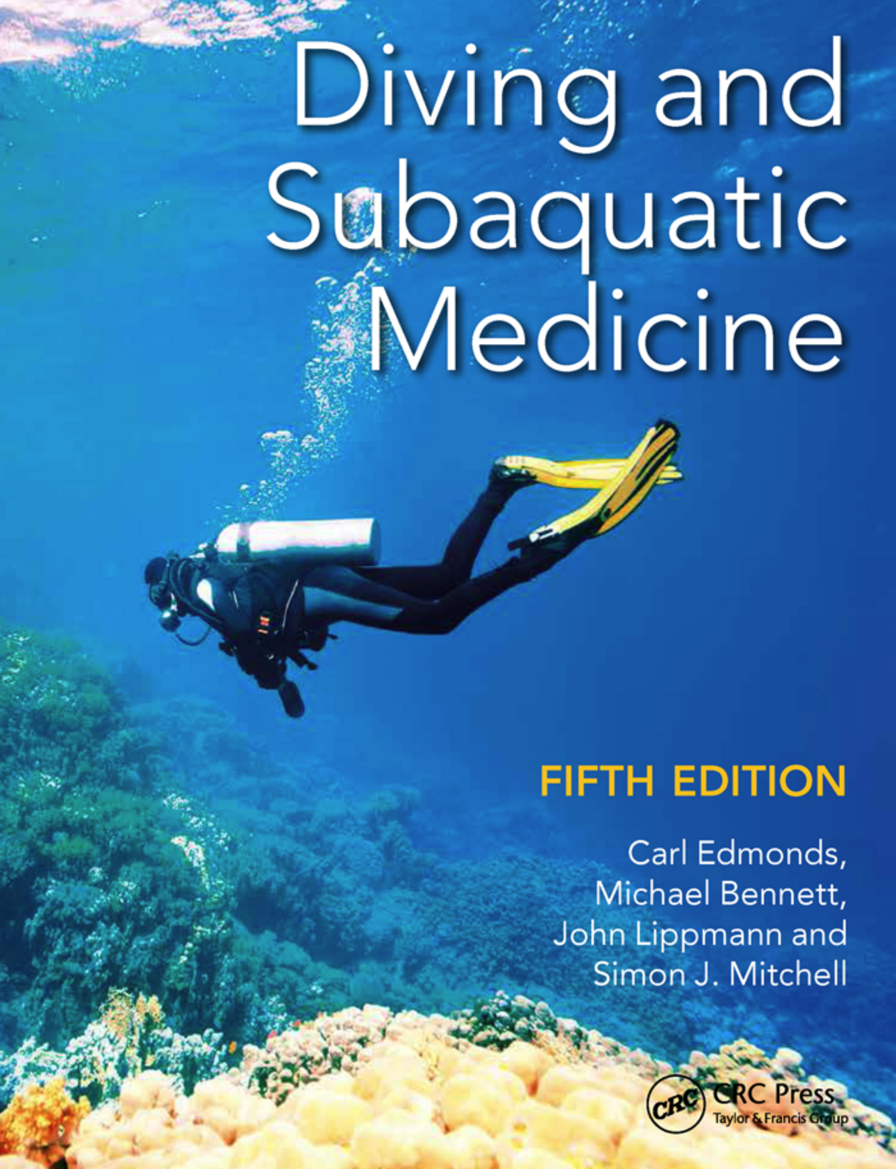

Diving and Subaquatic Medicine

FIFTH EDITION

Carl Edmonds,
Michael Bennett,
John Lippmann and
Simon J. Mitchell

CRC Press
Taylor & Francis Group

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Contents

List of abbreviations

ADS	atmospheric diving suit
ADV	automatic diluent valve
AGE	arterial gas embolism
ALS	advanced life support
ARDS	acute respiratory distress syndrome
ATA	atmosphere absolute
ATG	atmosphere gauge
BCD	buoyancy compensator device
BLS	basic life support
BOV	bail-out valve
BSAC	British Sub-Aqua Club
CAD	coronary artery disease
CAGE	cerebral arterial gas embolism
CCR	closed-circuit rebreather
CMF	constant mass flow
CPAP	continuous positive airway pressure
CPR	cardiopulmonary resuscitation
CSF	cerebrospinal fluid
CSL	Commonwealth Serum Laboratories
DAN	Divers Alert Network
dB	decibel
DCI	decompression illness
DCIEM	(Canadian) Defence and Civil Institute of Environmental Medicine
DCS	decompression sickness
DDC	deck decompression chamber
DPV	diver propulsion vehicle
EAD	equivalent air depth
ECC	external cardiac compression
ECG	electrocardiogram
ECMO	extracorporeal membrane oxygenation
ECoG	electrocochleography
EEG	electroencephalogram
ENG	electronystagmography
EPIRB	electronic position-indicating radio beacon
FEV_1	forced expiratory volume in 1 second
FIO_2	fraction of inspired oxygen
FVC	forced vital capacity
HBOT	hyperbaric oxygen therapy
HPNA	high-pressure neurological syndrome
IBCD	isobaric counterdiffusion
ICP	intracranial pressure
IDDM	insulin-dependent diabetes mellitus
ILCOR	International Liaison Committee on Resuscitation
IPE	immersion pulmonary oedema
IPPV	intermittent positive pressure ventilation
ISO	International Organization for Standardization
lpm	litres per minute
MOD	maximum operating depth
msw	metres of sea water
NEDU	Navy Experimental Diving Unit
NOAA	National Oceanic and Atmospheric Administration
NUADC	National Underwater Accident Data Centre
OPV	over-pressure valve
$PaCO_2$	alveolar pressure of carbon dioxide
$PaCO_2$	arterial pressure of carbon dioxide
PADI	Professional Association of Diving Instructors
PaO_2	alveolar partial pressure of oxygen
PaO_2	arterial partial pressure of oxygen
PCO_2	partial pressure of carbon dioxide
PEEP	positive end-expiratory pressure
