The author's own visits to Thursday Island, Darwin and Broome between 1962 and1989, to socialise with the divers, both new and old, swap yarns and to dive the pearl grounds, were meant not only to collate information but also to collect traditional diving know-how. If, at the same time, he found a unique and priceless gem that would set him up for the rest of his life, then so be it.

Key Words

Decompression illness, deaths, history, occupational diving

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PEARL DIVING FROM BROOME

Robert M Wong

Abstract

Pearl diving in Australian waters began towards the end of 19th Century. Over the years the current mode of diving has evolved.[1] This paper traces the modifications to diving from drifting vessels (drift diving) which have led to the current practise in pearl diving in Broome.

Historical perspective

Broome, a town in Western Australia 2,600 km northwest of the city of Perth, is well known for its pearling industry. The areas fished are the seas off the Eighty Mile Beach down to Port Hedland. This area has large tidal variations. The mean high water spring tide is 9.4 m, mean low water spring tide is 1.1 m, while mean high water neap tide is 6.4 m and mean low water neap is 4.3 m.

For those with a limited aquaintance with the sea, neap tides are small tidal ranges which occur twice a month when the tide producing forces of the sun and moon are in opposition. Spring tides are large tides which occur when the sun and moon are acting in conjunction, around the time of full and new moon. The tidal range for both is measured from half tide level.

The colourful history of Broome and its divers is very well covered by a number of authors.[2-4] Some of the historical aspects of this article comes from H Edward's book "Port of Pearls" and is reproduced here with the author's permission.

Pearl fishing in Western Australia dates back as far as 1861 when the British colonists first noticed the necklaces made from pearl shells worn by the local Aboriginal population. The Mother of Pearl (*Pinctada maxima*) shells were obtained by breath-hold diving in Roebuck Bay, off Broome, by the indigenous population. The birth of the pearling industry in Western Australia was breath-hold diving around Broome. In the early days of the pearling industry, the local Aborigines were "engaged", with little choice, for breath-hold diving.

However, when compressed air diving, using a hand powered pump with a canvas suit and brass helmet, was introduced, the divers were brought in from afar. They were mainly Japanese, Malays, Koepangers (from Indonesia) and Arabs. It is believed that the first Japanese divers were brought to work in Port Darwin in 1884.[2] Nowadays days, the divers are mainly Caucasian Australians and New Zealanders.

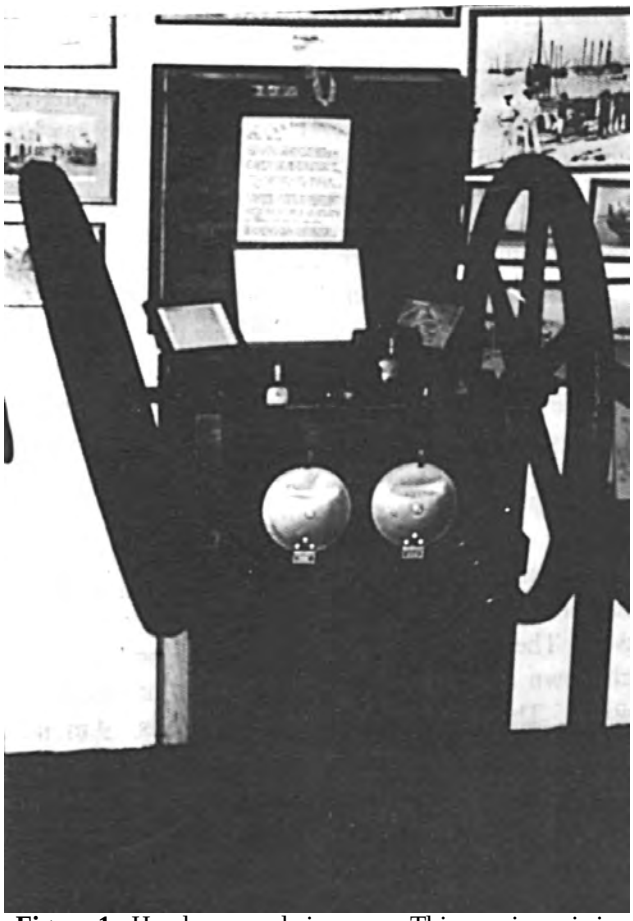

Figure 1. Hand powered air pump. This specimen is in the Broome museum

Compressed air diving was introduced to Broome in 1884. The depths achieved were limited by the ability, or more properly inability, of the pumps to provide sufficient air to the divers at depth.

