safety. These include fitness for diving, medications and diving, and advice in areas of scuba safety. Callers may be referred to physicians who specialize in dive medicine. Calls are answered 9 a.m. to 5 p.m., EST, Monday through Friday. ***This service is free to everyone.***

The DAN medical information line now handles over 9,000 calls each year.

Alert Diver - *Alert Diver* is the official newsletter of Divers Alert Network. *Alert Diver* is automatically sent to each DAN member every other month. Issues are also distributed free to medical professionals, government and law enforcement agencies, and at diving trade shows. *Alert Diver* is the industry leader in providing the latest in diving medical safety information.

Diving Safety Courses - Thousands of physicians, instructors and divers have benefited from DAN's one week and one day diving accident seminars. DAN's *Oxygen First Aid in Dive Accidents* program is a new and exciting course to teach the basics of administering oxygen to injured divers. All DAN courses provide recreational divers an unrivaled opportunity to increase their awareness and level of understanding of diving injuries and accident management. Specially prepared video tapes are also available as well as books and other educational materials.

Dive Accident Insurance - Divers Alert Network pioneered diving injury insurance for recreational divers. Diving injuries such as decompression sickness, air embolism, and pulmonary barotrauma are all covered. Also included under this plan are emergency air evacuation and all in-water injuries. DAN members are protected no matter where they dive.

Annual Report on Scuba Diving Accidents - DAN collects and analyzes recreational diving injuries in an annual report. Trends in injuries, types of injuries, and effectiveness of treatment are reviewed each year. Identifying specific causes of diving injuries and common denominators is very useful in educating the diving public in the prevention of accidents.

Report on Diving Fatalities - The latest DAN service to the diving public is a collection and analysis of recreational scuba diving fatalities. Mortality studies ar valuable in identifying specific causes of death, such as experience, activity, and health. By publishing this report, DAN hopes to increase diver awareness and ultimately attempt to reduce diving deaths.

<u>Scuba Diving Fatalities</u>

DAN began collecting fatality data in 1989, during which data were obtained on 114 recreational scuba fatalities. The aim of DAN's collection effort is to collect all fatality data on diver deaths which occurred in the United States, U.S. territories, and Caribbean basin islands. Of the 114 fatalities reported, three were not U.S. citizens.

For each fatality, an attempt was made to obtain a medical examiner's report, sheriff or police investigative report, and eyewitness accounts to assist in determining the nature and cause

Table 1 Age and Sex Comparisons

Age Group	Number	Percent	Male	Female
10 — 19	9	7.9%	9	0
20 — 29	20	17.5%	20	0
30 — 39	32	28.1%	28	4
40 — 49	24	21.1%	21	3
50 — 59	17	14.9%	15	2
60 — 69	11	9.6%	10	1
70 — 79	1	0.9%	1	0
TOTALS	**114**	**100%**	**104**	**10**

of death. DAN cross-referenced information from local and national investigating agencies to attempt to ensure that diving fatality information was accurate. A statement reporting form is used and the same will be available to IDAN.

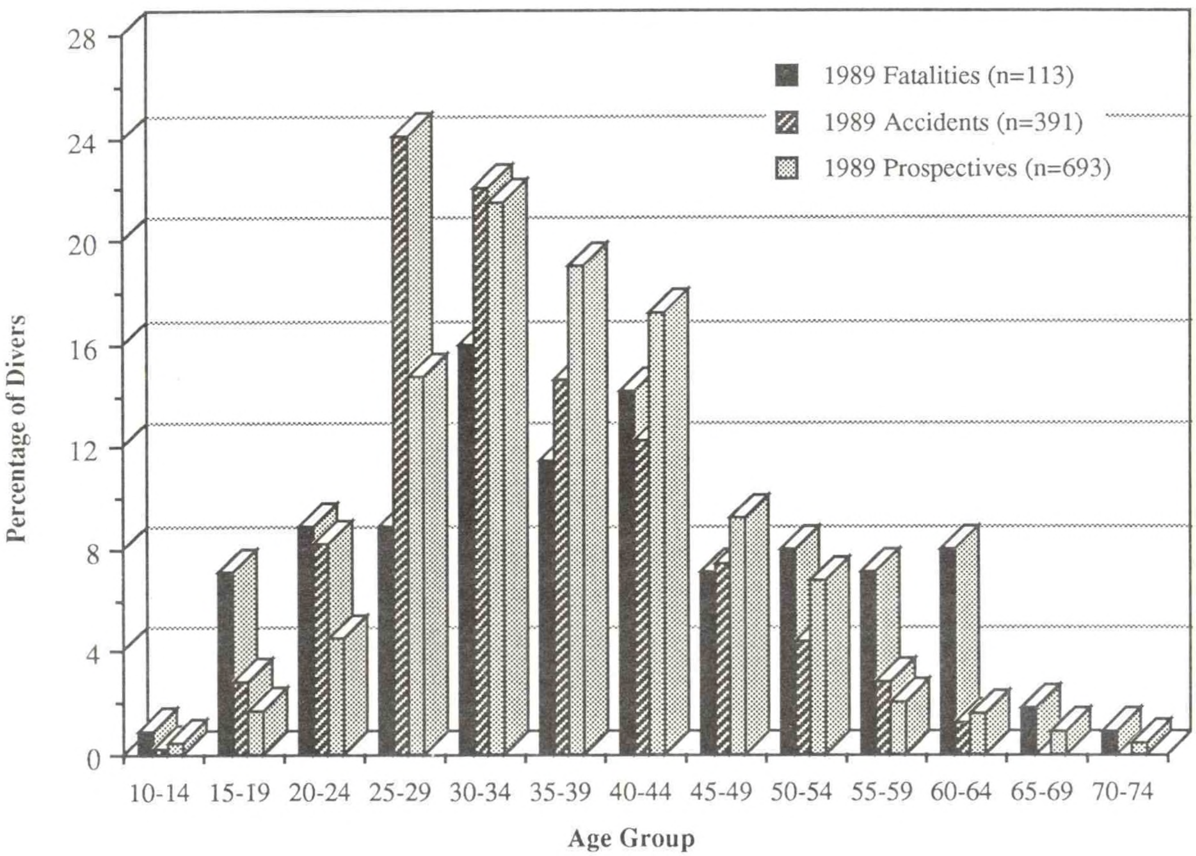
There may be as many as 2-2.6 million active recreational scuba divers in the USA. Over the last four years between 553 and 678 recreational divers reported receiving treatment for decompression sickness or air embolism each year. Because the total population of divers is approximate and the number of reported injuries does not include divers who do not seek treatment, the exact incidence of injuries cannot be calculated. Using the estimate of active scuba divers and the existing DAN data there therefore have been approximately 2.0 to 2.5 injuries per year for every 10,000 active divers. In addition, data gathered by the National Underwater Accident Data Center and Divers Alert Network indicate there have been 66 to 114 fatalities per year in the last four years,giving an approximate estimate of 2.4 to 4.2 deaths per 100,000 divers per year. This compares to 1990 National Safety Council fatality rates for swimming of 2.4 per 100,000 people and an injury rate of 14 per 10,000 people per year.

The report rates 86 diving deaths in the USA and 28 in the Caribbean and other international dive sites. Of these, 104 were men and 10 women. The age/sex distribution is shown in Table 1. Women appear to be under-represented as they normally represent some 27% of divers in the USA.

A comparison is made of diver ages in fatalities, treated dive accidents, and a prospective study population, randomly selected from insured DAN members in 1989. The observed fatalities in the combined group of 1989 divers was higher than expected in the 20 to 24 year-old group and in the 50 to 74 year-old groups. This may be due to inexperience or inadequate physical ability in the younger group and either known or undiagnosed health problems among the older diving population. DAN's findings for 1989 fatalities clearly suggest, at least in the older population, that associated health problems such as coronary artery disease, are in part responsible for scuba deaths (Table 2).

Ninety-two of 114 scuba fatalities involved individuals who were currently certified (Table 3). Seventeen individuals (14.9%) were diving without current scuba certification. Among the 17 uncertified divers, seven were under instruction, and ten lacked proper training available through scuba certifying or instructional agencies. By comparison, the 1989 accident data showed 95% of all divers had received official agency scuba certification, and 5% of injured divers were not certified. Three percent of these divers were under instruction and 2% were diving without agency training or certification. It would appear that lack of instruction, or improper training, is therefore a risk factor for death while scuba diving.

Table 2 Comparison of Age Range by Percentage in Three 1989 Populations



** Two prospectives did not provide their age.*

Table 3 Certification

Certified	92	80.7%
Noncertified	17	14.9%
TOTAL	**109**	**95.6%**

No information on certification levels in five divers.

Table 4 Diving Experience

Noncertified	17	14.9%
Novice (≤ 5 dives)	16	14.0%
Inexperienced (6 — 20 dives)	34	29.8%
Intermediate (21 — 40 dives)	17	14.9%
Advanced (41 — 60 dives)	5	4.4%
Experienced (≥ 61 dives)	17	14.9%
TOTAL	**106**	**92.9%**

Eight divers missing information.

The divers level of experience, and the criteria used to establish this level of experience, is given in Table 4. It is difficult in fatality cases to obtain the exact number of dives and years the individual has been diving. Therefore, analysis is based upon the number of dives reported to have been made by each individual. Nearly 60% of all fatalities occurred in divers who made 20 dives or less in their entire dive career. Additionally, some divers in the intermediate to experienced level were infrequency divers who only used scuba once yearly.

Aside from sightseeing pleasure, the dive activity for 61.4% of fatalities it is perhaps surprising to find 10.5% were under instruction (Table 5). Six of these 12 deaths were in divers undergoing initial scuba training and certification. In addition three occurred during advanced certification to dive master or advanced diver and other during dry suit training. None of the ten cave diving deaths had received specific cave diver training.

There were six cases where diver equipment was a problem. Equipment failure is believed to have possibly caused the death of two individuals. One fatality occurred because a free-flowing regulator caused panic and a rapid ascent in an adolescent. The other death may have been caused by the powerband breaking when the diver retracted it to load the speargun.

Equipment can be a factor in accidents even when there is no failure involved. Divers were reported to have not been familiar with there equipment they were using in seven cases. In six other cases divers knew they were using at least one piece of faulty equipment. Five divers were reported to be overweighted with 24 to 54 pounds of weight. One can only say that these circumstances most likely contributed to the events in the diver deaths and may have hampered self-rescue. They did not directly cause the deaths.

This first year of fatality collection by DAN (1) suggests several regions for concern as possible causes.

(a) A higher number than desired are the consequence of coronary artery disease leading to exercise and stress stimulated heart attack.

(b) Lack of certification by a qualified SCUBA training agency increases the risk of a fatality resulting.

(c) As experience increases the risk of a fatality decreases.

(d) Practices such as cave diving, wreck diving, spearfishing or diving alone need special caution.

Table 5 Dive Activity

Sightseeing	70	61.4%
Under Instruction	12	10.5%
Cave Diving	10	8.8%
Spearfishing/Game Collecting	9	7.9%
Work/Task	6	5.3%
Wreck Diving	6	5.3%
Night Dive*	5	4.4%
Ice Diving**	2	1.8%
Photography	1	0.9%
TOTAL	**121**	**106.3%**

* *Four night dives were also sightseeing dives, and one was also a work/task dive.*

** *One ice dive was also a photography dive, and one was also a sightseeing dive.*

Scuba diving accidents

DAN has been collecting U.S. sports diving accident statistics for several years. The information is obtained as a result of the emergency and non-emergency telephone call activity which has increased steadily as DAN has become better known (Fig. 1). The peak activity is during the summer months.

There were 678 accident cases resulting in treatment in 1989 compared to 553 in 1988. Of these DAN collected 560 forms from which 391 were considered complete and verifiable, sufficient to include in the data analysis below.

The age range of the victims was 13-63 with a mean of 34 (Table 6). From a percentage view the age groups 15-19 and 55-59 showed a significant increase from 1988, the former by a factor of 2 and the latter four times as many.

The number of women divers injured increased from 58 in 1988 to 102 in 1989 and were 26% of total accidents.

It is pertinent, as with the fatalities that 52% of the 1989 divers who had accidents held beginning level certification or were being certified (i.e. student, basic or open water diver). Yet 43% were trained at advanced level (Table 7).

Significant buoyancy control problems occurred in 84% of the novice group, which also had dived less than two years, or with less than 20 dives experience. Again 52% of the out of air and 51% of too rapid ascents were associated with these novice divers. Further, 50% of all accidents occurred on the first day of diving when the diver was still adjusting to the environment. This data suggests again the need for more thorough training and greater care when entering a new diving environment.

The accidents involved 190 pain only decompression illness (DCS Type I), 323 severe illness usually of a neurological nature (DCS Type II) and 107 air embolisms with 58 not clearly diagnosed.

Equipment was an associated factor in only 49 cases as shown in Table 8. Of these problems with the regulator (14) or buoyancy compensator (10) were the most common. Ten were due to using unfamiliar equipment emphasizing the need to use the best most reliable equipment and to be very familiar with its use.

Diver attributes or risk factors which point to those most commonly associated with decompression illness are shown in Figure 2 for decompression illness (DCS) and in Figure 3 for air embolism (AGE).

Importantly decompression illness seems associated with diving within no decompression table guidelines but deeper than 80 ft and with repetitive, multi-level dives. Gas embolisms on the

Figure 1

DAN Call Volume 1986-90

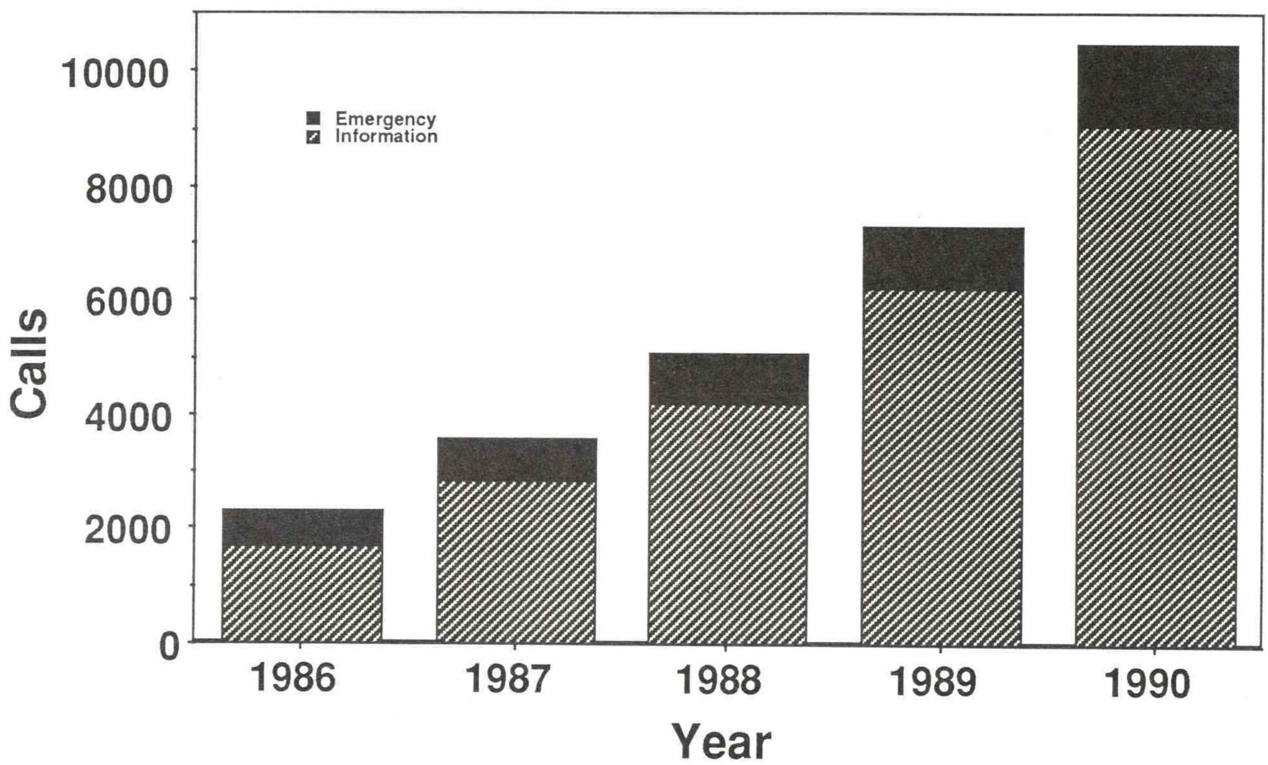


Figure 2 AGE Dive Risk Factors

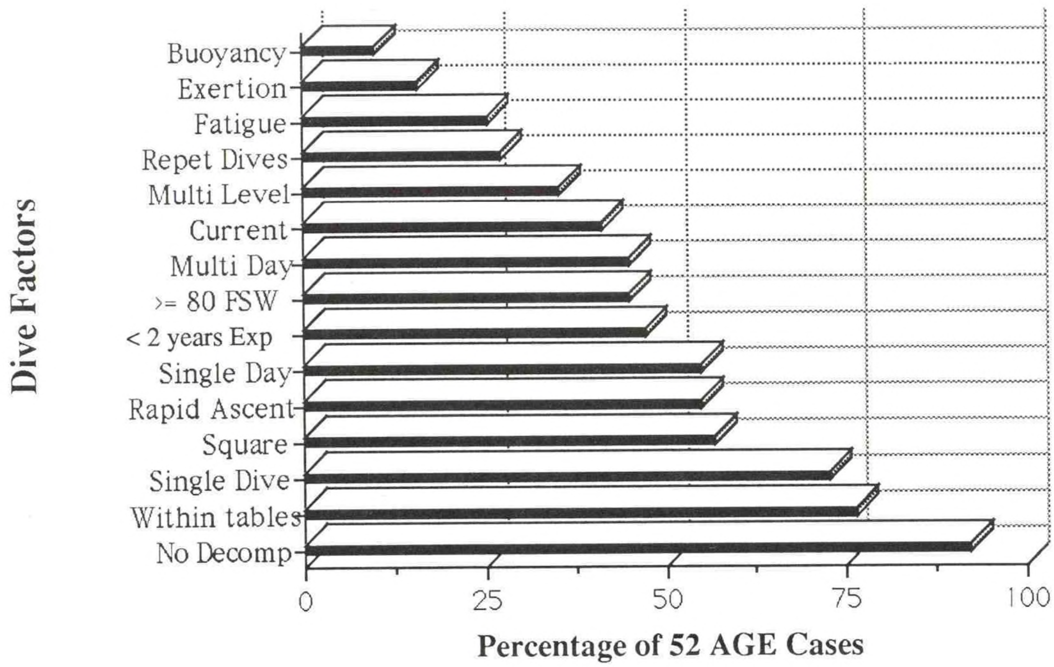


Figure 3 DCS Dive Risk Factors

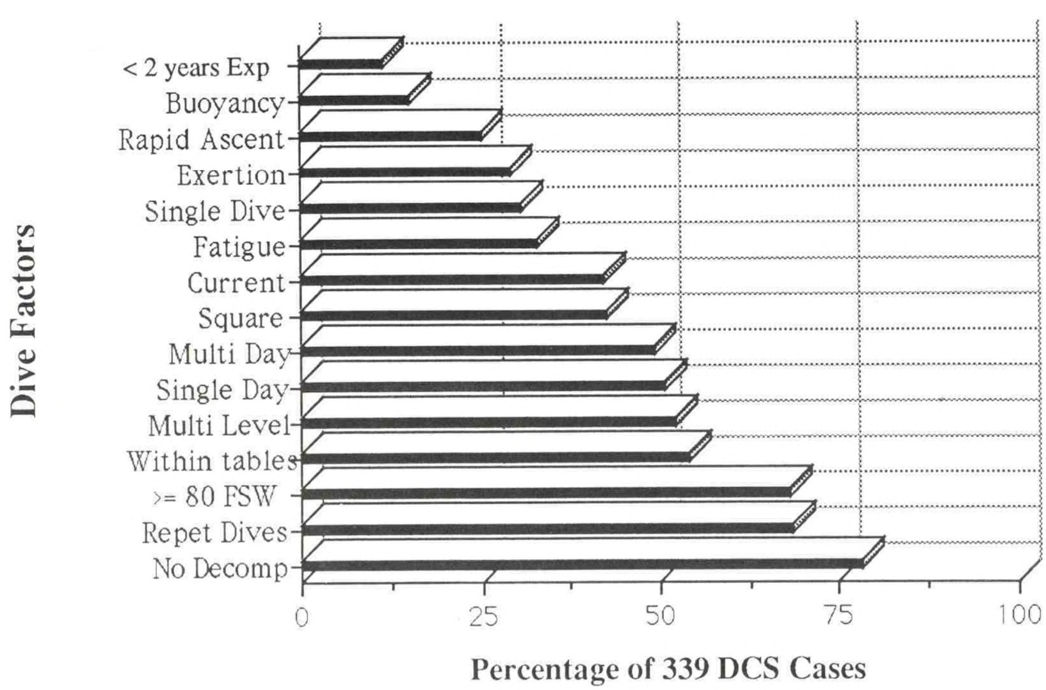


Table 6 Age Distribution of 1989 Accident Cases

Age	Frequency	Percent	Males	Females
10-14	1	0.3	1	0
15-19	11	2.8	8	3
20-24	32	8.2	22	10
25-29	94	24.0	71	23
30-34	86	22.0	64	22
35-39	57	14.6	45	12
40-44	48	12.3	34	14
45-49	29	7.4	20	9
50-54	17	4.3	10	7

Table 7 Certification Level of 1989 Accident Cases

Certification	Male	Female	Totals	Percent
Student	6	6	12	3.07
Basic	22	8	30	7.67
Open Water	115	47	162	41.43
Advanced	81	28	109	27.88
Divemaster	22	2	24	6.14
Instructor	32	9	41	10.49
Commercial	1	0	1	0.26
Other	4	2	6	1.53
Unknown	6	0	6	1.53
TOTALS	**289**	**102**	**391**	**100.00**

other hand are associated also with diving within the no decompression tables but with single square dives and a too rapid ascent often with a relative lack of experience of the diver.

Computer diving has become very popular with recreational diving and thousands of units are being used today. Fifteen percent of divers in the 1987 accident report were using computers compared to 31% in 1988. In 1989, 32% of all injured divers were using computers.

Table 9 demonstrates a comparison between computer assisted divers and those who use a dive table to calculate their profiles. The U.S. Navy Table is still a decompression table in common use, and is the only table used in this comparison. Computer divers are more likely to begin their dive at 80 feet or greater compared to table users and do more multi-level and repetitive diving. These diver preferences are much easier with decompression computers and divers may very well select themselves out of table use because they prefer this style of diving.

Due to failure to recognize the often subtle signs or symptoms of decompression illness divers in general wait far too long in seeking medical assistance or recompression. Over 50% of the diving accidents reported here waited more than 12 hours to call for assistance. Further 16% actually continued to dive after developing the first symptoms (Fig. 4).

As a result of this delayed reaction there is a significant delay too with recompression therapy (Fig. 5). The result of these delays is that a number of divers do not make a full recovery even after significant recompression therapy. Three months after the initial diving accident 18% of the divers were still experiencing residual symptoms or incapacitating neurological problems. Generally these will resolve over further time until after two years when an estimated 6-7% remain.

The problem of effective therapy is made much worse by poor first aid. It is now widely recognized that when a diving accident occurs two things can make a real difference to a good recovery besides speed of recompression therapy. These are the use of 100% oxygen and hydration. Yet in the divers who had accidents in 1989 only 126 of the 391 received any oxygen before therapy and only 82 oral fluids.

For this reason DAN has developed its own emergency oxygen equipment and now teaches divers a course for its use (Oxygen First Aid in Diving Accidents) and instructors (DAN Oxygen Instructor Course) as well as one on diving illness recognition.

Although this paper discusses diving accident epidemiology and the issues involved it is necessary to put this in perspective. Sports diving is very popular and increasing numbers are participating world wide. In the USA the number of accidents versus the number of divers is small and the individual risk of

Figure 4 Delay to Calling for Assistance

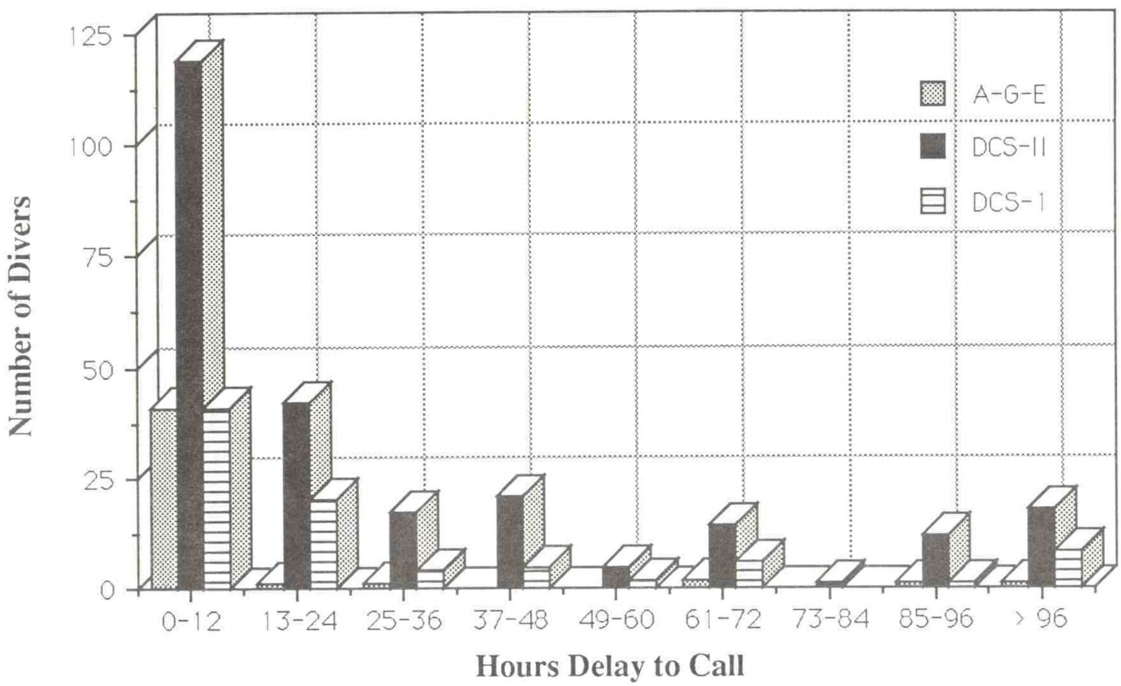


Figure 5 Delay to Recompression

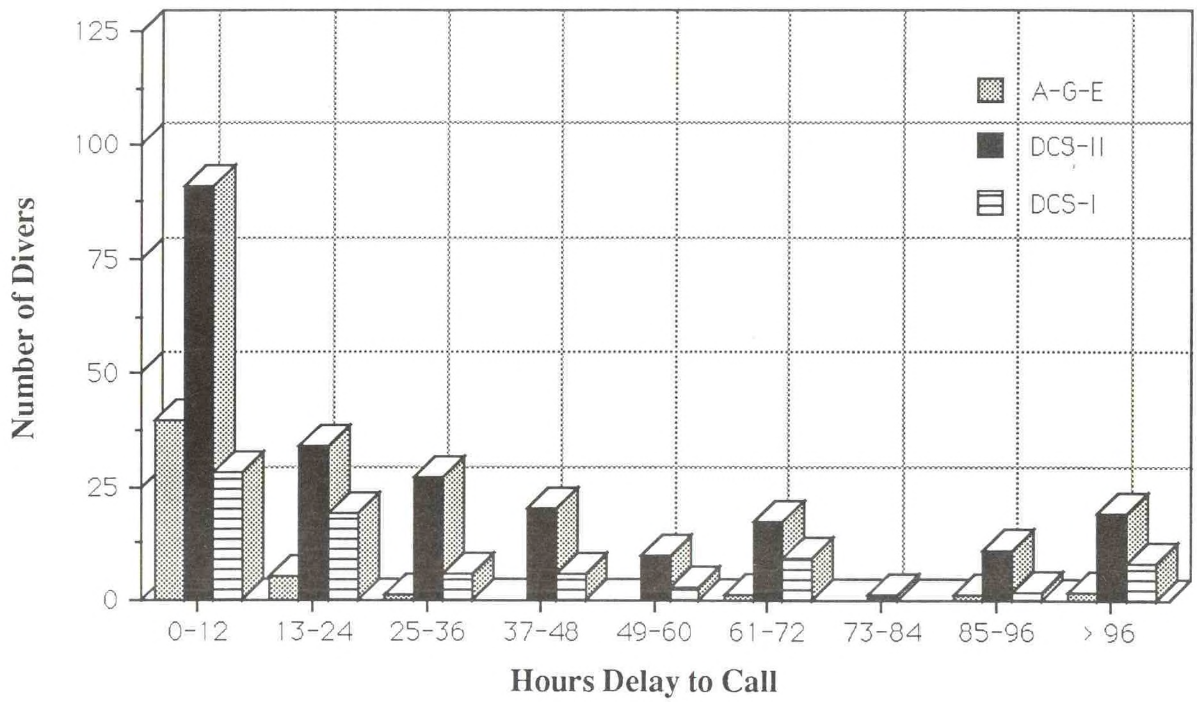


Table 8 Equipment Problems

Equipment	Frequency	DCS	AGE
Regulator	14	9	5
BC Vest	10	10	0
Weight Belt	2	1	1
Dry Suit	2	1	1
DC Computer	6	4	2
Inflator Hose	3	2	1
Contaminated Air	1	0	1
Unfamiliar Equipment	10	8	2
Timing	1	1	0
TOTALS	**49**	**36**	**13**

Table 9 Table vs. Computer Diving

	1989		1988	
	US Navy	Computer	US Navy	Computer
>= 80 fsw	38.5%	81.0%	67.0%	81.0%
Square	53.2%	28.6%	61.0%	42.0%
Multi day	48.3%	52.4%	48.0%	55.0%
Repet	58.5%	73.0%	57.0%	81.0%
Single day	51.7%	47.6%	52.0%	45.0%
	n = 265	*n = 126*	*n = 184*	*n = 84*

around 0.03% or less is better than many other sports. Nevertheless much can be learned by collecting not only the accident and mortality data but also from incident form which report a near accident. This is something which DAN will be doing soon.

The DAN form for reporting accidents and deaths are now available through IDAN and will be translated into appropriate languages. At present DAN Europe, DAN Australia and DAN Japan are intending to use the same forms as DAN USA. The data will be sent back to DAN USA so that we can then compare accident data internationally.

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NEUROPSYCHOLOGICAL EVALUATION IN 330 METER SATURATION DIVE

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ABSTRACT

Neuropsychological evaluation was performed in five divers in a 330 meter saturation dive. Test battery was developed to evaluate those functions in a short time and 7 times performed through this experiment. Some deteriorations of functions were noted in Stroop tests which need selective attention in the struggling situation on the bottom 330 meter. They were recovered to normal range with decompression stage. It is considered that we could evaluate those functions frequently enough to monitor those changes. The problems which raised from our experiment were discussed.

INTRODUCTION

Peters et al[1] reported that neurological and psychological disturbances following decompression sickness in divers are more common than they were previously believed.They stated these neurological deficits might be due to multiple supraspinal lesions. Becker[2] stated that saturation divers might have neuropsychological impairment even without decompression diseases and that were possibly due to multiple and longstanding stress exposed during the dive. He stressed the necessity to follow up those functions in details prior, during and post dive for few years. However, Curly[3] reported transient changes of neuropsychologic disorders will be dissapeared in 10 days after dive without permanent changes. Vaernes[4] pointed out repeated deep dives might lead to more pronounced neuropsychologic impairments, even after ordinary divings. Brubakk[5] stated that it is important to develop the method of evaluation to detect even minimal impairment for all divers.

Various evaluation methods of neuropsychological disorders had been utilized by different researchers (Table 1), but there are no established methods yet in this fields. Townsend[6] advocated that Halstead-Reitan Test Battery should be used in diving field. This is widely known and has been used most frequently to all aspects of neuropsychological impairments, however it takes 6-8 hours to perform this battery completely even skillful examiner. Most of researches picked some parts of this battery.

TABLE 1

VARIOUS EVALUATINON METHOD

BECKER(1984):	Neurological Test
	EEG
	Halstead-Reitan Battery
CURLEY(1988):	Brainstem Auditory Evoked Response
	Wechsler Memory Scale
	Trail Making Test
	Digit Symbol Modalities Test
	MMPI
VAERNES(1989):	Dynamometer
	Finger Tapping
	Pegboad
	Static Steadiness etc

Requirements of the appropriate evaluation test are to detect minimal impairment of neuropsychological functions and to monitor these changes with repeating evaluations. Our study has two folds;one is to develop test battery simple enough to evaluate neuropsychological functions with short time and frequent assessments during the same-experiment period. The other is to monitor those functions through 330 meter saturation dive with our developed battery.

METHODS

SUBJECTS

Five male subjects (Table 2) were selected from Japan Maritime Force for this 330 meter saturation dive. Prior to this experiment, all subjects were performed with both physical and psychological examinations which revealed no pathologic findings All subjects had experienced 200 meter saturation dive at least once prior to this experiment.

TABLE 2

SUBJECT

DIVER	AGE	HEIGHT (cm)	WEIGHT (kg)
M. S.	31	168	67
Y. K.	33	176	63
T. M.	33	158	64
T. K.	26	170	74
A. N.	31	173	76
Mean	30.8	169.0	68.8
SD	2.9	6.9	5.9

TOTAL EXPERIMENT PROFILE

The compression and decompression schedule and environmental control were shown in Figure 1. Compression procedures consisted of two stages of pressure hold at 150 meter and 250 meter, and a slower compression rate from 250 meter to 330 meter. The Duke-GKSS linear decompression procedures were employed. Environmental controls including breathing gas (oxygen,nitrogen, and helium etc) were shown in detail in Figure 1.

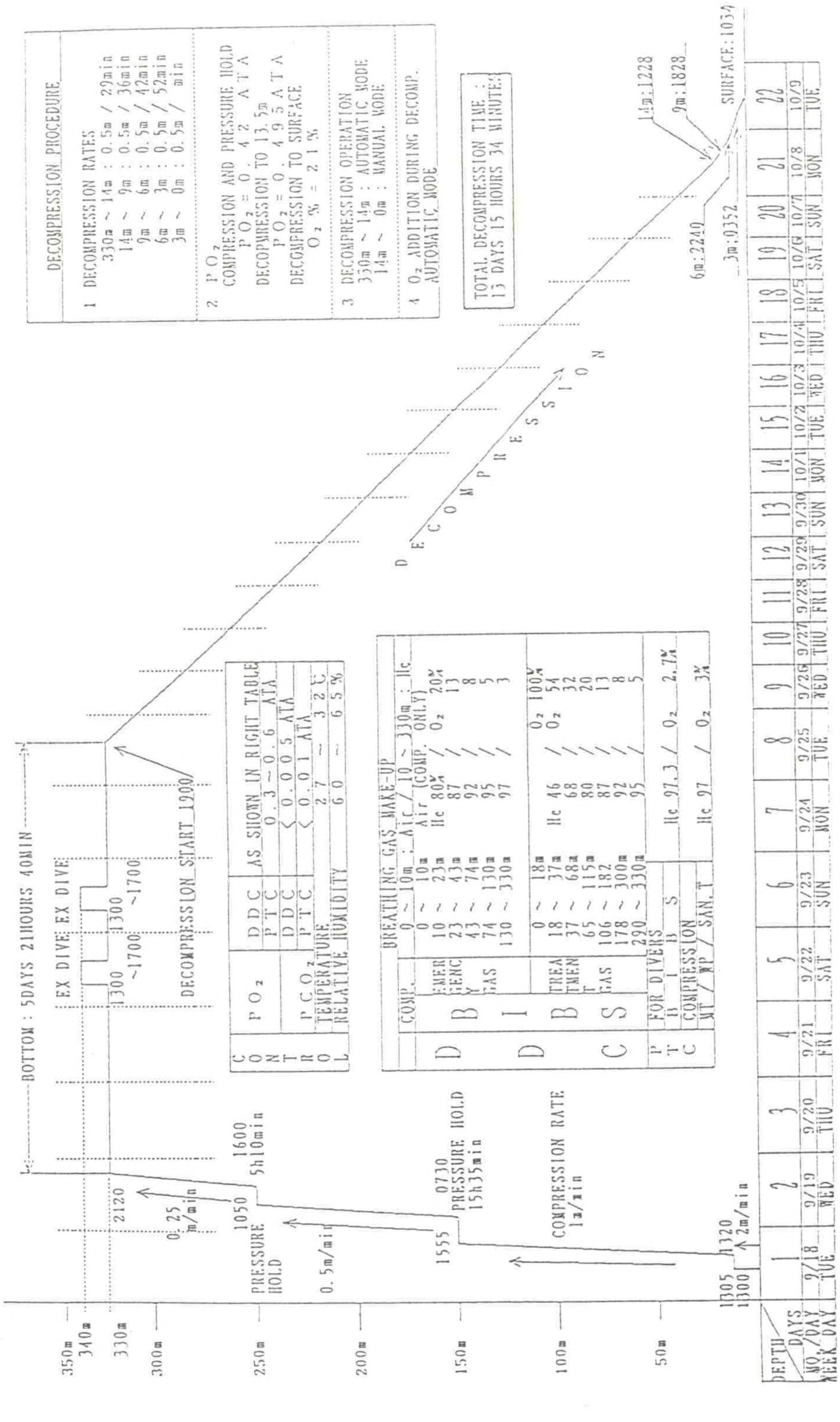


Figure 1. 330 m (EX 340 m) Saturation Dive Profile

Total duration of stay in the chamber is 22 days. Neuropsychological evaluation was performed 7 times and the dates of evaluation were shown with arrows in Figure 2. Prior to the compression, the evaluations were done twice out of the chamber and inside of the chamber to see the effect of closed environment in chamber. In the stage of incremental compression assessment were not performed. Once performed in the 330 meters bottom and twice in the decompression stage. Last two assessments were done one day and one week later after the experiment.

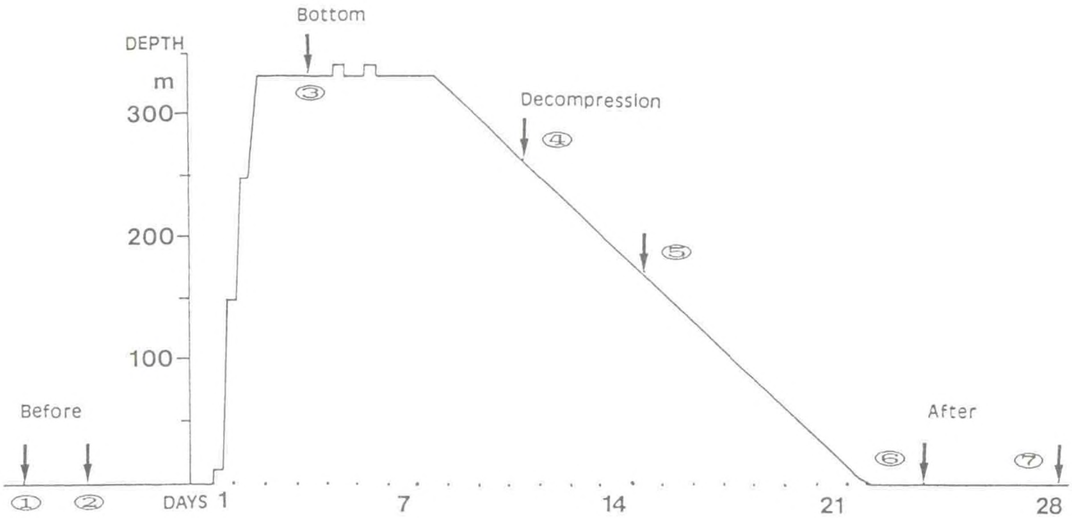


Figure 2. Evaluation Schedule

TEST BATTERIES

Our test battery are consisted of 7 items (Table 3). Tests with " * " marks were adopted from Wechsler Intelligence Scale which is the part of Halstead-Reitan Test Battery. 3 tests on the left side (BLOCK DESIGN, MAZE, DIGIT SPAN) were done twice pre and post dive out of the chamber. Four tests on the right side (DIGIT SYMBOL, CALCULATION, STROOP, VISUAL TRACKING) were performed totally 7 times. Procedure of tests were done from top to bottom in order.

TABLE 3

OUR TEST BATTERY

Only Pre and Post Dive	Repetitive
1. Block Design*	1. Digit Symbol*
2. Maze*	2. Calculation
3. Digit Span*	3. Stroop
	4. Visual Tracking

RESULTS

(1) Digit Symbol Test

Figure 3 shows the paper of digit symbol test. Each digit (1 to 9) correspond to a different symbol mark. Subjects were instructed to write down symbol marks as soon as possible in the colums under digits within 90 seconds. Requirements of this test is accuracy and speed for memory and attention. Normal standard score is 65 among 90 symbols. Results were shown in Figure 4 by mean score of 5 divers. They got above normal average scores in all tests. Some decline was noted in the bottom, but standard deviation was large in the bottom too, they were not significant statistically. They got even higher scores in later tests, probably the learning effects could not be denied.

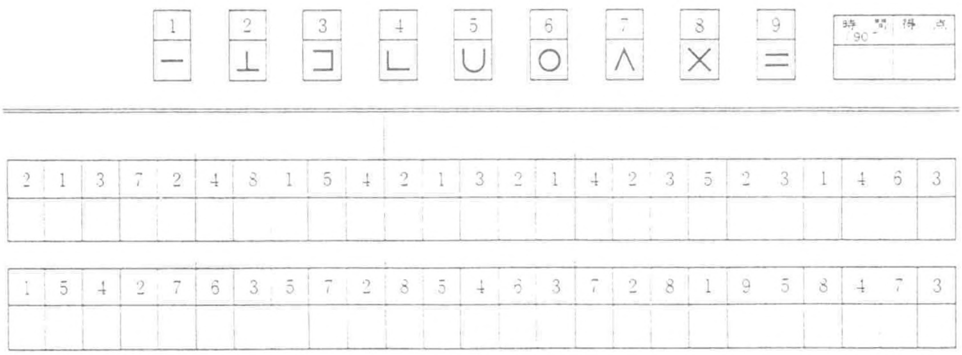


Figure 3. Digit Symbol Test

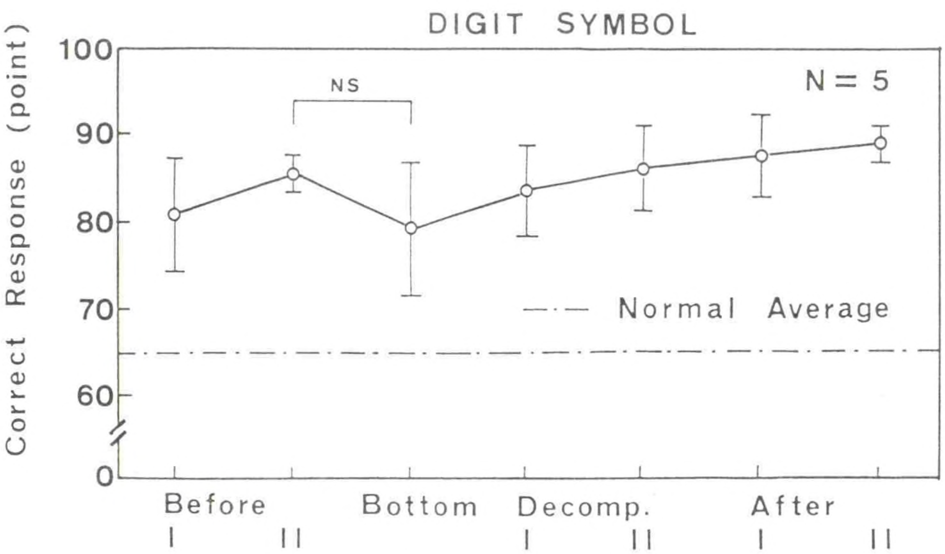


Figure 4. Result of Digit Symbol Test

(2) Calculation Test

Part of calculation test were showed in Figure 5. It is one of the subtest of the "Occupational Apptitude Test (Japan Labor Ministry)". It consists of 36 calculation items. Time limit is 3 minutes and 30 seconds. This test requires the accuracy and speed of calculation.

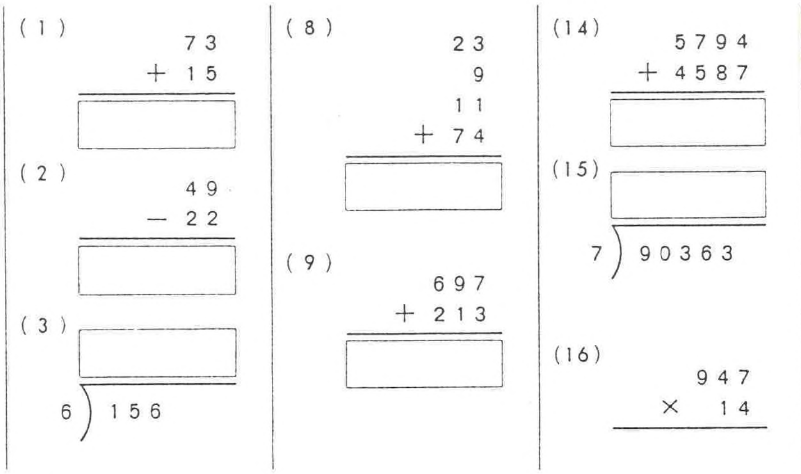


Figure 5. Calculation Test

Results were shown in Figure 6. Normal average scores in their age group is 15/36. They got better scores than the standard There were not significant change between before and bottom.

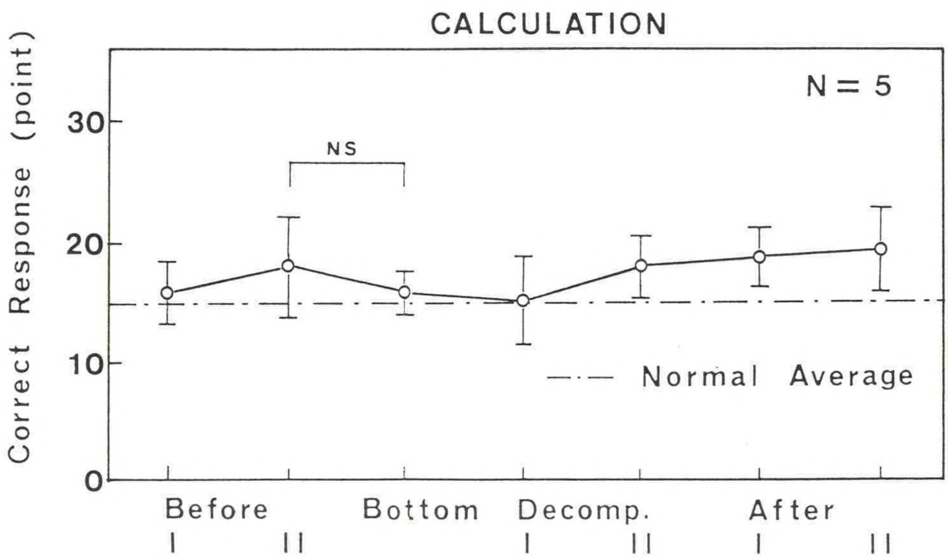


Figure 6. Result of Calculation Test

(3) Stroop Test

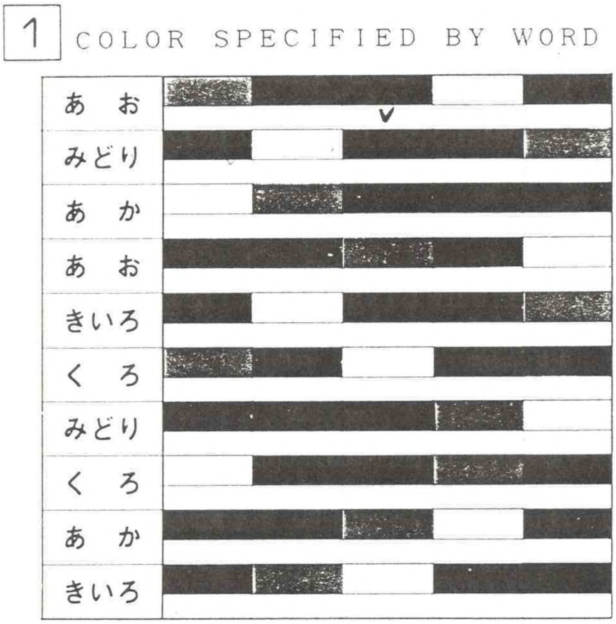
Stroop test consists of four tasks and each task is designed to evaluate capability of selective attention in various situation Some of them is to evaluate in cognitively struggled situation. Basic concept of this test is a matching assessment of color and colour name in various ways to interfere concentration with giving noise effect. Five colors (yellow, blue, red, green, and black) black) are used. There are 60 items in each task test. Time limit is 40 seconds.

The first test is to mark(check) under the same color as indicated name of color on the right end columns (Figure 7a) For example, name of color (blue) is listed on the left hand side and check mark (✓) under blue color from the right side.

The second test (Figure 7b) is the same as the first task, but the name of color might be painted with different color to give subjects some confusion for matching. For example, name of colour (black) was painted with green color. Subject has to mark the check under right color (black).

The third test (Figure 7c) is the other way around the first task. Subjects are to mark the name of color from the right side columns. For example, in the first column, color is yellow and name of colors are yellow, blue, green, black and red in order from left to right. Marked on yellow on the left end.

The fourth test (Figure 7d) is so called words matching test and most difficult of all 4 tests. Words which might be painted with different color to give additional struggling situations. For example, in the first column, word on the left side is red painted by black. Pick-up names are green, black, red, blue and yellow from left to right.



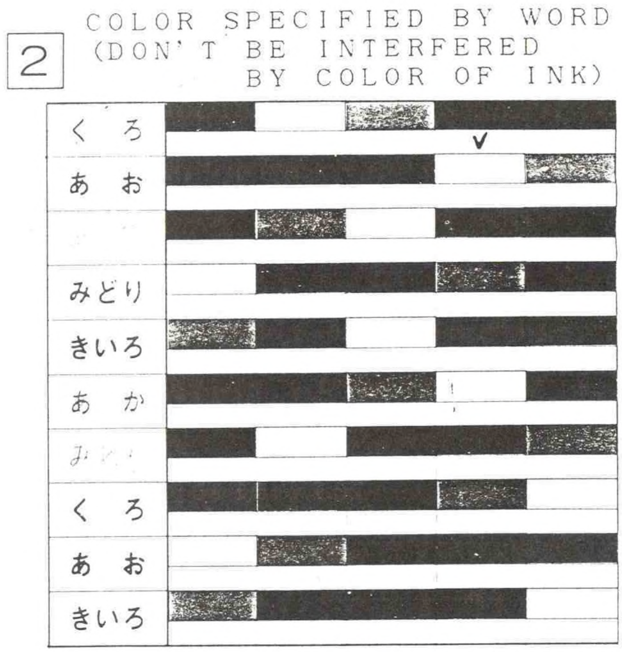


Figure 7-a. STROOP TEST (TASK 1)

Figure 7-b. STROOP TEST (TASK 2)

3 WORD OF COLOR OF INK

	きいろ あ お みどり く ろ あ か
	あ お きいろ く ろ あ か みどり
	く ろ あ か あ お みどり きいろ
	みどり く ろ あ か あ お きいろ
	あ か みどり きいろ く ろ あ お
	あ お あ か みどり きいろ く ろ
	く ろ きいろ あ お あ か みどり
	みどり く ろ あ か きいろ あ お
	あ か あ お きいろ みどり く ろ
	きいろ みどり く ろ あ お あ か

4 WORD OF COLOR OF INK
(DON'T BE INTERFERED
BY COLOR OF WORD)

あ か	みどり く ろ あ か あ お きいろ
みどり	く ろ きいろ あ お みどり あ か
あ お	あ お みどり きいろ あ か く ろ
[illegible]	きいろ あ か あ お く ろ みどり
きいろ	あ か みどり く ろ きいろ あ お
く ろ	みどり あ お きいろ く ろ あ か
きいろ	あ お く ろ あ か みどり きいろ
みどり	きいろ あ お く ろ あ か みどり
[illegible]	く ろ あ か みどり きいろ あ お
あ か	あ か きいろ みどり あ お く ろ

Figure 7-c. STROOP TEST (TASK 3)

Figure 7-d. STROOP TEST (TASK 4)

In the first task test (Figure 8a), normal average score is 44/60. Mean score of 5 divers were above standard. The scores were relatively lower in the earlier evaluations, but getting higher in the later tests.

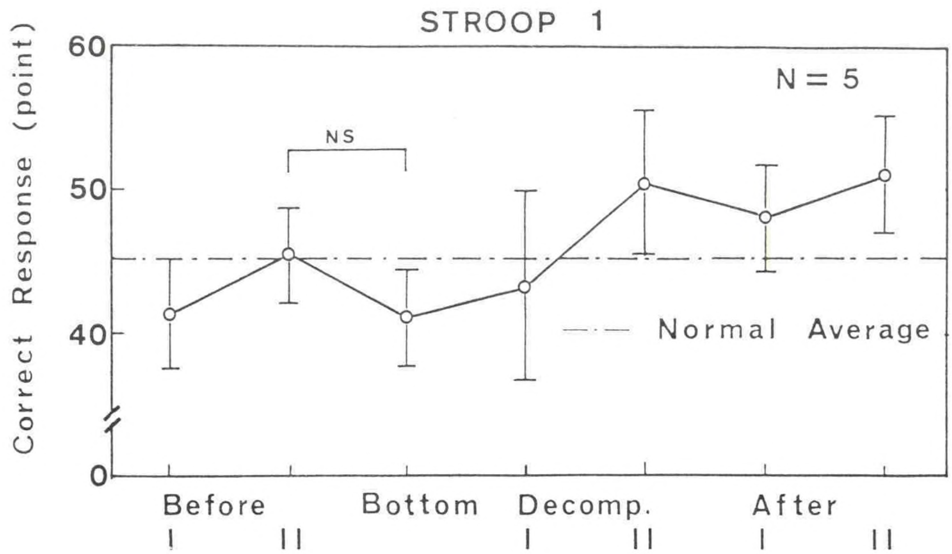


Figure 8-a. Result of Stroop Test (TASK 1)

In the second task (Figure 8b), the standard score is 42 / 60. Mean score of 5 divers at Before II were equal for normal average, on the bottom, scores were lower than normal standard with statistical significance ($p<0.05$). Scores were regained to normal range and the score is getting higher in the later test above normal.

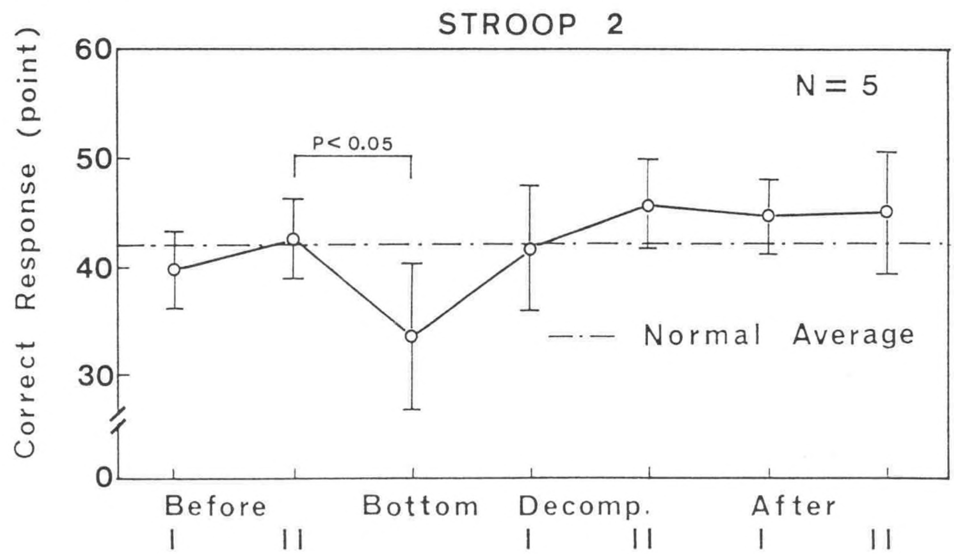


Figure 8-b. Result of Stroop Test (TASK 2)

In the third task (Figure 8c), the standard score is 35/60. Mean score of 5 divers is considered with normal range and the score is getting higher in the later test above normal.

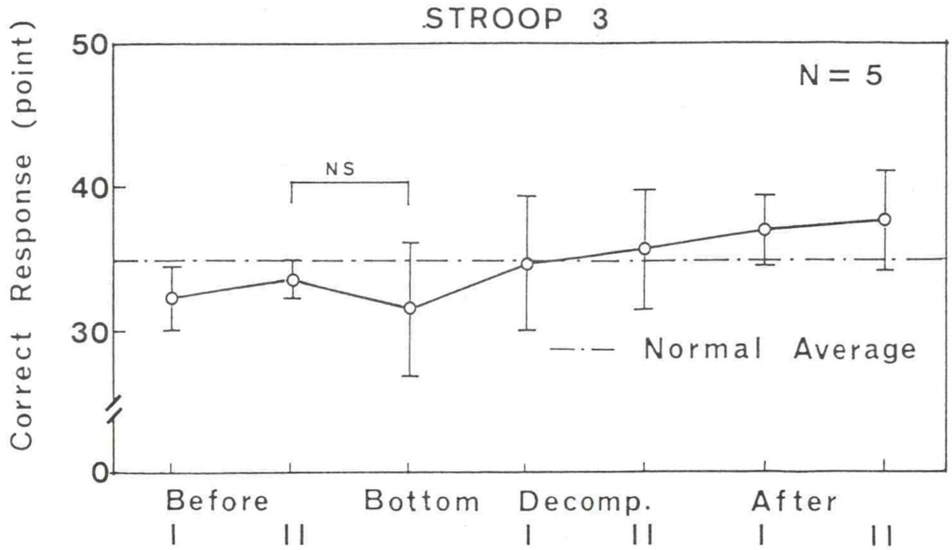


Figure 8-c. Result of Stroop Test (TASK 3)

In the fourth task (Figure 8d), the standard score is 30/60. Mean score of 5 divers on the bottom was extremely lower than the standard score with statistically significant (p<0.10), but become in normal range with decompression.

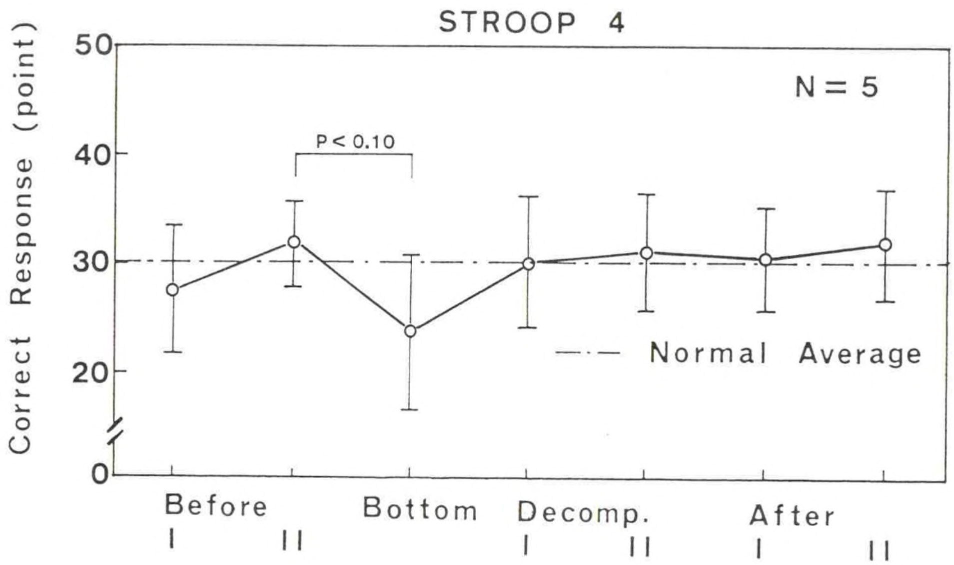


Figure 8-d. Result of Stroop Test (TASK 4)

Lower scores than normal were noted on the bottom in the 2nd and 4th task test which are considered as the interferred and struggling situation.

(4) Visual Tracking Test

This test was developed in our laboratory to investigate the coordination visual function and hand motion. Assessment is to track the movimg target on the CRT with the marker which can be operated by movement of a mouse aparatus. The target (circle of 5 mm diameter) moves horizontally with different speeds (cast shadowed sinusoid curve) and is to be followed with "×" marker on the CRT.

Since CRT was not able to be brought into the chamber, subjects had to see the target on CRT through the small window (Figure 9).

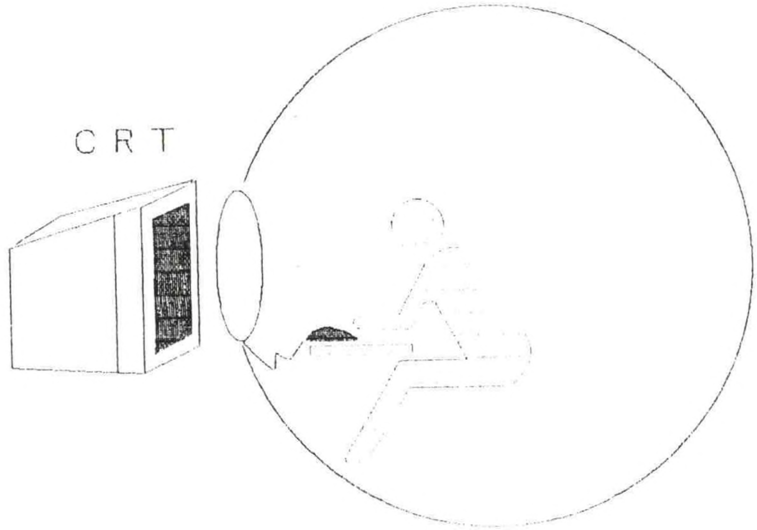


Figure 9. Apparatus of Visual Tracking Test

An example of computer output is seen in Figure 10. Sinusoid curve on the top is the movement of the target. Marker movement on the x axis was showed as a rather irregular curve in the same top top graph, which was overlapped with the movement of the target. Target movement of Y axis which are supposed not to be present because of only horizontal movement of the target was shown in the middle. The longitudinal line on the bottom is the lag distances between the target and the marker.

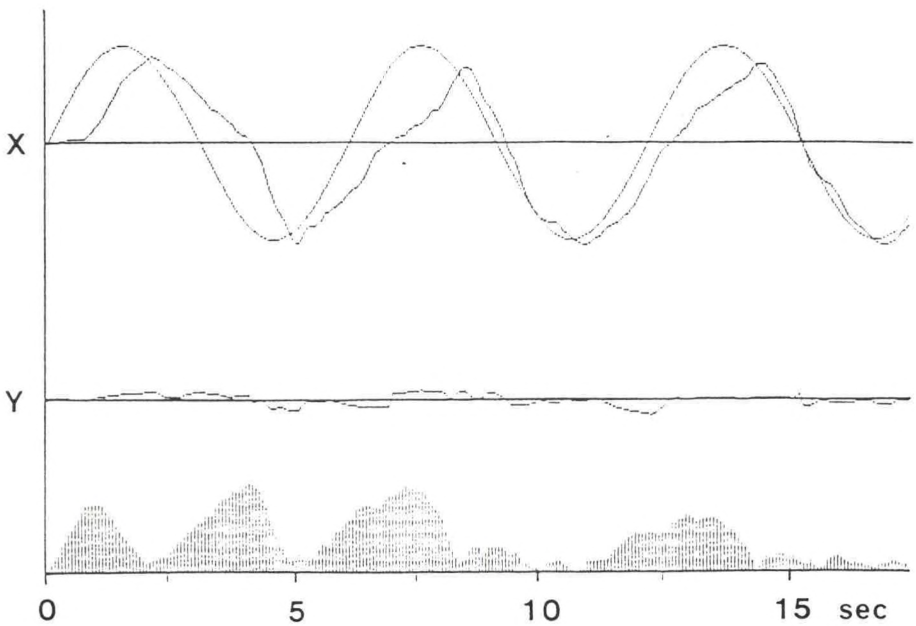


Figure 10. An Example of Computer Output

The lag distance indicates the level of capability of eye visual tracking and dexterity of hand motion. Mean error distances of 5 divers are shown in Figure 11.

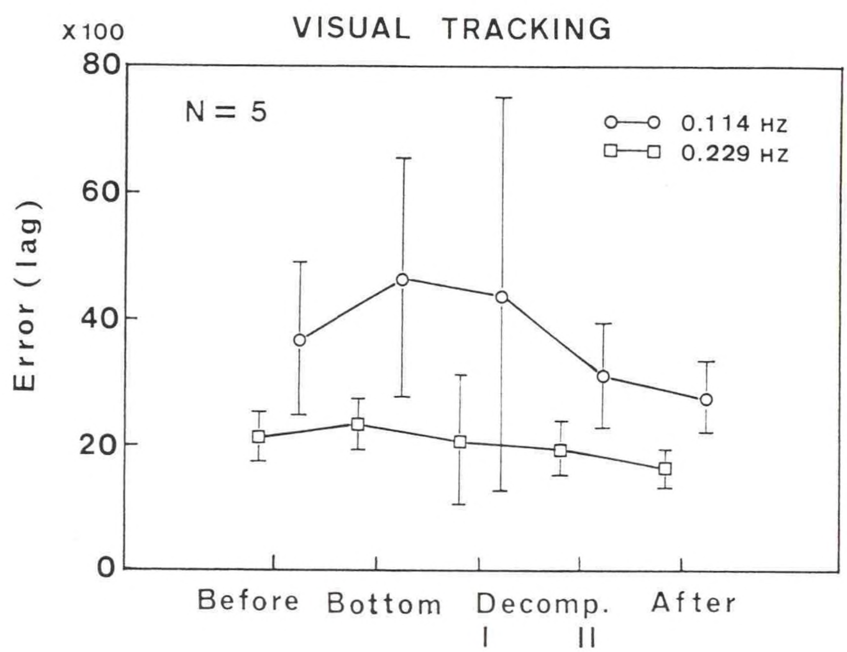


Figure 11. Result of Visual Tracking

The circle shows relatively low speed (0.114Hz) and the rectangle shows the higher speed (0.229Hz) of the target movement. Not much differences were noted in the low speed movement. However some increase of the lag distance was noted on the bottom and 250 meter on decompression. Standard deviation was large at that stages, so statistically not significant.

(5) Block Design, Digit Span and Maze Test

These test were performed only twice in pre and post experiment. Block design test is one of the subtest of WAIS Performance Test and it is to evaluate ability of visual spatial cognition and construction (Figure 12). Digit span test is one of the subtest of WAIS Verbal Test to evaluate capability of recent (short term) memory span (Figure 13). Forward and Backward span were assessed. Maze test is one of the subtest of WISC-R and it is designed to evaluate capability of insight and planning (Fig. 14).

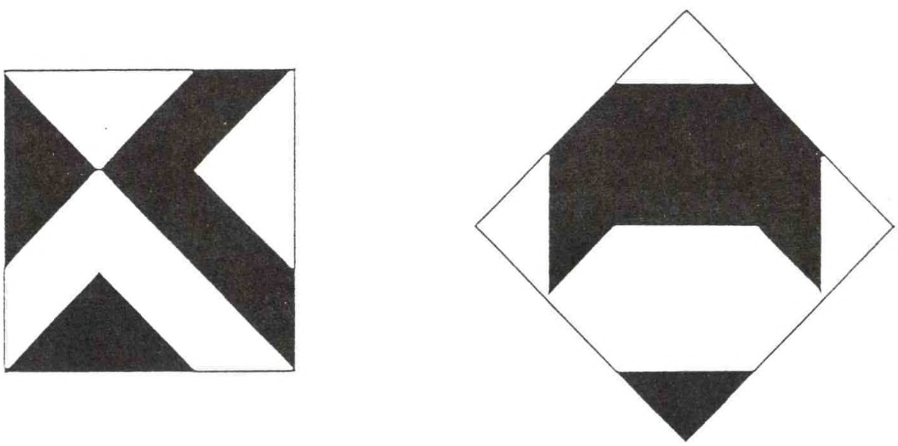


Figure 12. Examples of Block Design Pattern

順　唱	得点（桁数）	逆　唱	得点（桁数）
5 − 8 − 2 6 − 9 − 4	3	2 − 4 5 − 8	2
6 − 4 − 3 − 9 7 − 2 − 8 − 6	4	6 − 2 − 9 4 − 1 − 5	3
4 − 2 − 7 − 3 − 1 7 − 5 − 8 − 3 − 6	5	3 − 2 − 7 − 9 4 − 9 − 6 − 8	4
6 − 1 − 9 − 4 − 7 − 3 3 − 9 − 2 − 4 − 8 − 7	6	1 − 5 − 2 − 8 − 6 6 − 1 − 8 − 4 − 3	5
5 − 9 − 1 − 7 − 4 − 2 − 8 4 − 1 − 7 − 9 − 3 − 8 − 6	7	5 − 3 − 9 − 4 − 1 − 8 7 − 2 − 4 − 8 − 5 − 6	6
5 − 8 − 1 − 9 − 2 − 6 − 4 − 7 3 − 8 − 2 − 9 − 5 − 1 − 7 − 4	8	8 − 1 − 2 − 9 − 3 − 6 − 5 4 − 7 − 3 − 9 − 1 − 2 − 8	7
2 − 7 − 5 − 8 − 6 − 2 − 5 − 8 − 4 7 − 1 − 3 − 9 − 4 − 2 − 5 − 6 − 8	9	9 − 4 − 3 − 7 − 6 − 2 − 5 − 8 7 − 2 − 8 − 1 − 9 − 6 − 5 − 3	8
		順唱＿＿＿＿＋逆唱＿＿＿＿＝＿＿＿＿	

Figure 13.　Digit Span Test

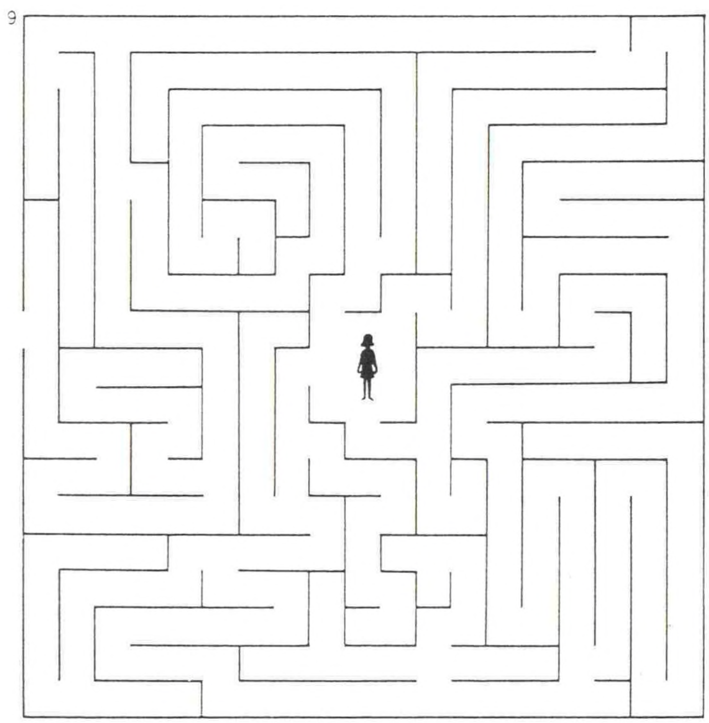


Figure 14.　An Example of Maze Test

The results of Block Design Test were shown in Figure 15. Mean scores of 5 divers are above normal average and the performance level is almost equal before and after experiment.