PEF	peak expiratory flow
PFO	patent foramen ovale
$PICO_2$	inspired partial pressure of carbon dioxide

PIO_2	inspired partial pressure of oxygen
PMCT	post-mortem computed tomography
PMDA	post-mortem decompression artefact
PMV	pressure maintaining valve
PN_2	partial pressure of nitrogen
PO_2	partial pressure of oxygen
PPV	positive pressure ventilation
RAN	Royal Australian Navy
RCC	recompression chamber
RGBM	reduced gradient bubble model
RMV	residual minute volume (also respiratory minute volume)
SCR	semi-closed-circuit rebreather
scuba	self-contained underwater breathing apparatus
SDPE	scuba divers' pulmonary oedema
SMB	surface marker buoy
SPUM	South Pacific Underwater Medicine Society
SSBA	surface-supply breathing apparatus
SWAS	salt water aspiration syndrome
UHMS	Undersea and Hyperbaric Medical Society
UPTD	unit of pulmonary toxic dose
USN	United States Navy
VC	vital capacity
VER	visual evoked response
VGE	venous gas emboli
VPM	varying permeability model
V/Q	ventilation-perfusion

Preface and excerpts from earlier editions

This book is written for doctors and paramedics who are called on to minister to the medical needs of those divers who venture on or under the sea. It was based on our experience in dealing with a vast number of diving accidents and with troubleshooting many diving problems, and it is also an attempt to integrate the experience and more erudite research of others.

The very generous praise bestowed by reviewers on the first edition of *Diving and Subaquatic Medicine,* and its surprising acceptance outside the Australasian region, inspired us to prepare further editions of this text.

In the later editions, we attempted to be less insular. Instead of an Australian book about Australian experiences, we sought the advice and guidance of respected friends and colleagues from other countries, and from other disciplines, especially in the United Kingdom, the United States, Canada, Japan and mainland Europe. This has not prevented us from being judgemental and selective when we deemed it fit. This is still a very specialized field where evidence-based medicine is in its infancy. Truth is not always achieved by voting, and consensus is often a transitory state. We have documented what we believe to be current best practice. The future will judge this.