It has to be stressed that in those early days, compressed air diving was extremely hazardous. Bert described cases of deaths and spinal cord decompression sickness (DCS) in Mediterranean sponge divers in 1868.[5] In Broome the divers also suffered death and permanent injuries, mainly from DCS but also from cyclones.

In 1892 Dr Bassett-Smith , a surgeon in the Royal Navy who visited Broome while on board HMS PENGUIN, published a case report of a death resulting from severe spinal cord decompression sickness in a diver after diving to 32 fathoms, 192 ft or 58 m (1 fathom=6 feet or 1.8 m).[6] Later Dr Graham Blick, a District Medical Officer in Broome from 1900-1908, reported that "diver's paralysis" was a common condition among divers and that no diver would consider his outfit complete without a soft catheter for bladder catherterisation in the event of spinal cord DCS.[7] The divers went to depths of 7 to 20 fathoms (12-36 m or 42-120 ft) sometimes even to 25 fathoms (45 m or 150 ft).

The dive profiles used were derived purely from trial and error. The early pearl divers had no knowledge of any decompression tables as these were not devloped until 1908, when Haldane's tables were produced for the Royal Navy.[8]

Attempts to introduce what is now conventional diving, with staged decompression using the Haldanian tables, were made in 1912 when 12 ex-Royal Navy divers and tenders arrived from England. They brought with them engine driven pumps to replace hand pumps. Before the end of that diving season, one of them was dead and another was paralysed. Eventually, the rest of the team left Broome. Diving depths and times reverted to the old technique of trial and error.

With the introduction of engine driven pumps, far greater diving depths were achieved, more divers developed DCS and more fatalities occurred. However, the number of dives undertaken is unknown so one cannot calculate the risk of death accepted by the pearl divers.

In 1913 Heinke and Co., who supplied the diving equipment used by the pearlers, donated a recompression chamber (RCC) to treat "diver's paralysis" (Fig 2). It was essentially a metal cylinder, without a porthole, into which the paralysed diver was put, pressurised and then slowly decompressed. That year 29 deaths were recorded and in 1914 the peak was reached with 33 deaths from diving, mostly from spinal cord DCS paralysis, infected bedsores and urinary tract infections.

Due to a combination of factors, among them the great distance from Perth, poor communications and lack of knowledge of how to dive safely, the pearl divers, out of necessity and self-preservation, evolved a system of diving techniques which was unique and worked well enough to contain the incidence of DCS to an "acceptable limit".

TABLE 1

DEATHS AMONG DIVERS IN THE BROOME PEARLING FLEET 1910 TO 1920

Year	Deaths
1910	11
1911	10
1912	9
1913	29
1914	33
1915	21
1916	19
1917	12
1918	1
1919	3
1920	4

Figure 2. Heinke and Co recompression chamber on display in a Broome park some years ago.

These well tried, but dangerous, recipes were passed from generation to generation of divers and form the basis of the profiles now in use, which are merely refinements of those recipes which cost hundredst of lives and thousands of cases of DCS to develop.

Interviews with divers who dived in the 1950s, 1960s, 1970s and 1980s led to an appreciation of the development of the dive profiles. The decompression procedures remained essentially unchanged. The most significant change was the introduction of oxygen in decompression and its use in recompression at sea.

Diving in the 1950s and 1960s

Some of the personal experiences of the bends were perhaps not entirely accurate as memory fades with time. Nonetheless, the dive profiles described by the divers were consistent.

The ex-divers interviewed came from Japan as “try divers”, basically they were on probation to test their suitability as divers. They worked as deck hands, and were taught to dive by the “Number 1 diver”. They would dive occasionally or would replace one of the two divers when one of them was ill. This training lasted from 6 months to a year.