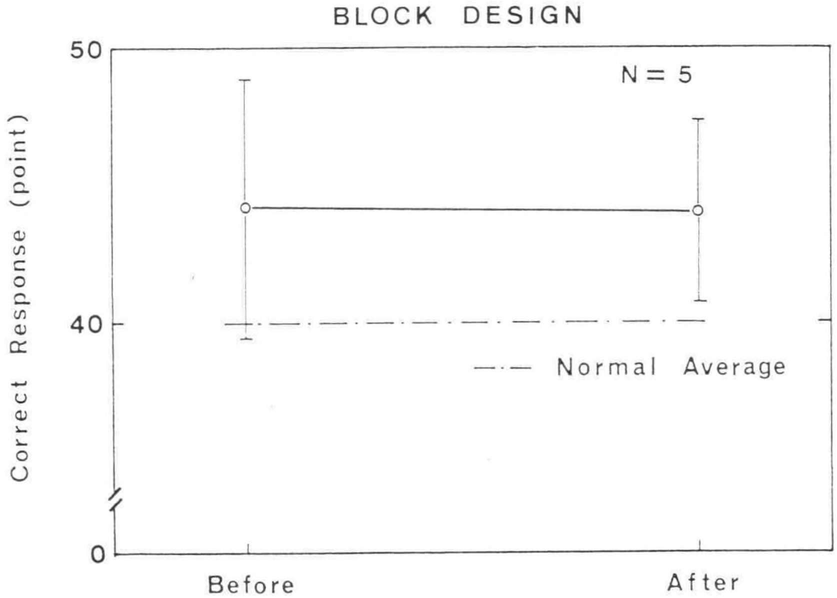


Figure 15. Result of Block Design Test

Figure 16 shows the results of Digit Span Test. Circle is forward and disk is backward task. They were essentially equal between before and after experiment.

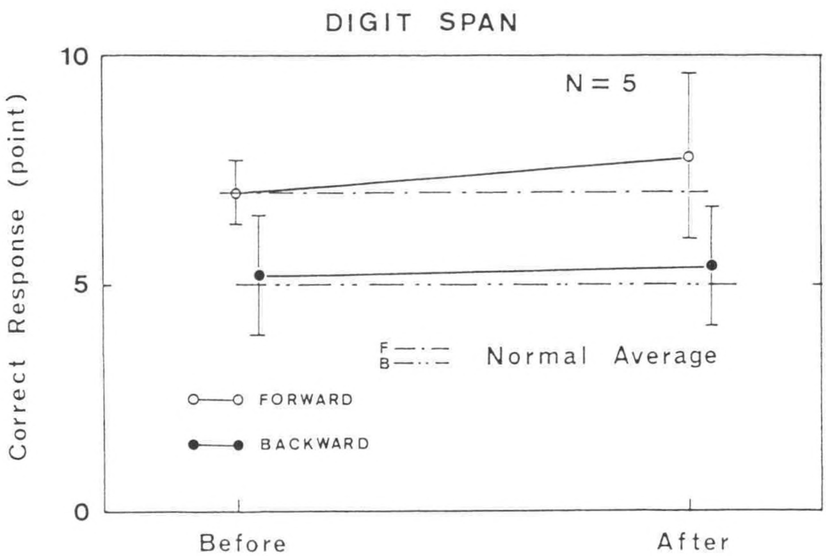


Figure 16. Result of Digit Span Test

Figure 17 is a part of the result of Maze Test. This is an example of the most difficult task (No.9). Mean time of 5 divers are about 60 seconds, there are no significant differences between before and after experiment.

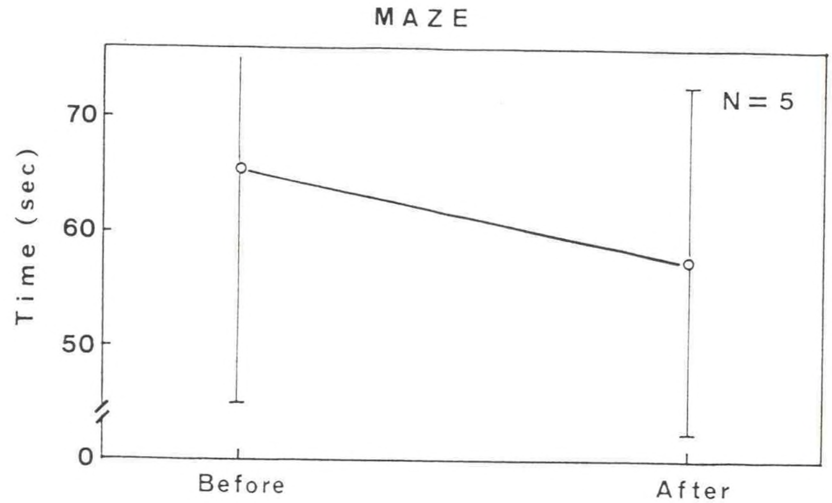


Figure 17. Result of Maze Test

DISCUSSION

In our investigation, most of our test did not show any significant changes through the experiment. Parts of Stroop Test and Visual Tracking Test show some deterioration of function on the bottom stage, but these changes disappeared with decompression. It is considered as the temporal deterioration of function which may suggest the minimal organic changes could be irreversible if they were present. No significant changes were noted in prior and post experiment in our test battery. We might not be able to rule out the possibility that our battery would not be sensitive enough to detect minimal deterioration of neuropsychological functions. Our results were consistent with Curly, although we did not evaluate visual focusing and physical abilities in which we found transient changes. On the bottom, selective attention in the struggled situation could be most deteriorated and coordination of visual and hand motion became poor insome subjects. It may suggest capabilities of work (or operation) could be limited to some extent with deteriorated function. We could not specify when those function would be deteriorated since we did not evaluate on the compression stage.

In some tests, higher scores were obtained with repetition probably due to learning effects which we may have to rule out (cancel) for the analyses of the results. We have to consider learning effect may mask the depletion of function. It may suggest the necessity to develop a test battery which do not have any learning effect.

SUMMARY

Neuropsychological evaluation is one of the important fields for diving. Methods and frequency of evaluations were not established yet. In our 330 meter saturation dive, our evaluations with developed test battery suggested some transient deteriorations were noted on the bottom. Some prospects could be suggested for future researches in this field.

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RENAL RESPONSE TO HEAD-OUT WATER IMMERSION IN KOREAN WOMEN DIVERS

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ABSTRACT

Head-out water immersion (HOI) induces profound diuresis and natriuresis, which may endanger the body fluid balance of a breath-hold diver during prolonged diving work. Several studies have shown that the renal response to HOI is attenuated in endurance-trained athletes. To investigate if a similar adaptation is acquired in professional breath-hold divers, we have evaluated renal responses to 3-h HOI in 5 Korean women divers and 11 nondiving housewives (controls). In both control and diver groups, the average urine flow during 3-h immersion was 4-fold greater and Na^+ excretion was 80 % greater than the respective preimmersion value. In all cases, the values for a given period were not significantly different between the two groups. The plasma levels of Na^+, K^+, osmolality and renal clearance of creatinine did not change significantly, indicating that filtered loads of water and solute were not altered by immersion. However, the osmolal clearance increased significantly and free water clearance changed from a negative value to a positive value during immersion, again the pattern of change being similar in the two groups. It is, therefore, concluded that the renal response to HOI is not changed in professional breath-hold divers (cachido).

INTRODUCTION

Negative pressure breathing and peripheral vascular compression during head-out water immersion (HOI) produce a redistribution of circulating blood with a relative central hypervolemia (1). This change in blood distribution, in turn, induces profound diuresis, natriuresis and in some instances kaliuresis (1). Such renal functional alterations could endanger the body fluid balance of a breath-hold diver during prolonged diving work. In breath-hold diving, divers are in the state of HOI while resting on the surface. A previous study on Korean women divers (2) indicated that more than 60 % of their total working time consisted of surface time. As a consequence of repeated negative pressure breathing for many years, these divers have developed higher inspiratory capacity and maximal inspiratory pressure than nondivers (3). Moreover, they exhibit many of the physiological characteristics of well-trained athletes (4). For instance, their maximal aerobic power (VO_2-max) is significantly greater (20 %) and heart rate and minute volume for a given oxygen consumption during exercise are significantly lower as compared to nondivers (5). Several studies (6-9) have shown that the renal responses to HOI are attenuated in endurance-trained athletes. If a similar adaptation is acquired in Korean women divers is not known. We therefore evaluated in the present study their renal response to HOI.

METHODS

Five professional women divers (Ama) and eleven nondiving housewives (control), who had no apparent cardio-renal diseases, were recruited from the same community in the village of Hae-Woon-Dae, Pusan, Korea. All of the diver subjects had been engaged in breath-hold diving work for more than 20 years, while none of the controls were experienced in rigorous physical training. The average physical characteristics were comparable between the two groups (Table 1). At the time of study, all subjects were ingesting a regular home diet. All diver subjects and most of control subjects were tested both in summer and winter.

The subject reported to the field laboratory at around 10:00 a.m. on the day of experiment, having eaten a breakfast 2-3 hours previously. After resting for 1 hour, sitting on a chair, the subject was immersed upto the neck in a constant temperature water tank in a seated position for 3 hours. Subjects were clothed in swimsuits. To normalize cold stress water temperature was adjusted to their own critical temperatures, determined as described before (10). The average critical water temperature was $28.1 \pm 0.4^{o}C$ for the diver group and $28.5 \pm 0.5^{o}C$ for the controls. Upon completion of immersion, the subject climbed out of the tank, dressed and rested on a chair for another 1 hour. The subject was not dehydrated and was not given any fluid during the 5-hour experimental period.

Urine samples were collected immediately before immersion, at the end of 3-hour immersion, and 1 hour following immersion. Blood samples were collected in the middle of each urine collection period. Urine and plasma samples were analyzed for creatinine (Wako Technical Bulletin No. 271-10509, Wako Pure Chemical Ind., Osaka, Japan), osmolality (Advanced Osmometer 3D2), and Na^+/K^+ (Radiometer Flame Photometer FLM3).

Statistical evaluation of the data was done using the Students t-test and all results were presented as the mean ± SE.

RESULTS

Fig. 1 illustrates the effect of HOI in water of critical temperature (28.1 ± 0.4°C for control; 28.5 ± 0.5°C for divers) on urine flow (V) and urine osmolality (Uosm) in control and diver groups. Data represent the mean of 16 experiments on 11 controls and 20 experiments on 5 divers. The V in the preimmersion period was approximately 1 ml/min in both groups. The average V during 3-h immersion was 3.5 ml/min in the control and 4.2 ml/min in the diver group, approximately 4-fold greater than the respective preimmersion value. Upon completion of immersion, the V reverted promptly to the preimmersion level. By contrast, the Uosm of both groups decreased markedly from about 700 mOsm/kg H_2O before immersion to 280 during immersion, and it quickly rose to about 80 % of the preimmersion level during the 1-h postimmersion period. The values of V and Uosm at a given period were not significantly different between the control and diver groups.

Fig. 2 depicts changes in urinary excretion of Na^+ (U_{Na} V) and K^+ (U_K V). In both control and diver groups, the U_{Na} V increased during immersion to a value approximately 80 % above the preimmersion level (151 ± 24 uEq/min for controls and 169 ± 16 for divers) and it quickly reverted during the postimmersion period. However, the U_K V changed not so extensively by immersion. In all cases, the values for a given period were not significantly different between the two groups.

Table 2 summarizes plasma levels of Na^+ (P_{Na}), K^+ (P_K) and osmolality (Posm) and endogenous creatinine clearance (Ccr), determined in 5 experiments for the control and diver groups. In both groups, the P_{Na}, P_K, Posm and Ccr did not undergo significant variations during the experiment, thus filtered loads of water and solute remained unaltered. This, in turn, suggest that alterations of water and solute excretions by immersion were associated with changes in renal tubular transport functions.

Fig. 3 shows the effects of immersion on the osmolar clearance (Cosm) and the free water clearance (C_{H2O}). In both control and diver groups, the Cosm increased significantly and the C_{H2O} changed from a negative value (-1.1 ml/min for controls; -1.2 for divers) to a positive value (1.2 for controls; 1.6 for divers) during immersion. The magnitude of change in both variables was not significantly different between the two groups.

Fig. 4 compares the net changes in urine flow (ΔV) and osmolar clearance (ΔCosm) during immersion. In both control and diver groups, the V was about 3 ml/min but the Cosm was only about 0.5 ml/min. These indicate that over 80 % of the immersion diuresis was achieved by an increase in free water excretion and less than 20 % by an increase in solute excretion.

DISCUSSION

The Primary purpose of the present study was to evaluate if there is any change in the body fluid volume regulation during HOI in professional Korean women breath-hold divers. The results indicated that their renal responses to HOI were not different from non-diving housewives' in both nature and magnitude. In both groups, the urine flow increase by about 4 folds during 3-h immersion (Fig. 1) and this was mainly due to an increased free water excretion (Fig. 4). The sodium excretion was also increased by immersion, but only to about 80 % above the preimmersion level (Fig. 2). These response to HOI are similar to those observed by others (11-13) in normally hydrated subjects.

The lack of changes in renal response to HOI in divers is interesting in view of the fact that the immersion diuersis and natriuresis are attenuated in endurance trained athlets. Böning et al (6-8) have observed a delayed and reduced output of fluid and sodium in athletes during immersion and proposed that an incomplete depression of ADH and aldosterone secretions and a delayed onset of increased glomerular filtration rate would be the underlying mechanisms. Similarly, Claybough et al. (9) have shown that the urinary sodium and volume excretions during immersion were substantially lower in trained (swimmers and runners) than in untrained subjects and that the urinary ADH was significantly declined by immersion in untrained subjects, but not in trained subjects. They therefore speculated that trained subjects have an increased osmotic sensitivity (i.e., reduced osmotic threshold) and a decreased volume sensitivity for ADH release, which may be an adaptive mechanism of body fluid conservation. As mentioned earlier, the VO_2-max of Korean women divers is only about 20 % greater than that of nondivers (4, 5). Thus, one may suspect that the degree of physical training in these divers may not be strong enough to induce such an adaptation as observed in athletes. However, in the study of Claybough et al. (9), the VO_2-max of runners was significantly greater than that of untrained, but that of swimmers was not. They, in fact, have pointed out that the attenuated renal response in athletes may not be attributed solely to endurance training. Thus, the reasons for the difference in renal response to HOI between divers and athletes are not apparent.

Several studies on humans (14, 15) and dogs (16-18) have demonstrated that a fluid shift into vascular compartment occurs during immersion. The diuretic response acts to minimize the plasma hypervolemia which would otherwise be quite massive (18). An adequate renal function is thus necessary to prevent stress to the circulatory system. In this respect, a normal renal response to immersion may be important for a diver in prolonged diving work.

Simultaneous measurements of fluid shifts and renal function during immersion are required to establish the validity of this view.

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Table 1. Subject characteristics

	Age (yr)	Ht (cm)	Wt (kg)	SFT* (mm)	Tcw+ (°C)
Control (N=11)	39.4 ±1.3	156.0 ±1.4	58.0 ±2.0	8.6 ±0.9	28.1 ±0.4
Diver (N=5)	39.6 ±3.5	155.0 ±3.6	53.4 ±0.9	7.3 ±1.0	28.5 ±0.5

* mean subcutaneous fat thickness determined by the method of Allen et al. (19).

\+ critical water temperature

Values represent the mean ± SE

Table 2. Plasma solute concentrations and creatinine clearance

		Preimmersion	Immersion	Postimmersion
P_{Na} (mEq/l)	Control	147 ± 2	145 ± 3	142 ± 3
	Diver	148 ± 2	148 ± 2	147 ± 2
P_{K}^{+} (mEq/l)	Control	7.1 ± 0.6	8.3 ± 1.7	8.7 ± 2.7
	Diver	6.4 ± 0.5	6.3 ± 0.3	6.2 ± 0.2
Posm (mOsm/kg H_2O)	Control	292 ± 2	293 ± 1	293 ± 2
	Diver	300 ± 5	297 ± 4	294 ± 4
Ccr (ml/min)	Control	123 ± 6	120 ± 11	123 ± 19
	Diver	124 ± 8	114 ± 13	96 ± 9

Values represent mean ± SE of 5 subjects in each group

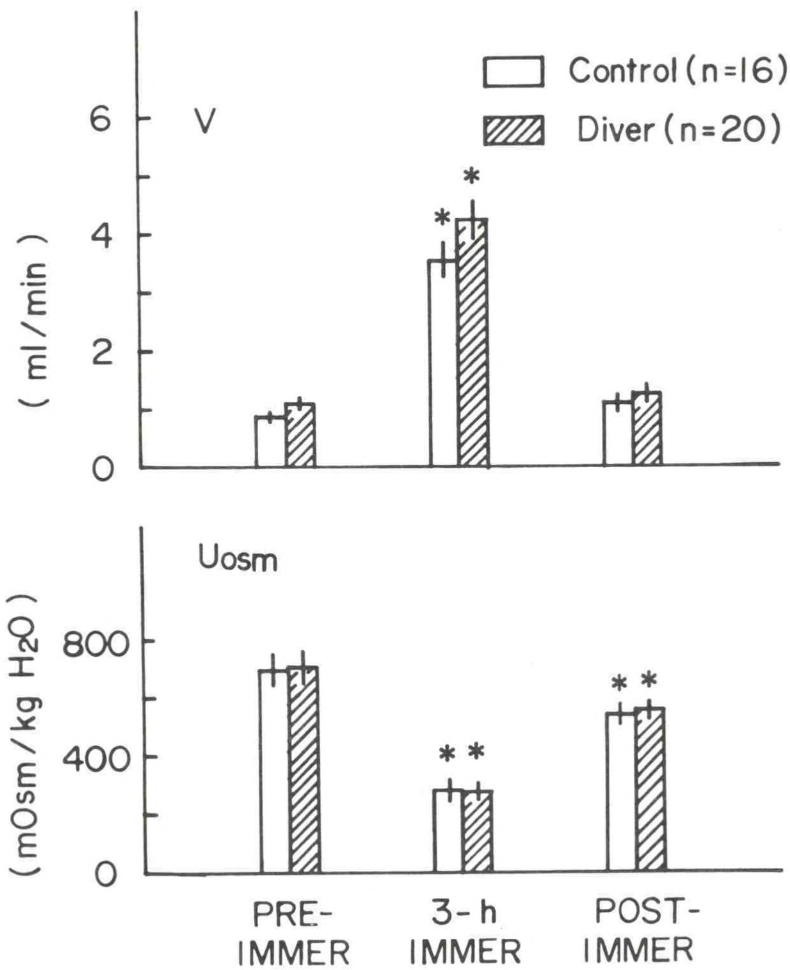

Fig. 1. Average rate of urine flow(V) and urine osmolality (Uosm) before, during and after immersion.
Values represent mean ± SE of 16 experiemnts in 11 controls and 20 experiments in 5 divers.
* significantly different from the preimmersion and postimmersion values

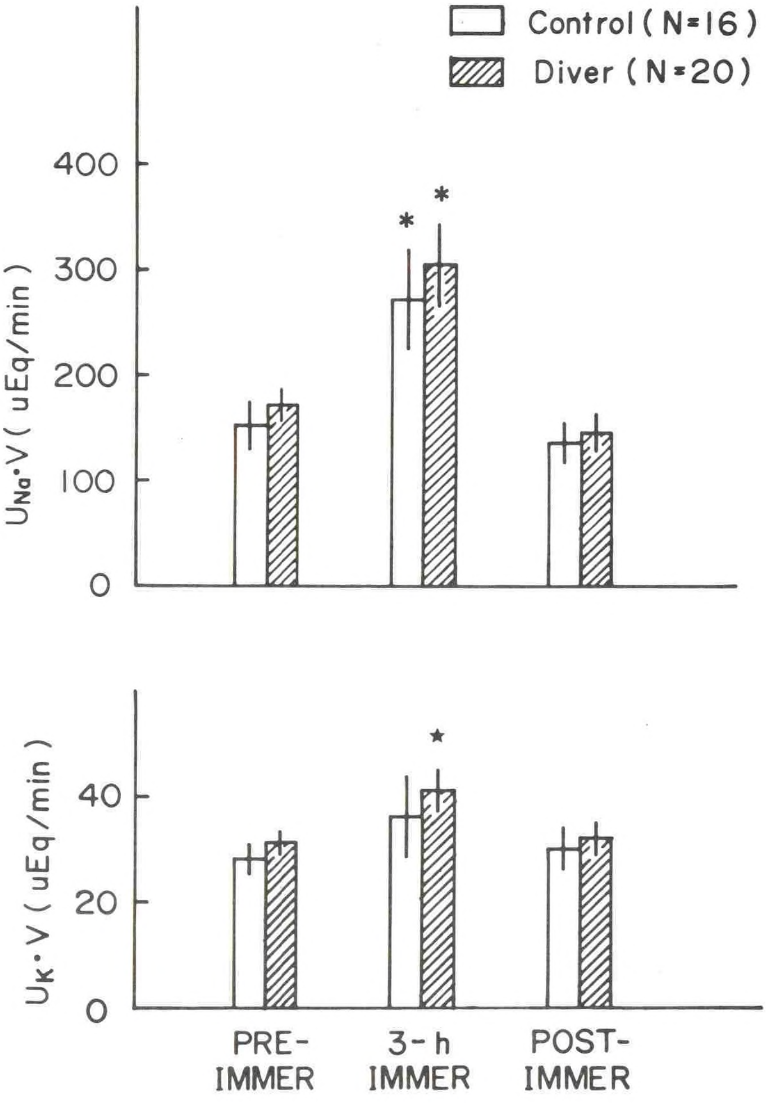

Fig. 2. Average urinary excretion rates of Na^+ and K^+ before, during and after immersion.
Values represent mean ± SE of 16 experiments in 11 controls and 20 experiments in 5 divers.
* significantly different from the preimmersion and postimmersion values

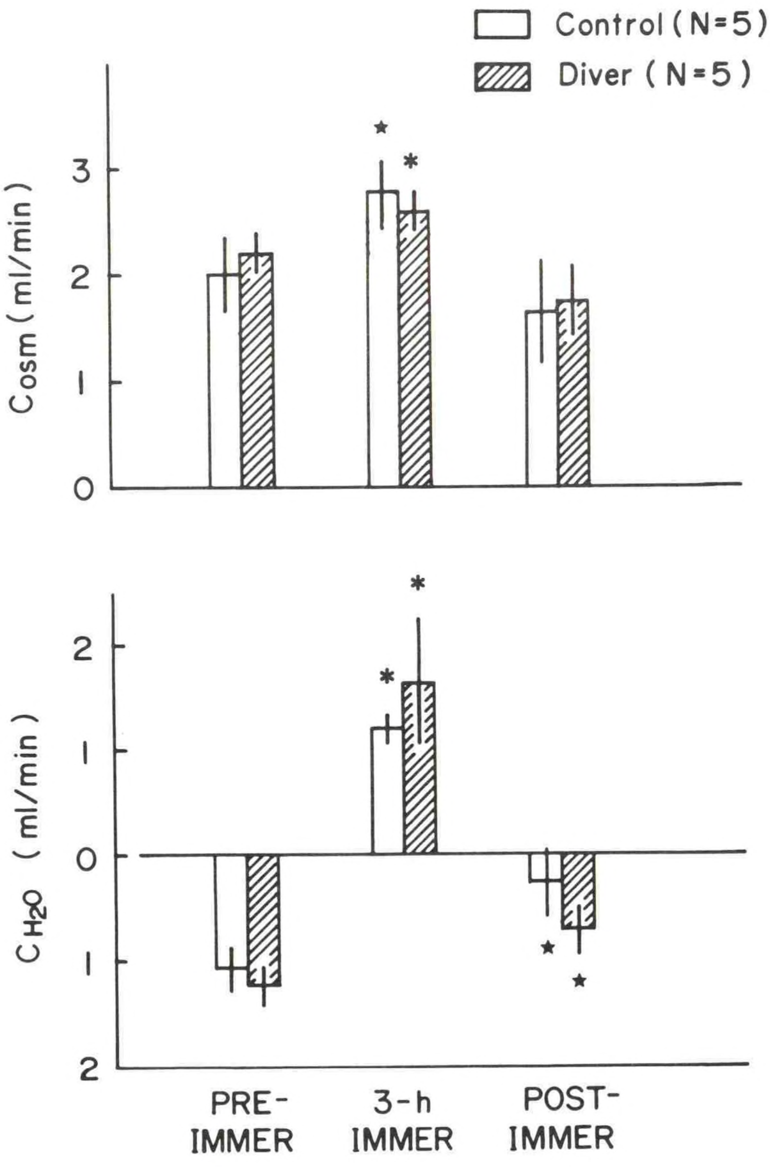

Fig. 3. Average values of osmolar clearance (Cosm) and free water clearance (C_{H2O}) before, during and after immersion. Values represent mean ± SE of 5 subjects in each group.
* and + : significantly different from the preimmersion value with p,0.05 and p<0.10, respectively.

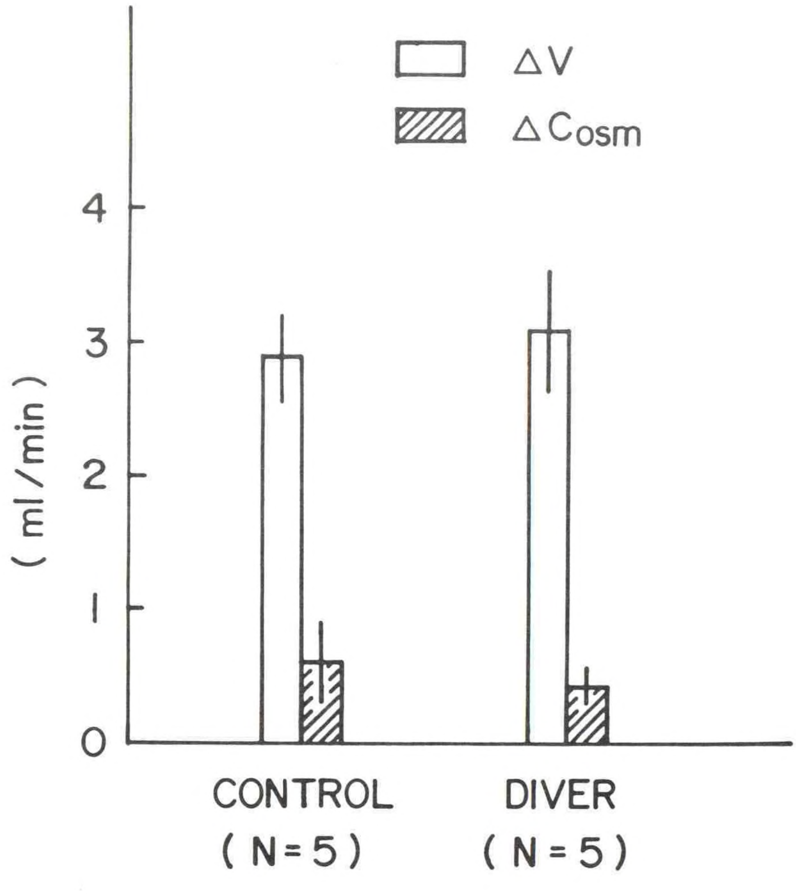

Fig. 4. Average increase in urine flow (ΔV) and osmolar clearance (ΔCosm) during immersion.
Values represent mean ± SE of 5 subjects in each group.

HEART RATE RESPONSES TO BREATH-HOLD DIVES IN JAPANESE MALE FUNADO DIVERS

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ABSTRACT

Bradycardia has been considered as a consistent cardiac response to breath-hold dive in both humans and animals. However, the mechanisms underlying this phenomenon are yet to be defined. No report has dealt with a continuous recording of heart rate during the prolonged daily diving activity in professional human breath-hold divers. Since the depth and seawater temperature as well as underwater exercise may be the factors to modify the heart rate response during diving, the present study was designed to examine continuous heart rates, depth, skin temperature, and water temperature during breath-hold dives in male funados (assisted divers) who wore wet-suits and descended to >10 m deep with a 7-10 kg weight. The average dive frequency was 33 times a day during a four-h work shift. A usual bradycardiac response was observed in all divers to breath-holding in a laboratory test (swimming pool). The heart rate response during actual daily dives, however, had a large individual variation; either increased, decreased, or no change. The response was independent of the skin temperature and depth. Each individual had his own consistent response to the breath-hold dive throughout the daily shift.

INTRODUCTION

According to the population survey in Japan (Takeuchi and Mohri, 1987), the total number of the ama in 1960's to 1970's was stationary and a small increase has been reported during the last decade. In 1921 the proportion of the male ama (48%) was almost equal to that of the female ama (52%), but it tended to decrease before, during, and just after the World War II (30%) (Yousef, Shiraki, and Wolfe, 1986). However in these two decades the male ama has been increasing in number, whereas the female ama has been decreasing, resulting in that the population female ama became one-fourth of that of male divers in 1987. Sixty-four% of professional divers in Japan, defined as divers who engage diving more than 4 months a year, are diving with breath-holding (Takeuchi and Mohri, 1987).

Although many studies have been conducted to understand the physiology of breath-hold diving in the ama, the daily diving pattern is not fully documented as yet. There are reports of diving patterns during the professional daily activities (Shiraki et al., 1985; Park et al., 1983; Scholander et al., 1962), but the depth of dives, changes in body temperature, and other physiological parameters such as heart rate have been obtained under a limited and unnatural condition of the ama (Shiraki et al., 1986; Park et al., 1983). Recently Hong et al. (1991) reported an automatic dive log (ADL) for use of recording natural diving pattern of the ama. Thus, the ADL combined with a computer allows us to monitor four sets of continuous data into a logger data memory; depth, sea water temperature, skin temperature, and heart rate.

Generally, a fin-kicking is an unavoidable exercise for a wet-suited diver during diving and the exercise in turn may accelerate the heart rate during diving. Thus, the effect of breath-hold per se during natural diving has been considered difficult to examine. A funado descends passively without fin-kicking by an assistance of a weight, thus we may avoid the effect of exercise on the heart rate response during observation of the daily diving activity in the ama.

In the present study, therefore we designed to monitor continuous changes in heart rate and depth during unrestricted daily diving activities in the funado and examined if the bradycardic response to breath-hold was also the case in professional dives during daily dives.

METHOD

FUNADO.

Three funado divers were volunteered in the present study at an ama village in Chiba Prefecture, Japan during August, 1991. Their physical characteristics shown in Table 1. We requested the ama not to change their usual life activity during our observation days. Their individual houses were located close to the shore and they left the shore at 10 o'clock by a motor boat to reach the diving ground in 5-10 min. The ama dived from the boat and ascended with the help of an weight of 7-10 kg but ascended without assistance. While floating on the surface, they sometimes dived without the assistance (kachido type dive). The average work time in a day of the present divers was about 4 hours. Their total dive frequency was 25 to 50 (average 33) times a day, including kachido-type dives. Observations were made during two consecutive days. On the first day we requested the ama to dive with their usual way; they descended with the weight of 7 kg and used fins (fin-kicking) to achieve a descending speed (0.8 to 1.0 m/sec) (Table 3). On the second day, we requested the ama not to do fin-kicking when they descended, accordingly they used a 10 kg weight to attain the usual descending speed (Table 3). One observer was always watching an assigned diver so that the observer could keep recording all diving profiles of the diver, and two observers with SCUBA were always attending the ama to watch the diving patterns.

AUTOMATIC DIVE LOG

A battery-operated four-channel ADL with the dimension of 175 mm x 95 mm x 35 mm, weighed 320 g (Vine Bionic System, Tokyo) was outfitted to each ama at the shore before he was on the boat. The ADL measured every 1.5 second the depth, chest skin temperature, seawater temperature (air temperature while the ama on the boat), and R-R intervals and stored the 4-hours' data. All data were transferred into a computer (PC-9801 RA, NEC, Tokyo). The heart rate in beats/min was converted from the R-R intervals. The electrodes for electrocardiogram for R-R intervals were attached in the position of the standard II lead and were secured with a specially arranged glue (tincture benzoin; benzoin 10g, Aloe 2 g, Storax 8g, and Balsam Tolu 4g in 100 ml of 77% ethyl alcohol) and adhesive tape (OA-430, Fukuda, Tokyo) to prevent seawater from touching with the electrode. A copper-constantan thermocouple was attached to the chest skin and secured with water vapor permeable surgical tape (Hogi, Tokyo).

The thermocouple and electrodes were kept attached until the end of the observation.

LABORATORY OBSERVATION

A preliminary study was carried out on a separate day to test the change in heart rate during breath-holding under a laboratory condition. Heart rate was monitored during head-up immersion in two difference water temperatures. In the first the ama immersed in a swimming pool of which water temperature was closed to that of the actual sea water (26°C) and the heart rate response to breath-hold was compared between face-up in air and face-immersed. In the second the ama immersed in water of 22°C in a large bath tab (150 cm x 90 cm x 90 cm) and heart rate response to breath-hold was measured during face-immersion. The air temperature was 27°C. During the test the divers wore their own wet suits and goggles.

RESULTS

LABORATORY OBSERVATION

Breath-hold in water exhibited bradycardia during either face-immersed in water or face-up in air. Heart rate decreased gradually to the end-point of the breath-hold and quickly returned to the original level upon breathing. The magnitude of the bradycardia during breath-hold was almost the same both with face-up in air and face-immersed. Moreover water temperature did not affect the magnitude of bradycardia during holding the breath (Fig. 1). These results were in agreement with earlier observations that simple face immersion alone has been demonstrated to produce the same degree of bradycardia as diving (Brick, 1966; Olsen, Fanestil, and Scholander, 1962).

DAILY DIVES

Although each subject showed a usual bradycardic response to breath-hold in the laboratory condition, this cardiac response was not always the case during the daily diving activity.

The first ama H. S. showed a typical bradycardic response to every dive (Fig. 2). Heart rate was increased when the ama performed a relative hyperventilation several times 20 - 30 sec prior to the dive on the boat. The heart rate decreased quickly when the ama held the breath to dive with the assistance of the weight. When the ama reached the bottom he moved around to look for abalones or other shell fishes for about 20 sec. The heart rate was increased when the ama arrived at the bottom and further increased during ascending. Upon surfacing the heart rate was kept increasing to become higher than the basal level. Then the heart rate returned to the basal level within one min. This cardiac response was consistent in every dive. The average reduction in the heart rate during breath-hold diving was 20 beats/min from the base line and 33 beats/min from the peak heart rate immediately prior to the dive (Table 2).

The second diver K.S. showed a bradycardic response during dive, but the pattern was somewhat different with the first diver. A tachycardia was followed by a short-term bradycardia at the bottom and then followed by a tachycardiac response during ascending (Fig. 3). The average reduction in the heart rate was

7 beats/min from the base line and 24 beats/min from peak value immediately prior to the dive (Table 2). Fig. 4 shows the effect of fin-kicking during descending on the heart rate response. The bradycardic response was biggest when the ama descended with a 10 kg weight without fin-kicking (Fig. 4, B), least when the ama performed a kachido-type dive (no assistance) (Fig. 4, C), and intermediate when the ama descended with a 7 kg weight and fin-kicking (Fig. 4, A). These results may indicate that an exercise (fin-kicking) attenuates the intraindividual response of bradycardia to breath-hold during dive. The tachycardic response upon surfacing was consistent regardless of the diving pattern.

The third ama N. S. showed virtually no bradycardic response during breath-hold diving (Fig. 5). A transient tachycardic response on surfacing was also the case in this ama. The cardiac response was not affected during descending with or without the weight (Fig. 5).

DISCUSSION

What caused these divergent responses among the ama? Many factors have been proposed as the etiological mechanisms for the bradycardia associated with breath- holding.

1. Stimulation of the skin of the face by the water (Brick, 1966). In the present study there was no individual difference in seawater temperature (~24°C), therefore, the effect of skin temperature is unlikely to assume as the reason for the different cardiac responses among the present ama.

2. Intensity of exercise (Salzano, Rausch, and Saltzman, 1970; Stromme, Kerem, and Elsner, 1970). To avoid exercise during descend by fin kicking, the funado divers were requested to avoid any exercise during descending, and the heart rate response was compared with that with exercise with fin kicking during assisted descend. The heart rate response was consistent during each diving activity throughout the day. Probably the exercise intensity may not be the contributing factor for the inter-individual difference in the cardiac response. However, it is apparent from the present observation (Fig. 4) that exercise modifies the magnitude of the intra-individual cardiac response to breath-hold during dive.

3. Individual difference in the chemoreceptor sensitivity, difference in PO_2 and PCO_2 (Olsen, Fanestil, and Scholander, 1962). It is beyond the speculation regarding this, however the difference in responsiveness of the chemoreceptor does not explain a wide divergent individual responses of heart rate from bradycardia to tachycardia during breath-hold diving.

4. Pressure per se also may attenuate heart rate (Hong, et al., 1973), but the pressure difference of the individual amas is very small (from 0.8 to 1.5 atmospheres absolute, ATA) in comparison with the experimentally produced hyperbaria of 12.5 AT where bradycardia was observed (Hong et al., 1973).

In conclusion, none of these factors completely explains the divergent inter-individual differences in cardiac response in the present ama.

In summary, the bradycardiac response is not always the case in the amas during their daily work. An extensive investigation is warranted to elucidate why the heart rate response to breath-hold is different between individuals and why the response to breath-hold during actual dives is dissociated with that in the laboratory condition.

It is of prime importance to know whether these individual difference in the cardiac response of the ama is related with the peripheral vasoconstrictor response, because the vasomotor reflex is directly associated with thermal problems of the ama.

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Table 1. Physical characteristics of the funado

Subject	Age (yr)	Weight (kg)	Height (cm)	Dive frequency (time/day)
H. S.	53	61	157	25-27
K. S.	40	72	170	24-32
N. S.	31	70	163	42-51

Table 2. Cardiac responses in the funado

Subject	Dive frequency per day	Heart rate, beats/min			
		Base line	Before	Bottom	Surface
H.S. (1)	25	81.0 ±0.5	96.4 ±1.4	63.1* ±1.0	97.3* ±1.1
H.S. (2)	27	82.4 ±0.6	101.6 ±1.1	58.7* ±1.1	101.6* ±0.9
K.S. (1)	24	76.6 ±1.4	87.3 ±1.7	69.1* ±1.2	96.6* ±1.1
K.S. (2)	32	77.0 ±1.1	93.2 ±1.6	69.9* ±1.1	100.3* ±1.3
N.S. (1)	42	81.7 ±0.6	87.6 ±1.0	74.9* ±1.2	115.4* ±0.5
N.S. (2)	51	82.0 ±0.9	99.2 ±1.0	80.1 ±1.8	117.7* ±0.6
Grand mean ±SE	33.5 ±4.4	80.1 ±1.1	94.2* ±2.4	69.3* ±3.2	104.8* ±3.8

Values are means ± SE. Values for grand mean are means ± SE for two days' measurements in three subjects (N = 6). Base line heart rate is average resting heart rate, before heart rate is the peak heart rate immediately prior to the dive, bottom heart rate is the nadir heart rate at bottom, and surface heart rate is the peak heart rate immediately after surfacing. The number in the parenthesis, 1 for observations of the first day when the ama dived with a 7 kg weight with fin-kicking during descending, 2 for observations of the second day when the ama dived with a 10 kg weight without fin-kicking during descending. *P<0.05 vs base line.

Table 3. Diving profile of the funado

Subject	Dive freq.	Depth (m)	dive time (sec)	Descending time (sec)	Descending speed (m/sec)	Ascending time (sec)	Ascending speed (m/sec)	Bottom time (sec)
H.S. (1)	25	8.5 ±0.4	45.6 ±1.0	10.2 ±0.6	0.85 ±0.02	11.6 ±0.7	0.75 ±0.02	23.8 ±0.9
H.S. (2)	27	9.8 +0.5	43.9 ±0.9	10.4 ±0.6	0.96 ±0.02	12.5 ±0.7	0.81 ±0.02	21.1 ±1.1
K.S. (1)	24	8.4 ±0.5	55.8 ±1.5	15.0 ±1.0	0.58 0.02	13.3 ±0.8	0.65 ±0.02	27.6 ±1.3
K.S. (2)	32	11.2 ±0.6	54.1 ±1.0	16.6 ±0.7	0.71 ±0.02	15.9 ±0.7	0.70 ±0.03	22.5 ±1.8
N.S. (1)	42	8.3 ±0.4	40.0 ±0.8	10.4 ±0.4	0.78 ±0.01	9.5 ±0.4	0.88 ±0.02	20.1 ±0.9
N.S. (2)	51	10.3 ±0.4	41.7 ±0.8	13.2 ±0.5	0.79 ±0.02	12.0 ±0.5	0.88 ±0.02	16.6 ±1.0
Grand mean ±SE		9.4 ±0.5	46.9 ±2.7	12.6 ±1.1	0.78 ±0.05	12.5 ±0.9	0.78 ±0.04	22.0 ±1.5

Values are means ± SE. Values for grand mean are means ± SE for two days' measurements in three subjects (N = 6). Dive freq. is number of dive per day. The number in the parenthesis, 1 for observations of the first day when the ama dived with a 7 kg weight with fin-kicking during descending, 2 for observations of the second day when the ama dived with a 10 kg weight without fin-kicking during descending.

FIGURE LEGENDS

Fig. 1. Heart rate responses to breath-holding during water immersion. A, breath-holding during face-up immersion in water of 26°C; B, breath-holding during face-down immersion in water of 26°C; C, breath-holding during face-down immersion in water of 22°C.

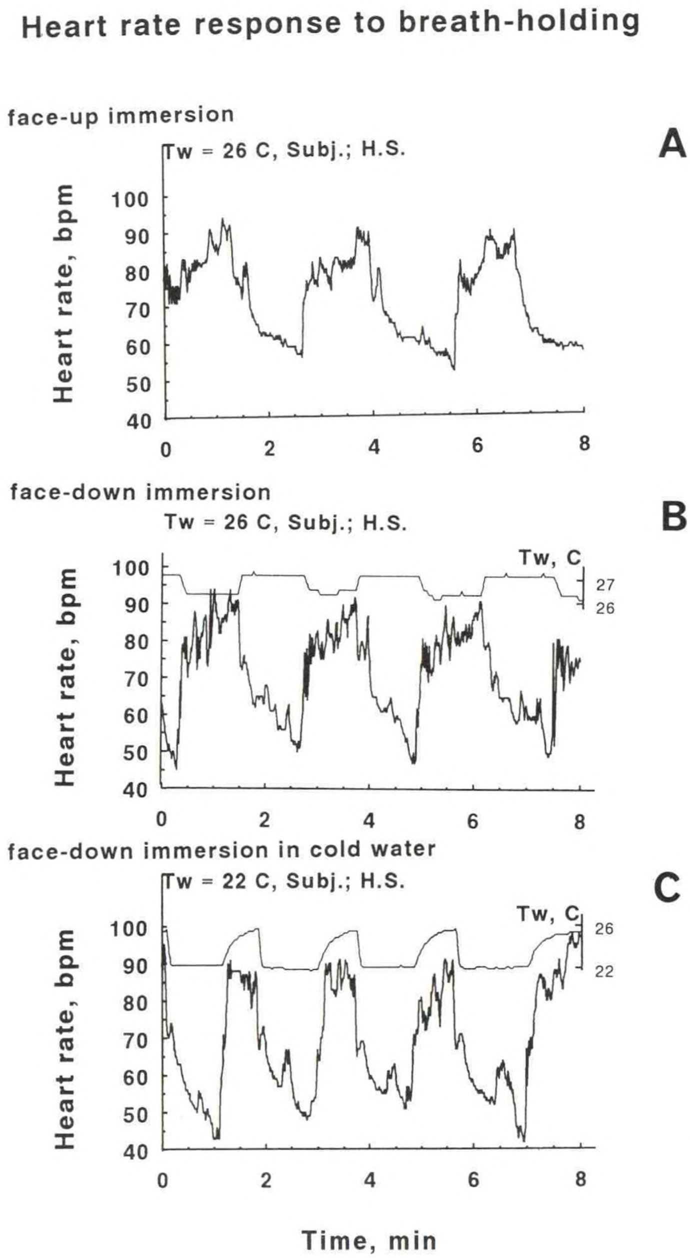
Fig. 2. Typical bradycardic response in subject H. S. during funado-type dive without fin-kicking. Upper panel (A) shows a consistent bradycardic response during diving. Lower panel (B) shows a typical bradycardia with the time-enlarged scale of the upper panel. Solid line represents heart rate and dashed line represents depth.

Fig. 3. Effect of fin-kicking (exercise) on heart rate response during dives. A, an incomplete bradycardic response when the ama (K. S.) dived with a 7 kg weight and fin-kicking (incomplete funado-type dive); B, a bradycardic response when the ama dived with a 10 kg weight and without fin-kicking (complete funado-type dive); C, least bradycardic response when the ama dived without weight and with fin-kicking (kachido-type dive).

Fig. 4. An incomplete bradycardic response in subject K. S. during diving with fin-kicking (exercise). Explanations are same as in Fig. 2.

Fig. 5. No bradycardic response in subject N. S. during funado dive without fin-kicking. Explanations are same as in Fig. 2.

Fig. 1



Heart rate response to breath-holding
face-up immersion
Tw = 26 C, Subj.; H.S.
A
Heart rate, bpm
100
90
80
70
60
50
40
0
2
4
6
8
face-down immersion
Tw = 26 C, Subj.; H.S.
B
Tw, C
27
26
Heart rate, bpm
100
90
80
70
60
50
40
0
2
4
6
8
face-down immersion in cold water
Tw = 22 C, Subj.; H.S.
C
Tw, C
26
22
Heart rate, bpm
100
90
80
70
60
50
40
0
2
4
6
8
Time, min

Fig. 2

w/o fin-kicking

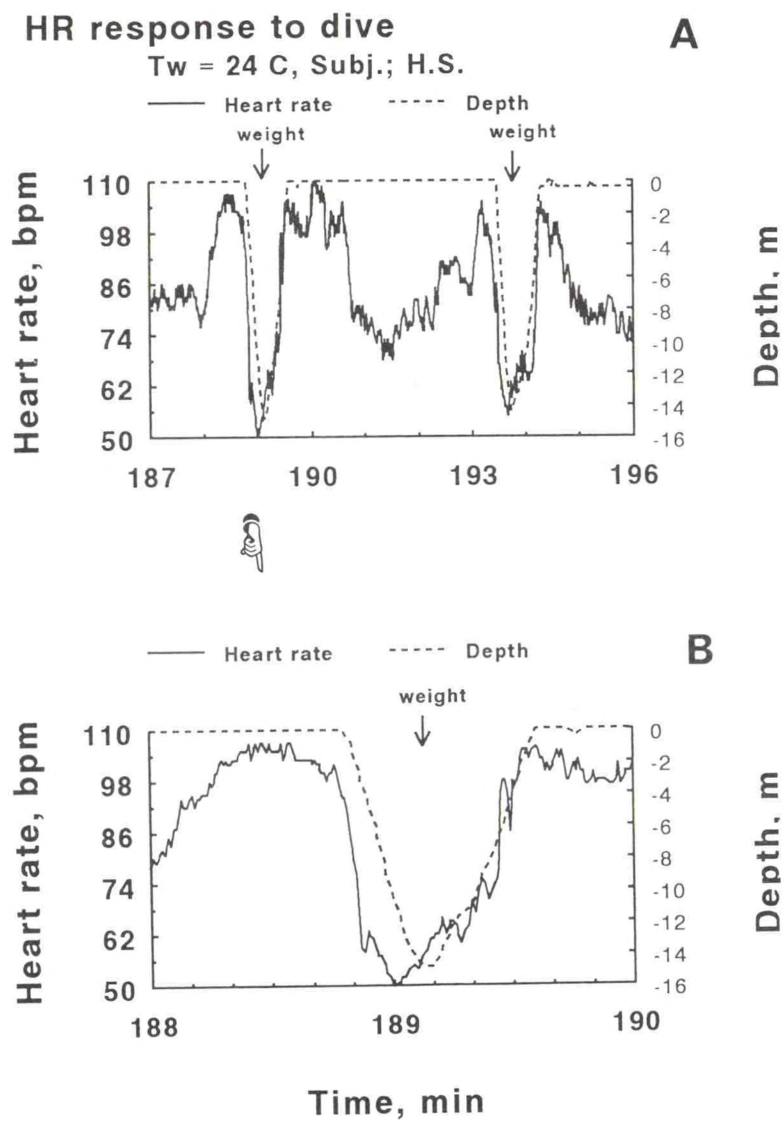
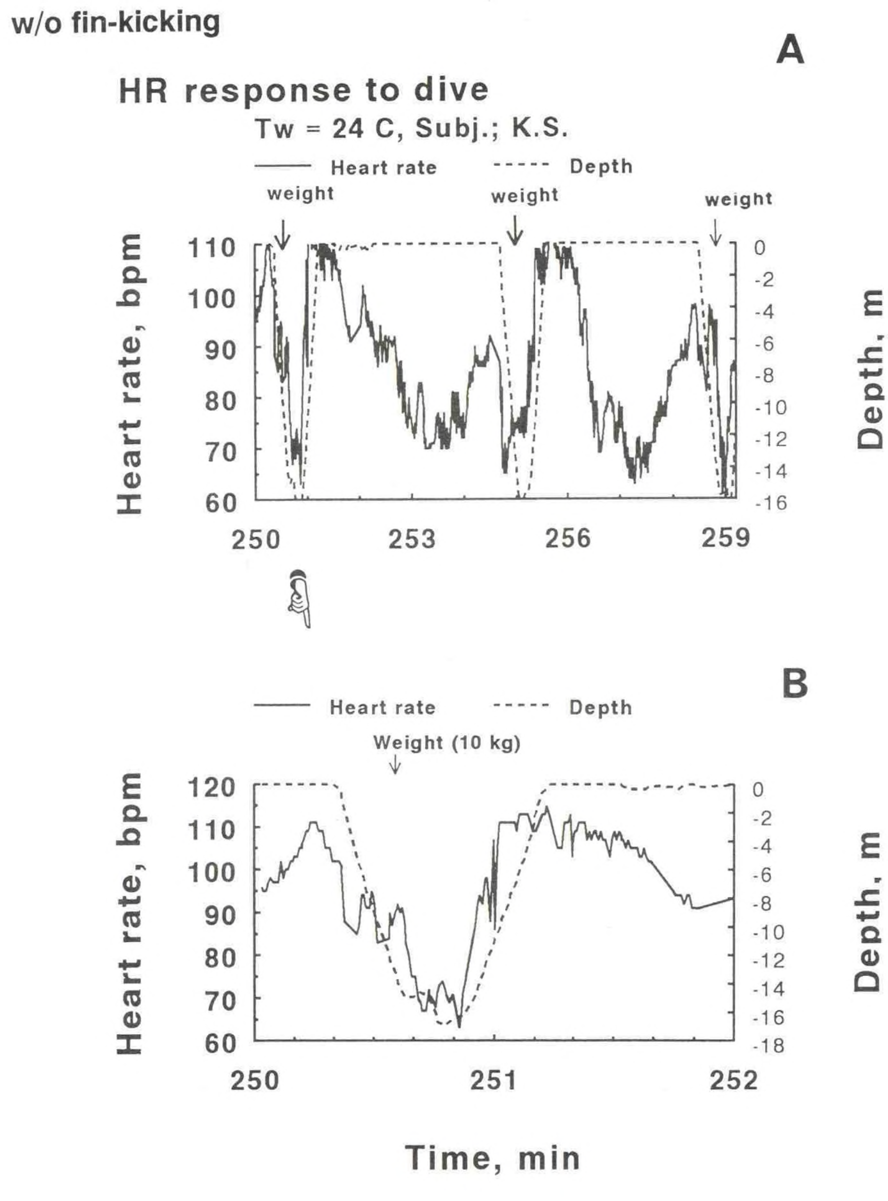
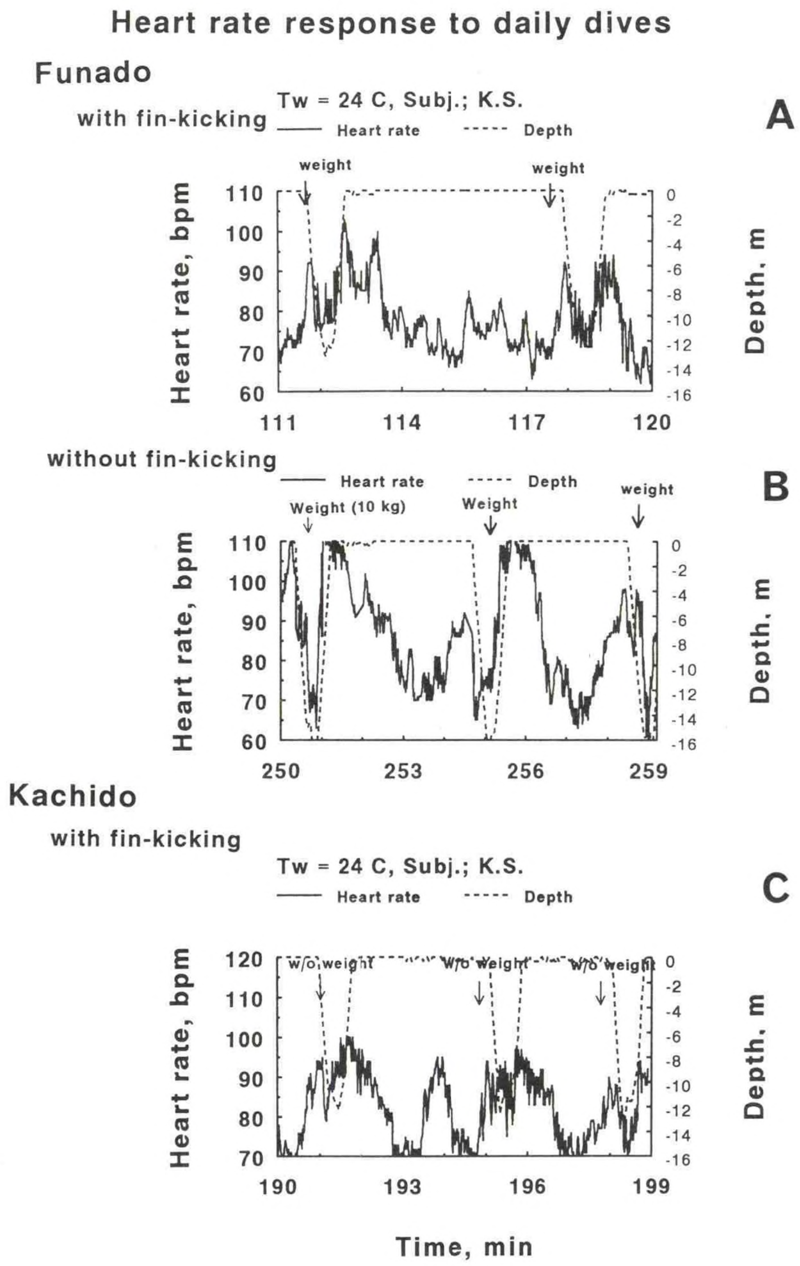


Fig. 3



w/o fin-kicking
A
HR response to dive
Tw = 24 C, Subj.; K.S.
Heart rate
Depth
weight
weight
weight
Heart rate, bpm
Depth, m
110
100
90
80
70
60
0
-2
-4
-6
-8
-10
-12
-14
-16
250
253
256
259
B
Heart rate
Depth
Weight (10 kg)
Heart rate, bpm
Depth, m
120
110
100
90
80
70
60
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
250
251
252
Time, min

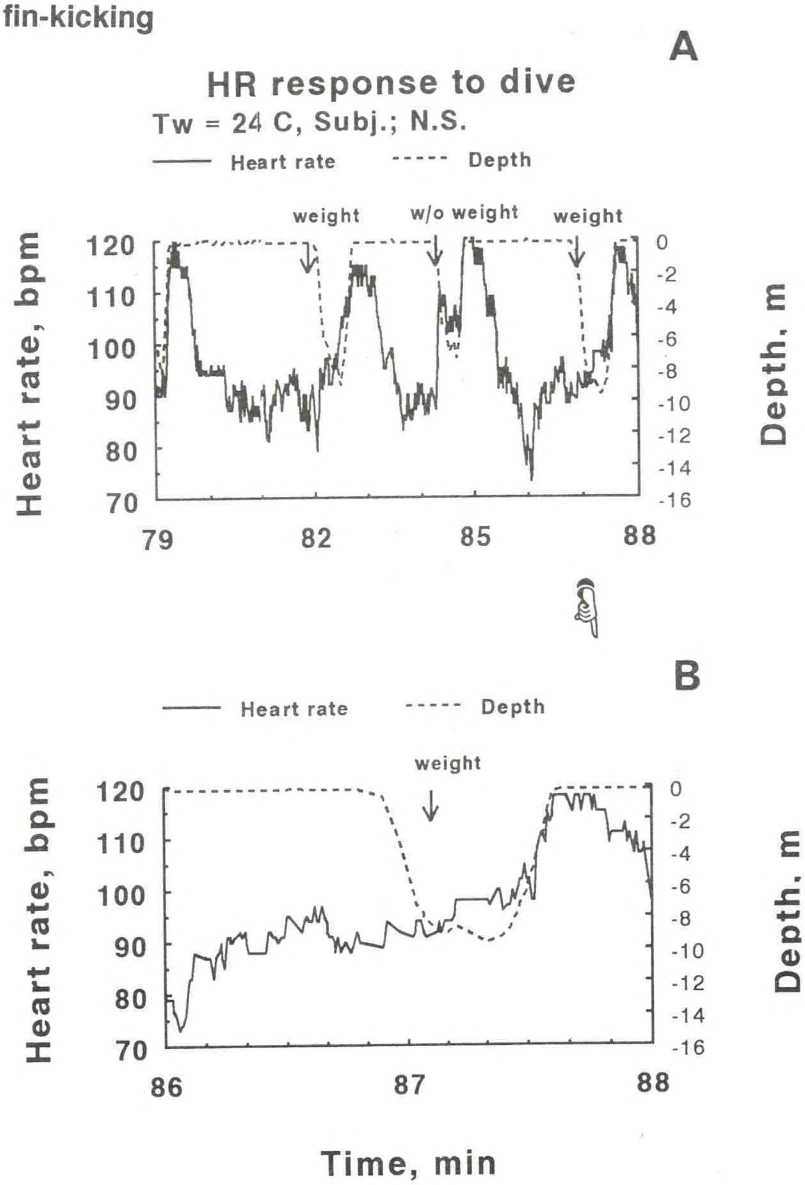
Fig. 4



Heart rate response to daily dives
Funado
with fin-kicking
Tw = 24 C, Subj.; K.S.
Heart rate
Depth
A
weight
weight
Heart rate, bpm
Depth, m
110
100
90
80
70
60
0
-2
-4
-6
-8
-10
-12
-14
-16
111
114
117
120
without fin-kicking
Heart rate
Depth
B
Weight (10 kg)
Weight
weight
110
100
90
80
70
60
250
253
256
259
Kachido
with fin-kicking
Tw = 24 C, Subj.; K.S.
Heart rate
Depth
C
w/o weight
w/o weight
w/o weight
120
110
100
90
80
70
190
193
196
199
Time, min

Fig. 5

w/o fin-kicking



NATURAL DIVING PATTERNS OF KOREAN AND JAPANESE BREATH-HOLD DIVERS (AMA)

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ABSTRACT

Daily diving patterns and thoracic skin and sea water temperatures were recorded during the entire work shift of Korean female unassisted (cachido) and Japanese male unassisted and partly assisted (funado) divers using an Underwater Physiological Data Logger developed in Buffalo and Japan. All three groups of divers were studied during the summer of 1989 and 1990. Additional studies were conducted during the winter of 1991 on Korean female divers who, unlike Japanese divers dive all year round. The water temperature of the diving grounds in summer was 24^{o}C in both Korea and Japan, and 10^{o}C during winter in Korea. Both Korean female and Japanese male cachido divers made 113-138 dives a day and stayed in the water a total of 170-200 min/day, of which only 52-63 min were spent diving submerged and the remaining time at the water surface. These diving patterns were not different between female and male cachido divers. Compared to Japanese male divers, Korean female divers dived to a shallower depth (3.7 vs 6.9 m) with shorter dive time (29 sec vs 37 sec) and shorter bottom time (14 vs 18 sec). Velocities of descent (0.72 vs 0.47 m/sec) and ascent (0.77 vs 0.56 m/sec) were also slower in female divers than in male divers. The diving pattern of Korean female divers was similar in both summer and winter. Although all cachido divers wore wet suits and thus were protected from severe cold stress, thoracic skin temperature decreased during a work shift by 7^{o}C in winter (versus 1^{o}C in summer) in Korean divers. A comparison of Japanese male cachidos with Japanese male funados indicates that funado divers stayed in the water (or on a boat in the diving ground) longer (201 vs 305 min/day), but perform only 23 dives per day. The average diving depth (9.7 m), duration (69 sec), and bottom time for each dive (45 sec) however, were significantly greater in funados. The velocity of vertical descent (1.0 m/sec) was also significantly greater in funados because they descend with a weight (10 kg). The rate of ascent was not different.

Key Words: Korean women divers, Japanese male divers; cachido; funado; Underwater Physiological Data Logger; breath-hold diving; wet suit diving.

Extensive physiological research on Korean and Japanese breath-hold divers has been conducted during last 3 decades. These studies include examinations of cardiorespiratory (Hong et al., 1963; Song et al., 1963) and thermoregulatory function (Hong, Rennie, and Park, 1986), with special emphasis on the nature of their adaptation to many years of breath-hold (BH) diving. However, even the daily diving patterns including the duration of diving work shift, frequency of diving, and effects of gender and of the season are not known and need to be determined under natural diving conditions.

In order to carry out various physiological and/or mechanical measurements which were not satisfactorily explored in the past, a group of scientists from Korea, Japan, and U.S.A. organized an international research team in 1989 and conducted several field studies to determine natural diving patterns. The present report presents in detail the daily diving patterns of ama divers. Diving patterns then were compared between male and female divers, between summer and winter, and between unassisted (cachido) and assisted (funado) divers.

A special data logger (or recorder) was conceived, designed and fabricated in the Department of Physiology of the State University of New York at Buffalo by Henderson et al. (Henderson et al., 1991) for the current study. This device measures every second the depth, thoracic skin temperature, sea water temperature and heart rate for periods up to 8 hours. However, the present communication deals with the diving pattern and the skin temperature changes only and the results on the heart rate changes will be published later elsewhere. Those readers interested in obtaining more detailed information on the diving pattern are advised to consult the original article by Hong et al. (Hong et al., 1991).

METHODS

Field studies were conducted in August 1989, September 1990, and February 1991 on Korean female divers, and in August 1989 and September 1990 on Japanese male divers. A total of 29 subjects (16 Korean female divers and 13 Japanese male divers) were recruited in the field. It should be noted that all Korean female divers and 4 Japanese male divers employed for the 1989 study were so-called "unassisted" (cachido) divers, while the remaining 9 Japanese male divers (studied in September, 1990) were "partly assisted" (funado) divers, who descend to the bottom of the sea carrying an 8-12 Kg weight but ascend without any assistance. All cachido divers wore wet-suits and fins while the funado divers employed for the present study were not allowed to wear full wet-suits but wore only short pants made of neoprene. While all Korean and Japanese male cachido divers wearing full wet-suits stayed in the water during surface intervals between dives, funado divers returned to the boat immediately after each dive to get warmed up with a propane gas stove deployed in the middle of the boat.

Each diver was asked to report to the field laboratory at 8-9 a.m. of the study day and, upon arrival, was asked to rest for 30 min during which the skin temperature probe and ECG electrodes were attached. All cachido divers then put on wet-suits and the logger was turned on (activated) to start recording. Korean divers walked into the sea from the shore and then swam to the diving ground while Japanese divers (both cachido and funado) left the shore by motor boat for the diving ground which took 5-10 min.

Although most data presented here were obtained from the use of the above described Buffalo Underwater Physiological Data Logger, the data on 5 out of 9 Japanese male funado divers (conducted during 1990 summer) as well as on 9 Korean female cachido divers (conducted during 1991 winter) were collected using a similar dive logger developed by Vine Bionic Systems, Tokyo, Japan. All measurements on Korean female divers were conducted at Hae Un Dai, Pusan, Korea; studies on Japanese male cachido divers were carried out at the villages of Matsuwa and Nagai located on the Miura Peninsula, while the studies on Japanese funado divers at the village of Chikura located on the Chiba Peninsula.

RESULTS AND DISCUSSION

The primary objective of this study was to compare the daily diving pattern among different groups of divers. However, it is important to examine within the same group of divers the yearly variations of diving pattern. For this purpose, the data obtained from Korean female cachido divers during summers of 1989 and 1990 were compared. As shown in Table 1, the total time in water, total diving time, total surface time and total number of dives, per day, were not significantly different between the two studies. Although other variables such as average single dive time, average single diving depth, and the rates of descent and ascent showed significant differences between the two studies, the differences were rather small. These results suggest that each group of divers has developed a diving pattern unique to them, with very little yearly variation.

In previous studies on wet-suited Korean female cachido divers, it was found that these Korean female cachido divers stayed in the sea 3 hours a day during the summer, with an average single dive time of 31.8 sec (Park et al., 1983). These findings are in remarkable agreement with the corresponding data obtained in the present study. In the same study, Park et al. (Park et al., 1983) also determined the rates of descent and ascent and found them to be 0.54 and 0.84 m/sec, respectively. In other words, the descent rate was comparable to the present result but, with some reason, the rate of ascent in studies by Park et al. (Park et al., 1983) was ~40% faster than that in the present study.

Between Korean female cachido divers and Japanese male cachido divers (Table 1), the total time in water (i.e., the diving work shift), the total diving time, total surface time and the total number of dives, per day, were not significantly different. However, the average diving depth was greater (6.9 vs 3.7 m) while the average singe dive time was longer (37.0 vs 28.9) in male cachido divers than in female cachido divers ($P<0.05$). Moreover, the rates of both descent and ascent were ~40% faster (~0.7 m/sec vs ~0.5 m/sec) in male cachido divers than in female cachido divers. In the only other study conducted on wet-suited male cachido divers of Tsushima (Katsugi), Japan,

Table 1. Various Parameters of Diving by Various Subject Groups

Parameters of dive:	Korean Female Divers (Cachido) 1989 summer (n=11)	Korean Female Divers (Cachido) 1990 summer (n=6)	Korean Female Divers (Cachido) 1991 winter (n=9)	Japanese Male Divers (Cachido) 1989 summer (n=4)	Japanese Male Divers (Funado) 1990 summer (n=9)
1) Total time in water (shift) (min/day)	188±6	179±4*	170±2	201±10	305±5
2) Total diving time (min/day)	52±2	54±9*	57±3	63±12	26±2
3) Total surface time (min/day)	136±7	125±5*	113±3	138±8	279±6 (on boat)
4) Total number of dives per day	115±9	129±23*	129±12	109±29	23±1
5) Average depth of single dive (m)	3.7±0.03	3.6±0.04	3.6±0.4	6.9±0.1	9.7±0.5
6) Average single dive time (sec)	28.9±0.3	26.8±0.3	28.2±2.5	37.0±0.4	68.5±4.3
7) Descent velocity (m/sec)	0.47±0.002	0.49±0.003	0.40±0.02	0.72±0.005	0.97±0.07
8) Ascent velocity (m/sec)	0.56±0.003	0.60±0.005	0.70±0.03	0.77±0.007	0.72±0.03

(Mean ± SE)

* n = 4

it was observed (Shiraki et al., 1985) that these divers take 2 shifts a day with the total time in water of 286 min per day, while the total number of dives per day was 175, both of which are ~50% greater than the corresponding data obtained in the present study. However, the average single dive time (38.6 sec) was comparable in both groups of Japanese male cachido divers.

Korean female cachido divers are allowed to dive all year round while Japanese divers are allowed to engage in diving work only during warm seasons (usually May-September). The water temperature in the diving ground in Pusan, Korea decreases from ~24°C during summer to ~10°C during winter. Despite such a marked difference in the sea water temperature, Korean female cachido divers are indeed engaged in diving work all year round. In order to assess if the diving pattern is influenced by the sea water temperature, the data obtained from Korean female cachido divers during 1989 summer were compared with those obtained during 1991 winter. Table 1 summarizes the results. Although there were significant differences between the summer and winter in the total time in water, the total surface time and the rates of descent and ascent, the magnitudes of the difference were rather small. Moreover, the total diving time per day, number of dives per day and the average depth-time profile of single dive was not different between summer and winter. These findings are markedly different from those observed previously in traditional Korean divers (wearing cotton bathing suits) before they started to wear wet-suits (in 1977). For instance, traditional cotton-suited divers were able to spend 210 min a day in water during summer but spent only 15-30 min a day in water during winter.

Shiraki et al. (Shiraki et al., 1986) compared the diving patterns of wet-suited Katsugi divers (male cachido divers of Tsushima) between summer [sea water temperature (Tw) = 27°C] and winter (Tw = 14°C) and found that the duration of work shift, diving frequency, and average single dive time were only slightly reduced (~10%) during winter as compared to summer. The studies by Shiraki et al. (Shiraki et al., 1986) also showed that the decrease in the rectal temperature during a work shift was rather small, amounting to only 0.38°C in 2 hours. The thoracic skin temperature decreased to 33.7°C during summer and to 29.5°C during winter in these Katsugi divers, which are slightly higher than the corresponding values obtained from Korean divers (26°C) in winter, most likely due to the slightly higher sea water temperature in Tsushima.

Finally, the daily diving patterns of cachido and funado divers were compared (Table 1). However, it should be pointed out that the funado divers employed for the present study are partly assisted divers and not fully assisted divers. Therefore, we should expect that the diving pattern of classic funado divers may be quite different from those obtained in the present study.

Despite these limitations, a comparison of diving patterns between Japanese male cachido divers and partly-assisted Japanese male funado divers shows many significant differences between the two groups. Table 1 shows that 7 out of 8 parameters of diving patterns were significantly different while only one parameter (i.e., ascent rate) was not different between the two groups. Interestingly, the total diving time per day was significantly shorter in funado divers while the total time in water (including the time on the boat between dives in the case of funado divers) was ~30% longer in funado divers, than in cachido divers. The number of dives per day was only 23 in funado divers, which represents 15-20% of that observed in other diver groups. On the other hand, the funado divers perform deeper and longer dives than cachido divers. As expected, the funado divers showed the fastest rate of descent among various diver groups. This is due to the fact that the funado divers descend with an 8-12 Kg weight. The ascent rate was not different between the two groups of divers.

In the present study, we computed the bottom time by subtracting the time spent for descent and ascent from the average diving time. The average descent time is 8-10 sec in all diver groups. Although the ascent time increased with the increase in depth of dive, there were marked increases in the bottom time in male divers as compared to female divers. The longest bottom time of 45 sec was observed in funado divers. As a result of such a longer bottom time associated with the deeper depths of dive, these funado divers can reach a depth other divers can not reach.

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EVALUATION OF STATIC WORK LOAD BY CIRCULATORY RESPONSES AND EMG POWER SPECTRUM CHANGES UNDER A 28 ATA HELIUM-OXYGEN ENVIRONMENT.

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ABSTRACT

The purpose of the present investigation is evaluate static work load under hyperbaric helium-oxygen environment from 1 to 28 ATA. Circulatory responses and electromyogram (EMG) power spectrum changes were studied during 7 minutes static work (half-rising posture: knee joint 120° and erect trunk) in four healthy males subjects. During the static work, heart rate (HR), systolic and diastolic arterial blood pressures (sABP, dABP) were measured. Stroke volume (SV) and cardiac output ($\dot{Q}$) were estimated using the thoracic impedance procedure. EMG of rectus femoris was recorded by two surface electrodes, and changes in the EMG power spectrum were obtained by comparing the ratio between the energy in the high and low frequency range (H/L ratio) after Fourier transform analysis.

During the static work, HR, sABP and dABP increased linearly from rest and did not reach steady state. $\dot{Q}$ and H/L decreased during the static work. Under hyperbaric environments, HR, $\dot{Q}$ and H/L ratio were less than those values obtained during 1 ATA control measurements. SV, sABP and dABP were not affected by ambient pressure change. HR increased remarkably at the end of the decompression to 1 ATA, and HR at 1 ATA post-decompression was higher than in 1 ATA pre-compression controls.