The extension of diving as a recreational and commercial activity has led to the bewildered medical practitioner's being confronted with diving problems about which he or she has received little or no formal training. Doctors interested in diving had previously found themselves without a comprehensive clinical text. We tried to remedy this. Our primary focus remains on the diving clinician, the physician responsible for scuba divers, the diving paramedic and the exceptional diving instructor who needs some guidance from a practical reference text.

Diving accidents are much better defined, investigated and treated than when we commenced writing on this subject, many years ago. It was our intent to present, as completely as possible, an advanced and informative book on clinical diving medicine. We have avoided the temptation to write either a simplistic text or a research-oriented tome.

This text encompasses the range of diving disorders experienced by divers. It presents all aspects of diving medicine from ancient history to the latest trends, in a concise and informative manner. Each disorder is dealt with from a historical, aetiological, clinical, pathological, preventive and therapeutic perspective. Summaries, case histories and revision aids are interspersed throughout. For the doctor who is not familiar with the world of diving, introductory chapters on physics and physiology, equipment and the diving environments have been included.

The inclusion of anecdotes and occasional humour may lessen the load on the reader, as it does on the authors. As in previous editions, each chapter is edited by one of the authors, with overview and peer review available from the others. This means that not always will there be exact agreement among authors, and there may be some variation among chapters. This is inevitable when evidence and consensus are not always complete. It is also healthy for the future.

Three of the four previous authors have departed from this scene, and the fourth is about to leave. The baton needs to be passed. Our legacy and intent are that our younger colleagues will experience as much excitement, fascination, achievement, camaraderie and fun from diving as we have.

Carl Edmonds, 2015
on behalf of all previous
and new authors of this text.

Dedication

This book is dedicated to the memory of Pluto, who died, even though he never left dry land.

I have often been asked who Pluto was. He was a much loved basset hound who strolled into our study when the original three authors were postulating about an appropriate dedicatee for their text. We could not decide between Paul Bert, Al Behnke, Jr., and J.B.S. Haldane. Pluto solved our dilemma.

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We wish to acknowledge the assistance given by the Royal Australian Navy, the Royal Navy and the United States Navy for permission to reproduce excerpts from their diving manuals, and to the many pioneers on whose work we have so heavily drawn, our families who have suffered unfairly, and our clinical tutors – the divers.

Numerous experts have been consulted to review and advise on specific chapters of this or previous editions. Our gratitude is extended to these valued colleagues, but they are not to blame for the final text. They include the following:

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PART 1

Diving

1

History of diving

BREATH-HOLD DIVING

The origins of breath-hold diving are lost in time. Archaeologists claim that the Neanderthal human, an extinct primitive human, dived for food, likely in the first instance gathering shellfish by wading at low tide before diving from canoes. By 4500 BC, underwater exploration had advanced from the first timid dive to an industry that supplied the community with shells, food and pearls.

From the ancient Greek civilization until today, fishers have dived for sponges, which, in earlier days, were used by soldiers as water canteens and wound dressings, as well as for washing.

Breath-hold diving for sponges continued until the nineteenth century when helmet diving equipment was introduced, allowing the intrepid to gamble their lives in order to reach the deeper sponge beds. Greek divers still search the waters of the Mediterranean Sea as far afield as northern Africa for sponges.

The ancient Greeks laid down the first rules on the legal rights of divers in relation to salvaged goods. The diver's share of the cargo was increased with depth. Many divers would prefer this arrangement to that offered by modern governments and diving companies.

In other parts of the world, industries involving breath-hold diving persist, to some extent, to this time. Notable examples include the Ama, or diving women of Japan and Korea, and the pearl divers of the Tuamoto Archipelago.