They had a concept of “strong” and “weak” divers. Strong and weak did not refer to physical strength, rather it was used to refer to the diver’s ability to avoid DCS. It was a natural occurrence akin in some ways to the high or low

Figure 3. Heinke and Co recompression chamber restored and on display in the museum.

bubblers found in Doppler studies. The weak divers would need to stage after each dive and would ascend slower than the strong divers. It was said that some of the strong divers never got bent.

They dived for pearl shell from March to December and would be away from Broome for a minimum of 3 weeks at a time, diving every day of the week except Sunday, when they would have a day off. This was different from the days of Bassett-Smith in the 1880s and 1890s when the luggers were away for months at a time. The lugger usually carried only 2 divers and very rarely 3. Interestingly enough, they only dived in deep waters after August of each year and this coincided with the time when the divers got serious bends. At the beginning of the year, they only dived in shallow waters.

The luggers would fish in shallow waters, but if the shells were fished out, then they had to go to deeper waters. Also during Spring Tides, visibility in the shallow was poor, and they had to go deeper.

The Mode of Diving

Irrespective of depths, they dived from sunrise to sunset, about 12 hours in winter and 13 hours in summer.

SHALLOW WATERS

These were usually less than 10 fathoms (18 m or 60ft), but up to 12 fathoms (22 m or 72 ft). Bottom times were around 50 to 60 minutes. There was no staging in shallow waters. If the patch of ground had few oysters, the divers would surface after only 15 minutes. They ascended slowly, the rate being controlled by the diver adjusting the air flow into the helmet. With the expiratory valve setting unaltered increasing the air flow inflated the suit making the diver more buoyant.

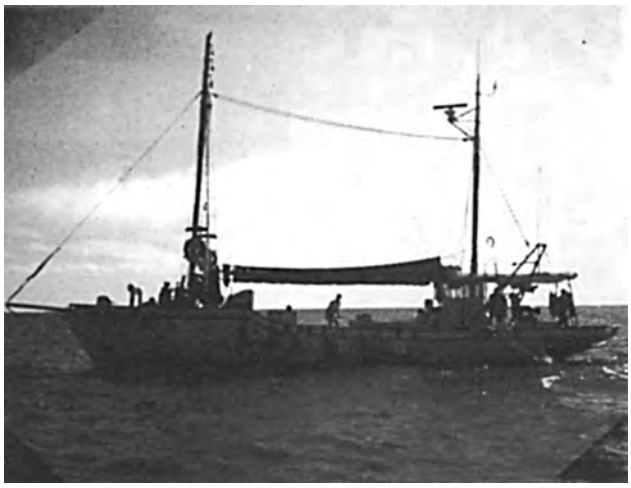

Figure 4. The last of the old pearling luggers.

As it usually took the lugger 15 to 20 minutes to turn around for another drift this time was the surface interval between dives whatever the depth.

MID-WATERS

At these depths, to about 15 fathoms (27 m or 90 ft), they used a shorter bottom time, usually around 45 minutes, but it could extend to an hour.

The ascent rate was slower than in shallow waters. The exact time is not known, as they wore neither depth gauges nor watches. The timing was kept by the tender on the lugger.

At this depth they would decompress after every dive, slowly ascending over about 3 minutes to 7 fathoms (13 m or 42 ft), approximately 2-3 fathoms per minute (3.6 to 5.5 m or 12-18 ft a minute). They spent 5 to 15 minutes at this depth and then took about 5 minutes to reach the surface (1.4 fathoms, 2.5 m or 8.5 ft a minute). The duration of staging was determined by Number 1 diver. The Japanese divers used to say that "a diver knows his body", meaning that if he ascended too quickly, he would know it, and if he did not stage, he would also know, presumably because he would suffer symptoms of DCS. The life line had markings at each fathom and the tender hit a gong, or made some other noise, to inform the diver that he had reached 7 fathoms (13 m or 42 ft) for decompression. Some of the "strong" divers would not bother with "staging" and would ascend faster. If the weaker divers follow suit, because of pride or embarrassment, they got bent.