As a parameter of static work load, HR might underestimate and EMG lowering phenomenon might overestimate the work load under hyperbaric helium environments. Extreme care must be taken for comparison of static work load between 1 ATA air pre-compression, post-decompression and the hyperbaric helium-oxygen environments.

INTRODUCTION

During saturation diving, the divers' work consisted of the three phases: 1) DDC (Deck Decompression Chamber for a prolonged diving operation and decompression), 2) SDC (Submersible Decompression Chamber, divers' transfer chamber between DDC and work site), and 3) work site in the sea or on the sea bottom. The heaviest work for divers and the tender was reported to be work in the SDC based on their subjective evaluation and heart rate trends. The SDC working space was extremely limited, because the internal diameter of the SDC was only 2.2 m, and the inside SDC space was further reduced by equipment. Men were also forced to work with a half-rising posture (flexed knee posture). We studied static work in the leaning posture as a model of SDC work (Fig.1).

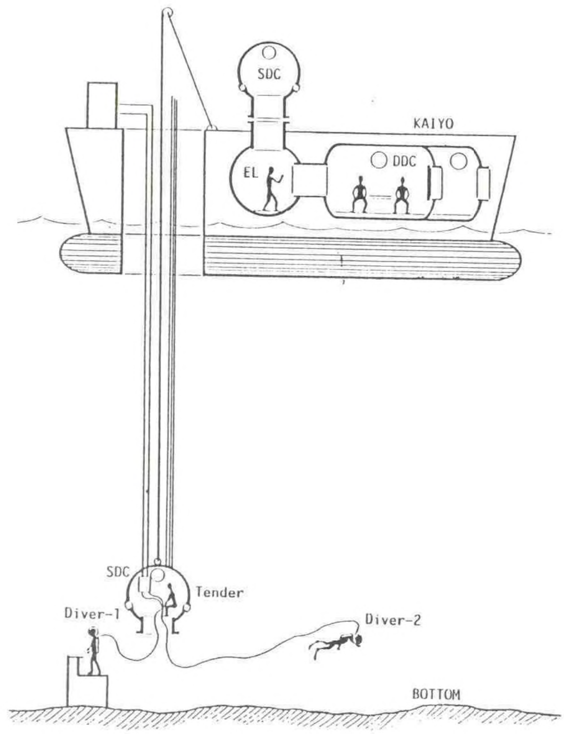

Fig.1 Major components of saturation diving system of JAMSTEC.

Surface support vessel *KAIYO* (semi-submerged catamaran type)
DDC (Deck Decompression Chamber)
SDC (Submersible Decompression Chamber)

The purpose of the present study is evaluate static work load under hyperbaric helium-oxygen environments. The most useful physiological work load parameter for the dynamic work is heart rate, but the heart rate decreases under a helium hyperbaric atmosphere this phenomenon is known as "hyperbaric bradycardia"(1,2,3). Significant changes in oxygen consumption and ventilatory volume are not found between atmospheric air and hyperbaric helium environments (4,5,6). Static work, we chose not utilize the same parameters as the respiratory and circulatory parameters often used to assess dynamic work (7). We evaluated static work load under a hyperbaric helium-oxygen environment with two parameters: circulatory function and the electromyogram (EMG). Studies of static work in a hyperbaric helium-oxygen environment have not been reported so far to our knowledge.

METHODS

Profile of dive :

A simulated saturation dive to an equivalent depth of 270 m with excursion dives to 300 m, code-named NewSeatopia-90, were carried out at the hyperbaric facility of JAMSTEC. The dive profile consisted of 5 consecutive periods: 3 days of pre-compression observations at 1 ATA air, 1 day of compression with helium from 1 ATA to 28 ATA at rate of 2.5 ATA per hour (one-hour compression stop at 16 ATA and at 26 ATA), 7 days pressure hold at 28 ATA with excursions to 31 ATA, 11 days of decompression, and 3-day post-decompression at 1 ATA in air (Fig.2). Every two days during pressure hold at 28 ATA, the wet chamber was compressed with the divers at 31 ATA for 7 or 8 hours to simulate excursion dives. The partial pressure of O_2 at 28 ATA was maintained at 0.35-0.40 atmospheres.

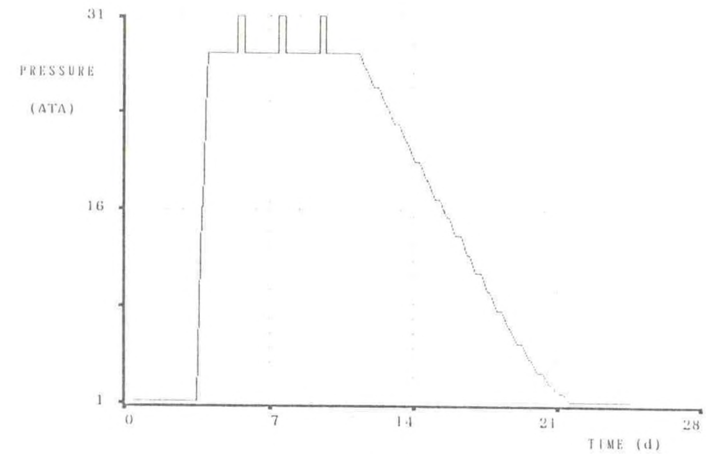

Fig.2 Dive profile of 28 ATA simulated saturation dive with excursion dive to 31 ATA, code-namedewSeatopia-90 (November,1990).

Experimental procedures :

The protocol of static work was brief and consisted of 7 minutes sitting rest, 1 minute of standing erect, 7 minutes of static work (half-rising posture, with the knee joint at an angle of 120° and an erect trunk), and 3 minutes sitting at rest in recovery, for a total of 18 minutes.

Heart rate (HR) was obtained every minute throughout the observations. At the end of the sitting rest and during every minute during half-rising posture and recovery sitting rest, systolic and diastolic arterial blood pressures (sABP & dABP) were measured by a digital sphygmomanometer (Panasonic EW231) and stroke volume (SV) was estimated by a thoracic impedance cardiograph (Nihon-Koden: AI-601G & ED-601G) with 4 band electrodes. SV was determined according to the procedure established by Kubicek(8). Mean values of 5 cardiac cycles were used to calculate SV values. Cardiac output ($\dot{Q}$), mean arterial blood pressure (mABP) and the total peripheral resistance (TPR) were calculated from HR, SV, sABP and dABP values.

The EMG of the rectus femoris was directly recorded on the digital recorder (SONY: DR-F1, with a 1 MB floppy disk) for 15 seconds during a one minute interval in the half-rising posture. Two surface electrodes were placed lengthwise along the direction of the muscle fibers. Each 15 seconds of EMG recording was divided into 60 sample records of 256 msec which were digitized at a sampling rate of 2 kHz. These data underwent power spectral analysis by means of a fast Fourier transform (9,10). Power spectra were computed in the frequency range 0-1000 Hz, with a resolution bandwidth of 3.906 Hz so that each spectrum contained 256 estimates. The sixty spectra were averaged. As an indicator of spectral shape, we calculated the ratio between the energy in the high (120-640 Hz) and low (8-40 Hz) frequency range to generate H/L ratio. The H/L ratios were also computed for the first 15 seconds of the half-rising posture maintained for 5 - 20 seconds (11,12,13).

Subjects :

The vital statistics of the four male subjects (mean±SD) were : age(yr), 25.8±2.22; height(cm), 176.0±6.73; and weight(kg), 68.4±2.90. All subjects were well-trained divers in excellent physical condition. The static work tests of each subject were carried out twice at pre-compression, four times at 28 ATA and once during post-decompression phases of the study.
One week before the study, subjects began training for the 7 minutes half-rising posture several times a day.

RESULTS & DISCUSSION

The subjects reported pain in the rectus femoris region a few minutes after the half-rising posture began. This pain became nearly unbearable during the 4th or 5th minute, although all subjects maintained the 7 minutes half-rising posture.

One minute in the standing position was presumably sufficient for circulatory function to adapt to the standing posture, because ECG's R-R interval will reportedly adapt to this posture within 20-30 sec from the supine position (14).

Circulatory changes:

The HR decreased at 28 ATA but increased after decompression (Fig. 3-A. HR during 1 ATA post-decompression exceeded the HR values during the 1 ATA pre-compression control period. During static work, HR increased linearly from resting levels and apparently did not reach steady state even at the end of 7 minutes half-rising posture. During the recovery period, HR returned to the pre-work level within one minute (Fig.3-A).

The SV remained essentially unchanged during the compression phase. However, SV decreased after decompression. During static work, SV trended lower in all environments(Fig.3-B).

The $\dot{Q}$ also showed little change between 1 ATA pre-compression, 28 ATA and 1 ATA post-decompression phases. During static work, $\dot{Q}$ increased very slightly compared to the sitting rest position, and $\dot{Q}$ was maintained approximately the same levels during standing (Fig.3-C).

The sABP and dABP, mABP and TPR values did not show significant differences between at three test environments, but increased linearly from their pre-resting levels during static work, although the values did not appear to reach steady state levels (Fig.4-A,B).

The atmosphere in the pressure chamber was slightly hyperoxic, with 0.35-0.40 atmospheres O_2. We speculate that the decrease in HR at 28 ATA is caused not only by the hyperbaric environment with high pressure and high density of respiratory gas (15) but also by the hyperoxic breathing gases (16,17). Changes in resting HR for compression and decompression phases showed a similar tendency that has been reported (18,19).

An increase in TPR mediated the mABP elevation primarily by an increased $\dot{Q}$ was reported previously (7,14). Our observations for static work at 1 ATA with air and at 28 ATA with helium are consistent with these earlier findings. Static exercises elevated mABP which we believe was mediated primarily by an increased $\dot{Q}$ with minimal, if any, contribution by TPR.

In spite of the subjects reported that they felt the right work at the beginning of static work, the circulatory indexes did not appear to reach steady state levels at end of the work.

Hyperbaric bradycardia levels returned to the pre-compression level as divers are maintained at a given hyperbaric pressure (20), and the hyperbaric influence on circulatory function is changed by the HR

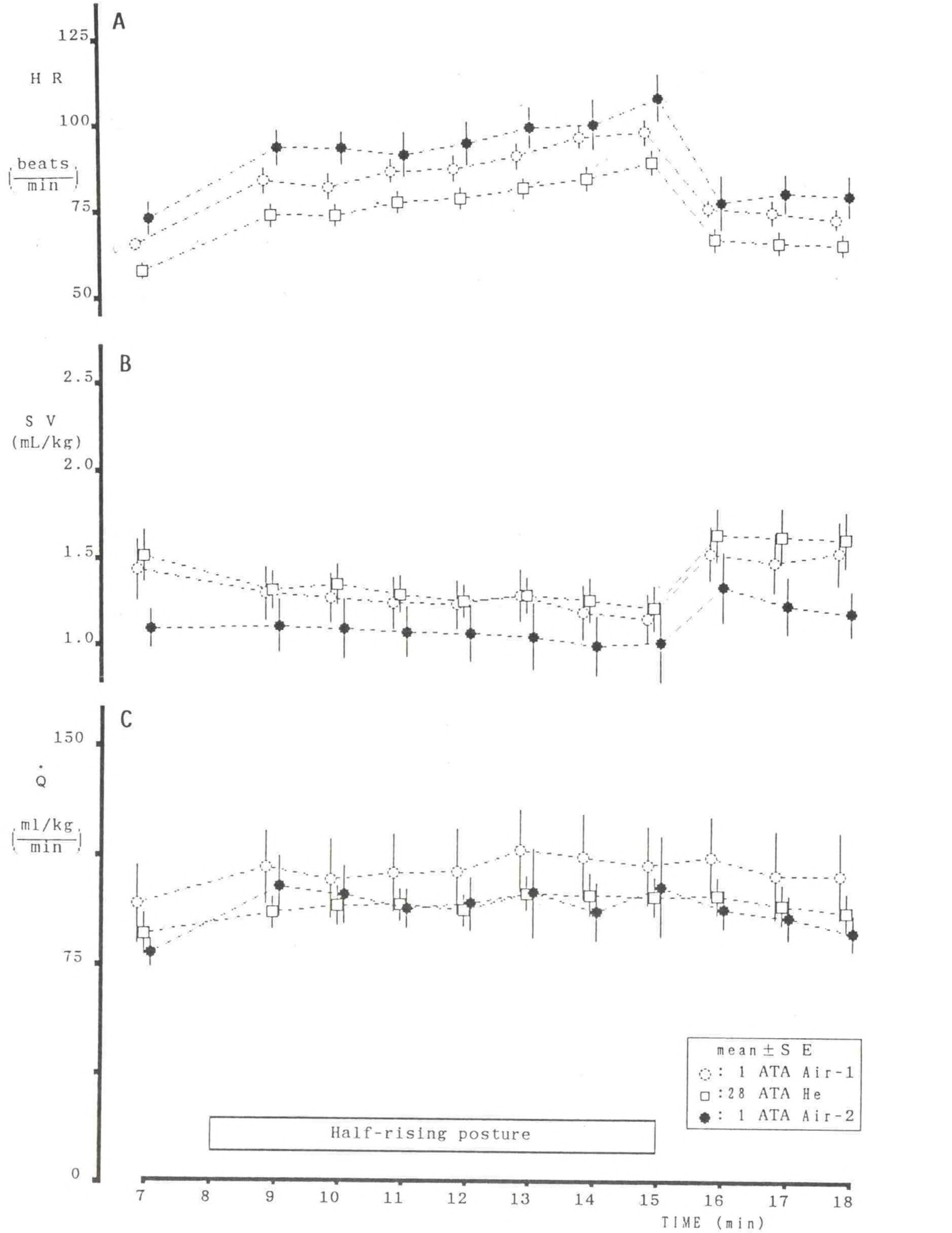

Fig.3 Effects of static work on circulatory responses.

Symbols and abbreviations are:
1 ATA Air-1, pre-compression phase;
1 ATA Air-2, post-decompression phase;
HR, heart rate(beats/min), SV, stroke volume(ml/kg); and
$\dot{Q}$, Cardiac output(ml/kg/min).

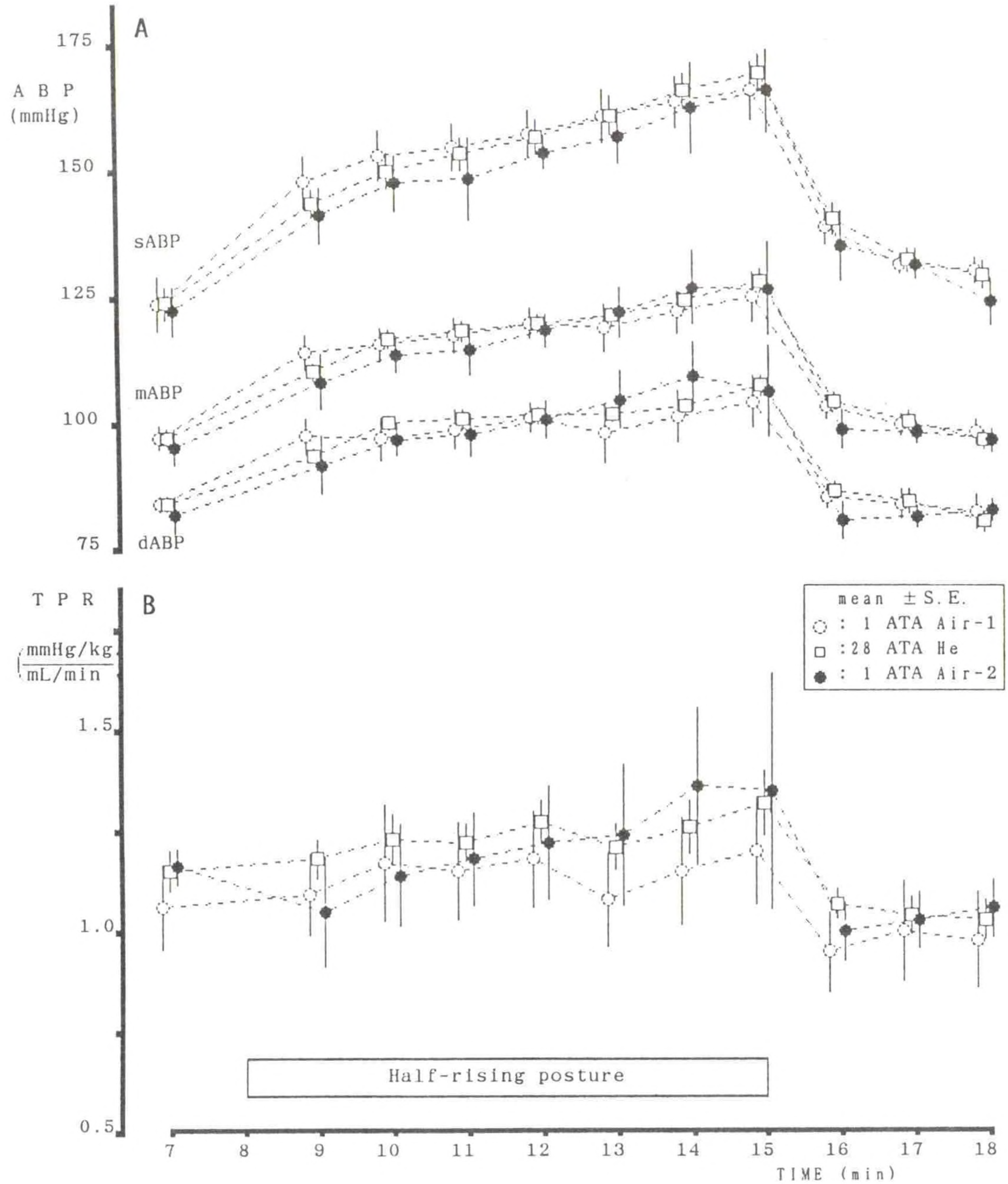

Fig.4 Effects of static work on circulatory responses.

Symbols are: ABP, arterial blood pressure (s,systolic; d,diastolic; m,mean mmHg), and TPR, total peripheral resistance (mmHg/ml/kg/min).

level (21). Circulatory indexes used to assess static work load must be considered on the basis of the hold time period a diver is exposed to hyperbaric conditions, and the diver's work load and work time.

Electromyogram:EMG changes :

An example of EMG power spectra during the static work test is shown in Figure 5. The peaks in the EMG spectra increased and shifted to a lower frequency with time.

The H/L ratio of EMG changes in the fatiguing runs showed an exponential decline, and the decrease of the H/L ratio was more pronounced at 28 ATA than at the 1 ATA pre-compression control phase. Significant decreases occurred between H/L ratios at the beginning of the half-rising posture and faster time at 28 ATA (Fig.6).

EMG analysis, which permit an assessment of muscle fatigue during voluntary contraction, shows a shift towards the lower frequencies in the power spectrum. This change is detected by a decrease in the amplitude of the high frequency and increase of low frequency in the EMG power spectrum. The "fatigue indexes" use various spectral estimates, such as the centroid frequency, median frequency, and the high/low frequency ratio. We used the H/L ratio to minimize the noise influence. Our results showed a similar shift of the H/L ratio (11,12) as a function of time in the half-rising posture.

The decrease of H/L ratio as a function of muscle fatigue at 28 ATA was faster than during the 1 ATA pre-compression conditions. It has been suggested that the decrease of H/L ratio may be brought about as a consequence of the muscle cooling, muscle fiber type composition, blood flow obstruction, and changes in extracellular cation concentrations(12). The deep body temperature in the subjects was measured as a vital sign twice a day, but we could not find a significant difference between deep body temperature during 1 ATA and 28 ATA phases. Inspired gas was slightly hyperoxic and $\dot{Q}$ was not reduced (Fig.3). Under these conditions, we speculate that blood flow distribution to the muscle may have changed in the hyperbaric helium-hyperoxic environment at 28 ATA, but this hypothesis can not explain the pattern of H/L ratio at 1 ATA post-decompression appear more similar to the 28 ATA series than to the 1 ATA pre-compression series in spite of the same air environment before and after hyperbaric exposure.

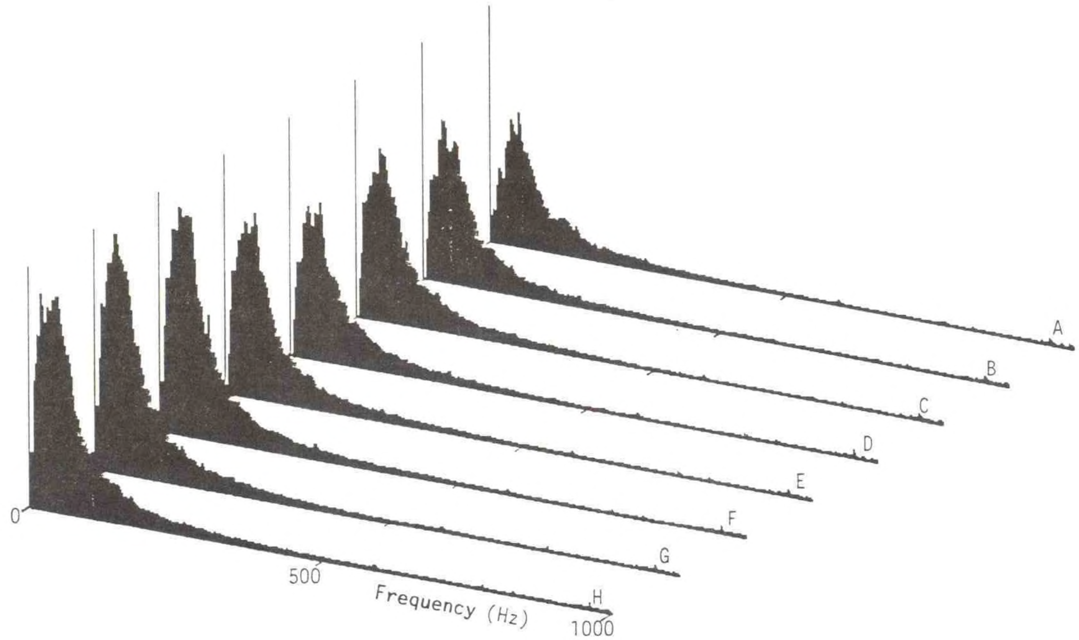

Fig.5 Power spectra of each 15 sec of EMG recording each minute during the half-rising posture.

A indicates the beginning of sampling and H indicates the end of sampling during half-rising posture hold for 7 minutes.

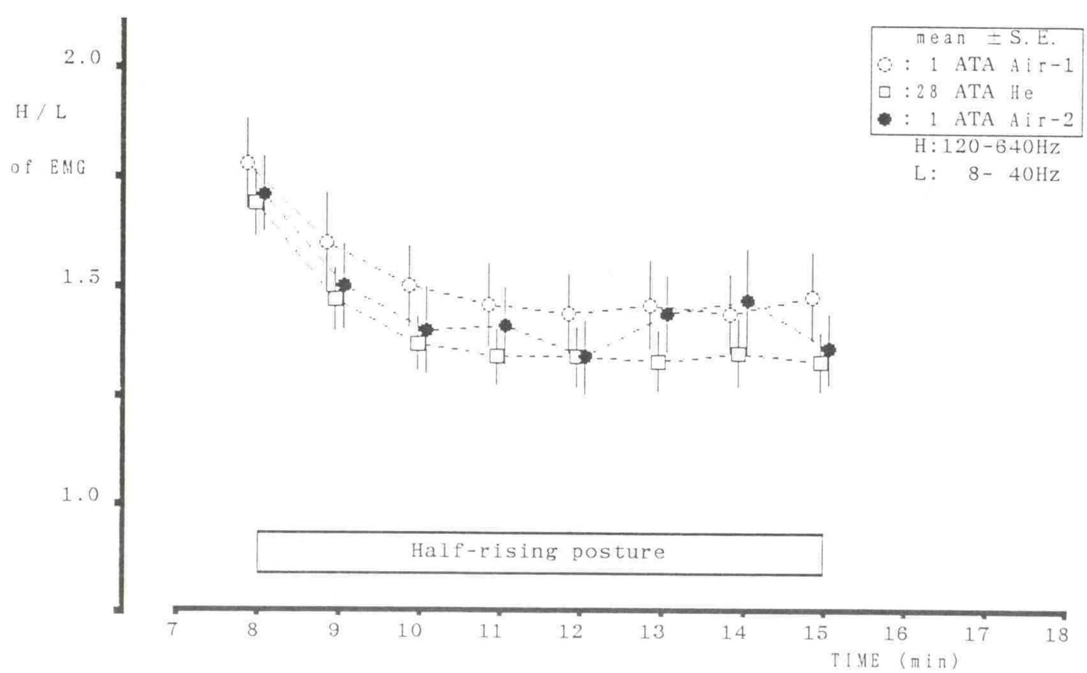

Fig.6 Mean values of the ratio between the energy in the high and low frequency range (H/L ratio) during the half-rising posture.

Vertical lines indicate ±1 standard error of the mean values ; sample size (N) was 8 at 1 ATA Air-1, 16 at 28 ATA, and 4 at 1 ATA Air-2, respectively.

To evaluate the static work load in a hyperbaric helium-oxygen environment, HR might underestimate the work load and EMG's lowering phenomenon might overestimate static work load. Extreme care must be taken when comparing static work between 1 ATA air pre-compression and post-decompression environment and the hyperbaric, helium-oxygen environment.

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EEG CHANGES INDUCED BY 33 ATA HELIOX COMPRESSION

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ABSTRACT

A saturation dive experiment of 33 ATA Heliox was conducted in 1990 at Undersea Medical Center. In order to predicxt the occurrence of HPNS, EEG was recorded from twelve locations in two subjects, one of whom, however, suffered from slight dizziness at 33 ATA. Two-dimensional EEG amplitude maps were generated to check if any abnormality may appear somewhere in the brain. The compression schedule was : 0 - 10m at 10.0m/min by air, 10 - 150m by the compression rate of 1.0m/min by Heliox, keeping 16 ATA for 13 hours, and finally to 320m by the rate of 0.5m/min. During the compression, the slow wave increase especially in theta band was observed in the anterior areas of the head. As many researchers reported, the decrease in alpha wave was also noticed but only temporarily. Keeping the pressure constant, adaptations occurred in the EEG such that the alpha decrease disappeared quickly to return to the previous state before the pressure increase. The pattern of the two-dimensional map also showed the adaptation especially in the alpha map. These EEG changes seemed to have relations to the mental condition of the two subjects. The theta increase approximately corresponded to the drowsiness complained by the subjects. However there were differences in the EEG changes among the two subjects as well as the mental changes. One of the subject who felt dizziness at 33 ATA showed more increase in theta activity and a central dominant two-dimensional map pattern. No epileptic waves were observed in both of this 33 ATA experiment and in the other experiments of less pressures which were previously performed. From this evidence we are sceptical of the use of Trimix.

METHOD

Two EEG subjects were the members of Underea Medical Center who had the experience of the saturation dives. K is a 29 year old naval officer and S is a 22 year old leading seaman. They had no physical abnormalities in the pre-experiment test. However, S felt a little fatigue before this experiment. EEG was recorded at twelve locations: Fp1, Fp2, F7, F8, C3, C4, T5, T6,01, 02, Fz and Pz. The reference electrode was placed on the earlobe. The monolpolar recording was made, while the subjects lay on the bed with closed eyes. EEG record was stored on FM magnetic tape and by the replay all data were A/D converted. By computer and human inspection all artifact contaminated epochs were discarded. Two-dimensional EEG amplitude maps were genenrated by Unbiased Polynomial Interpolation.(Ashida et al.,1984) Amplitude values in the text are root mean square potential value of four second epoch in micro-volt. EEG amplitude maps of alpha band (8-13 Hz) and theta wave (3-8 Hz) showed characteristic changes during the compression, while beta band (13-25 Hz) and delta band (1-3 Hz) did not show clear tendency. Therefore, The pattern changes in the aipha and theta bands were described in the two subjects.

RESULT

Alpha Map In the alpha map, subject K's map pattern of the control period was occipital dominant with slight laterality difference (left amplitude was larger than right: l<r). Maximum amplitude was between 8 and 9 microvolts. At 13 ATA the map pattern did not change much; the occipital dominance and the slight laterality difference continued. The alpha amplitude increased slightly in the occipital area. At 32 ATA the map changed to so-called central dominant pattern with the slight decrease in the amplitude. At 33 ATA themap returned to the occipital dominant pattern and the amplitude increased to above 11 microvolt. His left hemisphere showed larger amplitude especially in the anterior area.

In subject S, the map was the central dominant pattern with the laterality of left dominance. The maximum amplitude was above 11 microvolts. At 13 ATA the map changed to the occipital dominant pattern, where the maximum amplitude increased slightly. At 32 ATA the map changed again to the central dominant pattern. and the maximum amplitude increased to above 15 microvolts. The laterality moved to the right dominance. In 33 ATA map, the central dominance pattern returned but the maximum amplitude was observed in the right posterio-temporal area, where the amplitude decreased slightly to that of 32 ATA map.

Theta map Theta maps (amplitude map of theta band: 3-8 Hz) of K and S showed different tendencies, that may be related to the different mental conditions. In K, the control theta map had the frontal dominancy of maximum amplitude of 6 microvolts. Slight right dominance was found. At 13 ATA the amplitude increased a little and the map changed to a central dominant pattern with a slight left dominancy. At 32 ATA the amplitude remained almost same and the pattern showed clear symmetry. At 33 ATA an obvious increase in the amplitude upto 13 microvolts occurred in the frontopolar area with a slight left dominancy. The theta patterns in the 32 ATA map seemed to have relation to so-called frontal midline theta pattern.

In subject S, the control theta map was the central dominant pattern but showed the right dominancy. At 13 ATA the map changed to a symmetrical central dominant pattern and the amplitude stayed same. At 32 ATA the maximum amplitude area moved to the occipital area but still the feature of the central dominant pattern remained. At 33 ATA the theta amplitude increased greatly (upto 20 microvolt) and the left central dominancy was clearly observed. In short the pattern change in the theta maps was independent of that of the alpha maps. The remains of the large amplitude after reaching to 33 ATA was obvious, that means slower adaptation than that of the alpha activity.

DISCUSSION AND CONCLUSION

Two-dimensional map covers entire cortical surface, therefore, our observations are not confined in those at restricted recording locations, but can be extended to the total brain function as a whole. From this standpoint, our data confirmed the EEG findings of the previous researchers (e.g. Hunter and Bennett 1974). The findings were firstly alpha decrease and theta increase, secondly the quick adaptation and thirdly the individual difference.

The EEG changes in our experiments of high pressure heliox at various depths were concluded that heliox has the tendency to depress brain functions, not to excite them. The culminate excitation appears in the EEG as epileptic discharges, but they have never been observed in our experiments including the one of 33 ATA. From this evidence, we insist that the use of nitrogen, whose purpose is to avoid the excitation by the heliox in animal experiments, has least importance and rather harmful to increase the depressive tendency.

We are aware of the fact that epileptic spikes can appear in deep anesthesias, such as in enflurane anesthesia. During its deep suppression of cortex, the spikes appear in the brain depth. But in this state cortical EEG is completely flat and quite different from 33 ATA EEG. Therefore it is hard to conceive that such an extreme depression is caused by the high pressure heliox. The heliox dive according to our diving schedule will not develop epileptic spikes in EEG as well as clinical seizure.

Concerning to the second point, the quick adaptation is confirmed in the two-dimensional maps by the returns of the map pattern to the pre-compression one. Of course too rapid compression , where the adaptation can not cope with, is out of discussion. Our compression rate was 0.5m/min, during the compression deeper than 16 ATA, and there were a few periods of constant pressure.

However, better dive schedule should be investigated to find the most adequate compression rate without HPNS, using EEG technique.

Concerning to the third point, the personal difference in the reaction to the compression was observed in every experiments including the 33 ATA experiment, where one subject suffered from dizziness and nausea, while the other subject complained only temporal drowsiness. The EEG pattern of the latter subject was an occipital alpha dominant pattern in the control recording, while the former was not. The following is only tentative statement but it is our impression that the occipital alpha dominant pattern, that is a typical EEG at ease, seems to correspond to the subject of few complains.

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NMRI BEGINS HYDROGEN DIVING RESEARCH

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ABSTRACT

For several years the Naval Medical Research Institute (NMRI) has been tracking the emerging technology of "hydrogen diving" in the commercial and military diving communities, principally in France. The commercial interest in France is to enable their divers to reach deeper depths by using hydrogen as one of the inert gases in their breathing medium; thus surpassing the physiological limit while using a mix of helium/oxygen. NMRI's interest in hydrogen diving is not to dive deeper, but to investigate a means of hastening decompression time by metabolizing in vivo hydrogen gas and eliminating it through urination; a technique we call "enzymatic decompression" and derived from the process of injecting an enzyme that metabolizes the hydrogen. The process was actually proposed over 20 years ago by a NMRI scientist but the idea lay dormant until the French began conducting deep diving research with a hydrogen gas mix.

Three years ago NMRI investigators had accumulated enough data, through collaborative research with the French, to present a research proposal to the Office of Naval Research to investigate the effects of hydrogen in animals. The proposal was approved for funding and NMRI began assembling facilities to support the research.

When completed, the facilities will encompass three separate laboratories. The first phase is complete and permits investigators to study the effects of hydrogen in isolated tissues at pressures to 1,000 psi. The second phase is also complete and involved dedicating an entire laboratory space for renovation into a self-contained hydrogen research laboratory. Investigators use this second phase laboratory to study the effects of hydrogen in small laboratory animals at pressures, again, to 1,000 psi. The third phase involves the construction of a new stand-alone building and will house a large animal hyperbaric chamber (200 cf) capable of pressures to 1,750 psi. When the phase three facility is completed, NMRI can claim the first U.S. Navy facility designed specifically to study the physiological ramifications of using hydrogen gas in a breathing medium.

BACKGROUND

In the fall of 1983, CAPT Edward T. Flynn, MC, USN and Mr. Don Chandler, both of NMRI, visited Mons. H. Delauze and Dr. X. Fructus of COMEX in Marseille, France to discuss COMEX's progress in using hydrogen as an inert gas for mixed gas diving. At the time, they were preparing to conduct "HYDRA IV" and invited CAPT Flynn and Mr. Chandler to observe the dive. This began a scientific quadrivial collaboration (COMEX/CERB/CNRS/NMRI) that continued for seven years and, to a degree, is still in place.

Hydra IV was planned to 300 msw, but the dive was limited to 245 msw because the divers showed extraordinary narcosis when they switched to hydrogen gas at that depth. While the targeted storage depth was not reached, the dive produced valuable data in that it was the first time ever that hydrogen narcosis was demonstrated in man. HYDRA V followed and NMRI sent a team of scientists and technicians to the COMEX facilities to observe and gather data. The dive was to 450 msw with a He/H2/O2 mix which overcame the debilitating narcosis seen on HYDRA IV, albeit slight narcosis was evident after switching to the trimix. HYDRA VI dive was a 500 msw dive to study work capacity and thermal balance while breathing the hydrogen trimix with the divers wearing hot water suits and the LARA dive rig.

In 1987 a workshop on hydrogen diving was organized in Wilmington, North Carolina where attendees brought together all available information on the subject. Armed with information gleaned from the experts at the workshop, CAPT Flynn began to formulate a plan to introduce hydrogen diving research in the U.S. Navy; but looking toward biochemically enhancing decompression rather than simply going deeper with a lighter breathing gas, as had been the case for COMEX. CAPT Flynn looked towards developing ways to shorten required decompression times by the addition of an enzyme capable of converting gaseous hydrogen to water. This procedure, then, provided the genesis for coining the term "enzymatic decompression" which some prefer rather than "biochemically enhanced decompression." This paper uses the terms interchangeably.

In 1988 COMEX conducted a 500 msw open sea dive off Cassis, France with a NMRI observer on board the support vessel. Information from this dive plus data from the Wilmington workshop and observations made at COMEX were synthesized with the concept of biochemically enhanced decompression, or enzymatic decompression, and presented to the Office of Naval Research (ONR) for funding. Competition with other ONR proposals was keen but the program was approved for a five year study, the first year being fiscal year 1991.

To continue beyond five years, NMRI must prove, unequivocally, that hydrogen gas is superior to helium gas as a breathing medium in animal models. Enzymatic decompression using hydrogen gas is a concept that was first suggested over twenty years ago by a NMRI scientist, Dr. Lutz Kiesow. Only recently, however, has scientific data been conclusive enough to launch a major research study.

It is theoretically possible, for example, to inject an enzyme into a diver and, through the action of the enzyme metabolizing hydrogen gas into water, reducing the inert gas in his tissues by 30-50%. The water would then be urinated away, thus significantly shortening decompression time. The suggestion may sound like wild speculation at first blush, but scientific evidence shows that such technology is not only possible, but probable.

Using hydrogen gas as a breathing medium for divers is not a recent invention. As the following figure shows, it has a long history.

Table 1
HISTORY OF HYDROGEN AS A DIVING GAS
(Brauer, 1987 and Imbert, 1989)

1789	Lavoisier studied the potentially toxic effects of molecular hydrogen on the body by placing guinea pigs in a bell jar containing a mixture of hydrogen and oxygen.
1930's	Case and Haldane breathed a mixture of air and hydrogen at 10 atm for periods up to 10 minutes.
1940's	Arne Zetterstrom performed a total of six open sea dives, reaching a maximum depth of 160 msw. During the deepest dives, Zetterstrom used a gas mixture of 96% hydrogen and 4% oxygen.
1960's	Brauer studied the narcotic effects of hydrogen in mice at 120 atm.
1970's	Fife and Edel performed animal experiments to depths of 31 atm and human experiments to 10 atm.
1980's	COMEX performed a series of animal and manned dives culminating in 1988 with the HYDRA VIII dive. A team of four divers performed work on the sea floor at 500 msw.

NMRI'S PROGRAM

As alluded to earlier, NMRI is interested in hydrogen as a breathing medium for divers because of its potential for shortening decompression time by biochemical manipulation, rather than simply trying to reach man's physiological limit. However, it would be foolish, if not almost criminal, to launch such a program without comparing what we will discover with the research we have already done using helium as the inert gas. Because of this, we will be doing some very deep dives using animal models in order to make these comparisons. In order to accomplish this, NMRI established a three phase program; each with its distinctive objective. The conceptual designs were developed by a team of NMRI people under the guidance of Dr. Guy Imbert of CNRS, France.

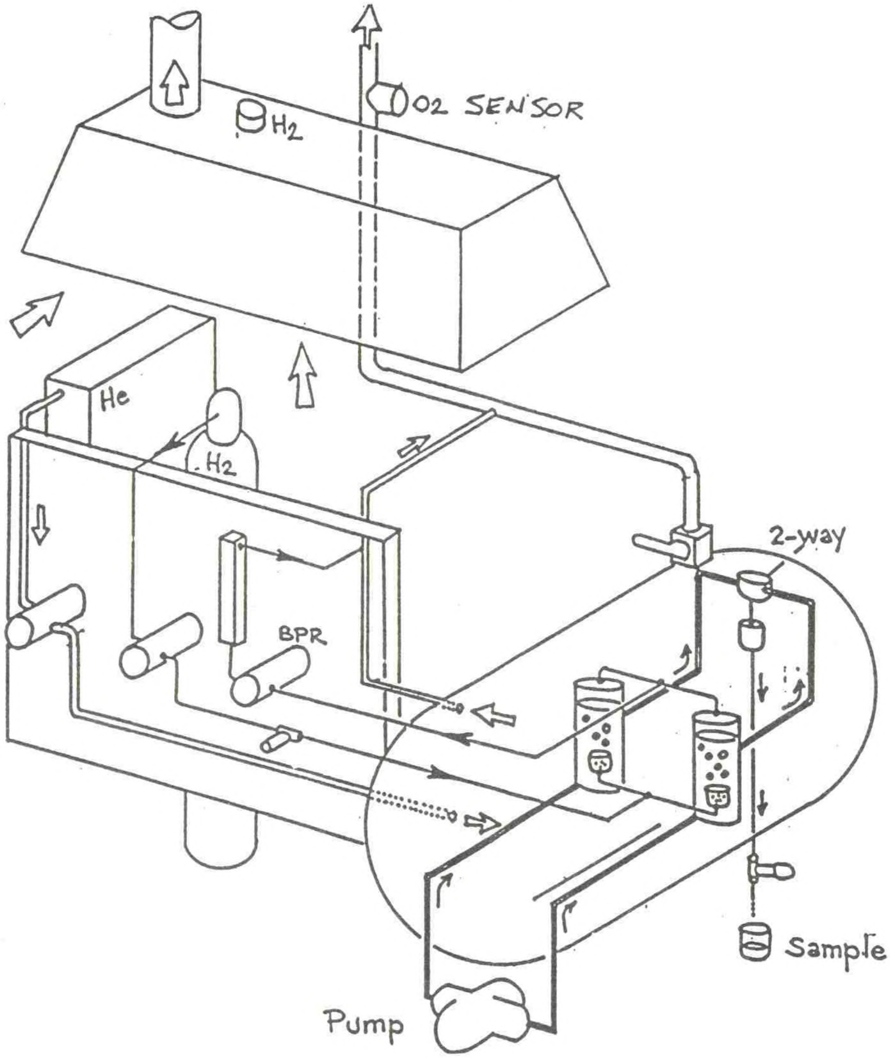
Dr. Imbert was with NMRI for three years, under the aegis of the NOAA/IFREMER agreement, providing technical and scientific guidance. At CAPT Flynn's urging, and with his assistance, Dr. Imbert defended the scientific program before a peer group of reviewers and gained approval for the program. Additionally, he worked with a team of NMRI engineers to design and procure the hyperbaric systems for each phase.

PHASE ONE

This first phase involved converting an existing laboratory small animal chamber as you see it in Figure 2. The investigators in the laboratory where this chamber is located will investigate the effects of hydrogen in isolated tissues at high pressures (to 1,000 psi). To accomplish this, hydrogen is circulated in an isolated system, bubbled through a suspension liquid, and exhausted to the roof through an inerted line. In operation, a 5 cuft chamber is compressed with pure helium, which also serves as an inert envelope, suppressing the risk of fire in the event of an internal leak of hydrogen. An overhead canopy, equipped with an explosion proof fan and a hydrogen sensor protects against the risk of an external leak.

This facility will allow study of inert gas effects on brain neurotransmitter release mechanisms and permit comparison between hydrogen and other inert gases. In addition, neurophysiologic studies of brain respiratory control mechanisms will be carried out here to determine, ultimately, the optimal gas mixture to best balance High Pressure Neurological Syndrome (HPNS) and narcosis.

Figure 1
PHASE ONE CHAMBER

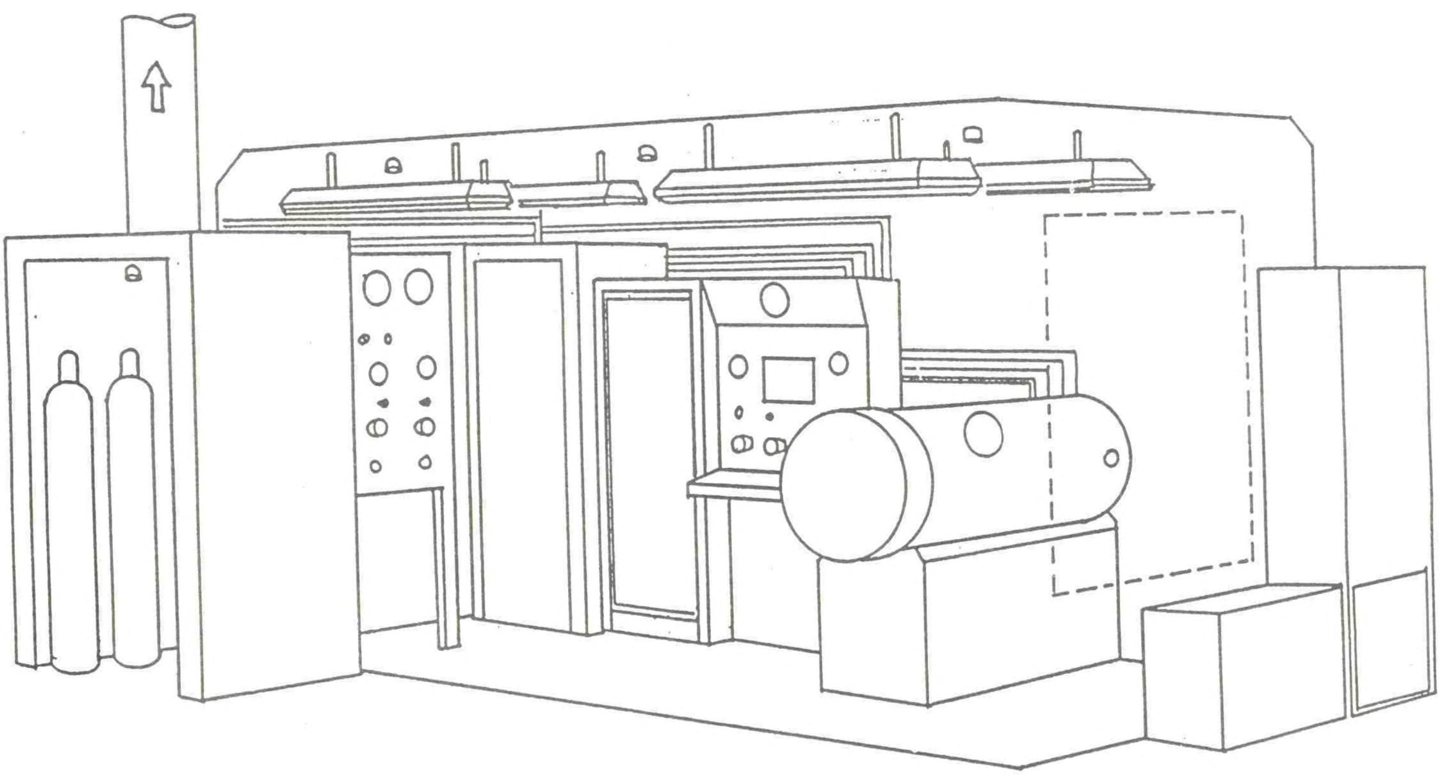


PHASE TWO

This phase was recently finished and involved a complete renovation of one corner of an existing building into a self-contained laboratory. The system installed in the lab is designed to investigate the effects of hydrogen in up to five exercising small laboratory animals at pressures to 1,000 psi. During operations, a 5 cuft chamber is compressed with helium/oxygen mixtures to a depth of 300 fsw. At 300 fsw, or deeper, a hydrogen/oxygen mix containing less than 2% hydrogen is introduced and compression is resumed with the hydrogen/oxygen mixture. Due to the volume of hydrogen gas that will be used, the system is housed in a special room designed in accordance with NFPA 50A-1989. All electical equipment within the room is either rated for Class I, Division 2 locations, in accordance with the National Electric Code, or is enclosed and purged with fresh air in accordance with NFPA 496-1989. The room atmosphere is monitored with hydrogen sensors and ventilated with explosion proof fans. Explosion venting is provided to minimize the consequences of a pressure vessel failure. Hydrogen storage is located outdoors.

This facility will be used for: 1) comparison of decompression potency of hydrogen gas vis-a-vis helium gas in small animals; 2) studies of the effects of hydrogen exposures on metabolism and thermal balance of small animals; and 3) studies of the efficacy of biochemically enhancing decompression with exogenous enzymes.

Figure 2
PHASE TWO LABORATORY



PHASE THREE

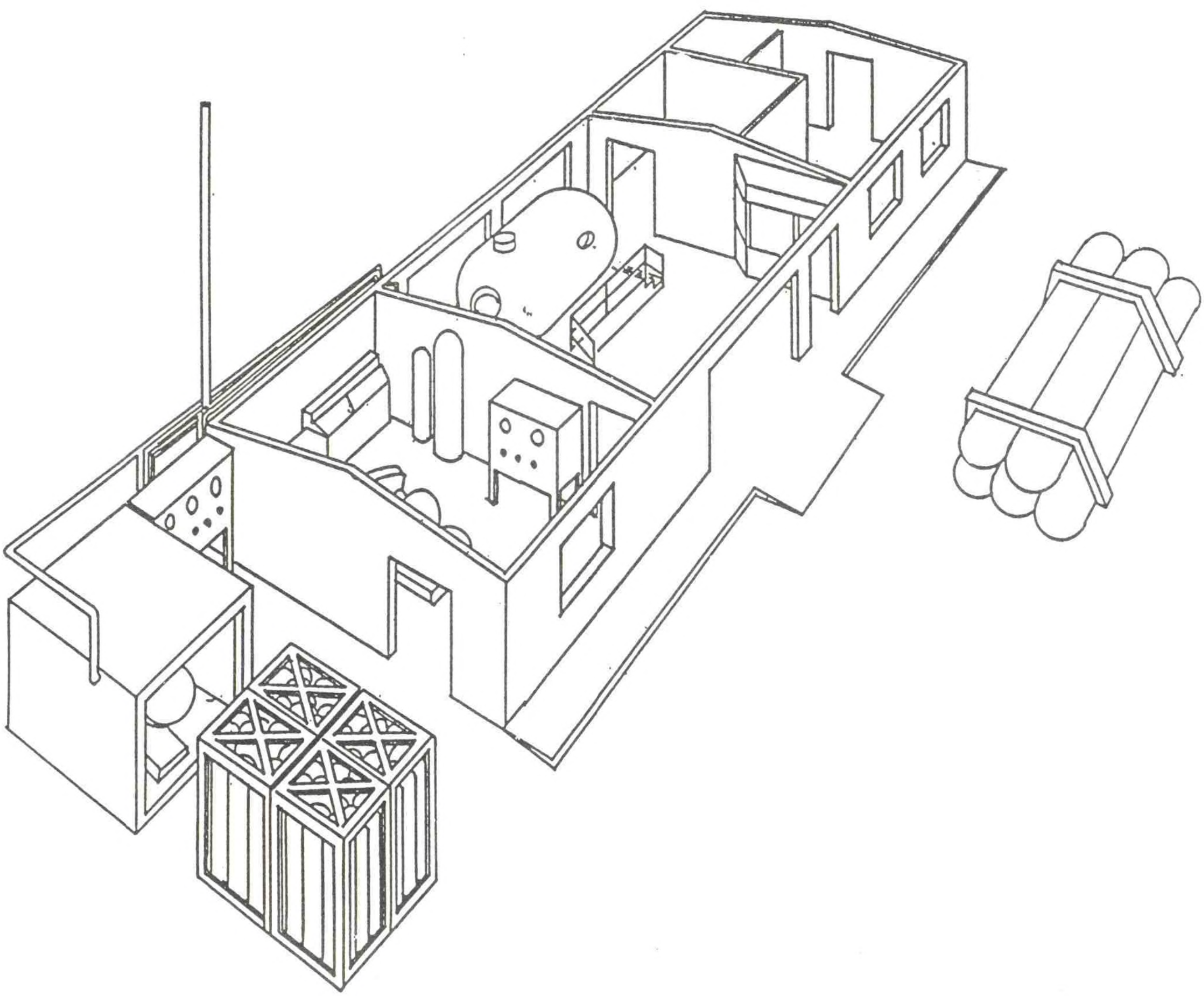
This phase of the program requires a stand-alone building which is presently under construction and will be completed in November of this year. It also requires a new large animal hyperbaric chamber which is presently being fabricated and due for delivery in January, 1992. The system is designed to investigate the effects of hydrogen in large laboratory animals, under saturation diving conditions, at pressures to 1,750 psi. During operations, the chamber will be compressed using the basic safety precautions we employ with the Phase 2 facility.

The building is being built in accordance with NFPA 50A-1989 and all electrical equipment within the chamber room will be either rated for Class I, Division 2 locations, or will be enclosed and purged with fresh air in accordance with NFPA 496-1989. Adjacent rooms will be sealed from the chamber room and maintained at an elevated pressure to allow use of standard electrical equipment. The chamber room atmosphere will be monitored with hydrogen sensors and ventilated naturally through large sliding doors. In the event of inclement weather, the system can be operated with doors closed, by ventilating the room with a large explosion proof fan located on the roof. The doors will be lightly fastened and act as explosion venting in the event of pressure vessel failure.

Hydrogen storage will be isolated from nonflammable gas storage. Both gas farms will be located outside. The hydrogen rated compressor will be also located outside, while the compressor for nonflammable gas will be located inside with building and life support machinery.

This facility will permit studies in large animal models under saturation conditions. Scientific studies will be a follow-on to those completed in Phase 2.

Figure 3
PHASE THREE FACILITY



SUMMARY

With these facilities, and the results from scientific studies over the past several years, NMRI has launched a major research study to investigate using hydrogen gas as a breathing medium for divers. While biochemically enhanced decompression is our main thrust, we will not ignore the opportunity to compare what we know about deep helium gas diving with what we will discover using hydrogen. Four years from now we should have some answers to questions about using a hydrogen/oxygen mixture for diving that many of us have puzzled over for many years.

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AN OVERVIEW: U.S. NAVY DIVING BIOMEDICAL RESEARCH AND DEVELOPMENT PROGRAM

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ABSTRACT:

The U.S. Navy is committed to developing biomedical technology to support all Navy manned diving operations. Program goals are to increase the safety and effectiveness of divers at current operational depths, and to provide physiological information which will allow useful work to be performed at deeper depths for longer periods of time. The program is divided into three broad task categories, decompression procedures, biomedical criteria for diver equipment, and diver health and safety. Program structure, recent accomplishments, and near term research objectives will be discussed.

INTRODUCTION:

The U.S. Navy's biomedical research and development program addresses numerous mission limiting problems. The most significant problems relate to, (1) determining optimal decompression schedule efficiency for a predictable risk of decompression sickness, (2) discovering the optimal recompression schedule and adjunctive drugs for treatment of cerebral arterial gas embolism, (3) defining and quantifying the operational limitations imposed by diver hypothermia and hyperthermia, (4) minimizing the magnitude and physiological impact of immersion diuresis, and associated dehyration, (5) minimizing the work of breathing and elevated levels of carbon dioxide imposed by the diver's underwater breathing apparatus, (6) discovering procedures and possibly medications that will minimize pulmonary and central nervous system oxygen toxicity, (7) developing procedures and identifying medications that minimize the high pressure neurological syndrome, (8) defining and minimizing the diver's risk for long term hearing loss, and (9) defining and minimizing the diver's risk of long term neurological sequelae secondary to deep diving.

For convenience, the research and development effort is divided into three program areas, (1) decompression procedures, (2) biomedical criteria for diver equipment, and (3) diver health and safety.

OBJECTIVES:

The specific objectives of the decompression procedures program area are to develop new decompression schedules for air and mixed gas bounce and saturation diving, and to investigate methods for safely decompressing crew members from a pressurized compartment of a distressed submarine. The new decompression schedules will use physiologically tested data, including animal and human inert gas uptake and elimination. New statistical methods, including maximal likelihood analysis, will be used to predict the risk of decompression sickness. The mathematical algorithm will be suitable for embedding into a computer chip, and will be versatile enough to allow real time calculation of the decompression obligation for multi-level bounce dives, and for saturation diving profiles that include an unlimited number of excursions. The program will accommodate any breathing gas mixture, for constant or variable partial pressures of oxygen, and will include emergency schedules for use when a dive needs to be aborted.

The specific objectives of the biomedical criteria for diver equipment program area are to develop protocols that maximize the performance of useful work, at deeper depths, for longer dives, and to specify the biomedical criteria for improved underwater breathing apparatus and thermal protective devices.

The specific objectives of the diver health and safety program area are to, (1) develop improved treatments for decompression sickness and cerebral arterial gas embolism, (2) re-evaluate oxygen exposure safety limits for operational diving, and for the treatment of decompression sickness and arterial gas embolism, (3) expand the diver's hearing conservation standard to include all operational diving scenarios, and (4) develop methods to monitor the long term health of U.S. Navy saturation divers.

RECENT ACCOMPLISHMENTS:

The most significant research and development program accomplishments during fiscal year 1990 were:

- Recommended to NAVSEA that ascent from saturation dives deeper than 200 fsw should continue to be at 4 fsw/hr; rates should be slowed to about 2.4 fsw/hr when shallower.

- Developed a real-time probabilistic nitrogen-oxygen model for human decompression that considers onset time of decompression sickness symptoms (will form the basis of new air tables to be delivered in 1991).

- Demonstrated that dietary carbohydrate loading improves work capacity and helps to maintain core temperature during intermittent work in cool water.

- Determined during 150 fsw saturation dives that hyperoxic heliox breathing mixtures prevent the exercise induced loss of maximal leg muscle power that is observed with normoxic heliox mixtures. Drinking oral glucose solution during exercise does not alter oxygen uptake or net thermal balance.

- Determined during 1000 fsw saturation dives that hyperoxic heliox reduces the rate of muscle fatigue observed when using normoxic mixtures. Caffeine increases body heat loss during exercise; light exercise ameliorates post-dive physical deconditioning.

- Completed and submitted to NAVSEA revised air purity guidelines for dry deck operations. Recommended a trial of a new hydrocarbon detector onboard submarines.

- Noted good agreement between maximum likelihood prediction, and findings of diver tolerance to respiratory loading during 150 fsw air dives.

- Recommended diver adjustable hydrostatic loading of underwater breathing apparatus to accommodate individual variations in respiratory mechanics.

- Demonstrated the feasibility of using electrical resistance heating of hands and feet to improve performance and comfort during 3° C. immersion. Recommended to NAVSEA the immediate development of operational units using available technology.

- Determined that cutaneous helium efflux at depth is insufficient to rapidly dilute alternate dry suit insulating gases. Carbon dioxide is an unsatisfactory insulation gas due to skin irritation at depth.

- Recommended that the head down position not be used during the transportation and management of patients with cerebral arterial gas embolism.

ULTIMATE PRODUCTS:

The ultimate products from the current decompression procedures program area are, (1) the first edition of a manual that specifies medically safe procedures for rescuing the crew of a disabled, pressurized submarine. Decompression schedules will be included for air, nitrox, and other gas mixtures relevant to likely Deep Submergence Rescue Vehicle scenarios (in final review), (2) a comprehensive, man tested, predictive model of decompression sickness for air and mixed gas bounce diving which can generate real time decompression schedules for any predetermined risk of decompression sickness. The model accommodates any desired partial pressure of oxygen, nitrogen, or helium for single dives, repetitive dives, surface decompression, variable partial pressure of oxygen, and altitude diving scenarios (delivery date: 9/93), and (3) a comprehensive, man tested, predictive model of decompression sickness for heliox saturation diving. The model will generate real time decompression schedules for any predetermined risk of decompression sickness. It can accommodate any desired partial pressure of oxygen and helium, as well as repetitive excursions of unlimited complexity (delivery date: 9/93).

The ultimate products from the current biomedical criteria for diver equipment program area are, (1) guidelines to design and select passive and supplemental active thermal protective gear, based on physiological responses to cold water immersion (delivery date: 9/92), (2) optimal design criteria for elastic loading of underwater breathing apparatus (delivery date: 5/93), and (3) a validated physiological model for underwater breathing apparatus dependent limitations of human performance underwater, incorporating breathing load, gas temperature, and inspired partial pressure of carbon dioxide (delivery date: 9/93).

The ultimate products from the current diver health and safety program area are, (1) a predictive, physiologically based model of human central nervous system oxygen toxicity, using maximal likelihood analysis, for use in single and multi-depth dives (delivery date: 9/92), (2) improved diver training and work schedules that are safer, more efficient, and minimize the fatigue that predisposes a diver to drowning and decompression sickness (delivery date: 9/93), (3) comprehensive recommendations for noise exposure limits for helmeted and non-helmeted divers. Recommendations will include a protocol for a hearing conservation program specifically for Navy divers (delivery date: 9/94), (4) identification of the pathological mechanisms for central nervous system and inner ear decompression sickness, along with new recompression protocols to improve treatment outcome (delivery date: 9/95), (5) improved recompression protocols for cerebral arterial gas embolism, with report of a clinical trial using lidocaine, and possibly other adjunctive drugs to minimize neurologic damage (delivery date: 9/95), and (6) a preliminary assessment of the unique health risks associated with Navy saturation diving. The report will address diver health protection, and evaluate indications for establishing a long term surveillance program (delivery date: 9/97).

MILESTONES FOR FISCAL YEAR 1993:

Current program plans call for the accomplishment of the following milestones by the end of fiscal year 1993:

- Complete draft of Change 1 for the "Pressurized Submarine Rescue Manual".

- Deliver comprehensive, man tested, predictive model of decompression sickness for air and mixed gas bounce diving.

- Deliver comprehensive, man tested, predictive model of decompression sickness for heliox saturation diving.

- Complete validate physiological model for underwater breathing apparatus dependent limitations of human underwater performance.

- Establish a standard cold water immersion stress test, for use in future comparative performance evaluations.

- Prepare efficient, safe, diver training and work schedules, including strategies to lessen physical deconditioning after prolonged saturation dives; include practical tests of diver physical fitness that will be used to measure deconditioning.

- Provide specifications for improved techniques and equipment to measure sound levels in wet and dry hyperbaric environments.

- Report the effectiveness of heliox recompression therapy for air induced central nervous system decompression sickness.

- Report the comparison of treatment outcomes after cerebral arterial gas embolism when using an enriched oxygen modification of U.S. Navy Treatment Table 6A, versus outcome after using Treatment Table 6.

- Deliver a mid-study analysis of lidocaine efficacy as adjunctive treatment for cerebral arterial gas embolism.

CONCLUSION:

The U.S. Navy remains committed to a program of biomedical research and development in support of operational diving. The requirements to improve the safety, efficiency, and flexibility of all diving missions is being met by a research and development program that is structured to address and meet those goals.

NEW SEATOPIA PROJECT

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ABSTRACT

The NEW SEATOPIA PROJECT is one of main area of post SEATOPIA PROJECT research at Japan Marine Science and Technology Center (JAMSTEC). Because Japan has a vast area of continental shelf with an abundunce of marine resources, research and development of this technology is essential.

Prior to this project, we had constructed the support vessel " Kaiyo " with an new SDC-DDC diving system installed on boad. In addition, we had made the push-pull type deep sea underwater breathing apparatus during the first phase.

There were three phases of this project. The first is the phase of arrival, to ensure the safety of open sea operation and medical fitness of divers. The second is the phase of expansion, to prove the capability of some underwater works using the conversion technique of working sites under lock-out diving by dynamic posisioning system. And the last was the phase of establishment, to confirm these technique and works using diver rotation system.

Our diving record in the open sea reached 300m depth in Jul.1988. In first phase, we had been solving many problems slowly but steadily. And in next phase, we tried and accomplished to join some pipes to the small structure on the underwater work site. Additionally, in last phase, we had been able to set up a small installation upon the preset structure. In Jul.1990, we had finished successfully these research and development on diving science and underwater working technology up to 300m depth.

INTRODUCTION

JAMSTEC has been engaged in research and development of diving technology, and physiology. From 1972 to 1975, we had completed an open sea saturation diving experiment series, the SEATOPIA PROJECT, up to 100m depth. After this project, we had been challenged and cleared deeper diving simulation experiments on land, the SEA DRAGON PROJECT, up to 300m depth.

The NEW SEATOPIA PROJECT commenced in 1985 and was completed in 1990. The work was based on two projects : the SEATOPIA and the SEA DRAGON(fig-1)

The NEW SEATOPIA PROJECT were conducted step by step, from 60m up to 300 depth. The project was separated into 3 phases, as follows (fig-2);

First Phase

Objective : arrival

- to ensure the safety of open water operations and physical fitness of the divers.

Second Phase

Objective : expansion

- to prove the capability of the underwater experiments using conversion techniques.

Final Phase

Objective : establishment

- to cofirm the feasibility of these techniques using diver rotation system.

This paper will focus on underwater experiments that were conducted during the NEW SEATOPIA PROJECT.

METHODS

And the Fig.3 shows the general arrangement of our experiment. In this figure, "KAIYO" is our diving support vessel which is a semi- submersible catamarran , and is equiped with the Dynamic Positioning System (DPS) and a SDC-DDC SYSTEM .

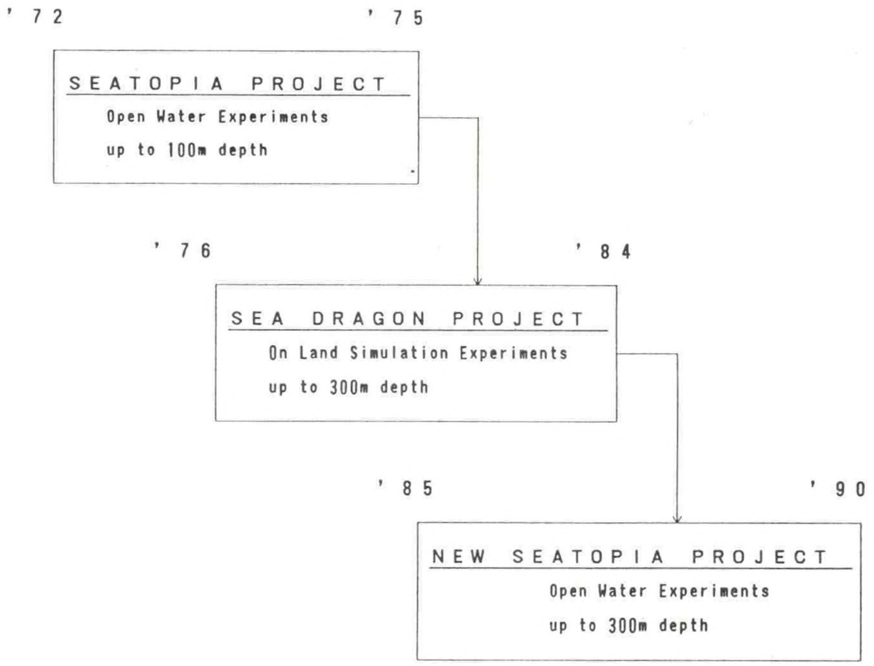


Fig.1 Manned Saturation Diving in JAMSTEC

	'84	'85	'86	'87	'88	'89	'90
Building "KAIYO"							
Open Water Training							
Unmanned Testing		60/100m	200/300m				
Open Water Simulation		60m	100m	200m 300m			
Open Water Lock Out Experiments		60m	100m 60m/	100m 200m	300m 200m	300m 200m	300m

Phase-I Phase-II Phase-III

Fig.2 The Chronological Table of the NEW SEATOPIA PROJECT

The divers were transported to the ocean bottom using a SDC. Upon arrival two divers secured themselves to the outside of the chamber while a third diver remained in the SDC as control person . The divers wore the push-pull type of underwater breathing apparatus (Fig. 4).

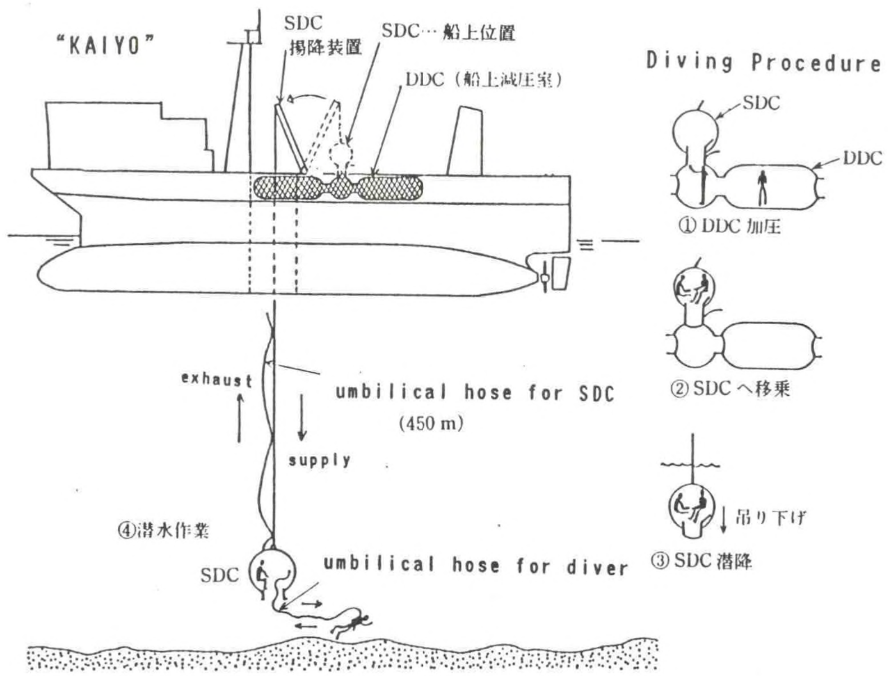


Fig. 3 The General Arrangement of our Saturation Diving Experiments

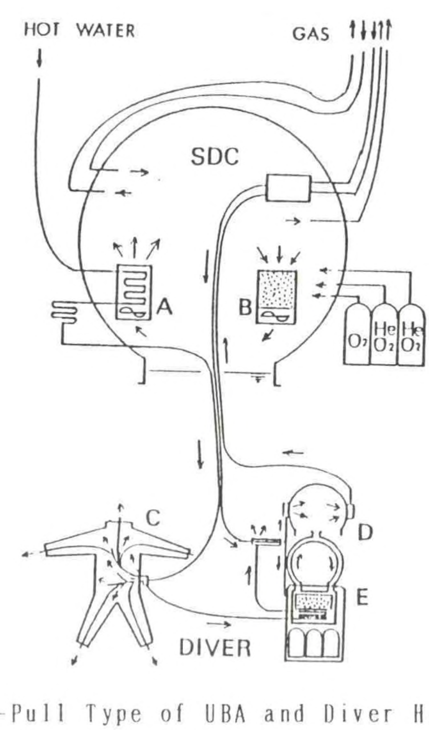


Fig. 4 The Push-Pull Type of UBA and Diver Heating System

Next , The Fig. 5 and Fig. 6 shows the two techniques used in the experiment. The upper diagram shows the conversion tequnique . This technique is used when a position change is necessary during a lock out dive . The lower diagram shows the continuous rotation of the two teams .

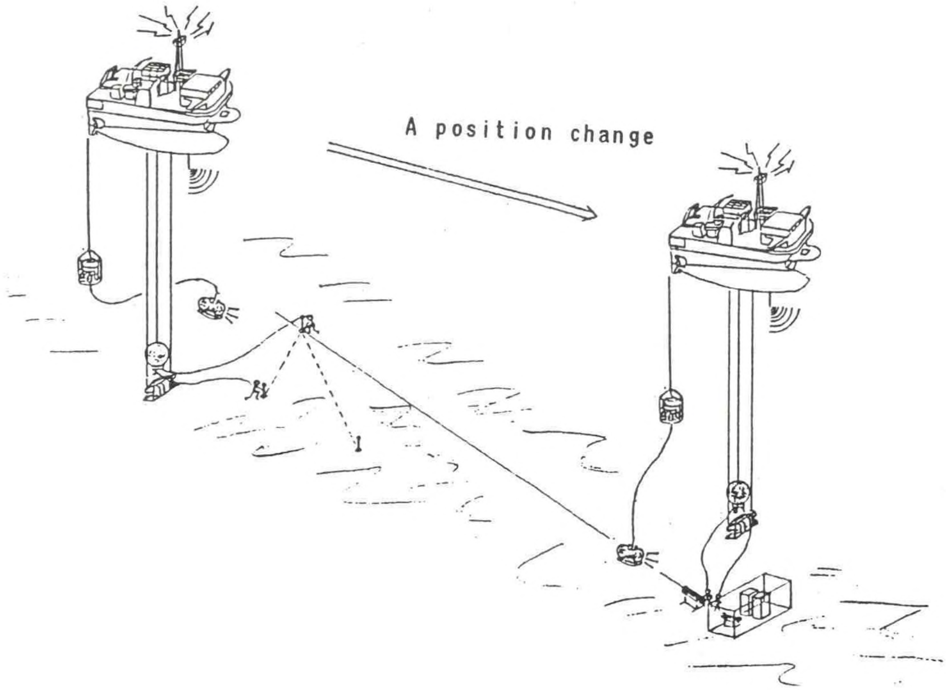


Fig. 5 The Diagram of the Conversion Technique

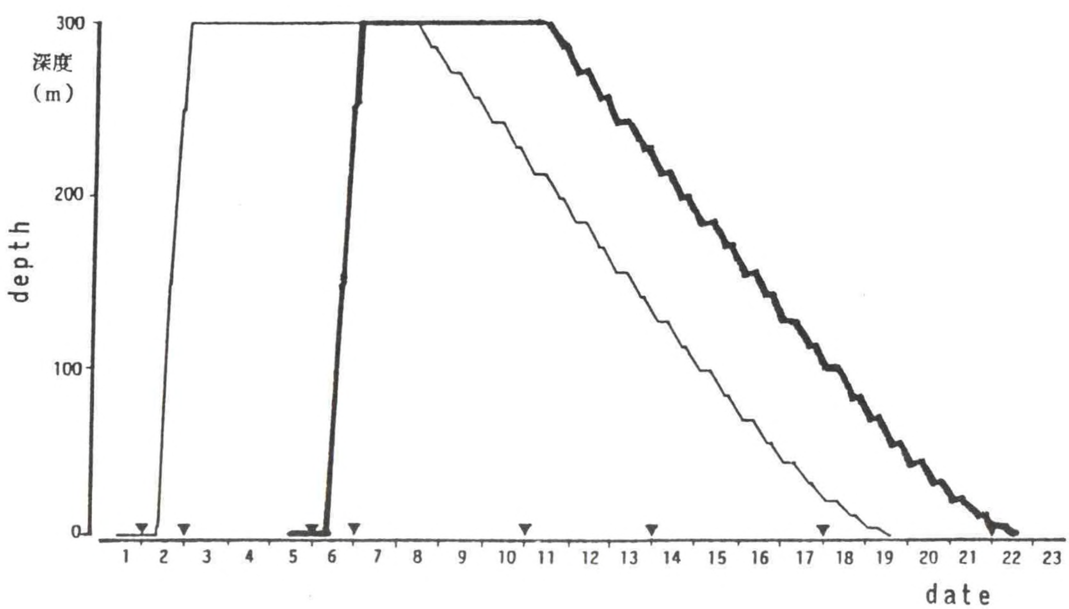


Fig. 6 The Dive Profile of the continuous rotation

The layout of ocean floor working situations are explained on this page (Fig. 7 and Fig. 8). In these figure, the underwater working stage is a large and a heavy object.