The Ama has existed as a group for more than 2000 years. Originally the male divers were fishermen, and the women collected shells and plants. The shells and seaweed are a prized part of Korean and Japanese cuisine. In more recent times, diving has been restricted to the women, with the men serving as tenders. Some attribute the change in pattern to better endurance of the women in cold water. Others pay homage to the folklore that diving reduces the virility of men, a point many divers seem keen to disprove.

There is a long history of the use of divers for strategic purposes. Divers were involved in operations during the Trojan Wars from 1194 to 1184 BC. They sabotaged enemy ships by boring holes in the hull or cutting the anchor ropes. Divers were also used to construct underwater defences designed to protect ports from the attacking fleets. The attackers in their turn used divers to remove the obstructions.

By Roman times, precautions were being taken against divers. Anchor cables were made of iron chain to make them difficult to cut, and special guards with diving experience were used to protect the fleet against underwater attackers.

An interesting early report indicated that some Roman divers were also involved in Mark Anthony's attempt to capture the heart of Cleopatra. Mark Antony participated in a fishing contest held in Cleopatra's presence and attempted to improve his standing by having his divers ensure a constant supply of fish on his line. The Queen showed her displeasure by having one of her divers fasten a salted fish to his hook.

Marco Polo and other travellers to India and Sri Lanka observed pearl diving on the Coromandel Coast. They reported that the most diving was to depths of 10 to 15 metres, but that the divers could reach 27 metres by using a weight on a rope to assist descent. They carried a net to put the oysters in and, when they wished to surface, were assisted by an attendant who hauled on a rope attached to the net. The divers were noted to hold their nose during descent.

The most skilled of the American native divers came from Margarita Island. Travellers who observed them during the sixteenth, seventeenth and eighteenth centuries reported that these divers could descend to 30 metres and remain submerged for 15 minutes. They could dive from sunrise to sunset, 7 days a week and attributed their endurance to tobacco! They also claimed to possess a secret chemical that they rubbed over their bodies to repel sharks. The Spaniards exploited these native divers for pearling, salvage and smuggling goods past customs. The demand for divers was indicated by their value on the slave market, fetching prices up to 150 gold pieces.

Free diving appears to have evolved as a modern sport in the mid-1940s, initially as a competition among Italian spearfishers. Currently the sport, which is steadily gaining popularity, encompasses a variety of disciplines. These include the following:

In 'no limits', a diver can use any means to travel down and up the line, as long as the line is used to measure the distance. Most divers descend down a line using a weighted sled and return to the surface aided by an inflatable balloon. Officially recorded depths in excess of 210 metres have been achieved using this method.

'Constant weight apnoea' diving is where descent and ascent occur along a line, although the diver is not permitted to pull on this line to assist movement. No weights can be removed during the dive. Monofins or bi-fins can be used.

'Constant weight without fins' is the same as constant weight apnoea but without the use of fins.

With 'variable weights', the diver again descends with the aid of a weighted sled, but this weight is limited. Ascent is achieved by finning or pulling up the cable, or both.

'Free immersion', which emerged in places where equipment was difficult to obtain, involves a finless diver (with optional suit, mask or weights) who pulls himself or herself down and then up a weighted line.

'Static apnoea' involves resting breath-holding (usually lying in a pool) with the face submerged. Officially recorded times in excess of 11 minutes have been achieved using this method.

'Dynamic apnoea' measures the distance covered in a pool during a single breath-hold.

EARLY EQUIPMENT

The history of diving with equipment is long and complex, and in the early stages it is mixed with legend. The exploits of Jonah are described with conviction in one text, but there is a shortage of supporting evidence. Further reference is made to him later, on the technicality that he was more a submariner than a diver. Because his descent was involuntary, Jonah was at best a reluctant pioneer diver. The history of submarine escape, when the submariner may become a diver, is discussed in Chapter 64.

Some claim that Alexander the Great descended in a diving bell during the third century BC. Details of the event are vague, and some of the fish stories attributed to him were spectacular. One fish was said to have taken 3 days to swim past him! It is most unlikely that the artisans of the time could make glass as depicted in most of the illustrations of the 'event'. This may have been a product of artistic licence or evidence that the incident is based more in fable than in fact.