At the end of the day, however, after the last dive, all divers would do a decompression stop. The depth was at 7-8 fathoms (13-15 m or 42-48 ft) for about an hour.

DEEP WATERS

They were careful to take 3-4 minutes to reach the seabed. At this depth, 15-25 fathoms (27-45 m or 90-150 ft) the bottom time was never longer than 40 minutes.

The ascent rate was slower than for the other 2 depth ranges. It took about 10 minutes to reach 7 fathoms (13 m or 42 ft) for their staging (1.8 fathoms, 3.3 m or 11 ft per minute). At the end of the day there was the usual one hour hang off at 7-8 fathoms (13-15 m or 42-48 ft).

Surface intervals were fixed by the time taken to get the lugger into position for the next drift, usually 10-20 minutes between dives.

After surfacing at the end of the day, there was a ritual in the undressing. The diver sat on deck and had the helmet and breast weight removed. He sat very still for about 20 minutes. If at that time he did not have symptoms of DCS, the corslet would be removed. He ate his dinner with his diving dress on. After dinner he sat motionless for another 20 minutes and, if all was well, then the dress would be removed and the diver went to bed, wearing his diving underwear and stockings. He pulled a blanket over himself and if he felt warm he knew that all was well. He would only then get changed. They obviously understood that post-dive exercise was inadvisable.

Decompression sickness and its management

Most of the older divers had suffered numerous episodes of DCS. They viewed musculo-skeletal DCS as an inconvenient and unavoidable occupational hazard. If the divers suffered pain during the night, they would get back into the water and hang off. They would go to the depth of relief and after half an hour or so start to ascend very slowly, usually taking all night. Interestingly enough, these hard hat divers' DCS tended to affect the knees, occasionally the elbows, but virtually never the shoulders. In deep waters spinal cord DCS was common.

Case Histories

CASE 1

Diver M, aged 63 in 1994, came to Broome in 1955 from Japan. He learned to dive from an old Japanese diver who had started diving long before the second World War. During his first year, he burst his tympanic membrane by too fast a descent to 9 fathoms (16 m or 54 ft). His apprenticeship took about 6 months.

In 1956, he dived daily to about 12 fathoms (21m or 72 ft), with a bottom time of about 50 to 60 minutes. The descent took about a minute. They dived for about 12 hours a day in winter and 13 hours a day in summer with 10-20 minutes between dives.

He suffered numerous episodes of musculo-skeletal DCS. This occurred usually after dinner when he lay down. Treatment of this kind of DCS was by recompression in water at depths of 7 fathoms (13 m or 42 ft). Duration varied from 1 or 2 hours to around 10 hours, depending on the level of pain and the response to the treatment.

He suffered 2 serious incidents of DCS. The first was in November 1956 after a dive in the deep waters, greater than 20 fathoms (36 m or 120 ft). He recalled that it was the middle of the day, and was definitely after lunch. Five minutes after surfacing he developed "tunnel vision" in his left eye. The periphery of the visual field started to darken and within minutes he had no vision in his left eye. Then he noticed an ache in the eyeball. He could not recall any other symptoms of note. There was no headache, no weakness, no numbness that he could remember. He was returned to 7 fathoms (13 m or 42 ft) and, after about 10 minutes, vision began to return. He remained at depth for 45 minutes and vision returned totally. He did not dive for the rest of that day, but dived again the next morning. He was adamant that there were no other associated symptoms.

Another incident was in September 1957. It was after the 8th dive of day 4 to depths of 23 fathoms (42 m or 138 ft). He recalled that about half an hour after dinner when he was lying down, he felt sick and nauseated and ready to vomit. He felt the top half of the body was numb, although he could use both arms. He managed to get on deck, his tender dressed him and he was returned to 23 fathoms (42 m or 138 ft). He thought that was about 8 p.m. As soon as he reached bottom, he started to ascend, about a foot (0.3 m) every 5 minutes or so. However, as he started to ascend, he felt a gripping pain inside his abdomen on the left side. He also felt difficulty breathing, as if a ball got stuck in his throat. The symptoms persisted for some 6 hours. He tried to ascend, but could not get above 20 fathoms (36 m or 120 ft), as the symptoms worsened when he tried.