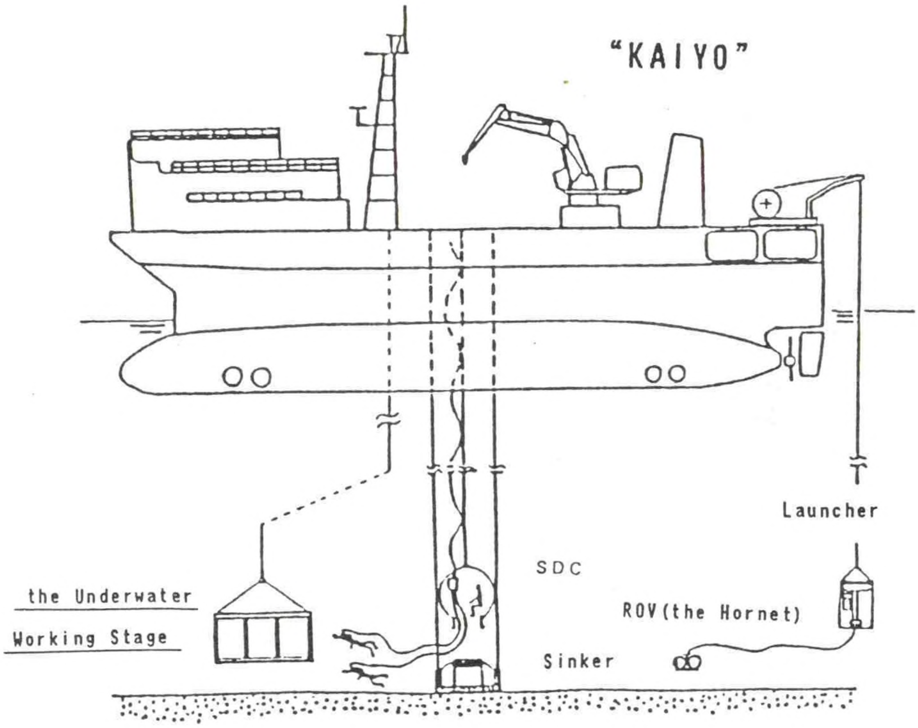


Fig. 7 The Placement of the Underwater Working Stage

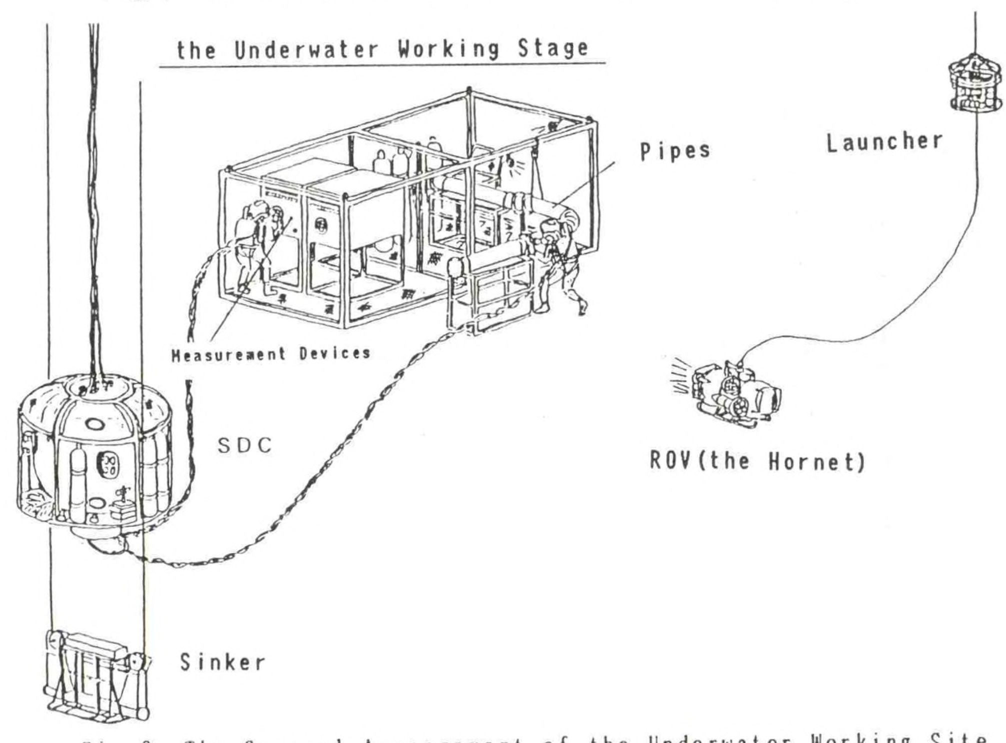


Fig. 8 The General Arrangement of the Underwater Working Site

RESULT AND DISCUSSION

In the Fig.8, The stage is pulled up from the deck , and remobed from " KAIYO" . Next ," A frame crane" is used to lower the stage into the water, the near bottom. During this time the ROV operator has been standing nearby guarding against any obstacles. ROV operator monitors the descent and landing of the stage . The descent is completed and it is positioned on the floor . Afterward, the pulling wire is released, divers sever the connection. When the stage's power supply , via cable , is turned on , the stage is ready for operation . And a counter way has been available in order to raise the stage back to the surface .

The next operation is the jointing together of the stage and the smaller four legged object . In this case , ROV and DPS are more delicate and fine. They are used for active positioning and leading . As the smaller object is lowered downward , the stage , equipped with four receptors , waits for its arrival . Using the ROV and DPS , divers make final preparations for attachment. And , divers assisted attachment is completed. The successful unification of two structures demonstrates the usefulness of this technique.

The third operation demonstrates the connection , to each other , of three underwater pipes (Fig.8) . The first pipe is fixed on the stage , the second pipe is joined to the first and third pipes at a 45 ° angle and the third pipe is preset near the bottom of the stage using an air balloon. First , a rough connection is made . After a leakage check is conducted the connection is secured. Finally , sea water is purged from the system. These stages of work were done completely by divers .

As in the construction phase this final stage of our work has proven itself to be feasible and beneficial.

As a result of our research we have outlined some important points , as follows ;

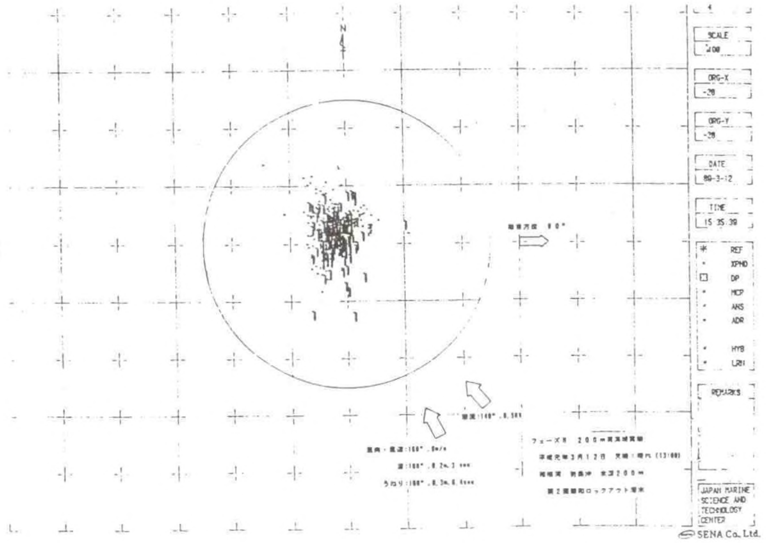
Important Factors for Open Water Deep Sea Diving Operations

1. Efficiency of Dynamic Positioning System
2. Heaving of Support Vessel

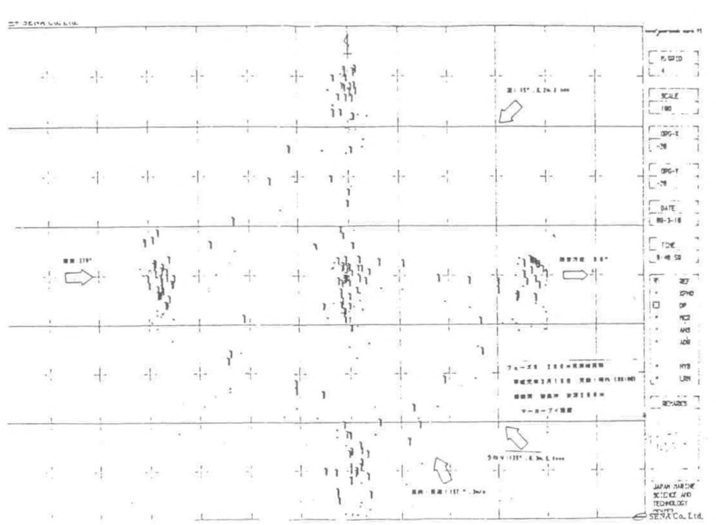
3. Monitoring of Underwater Activities

4. Support System for Divers and Underwater Works

For examples , Fig.9 are the DPS data sheets. The upper diagram is the normal dynamic positioning. The lower diagram is a display of the data using conversion techniques. The centrl group of dots represents the starting point and the other four groupes represent post-conversion. On both graphs the positioning areas were within 3 - 5m apart from setting point . As a result of this data we have found this function to our satisfaction.



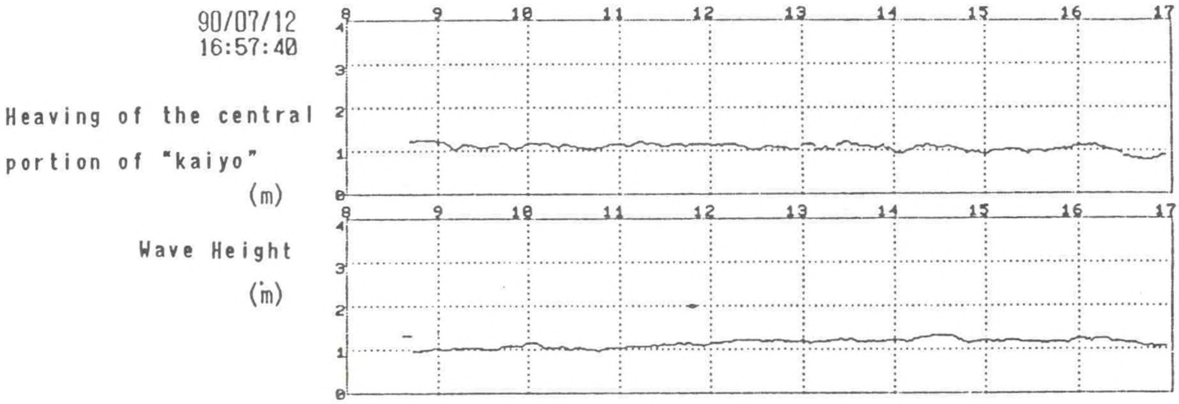
The DPS data sheet (the normal dynamic positioning)



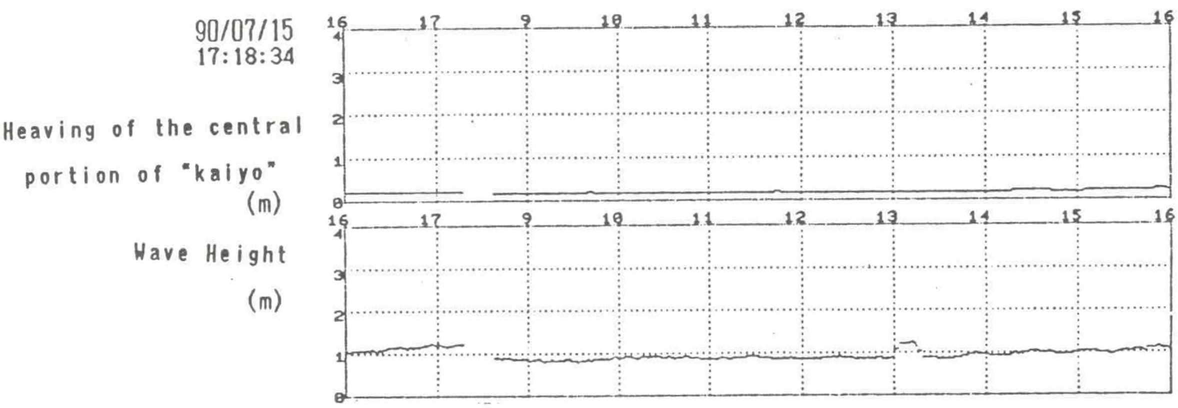
The DPS data sheet (using conversion techniques)

Fig.9 The DPS Data sheets

And the other example , the Fig.10 shows data from the heave monitor. Using this monitor we were able to receive heaving data of the SDC and the central portion of " KAIYO ", which is the point of SDC opratings. These graphs shows display data on similar sea states. But the first graph shows situations in which swell is prominent. And the second graph shows situations in which wave action due to winds is prominent. For open water deep sea diving the two are alike only in appearance. The central heave of " KAIYO " has been stronger from swells than from wind induced wave action. As a result monitoring of swell stregth during open water diving experiments is necessary.



The Heave Monitor's Data Sheet (Sea State:3, Swell is prominent)



The Heave Monitor's Data Sheet (Sea State:3, Winds is prominent)

Fig.10 The Heave Monitor Data Sheets

CONCLUSION

The NEW SEATOPIA PROJECT was completed in July of 1990. We have happily none of the accident during this project. Through these experiments, our operational techniques and equipments reliability have become highly advanced. And some important factors of open sea diving and working technique up to this depth have been come to hand. In future, we would be able to carry out more practical underwater works and scientific studies.

The present conditions of the research and development of manned diving are as follows;

Open Water Experimentation

1. Open water experimentation is currently inactive.
2. However , precautions are being implemented to prevent deterioration.
3. But , we will be maintaining the technical level , and dealing with some concrete needs.

On land diving simuration

1. Research and development of important factors is being conducted for more detailed information.
   ①. Basic diving technology
   ②. Researching diving medicines and hyperbaric physiology with the aid of animal experimentation.

Using these current conditions , we have outlined our proposed future plans, as follows ;

Future Planing

Concept : Scientist in the sea

Purpose : To make a contribution to the progress of marine science

Means : Manned diving technology

: Underwater working technology

: Other inwater activities

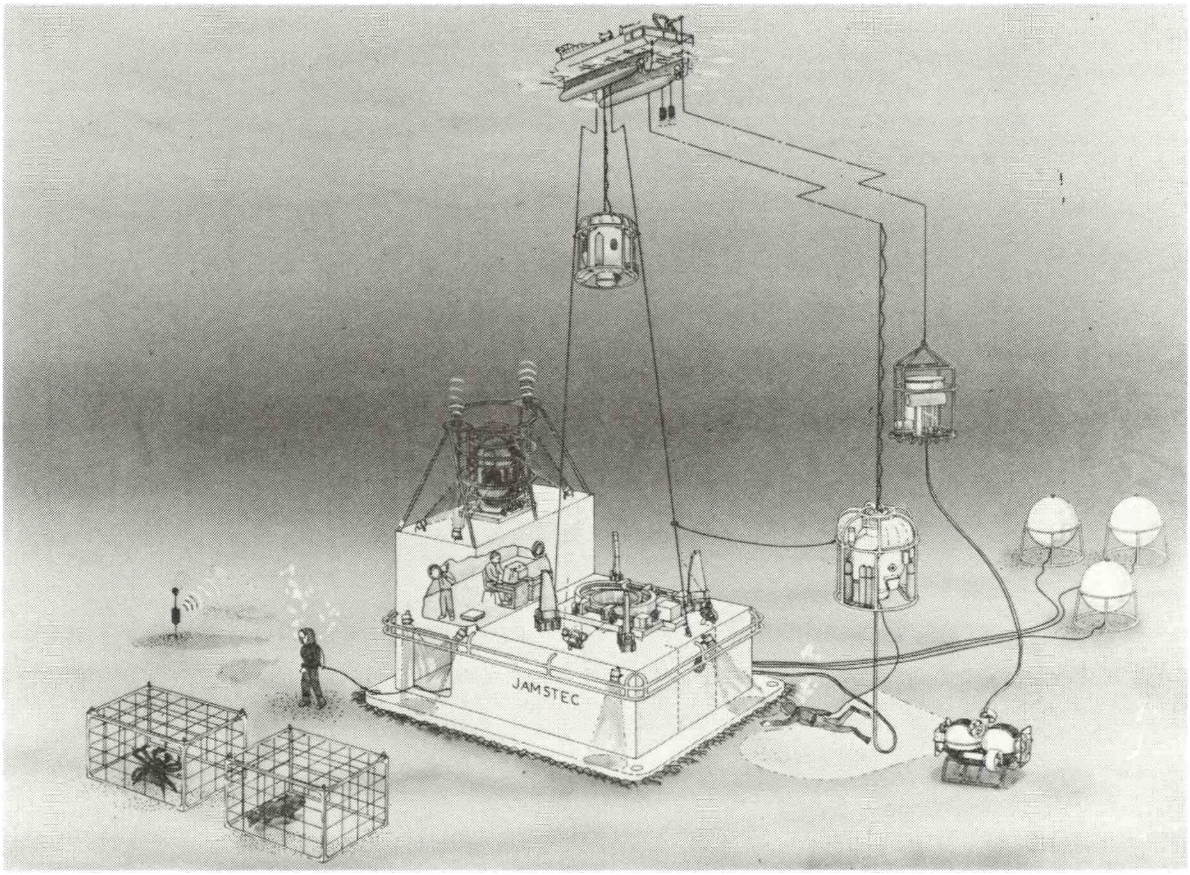
for examples

: Management and control studies of useful marine biological resources

: Ocean flux studies on the continental shelves

: Other applied scientific studies

near future, we will attack these new projects with energy , and have ted some indication as concerned as these problems among us. Because e that underwater activities , including manned diving technology , ial for research and development of marine science and natural , we propose you to share your concerns and ideas with us.



Concept of a Sea-floor Zuwai Crab Farm at 250 msw depth Continental Shelf.

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ABSTRACT

Concept "a sea-floor zuwai crab farm at 250 m depth" is a future possible japanese underwater activity imaged from a practical underwater study.

The zuwai crab *Chionoecetes opilio* is one of the most important marine products at the Japan Sea, but the catch amount is on the decreasing. Annual catch was 15,000 tons in 1964 and 2,400 tons in 1989. The crab lives at cold and deep continental shelf bottom, and very slow in growth.

To recover the resource of the crab, many research studies and controlling the fisheries have been carried out more than twenty years, by the prefectural fisheries offices and fisheries institutes around the Japan Sea. But there is no sign of stop decreasing.

To increase the zuwai crab resource, totally new departure has to be introduced. I think that the crab has a possibility to be cultivated at it's living 250 msw bottom, because of it's limited living depth and benthic active pattern. To realize this dreamy concept, three development phasis are assumd. The first phase is a practical study of the zuwai crab at the living depth, the second and the third phasis are dreamy concept for sea-floor zuwai crab farm at 250 m depth. The second phase will be a bottom nursery of the adult crab to increase reproduction capability, and the third phase will be sea-floor incubative and breeding laboratory to produce juveniele crab.

JAMSTEC started fundamental studies belong to the first phase, they are an ecological study of the crab, a technical and an economical assesment for the sea-floor zuwai crab farm. A result of the first experimental task at 250 m depth which held on June and July, 1991 are presented.

INTRODUCTION

Japan has a broad continental shelf which nearly correspond to the width of the land. This area is very important as a fishery ground. Coast and Inshore areas are utilized for marine cultivation - fishes, shells, algaes, and so on - by coastal fishermen, by fisheries cooperative society and by private companies. Several important marine resources are artificially hatched on land and discharged into the sea for increasing them using natural producing capability by Prefectural and National hatchery. Also, many resources are controlled to protect against the depletion by settlement of a closed fishing ground, determination of the closed season, and so on. Never the less, several important marine resources are continuously decreasing.

The zuwai crab is one of the most important but depleting marine products in Japan Sea area. Because of ecological characteristics of the crab, which lives nearly whole their life at the deep continental shelf bottom between 200 and 300 m, a concept of a Sea-floor Zuwai Crab Farm was proposed to cultivate them and to strengthen reproducing capability of them in their naturally aliving depth area. This concept will be realized utilizing sophisticated underwater research vechicles and diving technology.

This paper descrives background and outline of the concept "a Sea-floor Zuwai Crab Farm", and result gained at the first experimental study to realize it.

THE ZUWAI CRAB *Chionoecetes opilio*

The zuwai crab *Chionoecetes opilio* is one of the most important marine products at the Japan Sea. Fishery ground is at the continental shelf area, at the depth around 200 - 300m. Size and shape of the crab is different from male and female. Male has big shell- width is 10 - 13 cm, long legs and weigh around one kilogram. Female is less than 10 cm in shell width, and has very legs. Because of the beauty shape and taste, male is expensive compared to female. At the begining of the fishing season, one zuwai crab often costs about $ 100. The resources of the zuwai crab is decreasing by reckless fishing. Annual catch amount was 15,000 tons in 1964 and 2,400 tons in 1989.

The life cycle of the zuwai crab is estimated as shown in Figure 1, which was reesented by Dr. Kon. A feltilized egg of the zuwai crab is holded at the abdomen of the female crab. It hatch out as Pre-Zoea, then change to Megalopa. During these two stages, the crab behave as a pelagic larvae. After nearly one year pelagic duration, Megalopa change to juvenile crab, down on the bottom, and start benthic stage. A crab walk around the bottom of the deep xontinental shelf and grow up after around ten years without big seasoning and mature migration.

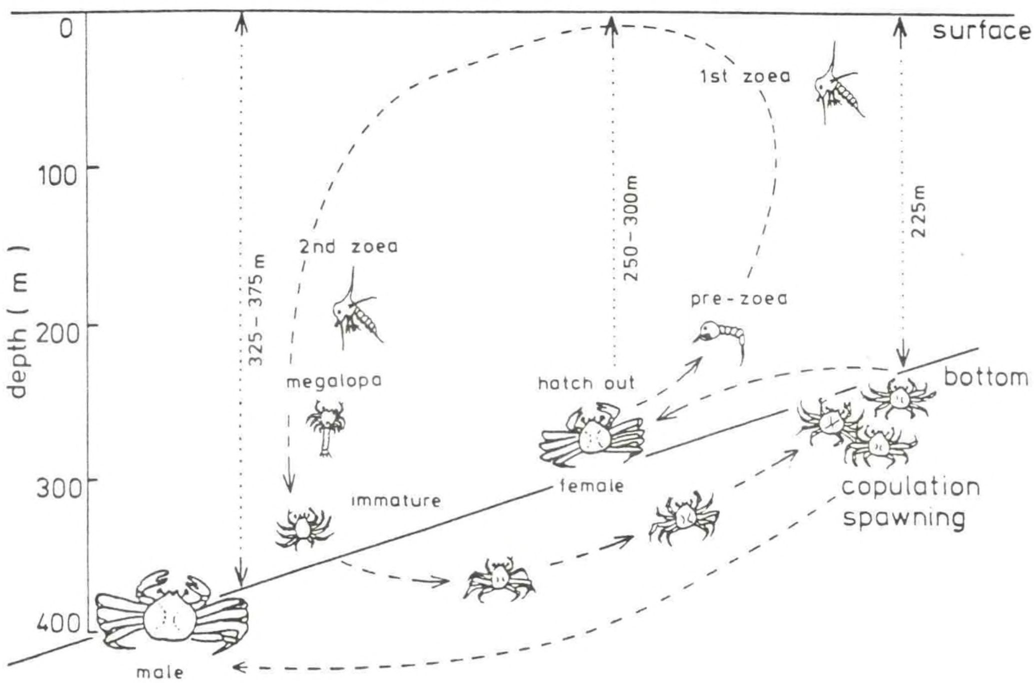

Figure 1. The life cycle of the zuwai crab estimated by Dr. Kon.

To recover the resource of the zuwai crab, settlement of a closed fishing ground, determination of the closed season, ecological study, resource assesment and on land experimental breeding test are carried out more than twenty-five years by the prefectural fisheries offices and fisheries institutes around the Japan Sea, unsuccessfully. Theoretically, prohibitation of the zuwai crab fishin g for few years will be tht best way to strengthen reproduction capability of th e crab.

Never the less, there are lot of another fishery by another fishermen at the same area, and many juvenile crab and female crab are caught without intension. So the prohibitation of the zuwai crab fishing is not a practical way.

CONCEPT OF A SEA-FLOOR ZUWAI CRAB FARM AT 250M

From the present situation, nobody can stop decreasing the zuwai crab resources and totally new concept have to be introduced. As it is almost impossible to produce numerous juvenile crabs on land by unknown obstacles, it will be possibile to cultivate adult crabs for breeding at it's living 250 m bottom, because of it's limited living depth and benthic active pattern.

JAMSTEC proposed a new concept named "Sea-floor zuwai crab farm at 250 m", as shown in Table 1. This consists of three phasis. The first phase is a basic and practical study of the zuwai crab at the living depth. The second and the third phasis are dreamy concept for sea-floor zuwai crab farm at 250 m depth. The second phase will be a bottom nursery of the adult crab to increase reproduction capability. The third phase will be sea-floor incubative and breeding laboratory to produce juveniele crab.

Table 1 New concept proposed by JAMSTEC

Project name : Sea-floor zuwai crab farm at 250 msw

- Phase 1. Basic study
  - a. Ecological study of the zuwai crab
  - b. Experiment to realize sea-floor farm
  - c. Technical assesment
  - d. Economical assesment
- Phase 2. Sea floor mariculture
  - Bottom nursery using surrounding barrier
- Phase 3. Sea floor laboratory
  - Sea-floor incubative and breeding laboratory to produce juveniele crab

BASIC STUDY TO REALIZE "SEA-FLOOR ZUWAI CRAB FARM AT 250M"

JAMSTEC started fundamental studies belong to the first phase, they are an ecological study of the crab, a technical and an economical assesment for the sea-floor zuwai crab farm. The purpose of this study is not only for realizing the farm, but also getting ecological informations using sophisticated research instruments and methods which had not been used before for these biological study.

PURPOSE AND METHOD

The first offshore experimental study was planned and completed on 28 June to 4 July, 1991. Outline of the experiment and the arrangement of the research instruments are shown in Table 2 and in Figure 2.

At the 250 m depth area at the Japan Sea, seven day research was conducted by dynamically positioned research vessel "KAITO", using observation ROV -HORNET launcher system, Framed camera system named "Big Mac", two small experimental Barriers for enclothing the zuwai crab, self recording current meter and mud sampler. ROV and Big Mac were used to observe Diurnal-Nocturnal activity of the natural crab, and the activity of the released crab in Barriers settled at the bottom.

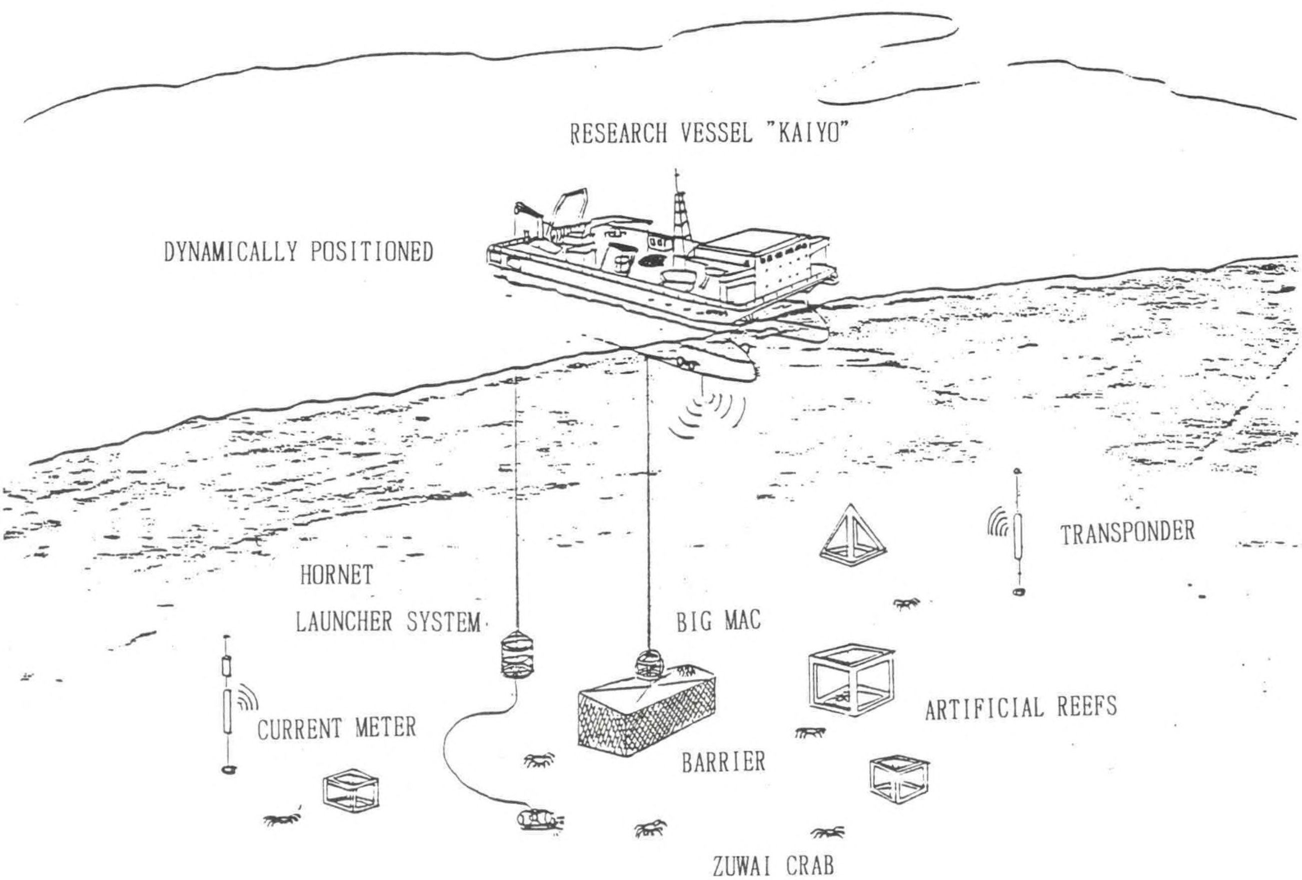

Figure 2. Ar rangement of the research instruments.

Experimental barrier is shown in Figure 3. Dimension of them are 2^L X 3^W X 2^H m, made by steel frame and special fishing net surrounding the side, weigh 160 kg. They are changed in upper shape, one has no upper cover and another has a small horizontal net at the upper edge of the side wall as obstacle. We tried to settle these barriers on the 250 m bottom with several zuwai crab to observed day and night whether crab is capable to escape from surrounding barrier. This is one of the most fundamental experiment to realize sea-floor farm, a same concept as a fence of stock farm of cow.

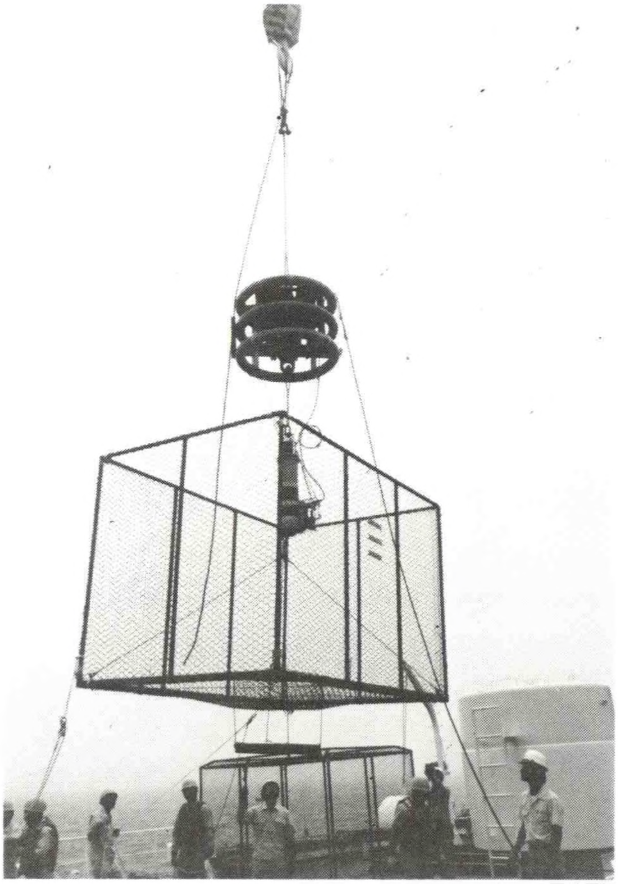

Figure 3. Experimental barriers. (2^L X 3^W X 2^H m)

Table 2 The first experiment

Place	: Japan Sea off Kasumi
Depth	: 250 m
Period	: 28 june to 4 July
Vessel	: KAIYO
Instrument	: ROV - HORNET Launcher System
	Big Mac with TV camera, Still camera, Releaser
	Barrier without upper cover
	Barrier with small upper cover
Purpose	: Diurnal-nocturnal activity of the zuwai crab
	Environment conditions - current, temperature
	The zuwai crab activity against barrier

RESULT AND DISCUSSION

Sea floor 250 m depth was covered by thin mud and numerous small star fishes. During daytime, the zuwai crab was slightly digged into the bottom and resting. As one female crab was observed for one hour and sometimes picked by ROV, it did not changed the position at all. During night time, a female crab was standing on the bottom and started running when ROV closed to it. From the result, the zuwai crab was proved to be a nocturnal habit.

Two barriers, were lowered close to the 250 m bottom about 0.5 m above the bottom, then cut down using echostic releaser by the command from the vessel, and settled on the bottom. Then observed later whether a crab was kept inside for a long duration. Two barriers were settled with a distance of 16 meter.

These two barriers were observed next day. The zuwai crab crimbed the vertical two meter height barrier but stopped by upper obstacle net. This means, the zuwai crab can climb a vertical net but may be difficult to pass over-hunged net. So, to make proper upper cover, sea-floor farm will be realized. The scale of the farm enclosed by circlic barrier will be few hundred meter in diameter at 250 m botton, as shown in Figure 4.

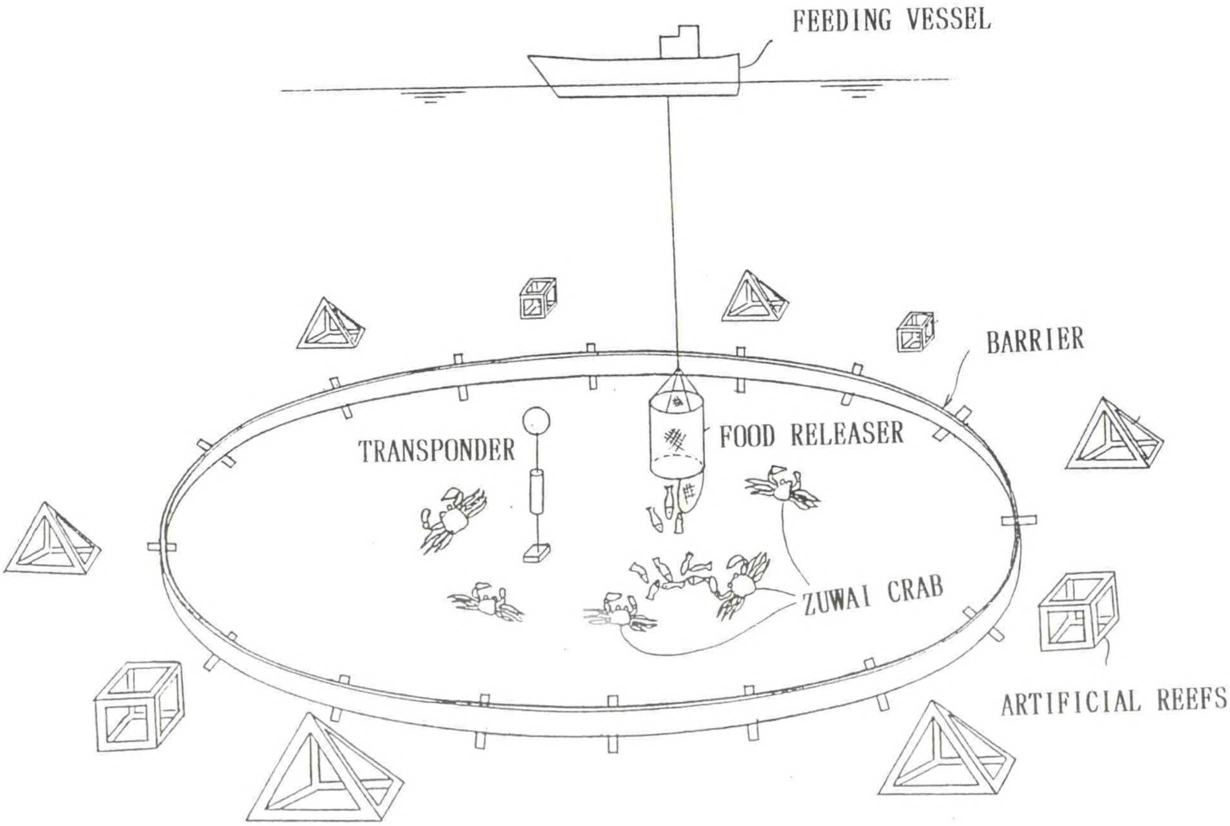

Figure 4. Image of a Sea floor Zuwai Crab Farm at 250m depth Continental Shelf.

CONCLUSION

The concept of "a Sea-floor Zuwai Crab Farm at 250 msw depth Continental Shelf" is a totally new idea for utilize deep continental shelf like as a ranch. As we have just started fundamental study from 1991, the result was very useful from ecological point of view, and also, to realize the concept of the sea-floor farm. The utilization of the sea-floor like these way will be possible in a recent future. At those days, many underwater activity will be done at the deep continental shelf area up to 300 m. This may be one of the most possible works which is equal to oil activities in Japan.

DEVELOPING A PLAN FOR THE FUTURE

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INTRODUCTION

The basic United States-Japan Natural Resources (UJNR) joint agreement provides a continuing forum to promote the development and conservation of natural resources through cooperation in applied science and technology; improve the environment for present and future generations; and increase and enhance the bonds of friendship between Japan and the United States. Over the years, the Panel on Diving Physiology and Technology has provided a framework that encouraged and fostered the exchange of information, joint research programs, and shared facilities for advancing knowledge in these fields. For that we are grateful to the Japan Marine Science and Technology Center (JAMSTEC), the Japan Science and Technology Agency (STA), the U.S. National Oceanic and Atmospheric Administration (NOAA) and its National Undersea Research Program (NURP). The focus of the series of papers and discussions over the next few days is on deep submergence, a new dimension to the UJNR Diving Physiology and Technology Panel. For these meetings on behalf of the U.S. scientists, I express thanks and appreciation to the UJNR chair, Mr. Ishii, the Physiology Sessions Chairmen Dr. Kai and Dr. Busch, and the Deep Submergence Session Chairman Dr. Hotta, and Mr. Stone. Moreover, it is important to recognize the role of President Uchida and Executive Directors and staff of JAMSTEC for this meeting and a long number of years of cooperation between our countries and institutions, particularly for dives made available in the Shinkai 2000 and 6500, and for the use of the hyperbaric chamber for research on diving physiology. My personal hope is for continued, but strengthened, cooperation, not only along the traditional path in hyperbaric physiology, but especially in new directions of deep sea research and exploration using deep submergence systems.

OBJECTIVES

The specific objective of the Deep Sea Science session is to create a framework for research during the coming decade that can take advantage of emerging capability of deep submergence vehicles. Certainly the framework will be built on the statements made by participants (and recorded in this Proceedings volume) as expressing their views and judgment and reflecting those of the community they represent. Future research operations can be built using facilities of Japan and the United States that offer a full spectrum of depth ranges to 6500 m: JAMSTEC with Shinkai 2000 (2000 m) and Shinkai 6500 (6500 m); the United States Navy Seacliff (6000 m) and Turtle (2000 m); and United States civilian assets such as Alvin (4000 m) operated by joint agreement between the National Science Foundation, Office of Naval Research, and National Oceanic and Atmospheric Administration; and Pisces (2000 m) operated for NOAA by NURP's National Undersea Research Center at the University of Hawaii. Joint operations in a region with more than one submersible should be considered as a possibility.

A less formal objective of this workshop is to establish a network for cooperative research involving scientists from both of our nations. Cooperative efforts between scientists could be between the two nations, as well as within the nations.

BACKGROUND

Oceanographic science is now at a point where knowledge of processes governing ocean and climate dynamics requires fine scale measurement and observation. This can only be done with precise control over sampling and with the ability to conduct manipulative experiments over time and space in a generally hostile environment.

Recent events have occurred to make real the previous dream of collaborative, multidisciplinary research in the deep sea using techniques other than traditional wire-line or acoustic oceanography. These techniques require deep submergence facilities such as Shinkai 6500 and Seacliff that are unique resources and are becoming more generally available. There is a need to husband resources and manage them to maximize cost effectiveness and the quality of science carried out through their use.

Over the past 2 years, staff of NOAA's Office of Undersea Research and Navy's Deep Submergence Group (OP-23) conducted discussions about closer ties between our programs that have complimentary roles. A Memorandum of Agreement between our two groups is nearing completion. [Ed. Note: the agreement was formally signed on December 3, 1991.] The agreement holds that NOAA and the Navy will jointly create, support, and carry out a research program in the deep sea using the Navy's deep submergence assets. The Pacific Ocean was selected as a test bed for the agreement because it is the deepest ocean, has the greatest number of deep submergence facilities located along its margins, Japan has interest similar to those of the United States, and the UJNR agreement affords the appropriate umbrella to facilitate future joint planning and joint cooperative operations. Mr. Gregory Stone of NOAA, assigned to JAMSTEC through the Japanese-funded fellowship program administered through NSF, working with the enthusiastic support of his mentor at JAMSTEC, Dr. Hiroshi Hotta, was well placed to support early efforts and generate a broader base of support for this workshop and its potential consequences.

PRODUCT

The initial product of the loose amalgam created by the common interests of NURP and JAMSTEC is this workshop. It was jointly planned and jointly funded by both groups. However, the ultimate product is the research framework provided by the ideas and concepts contained in the papers. Clearly not a plan, the ideas expressed none-the-less form a framework upon which to flesh out specific ideas that can be cast as proposals to prospective funding agencies. At the very least, ideas presented here will be used in the announcement of opportunities for the joint NOAA-NURP/USN-OP-23 deep submergence research program for the Pacific in 1992 and beyond.

I am pleased to have your participation in this workshop which is another significant milestone on the path of cooperation in science and technology between our two nations. In closing, it is appropriate to note that our community of scientists who use deep submergence vehicles do bring into close focus the words of the Psalmist who wrote:

> They that go down to the sea in ships,
> that do business in great waters,
> These see the works of the Lord,
> and his wonders in the deep.
>
> (Psalm 107, vs. 23-24)

Deep-sea Microbiological Research at The Japan Marine Science and Technology Center.

The introduction and current informations of ***D****eep-sea* ***E****nvironment* ***E****xploration* ***P****rogram,* ***S****uboceanic* ***T****errene* ***A****nimalcule* ***R****etrieval (DEEPSTAR) research group.*

Chiaki Kato and Koki Horikoshi

DEEPSTAR group, Japan Marine Science and Technology Center, 2-15 Natsushima-cho, Yokosuka, 237, JAPAN.

DEEPSTAR group, a new 15-year program that Japan Marine Science and Technology Center (JAMSTEC) has launched in 1990, aims at unveiling new phenomena discovered in deep-seas. Many microorganisms in the deep-sea are true extremeophiles, because they may thrive under extreme conditions, of low temperatures, high temperatures, high pressure, or in high concentrations of inorganic compounds. They have never experienced solar energy, and they have to metabolize compounds not derived from sunlight. It is distinctly possible that very ancient life-forms may be in hibernation in the worlds largest refrigerator. Microorganisms isolated from the deep-sea will give us new information on the origins of life and its evolution.

(1) Mid-term Plan for The DEEPSTAR group.

1) Purposes

In order to understand ecology and functions of deep-sea microorganisms, basic biological and ecological characteristics of deep-sea microorganisms will be studied. The purposes are to establish manipulation methods of such deep-sea microorganisms as thermophilic, barophilic, and barotolerant microorganisms inhabiting deep-sea hydrothermal vents and cold seeps, and to understand their basic ecological, morphological, physiological, biochemical and molecular-biological characteristics.

2) Organization

Director of the DEEPSTAR group is Dr. Koki Horikoshi (Professor of Tokyo Institute of Technology and the RIKEN Institute). The group will consist of three research teams: 1, Cultivation and Morphology Research Team (started 1990, leader: Dr. Teruhiko Akiba), 2, Metabolism and Physiology Research Team (will start at the middle of 1992), and 3, Gene and Protein Research Team (started 1991, leader: Dr. Chiaki Kato).

3) Research facilities

JAMSTEC has engaged in R & D of advanced deep-sea exploration technology, with notable successes, e.g., the manned submersibles *Shinkai 6500* (max. 6500m deep) and *Shinkai 2000* (max. 2000m deep) and the unmanned remotely operated vehicles. Its research efforts using such latest hardware also have resulted in certain worthwhile achievements, e.g., discoveries of hydrothermal vents on deep-sea floors.

The initial stage of research work has been done in a part of the RIKEN Institute, Wako-shi, Saitama (1990-1992). In 1993, the research facilities necessary for DEEPSTAR group will be constructed in JAMSTEC campus in Yokosuka near Tokyo.

4) Duration

Eight-years from October 1, 1990.

5) Budget and numbers of professionals

The level of funding is about 150 million yen for research in 1991 besides personnel expenses. And JAMSTEC is going to built the new research center for progressing this program from this year, which fund is 3 billion yen. We have thirteen professional researchers including the director, Dr. Horikoshi. And the numbers of professionals will be 30 or more within 2 - 3 years. Scientists who are interesting in this program have an equal opportunity to work in DEEPSTAR group in Japan.

6) Annual research plans

Annual research plans are as follows.

I. Cultivation and morphology of deep-sea microorganisms

*Studies on culture and preservation methods for deep-sea microorganisms

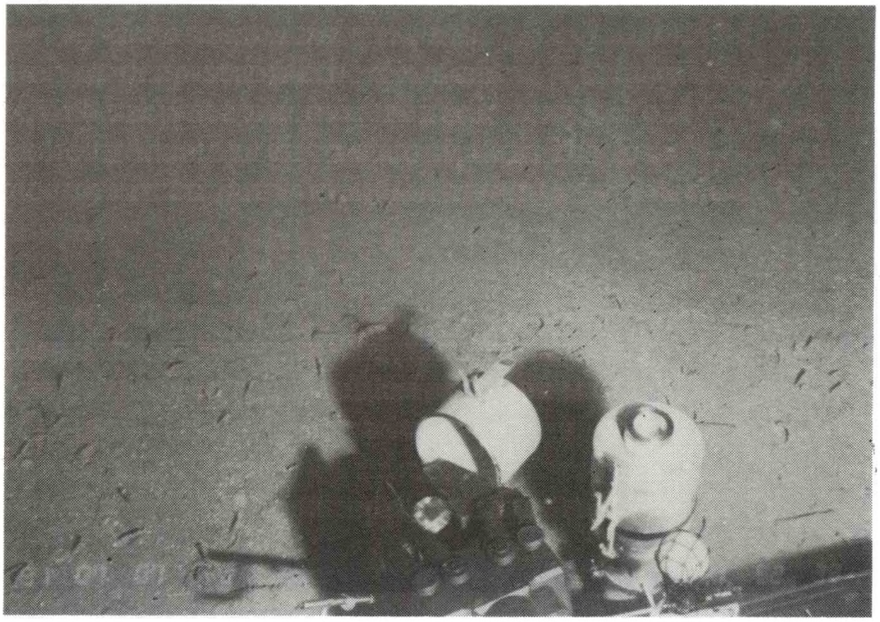
*Morphological studies on cells, organelle, etc.

*Taxonomical studies on deep-sea microorganisms

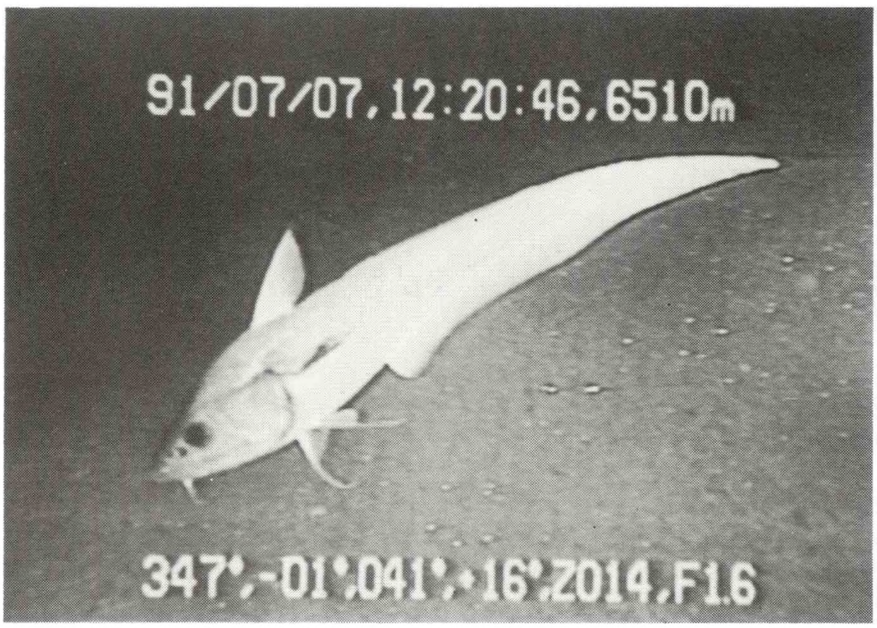
. Metabolism and physiology of deep-sea microorganisms
Studies on membrane function of deep-sea microorganisms
Studies on metabolic pathway of deep-sea microorganisms
tudies on secondary metabolic products of deep-sea microorganisms
tudies on environmental factors affecting the metabolism and physiology of deep-sea microorganisms

III. Genetics of deep-sea microorganisms
*Preparation of a genomic library of deep-sea microorganisms
*Cloning and expression of genes that are responsible for metabolism, physiology, and production of biological components
*Studies on structure and function of proteins
*Development of the host-vector systems of the deep-sea microorganisms

Picture 1. Hydrothermal vent at Okinawa-trough, 1394m depth. We are trying to isolate the hyperthermophilic microorganisms from this area.



Picture 2. "*Shinkai* 6500"'s manipulator are getting the deep-sea mud sample by using the sterilized mud-sampler at Japan trench, 6500m depth.



Picture 3. "Macrouid fish" is living at Japan trench, 6500m depth. This deep-sea fish may have some symbiosis microorganisms to get it's life energy from the deep-sea environment.

(2) Research support project for DEEPSTAR Group

In order to support the activities of DEEPSTAR group, the following support projects have started:

1) Development and operation of DMCCS.

To isolate and cultivate microorganisms from the deep-sea without decompression, construction of a Deep-sea Microorganisms Collecting and Cultivating System (DMCCS) is in progress and will be available to DEEPSTAR group after 3 years. Total developing cost will be approx. 700 million yen.

Using this system, a series of experiments with microorganisms can be made under the same pressure as they were found in deep-seas. The system, which reproduce deep-sea conditions, consists principally of four subsystems: 1) Pressure-retained sediment sampler; 2) Dilution equipment that dilutes microorganism mass in deep-sea sediment to manageable concentration; 3) Isolation device that isolates microorganisms into single cells; and 4) Culture chambers that cultivates the isolates for studying their physiological and biochemical characteristics. Each subsystem is relating to each other.

2) Preservation and distribution of deep-sea microorganisms.

In order to properly preserve and distribute deep-sea microorganisms obtained through activities of DEEPSTAR group, these microorganisms should be classified, preserved and distributed with an appropriate organization. This will be done by the Japan Collection of Microorganisms of the RIKEN Institute, Wako-shi, Saitama, Japan.

USE OF SUBMERSIBLES FOR RESEARCH ON DEEPWATER ZOOPLANKTON

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ABSTRACT

The deep water column is both the largest and the least known habitat on the planet. For most submersible users, it is the tedious distance that must be traversed in darkness to reach the bottom. Recent investigations with manned and unmanned vehicles have revealed a diverse fauna of crustacean and gelatinous zooplankton, including many unknown forms. Direct observation and collection from underwater vehicles allows scientists to study organisms that would never be seen in samples taken from the surface. With submersibles and appropriate special equipment, biologists have begun to record fine-scale distribution, behavior, physiological processes and ecological interactions. Beyond the initial requisite of discovering and characterizing the organisms that make up deepwater plankton communities, undersea research methods can clarify their relationships to the near-surface and benthic habitats, and their role in transferring energy and material between the top and bottom boundaries of the sea.

Current interests of U.S. scientists working in the water column include description and taxonomy of organisms, functional morphology, trophic interactions and physiological processes. Distribution with depth or in relation to small scale biological or physical parameters is also being investigated, as are behavioral phenomena like sensory orientation, bioluminescence and foraging, that can be best observed and interpreted in their natural context.

Scientists in this field have two important goals for the future. First, to improve technology for quantitative determination of the abundance, distribution, identity and behavior of organisms at various spatial scales, and for collection, handling and manipulation of specimens. Second, to use this technology to extend in situ investigations to other geographical regions and greater depths. Almost no work of this kind has been done in the Pacific and Indian oceans, the polar seas, or anywhere below 1000 m. Many new discoveries and valuable data have already come from initial explorations, and we can expect even more dramatic and significant results when more of the ocean becomes accessible.

INTRODUCTION

Although the earliest practical submersible, Beebe's bathysphere, was used for midwater observations, subsequent research submersibles have all been designed to reach and work on the bottom of the sea. As a result, the largest volume of habitat space on earth has been largely ignored by undersea researchers as they transit through it from the surface to the bottom. Knowledge of the distribution, diversity and biological characteristics of the invertebrates and fishes of this environment is mostly based on trawl samples, acoustic data, and the occasional specimens stranded in upwelling regions. We have only a rudimentary knowledge of the mesopelagic fauna, and less still of the organisms inhabiting the vast spaces below 1000 m. Valuable as they are, trawl samples probably retrieve only a fraction of the true numbers and diversity of animals, and reveal little about their small-scale distribution and interaction. Improvements in the design of nets and cod ends (Baker, Clarke and Harris, 1973; Childress et al., 1978; Wiebe et al., 1985) have increased the capture of live fishes and invertebrates, but trawl collections are still not an ideal way to study behavior or physiology of healthy organisms.

Direct underwater observation, collection and experimentation are valuable approaches to the study of such organism-scale phenomena as patchiness and aggregation, locomotion and orientation, feeding, reproductive behavior, bioluminescence and camouflage, sensory perception and predator avoidance. However there are many practical difficulties with direct in-situ research. Although SCUBA diving techniques have been very productive for work on macrozooplankton (Hamner et al, 1975; Madin and Swanberg, 1978), both depth and duration are severely limited. Extending work of this kind into deep water requires submersibles or remote vehicles, which are inherently more expensive and awkward than simple divers.

In this paper I will discuss the rationale for using manned and unmanned submersible systems for the study of zooplankton in deep water. Two systems currently in use for such work in the United States are then described, with a discussion of the special technology necessary for midwater research and the types of studies being conducted. Finally, I present some suggestions for future work, both technological and scientific, that U.S. investigators have identified as important areas for international collaborations.

WHY USE SUBMERSIBLE VEHICLES TO STUDY ZOOPLANKTON?

By placing our eyes, brains and hands almost directly in the deep ocean, submersible vehicles offer unique and significant possibilities to biologists. We can observe, record, manipulate or collect organisms, structures, spatial relationships and behavioral interactions that would never be detectable by indirect methods like trawling or acoustic surveys (Madin, 1990). Gelatinous organisms like medusae, ctenophores and siphonophores are so fragile that most of the deep-living species were unknown until discovered with submersibles (Larson, Madin and Harbison, 1988; Madin and Harbison, 1978; Mills, 1987; Pugh and Harbison, 1986, 1987, Pugh and Youngbluth, 1988a,b). One of the most important advantages of undersea research with submersible vehicles is the ability to discover and retrieve organisms new to science, and to gain fundamental information about their occurrence and biology. A primary requirement for midwater work in the foreseeable future will remain descriptive and taxonomic work in any new environment. We must be concerned with qualitative information of zoological as well as oceanographic significance.

Ephemeral biogenic and detrital structures like marine snow or appendicularian feeding filters can play an important role in both the production and vertical flux of particulate material (Alldredge and Silver, 1988), but are so delicate that they too are usually undetectable by conventional sampling methods. Direct underwater observation has been central to the discovery and characterization of these structures, and the quantification of their importance. Marine snow was first described by Japanese scientists using the "Kuroshio" undersea observation chamber (Suzuki and Kato, 1953), and American submersibles have been used for research on the distribution and composition of marine snow in midwater (Silver and Alldredge, 1981; Alldredge and Youngbluth, 1985).

Perhaps as important as the organisms themselves is their behavior and distribution, which can often only be observed in situ. The study of natural behavior of midwater organisms using captured animals in a laboratory is almost always suspect due to the inevitable stresses and artifacts of capture and confinement (Hamner, 1985). In most cases, direct in-situ observation is the only way to know what animals really do in their normal environment. The same is true for physiological processes, which are often greatly affected by the thermal, pressure and mechanical stresses of capture and transport of animals. Current in situ measurements of respiration and excretion rates are showing that rates can be significantly higher measured underwater than in the laboratory.

Besides the organisms and structure that we would never see or know about except for direct in-situ research, there are aspects of distribution and aggregation on small scales that cannot be resolved with surface-based sampling. For example, deep-scattering layers have long been known from acoustic data, but their source has not always been obvious. Submersible observations by Barham (1964, 1966) revealed that the source of distinct layers off the California coast was dense aggregations of a siphonophore, whose gas-filled floats made excellent sound reflectors. Dense aggregations of copepods, evidently in a state of diapause were discovered by observations from a one-man tethered submersible at Santa Barbara (Alldredge et al. 1984). Populations of benthopelagic medusae that drift within centimeters of the bottom have been described and quantified from submersible and ROV observations in several locales (Larson et al., in press).

Midwater may be a difficult environment in which to work, but it is singularly promising because of the wealth of adaptations of organisms that live and function in unbounded 3-dimensional space.

Their capabilities for orientation, aggregation, prey and mate location and bioluminescence, as well as physiological adaptations to temperature and pressure changes of vertical migration, are unique to this environment.

MIDWATER RESEARCH IN THE UNITED STATES

At present two submersible systems in the United States support most of the current research in the deep water column. These are the twin Johnson Sea-Link (JSL) manned submersibles operated by the Harbor Branch Oceanographic Institution in Fort Pierce, Florida, and the remotely operated vehicle Ventana, operated by the Monterey Bay Aquarium Research Institute in Pacific Grove, California. Both of these systems have been adapted for the special requirements of midwater work, as well as benthic operations. The ability to maintain neutral buoyancy at any depth, to maneuver with minimal turbulence, and to provide wide field visibility are primary requirements for submersibles operating in midwater. Equally important for successful science is the appropriate equipment on the submersible for imaging and collecting organisms, and handling and maintaining them after collection. This includes the right laboratory facilities for experimentation, documentation and preservation.

The two Johnson Sea-Link submersibles operate to 900 m, with dive duration up to 4 hours. The clear plexiglass front sphere of the JSL provides the excellent visibility that is important for midwater observations. A suite of collecting devices has been developed over the last two decades that allows the JSL to sample delicate organisms or structures intact (Youngbluth, 1984; Youngbluth, Bailey and Jacoby, 1990). Video and photographic equipment have also been adapted for optimum performance in the midwater environment. As important as the hardware is the skill of the pilots whose experience and finesse in maneuvering is essential to make successful observations and collections.

The Ventana ROV is a modified ISE Hysub operated with a fiber-optic tether cable (Barber, 1989; Etchemendy and Davis, 1991). It also has suction and static collectors for delicate organisms, based on those developed for the Sea-Link. Operations of the Ventana are for the present limited to the Monterey Canyon, which provides a variety of both midwater, bottom and canyon-wall habitats. Video and data from the vehicle are displayed continuously on the support ship and are also relayed by microwave link back to the Institute on shore (Davis, 1990). The long dive endurance of the ROV makes it easy to conduct extensive surveys, while the real time video on ship and shore facilitates participation in the survey by many scientists at once.

Current midwater research by American scientists using these vehicles includes both exploratory and experimental work. The Johnson Sea-Link has been used extensively in the Caribbean, near Bermuda, and off the Northeastern United States by M.J. Youngbluth, G.R. Harbison, L.P. Madin and their colleagues for studies of the taxonomy, distribution and behavior of gelatinous zooplankton, especially medusae, siphonophores and ctenophores (Larson et al, 1988, in press; Larson, Madin and Harbison, 1988; Larson, Mills and Harbison, 1989; Madin, 1988; Madin and Harbison, 1978; Mills, Larson and Youngbluth, 1987; Pugh and Harbison, 1986, 1987; Pugh and Youngbluth, 1988a,b).

In situ approaches can be equally effective for studying crustaceans and fishes. Observation and collections of deep-sea isopods have led to computer analysis of their unusual swimming behavior (Marshall, Diebel and Madin, 1991). Unexpected behavior of both midwater hatchet fish (Janssen, Harbison and Craddock, 1986) and larger pelagic fish (Harbison and Janssen, 1987) have been reported from Johnson Sea-Link dives. Other recent studies have used the submersible to carry out in situ studies of dispersal of odor plumes used by scavenging animals to locate food (Atema et al., 1991).

Some of the collecting devices on the JSL have recently been modified as in-situ respirometers to measure metabolic rates of fishes and zooplankton without inducing the usual stresses of collection and transfer (Bailey, Youngbluth and Owen, 1990).

Multi-beam acoustic equipment mounted on the JSL has been used to detect, quantify and map the near-bottom distribution of euphausiid swarms, confirming the acoustic data with direct visual and video observations (Greene et al., 1988). In situ observations documented large populations of euphausiids, some of them vertically migrating, others resident in the benthic boundary layer (Youngbluth et al., 1988). Bioluminescence studies in midwater by Widder et al. (1989) have take advantage of the neutral buoyancy and maneuverability of manned submersibles to record spontaneous and stimulated luminescence images from midwater zooplankton and fishes. The video images of bioluminescence can be characterized and in some cases correlated with the organism responsible. Collection of uninjured specimens, together with in-situ observations, enabled Robison (in press) to describe the characteristics and probable function of the luminous display of the benthopelagic holothurian *Enypniastes*.

Midwater investigations in the Monterey submarine canyon with the Ventana have concentrated on the occurrence, biology and importance of large appendicularians and their mucous feeding structures, on marine snow associated with them, and on newly discovered gelatinous organisms. Exceptionally large appendicularians in the genus *Bathychordaeus* are often very abundant in the Bay. Hamner and Robison have recently described the novel function and behavior of this organism from video records and collections made with the ROV (Hamner and Robison, in press), while Pilskaln et al. (1991) have considered the distribution and biogeochemical importance of the mucoid detritus produced by these appendicularians and other zooplankton. Collections from Ventana have led to the description of a new ctenophore in the genus *Kiyohimea* (Matsumoto and Robison, subm.), which was first described from Japan. Other investigations with the ROV included description of large populations of benthopelagic medusae (Larson et al., in press), and ongoing studies of siphonophores (Robison, pers. comm.).

FUTURE RESEARCH DIRECTIONS

One of the prime goals for U.S. scientists working with midwater communities is to extend their investigations to broader geographical ranges, greater depths, and more specialized environments. Most work in the United States has been near the coast, because the submersibles used do not dive deeper than 1000 m, and will not operate over depths greater than that for safety reasons. Even though many new discoveries have been made in the last decade of midwater research, we are still only scratching near the top of the deep ocean. The abyssal plains, the trenches and troughs, the Arctic and Antarctic, all remain aqua incognita to midwater biologists. We have every reason to believe that zooplankton and fishes inhabit the water column down to the greatest depths, and can expect to find a wealth of new organisms and relationships among them when we finally are able to explore the full ocean.

Reaching these environments will depend either on the development of new manned or unmanned vehicles, or new cooperative arrangements between scientists to equip and use existing vehicles in the world fleet. Certainly the easiest and fastest way to extend midwater research to greater depths is to outfit existing deep submersibles for water column collection and observation. The development of one or more sampler packages that could be used on different vehicles would be a useful step in this direction. Midwater research is inherently opportunistic, and valuable work can be done at almost any site in the deep sea. A set of samplers and other equipment similar to those mounted on the Johnson Sea-Links and Ventana, but adaptable to "submersibles of opportunity" would allow midwater biologists to take advantage of dive time wherever it was available, or to mesh, as an ancillary project, with other submersible or ROV operations. The ability to carry out midwater observations, collections and experiments on some of the deep-diving American, French, Japanese or Russian submersibles would be a great step forward.

Almost as important as gaining access to these midwater environments will be refinement of current technology for doing research there. At present we lack a good technique for quantifying sparsely distributed animals. There is a great need for a method, perhaps combining optics and acoustics, that will detect small numbers of organisms in large volumes of water, and determine their range, size and spacing with respect to others, preferably without disturbing them. This technology could make possible truly quantitative assessments of midwater faunistics and biomass.

Access to new environments and improved technology will help us progress to more sophisticated investigations into physiology and behavior of deep-sea zooplankton and micronekton. Important areas for study will include metabolic rates and their regulation, adaptations at physiological and biochemical levels to low temperatures and high pressures, especially by migrating animals, and mechanisms of feeding and assimilation. Animals in this environment are likely to rely on sensory mechanisms, whether visual, chemical or mechanical, that are extremely sensitive, and allow them to navigate within large volumes of seemingly homogeneous water. Investigation of their sensory behavior and physiology will require a combination of in situ and laboratory experimentation, with ultrastructural and electrophysiological study of collected animals. Perhaps one of the most fascinating investigations would be into the ecological functions of bioluminescence, a phenomenon that reaches a zenith of diversity and significance in midwater.

SUMMARY

Although the deep water column is the largest environment on earth, it is probably the least well explored and understood. The use of submersible vehicles, either manned or robotic, provides crucial capabilities that are enabling investigators to discover and describe many previously unknown organisms, and begin to understand their ecology, physiology and behavior. But we have only begun to lift the lid and peek at the biological diversity that exists in the deep-sea zooplankton and micronekton.

The essential specifications for submersibles working in midwater, whether manned or robotic, are maneuverability, visibility, and capabilities for imaging and collecting. Since many organisms encountered will be unfamiliar, collection of specimens is necessary for identification or description. Since many look or behave very differently in situ than in captivity, it is important to record their undisturbed appearance and activity. With specialized, but relatively simple equipment, scientists using two submersible vehicles in the U.S. have made considerable progress during the last decade in discovering and describing new fauna, and beginning to quantify its physiology and ecology.

The next major steps in this field are to extend in situ research beyond 1000 m depth, and into unexplored parts of the world ocean, and to improve the technology for observing and capturing animals, and quantifying their distribution and behavior. In the near term, the best opportunities to take these steps may lie in new cooperative arrangements with operators of deep-diving submersibles that have not previously done any water-column research. The fluid nature of the midwater environment makes investigations there inherently opportunistic. While it is difficult to make repetitive observations or conduct experiments fixed in space, site specificity is less important and midwater research can often be incorporated into other deep-sea cruises as

long as the proper sampling equipment can be used.

Submersible vehicles are still clumsy relative to humans for catching organisms or carrying out manipulative tasks. We should expect that improvements in maneuverability, robotic control, imaging and sensor technology will soon permit vehicles to be more adept at delicate operations. Advances in apparatus for sampling will lead to further capability for measuring rate processes in situ. If these techniques can be developed to measure other energetic parameters like feeding or growth, they will be a tremendous help in assembling community energy budgets. Investigations of locomotion and orientation, sensory physiology and behavior, reproductive biology, and bioluminescence will also benefit from an improved ability to conduct experiments and monitor long term events with undersea vehicles.

In addition to the fundamental biology and ecology of midwater, the kinds of research described here have a part in the global ecology of the oceans. With sufficient spatial coverage, we can start to describe a global zoogeography of the deepwater fauna, a group of organisms that may be the most widely distributed of any on the planet. Further investigation of their distribution, energetics and behavior will clarify the role of midwater animals in the transformation and transportation of particles, nutrients and chemicals from the surface to the benthos. The importance of midwater organisms in regulating these fluxes will depend on their abundance, behavior and rates of feeding and metabolism. Future studies using submersible vehicles will be essential for accurate data and realistic interpretation of these parameters.

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Characterization of an Amylase from a Psychrotrophic Vibrio Isolated from a Deep-Sea Mud Sample

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1. Introduction

Recent advances in the field of marine technology have made it possible to study in detail characteristics of the deep sea and its floor. One of the great advances is the development of the submersible vessels which can dive into the deep-sea. Utilizing the help of this technology, we have initiated a research project on the isolation, characterization and application of microorganisms from the deep-sea. Since the temperature of the deep sea water is constant at about 3°C, we have begun to isolate psychrophilic and psychrotrophic bacteria from deep sea mud samples. This report describes the properties of an amylase of from a psychrotroph isolated from a deep-sea mud sample collected at a depth of 1,200m from Sagami-Bay, Japan. This enzyme showed significant retention of the activity at low temperature and the low thermostability which are similar to those of the enzymes isolated from psychrotrophic microorganisms known so far.

2. Deep-sea Environment as an Extreme Environment

There are several conditions we can regard as extreme environments. The pH condition (below 3 and above 9), low and high temperatures (10°C and above 70°C), high salinity (15% or higher NaCl concentration), the presence of organic solvent (more than 1%), heavy metals, UV and X-ray irradiation are regarded as extreme conditions.