Snorkels, breathing tubes made from reeds and bamboo (now plastic, rubber or silicone), were developed in many parts of the world. They allow a diver to breathe with the head underwater. Aristotle inferred that the Greeks used them. Columbus reported that the North American Indians would swim toward wild fowl while breathing through a reed and keeping their bodies submerged. They were able to capture the birds with nets, spears or even their bare hands. The Australian aborigines used a similar approach to hunt wild duck. Various people have 'invented' long hose snorkels. The one designed by Vegetius, dated 1511, blocked the diver's vision and imposed impossible loads on the breathing muscles.

Some have interpreted an Assyrian drawing dated 900 BC as an early diving set. The drawing shows a man with a tube in his mouth. The tube is connected to some sort of bladder or bag. It is more likely a float or life jacket. The tube length was a metre or more and so impossible to breathe through.

Leonardo da Vinci sketched diving sets and fins. One set was really a snorkel that had the disadvantage of a large dead space. Another of his ideas was for the diver to have a 'wine skin to contain the breath'. This was probably the first recorded design of a self-contained breathing apparatus. His drawings appear tentative, so it is probably safe to assume that there was no practical diving equipment in Europe at that time.

Another Italian, Borelli, in 1680, realized that Leonardo was in error and that the diver's air would have to be purified before he breathed it again. Borelli suggested that the air could be purified and breathed again by passing it through a copper tube cooled by sea water. With this concept, he had the basic idea of a rebreathing set. It could also be claimed that he had the basis of the experimental cryogenic diving set in which gas is carried in liquid form and purified by freezing out carbon dioxide.

Diving bells were the first successful method of increasing endurance underwater, apart from snorkels. These consist of a weighted chamber, open at the bottom, in which one or more people could be lowered under water. The early use of bells was limited to short periods in shallow water. Later, a method of supplying fresh air was developed. The first fully documented use of diving bells dates from the sixteenth century.

In 1691, Edmond Halley, the English astronomer who predicted the orbit of the comet that bears his name, patented a diving bell that was supplied with air in barrels (Figure 1.1). With this development diving bells became more widespread. They were used for salvage, treasure recovery and general construction work. Halley's bell was supplied with air from weighted barrels, which were hauled from the surface. Dives to 20 metres for up to 1 1/2 hours were recorded. Halley also devised a method of supplying air to a diver from a hose connected to the bell. The length of hose restricted the diver to the area close to the bell. It is not known whether this was successful. Halley was one of the earliest recorded sufferers of middle ear barotrauma.

Swedish divers had devised a small bell, occupied by one person and with no air supply to it. Between 1659 and 1665, 50 bronze cannons, each weighing more than 1000 kg, were salvaged from the *Vasa*. This Swedish warship had sunk in 30 metres of water in Stockholm harbour.

Figure 1.1 Edmond Halley's diving bell, 1691. The weighted barrels of air that were used to replenish the air can be clearly seen.

The guns were recovered by divers working from a bell, assisted by ropes from the surface. This task would not be easy for divers, even with the best of modern equipment.

MODERN DIVING EQUIPMENT

The first people to be exposed to a pressure change in a vessel on the surface were patients exposed to higher or lower pressure as a therapy for various conditions – the start of hyperbaric medicine. The origins of diving medical research can also be traced to these experiments.

During the second half of the nineteenth century, reliable air pumps were developed. These were able to supply air against the pressures experienced by divers. Several people had the idea of using these pumps for diving and developed what are now called open helmets, which cover the head and shoulders. Air was pumped down to the diver, and the excess air escaped from the bottom of the helmet. The diver could breathe because the head and neck were in air, or at least they were until the diver bent over or fell. If this happened, or if the hose or pump leaked, the helmet flooded and the diver was likely to drown. The Deane brothers were the inventors and among the major users of this equipment, and John Deane continued to use it up to the time of the Crimean War.