About mid-day the following day, he was still at 20 fathoms. A nearby lugger, with a cousin of his on board, sailed alongside. After he had heard the story, the cousin told the tender to pull "M" up to 15 fathoms (27 m or 90 ft). He experienced a lot of pain on ascent. He spent another 4 hours at 15 fathoms (27 m or 90 ft), then the pain gradually subsided. When he attempted to ascend again, the pain returned. Nevertheless, he was hauled up to 7 fathoms (13 m or 42 ft), where he experienced a lot of pain. But after another 4 hours, the pain disappeared. Thirty six hours after the start of his treatment he surfaced. Feeling very weak, he was carried to his bunk. The lugger returned to Broome and he was taken to the hospital. No appropriate treatment was given. There was no recompression chamber in Broome. M was scared and he stayed ashore for a month. Then he returned to diving, however, he noted that he was fine if he only dived to 10 fathoms, if the depth was deeper, he would experience similar pain on surfacing. He persevered the following year, but could not go deeper than 10 fathoms (18 m).

In 1958, he returned to Japan. Some retired divers advised him to have treatments in some hot springs, which he did daily for 5 weeks. The treatment consisted of immersion in hot volcanic sand. A hole was dug in the coarse black sand and he was covered, except for his head, for 15 minutes. After 3 minutes the pain appeared, but it always subsided after 2 minutes. Religiously, he had this treatment. One day, he felt as if the pain from his abdomen had "come out of his body through his left leg and departed through his left big toe". This feeling happened daily for 2 weeks. After that he had no more pain. He remained in Japan until 1960 then he returned to Broome. However, when he dived deeper than 10 fathoms (18 m or 60 ft), the pain would return. Finally, he gave up diving and taught a young cousin to dive.

M now lives in Broome. When he gave up diving he worked with engines, now he works as a maintenance man. He appears to be fit and healthy. M has had long bone X-rays, but he does not know of any problems, although he is aware of divers with dysbaric osteonecrosis. He himself is fully mobile and has no problems with any of his joints. The only thing he admitted to on questioning was that he does have problems with noise discrimination, perhaps from the noise of the air inlet in his hard hat diving days or from working with engines.

CASE 2

The young cousin served his apprenticeship like M. He too suffered serious DCS affecting the spinal cord. This occurred in 1961 after diving in 15 fathoms (27 m or 90 ft). He was unable to walk. Similar in-water recompression was given and he was in water for 24 hours. There was no improvement. He was taken to hospital and transferred to Perth. No improvement was seen and he returned to Japan where he had hot springs treatment. Over time, he recovered slowly. In 1974, the cousin married and fathered 2 children.

CASE 3

Another retired diver, H came to Broome in the 1950s from Japan as a try diver. He was taught to dive by a diver called Hojo. H claims that he suffered 25 episodes of musculo-skeletal DCS each year. He, too, suffered a major bend that ended his diving career.

This serious DCS occurred in November 1960. He was diving off Port Hedland in waters between 19-23 fathoms (35-42 m or 114-138 ft). It was the third day of diving. He admits to missing his staging. Within 60 minutes of surfacing, he felt sick, with a strange sensation over his left side of his abdomen as if his intestines were being squeezed. When he tried to stand up, it felt as if

someone had thrown ice cold water over the lower half of his body. Although he could stand, his legs would not move. He was carried to the ladder and lost consciousness, only to wake up when his feet touched the seabed. He felt alright at depth and stayed for half an hour. Then started to ascend at about 1 foot (0.3 m) at a time and paused for half an hour at each depth until he reached 7 fathoms (13 m or 42 ft). Although he had not finished his treatment, he surfaced around midnight to urinate as he did not like to urinate in his diving suit. At that time he had been in the water since 7 p.m. He was again returned to the seabed to repeat the decompression procedure, again with a slow ascent to 7-8 fathoms (13-14.5 m or 42-48 ft), eventually surfacing at 10 a.m. the next morning. He had had approximately 14 hours of in-water recompression. In the afternoon, someone gave him a cup of tea, and after one sip, he felt sick again with pain in his gut. At about 3 p.m., he was recompressed, surfacing at 5 a.m. the following day.