High pressure is another extreme condition, which is typical in the deep sea environment. The hydrostatic pressure reaches 1,000 atm at the depth of 10,000m. In addition to the high hydrostatic pressure, the temperature of most of the sea water is around 3°C, whereas near hydrothermal vents, the temperature reaches 300°C. Some parts of the deep sea floors are rich in heavy metals. As shown above, the deep sea environment is considered to be extreme in terms of its high pressure and low or extremely high temperature. Researchers in DEEPSTAR group have recently begun to study the characteristics of deep sea microorganisms as organisms living in these extreme environment (detail presented by Dr. Chiaki Kato).

3. Deep-sea Microbiology

There are several interesting research approaches possibly taken to study deep-sea microorganisms; physiology, biotechnology, evolution and ecology. Physiological studies on deep-sea microorganisms in terms of extremophiles; barophiles, thermophiles, and psychrophiles should be the research objectives of the DEEPSTAR group. Deep-sea microorganisms will give us excellent tools in order to study physiological adaptation to high pressure, low or high temperature deep-sea environment. DEEPSTAR group also focuses the research on biotechnological application of deep-sea microorganisms as a new source of biocatalysts. For instance, enzymes from thermophiles and barophiles can be used as new stable catalysts in high pressure or high temperature bioreactors. Evolution and ecological studies should be another research field to DEEPSTAR group. It is possible that very ancient life-forms may be in hibernation in deep-sea floor; therefore, studying microbiology of the deep sea may give us new information on the origins of life Another research interest falls on ecological relationships among higher organisms and microorganisms in isolated deep-sea oligotrophic environment. Particularly, we are interested in symbiosis of microorganisms with large deep-sea organisms like fish, clams and shrimps.

4. Deep-sea Sediment As a Source of Psychrophiles

Psychrophilic microorganisms, which are often isolated from marine environment, grow only under low temperature. They have been isolated only from cold environments, such as arctic area or deep-sea. An intensive study was carried out later by Morita et al. on isolates from the Arctic region [1]. Morita defined psychrophiles as those bacteria which have an optimal temperature for growth at about 15°C, a maximal temperature for growth at about 20°C, and a minimal temperature for growth at 0°C or lower [2]. Those bacteria that could grow at low temperatures such as 5°C or lower but with higher optimal growth temperatures, he defined as psychrotrophs [2]. These psychrophilic and psychrotrophic microorganisms can be studied in physiological adaptation to cold environment and ecology of cold water seeps in deep sea.

Figure 1 shows the comparison between the numbers of bacteria isolated from deep-sea mud and ordinary soil. Bacteria from these samples were grown on artificial sea water and tryptone-based LB agar media at 16, 26 and 37°C. From the deep-sea mud sample, relatively high numbers of bacteria are grown at 16°C compared with those from the soil sample. Relatively high number of colonies were obtained from the deep-sea mud sample on the nutrient poor saline medium, whereas, bacteria from soil sample grew well on nutrient rich non-saline medium. It is concluded that deep-sea mud sample contains relatively high numbers of bacteria which grow well in nutrient-poor medium at low temperature, compared with those from ordinary soil sample which grow in nutrient-rich medium at 30-37°C.

5. A Psychrotrophic Strain Which Produces Amylase

The psychrotrophic bacterium was isolated from a deep sea mud sample collected at a depth of 1,200m in Sagami-Bay, Japan [3]. The sample was collected in a sterilized cylinder operated from the Shinkai-2000 submersible. The mud sample was divided into fractions on the ship immediately after the submersible vessel ascended to the surface. The sample, kept on ice, was then spread on to LB medium plates, and incubated at 15°C. Bacterial colonies on the plates were picked and examined further. One of the bacteria, which grew well also at 4°C, was identified as a Vibrio sp., with an optimal growth temperature of 22.5°C. The generation time was 1 hr. and 20 hr. at 22.5°C and 0°C, respectively. Figure 2 shows the growth characteristics of the strain No. 4-3 at various temperatures. The optimal temperature for growth was 22.5°C and no growth was observed at 27.5°C. This strain shows a maximum growth temperature of 25°C. We propose to classify this bacterium as a psychrotroph due to the growth capability at lower temperature. The strain 4-3 produces amylase in the culture supernatant. The amylase activity of the culture supernatant was examined at various temperatures (Figure 3). After 20 minutes reaction, about 40% of the activity was retained at 4°C compared with the activity retained for the same length of time at 36°C. Activity was mostly lost at 46°C and even at 36°C, the remaining activity decreased after 40 minutes incubation. In contrast, the amylase was stable after 60 minutes at 16°C.

The retention of significant activity at low temperature and the low thermostability of the Vibrio strain No. 4-3 amylase are similar to the properties of other enzymes isolated from psychrotrophic microorganisms [4,5]. These properties suggest that this enzyme may provide a useful tool for biochemical study of thermolability and it may be possible to apply this enzyme in processing of starch at low temperature.

6. Conclusion

1. Deep-sea environment is one of the most suitable sampling site in order to isolate psychrophilic and psychrotrophic bacteria.

2. A psychrotrophic bacterium, which produces an amylase, was isolated from a mud sample from a depth of 1,200m. The amylase was thermolabile and showed a high enzymatic activity at low temperature.

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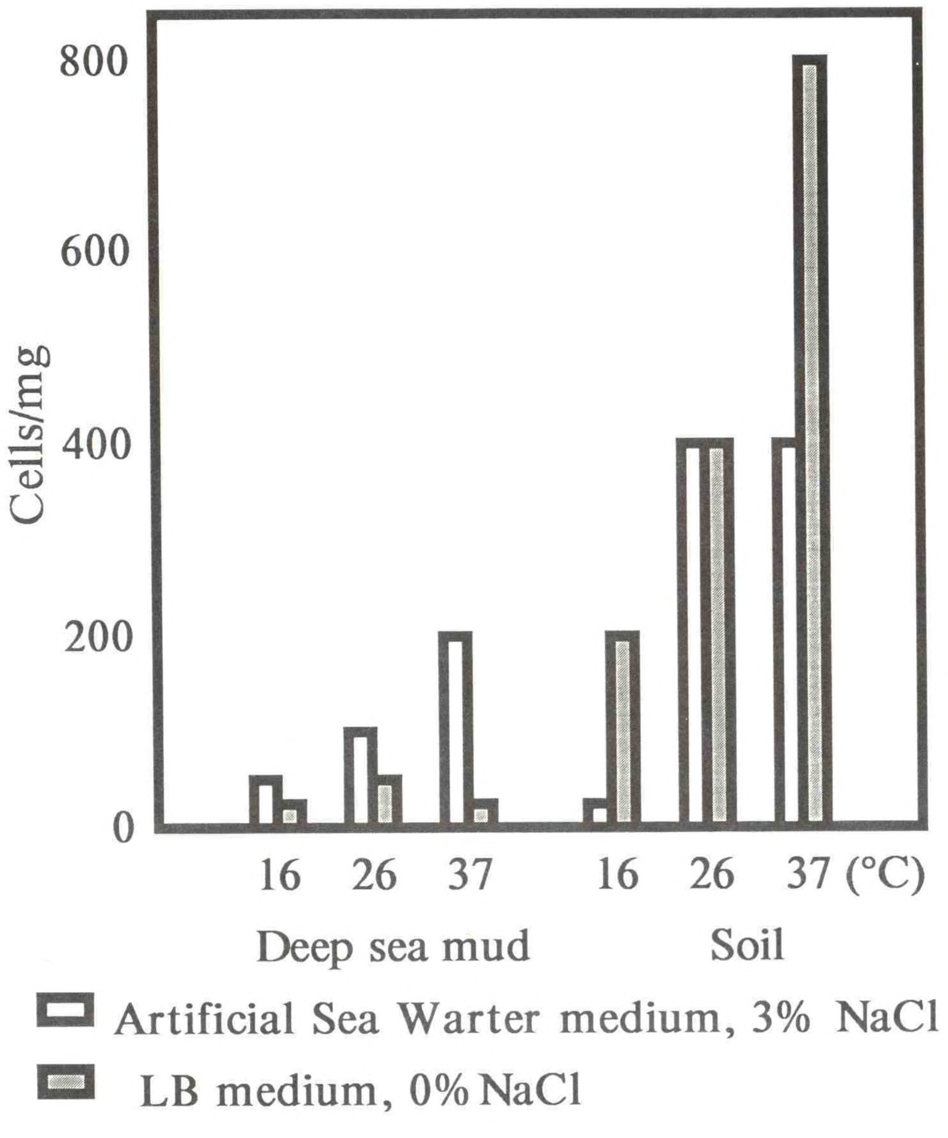

Figure 1. Occurrence of bacteria from deep-sea mud and soil samples.

A deep-sea mud sample and a soil sample were suspended in either artificial sea water liquid medium or LB liquid medium and spread onto respective agar plates. These plates were incubated at 16, 26, 37°C for 3 days and colonies appeared on the plates were counted.

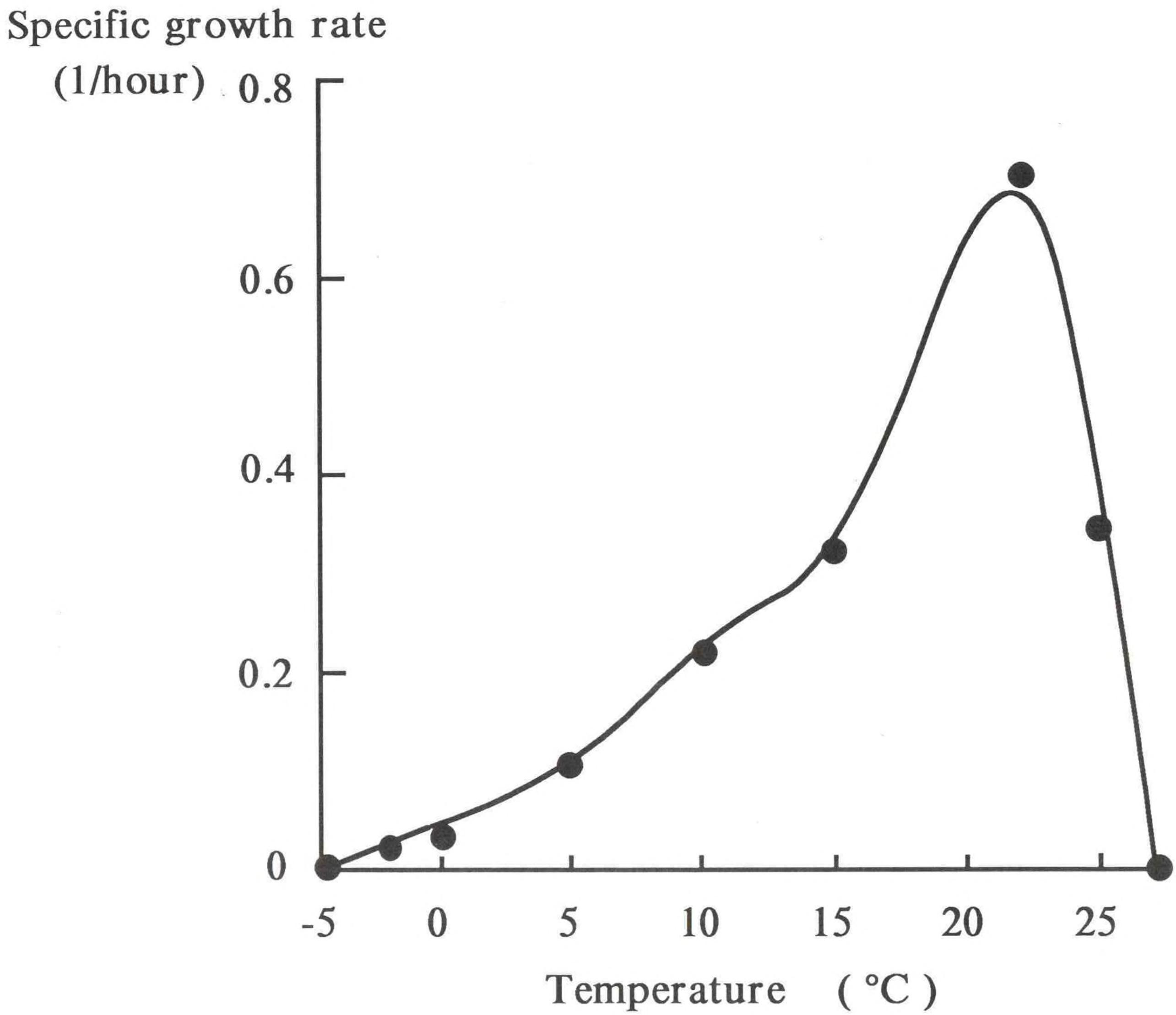

Figure 2. Growth of the psychrotrophic strain No. 4-3 at various temperatures.

The growth of the psychrotrophic strain No. 4-3 was measured at various temperatures in LB liquid medium containing 3% NaCl. The growth was measured by the optical density at 660 nm. The growth rates at the logarithmic phase were expressed as specific growth rates.

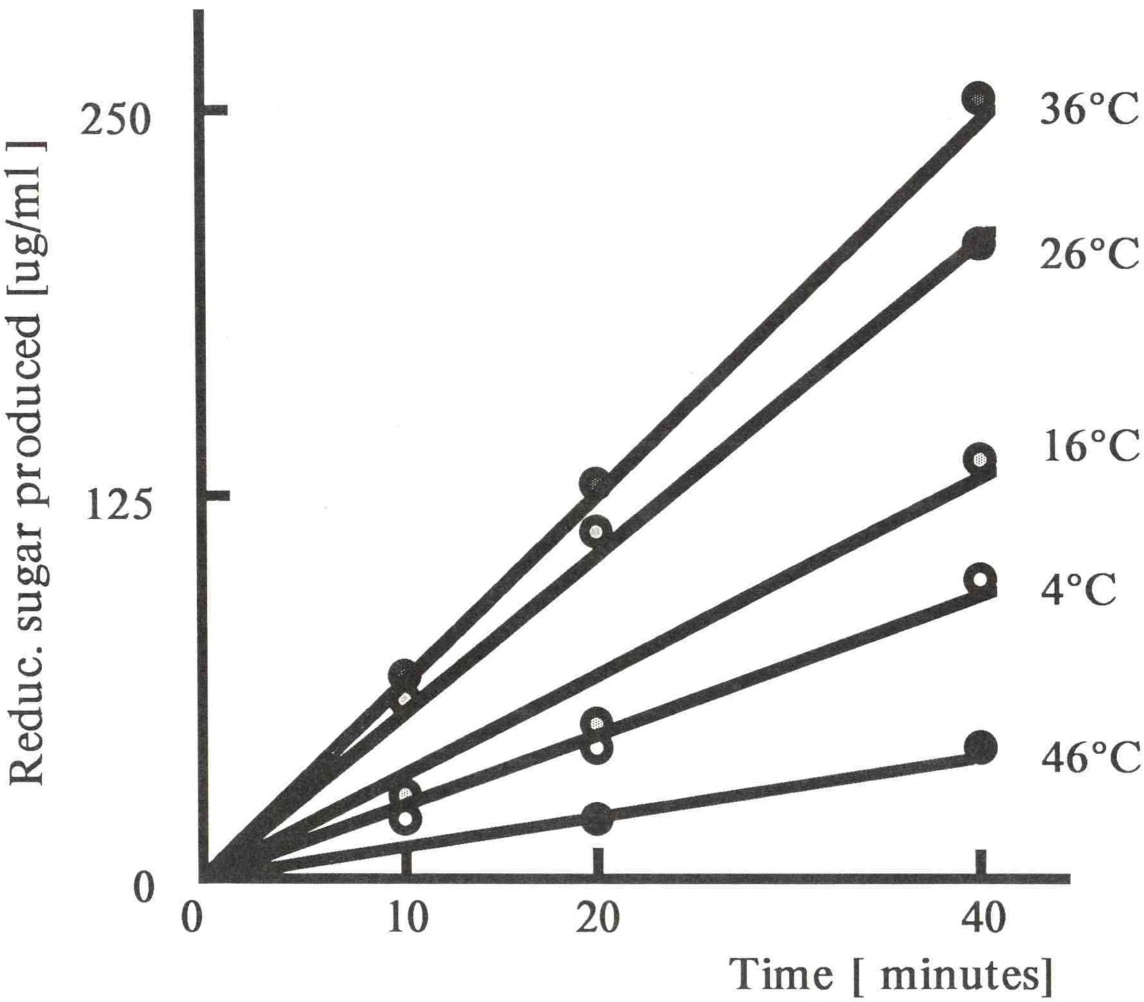

Figure 3. Activity of amylase from the strain No. 4-3 at various temperatures.

Amylase activity in the crude culture supernatant of the psychrotrophic strain No. 4-3 was measured by the amount of reducing sugar released from soluble starch at various temperature.

Marine Biological Wealth brought by the Submersibles -- New Light to Molluscan Systematics as an Example

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Abstract: The conventional sampling methods had never discovered chemosynthetic communities of hydrothermal vents and cold seepages associated with plate tectonics that were unveiled by modern manned and unmanned submersibles. Marine biologists realized that the outcomes of surveys in use of submersibles (including ROV) revolved the traditional concept of the deepsea life. The recent harvest of new vent mollusks by submersibles will prove that the molluscan systematics as well as physico-ecology of deepsea animals are required to be revised to great extent.

INTRODUCTION

The traditional concept of deepsea life is that in only the world of low temperature, big pressure, no light and poor food supply. Since Forbes in 1841 and many other subsequent pioneer marine biologists of the 19th century, many expeditions were conducted and more than thousands of deepsea bottom trawling, dredging and even underwater photographic surveys were made up to the date in various parts of the world oceans without finding any trace of biological communities of hydrothermal vents or cold seepages that are now not uncommon particularly in both Eastern and Western Pacific.

The discovery of the vent such as Galapagos Rift by the DSRV Alvin in 1977 might be expected by marine geologists, but no body ever predicted the presence of biological communities of which constituents are mostly undescribed taxa. This finding gave us the totally new knowledge of the second system of synthesize in the animal body besides intake of photosynthesized products and of the existence of chemosynthetic communities with huge biomass.

According to the recent review by Tunnicliffe (1991), about 230 new invertebrate species have been discovered from six hydrothermal vent sites, namely, Galapagos, 13°N EPR, 21°N EPR, Guaymas Basin, NE Pacific, Mid-Atlantic, and West Pacific (Marianas, Fiji and Lau). The present paper censuses precise number of gastropod taxa exclusively described from the vent sites based on various submersibles, such as DSRV's Alvin, Nautile, Shinkai 2000 among others, to endorse how submersible is formidable for unveiling the new aspect of molluscan systematics.

RESULTS

The census of new gastropod taxa described by the recent works by McLean (1981, 1984, 1988a, 1988b, 1989a, 1989b, 1990a, 1990b), Hickman (1984), McLean & Haszprunar (1987), Warén & Bouchet (1986, 1989), Okutani & Ohta (1988), Okutani (1990), Okutani & Fujikura (1990) and Bouchet & Warén (1991) resulted in Table 1, in which the probable "guest sepcies" are all excluded. From this investigation, it became clear that new gastropod taxa hitherto proposed solely based on submersibles' collection from hydrothermal vent sites are one new suborder (Leptopsina), four new superfamilies, 12 new families, 30 new genera and 59 new species and subspecies.

DISCUSSION

The so-called vent mollusks have seldom been reported before such a recent rush of discoveries of new taxa by submersibles and ROV's. Two gastropods, *Provanna pacifica* (Dall, 1908) and *P. lomana* (Dall, 1918) were inclusive of vent-associated species by Waren and Bouchet (1986). The latter species had been dredged from 'fault vents' where the first species of Vestimentifera was described, and the other might also originate from the similar sulphide-rich environment (op. cit.). Although it is not a gastropod, *Calyptogena soyoae* was first described on the basis of empty valves trawled from a bathyal muddy flat in Sagami Bay (Okutani, 1957). These valves are assumed to be brought to that station by predators, such as anomuran crab, as was proved by the discovery of a large aggregation of this clam about 30 years later (Okutani & Egawa, 1985). These may be only a few examples of discoveries of vent-associated mollusks prior to the recent disclosures of them by submersibles.

Gastropod mollusks may be the most frequent and diverse among vent-associated invertebrates which include new vestimentiferan worms, archaic cirripeds, Bythograeid crabs, large clams and mussels, and many other small-sized animals.

The first gastropod described from the Galapagos Rift was *Neomphalus fretterae* McLean, 1981. Fretter, Graham and McLean (1981) executed detailed anatomy of this limpet and McLean (1981) gave an extensive discussion on phylogeny and evolution of this species. He concluded that *N. fretterae* is a transitional stage from the Archaeogastropoda and Mesogastropoda and is derived from the Euomphalina which is mostly extinct in the early Mesozoic (Nakamura, 1986).

Since then, McLean (1985) preliminarily reported "Twenty-three species of limpets in at least five prospective families are known from seven deep-sea hydrothermal vent sites" and later (1988b), that "Seven superfamilies, including eight families, and 26 species of archaeogastropod limpets are known from hydrothermal vents". Warén and Bouchet (1989) summarized occurrence of gastropods in sulphide-rich East Pacific and listed nine families and two limpet groups that contained about 49

TABLE 1. Gastropods hitherto recorded from hydrothermal vent sites

[LEPTOPSINA]		
LEPTOPSACEA	Neoleptopsidae	*Neoleptopsis gordensis* McLean, 1990
		N. densata McLean, 1990
		N. verruca McLean, 1990
		N. oculta McLean, 1990
		Eulepetropsis vitrea McLean, 1990
		Paraleptopsis floridensis McLean, 1990
NEOMPHALACEA	Neomphalidae	*Neomphalus fretterae* McLean, 1981
		Symmetromphalus regularis McLean, 1990
	Cyathermiidae	*Cyathermia naticoides* Warén & Bouchet, 1989
		Lacunoides exquisitus Warén & Bouchet, 1989
LEPETODRILACEA	Lepetodrilidae	*Leptodrilus pustulosus* McLean, 1988
		L. elevatus McLean, 1988
		L. elevatus galriftensis McLean, 1988
		L. ovalis McLean, 1988
		L. cristatus McLean, 1988
		L. fucensis McLean, 1988
		L. guayamsensis McLean, 1988
	Gorgolepetidae	*Gorgoleptis emarginatus* McLean, 1988
		G. spiralis McLean, 1988
		G. pustulus McLean, 1988
PELTOSPIRACEA	Peltospiridae	*Peltospira operculata* McLean, 1988
		P. delicata McLean, 1988
		P. lamellifera Warén & Bouchet, 1989
		Nodopelta heminoda McLean, 1988
		N. subnoda McLean, 1988
		Rhynchopelta concentrica McLean, 1988
		Echinopelta fistulosa McLeaN, 1988
		Hirtopelta hirta McLean, 1988
		Melanodrymia aurantica Hickman, 1984
		Pachydermia laevis Warén & Bouchet, 1989
		Depreeigyra globulosa Warén & Bouchet, 1989
		D. planispira Warén & Bouchet, 1989
		Solutigyra reticulata Warén & Bouchet, 1989
		Lirapex humata Warén & Bouchet, 1989
		L. granularis Warén & Bouchet, 1989
	Pyropeltidae	*Pyropelta musica* McLean & Haszprunar, 1987
		P. corymba McLean & Haszprunar, 1987
SCISSURELLACEA	Scissurellidae	*Sinezona* sp. Warén & Bouchet, 1989
	Temnocinclininae	*Temonocinclis euripes* McLean, 1989
		Temnozaga parilis McLean, 1989
	Sutilizonidae	*Sutilizona theca* McLean, 1989
FISSURELLACEA	Clypeosectidae	*Clypeosectus delectus* McLean, 1989
		C. curvus McLean, 1989
		o *Pseudorimula marianae* McLean, 1989
SEGUENZOIDEA		*Moelleriopsis* sp. Warén & Bouchet, 1989
TROCHACEA	Trochidae	*Bathymargarites symplector* Warén & Bouchet, 1989
	Turbinidae	o *Thermocollonia jamsteci* Okutani & Fujikura, 1990
NERITACEA	Shinkailepadidae	o *Shinkailepas kaikatensis* Okutani, Saito & Hashimoto, 1989
CERITHIACEA	Provannidae	*Provanna lomana* (Dall, 1918)
		P. pacifica (Dall, 1908)
		P. ios Warén & Bouchet, 1986
		P. muricata Warén & Bouchet, 1986
		P. goniata Warén & Bouchet, 1986
		P. variabilis Warén & Bouchet, 1986
		P. macleani Warén & Bouchet, 1989
		o *P. marianaensis* Okutani, 1990
		o *P. nassariaeformis* Okutani, 1990
		o *Alviniconcha hessleri* Okutani & Ohta, 1988
		o *Ifremeria nautilei* Bouchet & Warén, 1991

TABLE 2. Two examples of report on hydrothermal vent gastropods. A: McLean (1985), snd B: Warén & Bouchet (1989)

A Distribution of hydrothermal vent limpets; GR: Galapagos Rift; 13°N, 21°N: on the East Pacific Rise; JdF: Juan de Fuca Ridge; FE: Florida Escarpment.

Vernacular name	GR	13°N	21°N	GB	JdF	FE
Group A—Tapersnout						
Half-node		+	+			
Concentric		+	+			
Opercular		+	+			
Tube-spine			+			
Haliotiform		+				
Elongate		+				
Delicate		+				
Group B—Dimorphic						
Beaded	+	+	+			
High-smooth	+	+	+			
Scabrous	+	+	+			
Oval-smooth		+	+			
Juan de Fuca					+	
Guaymas				+		
Emarginate			+			
Micro-emarginate		+				
Galapagos-emarginate	+					
Group C—Symmetrical						
Transparent	+	+	+			
Reticulate			+			
High-conical				+		
Florida						+
Neomphalidae						
N. fretterae	+	+	+			
Slit limpets						
Asymmetrical	+	+	+		+	
Regular			+			
[Totals]						
23	7	14	14	2	2	1

B *Geographical distribution of gastropod family in sulphide-rich east Pacific localities*

	Galapagos Rift Zone	13°N	21°N	GB	JdF
Scissurellidea (1 sp.)*	–	–	–	–	×
'Slit limpets' (3 spp.)*	×	×	×	–	×
Neomphaloidea (*c.* 20 spp.)	×	×	×	–	×
Lepetodriloidea (9 spp.)†	×	×	×	×	×
Pyropeltidae (2 spp.)‡	–	–	–	×	×
'Symmetrical limpets' (3 spp.)§	×	×	×	–	–
Trochidae (1 sp.)	–	×	×	–	–
Seguenzoidea (1 sp.)	–	×	–	–	–
Provannidae (6 spp.)	×	×	×	×	×
Buccinidae (1 sp.)‖	–	–	–	–	×
Turridae (2? spp.)	×	×	×	–	–

Figures in brackets indicate approximate number of species known from sulphide-rich environment. × indicates that the taxon is present, – that it is not known. *GB* Guaymas Basin; *JdF* Juan de Fuca Ridge; other localities as in **Material and methods.**

* McLean pers. commun. † McLean 1988. ‡ McLean & Haszprunar 1987. § McLean 1985. ‖ Tunnicliffe & Fontaine in press.

species in all (Table 2). The most of the worked-out results from the above-mentioned preliminary comments by McLean and Waren and Bouchet are all incorporated in Table 1.

In contrast to rapid and diverse reports of unusual new gastropods, studies on Western Pacific vent gastropods are still underway. However, findings of a neritacean limpet in a warm seepage near Ogasawara (Shinkailepas kaikataensis), large hairy snail (Alviniconcha hessleri) from Mariana and Fiji followed by another strange-looking snail (Ifremeria nautilei) from Fiji Rift area are striking. Bouchet & Warén (1991) allocated such bizzare genera as Alviniconcha and Ifremeria in the newly established family Provannidae typified by small species group of the genus Provanna.

Besides the new light to molluscan systematics very briefly mentioined above, many more facts, including chemosynthetic biota in deepsea, have been unveiled by activities of submersibles. However, as has been pointed out by some workers concerned, there remained more questions to be answered. For example, mechanism of formation and maintenance of biological communities against limited life of vent/seepage activities, mechanisms of gene flow and gene pool through such an isolated and sporadic habitats, evolution of limited numbers of taxa exclusively confined to vent environment in relation to non-vent taxa and so on.

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DEEP NEKTON: PROSPECTS FOR FUTURE STUDIES USING UNDERSEA VEHICLES

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ABSTRACT

Nekton (fishes, squid, and large swimming crustaceans) are ecologically and commercially important. Significantly more difficult to investigate than benthos and plankton, they have received relatively little attention from users of undersea vehicles. Methods for their study are evolving and this evolution should continue.

Scientists need to be able to identify the organisms seen or recorded on video or photographically and to capture voucher specimens to verify identification and for other studies. Quantitative assessment methods are needed to progress beyond simple description of faunas. These techniques will provide data to compare with that obtained by other, more traditional means and to allow comparisons between undersea vehicles regarding avoidance and sampling efficiency. Finally, techniques for performing *in situ* experiments on nekton must be developed.

Existing problems include the expense and difficulty of obtaining first quality video records of fast swimming animals, collecting those organisms, maximizing the ability to see them in the deep sea darkness or in reduced visibility, and minimizing avoidance by constructing better vehicles.

Study areas that should receive priority include: quantitative population surveys of deep-water species; habitat utilization studies and habitat surveys that can be used to predict occurrences of species assemblages; behavioral studies, particularly of reproduction, recruitment, and migratory behaviors; and ecological studies of the unique fishes associated with vents and seeps and on the effects of the concentrations of vent organisms on abundances of local non-vent nekton. Finally, it should be possible to perform tag and release studies in deep water using either highly visible tags that could be seen during surveys or acoustic tags to provide information on depth and horizontal movements to be monitored at the surface or from an undersea vehicle.

INTRODUCTION

Nekton (fishes, squid, and large swimming crustaceans) have received relatively little attention from users of undersea vehicles. To a large extent, this is probably because these organisms, as good swimmers and thus good avoiders, are significantly more difficult to study than benthos and even plankton. When avoidance is coupled to a midwater habitat, the difficulties involved seem insurmountable. Yet, because of their commercial, ecological, and scientific importance, nektonic organisms cannot be ignored; methods and technology for studying them are slowly evolving and this evolution should continue.

Fisheries and environmental management agencies are particularly interested in such studies for several reasons. First, many previously exploited species are showing signs of population distress: catch per unit effort and landings are falling, average size of individuals is decreasing, etc. It is widely recognized that present assessment techniques cannot be used to sample areas of uneven topography, and new methods must be developed. Second, in a time of decreasing budgets and aging equipment, the expense of traditional trawl surveys is too high to support. Finally, the hypothesis that trawling damages the environment has recently gained adherents, but there is little evidence to test it -- and it cannot be tested by using the "suspect" equipment of trawls.

NARRATIVE

Perhaps the most useful account of early attempts to study marine organisms <u>in situ</u> was given by Beebe in <u>Half Mile Down</u> (1934). These initial efforts were not notably successful. The first successful use of an undersea vehicle specifically for the purpose of marine biological studies was by Barton and Beebe between 1930 and 1934. Supported by the New York Zoological Society, the two used the Bathysphere, a tethered steel ball 4.5 feet in diameter, to descend 3028 feet (about 930 meters) off Bermuda. Beebe reported his results and subsequently described several new species on the basis of sightings alone -- no specimens of those fishes have ever been collected, and the species are not considered valid. Not much significant activity occurred subsequently until 23 January 1960, when the Bathyscaphe "Trieste" dove to over 10,000 meters (35,800 feet) in the Challenger Deep of the Marianas Trench.

The discovery during World War II of deep sound scattering layers (DSL's) and their diurnal migratory behavior added impetus to post-war work on pelagic organisms. In the late 1950's interest in using submersibles to study the deep sea, and to study nekton in particular, increased. The availability of the "Alvin" and other scientific submersibles increased the potential for significant research. Barham (1966, 1970) in the Pacific and Backus et al. (1968) in the North Atlantic dove into DSL's and found that to a large extent they were composed of small fishes (primarily myctophids with gas-filled swim bladders) and siphonophores. Despite the many research submersibles constructed in the early sixties, little effort was made to use these vehicles to study nekton, and there have been comparatively few studies subsequently. Most of the research using undersea vehicles has involved hydrothermal vents and in-situ experiments, probably because until now, as Rowe and Sibuet stated in 1983, "experimental manipulation, rather than surveying, is probably a DSRV's best biological use". These discoveries and the increased role of submersibles were reflected in N.B. Marshall's reviews of deep-sea biology. In the first, Aspects of Deep-Sea Biology (Marshall, 1954), submersibles and undersea vehicles in general are unmentioned and no results discussed can be traced to them; in the second, Deep-Sea Biology (Marshall, 1979) the results of investigations using submersibles are prominent.

About 5 years ago I began to use submersibles to study nekton. Since 1987 I have used submersibles extensively to study fishes, although in relatively shallow waters -- 300 meters or less. Prior to that time, I studied deep-sea fishes using large and small conventional and opening-closing nets fished to over 5000 meters, and cameras, traps and long lines deployed to 6000 meters. However, because of my earlier studies of deep fishes, squid, and shrimp, I have strong opinions about what needs to be done in deeper water using undersea vehicles to study these organisms, how that might be done, and the direction in which the scientific community ought to be heading to accomplish these goals.

Scientific needs drive many technological and methodological developments, although technological advances frequently are made in the course of satisfying non-scientific needs. In my opinion, the most important of these are: First, the ability to identify the organisms seen or recorded by video or photographically; second, the necessity of capturing individuals for voucher specimens (identification verification) and for other studies; and third, methods for quantitative assessment are required to progress beyond simple description of faunas. In the future, these techniques will be used to provide data for comparison with those obtained by other, more traditional means and to allow comparisons between undersea vehicles regarding avoidance and sampling efficiency. Finally, techniques for performing in situ experiments on nekton (physiology, tagging, and release) must be developed.

There are a host of existing problems, many of which are not unique to nekton studies. The expense and difficulty of obtaining first quality video records is primary. Video cameras of excellent quality exist today, although they are expensive. Unfortunately, they require a fairly high light intensity to operate effectively; this probably compromises their usefulness in nekton photography -- there are undoubtedly avoidance problems caused by the high intensity of the light used to enable us to capture visual images. Resolution of the difficulties involved in even obtaining visual records of fast swimming animals is another problem -- if one ignores the avoidance problem, then one may assume that the organisms "captured" by the video are representative and a possibly random sample. That is, they could be taken as a count along a transect; however, many of them are swimming relatively rapidly and thus their images may be neither clear nor complete. Because of the high swimming speeds, the camera cannot easily be moved and focused in time to get good pictures of the animals. This is a technological problem: How can we resolve both of these problems (reduce avoidance and obtain good pictures of fast moving organisms) to provide a permanent non-destructive sample of the animals seen that can be used for later analyses?

How can a submersible or ROV collect nekton? The difficulty of seeing nektonic animals in the low light of the deep sea or when visibility is reduced makes surveys difficult and emphasizes the necessity of obtaining voucher specimens to verify identifications, particularly of closely related species. Frequently, animals photographed cannot be identified without such specimens. To some extent this problem can be minimized by simply identifying organisms to the level of the most readily identifiable taxon, i.e., generic or even familial categories. However, in doing so, much of the information that can only be gathered by in situ techniques is lost; for instance, the differences in behavior, habitat preferences, feeding habits, etc., existing between closely related species cannot be studied if one simply lumps all of them at the generic level. The combination of increasing observer expertise gained by experience, and voucher specimens that can be seen in situ, photographed, then collected and identified on deck immediately after capture is very valuable and enables trained observers to readily identify different, but similar, species in situ without collection. Actual collection is hard to do: nektonic organisms usually do not sit and wait to be captured; they are streamlined and are thus not readily collected by suction devices even if the organisms do sit still. If they do not remain stationary, present vehicles are certainly not capable of chasing them for capture. The animals either have to be poisoned or narcotized in some way so they can be caught, or collected through (non-submersible) techniques such as traps or baited hooks and observed in situ before being brought to the surface. These techniques are presently usable, although time consuming; the technology for their development and refinement exists today although it has not been exploited.

Visibility from the vehicle used is another problem. Shallow water submersibles usually have fairly good visibility; ports tend to be either large or numerous. In contrast, deep-water vehicles have generally poor visibility because there are only a few small ports. The pilot usually is the crew member who can see the best, but is also the crew member least qualified to make scientific observations, although many pilots are very knowledgeable and have made significant contributions toward accomplishing scientific missions. Thus, to make quantitative observations in deep water is difficult because it is not easy to view a consistent path and the observer cannot look directly forward -- the region where nektonic organisms are most likely to be encountered before they avoid the vehicle. An ROV fitted with the appropriate cameras could accomplish what submersibles cannot.

Finally, we do know that individuals of many species avoid undersea vehicles. Whether this is due to noise, light, a pressure wave effect, or other presently unidentified factors we do not know. Observations are critically needed to allow formulation of testable hypotheses leading to construction of vehicles that produce less avoidance. I am aware of no such experiments, although there is a fair amount of anecdotal evidence demonstrating that avoidance is a problem. Systematic comparisons should be made using human observers, low light cameras, side scan sonar, color video, etc., from a single vehicle under the same circumstances. Single parameters could be varied using the same vehicle: changes in light intensity, motors or propellors, streamlining, etc., could produce significant effects on the numbers of animals detected from the vehicle. A series of such observations using different vehicles under similar (preferably the same) conditions would yield very interesting comparative data. These could then be compared to results of simultaneous or serial net tows. Observations such as these could be made in either midwater or near the bottom. Because the species assemblages in each case are generally different, data obtained from one environment would not necessarily be applicable to the other. However, working near the bottom has the advantage of being relatively two-dimensional and thus minimizes the variables involved. Lessons learned working with benthic nekton could then be applied or tested in midwater studies.

Some biological questions that should be investigated stand out. First: population surveys of deep-water species will provide data useful to ecologists and to fisheries managers. Although standard trawl surveys can supply information on some species, vehicular studies will give comparative data on avoidance, may indicate species that either avoid or escape the net, and individuals that are uncollected. Towed vehicles may also be a more efficient use of ship time because they can be set and towed for much longer than can nets. Second: habitat studies are needed both to relate occurrences and distributions of species to the habitat and to provide substrate maps that can be used to predict occurrences of species assemblages or, in the case of differentially distributed species, different sexes or size classes. Third: the faunas of untrawlable bottoms are poorly known, and the most efficient (only) way to study them comprehensively is by undersea vehicle in combination with free vehicles such as traps, etc. Fourth: the fauna of hydrothermal vents and a variety of fluid seeps have been and are being intensively studied, but little is as yet known about the lives of the unique fishes associated with these communities or about the effects of the concentrations of vent organisms on production and standing stocks of local non-vent animals, many of which are nektonic. Finally, it should be possible to perform tag and release studies in deep water. Fishes could be tagged using breakaway hooks; methods have not been developed to tag cephalopods and shrimps _in situ_, but might be. Such studies could use highly visible tags that could be seen during surveys, and they could also include acoustic tags to provide information on depth and horizontal movements to be monitored at the surface or from an undersea vehicle. Of course there are a multitude of other studies to be done, including studies of behavior, particularly of mesopelagic species (such as those done by Backus and Barham), horizontal and vertical distribution, reproduction (a species that is particularly suitable for such studies is the commercially valuable orange roughy, _Hoplostethus atlanticus_), recruitment and early life history, and _in situ_ physiology using caged or trapped animals (such as those done by Smith, 1978; Smith and Laver, 1981; and Smith and Brown, 1983).

In what direction should undersea vehicle technology develop? Is it better to emphasize the development of manned or unmanned vehicles? The resources available for undersea technology and operations are limited and are probably insufficient to develop both kinds of vehicles to a satisfactory level. For several reasons it may be worthwhile to emphasize developing unmanned vehicles, both ROV's and AUV's (Autonomous Undersea Vehicles), rather than manned submersibles. Manned vehicles by their nature are more dangerous -- if no person is in the vehicle, many safety factors can be reduced or eliminated, allowing a less expensive or more sophisticated vehicle. Manned vehicles cost more to build and to operate because they require a much larger and therefore more expensive pressure housing (the personnel compartment), more safeguards, and are operationally less efficient, i.e., they require heavier deck handling equipment for launch and retrieval, can't dive as long, can't be used as often, and are more weather dependent. Thus, they are able to gather less information relative to the resources required for their construction and operation. On the other hand, present unmanned vehicles are less flexible in use because of their tethers and have poorer visibility than manned vehicles; video and still cameras are still not as good as a human eye. It can be argued that manned vehicles will always have advantages because an observer _in situ_ is more flexible than any vehicle run from the surface.

It seems to me that future unmanned vehicles can overcome many of these restrictions and become considerably more versatile than presently existing ones. There will always be a role for submersibles, but much of the work for which they are now used could be done more efficiently by ROV's or AUV's. The reduction in the use of manned vehicles in favor of unmanned ones over the last decade supports this hypothesis; the primary users of undersea vehicles have been and are petroleum and construction companies that must work underwater, often under dangerous and difficult conditions. For their purposes (admittedly not necessarily the same as those of scientific users), it has been more useful to develop ROV's and minimize manned submersible use. Thus, the number of "shallow water" manned submersibles has decreased drastically over the same period. Therefore, I suggest that we consider developing unmanned vehicles adequate to support scientific research, including deep water. These vehicles would be capable of accomplishing work that is now impossible to do using manned submersibles. An example of this would be making visual belt transects at constant above-bottom altitude to obtain relative and absolute population estimates for benthic macrofauna and fishes. It may also be true that the reduced disturbance caused by an unmanned vehicle would make studies of easily disturbed organisms (i.e., nekton) more easily accomplished.

CONCLUSIONS

Today many scientists question whether there is a need to do deep-water research now or at all. There is very little present United States support for deep-water studies. In a time of limited funds, many agencies such as the National Science Foundation prefer to emphasize research on more fragile or threatened environments such as tropical rain forests. In fact, it is not uncommon to hear non-deep-sea oceanographers say that the deep sea should not be a priority research area now because it has a negligible effect ecologically, it isn't a threatened environment, it is little affected by man, and it does not affect humans much.

We should invest money, time, and energy in deep-sea research. First, despite political pressure and reluctance to use the oceans as dumpsites, terrestrial waste disposal problems will probably force us to look more closely at the deep ocean as a repository for highly toxic or radioactive waste. The more information available about the deep sea, the more easily decisions can be made concerning areas of potential utility for such purposes. Second, marine mining may become economically feasible in the near future and we will need to know what the effects of that activity are on the sea bottom and the water column into which tailings are dumped. Third, how can we know that the deep sea is relatively unaffected and has a relatively small role in oceanic energy budgets unless we study it? Fourth, if the deep sea is a relatively undisturbed system, it can provide us with an opportunity for study before an emergency arises; after all, although the deep sea may be relatively well insulated from the effects of human activities, once it <u>has</u> been affected, the effects will remain for a long time. The deep sea is a unique habitat that deserves study precisely because its fauna is unique in so many ways: physiologically (Somero, Dahlhoff, and Gibbs, 1991), morphologically and taxonomically (Marshall, 1954, 1979), behaviorally (Barham, 1970) and so on. Finally, study of the deep sea allows us to address certain fundamental questions about the history of the earth, the origins of life, and dynamic processes of planetary and biological evolution. Although deep-sea biologists subscribe to these reasons, most of them do not carry much weight with non-scientists (or even many scientists) because they lack immediacy and direct applicability. Ultimately, we must convince not only our non-deep-sea colleagues of the importance of our work, but we must also convince the non-scientists who provide the funding.

There are many scientifically interesting and important problems to be addressed in deep-sea research. The technology to accomplish many of these studies is available or can be developed. The problems preventing development of deep-sea research and vehicles to accomplish it are primarily political; therefore a primary goal of deep-sea scientists and engineers must be to develop more convincing reasons for supporting deep-sea research or more convincing ways to present "traditional" reasons. If we fail to accomplish this goal, increased support for deep-sea research in the United States seems unlikely, U.S. scientists will lose access to the deep sea, and other nations such as France, Japan, and the Soviet Union will accomplish much of the research in the next decade.

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A seabottom observation project in the Sagami Bay
by the Hydrographic Department of Japan

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ABSTRACT

Hydrographic Department of Japan (hereafter reffered as JHD) has been conducting seabottom site survey using ROV(remotely operated vehicle) named MARCAS 2500 to determine a seabottom site suitable for construction of seabottom observation station since the fisical year of 1989. In parallel with above surveys, seabottom observation instruments to detect horizontal and vertical displacement of the ocean floor have been developped. This paper describes recent progress of these studies and future plan.

1. Subject of seabottom survey using ROV

The Sagami Bay is assumed as one of the plate boundary between Philippine Plate and Asian Plate. The hypocenter of Kanto earthquake(1923) also occurred in this plate boundary. For promoting earthquke prediction programe, demand for seabottom observation will be increased in future. JHD has been conducting seabottom site surveys from 1989 using ROV. Trough these surveys, the proposed site for setting a seabottom observation station is determined at the southwestern slope of the Miura knoll (Fig.1). As well as site surveys, marine engineering and supporting system for a seabottom observation station have also been developped using ROV. The results of site survey and other developpement using ROV are listed in Table 1.

2. Construction of seabottom horizontal distance meter

A seabottom horizontal distance meter has been developped since 1989 by JHD and JHA for detection of horizontal distance at the ocean bottom. This meter is composed of transmitter and receiver ,which are connected by seabottom cable. A travel time between them is converted to horizontal distance.

The chirp wave of 30kHz-50kHz is used and resolving power is enhanced by calculatting correration between original wave of tranmitter and recieved wave.

A schematic diagram of horizontal distance meter is shown in Fig 2. Result of correration between original wave of transmitter and recieved wave is also shown in Fig.3.. This result indicates that one wave-length resolving power can be attained by correlation method using chirp wave.

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3. Construction of seabottom vertical displacement meter

This instrument is designed for detection of vertical displacement. The Sensor and principle of this meter is illustrated in Fig. 4. A quartz pressure gage is installed in the sensor part. A offset gravity, which is depend on water depth, can be adjusted by valance weight. The target of sensitivity is several cm/year.

4. conclusion

The recent progress of ocean bottom observation plan by JHD and JHA are described. The final experiment using these observation instruments is to be conducted in the fisical year of 1992. This project may pave the way for the advance of earthquake research.

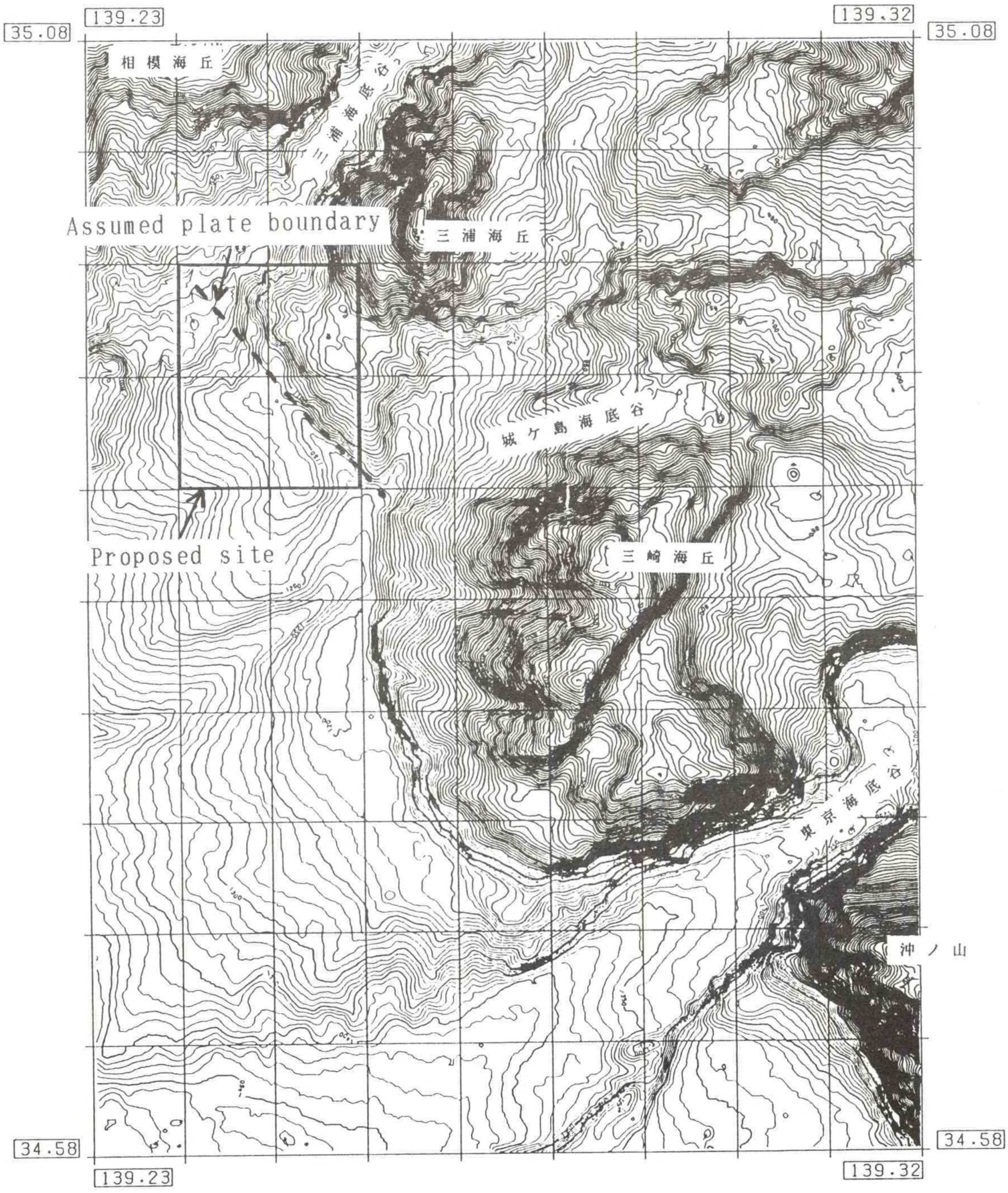


Figure 1

Proposed site for setting horizontal and vertical displacement meter

Figure 2

Conception of horizontal distance meter

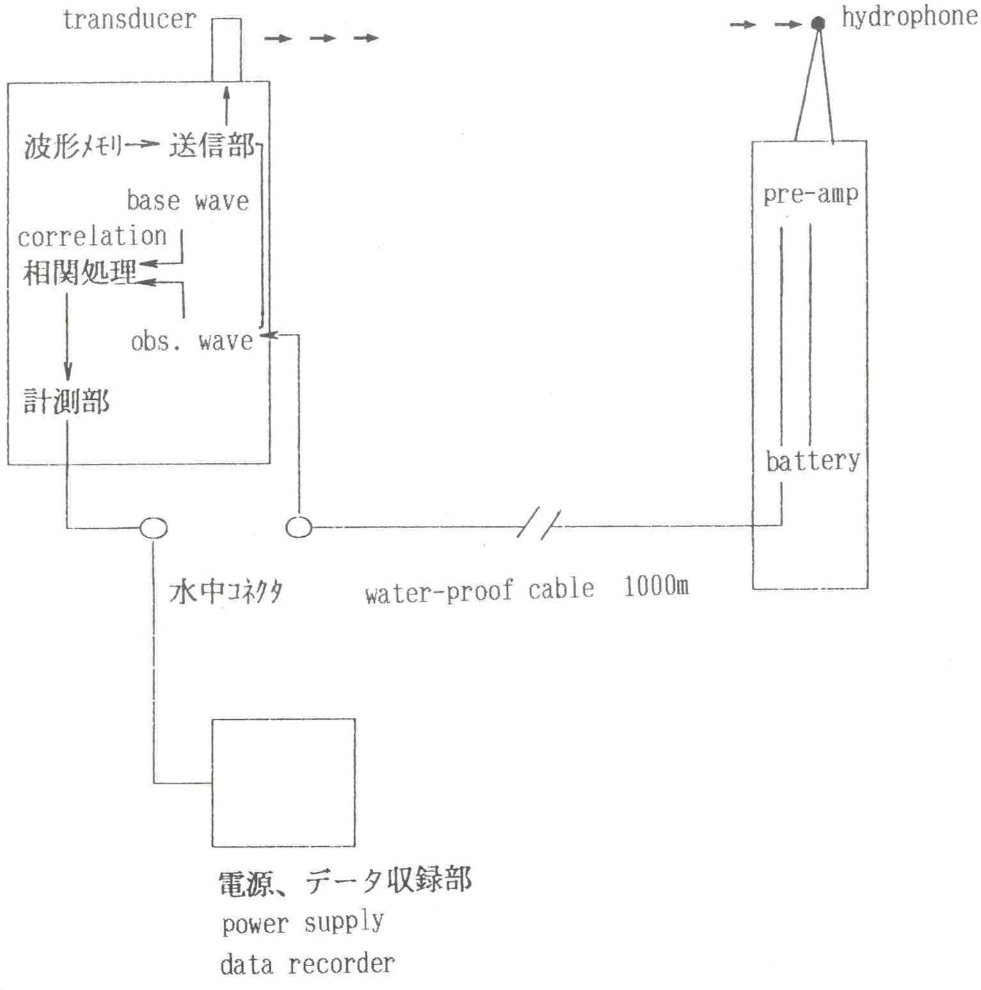
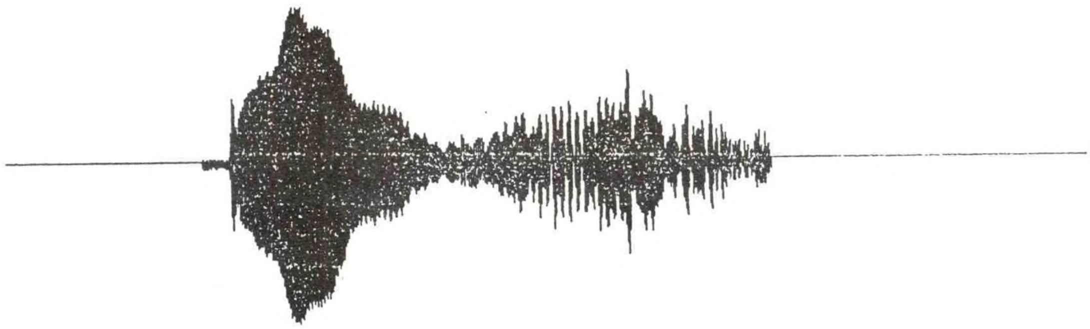


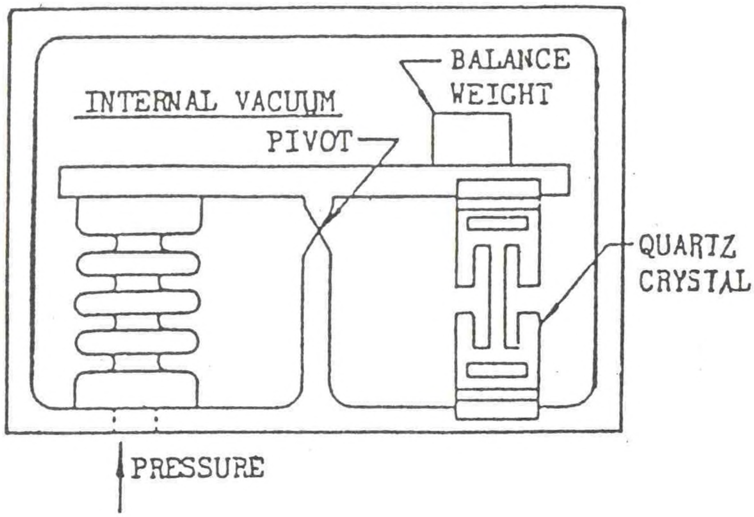
Figure 3. Result of correlation of chirp wave

(a) Transmitter wave in water tank

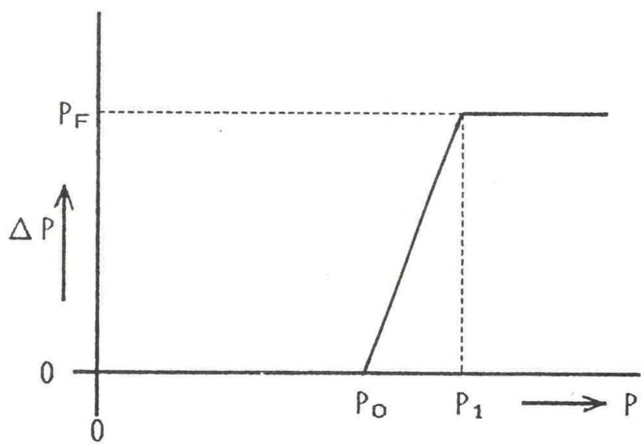


(b) result of correlation between transmitter wave and recieved wave

Figure 4. Schematic diagram of sensor part of vertical displacement meter



Sensor of quartz pressure gage



Sensitive range of off-set pressure gage
p_0:off-set pressure
p_1:range of quartz pressure gage

Table 1

Seabottom survey and experiment by ROV

1. survey sites: southwestern slope of Sagami knoll and Miura knoll

2. seabottom experiment affairs:

   a: setting of frames for observation instrument.

   b: position determination of seabottom site by acoustic transponder system.

   c: establishment of access to frames by transponder system.

   d: driving in a pile by manipulator of ROV.

   e: connecting a water-proof conector by manipulator of ROV.

   f: extension of seabottom cable.

SUBMARINE PUMICE VOLCANO IN THE IZU-OGASAWARA ARC – A SUBMERSIBLE STUDY OF THE MYOJIN KNOLL

Makoto YUASA

Geological Survey of Japan

Abstract

Submarine pumice volcano is a new idea of arc volcanic activity. Recently, several submarine calderas have been newly found on the volcanic front of the Izu-Ogasawara Arc. These submarine calderas erupted much amount of pumice and show high gravity anomalies in the central part and small amplitude of magnetic anomalies on the volcanic edifice. They have no correspondence in the usual classification of calderas proposed by many authors. I proposed the possible origin of these calderas as pumice cones at the 19th Meeting of UJNR Panel on Sea-bottom Surveys in 1990.

In 1991, "Shinkai 2000" visited the Myojin Knoll, one of the typical pumice volcano in the Izu-Ogasawara Arc.

Myojin Knoll locates at lat.32°06'N, long.139°51'E on the Shichito-Iwojima Ridge, which corresponds to the volcanic front of the Izu-Ogasawara Arc. The basal diameter of the knoll is about 18 km and the height is 950 m. The knoll accompanies caldera structure on the summit. The caldera rim is nearly circular and 5-7 km in diameter. The caldera floor is about 1400 m depth and 5-6 km across. There exists a central cone on the floor. The somma is flat-topped and generally 600-700 m in depth, although the west part of somma named Myojin Knoll has a shallow point of 364 m depth. Relief of the caldera wall is about 700-900 m and the inner slope is as steeper as 20-30°.

Large amounts of rhyolitic pumice and calcareous rocks had been recovered from the outer and inner slopes of the knoll by dredge. The majority of pumice contains plagioclase, clinopyroxene and orthopyroxene phenocrysts with rare hornblende. In places, hornblende diorite and other igneous xenoliths containing hornblende with radial growth texture are included in the pumice.

Low gravity anomaly is observed on the eastern outer slope, whereas the central part of the caldera is relatively high. Accordingly, the caldera seems to be of the high gravity anomaly type. No remarkable magnetic anomaly is recognized in this caldera.

The observation started from the top of central cone. There exist outcrops of lava on the central cone. Lava block with thin coating of hydrothermal manganese oxide was obtained by the sub. The central cone consists of dacitic lava and its fragmentary ejecta. Near the top of the central cone, an outcrop suffered by hydrothermal alteration was observed. White-colored clayey material was found by the manipulator of the sub, but it was not sampled. After the observation on the central cone, the submersible moved to the wall keeping the safety height from the caldera floor. No observation was carried out for the surface of caldera floor.

The outcrop of partly altered dacitic lava was found at the lower wall. Lower part of the wall was often covered by fine-grained sediment. There is no pumice gravel on the lower wall. This is a characteristic feature of the lower wall contrasting with the upper wall as mentioned next.

Upper wall was covered almost completely by much amount of pumice gravel. When the submersible ascended to the upper part at 900 m depth, it encountered much amount of pumice gravel. The gravel was well sorted but not layered. Sometimes the occurrence of gravel looks like a gravity flow from the upper part of the wall. There was partly coarse-grained deposit on the fine-grained pumice gravel. Both deposits are well sorted. Therefore it concludes that these pumice deposits are originated from pumice fall.

On the uppermost part of the wall, about 650 m, graded beddings of the pumice layer were found.

From these observations, the following development history of the Myojin Knoll may be proposed.

First stage, there would be a small stratovolcano or lava dome consisting of dacitic volcanics. Explosive pumice eruption occurred and crater would become wide. Huge amount of pumice accumulated around the crater of the former volcano. If the eruption had occurred on land or under the shallow water condition, pumice should not accumulate around the crater. Pumice would scatter and float far away. Submarine condition needs to make a pumice volcano. After that, a central cone formed on the floor and hydrothermal activity followed.

DEEP SUBMERSIBLE AND ROV NEEDS FOR MID-OCEAN RIDGE RESEARCH

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ABSTRACT

A wide variety of ambitious studies of the global mid-ocean ridge system have been suggested in various planning workshops convened by the RIDGE Initiative. These studies would benefit greatly from new or improved deep-sea submersible, ROV and AUV capabilities. Some examples of needed technologies are 1) ROV's or AUV's which could conduct repeat surveys over a mid-ocean ridge hydrothermal vent system in conjunction with a seafloor observatory, 2) expendable water column profilers which can be dropped from aircraft or surface ships in order to detect the presence of hydrothermal activity, 3) an advanced AUV which could be deployed quickly in response to volcanic, tectonic, or hydrothermal events detected on mid-ocean ridges, and 4) a high speed AUV which could conduct water column hydrothermal surveys behind a surface ship engaged in related geophysical or bathymetric surveys along the mid-ocean ridge axis.

INTRODUCTION AND DESCRIPTION OF THE RIDGE INITIATIVE

Much of the recent research effort on mid-ocean ridges has revolved around the RIDGE Initiative (Ridge Inter-Disciplinary Global Experiments) which began as an attempt to organize and focus U.S. research activities on the global mid-ocean ridge system. RIDGE has now become an international initiative (InteRidge), which is attempting to coordinate similar research activities on an international level. As identified at the initial planning workshop convened in 1987, the primary goal of the RIDGE Initiative is "to understand the geophysical, geochemical, and geobiological causes and consequences of the energy transfer within the global [oceanic} rift system." This initial workshop also identified the following six component processes which must be extensively examined in order to gain a full understanding of this focused energy flux from the mantle to crustal and oceanic reservoirs [RIDGE Initial Science Plan, 1989]:

1) mantle flow, and melt generation and emplacement along oceanic spreading centers

2) the transformation of molten magma into crystalline oceanic crust

3) the segmentation and episodic accretion of oceanic lithosphere

4) the physical and chemical interaction between circulating seawater and oceanic lithosphere

5) the biological interactions within ridge-related hydrothermal systems

6) the temporal/spatial variation of ocean-ridge hydrothermal venting and its influence on the oceanic environment

A wide variety of fairly specific ridgecrest experiments and studies have been suggested in various planning workshops convened by the RIDGE Initiative. Many of these experiments are ambitious studies which could not be conducted with presently-available technology. The following are a few examples of ridge-crest studies which would either require or greatly benefit from new deep-sea submersible and ROV capabilities.

RECENT ADVANCES IN THE SAMPLING OF HYDROTHERMAL VENT FLUIDS

Soon after the first submarine hot springs were discovered on the Galapagos Rift and at 21°N on the East Pacific Rise [Corliss et al., 1979; RISE Project Group 1980], it became apparent that obtaining uncontaminated samples of the submarine hydrothermal fluids would be a difficult task. The M.I.T. group, working in conjunction with Barrie Walden and the Alvin submersible engineering team, designed a 750 ml titanium syringe sampler designed specifically for collecting vent fluid samples from manned submersibles like Alvin [Von Damm et al., 1985]. A number of these M.I.T. syringe samplers have been constructed and they have been very useful for collecting samples for fluid chemistry from high temperature (black smoker) vents.

Despite the utility of the M.I.T. syringe samplers, it has become apparent that these samplers are not ideally suited for all sampling situations. In particular, these syringe samplers are not well-suited for sampling diffuse, low temperature vents where the fluid flow is not focused into a single flow from a clearly-defined orifice. In the case of sampling such diffuse flows, the actual flow velocity is often too low to adequately flush the snout and dead volume of the titanium syringe, with the result that a considerable fraction of ambient seawater is incorporated into the sample when the bottle is triggered.

In response to this problem, the NOAA Pacific Marine Environmental Laboratory has constructed a "manifold sampler" designed to act as a versatile sampling apparatus for both high temperature and low temperature vents [Massoth et al., 1988]. As shown in Figure 1, the manifold sampler represents a completely different approach to sampling hydrothermal vent fluids. Instead of first measuring vent fluid temperatures with a discrete temperature probe, and then collecting a discrete fluid sample with a bottle or syringe sampler held in the submersible "hand", the manifold sampler combines these functions into a single operation. The submersible arm is used to insert the movable snout of the manifold sampler into the vent orifice, and then

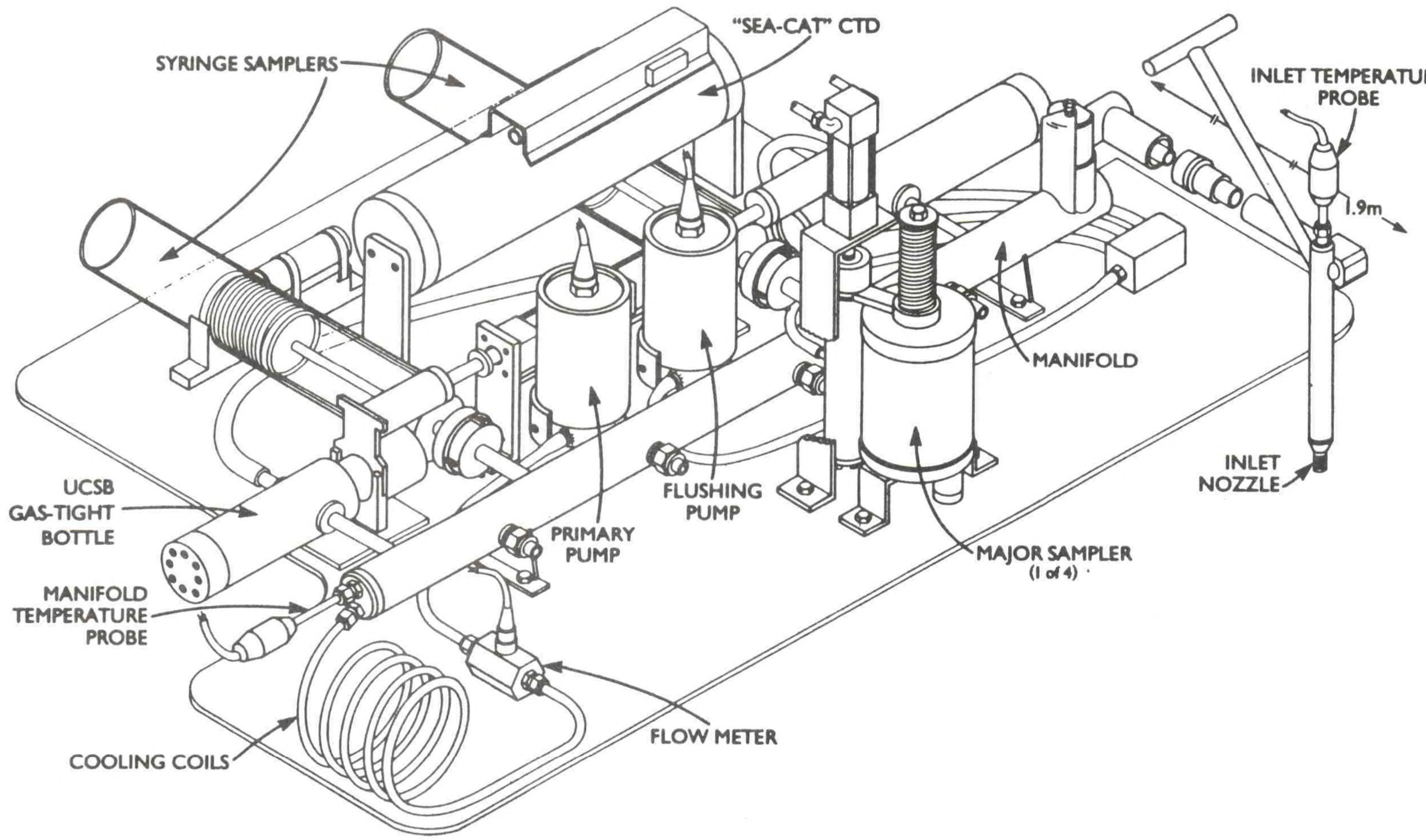


Figure 1. The manifold sampler developed by the NOAA/PMEL [Massoth et al., 1988].

water is pumped at variable speed into the snout and through the manifold, thereby flushing the manifold. A temperature probe in the manifold sampler snout allows the observer to determine the relevant temperature of the vent fluid being sampled. Multiple sampling bottles are attached to the manifold, and these bottles can be individually flushed with a separate pump system, and then triggered individually. Particulate samples can also be collected by pumping through a filter system. By monitoring the temperature indicated in the manifold sampler snout and at the same time adjusting the pumping rate of the variable speed flushing pump, it is possible to collect relatively uncontaminated samples of very diffuse low temperature vent flows. The manifold sampler also makes submersible operations on the seafloor more efficient because multiple samples can be collected from a vent with only a single manipulation with the submersible arm. Use of the manifold sampler also results in better sampling because there is a one-to-one correspondence between fluid temperature as measured at the manifold snout and the fluid properties as collected in the individual sampling bottles.

Another recent development which has aided studies of submarine hydrothermal fluids is the design of special gas-tight titanium sampling bottles. The original M.I.T. titanium syringes collected adequate samples of vent fluids and dissolved gases as long as the dissolved gas contents were moderate. However, several hydrothermal vents have been encountered which have dissolved gas contents greater than 1 liter of gas per kg of fluid. Such gas concentrations exceeded the sealing capabilities of the teflon gaskets of the M.I.T. syringes, with the result that the syringes leaked both fluid and gas as the external hydrostatic pressure was reduced during the ascent of the submersible to the surface. This problem has been solved with the gas-tight bottles designed and constructed at U.C. Santa Barbara. As shown in the cutaway view in Figure 2, the bottles consist of a 150 ml volume which is sealed by a hydraulically-actuated valve driver. The bottle volume is evacuated to high vacuum before each dive, and then the bottle is filled by opening the valve driver in situ with a hydraulic actuator such as that mounted on Alvin's hand. Alternatively gas-tight bottles can be mounted on the NOAA/PMEL manifold sampler (see Fig. 1). These gas-tight bottles have been designed to withstand external or internal pressures of ~5000 psi, so that very gas-rich fluid samples can be collected without any subsequent loss of sample integrity due to internal overpressuring of the bottles. Because of the high pressure differential between the evacuated volume of the bottle and the ambient hydrostatic pressure, the volume of the gas-tight bottle fills in about 0.1 seconds when the bottle is triggered. This aspect of the gas-tight bottles makes them extremely useful when point-sampling in time is required. For example, the gas-tight bottles were used in this rapid sampling mode during a recent experiment in which Alvin sampled buoyant hydrothermal plumes in the water column.