Standard rig, or **standard diving dress,** was first produced in 1840 by Augustus Siebe (a Russian immigrant engineer who later became a naturalized British citizen). This equipment consisted of a rigid helmet sealed to a flexible waterproof suit (Figure 1.2). Air was pumped down from the surface into the helmet, and excess air bled off through an outlet valve. The diver could control buoyancy by adjusting the flow through the outlet valve and thus the volume of air in the suit. This type of equipment, with a few refinements, is still in use.

Siebe's firm came to be the major manufacturer, but his role in the design may have been overstated, possibly for the marketing advantages gained by his firm, which marketed the first acceptable equipment of this type. The origins and evolution from open helmet and standard dress were the subject of a study by Bevan, who discussed several designs that were developed at the same time, with borrowing and stealing of ideas from each other.

Figure 1.2 Augustus Siebe's first helmet.

By the mid-nineteenth century, several types of diving suits and a bell were used by the Royal Engineers on dives on the wreck of the *Royal George,* which obstructed the anchorage at Spithead. The Siebe suit was found to be greatly superior to the other designs. Siebe's apparatus allowed the diver to bend over or even lie down without the risk of flooding the helmet. Also, the diver could control his depth easily. A diver in an open helmet had to climb a ladder or rely on his tenders to do this.

In more modern versions, the helmet is fitted with communications to allow the diver to confer with another diver or the surface. One of the developments from the Siebe closed helmet was the US Navy Mark 5 helmet. It probably set a record by being in service for 75 years.

The Royal Engineers were taught to dive by civilian divers in 1939–40 while on the *Royal George*. They then established a training facility at Gillingham in 1844 where they reintroduced diving to the Royal Navy, which set up their first diving school on HMS *Excellent* later that year.

Decompression sickness was noted, albeit not recognized in divers, following the development of these diving suits. Divers were given fresh dry undergarments because the 'rheumatic' pains they suffered were attributed to damp and cold. Other divers suffered paralysis that was attributed to fatigue from zeal and overexertion. Most of these men would have been suffering from decompression sickness because they were diving for up to three times the accepted limits for dives without decompression stops.

Decompression sickness was also observed in workers employed in pressurized caissons and tunnels. In these operations, the working area is pressurized to keep the water out. The history of decompression sickness is discussed in Chapter 10.

Paul Bert and J. S. Haldane are the fathers of diving medicine. Paul Bert published a text book *La pression barométrique* based on his studies of the physiological effect of changes in pressure. His book is still used as a reference text even though it was first published in 1878. Bert showed that decompression sickness was caused by the formation of gas bubbles in the body and suggested that it could be prevented by gradual ascent. He also showed that pain could be relieved by a return to higher pressures. Such cases were initially managed by the diver's returning to the pressure of the caisson. However, specially designed recompression chambers were introduced and utilized at some job sites within a few years.

J.S. Haldane, a Scottish scientist, was appointed to a Royal Navy committee to investigate the problem of decompression sickness in divers. At that time the Royal Navy had a diving depth limit of 30 metres, but deeper dives had been recorded. Greek and Swedish divers had reached 58 metres in 1904, and Alexander Lambert had recovered gold bullion from a wreck in 50 metres of water in 1885, but he had developed partial paralysis from decompression sickness.

Haldane concluded from Paul Bert's results that a diver could be hauled safely to the surface from 10 metres with no evidence of decompression sickness. He deduced from this that a diver could be surfaced from greater than 10 metres in stages, provided that time was spent at each stage to allow absorbed nitrogen to pass out of the body in a controlled manner. This theory was tested on goats and then on men in chambers. Haldane's work culminated in an open water dive to 64 metres in 1906 and the publication of the first acceptable set of decompression tables. Haldane also developed several improvements to the diving equipment used.