Unable to walk, he had to be carried to Port Hedland Hospital, where he remained for 3 or 4 days. T here was no appropriate treatment available. He was given some sedation and was discharged. Interestingly enough, he flew home to Broome rather than travel by road and remembered that in the air, he felt very sick again.

It took about one month before he started walking again. But it was another year before he regained enough strength to walk normally. He gave up diving after this episode of DCS. He remains in the pearling industry. The family business is conducted by his sons who are pearl divers.

During the 1950s and 60s, there were 4 deaths that the divers were aware of, unfortunately, no details were available and the divers could not remember very much. They remembered that one was a Japanese, who died from a “heart attack”, the others were Chinese, Malay and an Arab. They all died from serious DCS in deep waters and were dead when they surfaced.

Diving in 1970s and 1980s

The method of diving outlined continued in much the same fashion until the 1970s. This was the decade which saw major changes.

When the news of the success of abalone diving using the hookah system, instead of scuba, reached Broome it spelt the end of hard hat standard dress diving. Hookah is a surface supplied breathing apparatus (SSBA) using a compressor, pressurising a reservoir, to supply air to a wet suited diver, using a scuba second stage regulator on a long hose , who wears a mask covering nose and eyes.

In 1971 hookah diving was introduced to Broome where divers were still using the old fashioned hard hat.

The impetus for change came from Peter Cummings, who at the time was fleet manager of Pearls Pty Ltd (PPL), which in 1971 was the largest pearling company in Broome. Peter, who was an ex-Royal Australian Navy (RAN) officer, got in touch with a naval colleague, Commander Batterham, to get the help of some abalone divers. The first contact made was an ex-abalone diver, Dale Chapman, who enlisted Allan Stanley Badger and Bruno McKenna. Allan was a spearfishing champion and an abalone diver from New South Wales and Bruno was an abalone diver from Mallacoota in Victoria. These men arrived in Broome in April 1971.

Initially, these divers worked from the 60 ft (18 m) lugger *John Louis*, which Cummings, Chapman and David Dureau (a son of one of the owners of PPL) sailed down from the Torres Strait. The *John Louis* is now housed in the Darling Harbour Maritime Museum. The initial team consisted of Peter Cummings as skipper; Chapman, Badger and McKenna as divers; Frankie Bowie, a Torres Strait Islander, as engineer and David Dureau as deckhand.

The diving was done with the air hoses dangled over the sides of the lugger and when in motion, the divers were lifted off the seabed which made it very difficult to pick up shells. During the first months, they only managed to pick up about 16% of what the Japanese divers, who walked along the bottom, did. Not making much money, Bruno McKenna left Broome after about 6 weeks.

In 1971, the divers made use of SOS decompression meters (DCM), known at the RAN School of Underwater Medicine as “Bendomatics” because of the number of sport divers presenting with DCS who had used them. This was a gauge with a bladder inside where increased pressure forced gas through a ceramic filter simulating gas uptake. The dial showed green, safe to ascend, and red meaning into decompression time. The divers surfaced when the pointer came close to the red marking. They would stay on deck until the needle return to the black, theoretically degassed. It was common to dive to 18-21 m (60-70 ft) in 1972 and a lot of time was spent on the surface watching the DCMs. There was a lot of variation between DCMs, so the divers took an average reading! Eventually, after some 4 years, the divers considered the DCMs to be “too conservative and restrictive” and they stopped relying on them. Allan Badger could not recall any diver suffering any incidents of DCS using the DCMs with their system of average reading (average of the readings of the 4 DCMs after each dive).

Diving for pearl oysters was very secretive and competitive and the Japanese divers would not disclose their secrets.

The manager of PPL in Broome, Alby Ross recruited two men who had a lot of experience in pearl

Figure 5. Tender of hard hat diver on outrigger platform.

diving operations working as tenders on board Japanese pearling luggers. One of these was Jimmy Hunter, an Aborigine, the other was Guy Williams, a Torres Strait Islander. They had learned a lot about the way the Japanese dived.