SEAFLOOR OVBSERVATORY

One of the most ambitious ideas which has come out of the RIDGE Initiative is the concept of a seafloor observatory designed to monitor the temporal variability of a small section of the mid-ocean ridge over a decadal time scale. Such an observatory might consist of a group

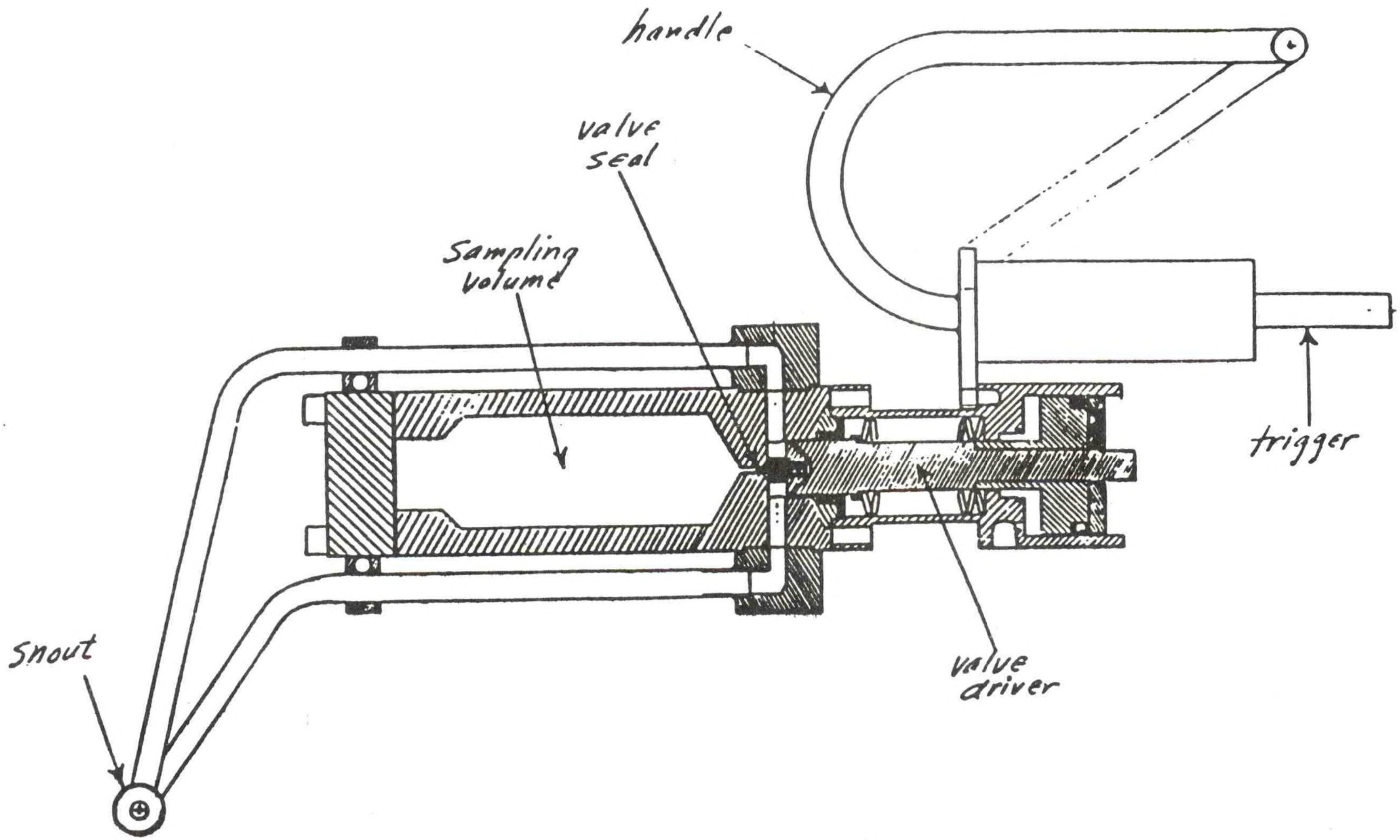


Figure 2. Cutaway view of 150 ml gas-tight titanium sampling bottle designed and constructed at U.C. Santa Barbara for use with submersibles like Alvin [Lupton, unpublished].

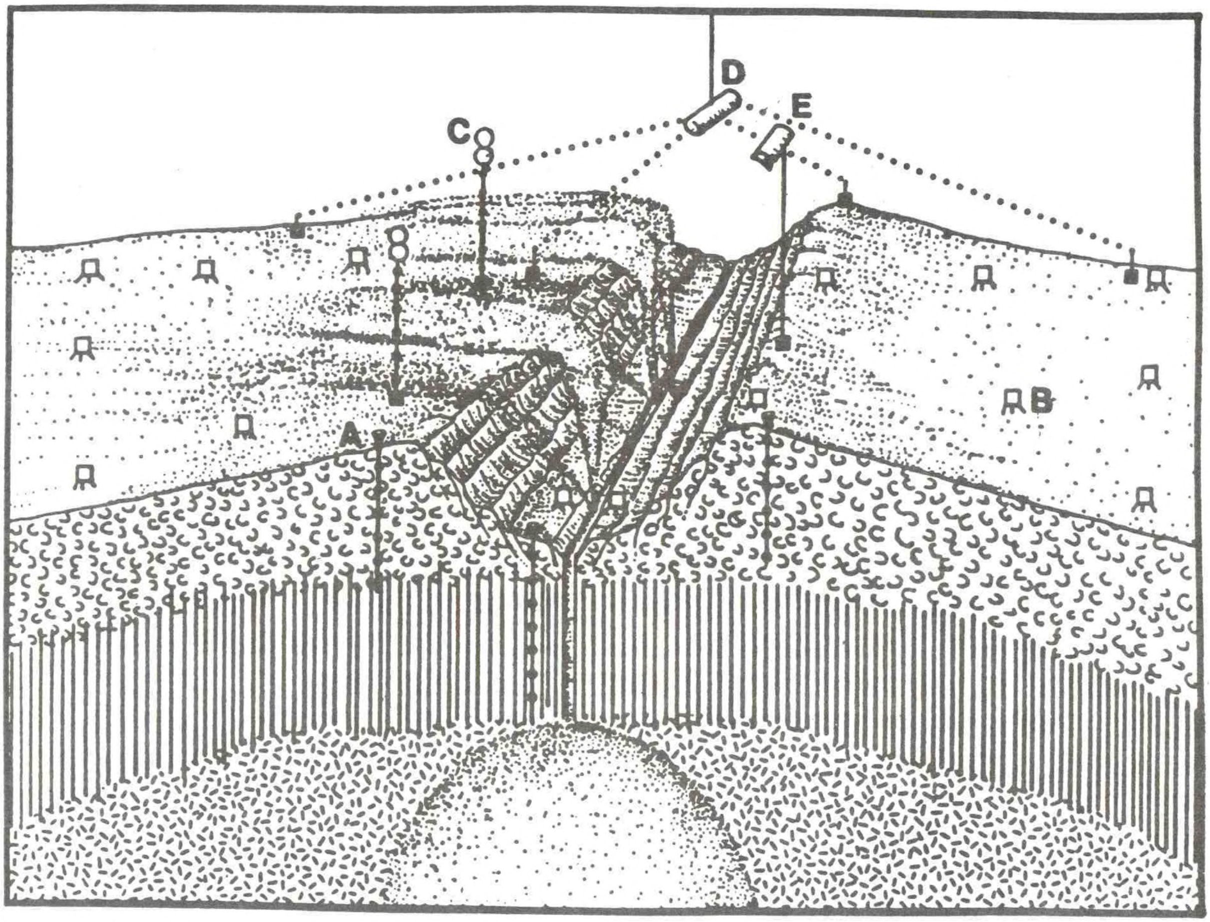
of coordinated experiments designed to monitor a wide variety of characteristics of the ridgecrest, including seismicity, ground deformation, variations in total hydrothermal flux, changes in hydrothermal fluid chemistry, and variations and growth in vent sulfide structures and the distribution of vent biota. As shown in Figure 3, the seafloor observatory might include instruments deployed in drillholes, on the seafloor, or on water column moorings. Instrumentation might include seismometers, tiltmeters, flow meters, water samplers, borehole pumping and injection experiments, sediment traps, thermal and conductivity sensors, transmissometers, etc. In support of such a seafloor observatory, technology development is badly needed in the areas of new seafloor sensors, power generation and distribution, data telemetry, and instrument placement and servicing. Improved ROV's which could reduce the amount of manned submersible time required for setting up and maintaining such an observatory would greatly reduce the cost of the overall experiment.

Figure 4 illustrates an extreme example of how an ROV or AUV could contribute to such an observatory. One approach to monitoring temporal changes in the thermal and chemical fluxes from a hydrothermal vent field is to instrument each vent with stationary monitoring devices. However, a more efficient method to assess changes over the area of a vent field might be to conduct repeat surveys of the field using an ROV or AUV. The ultimate survey tool would be a long-lived AUV which might spend most of its time parked in a seafloor "shed" or station charging its batteries. The vehicle would then periodically drive a pre-set "lawnmower" pattern over the vent field, taking video images and recording temperatures and chemical properties of the venting fluids, and then finally returning to its shed until the beginning the next survey.

EVENT DETECTION AND RESPONSE

The RIDGE Initiative workshops have placed considerable emphasis on improving our ability to detect and respond to volcanic, tectonic, and hydrothermal events on the mid-ocean ridge system. The scenario for event detection and response might be to first detect and locate an event via submarine hydrophones, seismometers and other detectors, and then respond by actually observing the event in progress on the seafloor or in the water column. The "event" might consist of a seafloor volcanic eruption, or of a catastrophic release of hydrothermal vent fluid such as produced the megaplumes observed on the southern Juan de Fuca Ridge [Baker et al., 1987]. The ultimate goal of such event detection efforts is to observe a seafloor eruption or fluid release first-hand with manned submersibles or ROV's while it is in progress on the seafloor.

Figure 5 summarizes some of the detection techniques in our present-day arsenal, including some which are under development. The present technology is not adequate to our goals of event detection and response. Critical technology is needed in the area of improved sonobuoys and air-dropped XBT's (expendable bathythermographs) or XCTD's (expendable CTD's), improved data transmission from seafloor instruments to satellites, etc., and improved submersibles and ROV's which can be rapidly deployed after an event is detected. For example,



Schematic overview of a remote seafloor observatory along a representative portion of the mid-ocean ridge system. The observatory or natural laboratory might include arrays of instrumented drill holes (A) including seismometers, flow meters, water samplers, and pumping or injection experiments. On the seafloor, widespread arrays of tiltmeters and ocean-bottom seismometers (B) would provide information about deformation and volcanic inflation. Water-column moorings (C) could include flow meters, sediment traps, thermal and conductivity sensors and transmissometers for real-time monitoring of hydrothermal effluent and oceanographic mixing. Periodic ranging experiments (D) could constrain rates at which spreading is actually taking place in the most active portions of the ridge system. Direct chemical and flow metering of high- and low-temperature effluent activity would allow correlation between nutrient fluxes and photo-documented biological communities. Continuous-scan sonar systems (E) could provide regular high-resolution wide-aperture imagery of the entire field to document any changes.

By implementing a program of long-term time-series documentation of variation and covariation among many of the related, active processes occurring at ridge crests, researchers will gain invaluable new constraints on models of the interdependence among those processes.

Figure 3. Schematic of possible seafloor observatory on an active mid-ocean ridge [RIDGE Initial Science Plan, 1989].

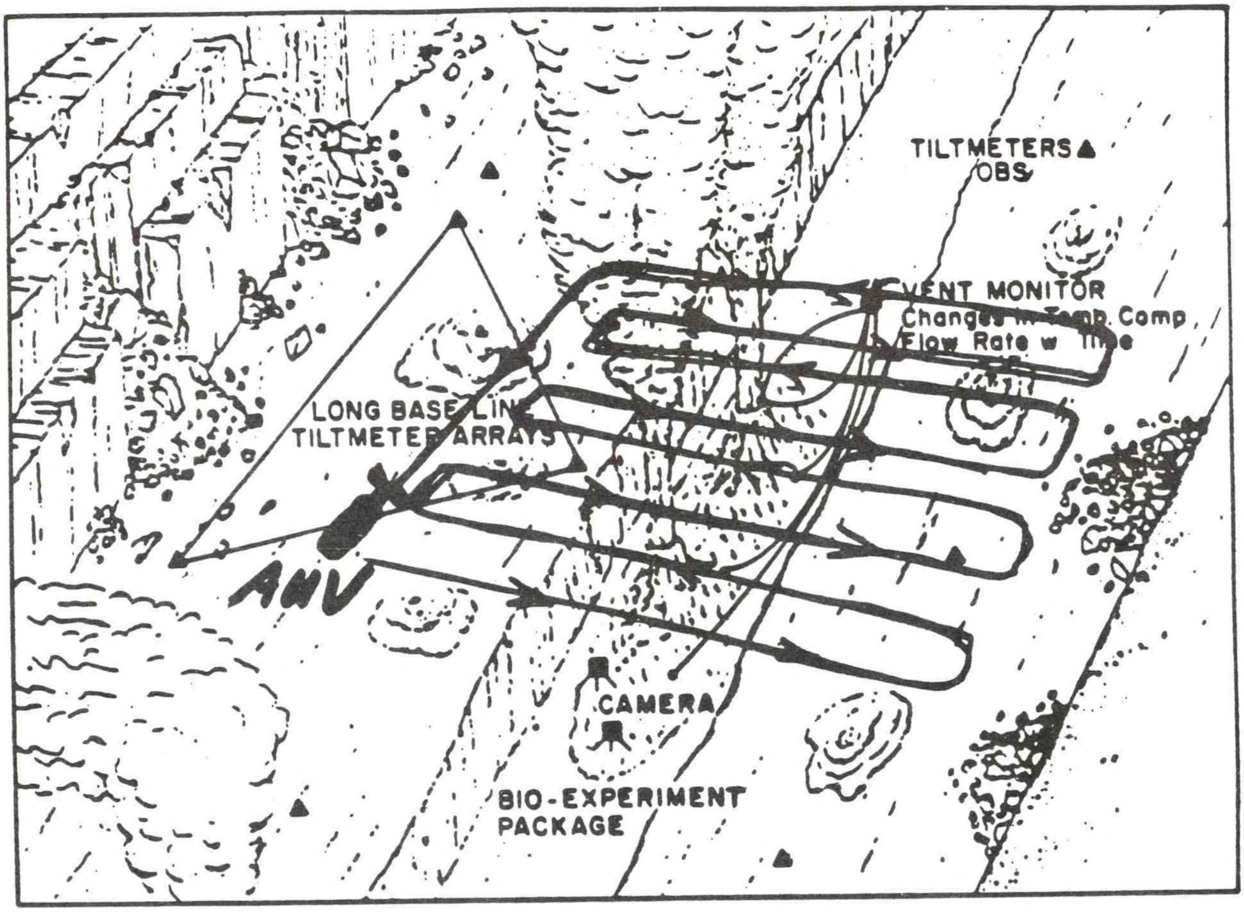


Figure 4. Illustration of how a long-lived AUV (autonomous underwater vehicle) might conduct repeat surveys of a mid-ocean ridge hydrothermal vent field by periodically driving a lawnmower pattern in the water column directly above the active vents.

although sonobuoys exist today, they are not sensitive enough for many mid-ocean ridge applications. Similarly, the available XBT's are not accurate enough for megaplume detection and are not designed to profile into the deep water column where such plumes would be found. Finally, although present day ocean bottom seismometers (OBS's) are sensitive enough for event detection on mid-ocean ridges, they typically do not have any real time data link with the surface, and therefore do not provide feedback for decision-making for other response activities. The ultimate event detection tool might be an AUV which could be dropped from an aircraft and would drive through the study area, collecting video images, making water column temperature and chemical measurements, and relaying this information as well as OBS data to the surface via through a data link.

ALONG-AXIS SURVEYS OF HYDROTHERMAL ACTIVITY

An important goal of the RIDGE Initiative is to understand the relationship between the distribution of hydrothermal activity and the tectonic/morphologic features of the ridge. Very few sections of the mid-ocean ridge system have been systematically surveyed for hydrothermal activity because such surveys are very slow and costly using presently-available technology. The two techniques which have been used for assessing the distribution of hydrothermal activity are 1) photographic surveys using towed camera systems, and 2) hydrographic surveys of water column hydrothermal plumes. Technology presently under development which should improve the second approach includes the development of new in-situ sensors for hydrothermal tracers such as Mn, Fe, methane, etc., and the development of accurate expendable CTD's which could be deployed from surface ships.

It is clear from the RIDGE Initiative workshops that along-axis bathymetric and geophysical surveying will continue to be important in future studies of the mid-ocean ridge system. Unfortunately, such surveys are typically conducted from surface ships traveling at 5 to 10 knots, whereas the hydrothermal plume surveys described above require much slower ship speeds due to the considerable drag on the hydrographic wire and towed package. Figure 6 shows a schematic of how these geophysical and hydrographic survey techniques might be combined. An AUV with sufficient speed and endurance could be deployed from a surface ship conducting routine geophysical or bathymetric surveys of the ridge axis. The AUV, which would be fitted with in-situ chemical sensors as well as standard CTD and transmissometer sensors, would be controlled by an acoustic link with the surface ship. Data would be transmitted in real time from the AUV to the surface ship via this same acoustic data link. The AUV would porpoise in a saw-tooth pattern behind the surface ship, thereby surveying the water column for the presence of hydrothermal plumes. Although the surface ship would occasionally be required to stop in order to recover and service the AUV, the overall result would be that large regions of the mid-ocean ridge axis could be simultaneously surveyed for morphologic and hydrothermal characteristics.

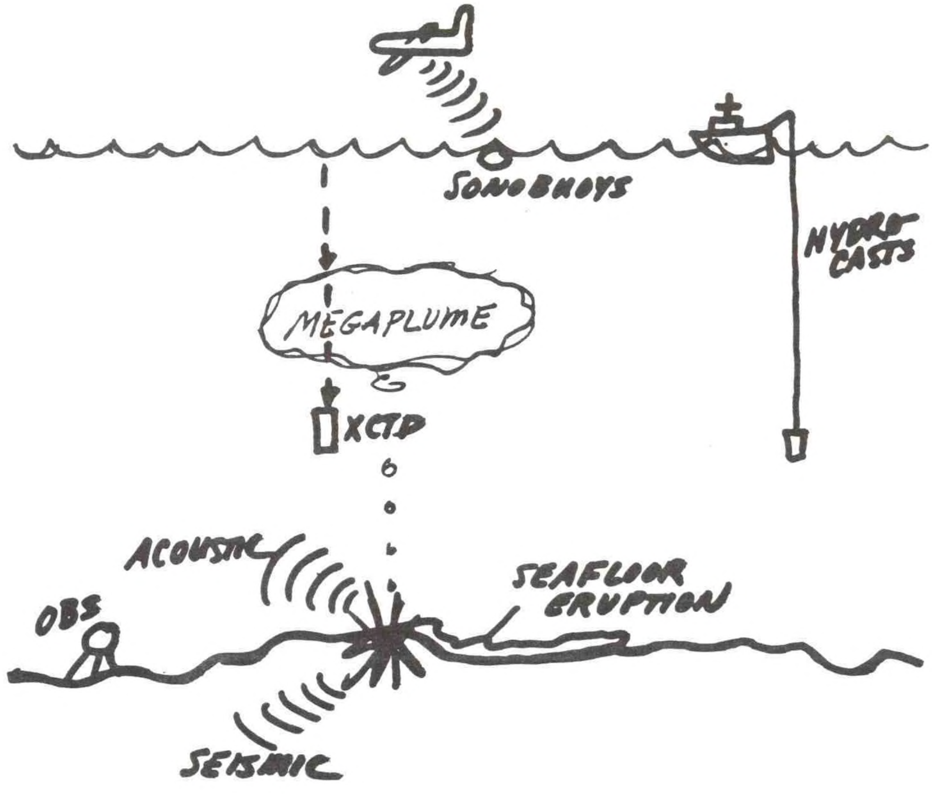


Figure 5. Sketch of presently-day and future techniques available for event detection and response. Events might include anything from water column megaplumes produced by sudden releases of hydrothermal fluid to seafloor volcanic eruptions.

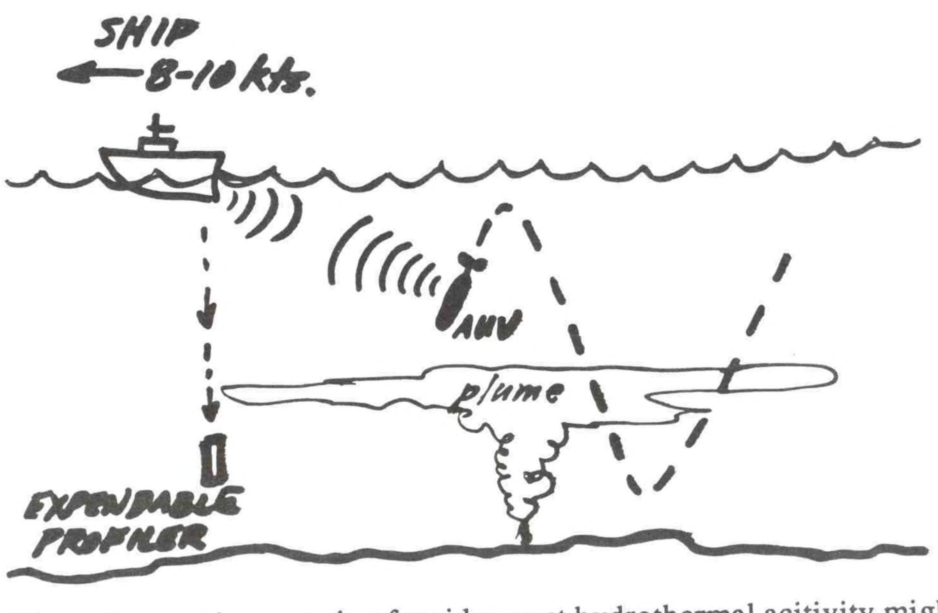


Figure 6. Sketch of how along-axis surveying for ridgecrest hydrothermal acitivity might be conducted in the future by using a high speed AUV fitted with various hydrothermal plume sensors which porpoises along behind the surface ship.

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In situ measurement and observation of hydrothermal activity
- a feasibility study of new usage of submersible

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Sea-going research on hydrothermal activity using a submersible has been one of the most highlighted works of the marine geo-science field over the last decade. New equipment, such as multi-narrow beam echo sounder and wide swath side scan sonar, and technical advancement, e.g., various kinds of in-depth instrumentation on the seafloor or in a bore hole, are requirung more elaborate usage of submersibles.

Doing the in situ experiment and measurement on the sea bottom can only be achieved by the integration of inter- and multi-disciplinary collaboration in the fields of science and technology. The Science and Technology Agency of Japan has been conducting inter-disciplinary projects using its special funds, e.g., Special Coordination Funds for Promoting Science and Technology. The Ocean Development Division of the agency has just started the feasibility study seeking a new step for the sea-going research and development. This study recommends inclusion of international corporation efforts as well as an integration of inter- and multi-disciplinary programs.

FRONTIER OF SEAFLOOR HYDROTHERMAL RESEARCH

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ABSTRACT

The back-arc basins in marginal seas behind volcanic island chains of the central and western Pacific Ocean are at the frontier of new discoveries of seafloor hydrothermal activity. Knowledge of the chemistry, physics and biology of the hydrothermal sites in these basins is essential to achieve a global understanding of the role of seafloor hydrothermal processes in the ocean environment, climate change, mineralization, and biologic adaptation. Research approaches similar to those being utilized in investigations of hydrothermal systems at oceanic ridges are needed to develop complementary knowledge of hydrothermal systems in back-arc basins. These investigations include solution chemistry, ore-forming processes, magnetic signatures of hydrothermal activity, conductive and convective heat transfer, hydrothermal plume behavior, and vent biota.

INTRODUCTION

The back-arc basins that are situated in marginal seas behind volcanic island chains of the central and western Pacific Ocean are at the frontier of seafloor hydrothermal research. Hydrothermally active basins include the Mariana Trough, Okinawa Trough, and Havre Trough, and the Manus, Woodlark, New Hebrides, North Fiji, and Lau basins. Basins that are hydrothermally inactive at present include the Japan Sea, Kuril, Shikoku, West Philippine, Coral Sea, Tasman, and New Caledonia basins (Fig. 1; Cronan, 1986). Prior seafloor hydrothermal investigations have concentrated on the oceanic ridges of the eastern Pacific Ocean (East Pacific Rise; Gorda-Juan de Fuca ridge system), and the Atlantic Ocean (Mid-Atlantic Ridge). The prior investigations at oceanic ridges may be used to guide new investigations in back-arc basins. It is necessary to study the full spectrum of seafloor hydrothermal systems to determine their impact on the global ocean environment, and their roles in mineralization and biologic adaptation.

RESEARCH NEEDS

Mass and heat transfer between the lithosphere and the ocean by subseafloor convection of seawater is driven by magmatic heat. The basic processes are similar at oceanic ridges and at spreading centers in back-arc basins (Fig. 2). In fact, the basic simi-

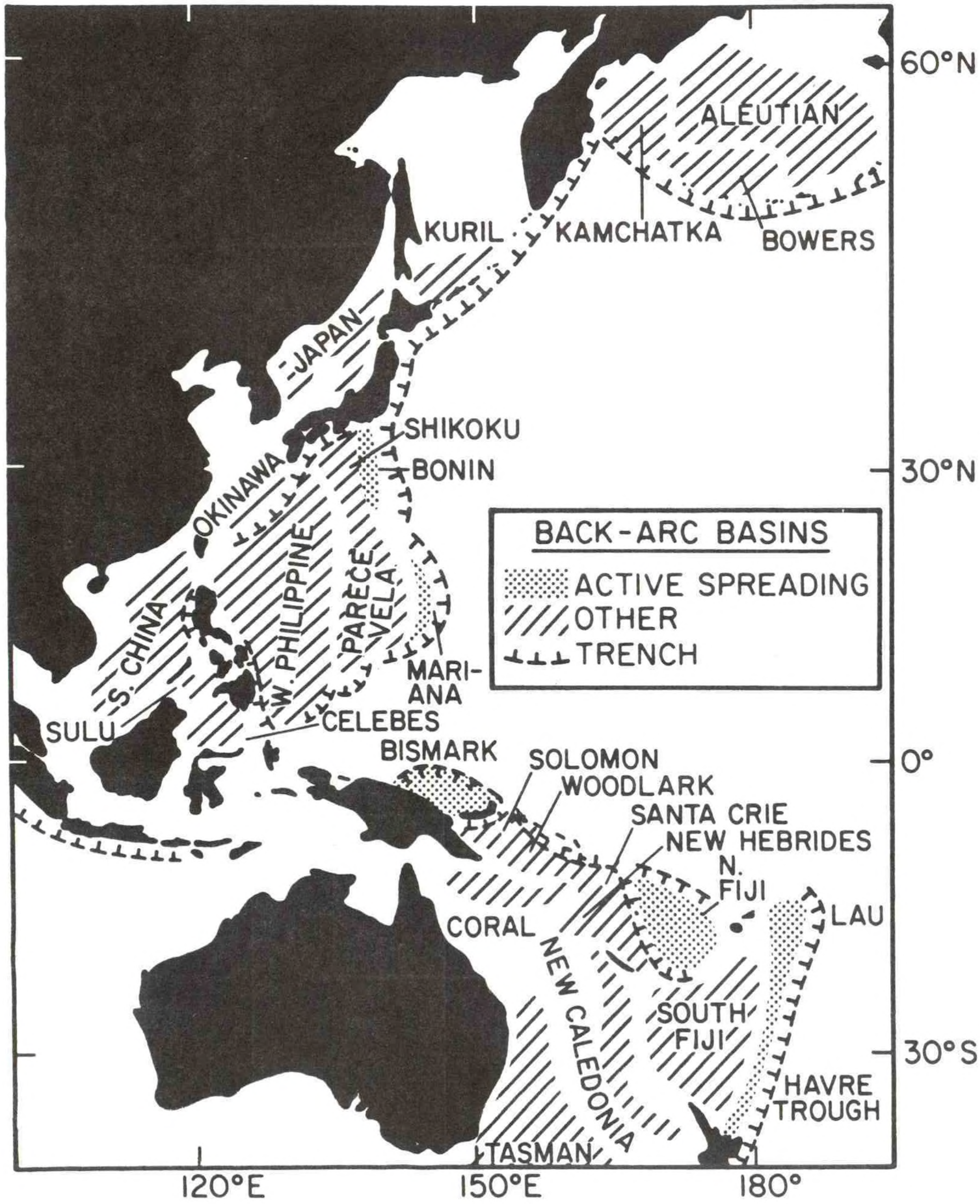

Figure 1. Map of back-arc basins of the western Pacific (from Rona, 1984; modified from Karig, 1971; Watanabe, Langseth, and Anderson, 1977).

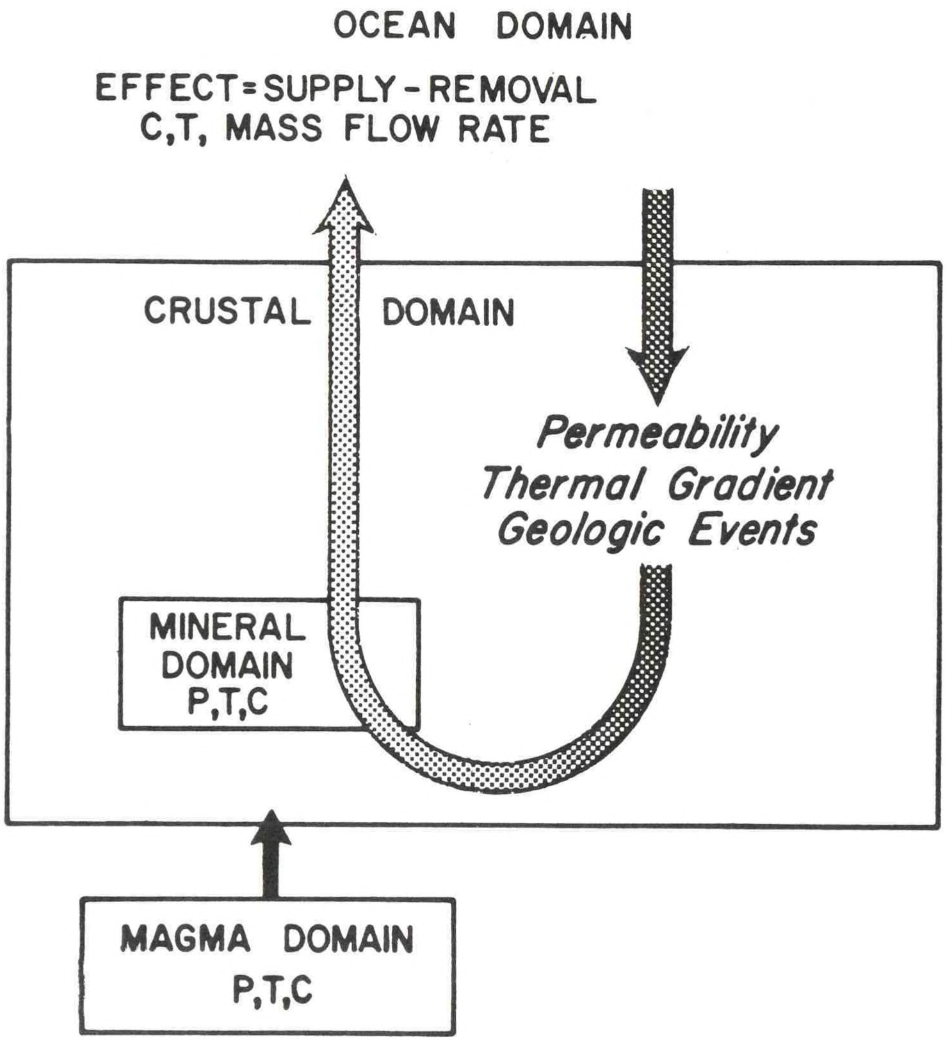

Figure 2. Diagrammatic representation of the components of a subseafloor hydrothermal convection system involving the down-welling of cold, dense, alkaline seawater through permeable oceanic crust, heating by flow in proximity to magmatic heat sources, upwelling of hot, thermally-expanded seawater and reaction with minerals under ambient pressure (P), temperature (T) and composition (C) fields to evolve acid, metal-rich hydrothermal solutions that interact with rocks along flow paths and discharge into the ocean (from Rona, 1988).

larity of these processes led a prominent geochemist to declare ten years ago that investigations of hydrothermal activity in different seafloor geologic settings was "stamp collecting." Since that time, it has become clear that the chemical, thermal, ore-forming, and biologic characteristics of hydrothermal systems differ at various seafloor settings. In order to define these differences and to develop an understanding of contributions of hydrothermal venting from the the different settings as components of global change, investigations that are of hydrothermal systems in back-arc basins must complement ongoing investigations at oceanic ridges. Types of investigations that have proven important at oceanic ridges that should be extended to back-arc basins are presented below.

Solution Chemistry

Differences in solution chemistry are related to reaction of seawater that circulates in subseafloor hydrothermal convection systems with surrounding rocks under different pressure, temperature and composition fields (Fig. 2). For example, at a given seafloor setting, differences in hydrothermal solution chemistry are expected for reactions with the mafic (Seyfried and Janecky, 1985) and ultramafic (Janecky and Seyfried, 1986) portions of the oceanic lithosphere. Other differences in solution chemistry are expected for reactions with tholeiitic basalt at oceanic ridges and with andesite/rhyolite/basalt volcanic suites at spreading centers in back-arc basins (Hajash and Chandler, 1981). In situ solution sampling and laboratory studies of seawater/rock reactions are needed to determine hydrothermal solution chemistry and mass fluxes at various back-arc basin settings.

Ore-Forming Processes

Chemical and physical properties of hydrothermal solutions control their behavior and characteristics in ore-forming processes. For example, Sato (1972) was early to recognize the role of solution density relative to that of ambient seawater in determining the form of seafloor hydrothermal deposits (Fig. 3). The major types of volcanic-hosted and sediment-hosted hydrothermal deposits recognized in the geologic record have been found at oceanic ridges (Rona, 1988). However, a compilation of information on volcanic rock types associated with hydrothermal massive sulfide deposits in the geologic record (508 deposits; Mosier, Singer, and Salem, 1983) indicates that only 17 percent of the deposits are associated with basalts that may have formed at oceanic ridges (Fig. 4; Rona, 1988).

The most numerous (56 percent) and largest massive sulfide deposits known in the geologic record, up to 231 × 10^6 tonnes (Rio Tinto, Carboniferous of Spain), are hosted in rhyolites. Rhyolites may be assigned to either a subduction-related basalt andesite-dacite-rhyolite volcanic suite, or to an extension-related bimodal basalt-rhyolite suite representative of island-arc or continental rift-related geologic settings (Martin and Piwinskii, 1972;

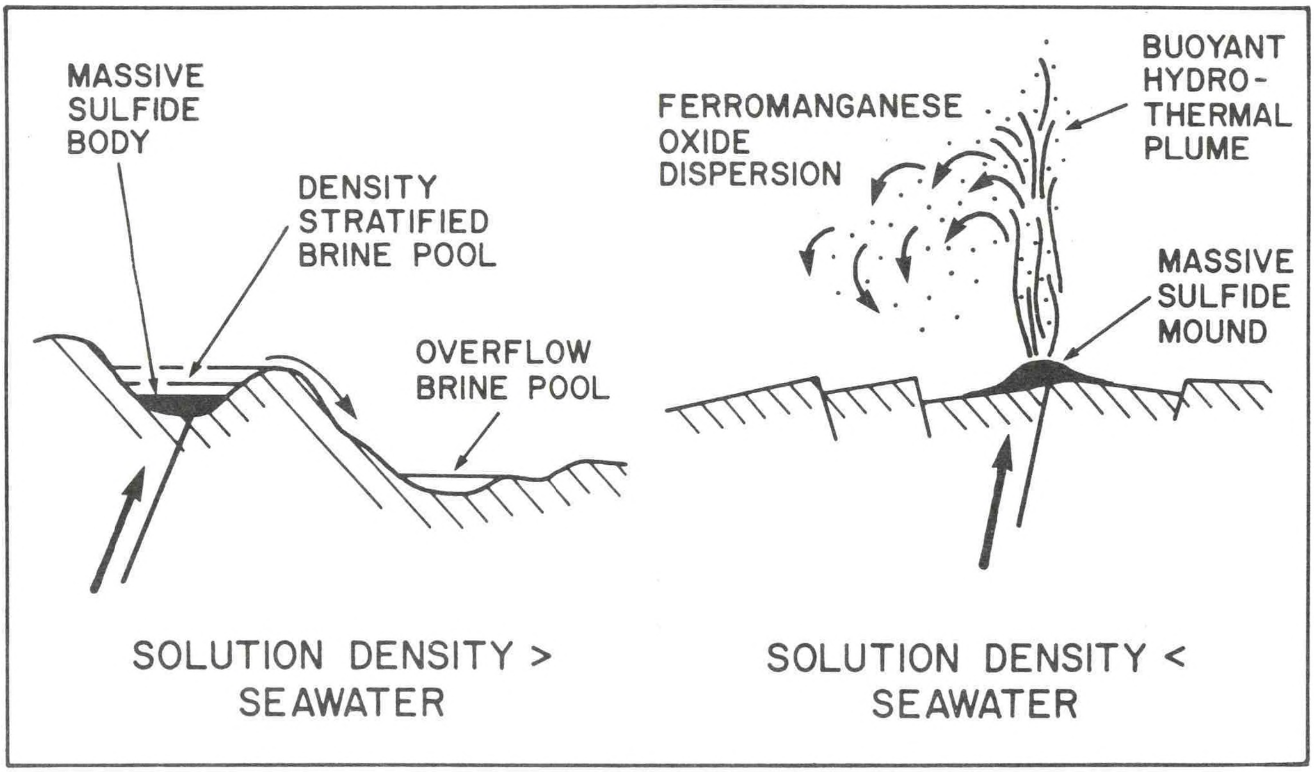

Figure 3. Sketch showing how density of a hydrothermal solution relative to surrounding seawater influences plume behavior and formation of seafloor mineral deposits (from Rona, 1988).

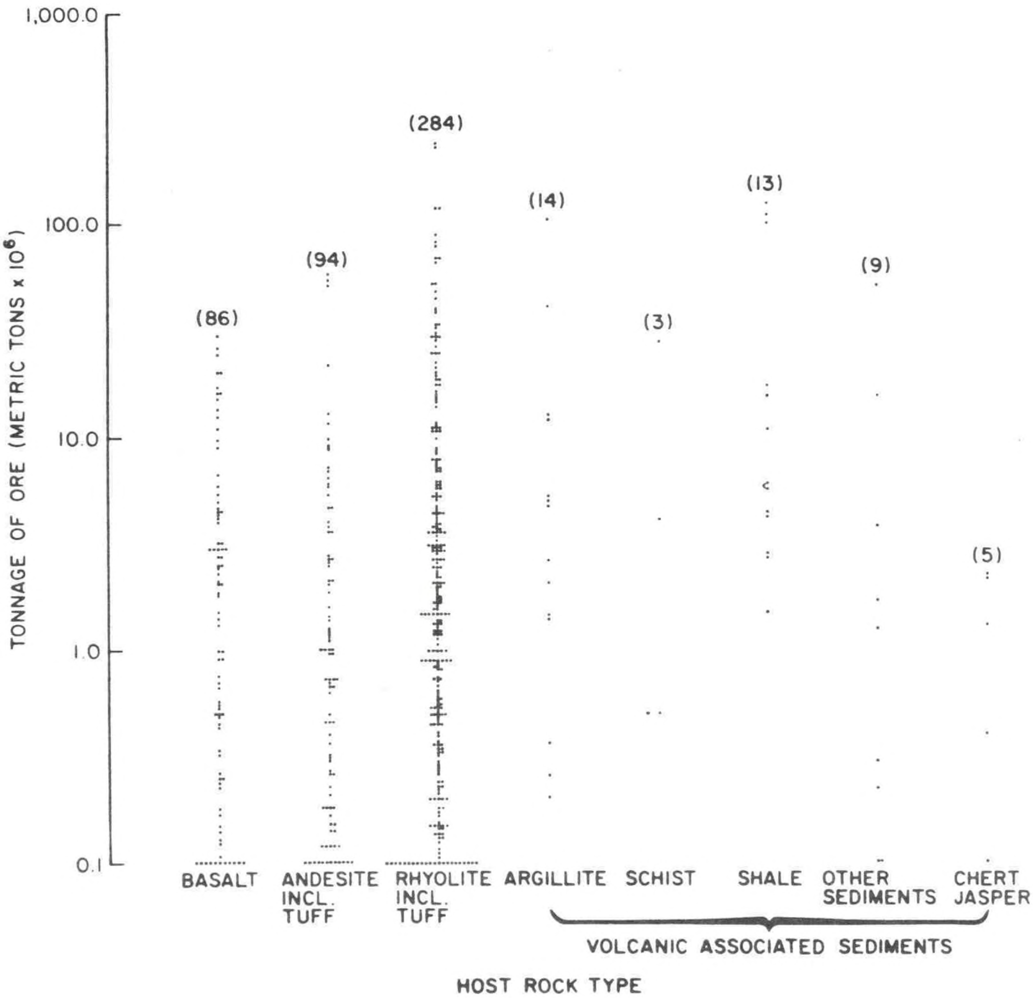

Figure 4. Plot of size of 508 known massive sulfide ore deposits on land versus type of volcanic host rock immediately underlying each deposit (from Rona, 1988, based on data compilation by Mosier, Singer, and Salem, 1983). The number in parentheses above each column of points is the number of deposits plotted.

Sillitoe, 1982). Therefore, back-arc basins are prime sites for discovery of present-day analogues of ancient massive sulfide deposits (Skinner, 1983). Systematic exploration for and characterization of seafloor hydrothermal deposits will be a rewarding component of research in back-arc basins (Rona, 1978, 1983).

Magnetic Signature

A positive magnetic anomaly representing the normal polarity of the Earth's present magnetic field is associated with the axial zone of spreading centers in ocean basins and back-arc basins. A low in magnetic intensity superimposed on the axial positive magnetic high was observed to coincide with the certain hydrothermal fields at the Mid-Atlantic Ridge (Fig. 5; TAG hydrothermal field; McGregor and Rona, 1975), in the Red Sea (Atlantis II Deep; Rona, 1978), on Iceland (Reykjanes hydrothermal field; Björnsson, Arnórsson, and Tómasson, 1972), and in New Zealand (Wairakei hydrothermal field; Studt, 1959).

Laboratory measurements of magnetic properties of rocks and modeling of magnetic properties of oceanic crust indicate that the low may originate by alternative processes (Wooldridge _et al_., 1990, 1992). Principal processes comprise alteration of the magnetic mineral component of basalt by high-temperature hydrothermal solutions, the Curie Point effect of a magma body, and thinning of oceanic crust. The pattern of distribution of the magnetic low at the various seafloor hydrothermal fields and drilling in the case of the Reykjanes field (Björnsson, Arnórsson, and Tómasson, 1972) have indicated that hydrothermal alteration is a major factor in creating the low in the cases studied (Rona, 1978). When alteration is involved, the low in magnetic intensity may be applied as a signature of both present and past hydrothermal activity in oceanic crust (Rona, 1978). The magnetic signature will be a useful method to guide exploration for seafloor hydrothermal sites in back-arc basins and to model to subseafloor characteristics of hydrothermal systems in coordination with other geological observations.

Convective Heat Transfer

Transfer of heat from the Earth's interior to the ocean occurs by conductive heat flow through oceanic crust and by convective heat flow. Conductive heat flow is a standard measurement in sedimented areas of seafloor spreading centers, although no method has yet been devised for such measurements in sediment-free areas (Langseth and Von Herzen, 1971). Convection is considered to predominate over conduction at seafloor hydrothermal fields where two sources of convective transfer are recognized (Fig. 6). One source is discrete flow, which is the focused discharge of hydrothermal solutions from individual vents in mineralized chimneys. Heat flux from discrete sources can be calculated from direct measurements (Converse, Holland, and Edmond, 1984; Macdonald _et al_., 1980), and by modeling based on jet and plume theory (Rouse, Yih, and Humphreys, 1952; Morton, Taylor, and

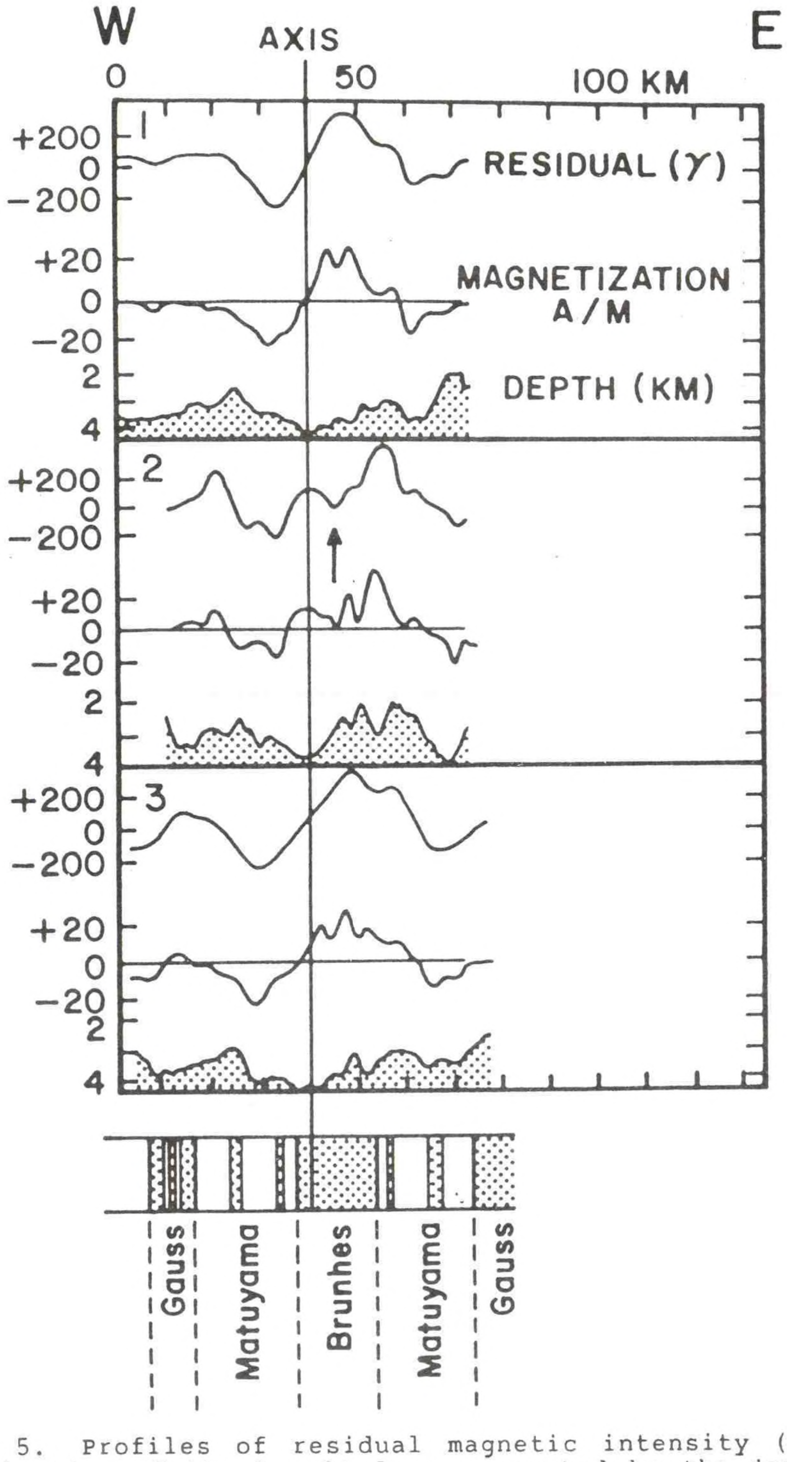

Figure 5. Profiles of residual magnetic intensity (γ; gammas), magnetization of the basalt layer computed by the inverse method (A/m; 1 ampere/meter = 0.001 emu/cm^3), and depth (km), across the axis of the rift valley of the Mid-Atlantic Ridge at latitude 26°N (from Rona, 1978, modified from McGregor et al., 1977). A distinct low in magnetic intensity within the positive axial magnetic anomaly (Brunhes magnetic polarity epoch) and in the computed magnetization (arrow in profile 2), coincides with the TAG Hydrothermal Field. The magnetic low is absent in profile north (profile 1) and south (profile 3) of the field.

Turner, 1956; Turner, 1973; Lowell and Rona, 1976; Little, Stolzenbach, and von Herzen, 1987).

The second source of convective heat transfer at seafloor hydrothermal fields is diffuse flow. Diffuse flow comprises the disseminated discharge of hydrothermal solutions through areas of the seafloor (Fig. 6). Hydrothermal sites are permeated with patchy areas of diffuse flow up to tens of meters in diameter (Converse, Holland, and Edmond, 1984; Little, Stolzenbach, and von Herzen, 1987; Rona and Speer, 1989). Fluxes from diffuse sources are difficult to measure because flow velocities and fluid temperatures are low and discharge is unevenly distributed.

Rona and Trivett (1990, 1992) measured the near-bottom water temperature field at altitudes of 1 m and 20 m above the high-temperature portion of a seafloor hydrothermal field (ASHES vent field in the caldera of Axial Volcano at the Juan de Fuca Ridge) using a vertical array of temperature sensors mounted on a submersible. They employed a standard plume model to estimate the diffuse component of heat transfer from this data set. They then compared this estimate to their calculation of the discrete component based on direct measurements of flow rate, vent diameter, and exit temperature at each of the individual vents. The diffuse component ($15-75 \times 10^6$ W) was an order of magnitude greater than the discrete component (4.42×10^6 W) for this particular field. Similar studies are needed at other seafloor hydrothermal fields at oceanic ridges and in back-arc basins to test the hypothesis that diffuse flow is the dominant process of convective heat transfer in the oceans.

Hydrothermal Plume Behavior

Mass and heat are transferred from seafloor hydrothermal vents to the ocean in plumes which are formed by discharge of hydrothermal effluents that differ in temperature and composition from ambient seawater. Knowledge of the behavior of hydrothermal plumes is essential to understanding the chemical and thermal impacts of hydrothermal venting on the ocean environment, as well as ore-forming processes (Sato, 1972).

Hydrothermal plume behavior is related to cross-sectional area of discrete or diffuse sources, mean velocity of discharge, and density deficit of the injected fluid, as well as to the density gradient in the overlying water column (Morton, Taylor, and Turner, 1956; Turner and Gustafson, 1978). The physical characteristics of a plume, including its size, velocity, temperature, and salinity, evolve from the initial source condition to a neutrally buoyant state at or above the seafloor depending on the relations cited. Anomalous chemical and thermal characteristics of the hydrothermal fluid are modified by mixing with surrounding seawater, which may be entrained and transported with the plume.

A range of plume behavior results from the factors cited. For example, the hot, metal-rich brines that discharge at sites along the axis of the Red Sea like the Atlantis II Deep are denser

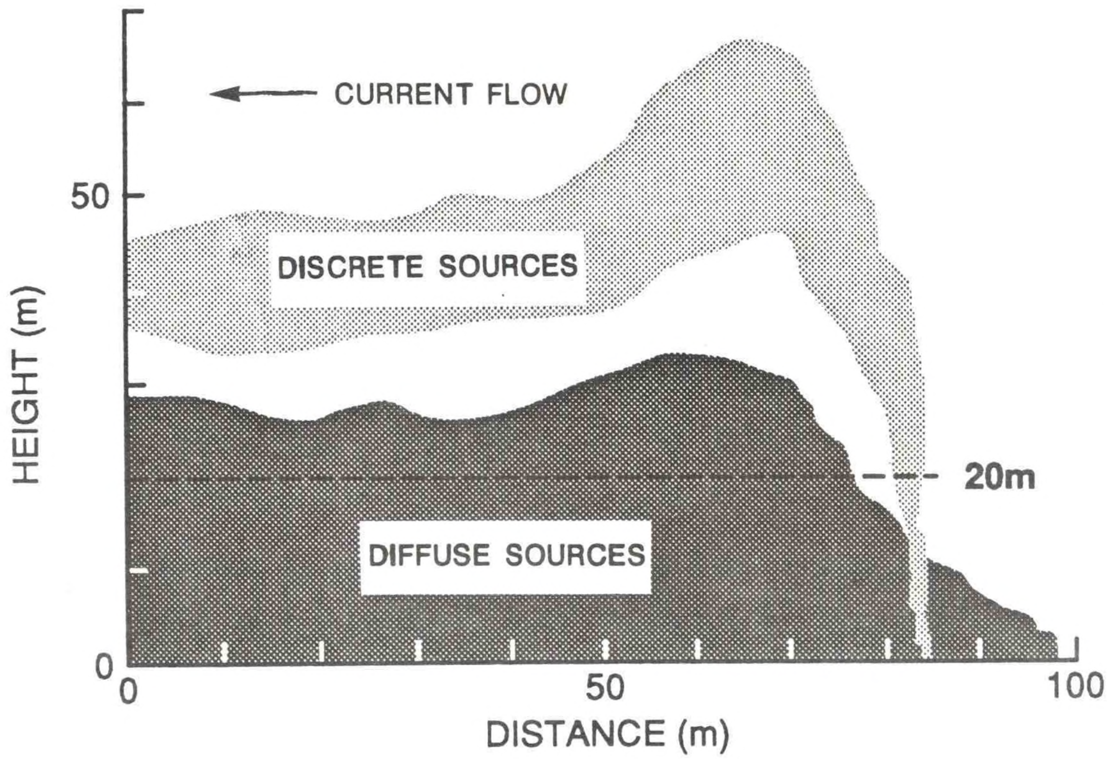

Figure 6. Sketch showing characteristics of discrete and diffuse components of seafloor hydrothermal discharge. The discrete component discharges from individual vents and buoyantly rises to a higher level in the water column than the diffuse component which discharges from a large area of the seafloor (from Rona and Trivett, 1992).

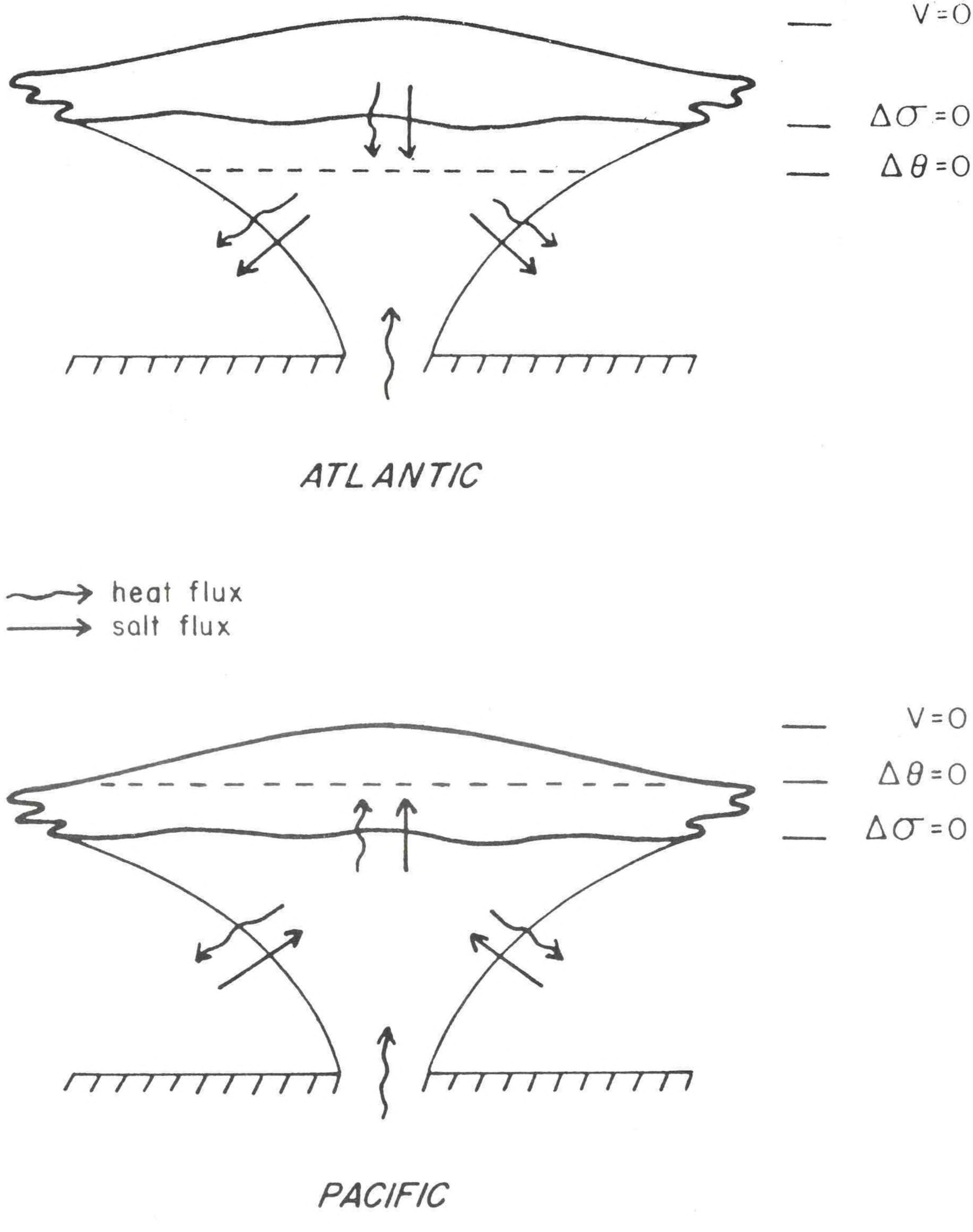

Figure 7. Schematic of temperature (θ) and salinity components of buoyant hydrothermal plumes in the Atlantic Ocean and the Pacific Ocean, where the background salinity profile in deep water is opposite (modified from Speer and Rona, 1989). At the seafloor the salinity difference between vent water and ambient seawater is assumed to be zero. Approximate levels where the temperature difference (Δθ), density difference (Δσ), and velocity (V) are zero are marked.

than surrounding seawater (Degens and Ross, 1969). Therefore, these solutions pond in seafloor depressions isolating them from the overlying water column and concentrating metallic mineral precipitates into sizable deposits. In the Atlantic Ocean, salinity decreases downward. A hydrothermal plume at the TAG hydrothermal field at the Mid-Atlantic Ridge entrains and transports less saline water as it buoyantly rises about 360 m to a level where the equilibrium temperature and salinity are relatively cool and fresh compared to surrounding seawater (Fig. 7; Rona and Speer, 1989). In the Pacific Ocean, salinity increases downward. A hydrothermal plume at the Endeavor segment of the Juan de Fuca Ridge entrains and transports more saline water as it rises to a density equilibrium level about 200 m above the bottom where the mixture is warm and salty relative to surrounding water (Fig. 7; Lupton et al., 1985). Similar studies in back-arc basins will be contribute to determination of the effect of plumes on the surrounding ocean and their role in concentrating mineral deposits on the seafloor.

Acoustic Imaging of Hydrothermal Plumes

NOAA and the Naval Research Laboratory (NRL) are collaborating in the development of a sonar system to image and measure flow velocities in hydrothermal plumes to facilitate characterization of the dynamic behavior of the plumes (Rona et al., 1991). Palmer, Rona and Mottl (1986) first proposed acoustic imaging of hydrothermal plumes and demonstrated its feasibility. Prior plume investigations have employed several methods, as follows: (1) video and photo imagery limited to illumination of small volumes adjacent to a vent (Macdonald et al., 1980; Converse et al., 1984); (2) asynchronous individual profiles of temperature, salinity and optical light scattering properties (conductivity-temperature-depth (CTD) nephelometer/transmissometer profiles (Baker and Massoth, 1987; Nelsen et al., 1986/87; Rona and Speer, 1989); (3) records made with standard sonar instruments that have suggested the potential of acoustics to characterize large plume volumes (Orr and Hess, 1978; Hay, 1984; Palmer, Rona, and Mottl, 1986; Thomson, Gordon, and Dymond, 1989; Palmer and Rona, 1990); and (4) laboratory tank simulations (Turner and Gustafson, 1978; Armishev and Berezutskii, 1988).

The hydrothermal plume imaging sonar system under development is based on acoustic backscattering from particulate matter in the form of metallic mineral particles precipitated and suspended in the plume. Sizes of particulate matter suspended in hydrothermal plumes (microns) (Feely et al., 1987; McConachy, 1988) are orders of magnitude smaller than the wavelength of the acoustic source used in our experiment (330 KHz; 0.5 cm). Rayleigh scattering from targets very small relative to the wavelength of impinging acoustic radiation is the primary mechanism for the imaging. The suspended metallic mineral particle content of hydrothermal plumes at the East Pacific Rise is sufficient to account for acoustic detection (Palmer, Rona, and Mottl, 1986).

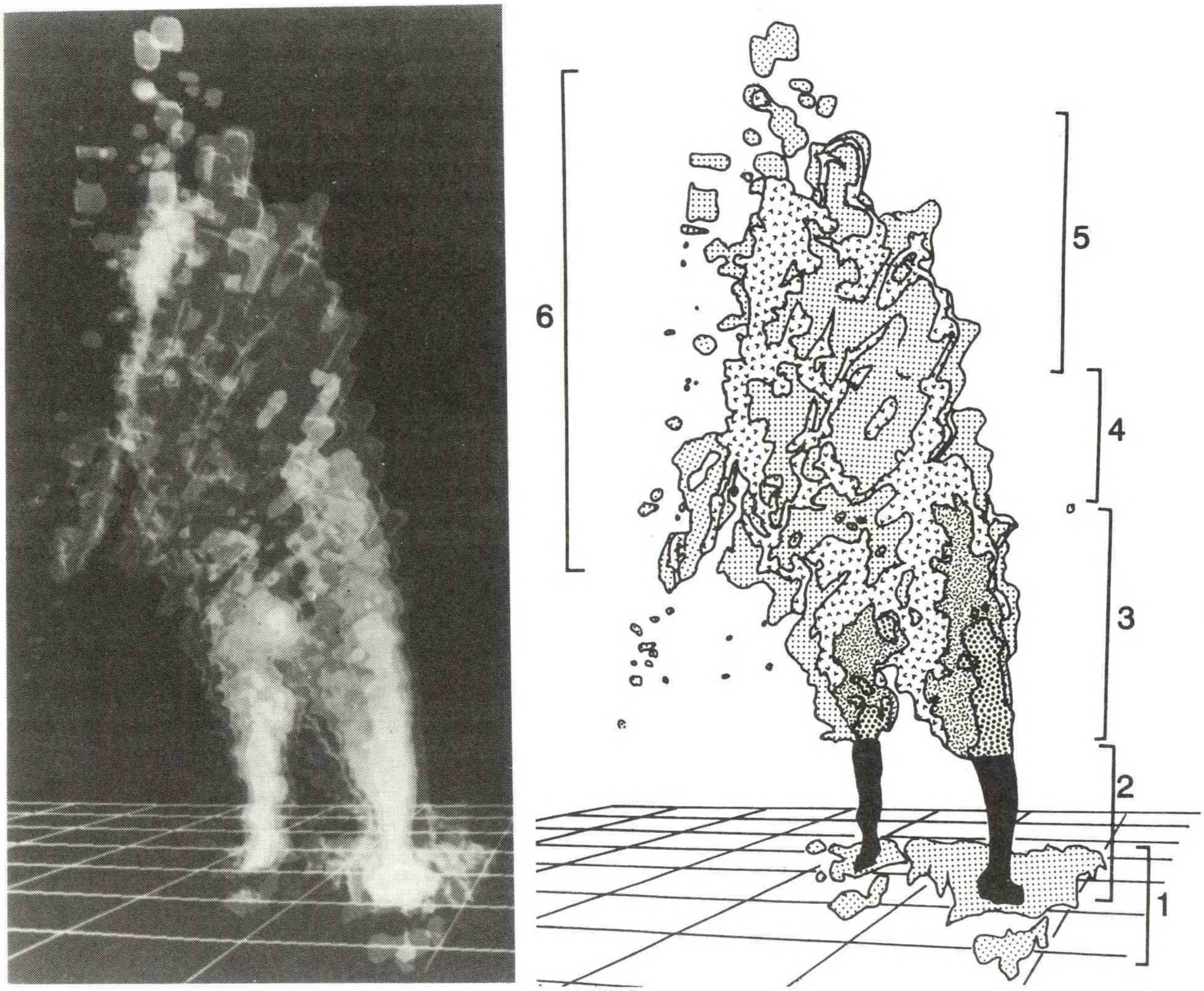

Figure 8. Three-dimensional reconstruction of an acoustic image of the lower 40 m of two buoyant plumes discharging from adjacent black smoker vents at a depth of 2635 m on the East Pacific Rise near 21°N, 109°W (image left; line drawing right; Rona et al., 1991). Zonation of the flow regime (1-6) inferred from areas of equal surface intensity of acoustic backscatter (patterned) and chimneys (solid) are shown on the line drawing. The rectilinear grid is 5 x 5 x 5 m.

A prototype sonar system mounted was used on a submersible to record a digital data set of acoustic backscattering information of black smoker plumes at the East Pacific Rise near 21°N, 109°W (Rona et al., 1991). Three-dimensional graphic reconstructions from the digital data set depict volume and show zones of flow organization (meters to tens of meters) in the lower 40 m of buoyant plumes emanating from two adjacent black smoker vents (Fig. 8). The two plumes coalesce, bend in the prevailing current, exhibit short-term (minutes) variations in cross-section and rapid (seconds) turbulent eddy variations at small scales (< 1 m). A Doppler capability to measure flow rates is being added to the sonar system. The plume imaging sonar system will be an important component of research at seafloor hydrothermal fields at oceanic ridges and in back-arc basins to study plume dynamics, to determine fluxes when combined with chemical and thermal measurements, and for long-term monitoring of the activity of the hydrothermal fields.

Vent Biota

Following the initial discovery of vent biota at the Galapagos spreading center in 1977 (Corliss et al., 1979), biologists were surprised by the biodiversity of vent communities discovered at other locations. Chemosynthetic bacteria are at the base of the food-web at all of the locations known, but the megafauna differs. Large vestimentiferan tubeworms and giant vesicomyid clams populate the vent fields at the Galapagos Rift (Corliss et al., 1979) and the East Pacific Rise (Spiess et al., 1980); smaller varieties of tubeworms and clams live at vents on the Gorda-Juan de Fuca Ridge system (Tunnicliffe, Juniper, and de Burgh, 1985); large gastropods are prominent in vent communities of the Mariana Trough (Craig et al., 1987) and the Lau Basin (Fouquet et al., 1990); vestimentiferan worms and vesicomyid clams have not been found at vent fields in the Atlantic where a new variety of shrimp with a novel organ inferred to sense infrared radiation predominates (Rona et al., 1986; Williams and Rona, 1986; Van Dover et al., 1989). Investigations of vent communities at back-arc basins are needed to fill major gaps in present knowledge of the global distribution of biodiversity.

Seafloor hydrothermal fields are not only ecosystems that support biodiversity based on a chemosynthetic food-web, but also appear to be sanctuaries for ancient life forms. A benthic invertebrate with hexagonal form typically 5 cm in diameter that is found on a carbonate sediment substrate in the TAG hydrothermal field at the Mid-Atlantic Ridge (Rona and Merrill, 1978) has been identified as the trace fossil *Paleodictyon nodosum* found in marine sediments 70-340 $\times 10^6$ years old exposed in Austria and Wales (Seilacher, 1977). Archaebacteria, strains of ancient bacteria, have been identified at hydrothermal vent fields (e.g., Huber et al., 1989). Studies of biodiversity and the history of different life forms at hydrothermal sites in back-arc basins are critical to answering basic questions of evolution and dispersal of vent biota. Further research may lead to advances in aquaculture and additional discoveries of new life forms.

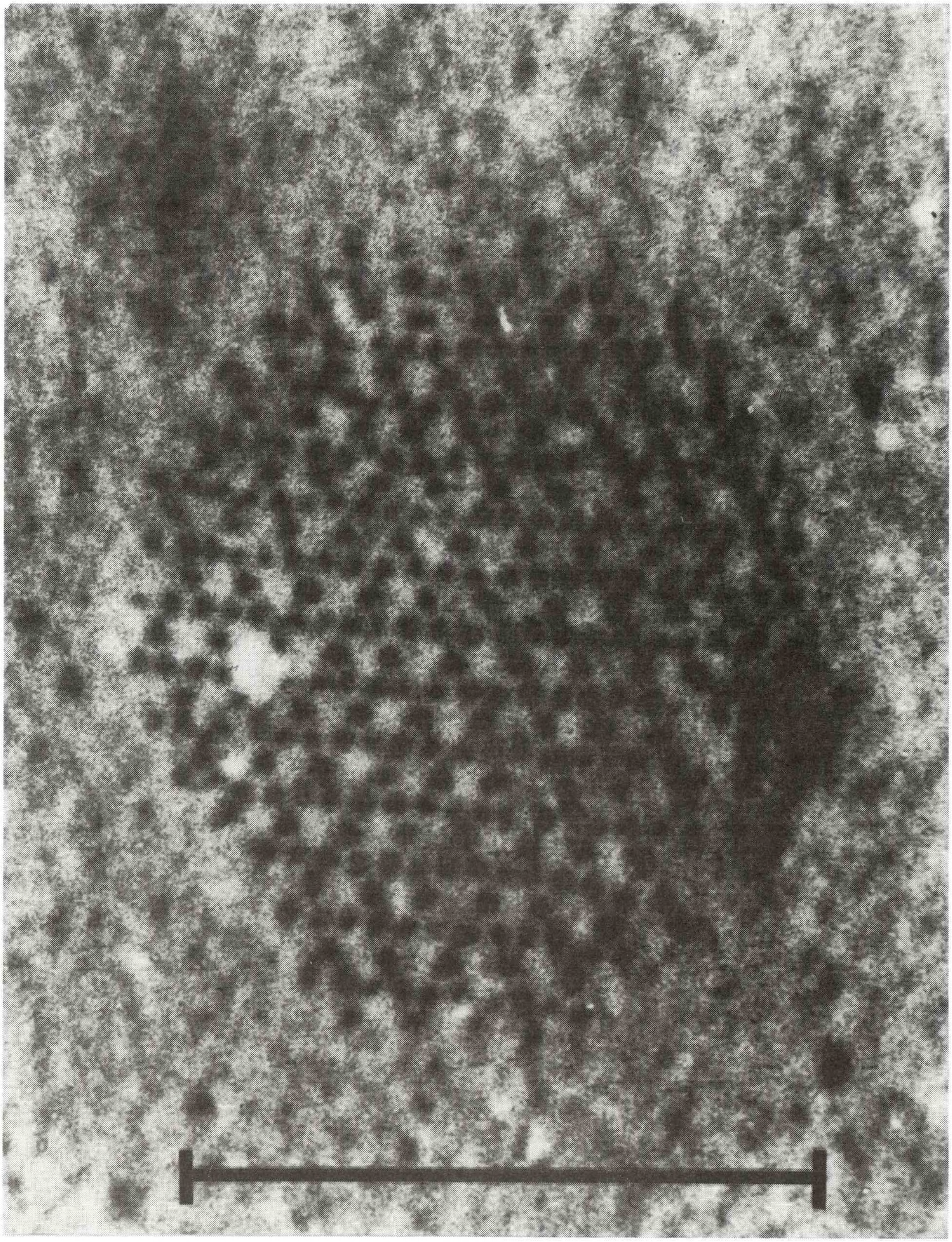

Figure 9. Photograph of the "living fossil" Paleodictyon nodosum found in the TAG hydrothermal field area in the rift valley of the Mid-Atlantic Ridge near 26°N, 45°W (from Rona and Merrill, 1978). The scale bar at the bottom of the photo is 5 cm long.

CONCLUSIONS

Back-arc basins of the central and western Pacific are at the frontier of seafloor hydrothermal research. Geological, geochemical, geophysical and biological investigations of hydrothermal areas in back-arc basins are essential to resolve global questions of the role of seafloor hydrothermal processes in thermal regimes of the ocean and oceanic crust, chemical mass balances and budgets, ocean composition, climate, ore-deposit formation and biologic adaptation. The questions concerning hydrothermal processes in back-arc basins can be efficiently and effectively addressed by international scientific collaboration utilizing methods and experience developed from hydrothermal studies at oceanic ridges.