In 1914, US Navy divers reached 84 metres. The next year they raised a submarine near Hawaii from a depth of 93 metres. This was a remarkable feat considering that the salvage techniques had to be evolved by trial and error. The divers used air, so they were exposed to a dangerous degree of nitrogen narcosis, as well as decompression sickness.

SELF-CONTAINED EQUIPMENT

Self-contained underwater breathing apparatus (scuba) is used to describe any diving set that allows the diver to carry the breathing gas supply with him or her. There are several claims to its invention, based on old drawings. The first workable form probably dates from the early nineteenth century. There is a brief report of an American engineer, Charles Condert, who made a scuba in which the compressed air was stored in a copper pipe worn around his body. The gas was released into a hood that covered the upper half of his body. Accumulation of carbon dioxide was controlled by allowing the respired gas to escape through a small hole. It was then replaced by fresh gas from the storage pipe. Condert died while diving with his equipment in the East River in New York in 1831.

In 1838, Dr Manuel Guillaumet filed a patent in France for a back-mounted, twin-hose demand regulator that was supplied with air from hoses to the surface. A patent for a similar device was also filed in England earlier that year by William Newton, but it seems likely that this was done on behalf of Guillaumet.

Another early development was the Rouquayrol and Denayrouze device of 1865 (Figure 1.3). This set was supplied with air from the surface that was breathed on demand via a mouthpiece. It was fitted with a compressed air reservoir so that the diver could detach himself or herself from the air hose for a few minutes. The endurance, as a scuba, was limited by the amount of air in the reservoir.

The first successful scuba with an air supply appears to have been developed and patented in 1918 by Ohgushi, who was Japanese. His system could be operated with a supply of air from the surface or as a scuba with an air supply cylinder carried on the back. The diver controlled the air

Figure 1.3 The aerophore, devised by Rouquayrol and Denayrouze, 1865. This device was widely used and was an important milestone in the development of the modern scuba.

supply by triggering air flow into the mask with the diver's teeth. Another scuba was devised by Le Prieur in 1933. In this set, the diver carried a compressed air bottle on the chest and released air into the face mask by opening a tap.

In 1943, Cousteau and Gagnan developed the first popular scuba as we know it today. It was an adaptation of a reducing valve that Gagnan had evaluated for use in gas-powered cars and was far smaller than the Rouquayrol-Denayrouze device.

Closed-circuit oxygen sets were developed during the same period as the modern scuba. In these rebreathing sets, the diver is supplied with oxygen and the carbon dioxide is removed by absorbent. These sets are often called scuba, but they may be considered separately because of the difference in principles involved. The patent for the first known prototype of an oxygen rebreather was given to Pierre Sicard, who was French, in 1849. The first known successful rebreathing set was designed by English engineer H. A. Fleuss in 1878. This was an oxygen set in which carbon dioxide was absorbed by rope soaked in caustic potash.

Because of the absence of lines and hoses from the diver to the surface, the set was used in flooded mines and tunnels where the extra mobility, compared with the standard rig, was needed. Great risks were taken with this set and its successors when used underwater because the work of Paul Bert on oxygen toxicity was not widely known. This equipment was the precursor of oxygen sets used in clandestine operations in both world wars and of other sets used in submarine escape, firefighting and mine rescue.

MODERN MILITARY DIVING

The military use of divers in warfare was, until 1918, largely restricted to the salvage of damaged ships, clearing of channels blocked by wrecks, and assorted ships' husbandry duties. One significant clandestine operation conducted during the First World War was the recovery of code books and minefield charts from a sunken German submarine. This was of more significance as an intelligence operation, although the diving activity was also kept secret.

During the First World War, Italy developed a human torpedo or chariot that was used in 1918 to attack an Austrian battleship in Pola Harbour in what is now Croatia. The attack was a success in that the ship was sunk, but, unfortunately, it coincided with the fall of the Austro-Hungarian Empire, and the ship was already in friendly hands! The potential of this method of attack was noted by the Italian Navy. They put it to use in the Second World War with divers wearing oxygen rebreathing sets as underwater pilots. In passing, it is interesting to note that the idea of the chariot was suggested to the British Admiralty in 1909, and Davis took out patents on a small submarine and human torpedo controlled by divers in 1914. This was pre-dated by a one-person submarine designed by J.P. Holland in 1875.