After lengthy discussions, Chapman and Badger wanted to use shot lines with lead weights and work ropes and drogue to slow the lugger. They also wanted some kind of outrigger (boom) to separate the divers when drifting. Cummings was not prepared to spend the money for the modifications and had also said that a drogue was out of the question. Cummings, being an ex-naval officer, did not take kindly to being told what to do by his men, so there was some conflict. When Cummings unexpectedly returned to Melbourne on business, the divers managed to get what they wanted.

Most of the major changes in pearl diving occurred in 1971-72. The divers "acquired" the outriggers from the Japanese luggers which were lying around in the yards of PPL. These outriggers were wooden booms which had small wooden platforms at the distal end of them on which the Japanese tenders used to sit to tend to the life and air lines of the divers (Fig 5). Badger calls them "Japanese verandahs".

From the outriggers, these new style divers rigged shotlines, with lead weights on the lower end, from the shot lines were work ropes which trailed along the seabed. The original work ropes were only 6 m (20 ft) long, which was too short for effective pearl collecting. Furthermore there were no neck bags to put the oysters in, although they had abalone bags which they placed on the shotlines.

In June 1971, some 2 months after the PPL team started, Bruce Farley, an abalone diver from South Australia, arrived in Broome to work for the Brown family in the oyster farm in Cygnet Bay. Farley brought with him his abalone runabout and diving gear intending to use it for shell collection. He discovered that his gear was

Figure 6. The Cornelius at low tide. She is now used for touring in Broome waters.

unsuitable and started to use the Brown family's lugger.

As the months passed Chapman and Badger would discuss the various diving techniques, in the local pub, with Farley who mentioned the use of "neck bags". After this, Badger made use of all the available equipment and techniques. The result was that the catch improved dramatically, reaching a catch rate equal to that of the Japanese. At the end of their first year, they added pulleys to the end of the outriggers for the shot lines.

By 1972, these ingenious divers had replaced the wooden booms with longer steel pipes designed and welded by Alan Nunn of Newcastle, a boiler maker and spearfisherman, who could make up whatever gear the divers needed. He was recruited by Allan Badger. Dale Chapman also recruited John Monk of Melbourne, a hard working abalone diver and spearfisherman.

When Chapman and Badger arrived in Broome, the divers went to sea for a month at a time as they did in the 50s and 60s. They dived every day except Sunday, but no diving was done during spring tides. However they did not return to Broome, but sailed to Cape Bossut near La Grange Bay to lay up for a week of fishing and resting.

Badger thought that was a waste of time and decided to return to Broome during the spring tides. The management of PPL was displeased by this practice, but in time, everyone followed suit. This is now standard practice.

The Australian way of diving, hookah diving, became common practice in 1972 and even Japanese divers started to adopt the technique. By 1975, the last hard hat diver had retired and the entire industry used hookah. Chapman had by then became a contractor and entered into the business side of pearl diving, while the rest of them became subcontractors.

Use of oxygen in decompression

Badger had numerous incidents of DCS. He spoke to his friend Rick Poole from ProDive in Coogee about his mode of diving. Rick introduced him to two salvage divers, one of whom was Bill Fitzgerald who suggested, in 1976, to Badger that he might try oxygen at 9 m (30 ft) for decompression. He used non-static rubber hose and AGA full-face mask for this procedure.

The use of oxygen for decompression was kept very much a secret. Badger started using oxygen for only 5 minutes at the end of the day but gradually the amount was increased to 30 minutes at a time depending on the depth of the dives. He did not use oxygen between dives. His technique was noted by others, yet because of the secrecy surrounding this practice, no one knew what he was doing. However as he could hear engines being started up in the night to put divers in the water for recompression as cases of DCS continued to occur on other luggers, Badger felt obliged, for humanitarian reasons, to divulge his secret technique and told others about his technique of oxygen decompression in the water.

In time, Badger was asked by Alec Myer, the managing director of PPL to teach the Japanese divers in the use of oxygen in decompression. Badger wrote a 5 page document explaining the reasons and technique. Farley learned the technique and developed his own system and applied it after some drift dives during the day as well as at the end of the day.