ACKNOWLEDGMENTS

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ESTABLISHING A SEAFLOOR OBSERVATORY: NOAA VENTS PROGRAM'S LONG-TERM SEAFLOOR AND HYDROTHERMAL MONITORING EXPERIMENTS

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ABSTRACT

Building on the past eight years' results of focused hydrothermal research along northeast Pacific seafloor spreading-centers, the NOAA VENTS Program is currently placing a major emphasis on developing a wide variety of in situ, long-term, and real-time monitoring strategies that will provide physical and chemical data which will, in turn, help make it possible to model and predict the chemical and thermal effects of hydrothermal venting on the North Pacific ocean. A key element of this research strategy is a planned collaboration with a large number of other non-NOAA scientists to establish a pilot seafloor spreading-center observatory in 1995.

PREVIOUS RESEARCH

During the past eight years the NOAA VENTS Program has been focused on determining the effects of hydrothermal venting from sites along the Juan de Fuca Ridge seafloor spreading center on the chemical and thermal budgets of the North Pacific ocean (Hammond *et al.*, 1991). In order to accomplish these objectives, VENTS Program research is concentrated on three general tasks:

* Determination of the source strengths of hydrothermal emissions and their relationships to volcanological and tectonic factors that influence the location, vigor, and duration of hydrothermal venting,

* Determination of the patterns and pathways of the regional transport of conservative and nonconservative hydrothermal emissions,

* Implementation of a geophysical, chemical oceanographic, and physical oceanographic monitoring strategy in order to establish the short- and long-term variability of venting.

The VENTS Program's sustained commitment to hydrothermal studies in the Northeast Pacific has resulted in the discovery and documentation of numerous hydrothermal processes or features. A significant factor which contributes to the scientific success of the VENTS program is its strong link to the academic research community and other governmental agencies through an extensive network of collaborative research. To date, some of the most notable achievements of the program include:

* Completion of high-resolution Sea Beam bathymetric mapping of the entire Northeast Pacific spreading-center system,

* Completion of a series of along-axis surveys of active hydrothermal venting which made it possible to establish the relationships between the distribution and vigor of venting and the state of magmatic inflation of individual ridge segments,

* Determination of the first integrated heat and mass fluxes from entire hydrothermal vent fields through the use of innovative CTD/transmissometer tow-yo survey techniques,

* Completion of the first seafloor-gravimeter survey of a deep-ocean seamount (Axial Volcano, which is located along the central segment of the Juan de Fuca Ridge),

* Documentation of large-scale chemical scavenging processes within rising hydrothermal plumes which significantly affect the global seawater budgets of several elements including phosphorus, an important micronutrient,

* Detection, using *in situ* seafloor instrumentation, of simultaneous ground motion and water-column temperature events, which are inferred to have resulted from a flank eruption of Axial Volcano,

* Determination of variations in large-scale current flow along, and near, the Juan de Fuca Ridge which affect the dispersal of hydrothermal effluent.

Important discoveries include:

* Large-scale, intra-segment diversity of hydrothermal plumes. The distinct chemical diversity between hydrothermal fluids characteristic of major vent fields within the same segment may be evidence for discrete inter-segment magmatic events.

* Large-scale episodic hydrothermal events (called megaplumes), the magnitude of which may effect estimates of hydrothermal mass and heat fluxes from spreading-centers.

* Phase-separated vent fluids in the ASHES vent field at Axial Volcano. Vapor-phase vent fluids issuing from discrete sites for periods of at least several years reveal the existence of long-lived, boiling hydrothermal systems.

* Variability of the ^{3}He/heat ratio in hydrothermal fluids. Changes in this ratio appear to be directly related to the evolutionary state of the subsurface volcanic system. Variability of the ratio has important implications for quantifying the amounts of other, chemically nonconservative constituents of hydrothermal effluent.

* Discovery of an extrusive volcanic eruption near the North Cleft hydrothermal site on the southern Juan de Fuca Ridge between 1981 and 1991. Although approximately three-quarters of the Earth's surface was, and is, being created at seafloor spreading centers, this discovery marks the first-ever documentation of a historical deep-sea eruption.

* Initiation of acoustic (T-phase)detection and location of episodic seafloor spreading-center events along the entire northeast Pacific seaflor spreading-center system.

FUTURE RESEARCH PRIORITIES

Based on the perspective gained from the past eight years of focused hydrothermal research along the Juan de Fuca Ridge, it appears certain that future major advances in understanding and quantifying hydrothermal impacts on the North Pacific ocean will depend to a significant extent on developing abilities to continuously monitor a host of oceanographic and geophysical processes which directly affect the location, duration, type, and vigor of venting. Accordingly, developing and deploying chemical and physical oceanographic as well as certain geophysical and acoustic monitoring instrumentation will be a major priority for the VENTS Program during the next several years.

During the past several years, the VENTS investigators have have placed increasing emphasis on development and deployment of instrument systems which collect year-long data streams of oceanographic and geophysical data at key vent fields along the Juan de Fuca Ridge. These efforts have resulted in as much as seven-year-long current-meter and temperature records at the North Cleft site on the southern Juan de Fuca Ridge, the location where the megaplume bursts and eruptive volcanic activity have occurred during the past several years. There is also a continuing, six-year-long caldera deformation and temperature survey ongoing within the summit of Axial Volcano on the central portion of the Juan de Fuca Ridge.

As well as developing the ability to monitor hydrothermal and hydrothermally related processes for long periods of time, strategies are also being developed which will make it possible to continuously monitor a number of spreading-center processes over spatial scales ranging from single vent orifices to the entire spreading-center system. Examples of monitoring capabilities and instrument systems under active development and testing include:

- SUAVE- An *in situ*, real-time, continuous chemical scanning system for mapping selected elements within hydrothermal plumes using colorimetric analysis techniques. This instrument system can be used in conjunction with CTD tow-yos, mounted on deep submersibles such as *Alvin*, or, eventually, deployed on the seafloor for long periods of time. At present, the system is configured to measure Mn, Fe^{2+}, Fe^{3+}, $Si(OH)_4$, and H_2S.

- Acoustic Extensometer - A system for determining horizontal deformation of the seafloor in hydrothermally active regions. This instrument system is deployable either from a surface ship or from a submersible, remains in place on the seafloor for months/years, and provides information which will help to relate crustal extension with hydrothermal variability, including the generation of megaplumes. The system, which is presently configured to monitor horizontal extension over a distance of about 1 km, consists of several acoustically linked transmitters and receivers as well as temperature-sensor arrays. The transmitter/receivers send and receive periodic, timed 50 Hz pulses which make possible calculation (and storage) of travel-time sequences, and thus crustal extension, between any elements in the array.

- Rumbleometer - A seafloor instrument package that includes pressure, short-baseline tilt, temperature, and current velocity sensors as well as a 1-Hz vertical seismometer. Arrays of these instruments will be deployed to detect vertical crustal deformation and, especially, volcanic harmonic tremor.

- T-Phase - The T-phase acoustic event-detection system utilizes US Navy hydrophone arrays to detect and locate seafloor events along northeast Pacific speading-centers. Data will be acquired in near real-time and thus are envisioned to eventually enable program investigators to respond to active occurrences of episodic volcanic and/or hydrothermal activity. A major objective of T-phase research is to utilize information gained from *in situ* instrument arrays to help discriminate the exact nature of the sound-generating sources, e.g., to be able to discriminate between signals generated by earthqueakes, volcanic eruptions, etc.

With the exception of the T-phase data, most other systems' data are, at present, internally recorded and recovered at yearly intervals when the instruments are recovered, refurbished, and redeployed. Efforts are underway to design an acoustic data telemetering and moored buoy system which will be capable of transmitting seafloor data to a satellite on demand.

CONCLUSION

The VENTS Program's recognition of the importance of continuous, long-term measurements to document the causes and effects of spreading-center processes, including hydrothermal activity, is shared by the US National Science Foundation's RIDGE Program. The fact that hydrothermal and other spreading-center processes have been extensively studied at several sites along the Juan de Fuca Ridge, together with the ridge's close proximity to the west coast of the US, makes this region a natural choice for developing and testing the various instrument systems which will be necessary to acquire such data. Accordingly, the VENTS Program and the RIDGE program have made a decision to collaborate in establishing a pilot seafloor observatory experiment at the North Cleft site. Planning for this effort was initiated during a jointly sponsored VENTS/RIDGE workshop held in Seattle in November, 1991. The goal of this joint effort is to deploy a large number of interrelated, at least year-long experiments at the North Cleft hydrothermal site in 1995. It is anticipated that this effort will involve a large number of investigators from the US academic research community as well as scientists from NOAA, the US Geological Survey, and other non-US agencies and institutions.

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U.S. NAVY'S DEEP SUBMERGENCE PROGRAM

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ABSTRACT

The Secretary of the Navy reinvigorated the Navy's oceanographic activities in 1984. These new initiatives expanded the use of the Navy's deep submergence vehicles for oceanographic research. During the next several years the Navy rebuilt and upgraded its deep submergence vehicles and procured several remotely operated vehicles. SEA CLIFF was rebuilt with a titanium sphere to increase its depth capability to 6096 meters and TURTLE was upgraded to 3048 meters.

These deep submergence vehicles (DSVs) and remotely operated vehicles (ROVs) are operated from the support ship M/V LANEY CHOUEST, acquired in 1988 to expand the range and endurance of deep submergence operations. With berthing for 40 in addition to the crew, the M/V LANEY CHOUEST provides an excellent platform for conducting deep ocean science having features such as a sea beam bathymetric system, dynamic positioning, an integrated navigation system, A-frame DSV launch/recovery system, and wet and dry scientific labs.

HISTORICAL PERSPECTIVE

Since the earliest days of modern civilization, man has relied upon the resources of the ocean for his livelihood. Covering nearly three-quarters of the planet's surface, the oceans have linked the ideas and cultures of people; and advanced the knowledge of our very existence.

America has long depended upon the use of the seas for commerce and trade. We Americans have also had a fascination with underwater vehicles from the earliest days of our nation's founding. Inventors and engineers have designed and built submersibles. Inventors and their submersibles, such as David Bushnell and TURTLE in 1776, Robert Fulton and NAUTILUS in 1798, and John Holland and his submarines at the turn of this century, influenced and inspired the beginning of the U.S. Navy's submarine service.

But there were also men who held a different vision for the use of submarines. Inspired by Jules Verne's "Twenty Thousand Leagues Under the Sea", inventor Simon Lake believed the real future of submarines was in the field of scientific underwater research. His ARGONAUT that he built in 1897 resembled some of our modern day submersibles with a diver's air lock and wheels. Naturally, these first submarines and submersibles were shallow diving with limited range and endurance.

It was not until the early 1930's when Dr. William Beebe and Otis Barton teamed up to construct a bathysphere did deep ocean science really advance. Diving to over 3,000 feet off Bermuda in 1934, Dr. Beebe identified many new benthic creatures. However, the bathysphere was hindered by lack of mobility. The Swiss inventor August Piccard and his son Jacques constructed the bathyscape TRIESTE in 1953. The U.S. Navy recognized the potential of this vehicle for deep ocean exploration and bought the TRIESTE in 1958. After modifications and a new personnel sphere, the TRIESTE reached the bottom of Challenger Deep in 1960 setting the record for the deepest dive.

The bathyscaphes were large, expensive to operate, and difficult to maneuver. New submersible designs and construction advanced rapidly in the 1960's with France, Japan, and the United States leading the way. Tragically, it was the loss of the submarine THRESHER with all hands in 1963 that was the impetus to the current U.S. Navy Deep Submergence Program.

The Current Program

The Deep Submergence Systems Division of the Chief of Naval Operations was established to manage the new program. We are responsible for setting policy relating to deep submergence vehicle operation as well as the Navy diving program.

Central to our operations are two deep submergence rescue vehicles (DSRVs), one of which is always on standby should it's services be required to rescue the crew of a disabled submarine. The DSRV is comprised of three interconnecting spheres and a transfer skirt for mating with a submarine. The forward sphere holds a pilot and a co-pilot, and the middle and aft spheres will hold up to 24 rescues. The system is air transportable; and upon notification, the DSRV, supporting equipment and personnel are transported from it's San Diego homeport loaded aboard military aircraft to the closest suitable airport/seaport combination near the distressed submarine. The DSRV is then loaded aboard a mother submarine which will act as it's base during the submarine rescue. The DSRV's are available for scientific research when they are not training for the rescue scenario or otherwise employed.

Also at the Deep Submergence Unit in San Diego are the two Navy operated deep submergence vehicles, SEA CLIFF and TURTLE. In 1984, then Secretary of the Navy John Lehman, reinvigorated all oceanographic activities within the Navy including expanding the use of these submersibles for oceanographic research. During the next several years the Navy rebuilt and upgraded its deep submergence vehicles and procured several remotely operated vehicles. The SEA CLIFF was completely rebuilt with a titanium personnel sphere giving it a 6096 meter depth capability, enabling it now to reach about 98 percent of the ocean floor.

The internal electronics, sonar, and cameras were improved and an integrated data logging system has been installed to record key vehicle parameters and scientific data. The upgrade program continues and both SEA CLIFF and TURTLE have new manipulator systems to greatly improve sampling capability.

SEA CLIFF's sister submersible, TURTLE, was upgraded to 3048 meters in 1987 and has the same scientific capabilities. In recent years the Navy has acquired a number of state of the art remotely operated vehicles including two 1524 meter Super SCORPIO work ROV's. Next year, a 6096 meter capable Advanced Tethered Vehicle will be placed in service.

The most important addition to our deep submergence assets was the submersible support ship, LANEY CHOUEST, acquired in 1988 which has greatly improved our capability to support deep ocean science. The vessel is 73 meters long, 19 meters wide, and has a range of 6,000 nautical miles at a cruising speed of 12 knots. This modern ship has dynamic positioning and a SEA BEAM bathymetric survey system with real time post processing. It also has an integrated navigation and acoustic vehicle tracking system for short baseline and long baseline tracking of the submersibles and ROVs. Both wet and dry labs are available to the scientists. The ship has berthing for 40 in addition to the crew.

In addition to the expanded range, improved habitability, and scientific equipment, the LANEY CHOUEST provides a significant operational improvement in the stern mounted A-frame launch system, which permits day and night launch and recovery of the DSVs to state four seas. Remotely operated vehicles are handled amidship by a retractable salvage boom.

For the past five years operations have been conducted mainly along the western coast of the United States. Scientific work has been conducted in the northeast Pacific at Gorda Ridge in 1986 and 1988 and at Endeavor Ridge in 1991. Trips were made to Hawaii in 1989 and 1990, and we anticipate SEA CLIFF will make a scientific cruise to Hawaii in the summer of 1992.

The Future of Deep Submergence

Where do I see the Navy heading in using their deep submergence assets in the future? I see a bright future, despite funding constraints, for expanding the use of manned and unmanned vehicles for deep ocean science. Through recently developing cooperative programs with NOAA's Undersea Research Program, I anticipate more scientists will have access to these vehicles for research. SEA CLIFF and TURTLE offer scientists the ability to use highly specialized equipment for sampling and manipulation.

I predict in the not too distant future you will see deep submergence vehicles installing and servicing underwater laboratories.

Unmanned remotely operated vehicles and autonomous vehicles offer the potential for increased bottom time, safety, affordability; as well as improved and expanded access to the deep ocean for scientists and observers ashore- including the ability to conduct experiments from these vehicles while controlling them remotely ashore via satellite links. The combined use of a deep submergence vehicle and a remotely operated vehicle aboard a single support ship increases the availability of data for a given science expedition as well as enhancing safety.

Conclusion

Since Dr. Beebe's early dives, man has still seen less than one percent of the ocean bottom. Imagine what discoveries remain to be found! The U.S. Navy's tradition of exploration and interest in deep ocean technology will continue to advance our knowledge of the earth's processes by diving into the future.

JAMSTEC Submersibles Past and Future -Summary of new findings and proposal for future scientific program-

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Abstract

JAMSTEC Activities for recent several years will be briefly summarized and prososal of future dive program for the Japanese subduction zones will be present. Scientific findings by submersibles are as follows;

In the Okinawa Trough, just behind the Ryukyu Arc volcanic front, three active hydrothermal vents and related animal communities were found. In the Nankai, Suruga and Sagami Troughs, along central Japan, cold seep communities were found along the subduction zones. In the Japan Sea, one of the largest backarc basin, nascent subduction phenomena were observed along the western margin of the Okushiri Ridge, west of the northeast Japan. In the Japan Trench, east off northeast Japan, the deepest clam communities and fissures relate to the normal fault movements by the subducting Pacific plate were found. As for the Izu-Bonin Arc, which extends south of the central Japan, active hydrothermal venting was also found in the caldera of the Suiyo Seamount. We propose the comparative study of the major arcs along the Japanese Islands as for the future program of JAMSTEC.

Introduction

The Japan Marine Science and Technology Center, JAMSTEC, initiated deep sea research around the Japanese Islands by using submersible "the Shinkai 2000" from 1985 as well as "the Shinkai 6500" from this year, and the results are reported in the special volumes of JAMSTEC DEEPSEA RESEARCH.

Several new findings were performed since their early stage of the dives. Here is a brief summary of the JAMSTEC activities in recent 5 years as for the deep sea study with submersibles. As for deep sea animal communities, hydrothermal vent communities were found in three sites in the Okinawa Trough, Izena Hole, Iheya Ridge and Minami-Ensei knoll and as for the animal communities related to cold seepage were found in the Nankai, Suruga and Sagami Troughs as well as the Japan Trench forearc regions. Hydrothermal venting in relation to black and/or white smokers were found in the backarc rift of the Okinawa Trough and the volcanic front of the Izu-Bonin Arc.

Here, we intend to summarize the major results which were obtained in the Okinawa Trough, the Nankai, Suruga and Sagami Troughs, the Japan Sea, the Izu-Bonin Arc and the Japan Trench, as for the dive results with consideration to the origin of deep sea community and the hydrothermal venting.

1. Okinawa Trough

In the Okinawa Trough just behind the Ryukyu Island arc system, submersible dives were carried out both in the backarc rift as well as the arc and forearc regions. Before the submersible dive, precise multi-narrow beam bathymetric surveys were done around the dive sites. As for the central part of the Ryukyu backarc rift, Hydrographic Office, Maritime Safety Agency had carried out the precise seabeam surveys and made three topographic maps. In the central part of the Okinawa Trough, Iheya Ridhe and Izena Hole are located at the center and the edge of the Trough(Kasuga et al., 1987; Kato et al., 1988). Active hydrothermal black smokers were found 1989 by the Shinkai 2000 at Jade site and Clam site whose temperature is almost boiling point 320°C as for the black smoker and 270°C as for the white chimney(Nakamura et al., 1989; Urabe, 1989; Aoki and Nakamura, 1989; Marumo, 1989; Kimura et al., 1989; Tanaka et al., 1989). The chemical compositions of the ore minerals which were obtained from the black smokers are similar to those of the Kuroko deposits of northeast Japan arc at 15 Ma(Halbach et al., 1989; Urabe, 1989; Marumo, 1989). With black smokers, a pockmark emitting CO_2-rich fluid at the Jade site in the Izena Cauldron was also found (Nakamura, et al., 1990). At the Minami-Ensei knoll, 140km southwest of the Amami Oshima, 270°C white chimneys were also found in relation to the communities dominated by the deep-sea mussel (Hashimoto et al., 1990). The Ryukyu arc is thought to be sundered from the Asian continents sometime in the middle Miocene in the southern portion and in the middle part, rifting is now going on along the Okinawa Trough(Leutuozey and Kimura, 1986; Miki et al., 1990; Furukawa, 1991).

2. Nankai Trough

In the Nankai Trough south off Shizuoka Prefecture, thick accretionary prism is developing along the landward slope of the trough. Deepsea clam communities were found during the Kaiko project and the Kaiko-Nankai projects since 1985 (Le Pichon et al., 1989; Nakamura et al., 1989). The the Shinkai 6500 dove in this region this year and found the eastern extension of the clam communities of the sites which had been found during the Kaiko project in 1985. The Nankai community is large compared any other communities around the Japanese Islands (Fujioka and Taira, 1989). The precise measurements of the cold seepage will be performed near future by using submersibles.

3. Suruga Trough

The Suruga Trough is the just boundary between Eurasian and the Philippine sea plates, and the topography of the both sides of the Suruga Trough are quite different with each other (Taira and Fujioka, 1987; Nakamura et al., 1989). During the the Kaiko project, Ocean Bottom Tiltmeter(OBT) was tried to install on the flat surface of the Philippine Sea plate, on the erosion surface of the Izu peninsula(Nakamura et al., 1989). The the Shinkai 2000 and the the the Shinkai 6500 revealed the geologic history of both side of the Suruga Trough (Niitsuma et al., 1990; Otsuka and Niitsuma, 1991; Yamazaki and Kato, 1988). The western boundary of the plate shows abrupt subsidence since Quaternary however, eastern boundary does not show such subsidence. This means the possibility of the different mode of subduction at northern tip and southern portion of the plate boundary. The former may be affected by the collision of the Izu mass with the Honshu Arc at sometime in Quaternary.

4. Sagami Bay

The Sagami Trough runs in the midth of the Sagami Bay from NNW to SSE direction which is the boundary between the Philippine Sea and the

North America plates. Mode of subduction of the Philippine Sea plate along the Sagami Trough is different at different places in the Sagami Bay (Fujioka et al., 1989). The Sagami Bay is divided into three different morphologic domains, western, central and eastern parts. Along the eastern slope of the Izu Peninsula, giant community consisting mostly of the bivalves, crabs were found by the the Shinkai 2000 (Sugiura and Egawa, 1986; Tanaka et al., 1987; Fujioka et al., 1991; Fujioka et al., 1989). The heat flow measurements were performed in this area whose values are extremely high as compared with other region (Fujioka et al., 1989; Kinoshita et al., 1991). Maximum value is almost 2000 mW/m^2 which is comparable with the values observed in the hydrothermal region such as Mid-Oceanic ridge and Okinawa Trough. Carbonate rocks were recovered from the same area. At the western slope of the Okinoyama bank chain at water depth around 1100m, cold seep communities were found by deep-tow, ROV Dolphin 3K and submersible the Shinkai 2000 (Hashimoto et al., 1990; Kanie and Hattori, . These communities are thought to be sustained by seepage of the water along the thrust zone just east of the Sagami Trough.

5. Izu-Bonin Arc

The Izu-Bonin Arc is an oceanic island arc consisting mostly of volcanogenic materials from the Eocene. Submersible dives were carried out mainly along the volcanic front and backarc rift. Hydrothermal vents were found this year from the summit of the Suiyo Seamount south off the Nishinoshima island. White chimney represent high temperature up to 230°C which is the highest temperature ever measured in the Izu-Bonin area. Deep sea communities associated with warm seepage have been also found by the Shinkai 2000 at the Kaikata Seamount and the Mokuyo

Seamount. In the backarc side, the Nishihichito ridge which is thought to be composed of older volcanics shows en echelon distribution pattern. Manganese nodules and limestones were reported from the Nishihichito Ridge and this year these rocks were recovered and observed by the Shinkai 2000 on the slope of the Tenpo Seamount.

Cobalt rich crust s were also found on the Tenpo Seamount which suggests the hopeful manganese ore deposits near the Japanese Islands.

6. Japan Sea

Along western coast of the Japan sea side, thrust type of earthquakes happened one of which was the Nihonkai-chubu earthquake. Nakamura(1983) and Kobayashi(1983) proposed simultaneously the existence of the plate boundary between the North America and the Northeast Japan plate. Along the Okushiri Ridge west of the Northeast Japan, basaltic pillows and cherts were found and the chemical composition of these basaltic rocks represent similar affinity to the MORB. This set strongly suggest that the Okushiri ridge is the nascent subduction zone of the Japan Sea plate underneath the Japanese Island and bacteria mat may be sustained by the seepage of the nascent subduction. At just western foot of the Okushiri Ridge, precipitation of white materials with small communities of gastropods along 10-20cm width fissures.

7. Japan Trench

The Japan Trench off Miyako city was studied during IPOD Legs 56, 57 and 87 as well as the Kaiko program. Notable horst and graben structures are seen in the multi-channel seismic profiles prepared for the site survey of the IPOD and mega-shear zones are also notable in the landward slope of the Japan Trench. The Kaiko dive confirmed the existence of the deepest community along the landward slope, however, the deepest clam community in the world was found in the lower slope this year. The community was distributed from 5901m to 6366m depth along the small gullies covered with thick debris flow sediments. Limited distribution of the clam communities suggests that the clam community is sustained by the seepage along the mega-shear zone which is observed on the seismic profile.

In contrast in the seaward slope of the Japan Trench, seismic zones of 1933 and 1896 Sanriku earthquakes and related Tsunamis are located just on the dive sites. Small fissures and cracks whose sizes are several meters height, several meters widths were found. The direction of the fissures are almost parallel to the general strike of the Japan Trench axis. The thickness of the covered sediments and talus debris were thin so that the age of the formation of these fissures and cracks are estimated to be quite young, possibly related with the Sanriku earthquakes.

8. Summary

Submersibles the Shinkai 2000 and 6500 of the Japan Marine Science and Technology Center started scientific dives around the Japanese Islands and the results of the new findings will be summarized as follow;

1) In the Okinawa Trough, just behind the Ryukyu Arc volcanic front, three active hydrothermal vents and related animal communities were found.

2) In the Nankai, Suruga and Sagami Troughs, along the central Japan, cold seep communities were found along the subduction zones.

3) In the Japan Sea, one of the largest backarc basin, nascent

subduction phenomena were observed western margin of the Okushiri Ridge, west of the northeast Japan.

4) In the Japan Trench, east of northeast Japan, the deepest clam communities and fissures relate to the normal fault movements by the subducting Pacific plate were found.

5) As for the Izu-Bonin Arc, which extends south of the central Japan, active hydrothermal venting was also found in the caldera of the Suiyo Seamount.

9. Proposal for new program

1) Introduction

Around the Japanese Islands, there are five major subduction zones, namely, the Japan Trench, the Izu-Bonin Trench, the Suruga and Sagami Troughs, the Nankai Trough and the Ryukyu Trench. They form arc-trench backarc systems in the marginal areas of the Japanese Islands. Geological and geophysical studies on these arc trench systems have been carried out by the Japanese and overseas Institutions for geology, geophysics, geochemistry and biology during the decade.

Knowledge about earthsciences concerning the above mentioned arc-trench and backarc systems have been accumulated with findings of active hydrothermal vents and deep sea biological communities in the subduction zones including the backarc regions. Information on the deeper part of the crust and upper mantle has also been accumulated by the elaborating studies by various kinds of deep sea research tools. However, systematic surveys have not yet been carried out by using manned submersible across arc areas in order to observe the surface nature of the deep ocean floor and to obtain samples of sediments and rocks as well as biological and chemical samples. In the future decade, knowledge about the space and time distribution of geophysical phenomena for subduction zones are important for better understanding the surface nature of subduction zones in the Western Pacific region.

2) Proposal for the Future Program around the Japanese Islands

JAMSTEC proposes the following geoscience research in the Japanese subduction zones by using the submersible the Shinkai 2000 and the Shinkai 6500. They are namely; 1) Continental Rift vs. Oceanic Rift, 2) Accretion vs. non-accretion and 3) Across arc submersible transect.

1) Comparative Riftology

In the Okinawa Trough, active hydrothermal vents up to 320°C were found with calyptogena communities. The Okinawa Trough was thought to be open sometime in the middle Miocene in the southern portion and sometime in Quaternary in the middle portion. During the early stage of the opening of the Okinawa Trough, the arc rifted from the Chinese continents.

In contrast, the Izu-Bonin Arc is an oceanic island arc which has small nascent rifts in the backarc side of the arc parallel to the elongation of the arc.

Even though both arcs belong to the Philippine Sea Plate, the arc materials are different . Studying the essential difference between the continental rift and oceanic rift is fundamental to understanding the continental and island arcs.

2) Accretion or non accretion

Nankai Trough has accumulated hemipelagic sediments to form an accretionary prism on the landward extension of the Shimanto Belt. The Izu-

Bonin Arc does not have sediment accretion in the forearc region of the Arc, but instead a serpentine diapir has been recognized along the lower slope of the Izu-Ogasawara Trench. In the former areas, frequent appearance of the mud diapirs instead of serpentine diapirs, are found.

Understanding the major difference between mud diapir and serpentine diapir is of prime importance in research on the forearc nature of the subduction zone.

3) Across Arc Transect-TRANSARC PROGRAM-

Across Arc submersible transects of the major arc-trench and backarc system of the Japanese Islands will provide a better understanding of the tectonic situation of the arc-trench and backarc systems of the Western Pacific region. We propose TRANSARC PROGRAM in which all the Japanese island arc trench and backarc systems will be surveyed by the submersibles for topographic, geologic, geophysical and biological comparison.

4) Long-term monitoring system

Long-term monitoring system of hydrothermal and cold seepage and related animal communities by using network of geophysical and geochemical apparatus along the target areas above described. are necessary for the better understanding of geological process under the subduction zones. Tectonic deformation style of the subducting oceanic plate under the island arc will be also observed by long-term monitering system as for seismicity, tilting and so on.

Fig. 1


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Fig. 2

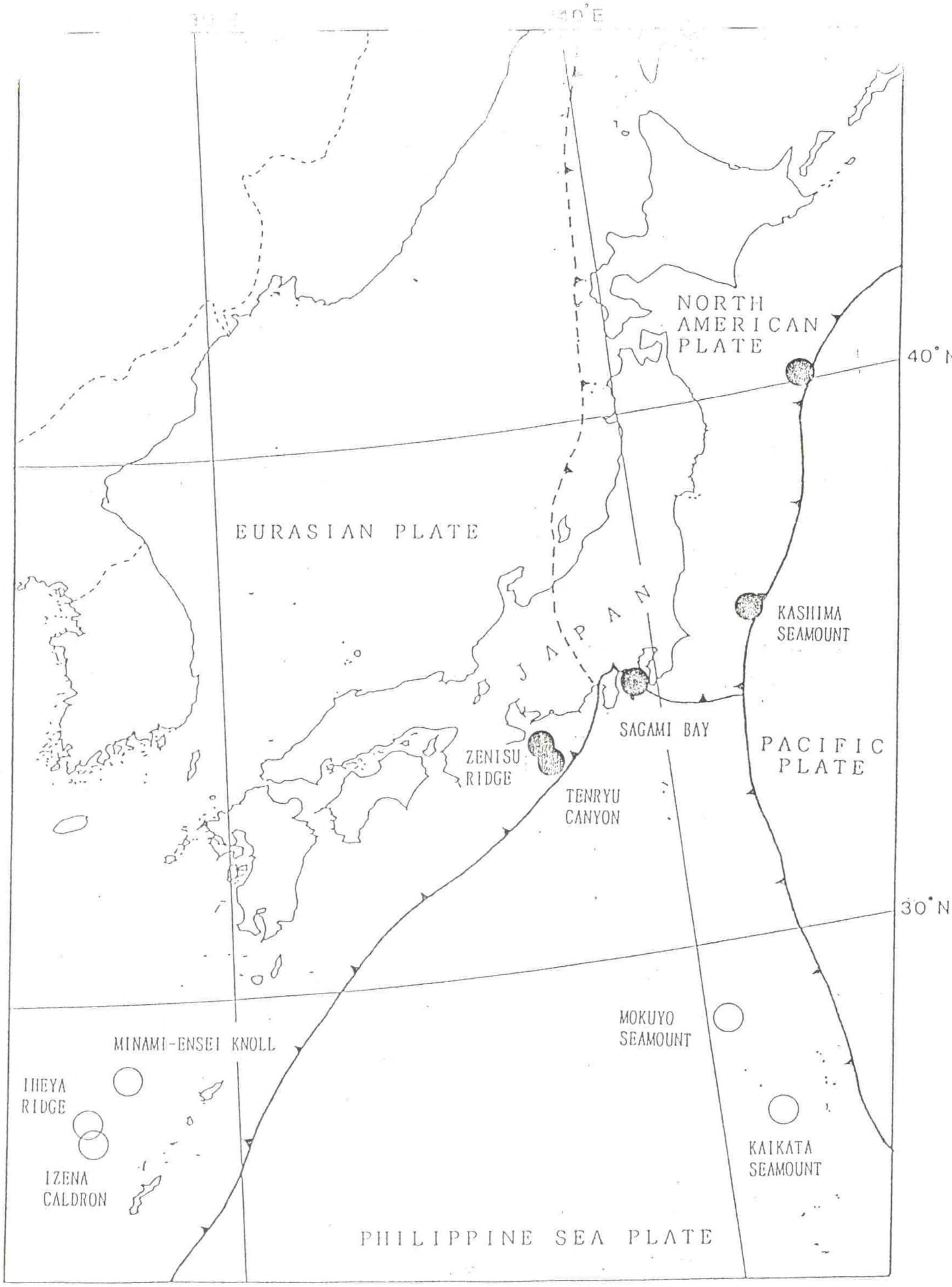

Plate Boundaries and Deep Sea Biological Communities around Japan

: Plate Boundaries
: Cold Seep Communitiess
: Hydrothermal Vent Communities

Proposal for the across arc submersible transect around the Japanese subduction zones

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Abstract

Around the Japanese Islands, there are five major subduction zones, namely, Japan Trench, Izu-Bonin Trench, Suruga and Sagami Troughs, Nankai Trough and the Ryukyu Trench. They form arc-trench backarc systems in the marginal areas of the Japanese Islands. Geological and geophysical studies on these arc trench systems have been carried out by the Japanese and overseas Institutions for geology, geophysics, geochemistry and biology during the decade.

Knowledge about earthsciences concerning the above mentioned arc-trench and backarc systems have been accumulated with findings of active hydrothermal vents and deep sea biological communities in the subduction zones including the backarc regions. Information on the deeper part of the crust and upper mantle has also been accumulated by the elaborating studies by various kinds of deep sea research tools. However, systematic surveys have not yet been carried out by using manned submersible across arc areas in order to observe the surface nature of the deep ocean floor and to obtain samples of sediments and rocks as well as biological and chemical samples. In the future decade, knowledge about the space and time distribution of geophysical phenomena for subduction zones are important for better understanding the surface nature of subduction zones in the Western Pacific region.

JAMSTEC proposes the following geoscience research in the Japanese subduction zones by using the submersible Shinkai 2000 and Shinkai 6500. They are namely; 1) Continental Rift vs. Oceanic Rift, 2) Accretion vs. non-accretion and 3) Across arc submersible transect.

1) Comparative Riftology

In Okinawa Trough, active hydrothermal vents up to 320°C were found with calyptogena communities. The Okinawa Trough was thought to be open sometime in the middle Miocene in the southern portion and sometime in Quaternary in the middle portion. During the early stage of the opening of the Okinawa Trough, the arc rifted from the Chinese continents.

In contrast, the Izu-Bonin Arc is an oceanic island arc which has small nascent rifts in the backarc side of the arc parallel to the elongation of the arc.

Even though both arcs belong to the Philippine Sea Plate, the arc materials are different . Studying the essential difference between the continental rift and oceanic rift is fundamental to understanding the continental and island arcs.

2) Accretion or non accretion

Nankai Trough has accumulated hemipelagic sediments to form an accretionary prism on the landward extension of the Shimanto Belt. The Izu-Bonin Arc does not have sediment accretion in the forearc region of the Arc, but instead a serpentine diapir has been recognized along the lower slope of the Izu-Ogasawara Trench. In the former areas, frequent appearance of the mud diapirs instead of serpentine diapirs, are found.

Understanding the major difference between mud diapir and serpentine diapir is of prime importance in research on the forearc nature of the subduction zone.

3) Across Arc submersible transects of the major arc-trench and backarc system of the Japanese Islands will provide a better understanding of the tectonic situation of the arc-trench and backarc system of the Western Pacific region.

We propose a future project of the arc-trench and backarc systems named "Across arc submersible transect in the Japanese subduction zones".

HANDY DEEP-TOWED BOTTOM OBSERVATION SYSTEM USED WITH THE R. V. HAKUHO MARU

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Abstract

A relatively handy bottom surveying system connected with a surface ship by 6 km long composite fiber-optical/electric cable is being used on the research vessel Hakuho Maru of the Ocean Research Institute, Univ. of Tokyo. The deep-towed underwater vehicle is composed of a pair of stereo color television cameras with a still camera in each, four 300 watts halogen lamps, CTD, six rosette water samplers and a command-operated releasing clamp. An acoustic transponder is attached to its frame.

The vehicle is not equipped with its own propellers but only maneuvered by in-and-out operation of a cable winch and dead slow motion of the surface ship. Its three-dimensional position relative to the surface ship is determined by means of an SSBL (Super-Short Base-Line) acoustic transponder system installed on the Hakuho Maru. We can observe the bottom at a speed slower than 1 knot or keep the vehicle nearly at a fixed spot.

The 14.4 mm ϕ armored cable contains 6 optical fiber channels, 4 electric signal lines and 6 power cords. Video images are transmitted to a shipboard labratory *via* two optical fiber channels to be displayed on two TV screens on a real-time basis and recorded in S-VHS cassettes together with voice of console operators. Associated information such as time in GMT and water depth fed by the ship's Seabeam through the Local Area Network (LAN) is superimposed on the video records. True vehicle depth measured by a pressure gauge is indicated on the CTD graphic display and recorded in a floppy disk.

Stereographic photographs are taken on 35 mm, 100-ft long ASA400~3,200 strip films. Shutter working synchronous with film winding gear is controlled by a shipboard operator *via* a signal line. Each hydrocast bottle and a clamp are also commanded *via* a signal line. The clamp will be used to release a special instrument like a small pop-up OBS or an acoustic and flushing marker. The CTD (Chlorinity-Temperature-Depth Recorder) to suit this system is attached on the center frame. A CRT analog display and a plotter are particularly designed to detect thermal and chlorinity anomalies near the bottom.

This instrument was successfully used in two research cruises; KH 90-1 at the Japan Trench and KH 90-3 at the Manus Basin to observe unique bottom features such as outcrops of lavas and hydrothermal vents in the deep ocean.

1. Introduction---Concept of the System

Recognizing importance of direct visual observation of the deep ocean bottom we have used deep-sea cameras on board the R.V. Hakuho Maru since her early days of sea-going works. A number of photographs of both biological and geological matters on the bottom were collected in her cruises mostly in the Pacific Ocean. Several important records were reproduced in the cruise reports (*e.g.*, Tomoda & Nasu, 1972 for cruise KH 69-2; Tomoda, 1973 for KH 71-1; Kobayashi, 1982; 1984; 1988; 1989 for cruises KH 82-4, 84-1, 86-2, 87-3). Photographs taken by this tool were compiled and published with technical explanations and scientific discussion in two separated articles; one for biology (Ohta, 1983) and the other for geology (Fujioka, Watanabe & Kobayashi, 1989).

Detailed features of pillow basalts occurring at Loihi, Zenisu and Syunsetu Seamounts as well as ripple marks on both shallow and deep bottom sediment surfaces can be comprehensively examined using these records. Advantage of the still camera is its handiness of system which can be operated by usual hydrographic winch. However, its greatest difficulty is that we can see the targets only after the camera is retrieved and film is developed. We have often lost way to revisit the most interesting site we found by the photographs. Additional work such as hydrocast and temperature measurement at exactly the same sites is almost impossible.

When the new research vessel Hakuho Maru was completed in 1989 (Kobayashi, 1990a, b; Furuta *et al.*, 1991), we attempted to install a new device to continuously monitor the bottom as deep as 6,000 m by cabled TV cameras together with several other instruments capable of some simultaneous measurement and operation (Fig. 1). The first-priority objective is certainly real-time visual observation of the bottom in a laboratory on the ship, whereas records of the images in video tapes and still photographs of selected spots are also necessary. Continuous monitoring of chlorinity, temparature and depth (CTD) at the same position of the cameras is desirable. In addition sampling of water at several desired sites and release of one small equipment such as acoustic marker or flusher are preferred (Ishisaki, Morikawa & Nemoto, 1991). We call this system "Deep-Sea Multi-Monitoring System" or "DESMOS" in abreviation. We will, hereafter, use this acronym in the present article.

Precise location of the DESMOS underwater vehicle is controlled by the Super-Short Base-Line (SSBL) acoustic navigation system manufactured by the Oki Electric Industry Co., Ltd. and installed on the hull of the ship. A small transponder is attached with the cameras so that its position relative to the ship is provided on a cathode ray screen or an X-Y plotter and stored in floppy discs in the laboratory.

Considering limited deck space and restricted time for one operation on the Hakuho Maru we adopted a principle that the DESMOS has to be very handy and compact. On-board operation should be handled by less than 3 persons including a winch operator. Total weight of the vehicle in air should not exceed 1 ton. For this reason it was designed without propulsion. Only

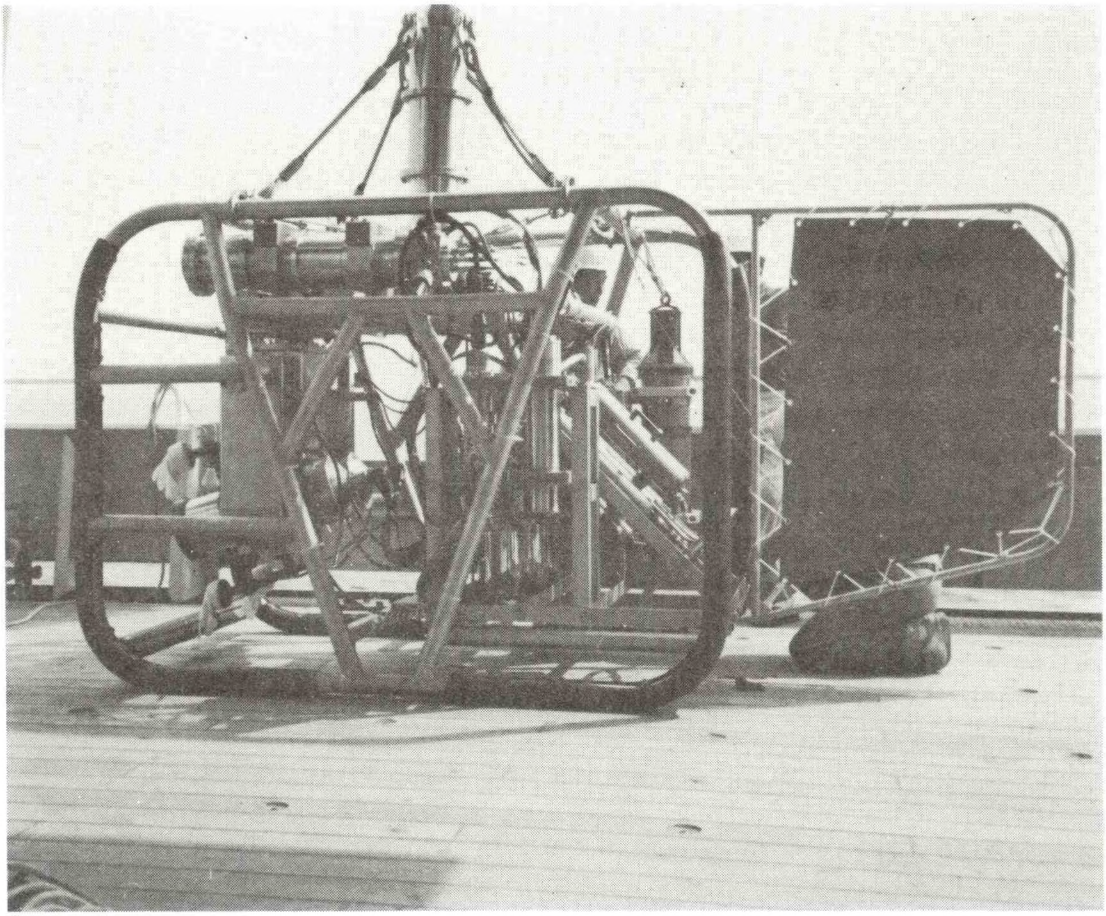


Fig. 1. Photograph of the underwater vehicle on board the R.V. Hakuho Maru

two-axes rotation of cameras was facilitated. Position of the system can only be maneuvered by in-and-out operation of winch as well as by the ship's dead-slow motions.

Composite cable composed of fiber-optical and electric cables is used for transmission of signals and electric power. Diameters of the cables were kept minimum to reduce resistance of water. Angle of cable versus horizontal water speed was numerically simulated using the Pode method. Diameter of 14.4 mm and weight of 500 kg/km were thus selected. Cable winch was also designed to be compact and as light as possible, since it has to be removable when the ship is operated for other disciplines. Length of cable was restricted to be 6,000 m due to the maximum capacity of winch with such a reasonable size.

Contract was made with Ocean Cable Company (OCC), Ltd. to manufacture the 6,000 m composite cable and complete the total system. The underwater TV and still cameras were prepared by OVS Co., Ltd. The winch was built by Tsurumi Seiki Company, Ltd.

2. Arrangement of Deep-Towed Vehicle

Frame of the underwater vehicle is made of stainless pipes to reduce total weight. The following items are attached in the frame as shown in Fig. 2;

(1) A set of two video cameras with a still camera accommodated in each

(2) A set of four light bulbs (300 W each)

(3) Movable stage of cameras and lights [±45° horizontal rotation, 10 ~ 90° tilting]

(4) CTD sensor

(5) A set of six water samplers (1.2 *liters* each)

(6) Tiltmeter for vehicle

(7) Altimeter measuring height from the bottom surface (0 ~ 50 m)

(8) Signal converters (Conversion between optical and electric signals plus AD)

(9) Transformer for electric power

(10) Releasing latchet operated by electric commands from the ship's console

(11) Stabilizer wing

(12) Cable connector

All the pressure resistant vessels are made of SUS 316 metal and

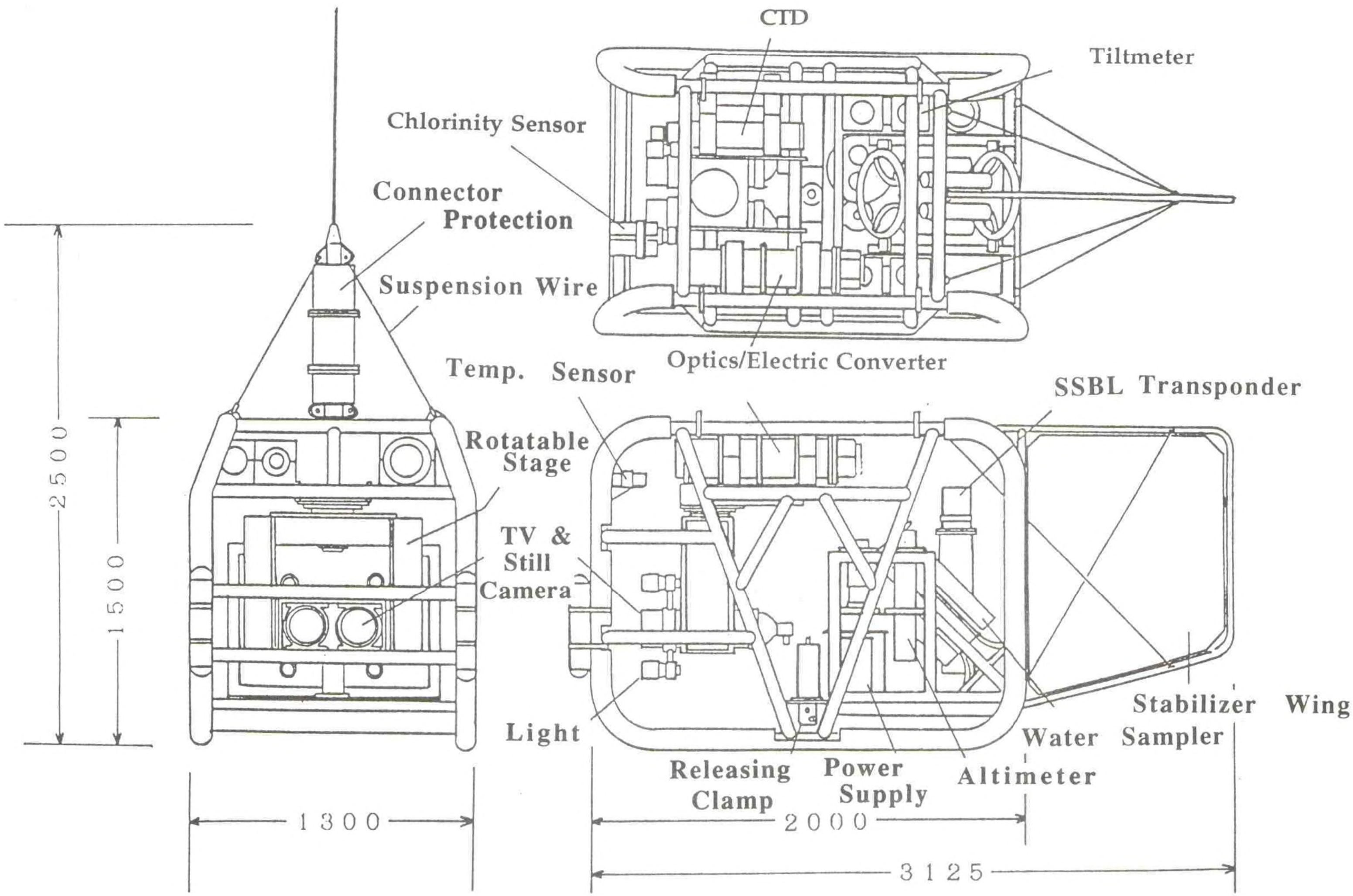


Fig. 2. General arrangement of the underwater vehicle

guaranteed for 6,000 m water depth. Eventually the total weight of the underwater vehicle is approximately 800 kgs in air.

2. 1. Television and still composite cameras

In order to obtain the best available quality of observed images the S-VHS system of video recording (lines of horizontal scanning > 420) was adopted. It records and transmits brightness and color signals separatedly so that two signal cables (four for two cameras) are necessary. Two cameras of color CCD single plate type are installed in parallel positions to enable us stereographic observation of the bottom materials. Lens is 180 mm in diameter and has focus distances varying between 25 and 75 mm. Focus and zoming can be adjusted by an electric command from the console. Illumination of target body is provided by underwater lamps using four halogen bulbs with 300 W each. Distances between light sources and cameras should be as large as possible to avoid refraction by floating dusts, although size of movable stage is mechanically limited. Actually their distance is about 300 mm.

Still camera is installed inside the TV camera as shown in Fig. 3. A mirror shutter is driven by a motor operated both automatically (with any preset frequency less than 1 cycle/sec) and by a command from the console. High sensitive color film of ASA 400 ~ 3200 sensitivity and 35 mm in size contained in the underwater vessel is automatically wound after each shot of shutter. Maximum 1,600 photographs can be taken in one dive. The film is so sensitive that no flushing light is needed. Illumination for TV is sufficient to still photography. Exposure is automatically controlled by IRIS system. Data of 16 digits for date and time can be written in a corner of photograph.

2. 2. Movable stage for cameras and light

Two cameras and four lamps are fixed to one stage which can be rotated by 45° to both sides, tilted downward by 90° and upward by 10° with a speed of 4°/sec. The motion is driven by an AC motor immersed in oil in response to a com-mand from the console.

2. 3. CTD sensor

Sensor of Chlorinity-Temperature-Depth (CTD) recorder manufactured by the SeaBird Electronics Co. (Model SBE 9/11) and modified by Tsurumi Seiki Co. is installed in the vehicle. Specifications of the CTD are listed in Table 1.

2. 4. Water samplers

A set of six Niskin-type rosette samplers with capacity of 1.2 *liters* each are contained in tail-bottom of the vehicle to collect bottom water at 6 different spots indicated by commands from the console.

2. 5. Tiltmeter and altimeter

Heading and tilting of the vehicle are measured by a compass magnet and gimbal sensors with an accuracy of 1°. Height of the vehicle from the bottom

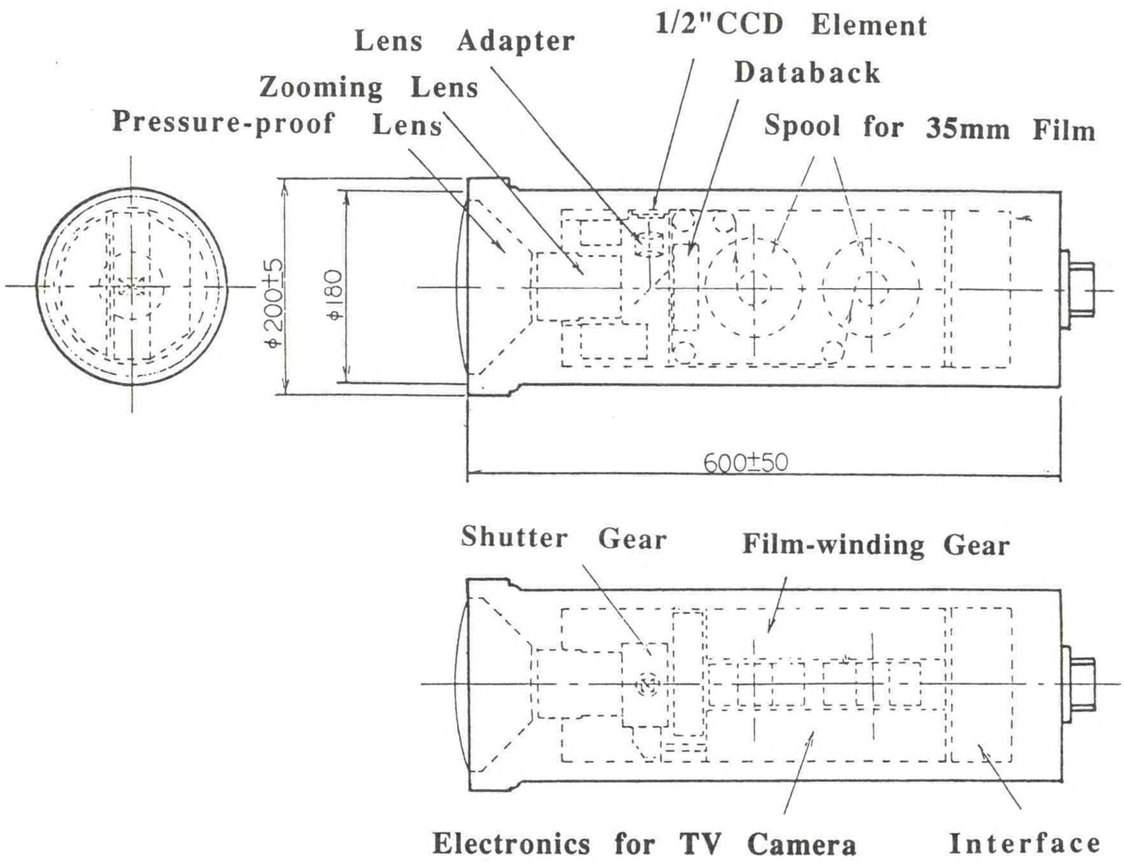


Fig. 3. Composition of TV-still composite camera

Table 1. Specifications of CTD

Sensor	Item	Specification
Chlorinity	Type of Sensor	3 electrodes type
	Range of Measurement	0 ~ 70 mS/cm
	Accuracy	± 0.003 mS/cm
	Stability	0.003 mS/cm/month
	Power of Resolution	0.004 mS/cm
	Time for Response	50 msec
Temperature	Type of Sensor	thermister
	Range of Measurement	-5 ~ 35 °C
	Accuracy	± 0.004 °C
	Stability	0.002 °C/month
	Power of Resolution	0.003 °C
	Time for Response	50 msec
Depth	Type of Sensor	thermister
	Range of Measurement	0 ~ 6,894 dbar
	Accuracy	± 0.02 % FS
	Stability	0.1 % FS/month
	Power of Resolution	0.07 dbar
	Time for Response	10 msec
Miscellaneous	Sampling Rate	CTD 1 set/125 ms
	Speed of Data Transmission	FSK Transmission
	Size	Main ϕ133 x L 650 mm C ϕ 48 x L 203 mm T ϕ 48 x L 227 mm Pump ϕ 61 x L 311 mm
	Signal Amplifier	ϕ130 x L 300 mm
	Material for Vessel	Anti-corrosive Al
	Weight	In Air: 20 kg, In Water: 17 kg

is detected by a sonor using 50 kHz acoustic transmission. The maximum detectable height is about 100 m (the optimal height is 0 ~ 50 m) with an accuracy of 5 % of the height.

2. 6. A huck with mechanical release

This vehicle can hold one small instrument less than 1 ton in weight in air. Its clamping huck is mechanically released by a command from the ship. It can install a special long-term observation device such as ocean bottom seismometer or a marker on an exact site of the bottom at which a particular phenomenon is discovered.

2. 7. Cable connector

A waterproof fiber optic cable connector with capacity of 700 MPor pressure was specially developed for this system. A usual underwater connector filled with oil is used for electricity. These lines are connected separatedly on the top of the vehicle and covered by a metal cylinder to mechanically protect the connectors.

2. 8. Chain suspended from the vehicle

A pendulum weight is suspended by a 230 ~ 250 cm long chain under the vehicle in order to estimate its distance from the bottom and dimension of bottom objects. Exact sizes of the bottom objects and distance to them can be quantitatively analyzed by comparing two stereographic photographs.

3. Cable and Cable Winch

Composite cable composed of six fiber optic cords covered by stainless steel pipe, four signal electric and six power cords covered by plastic sheath and zinc plated steel armor (Fig. 4). Optical fiber was chosen considering reduction of attenuation of TV and other signals as well as to avoid electric noises.

Among six fiber optic cords four are used for color TV signal transmission and two for other signals (9,600 bauds for round trip). One pair of electric cords is used with CTD and a pair of 3 cords are for electric power (2.8 kW).

Converters from fiber-optical to electric and from electric to fiber-optical signals each are installed in both the underwater vehicle and in the cable winch on board the Hakuho Maru. Signals after convered to electric are sent through a slip-ring on the winch drum to a console in the laboratory.

Electric power is transmitted to the cable in 1,100V through a transformer supplied from the ship's souce in 440 V (60 Hz, 3 phases). The vehicle has one transformer converting it to appropriate voltages.

A winch was specially designed to wind the total 6,000 m of the composite fiber-optic/electric cable with diameter of 14.4 mm. Great care was taken to

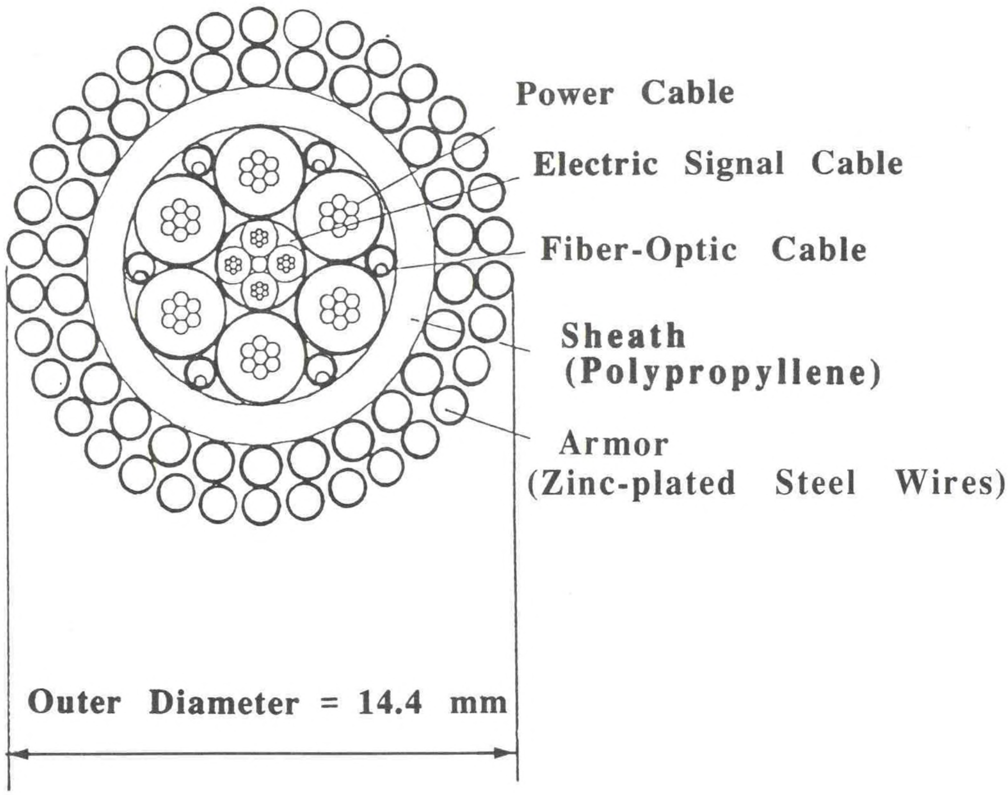


Fig. 4. Cross-section of fiber-optic and electric composite cable

Table 2. Specification of Composite Cable

Item		Specification
Outer Diameter		14.4 mm
Optical Fiber (6 cords)	Cover	Stainless Steel Pipe
	Size of Fiber	10/125 μm G1 Fiber
	Attenuation	< 1 db/km (1.3 μm)
Signal Lines (4 cords)		0.18 (Woven Steel Wire)
Power Lines (6 cords)		1.4 (Woven Steel Wire)
Armor for Tension		Zinc-plated Steel Wire (Double)
Total Length of Cable		6,000 m
Limit for Breakdown		> 10 tons
Total Weight		660 kg/km in air, 520 kg/km in water

wind up the cable under a steady tension (maximum 4.5 tons) without a traction winch. Diameter of the winch drum is 800 mm to avoid sharp bend of the cable. Its outer diameter after winding 6,000 m cable is 1,480 mm with width of 1,217 mm. The winch is operated by a hydraulic motor (VIKING series manufactured by Hagglunds Co.) using oil of 160 kgf/cm^2 by 280 *liter*/min supplied from the main pump of the Hakuho Maru. By this mechanism the winch is relatively compact and weighs about 5 tons. Operation of the winch can be controlled and monitored both beside the machine and from the laboratory. Winch is installed on the starbord center of the working deck where influence of ship's pitching is minimum. The cable is suspended by a side horizontal-beam crane which can hold it without too much bending before going down to the bottom (Fig. 5).

4. Operation Console

Signals provided by the composite cable through the slip-ring of the winch are sent to a console. A removable container with a size of an international standard (IC: 8' x 8' x 20') is used to accommodate most of on board instruments and installed on the upper port-side deck of the Hakuho Maru by four twisted locks. It is connected with a main electronics lab by flexible bellows like a boarding gate in airport. The container can be removed from the ship and stored in the campus of the institute together with the instruments while the ship is operated for other disciplines.

The consoles (Fig. 6) in the removable laboratory are equipped with the following units;

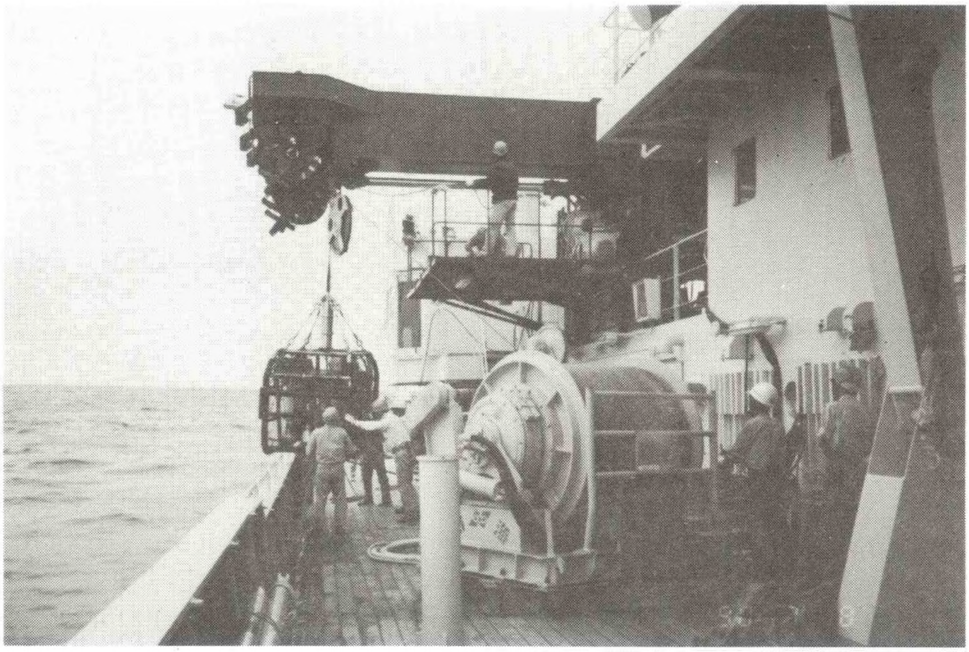
(1) Vehicle commanding system composed of a camera control unit (zooming, focusing, shutter *etc.*) as well as commanding unit for rotating stage, water samplers and mechanical release.

(2) Data display rack indicating heading, tilting and altitude of vehicle together with direction of cameras and counts of film on a display screen. Shot time of still camera is printed. These data are also recorded in a floppy disk.

(3) Video rack consists of two screens showing the bottom images in stereographic manner with ship's cruising data fed via Local Area Network (LAN) system superimposed. The images are recorded in video tapes.

(4) CTD rack; signals sent from the CTD sensors are demodulated and deciphered by a 32 bit mini-computer, shown on a graphic display unit and recorded in a floppy disk.

(5) Winch controller; a controlling handle of the winch with display of wireout length, wire tension and wire speed. An operator (usually ship's engineer in the Hakuho Maru) can maneuver the winch inch by inch while observing the bottom in the TV screen.



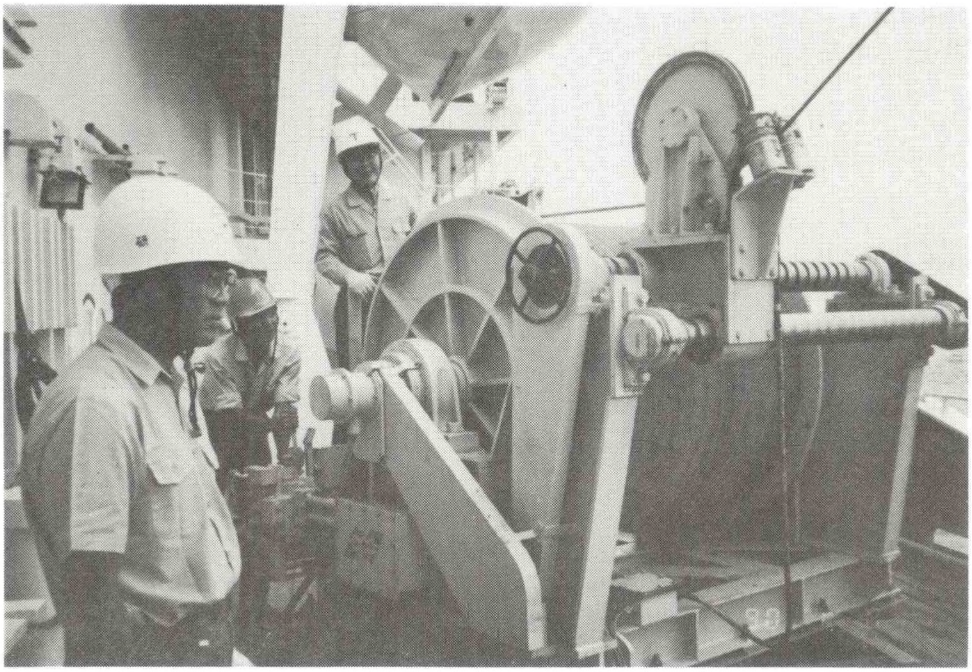


Fig. 5. Photograph of cable winch on board the R.V. Hakuho Maru

Fig. 6. Photograph of consoles in a removable laboratory on board the R.V. Hakuho Maru

5. Positioning of the Towed System

Position of the underwater vehicle is fixed by the SSBL system of the R. V. Hakuho Maru. The transmitter-receiver units are installed at the bow bottom hull of the ship and lowered by maximum 2 m below the hull during the measurement to avoid acoustic disturbance due to bubbles generated by the moving ship. Size of each unit is cylindrical with a diameter of 390 mm and length of 300 mm.

Frequency of trasmitted acoustic waves is 10.5 ~ 13.0 kHz. The interogate/ command unit on board the ship controls transmitted signals. Transponder recieves and responds to it by slightly a different frequency between 13.5 and 15..0 kHz which is preset by a rotary switch in the transponder. Array of 16 elements of acoustic detectors is equipped with the ship's reciever unit which can detect slant range and direction of signals. The ship's motion (rolling and pitching) and heading measured by a gyroscope installed in a special laboratory for gravimeter. Three-dimensional position of the trans-ponder is thus calculated relative to the ship. If another transponder is set on the bottom, position of the vehicle in respect to the bottom can also be indicated. Accuracy of X-Y-Z values obtained by this SSBL system is within 1.4 % of the slant range.

A transponder of regular type including capability of release of weight by an acoustic command is usually attached to the underwater vehicle. Its size is 95.2 cm long and 20.6 cm in diameter. It weighs about 39 kgs in air and 19 kgs in water. If a special transponder used for exclusively underwater vehicle is built without acoustic release, its size and weight (plus price) may be much reduced.

Position of the underwater vehicle is shown relative to the ship in screens located in the renovable lab, electronics lab and chart room behind the steering house. It can be plotted on a plotting sheet or map with A3 size by an X-Y recorder. The position of vehicle is also recorded in a floppy disk with date and time of measurement together with heading of the ship.

6. Deep-Sea Observation at the Japan Trench

The DESMOS system was first used in a cruise KH90-1 of the research vessel Hakuho Maru between June 25 and July 10 at the southern Japan Trench region. The ocean bottom structure of the trench walls as well as the Gyoban Seamount Chain east off the trench was surveyed much in detail by the Seabeam sounder, 3.5 kHz subbottom profiler and proton magnetometer (Kobayashi, 1991). Five sites were selected from scientific and logistic viewpoints (Fig. 7). Among these 5 sites two (Stn 01 & 02) are on the seamounts, whereas two (Stn 04 & 06) at the trench wall exceeds 5,000 m in water depths.

The deepest operation is at 5,510 m on the lower landward slope of the Japan Trench (Stn 06) around 04:00, July 08, 1990 [GMT] with the maximum length of cable out of approximately 5,800 m. This site aimed at identifying

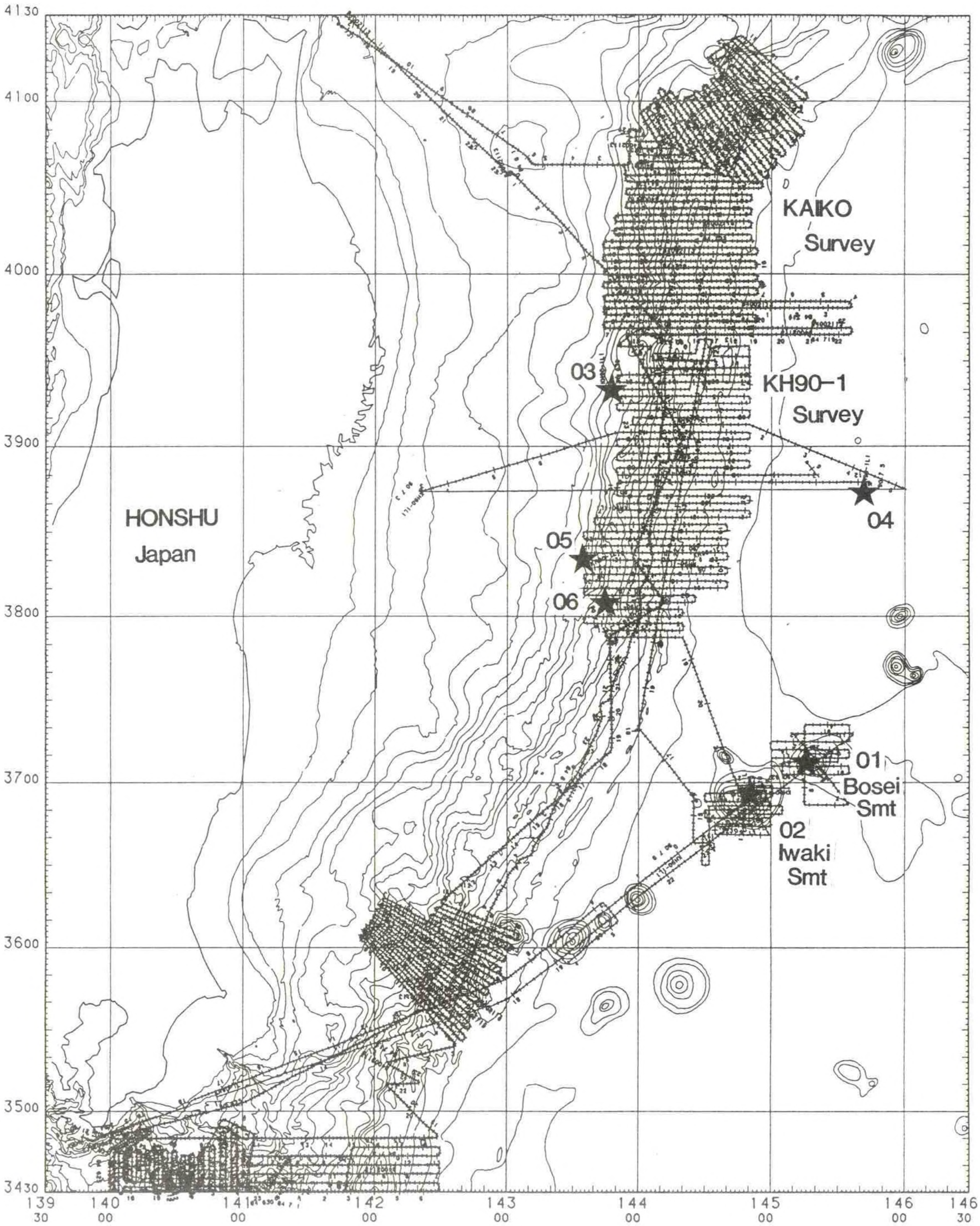


Fig. 7. Ship's tracks for geophysical measurement and sites of the DESMOS observation in the southern Japan Trench region

sediments formed by landslides and, if possible, peculiar biota associated with them. The observation indicated no positive evidence of recent slumping and active seepage of deep interstitial water. High biomass at this site (~ 10 gr/m^2) implies large supply of nutrients either from the surface or by downslope transport.