Diving played a greater part in offensive operations during the Second World War. Exploits of note include those of the Italian Navy. They used divers riding modified torpedoes to attack ships in Gibraltar and Alexandria. After a series of unsuccessful attempts with loss of life, they succeeded in sinking several ships in Gibraltar harbour in mid-1941. Later that year, three teams managed to enter Alexandria harbour and damage two battleships and a tanker. Even Sir Winston Churchill, who did not often praise his enemies, said they showed 'extraordinary courage and ingenuity'. Churchill had previously been responsible for rejecting suggestions that the Royal Navy use similar weapons.

In Gibraltar, a special type of underwater war evolved. The Italians had a secret base in neutral Spain, only 10 kilometres away, and launched several attacks that were opposed by British divers who tried to remove the Italian mines before they exploded.

Divers from the allied nations made several successful attacks on enemy ships, but their most important offensive roles were in the field of reconnaissance and beach clearance. In most operations, the divers worked from submarines or small boats. They first surveyed the approaches to several potential landing sites. After a choice had been made, they cleared the obstructions that could impede the landing craft. One of the more famous exploits of an American diving group was to land unofficially and leave a 'Welcome' sign on the beach to greet the US Marines, spearheading the invasion of Guam. The British Clearance Divers and the US Navy Sea, Air, Land Teams (SEALs) evolved from these groups. The Clearance Divers get their name from their work in clearing mines and other obstructions, a role they repeated during and after the Gulf War.

The research back-up to these exploits was largely devoted to improvement of equipment and the investigation of the nature and onset of oxygen toxicity (Chapter 17). This work was important because most of these offensive operations were conducted by divers wearing oxygen breathing apparatus. The subjects were the unsung heroes of the work. This group of scientists, sailors and conscientious objectors deliberately and repeatedly suffered oxygen toxicity in attempts to understand the condition.

Oxygen-nitrogen mixtures were first used for diving by the Royal Navy in conjunction with a standard diving rig. This approach was based on an idea proposed by Sir Leonard Hill and developed by Siebe Gorman and Co. Ltd. The advantage of this equipment is that, by increasing the ratio of oxygen to nitrogen in the breathing gas, one can reduce or eliminate decompression requirements. It is normally used with equipment in which most of the gas is breathed again after the carbon dioxide has been removed. This allows reduction of the total gas volume required by the diver.

During the Second World War, this idea was adapted to a self-contained semi-closed rebreathing apparatus that was first used extensively by divers clearing mines. This development was conducted by the British Admiralty Experimental Diving Unit in conjunction with Siebe Gorman and Co. Ltd. The change to a self-contained set was needed to reduce the number of people at risk from accidental explosions in mine-clearing operations. The reduction, or elimination, of decompression time was desirable in increasing the diver's chances of survival if something went wrong. The equipment was constructed from non-magnetic materials to reduce the likelihood of activating magnetic mines and was silent during operation for work on acoustically triggered mines.

DEEP DIVING

The search for means to allow humans to descend deeper has been a continuing process. By the early twentieth century, deep diving research had enabled divers to reach depths in excess of 90 metres; at which depth the narcosis induced by nitrogen incapacitated most humans.

After the First World War, the Royal Navy diving research tried to extend its depth capability beyond 60 metres. Equipment was improved, the submersible decompression chamber was introduced and new decompression schedules were developed that used periods of oxygen breathing to reduce decompression time. Dives were made to 107 metres, but nitrogen narcosis at these depths made such dives both unrewarding and dangerous.

Helium diving resulted from a series of American developments. In 1919, a scientist, Professor Elihu Thompson, suggested that nitrogen narcosis could be avoided by replacing the nitrogen in the diver's gas supply with helium. At that stage, the idea was not practical because