Two examples of the records of operation and observation are described below;

6. 1. Seamount Bosei

At the southwestern mid-slope terrace of Bosei (Mizunagidori) Seamount (crestal depth is 2,200 m) east off the southern Japan Trench (Stn 01 at 37°07'N; 145°17'E, Fig. 8) a number of angular pebbles and cobbles of apparently igneous rocks were observed at depths ranging between 2,970 and 3,340 m (02:31 ~ 05:11 in June 28, 1990 [GMT]). Most of them appear to be encrusted with Mn or Fe hydro-oxides causing dark black color. Occasionally white stones identified to be apatite blocks are seen. Some are covered by coarse sands (Fig. 9-1~ 9-3).

6. 2. A mud diapir on the outer swell of the trench

In the east-west multi-channel seismic profiling line on a latutude of 38°45'N we discovered a small mound with a height of about 100 m at 145°42.2'E. It is on the crest of the trench outer swell at a depth of 5,300 m, which is nearly 700 m higher than surrounding normal Pacific Ocean floor. It was first found in the seismic line and later confirmed by Seabeam survey along an NS crossing track (Kobayashi, 1991). Shape of the mound is oblate with diameters of 3 km along NE-SW and 1 km along NW-SE (Fig. 10).

Judging from the 3.5 kHz records, the bottom is covered by 100 m thick transparent layer with several thin reflecting stripes, probably due to ash layers. The mound is situated close to a fault trending NE-SW and dislocating the top transparent layer by more than 100 m with west side down in a manner of the normal fault. Moats with a depth of 40 m in the west and 10 m in the east were recognized. Considerable upward drag of surrounding layers is clearly seen around the mound, implying injection of diapirism. It is a crucial evidence to suspect its diapir origin. If this conclusion is valid, the mound is the first mud diapir or what is called *mud volcano* in the oceanward floor of the trench.

In order to provide additional evidences we attempted to observe the bottom features of the mud diapir (Stn 04 in Fig. 7). Weather was bad with southeasterly wind stronger than 10 m/sec and with relatively high waves. To keep positions of the ship and underwater vehicle most precisely on a designated line, the ship was maneuvered with aft against wind. The hull shape of the Hakuho Maru is designed so as to get the least pitching and good maneuverability in this manner. The ship and vehicle moved by dead-slow speeds relative to the bottom at approximately 0.5 knots. Vehicle passed through the slope close to the crest of the mound from 06:00 to 07:00 (GMT) as shown in Fig. 10.

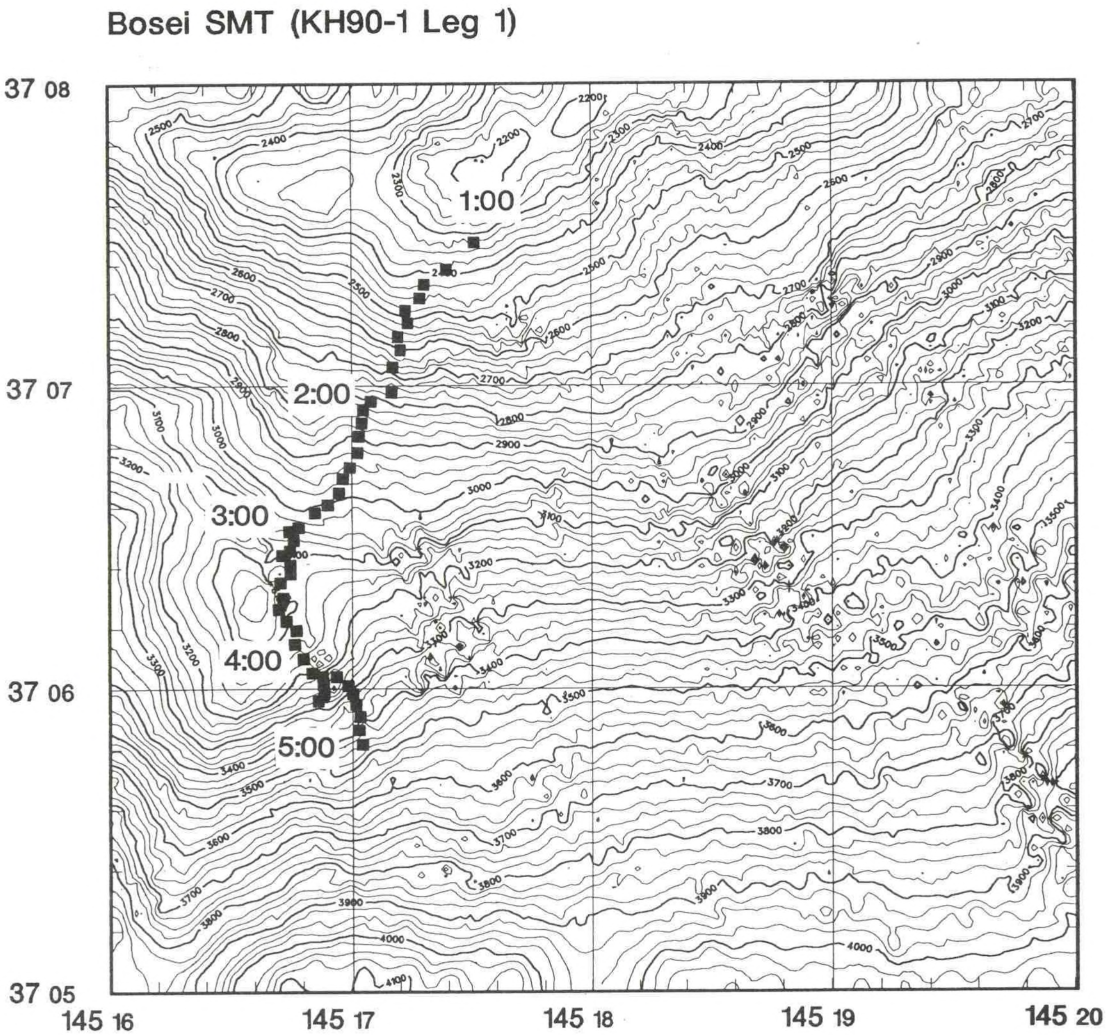


Fig. 8. Tracks of the underwater vehicle plotted on a bathymetric map of Bosei (Mizunagidori) Seamount east off the southern Japan Trench (denoted by solid squares). Numerical figures besides dot indicate time in GMT. Contour interval; 25 m

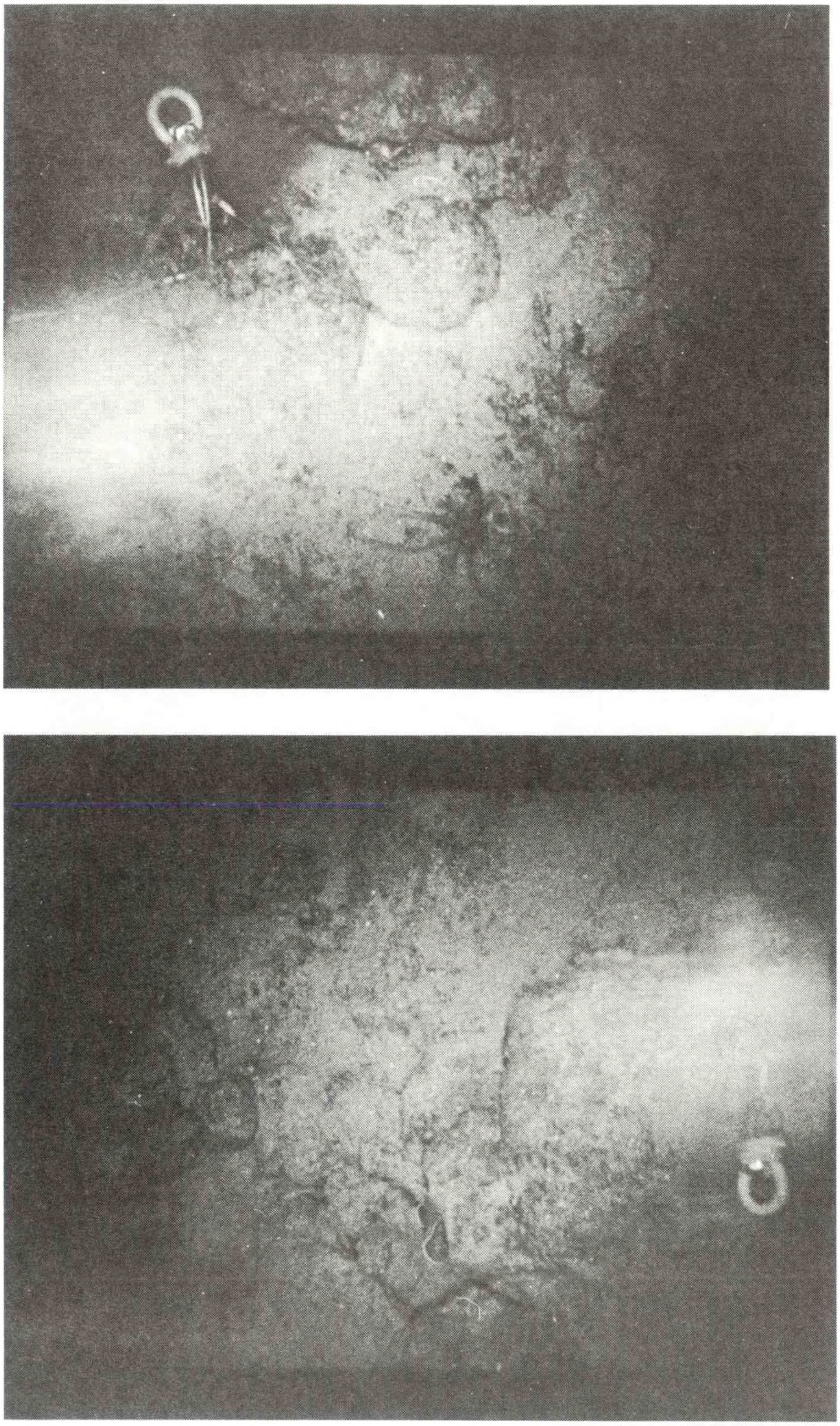
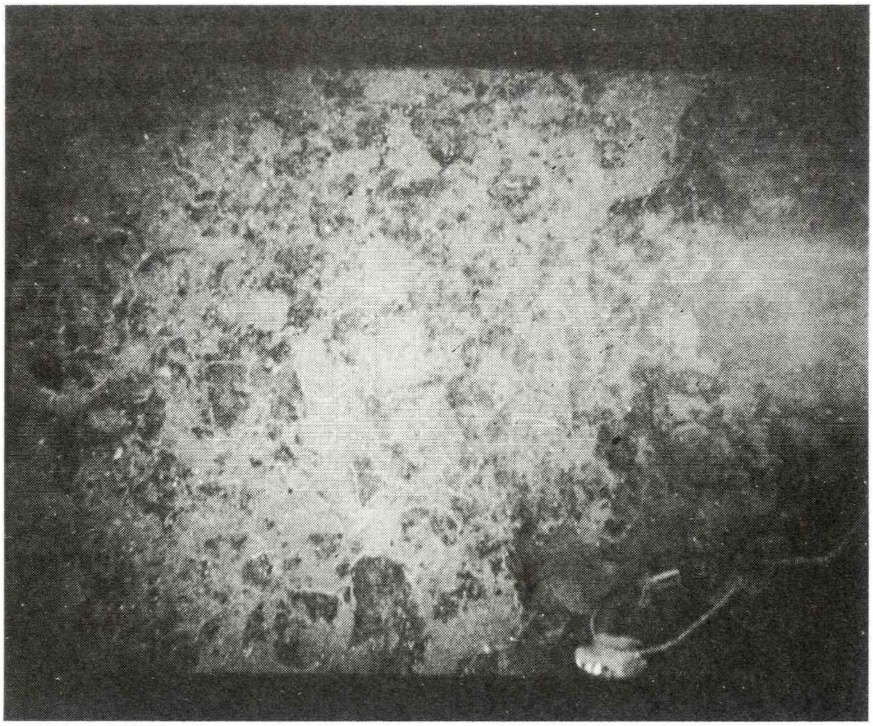


Fig. 9-1. Outcrops of pillow lavas photographed by DESMOS at the crestal slope of Bosei Seamount in the Joban Seamount Chain east off the JapanTrench. A shackle in the photograph is about 5cm in diameter and 2 m far from the camera. [above]; D = 2,970 m at 02:24 GMT. [below]; D = 2,980 m at 02:30 GMT.



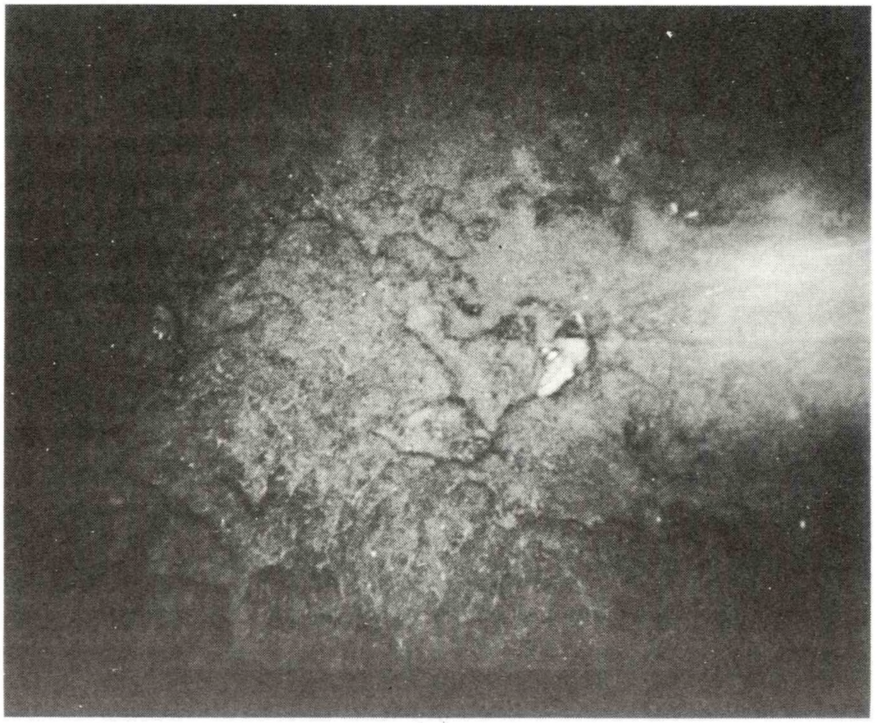


Fig. 9-2. Outcrops of breciated lavas photographed by DESMOS at relatively gentle slope of Bosei Seamount in the Joban Seamount Chain east off the Japan Trench. [above]; D = 3,010 m at 02:41 GMT. [below]; D = 3,010 m at 02:47 GMT.

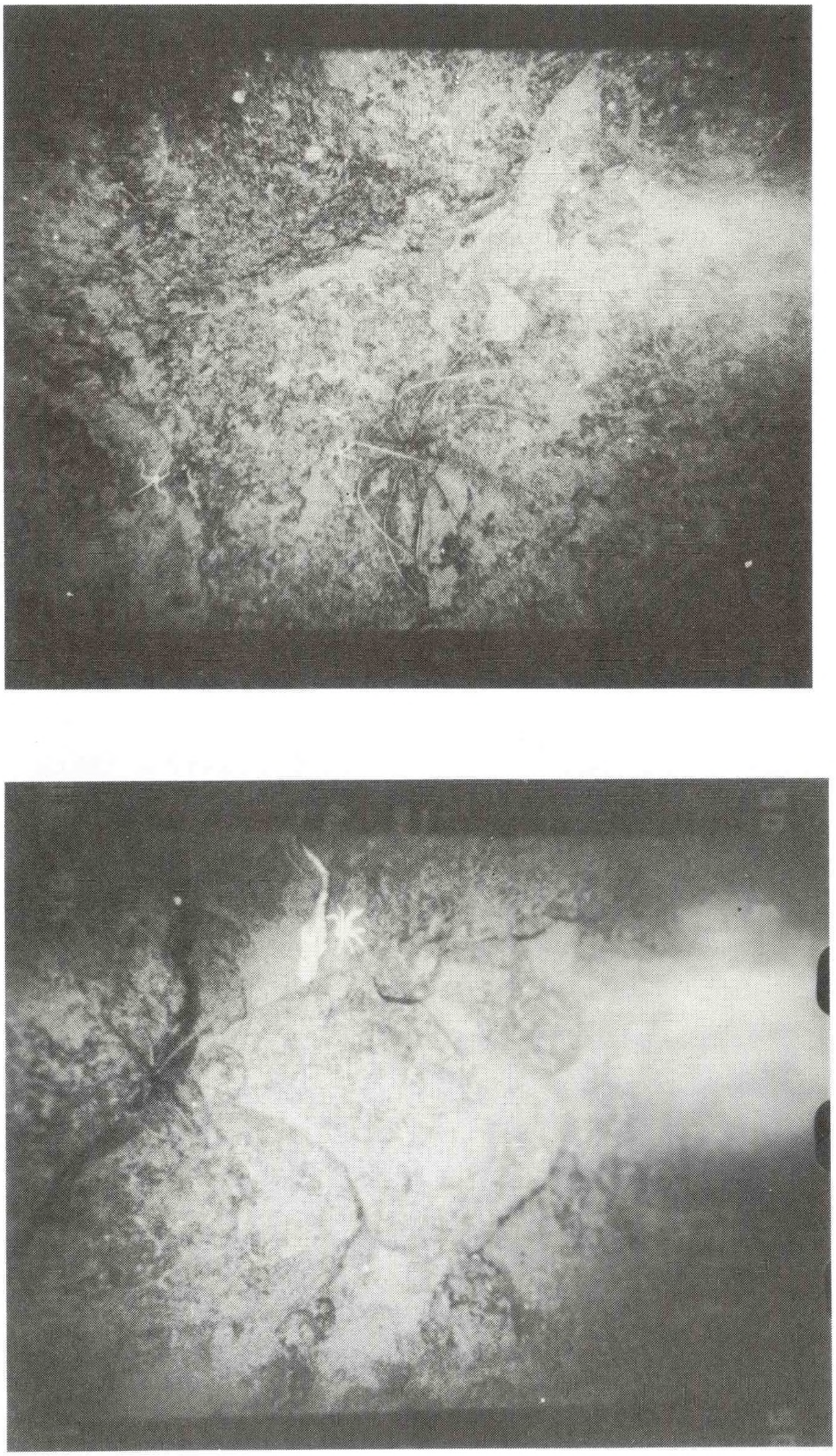


Fig. 9-3. Outcrops of massive lavas photographed by DESMOS at a slope terrace of Bosei Seamount in the Joban Seamount Chain east off the Japan Trench. [above]; D = 3,110 m at 03:18 GMT. [below]; D = 3,110 m at 03:48 GMT.

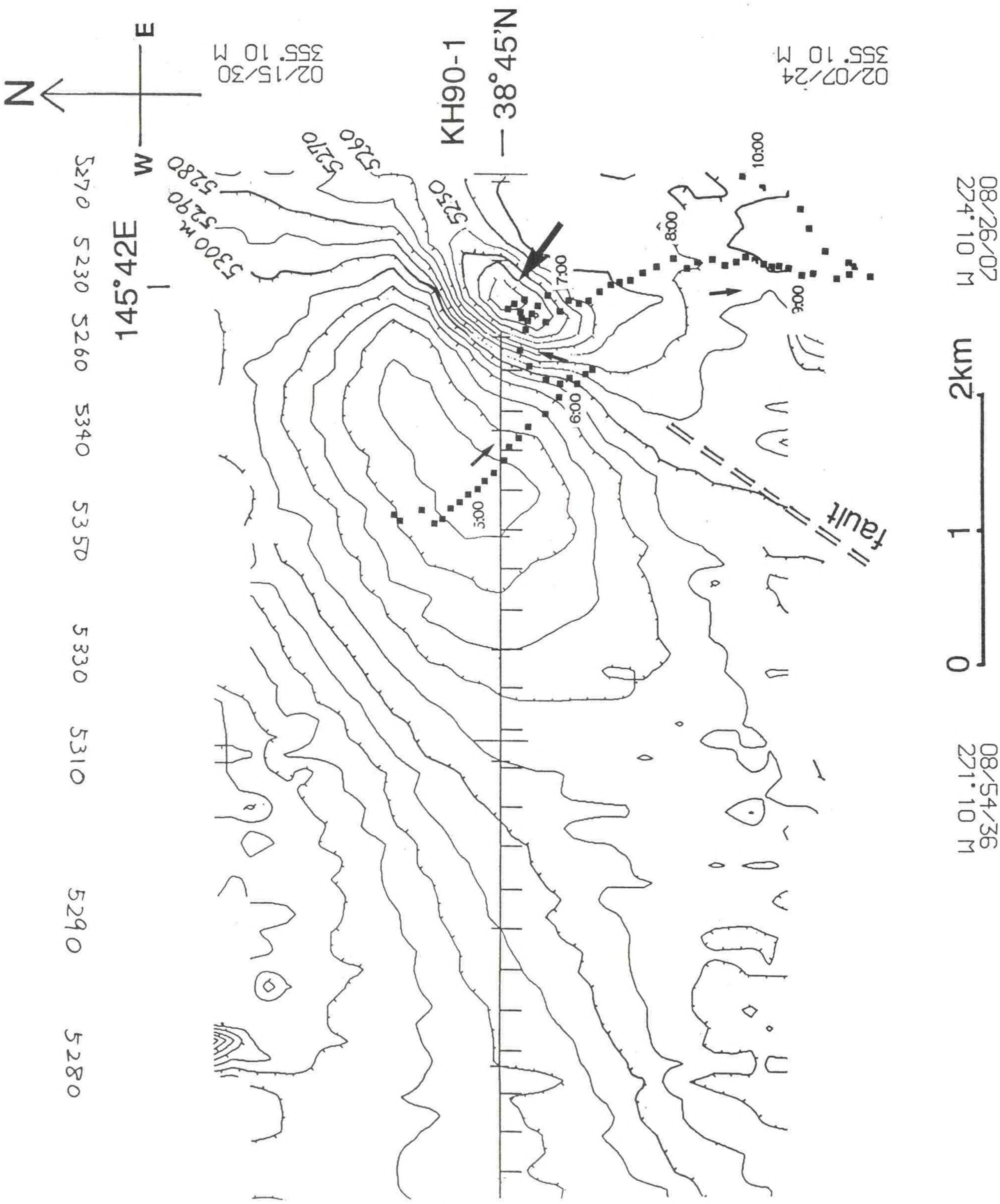


Fig. 10. Tracks of the underwater vehicle plotted on a bathymetric map of a mud diapir on the outer swell of the Japan Trench (denoted by dots). Numerical figures besides dot indicate time in GMT.

TV images and still camera photographs (Fig. 11) revealed that its bottom surface is composed of apparently semi-consolidated mudstone covered by thin soft mud of gray in color. Near the crest the bottom is more rough with boulders of a few cm to several tens cm in diameter. Color of their surface is dark probably encrusted with Mn-hydrooxides. No bivalves were found, although a number of benthic animals such as sea cucumbers, sea anemonea and some gastropods were observed. This observation seems to indicate that no active venting of deep interstitial water occurs. Diapirism appears to have occurred several thousands years ago.

The DESMOS was also used thereafter in a cruise KH90-3 at the Manus Basin, Bismarck Sea in the southwest Pacific. Hydrothermal ventings associated with chimneys of metal sulphides, plumes of methane and communities of benthic animals were found there by this instrument (Sakai, in press). Maneuverability of the underwater vehicle was particularly good in this cruise, since the sea was very calm during this operation without appreciable wind and current.

7. Summary and Perspectives

(1) A relatively handy deep-towed bottom observation system called "Deep-Sea Multi-Monitoring System (DESMOS) was built for the new research vessel Hakuho Maru completed in May 1, 1989.

(2) Insturuments contained in its underwater vehicle capable of observing the ocean bottom as deep as 6, 000 m include; (a) two high-quality color TV cameras with still camera in each, (b) four light bulbs with total 1,200 W, (c) a rotatable stage on which cameras and lamps are installed, (d) CTD sensor, (e) six water samplers operated separately by commands from the ship, (f) a clamp for a small tool released by a command, (g) Tiltometer and altimeter for vehicle

(3) Underwater vehicle is connected with the ship by a composite fiber-optical and electric cable with an outer diameter of 14.4 mm armored by steel wires to insure sufficient strength for towing the vehicle at maximum speed of 2~3 knots.

(4) Clear stereographic images of the bottom are continuously obtained in real-time basis in two TV screens and recorded in video tapes on board the ship.

(5) Total 1,600 still photographs can be taken either by commands from the ship or with a constant frequency pre-designated with the cameras.

(6) CTD data are displayed on a console in a laboratory. Other related data are also indicated on the console.

(7) Six indivisual water sampling and one release of a small device at desired spots can be commanded from the laboratory.

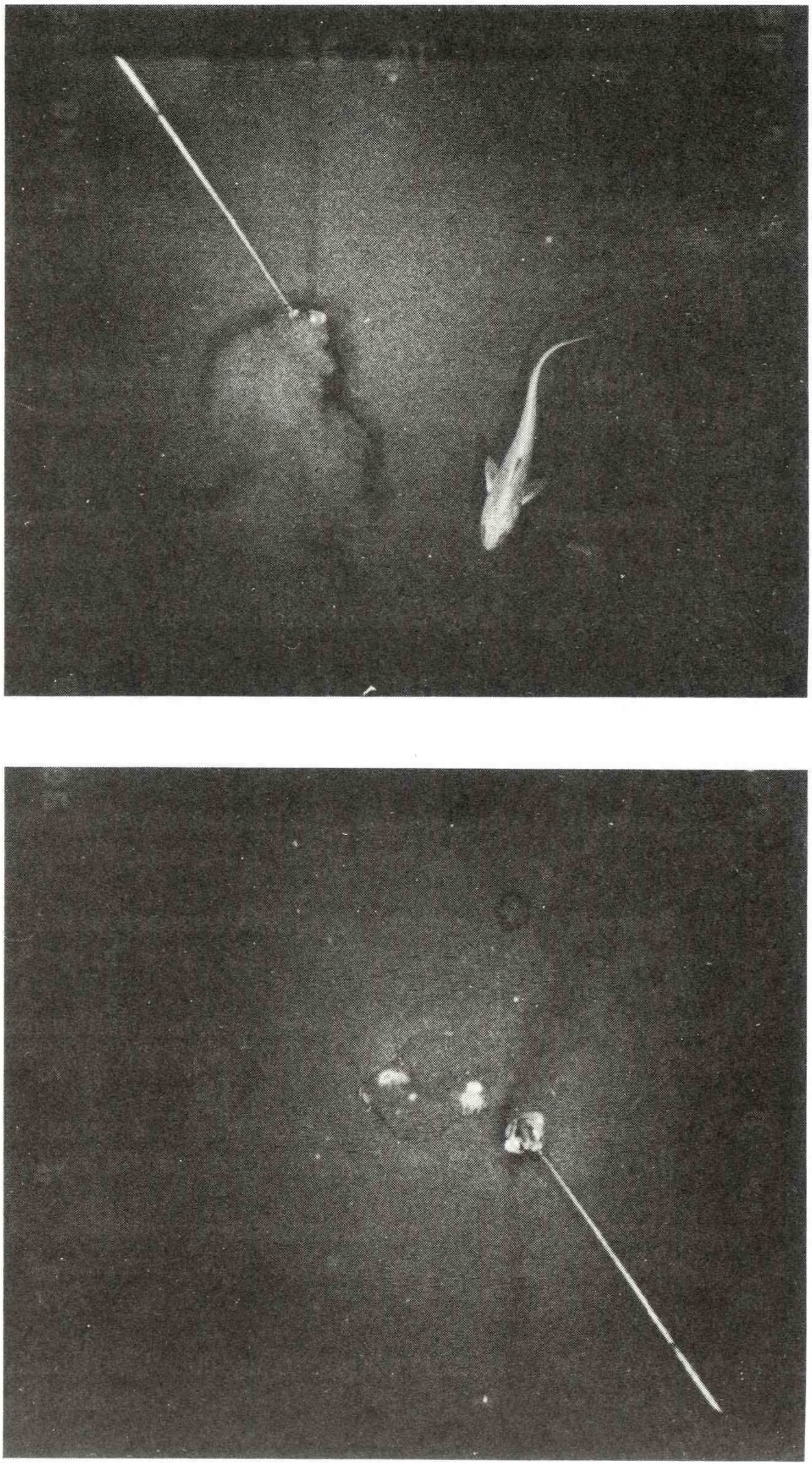
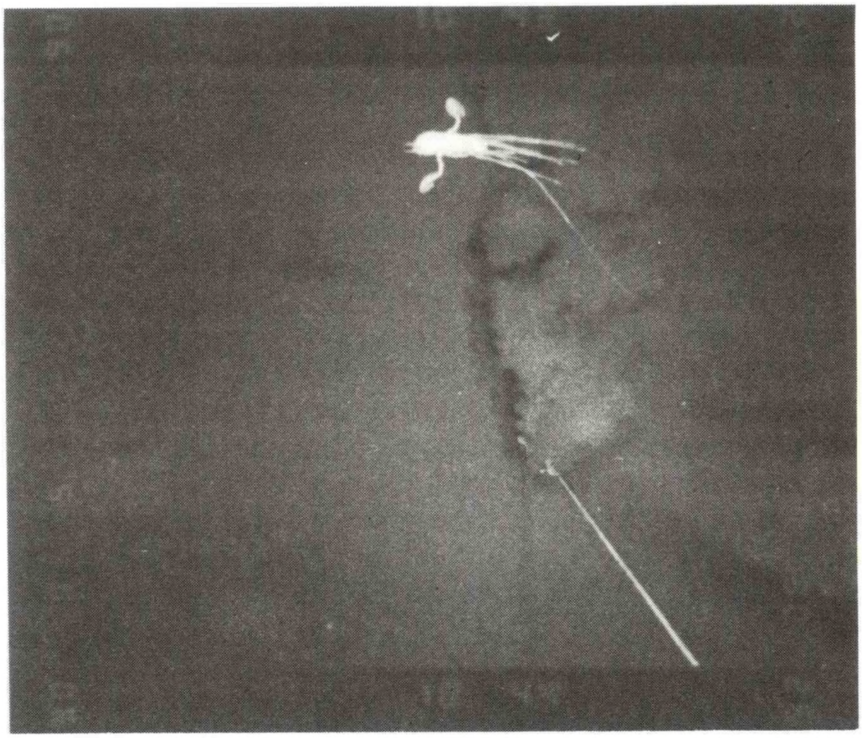


Fig.11-1. Muddy bottom with fish or bottom-dwelling animals photographed by DESMOS on the slope of mud diapir mound in the outer swell of the Japan Trench. [above]; D = 5,420 m at 07:40 GMT. [below]; D = 5,430 m at 08:48 GMT



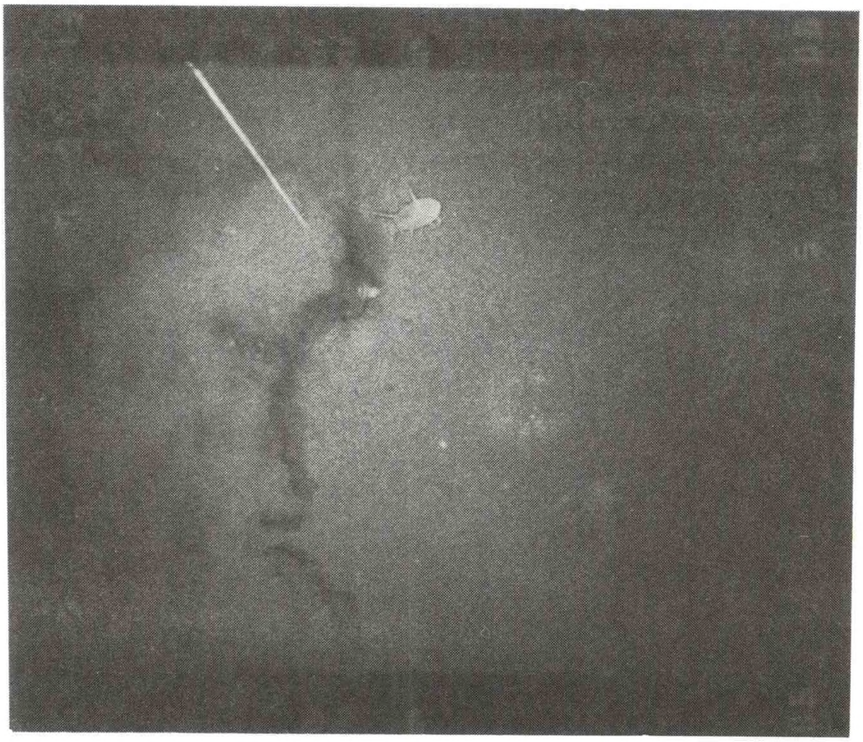


Fig.11-2. Muddy bottom with bottom-dwelling animals photographed by DESMOS on the slope of mud diapir mound in the outer swell of the Japan Trench.
[above]; D = 5,400 m at 07:30 GMT. [below]; D = 5,390 m at 07:09 GMT

(8) Winch can be operated in the laboratory while observing the bottom images. Necessary data of cables such as length, tension and winding speed are indicated on a console.

(9) The underwater vehicle has no own propulsion system. It is precisely maneuvered by winch and ship's motion.

(10) Three-dimensional position of the vehicle is determined by the SSBL system using a transponder attached to the vehicle.

(11) This DESMOS was properly operated at the Japan Trench walls as deep as 5,486 m and on a rugged slope of seamounts east off the trench.

This DESMOS will further be used to monitor the bottom features in an area and to find particular phenomena such as hydrothermal or cold ventings or to revisit ocean bottom observatories. At present existing problems on connection of cables and data transmission are still recognized but will soon be overcome without much difficulty.

Acknowledgements

The authors are very grateful to Mr. H. Ishisaki of OCC Co. and Mr. S. Seki of Tsurumi Seiki Co. for their technological effort on board leg 1 of the Hakuho Maru KH 90-1 cruise. We acknowledge officers and crew of the Hakuho Maru for their great help and excellent work in the shipboard operation of the DESMOS. Financial support of Monbusho (Ministry of Education, Science & Culture) of Japan to the construction and operation of this instrument is greatly appreciated.

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Mid-Ocean Ridge Systems: Submersible Science Requirements

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Oceanic ridges are a major component of the dynamic geologic system that forms, modifies and changes the surface of the earth. Research studies using detailed data from acoustic systems, underwater TV and camera systems, and research submersibles provide new perspectives on the complex and poorly understood special and temporal scales of tectonic and volcanic processes along ridge crests and transform faults. Requirements for research submersibles and other sophisticated underwater research vehicles and systems for integrated geological, chemical and biological studies are discussed. They include examination of a spectrum of representative sites including high and low temperature fluids, transform localities, and sedimented and unsedimented regions. In situ instrumentation for long-term measurements must be developed and deployed to understand the hydrothermal and dynamic processes of the system.

THE HURL INTEGRATED SHIPBOARD OCEAN FLOOR RESEARCH SYSTEM

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ABSTRACT

A shipboard research system capable of operating in waters of up to 2,000 m has been designed and implemented by the Hawaii Undersea Research Laboratory (HURL), University of Hawaii. It uses a remotely-operated ocean bottom survey camera system, ROV, bottom TV grab, the PISCES V submersible, and a submersible emergency recovery system aboard the 225-foot R/V KAIMIKAI. All systems are operated from the stern of the KAIMIKAI with a mounted Caley telearm and articulated A-frame system.

The system was designed for multi-purpose use of the telearm for launch and recovery of the PISCES V submersible on a lift recovery line (with or without diver assistance), or night-time operations with an electro-optical cable using either the HURL ocean floor sidescan, or photo and video system operated at 10 m above the ocean floor. The 1.14-inch diameter cable is also used to operate the RCV-150 garage/ROV system. The garage/ROV system has also been designed to act as a submersible rescue system with a submersible lift capability.

This integrated system approach to deep ocean floor research will make it possible for HURL to carry out research programs on seamount ocean resources and ocean chemistry and climate in the EEZ of Hawaii, the equatorial Pacific and the Guam/Northern Marianas area EEZ.

THE OCEAN RESOURCES RESEARCH PROGRAM OF THE HAWAII UNDERSEA RESEARCH LABORATORY

Introduction

The ocean covers 71% of the planet's surface. It has considerable capability to provide major amounts of resources to the growing human population, specifically in the areas of food, energy and mineral resources. However, before any of these resources can be efficiently extracted in a manner which is environmentally sound, they must be well understood. For this reason, NOAA has established a number of priority research areas in the realm of resource characterization and management. One of these areas focuses specifically on ocean lithosphere and mineral resources. The Hawaii Undersea Research Laboratory is an integral part of NOAA's undersea program and is designated as NOAA's National Undersea Research Center at the University of Hawaii.

The NOAA mineral resources research priorities include determining the distribution of potentially valuable mineral resources on the sea floor particularly within the U.S. EEZ and assessing the processes responsible for the formation of these mineral resources. In addition, considerable emphasis is placed on characterizing the impacts of the potential development of these ocean mineral resources. Within the context of the HURL program, the NOAA research goals are currently focused on American Flag Pacific Island EEZ locations that can be productively investigated with the PISCES V submersible, the ROV-150 and the shipboard cameras and shipboard sampling equipment. The program concentrates on the seamounts of the Hawaiian EEZ, Johnston Island, Guam and Northern Marianas EEZs.

On the seamounts within these four EEZs, the principal mineral resources are manganese crusts and polymetallic sulfides. Some isolated seamount manganese nodule deposits are present in association with crusts although in general the majority of nodule deposits are below submersible operating depths. Sand, gravel, clay and placer deposits are also present. However, in general they are too shallow to justify submersible operations. They are better investigated through the use of coring, divers or ROVs. Phosphorite deposits are also present but generally as infillings or substrates of manganese crusts. For these reasons, the HURL minerals program will concentrate on hydrothermal sulfides and manganese crusts in 1992.

The HURL Hydrothermal Sulfide Program

The sulfide part of the program focuses on the Northern Marianas and on Loihi Seamount. The Northern Marianas program and Loihi Seamount program are two of the four areas of concentration for 1992 HURL dive operations (the other two being the minerals program and seamount fisheries program). The Loihi work is focused on detailed mapping, chemistry of the vent waters and continuous monitoring through the use of a bottom station. Early work has identified extensive nontronite iron-rich clay and suggestions of sulfides at depth in the structure. Loihi is slowly but surely becoming a better understood system and may act as a model for other, analagous submarine and terrestrial deposits.

The Marianas program focuses on the active volcanic sites along the Mariana arc and back arc, particularly those sites to the north of the main inhabited islands. The main focus of the work will be on hydrothermal areas, areas of known seismic activity and the hydrothermally enriched vent waters emanating from these areas. This work will result in the better understanding of the submarine arc and back-arc basins, their development and their relationship to the overall forces shaping ocean basins. For 1992, there will not be a hydrothermal sulfide program beyond the Loihi and Northern Marianas programs.

The HURL Manganese Crust Program

The largest part of the HURL marine minerals program is the manganese crust work. This work will concentrate on several seamounts and plateau areas primarily in the Hawaiian and Johnston Island EEZs. In order to address the NOAA mission, one of the major foci of the crust work will be the detailed mapping of promising deposits. Such mapping involves a range of submersible activities.

A question of considerable significance that has only begun to be explored is that of crust continuum. Whether the crust is continuous and can be correlated from one seamount to the next and from one side of a seamount to the other is very important in terms of the potential extractability of this resource. As part of this investigation, the role of mass wasting becomes very significant. Several of the seamounts investigated to date, particularly Cross and Loihi seamounts, show significant areas of mass wasting. Mass wasting may remove any crust formed in this environment. It can also concentrate crust deposits in debris piles at the bottom of slopes. This will necessitate a revision in the possibilities for mining equipment design. One project currently underway which is taking advantage of this possibility is an in situ leaching technique which would not require mechanical ripping of the crust but would rather extract the valuable metals with an acid leach in a tent on the sea floor.

To further the goal of assessment of crust continuity a series of stratigraphic markers are needed in the crust. To date the most promising prospects for this are enrichments in phosphorite and platinum group elements particularly platinum. It appears from the initial research that the platinum is enriched in at least two very distinct and widespread layers. The ongoing research will need to collect carefully oriented sample sets and measure the amount and disposition of the platinum concentration. These samples will be used for correlation between geographic areas as well as between metals in the platinum group. The platinum-rich layers and associated iridium anomalies may be recording the influx of cosmogenic material, perhaps from the impact of meteorites. The phosphorite-rich layers are indicating a major change in ocean chemistry. This means that the crusts are serving as recorders of paleoceanography, compressed into a scale covering much more time than we could expect to see in a core and `averaging out' minor trends through their slow growth rate. Manganese crusts have the potential to be another major tool in the investigation of paleoceanography. As part of this work a greater effort needs to be made to accurately date the crusts and their various layers. The key to this is well oriented samples collected from very well known locations. The capacity to take these samples is the major contribution of the submersible.

To further this capacity, equipment is being designed and tested to allow the submersible to cut manganese crust samples off the bottom. Such specially designed tools would first need to be tested on land, later on relevant dives to a manganese rich area. In addition to quantifying the stratigraphic properties of the crust and their continuity, the samples cut by such equipment could be used for the testing of engineering properties such as hardness, shear strength and resistance to cutting. The data gathered from these samples would be used to optimize the design of potential crust mining equipment.

One of the major problems faced by the current group of crust mining equipment designs is that they are very subject to the problems of roughness on a microtopographic scale. Microtopography is a critical parameter in the design of any mining equipment. This is a major focus of any site specific investigation. The techniques for making microtopographic analysis by submersible is an important technique. This includes the spacing of stereo cameras and the ability to cover given areas of terrain in a systematic way. With any proposed mining work the environmental questions are clearly of major significance. Important questions that need to be answered include the recolonization of mined areas as well as the mortality induced on benthic organisms by mining activities. There is a question as to whether larvae of benthic organisms in fact avoid manganese crusts. The recruitment of benthic organisms is not well understood but is certainly important if communities are put under stress by mining operations. The underwater mapping of benthic communities is critical data to any EIS work.

It would be desirable to have the submersible work in conjunction with the major mining evaluation of an area that has considerable crust potential. Such an area is that south of Johnston Island. This area has been proposed as the site of a joint U.S.-Japanese test of the continuous line bucket mining system in 1992. In conjunction with this test, it is highly desirable to evaluate the mining test area by submersible. This would include both an assessment of the amount of crust present as well as the amount recovered by the miner. Further, the degree of damage to the benthic environment in the direct path of the miner as well as to the sides of the mined area could be assessed. The efficiency of the entire operation can be quantified. Through careful survey of the affected site both before and at several time intervals after the mining test a detailed picture could be developed of the expected results of mining. Long-term experiments are planned to quantify the speed and type of recolonization. By careful control, impacted areas could be paired with non-impacted areas for quantitative assessment.

Planned work on Johnston Island includes detailed mapping work to assess the continuity of the crusts, sampling work to test out new pieces of gear, collection of microtopographic and other engineering data as well as benthic biological data. Data and samples collected could be analyzed for clues as to the exact processes of metals incorporation into the crusts and minerals formation in general.

The HURL minerals program focuses on manganese crusts and sulfides. The sulfide work will take place in conjunction with the projected Loihi and Northern Marianas programs. The crust work will focus on those areas where submersible utilization is the most efficient. This will include the taking of oriented samples, detailed mapping of small features, the collection of oriented samples for the analysis of crust continuum and stratigraphic horizons, the testing of engineering materials properties and real time tests of bottom equipment. The HURL marine minerals program directly addresses NOAA's national ocean resource goals and attempt to provide the background for wise decisions about future marine minerals developments based on a thorough understanding of the marine benthic environment and the processes of marine minerals formation and metals enrichment.

The HURL Seamount Biological Resources Program

Pacific Seamounts and islands, especially those located in the Hawaiian and Northern Marianas sections of the EEZ, are sites of extensive benthic and pelagic communities. These communities include precious (pink) as well as soft corals and several diverse species of fish that use the upwelled nutrient-rich water around the seamounts as a basic food source. Very little is known about these communities or about how the communities have been affected by both legal and illegal fishing and coral dredging. The faunal interaction in these environments are poorly known. With the use of PISCES V and the ROV RCV 150, we are preparing to mount a major expedition aboard the new support vessel R.V. Kaimikai-O-Kanaloa to Hancock Seamount in 1992. Areas of the Hawaiian EEZ such as Hancock have been inaccessible to date because of our lack of a suitable support vessel.

DESIGN PHILOSOPHY FOR THE DEDICATED OCEAN FLOOR RESEARCH VESSEL

In order to accomplish the HURL programmatic goals, a HURL ship design team developed the following criteria. It will be 220 feet in length, carry a crew of 13, and will have facilities for 17 scientists and technicians. The ship will have A-frame launch capability, wet and dry labs, rock preparation, and photographic processing facilities.

Twin screws and a bow thruster will give the vessel the required maneuverability. The vessel is planned to operate at a cost of around $10,000 per day. In order to minimize fuel consumption, an SCR diesel-electric propulsion plant is required. The submersible (PISCES V) and ROV (RCV-150) launching deck is designed to have a freeboard of two meters. A compromise freeboard height between proximity to the ocean surface and a dry deck. The plan called for the conversion of a pre-existing vessel for the submersible and ROV mothership as the most cost-effective way of accomplishing these goals.

After a lengthy nationwide search, HURL selected the hull of a seismic supply vessel, the R/V WESTERN STRAIT. This 180-foot supply vessel, U.S.-built in 1979, is is ideal for conversion. Although built on an offshore supply vessel design, the vessel never had mud and chemical tanks installed and was never used in the hull-damaging shore-to-rig transport mode. The diesel-electric power plant is ideal for slow but efficient operation.

Upon thorough examination of the vessel, we found the hull and the diesel-electric power plant to be in very sound order. The vessel is currently being prepared for conversion, including the addition of a 40-foot length mid-body. The new vessel will be renamed the R/V KAIMIKAI-O-KANALOA (Fig. 1).

OPERATIONS DESIGN OF THE R/V KAIMIKAI-O-KANALOA

This vessel will be a mothership for submersibles and ROVs operated by the Hawaii Undersea Research Laboratory. The converted vessel will be designed to accommodate 30 persons and be able to remain at sea for up to 50 days, operating in all oceans throughout the world. Limits on the vessel's maximum speed capability will be balanced with economy in operational costs. It will be outfitted to make the best possible SOA while consuming no more than 2400 gallons per day at a sustained cruising speed.

In order to maximize the use of the vessel and to increase the research productivity of the program, nighttime operations will be conducted with the RCV-150 ROV and ocean bottom photo-imaging. The RCV-150 can be lowered by cable to the ocean floor. It is equipped with manipulators and is therefore, capable of a variety of instrumented observations. The RCV-150 will enable us to effectively double our productivity while also serving as a standby submersible rescue vehicle.

The length of the mothership will be 220 feet. It will be named the R/V KAIMIKAI-O-KANALOA. It will have a breadth of approximately 40 feet, with a minimum freeboard of approximately 6.5 feet (Fig. 1). A high bow will facilitate operation in rough seas as will motion compensation in the form of anti-roll tanks. The superstructure will be far enough forward to allow for a backdeck. The after 50-feet will be open and clear. The forward 30-feet of the backdeck should be protected space (i.e., hanger area) to shelter the submersible for maintenance work while underway. The wings of the hanger area will be used for office space and/or spare parts storage. The submersible will be moved from the hanger to the open deck on a track system.

A 30-ton hydraulically-operated crane will be mounted forward on the open deck to permit moving the submersible between the ship and shore. Between stations, the PISCES V will be hoisted by a motion compensated handling system located at the top of a movable A-Frame. The A-frame will be located on the stern. The submersible is lifted off of the main deck, extended over the stern and lowered to the ocean surface. Important to these operations is the height of the main aft deck above the ocean surface, low enough for safety and ease during the launch and retrieval, yet high enough to remain relatively dry in moderate to rough seas. Experience has shown that a freeboard of approximately 2 meters is optimal.

Dual stack(s) will be located forward of the hanger area, high enough to insure that stack gases will remain well clear of the afterdeck area. A bow thruster is installed. The ship will have maneuvering stations in the pilothouse, on both wings, and in an after steering station. Either co-located within the after steering station or in a separate after station will be controls for the A-frame and for a below-the-deck winch. One or more small articulating cranes will be available to facilitate handling stores and other equipment, gangway, etc. The ship will be air conditioned and heated throughout. Working and living spaces will have thermostats in order to control temperature within that space. The air conditioning system will include dehumidification, which can be selected for when operating in high-humidity areas.

The ship will be built for ease of maintenance. For instance, overhead panelings shall be drop type or quick release vice screw-in panels. As much as possible, electrical wiring, piping, etc. shall be run internally. It will be highly desirable to keep the vessel under 300 registered tons, and the ship will be delivered in class (ABS) for hull and machinery. Inclining tests will be accomplished and a stability booklet provided. The vessel shall be provided with a loadline.

Plans for support ship conversion have been drawn up by Rodney E. Lay & Associates, Naval Architects. All the ship's laboratories, submersible hanger, interior and staterooms are designed according to similar conversions undertaken by the Harbor Branch submersible support vessels, R/V SEAWARD JOHNSON and the R/V EDWIN LINK. A considerable cost savings on this project was realized by planning to equip the interior of the vessel with catalogue order items, thus minimizing any custom work to be done during the conversion period.

A 25-year life span is anticipated for the R/V KAIMIKAI-O-KANALOA. Yard completion is projected for June of 1992 and operations in Hawaii are being planned for December of 1992 with the new vessel.

Offshore supply and seismic survey vessels of length greater than 180 feet make ideal candidates for conversion to dedicated submersible/ROV research vessels. A length of 220 feet makes an ideal compromise between sea-kindness and the ability to keep the vessel under 300 registered tons.

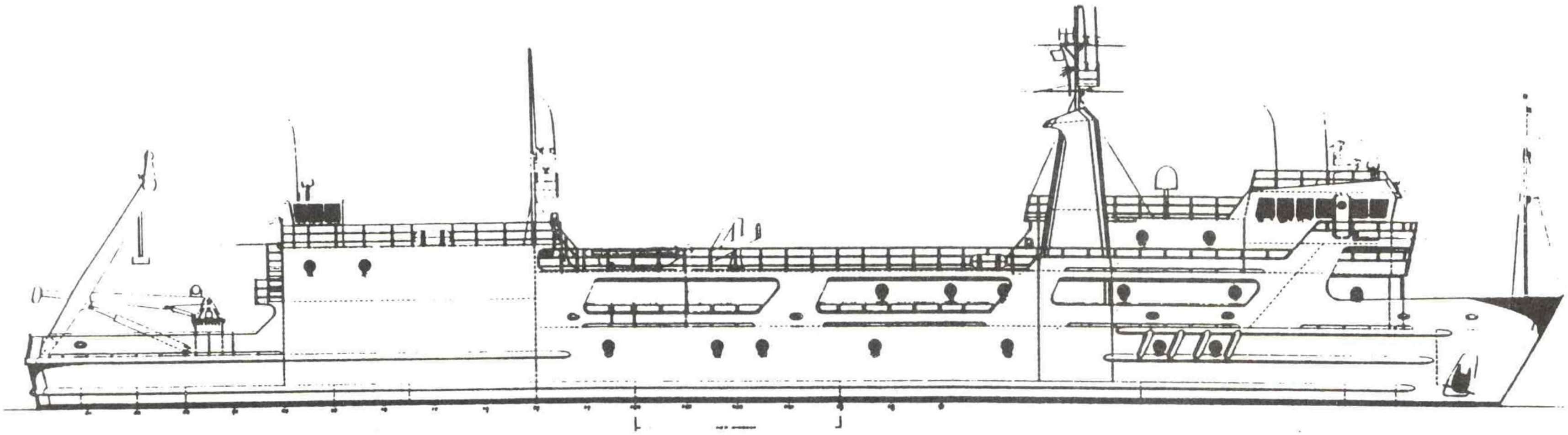
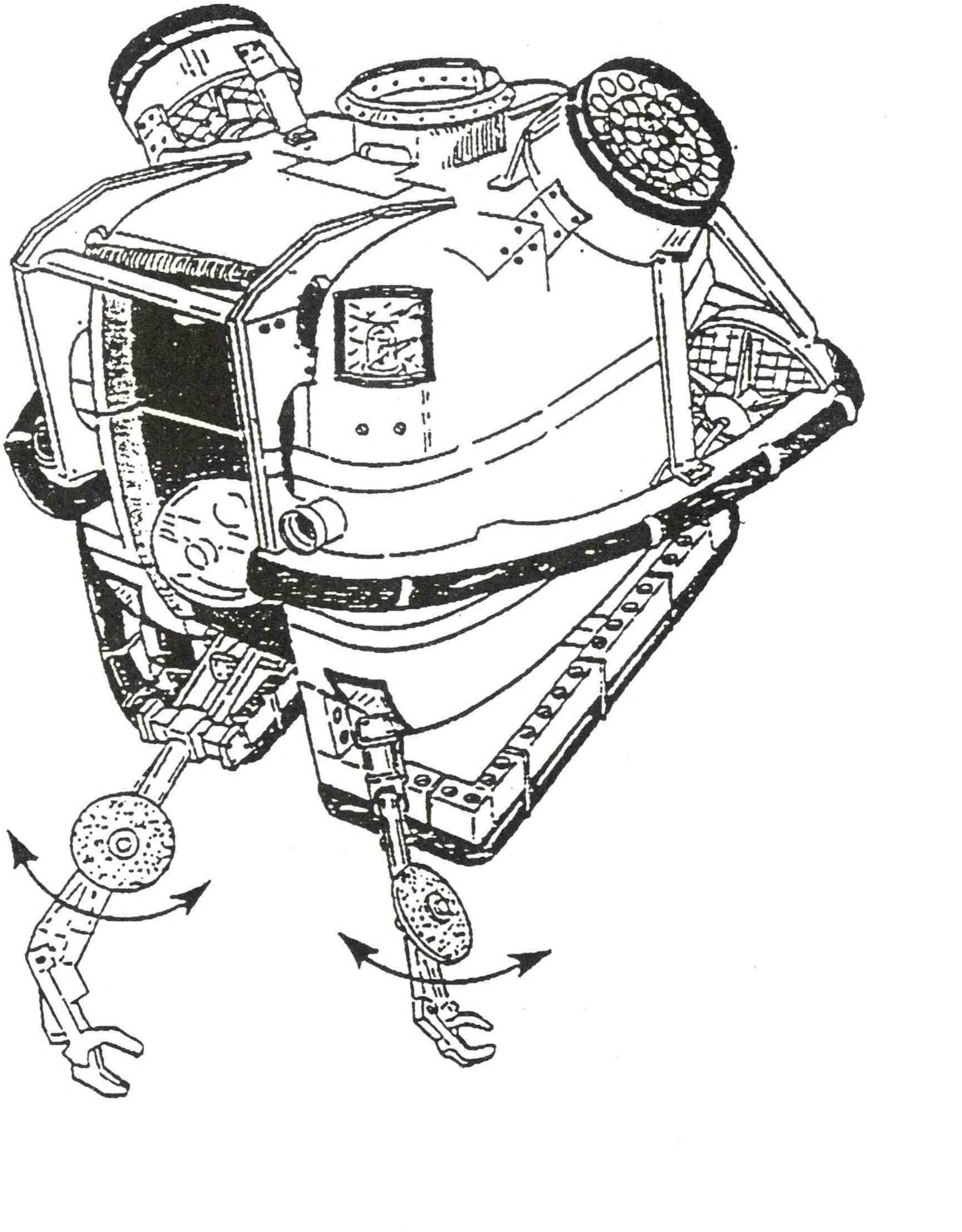
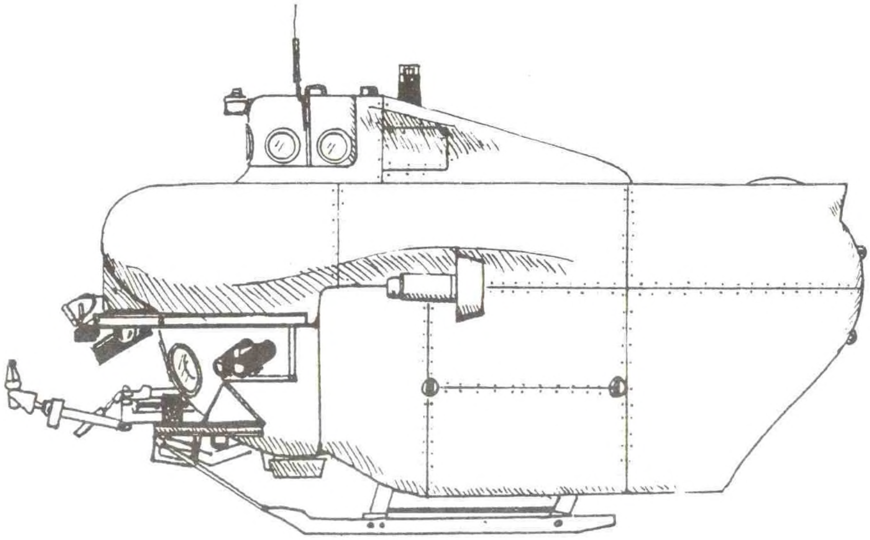


Figure 1. Profile of the Hawaii Undersea Research Laboratory's new submersible/ROV support vessel, the R/V KAIMIKAI-O-KANALOA.



RCV 150 2nd MANIPULATOR OPTION ASSEMBLY



P5
DEEP OBSERVATION SUBMERSIBLE

SPECIFICATIONS
General Data
Length: 20'
Width: 10'6"
Height: 11'
Weight: 12 tons
Payload: 600 lbs.
Crew: 1 Pilot 2 Observers
Life Support: 140 hours for 3 people
Max. Operating Depth: 6,280 ft.
Power: Two lead-acid battery systems:
  120 VDC at 330 Ah capacity
  12 - 24 VDC at 220 Ah capacity
Propulsion: Two side mounted reversible thrusters tiltable through 90°.
Speed: 2 Kts.
Duration: 6-8 hours

CONSTRUCTION
Builder: International Hydrodynamics of Vancouver, British Columbia
  Classed by American Bureau of Shipping
Materials: Personnel sphere, Trim sphere, and Aft sphere: HY 100 steel
  Frame: Welded, oil-filled, pressure compensated tubular steel.
Viewports: 3 forward looking acrylic windows, 6" diameter.
Penetrators: 316 SS inserts to pass electrical, hydraulic, air, and oxygen supplies through the hull.

LIFE SUPPORT
Oxygen and CO_2 absorbent for daily use is sufficient for twice normal mission duration. Independent emergency supplies available for 120 hours for 3 people. Full face air masks available in case of cabin air contamination.

SYSTEM
Buoyancy Control
Soft ballast tanks displace a total of 1904 lbs. using H.P. air. Dropable descent/ascent weights. Hard ballast tanks and hydraulically powered seawater pump give 450 lbs. of trim adjustment.

H.P. Air
Carried in 8 externally mounted cylinders with a total capacity of 890 scf at 3000 psi. Used for ballast system and emergency breathing apparatus.

Oxygen
Two 20 Liter cylinders available for daily use. Independent emergency supply located in aft sphere has a capacity of 454 cu. ft. at 2640 psi.

Ventilation
Cabin atmosphere is monitored by oxygen and CO_2 analyzers. Oxygen level is maintained by constant flow. CO_2 is removed by electrically powered scrubber unit and grandular CO_2 absorbent material.

Hydraulic System
Electric pump and solenoids provide 4 gallons per minute at 200 psi to the following equipment:
- Manipulator
- Basket lift
- Ascent/Desend weight drop cyclinders
- Thruster tilt
- Battery box movement
- Camera pan and tilt
- Spares and special equipment

Controls and Instrumentation
The pilot has available all controls necessary for the operation of all submersible systems in both normal and emergency situations including thruster controls, buoyancy controls and indicators, battery condition instruments, depth and pressure gauges, magnetic compass, life support monitoring instruments and controls, radio and under-water telephone

EQUIPMENT
The submersible is equipped with the following items and can be configured as necessary to accomodate a variety of mission requirements.
- Osprey TVP video & photographic camera
- Hydraulically operated manipulator
- General purpose science basket
- Seabird Electronics Seacat CTD profiler
- Wesmar SS 146 sonar
- EDO Western Micro-Navtrack ultra-short baseline acoustic tracking system.
- External lights
- Externally mounted thermistors - internal meters
- Pinger locating system

SAFETY FEATURES
Jettison Equipment:
  1 man dropweight at 400 lbs.
  2 fwd dropweights totaling 300 lbs.
  Manipulator claw at 30 lbs.
  2 thrusters totaling 238 lbs.
Extended life support capacity.
Salt water leak detectors in battery boxes and aft sphere.
Acoustic tracking/locating system.
Strobe light for locating on surface.
Smoke flares.
Emergency breathing system.
Fairings to prevent fouling of external equipment.

Cooperative UJNR Submersible Science Programs

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The UJNR Panel on Diving Physiology and Technology has provided a successful mechanism for United States and Japanese scientists to work together in the area of deep sea research. This has largely been due to conducting cooperative submersible diving missions in the Japanese SHINKAI 2000 and SHNIKAI 6500. Over the past several years, the Japan Marine Science and Technology Center (JAMSTEC) has made available to NOAA dive days in these submersibles. NOAA in turn has issued a request for proposals to the United States submersible science community for the use of these submarine dives. The proposals are then reviewed and the best science programs are then recommended to JAMSTEC. If the NOAA endorsed science program meets the operational requirements of the JAMSTEC submersibles and is compatible with JAMSTEC's own science mission, the research is carried out. This system has worked well, allowing both U.S. and Japanese scientific considerations to be made and a fair and open solicitation to the U.S. scientific community.

The cooperative UJNR submersible science program has grown to the point where, at this 1991 Panel meeting, a special session was convened to identify the future deep sea science needs to be addressed by the Panel's activity. From this very successful session, represented in these proceedings, a number of different science themes were identified. As a result of this meeting and the plans of JAMSTEC's deep sea research group, the 1992 UJNR cooperative diving activity will be called "Izu-Maria" and is part of a larger JAMSTEC study called TRANSARC. These programs will address multi-disciplinary studies in the trenches and arcs on the seafloor; the 1992 UJNR program is focused in the Izu-Mariana region around Japan.

As submersible use became more common for scientific investigations over the past 20 years, the UJNR panel has provided one of the best mechanisms for the United States and Japan to work effectively together with these tools. It is anticipated that this fruitful cooperation will continue to grow and expand in future years.

INFORMATION

HUMAN-TECHNOLOGY INTEGRATION AS APPLIED TO ADVANCED DIVING SYSTEMS

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ABSTRACT

In the past, semi-closed and closed circuit diving systems have been designed that met the physiological requirements (sometimes minimally) of the diver. They did not, however, give much credence to the user's other needs, ie., comfort, maintenance, etc. This is understandable since the user population for such systems was extremely small, primarily military with larger budgets than the private or academic sectors. Along with this, the currently issued units were designed in the early 1970's with modifications to the center section and electronics. These modifications were not based on human factors principles, merely one physiological aspect.

With the current levels of technology, there is no question that human-technology integration can in fact be quite feasible without adding extra expenditure to the budget. Delta P and R.L. Fox and Associates had been tasked by the W.E.D. Research and Development group to design a semi-closed diving system with a helmet that uses various technologies such as a helmet mounted display, eye phones, etc. At the same time, these two companies were involved with the design of a fully closed diving system for Sea Survey, a diving services company in Cambridge, England.

In both designs, off-the-shelf, easily maintained components were chosen as often as possible. This included such items as disposable canister and standard oxygen sensors. Along with this, an electronics package for the closed system was developed to support such elements as dive computer, oxygen partial pressure, data logging for various environmental variables, PC downloading, etc.

INTRODUCTION

Since 1982, Sea Survey,PLC (previously Carmellan Research, Ltd.) has been actively involved in both commercial and scientific diving operations with the use of closed circuit diving systems. As a result of the test and evaluation of several diving systems, Sea Survey selected the SeaPak 155 by Biomarine Industries. The reason for this decision was simply that it was the "least of all evils"; essentially, none of the systems available were considered commercially acceptable, but since these were all that were on the market, these were the choices. The reason for the discussed project was to meet the needs of Sea Survey, ie., a closed circuit diving system that required little maintenance, readily available parts, rechargeable batteries, etc..

Periodically, the Walt Disney World Company will carry out surveys of the guests so as to determine their current feelings. In 1989, the most common criticism of the pavilion The Living Seas was the simple fact that it was supposed to be representing a futuristic undersea community, and the divers were using traditional sport diving equipment that was commonly seen in any dive store. With this in mind, The Walt Disney World Company decided to develop a system that would be:1. unique to the Living Seas, 2. very functional and would be applicable to daily regimens of the divers, 3. would either be "cutting edge" technology, or at least apply current technologies that were not integrated into the diving community, and 4. easily adaptable to future designs, ie. a mask with a helmet mounted display (HMD), communications, video phones, etc.. After lengthy discussions with the Living Seas, a semi-closed circuit diving system was selected for the following reasons:1. considerably less costly than a closed system, 2. simplicity in use, and 3. extremely low maintenance.

APPROACH TO DESIGNS

The contract for the design of the Living Seas' semi-closed diving system was awarded to Delta P, with R.L. Fox and Associates specified as the subcontractor. Delta P was responsible for the human factors and project management with R.L. Fox and Associates providing the engineering. Since the two individuals, Rick Fox and the author, were currently involved in the design of the Sea Survey closed diving system, it was decided to incorporate as much of the same concepts as possible in both. The reason for this was primarily that we felt we were taking the most practical and applied approach to the Sea Survey unit, and this was essentially what the Living Seas' determined they wanted in their semi-closed system.

Initially, we evaluated the various components of the systems to determine which aspects could be redesigned using much readily available components and, at the same time, applying current technology where possible. It was determined that the elements to incorporate significant changes were:

1. Utilize disposable, prepacked absorbent,
2. Replace the battery pack with a rechargeable system,
3. Completely redesign the electronics pack with current technology, and
4. Incorporate a buoyancy system for the diver.

Only items #1 and 4 were applicable to the semi-closed system.

Secondly, we needed to evaluate other critical components and select manufacturing sources that could provide elements that could be used internationally. Essentially the only item we found to fall into this category was the cylinders; in the United Kingdom, oxygen was not permitted to be stored in aluminum cylinders.

DESIGN PHASE

Once the design phase began, this was where the two projects essentially split. Due to the complexity of the closed system coupled with the uniqueness of the Living Seas' project, we decided to handle each independently. We did find, however, that certain elements needed to be combined during decision making since those elements had a great deal in common; for example, the intention of future use of a full-face mask with communications and HMD.

One of the most critical components of any closed or semi-closed system is the carbon dioxide scrubbing capability. In both of the designs, it was decided to use disposable, prepacked canisters. For the semi-closed system, an agreement was developed with Molecular Products of Essex, England so as to pack their canister for anesthesia use with high-performance diving sodasorb (Molecular Products, 1990). For the larger canister for the totally closed unit, a design for a disposable canister will developed. Presently, the "traditional" radial flow design will be followed. The intent is to wait for an evaluation of the various types of flow patterns and current designs before making a final decision. This evaluation will be taking place at the NASA Ames Research Center's Life Support Division over the next year (personal communication, B. Webbon, NASA/Ames Research Center, 1991). This testing will examine the radial, axial, and cross-flow designs. We will review their findings and proceed accordingly.

The environmental parameters that we had to design for regarding the Living Seas' system were very straight forward. We were provided with a specific time duration, constant water temperature, low energy expenditure, constant luminance, specific buoyancy needs, etc.. The closed system needed to meet the needs of a wide range of water temperatures, high energy expenditure, etc.. Since both systems required a buoyancy compensator, but possessed significantly differing working conditions, a decision was made to use totally different designs. The Living Seas required that as little as possible be visible on the diver's anterior plane; essentially, they only wanted to see the securing system. At this point it was decided to incorporate a "horseshoe-shaped" bag inside the casing since the Living Seas only required ten pounds of lift. Along with this, a modification of the "Hawaiian Pak" design appeared to be the most applicable. Due to the variety of situations that Sea Survey would be involved in, an external, jacket-type buoyancy system was selected.

The electronics package is one of the most critical components of the closed system. The plan was to contract with an existing company with experience in underwater computerized control systems. Quatek in Cambridge, England was decided upon since it had a history of developing dependable dive computers in Europe. Essentially, we needed a system that would not only control the oxygen partial pressure and solenoid valves, but would also provide an incorporate system for data logging, PC downloading, and graphic analysis of individual oxygen sensor efficiency, temperature, dive computer support, etc. These elements have been designed into a single wrist mounted unit with scrolling capabilities to access all pertinent data. The initial display was designed based upon the works of Vaughn and Kinney (Vaughn and Kinney, 1980 and 1981). This was followed by various tests carried out by Delta P in order to verify the effectiveness of the display. These variables used in the tests included varying luminance and turbidity. One area of concern was the cable that was being used to connect the display unit with the electronics pack. Due to a number of problems regarding the strength of the cable and the connection points, a larger-than-desired cable was selected in order to assure the resolution of the problems.

SUMMARY

As of this date, the semi-closed system's design is completed and the prototype is assembled except for the cover. The closed system electronics is completed, and the design will be completed in approximately four weeks. As of this writing, the manned and unmanned test and evaluation will take place in mid-November. The unmanned and manned testing will take place at the Royal Naval Facility in Alverstoke, England and the Diving Diseases Research Center in Plymouth, England, respectively. We feel that the units that have been designed meet the criteria that was established from the beginning. As in any endeavor, modifications and compromises were necessary in order to accomplish the tasks. The best thing that can be said about these units are that since the designers are also individuals that currently work in diving operations, said units have met our needs. Various elements have been tested in the field and have met or exceeded the expectations.

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