Ascent rate

Initially when hookah was used in the industry, the standard rate of ascent of the USN Decompression Table was adopted and this continued for about 4 years. Badger made the observation that divers who ascended slowly did not seem to get DCS, particularly the old hard hat divers who were accustomed to a slow rate of ascent. Furthermore, his previous experience as an abalone diver had convinced him that a slow rate of ascent was safer and after some deliberation, he advocated a slow rate of ascent, hand over hand on the shot rope. This was not adopted universally within the pearling industry. The Japanese who switched over to hookah also ascended slowly but had no specific timing, but it was faster than hand over hand.

Development of the deep profiles (28-37 m)

Since the hard hat diving days of the sixties deep waters had not been dived. In 1981 a new patch of ground was discovered with large shells at depths of 28-35 m. Initially, the divers were not sure how to dive to this depth using the new equipment, except that it should be done with great care, because of the serious DCS symptoms which had affected the old hard hat divers in this depth range. However when using the USN Decompression Tables they could not achieve the desired number of dives, so a differemt way of diving had to be devised.

The only people with any experience of diving these depths were the Japanese divers, but they were very secretive about their diving techniques. However one Japanese head diver, Takata, was prepared to talk about the various techniques with Badger.

Initially, when diving in waters deeper than 30 m, Badger emulated the Japanese and did 8 dives with 30 minutes bottom time in the day. The ascent scent rate was slow, hand over hand on the shot rope, with a decompression stop at 9 m (30 ft) for 5 minutes followed by a slow ascent to the surface. The ascent from the bottom took about 20 minutes. The surface interval was to be no more than 20 minutes, as he had observed that longer surface intervals would produce DCS cases. This technique produced a significant amount of DCS which caused Badger to reduce the number of drift dives from 8 to 7 a day. After drift 7 all the divers would decompress on oxygen. The decompression procedure would take 3 hours (1.5 hours on air and1.5 hours on oxygen). They had 4 divers in the water at the same time. They decompressed in pairs, one on air and the other on oxygen, for 30 minutes then the divers would switch breathing gases. Each gas was on a separate line with a separate regulator. This technique was a secret between 1979 and 1981. This mode of diving formed the basis of the susequent “non-rotational” dive schedules.

Badger experimented with oxygen between dives and found that divers still suffered from DCS if the ascent rate was too fast, irrespective of oxygen usage. He decided upon a slow ascent rate and made use of oxygen decompression only at the end of the day after the last drift. He gave up the use of oxygen between drifts. He believed, as did the Japanese, that post dive physical exertion was detrimental, so his divers did not clean shells after their dives. With different opinions and experiences the various key figures developed their own diving schedules, all aimed at maximising bottom time in the daylight hours.

Badger also believed that each diver has his own decompression time. Some of the younger and fitter divers could get away with little or no decompression, whereas he felt that he needed more and more decompression time, especially as he got older.

Farley and Nunn, on the other hand, developed their own system and decided to use 2 teams of divers, thus saw developing the "rotational schedules". Instead of having a fixed 20 minute surface interval, the rotational schedules had surface intervals from 60 minutes upwards, depending on the depths of the dives. The drift dives were 35 minutes each. The rate of ascent used was also slow and oxygen was used in decompression between drifts as well as at the end of the day. Decompression was initially on oxygen at 12 m (40 ft) followed by air at 3 m (10 ft). Surprisingly no convulsions, which would have almost certainly led to drowning, were reported. During the 1980s the oxygen stop was changed to 9 m (30 ft) but even as late as 1987 at least one company regularly decompressed divers at 11 m (36 ft) on oxygen.

When on deck, the divers would clean pearl shells. Farley's method of provicing oxygen was to turn a switch on board the vessel which would deliver oxygen instead of air to the diver's regulator. Badger believed that there was an inherent danger in this because a diver could be switched to oxygen while at depth.

Treatment of DCS with in water oxygen

Until Badger experimented with oxygen the industry, on the whole, treated DCS with in water recompression using air. Farley suffered numerous episodes of DCS. His treatment initially was to return to the depth of dive then ascended slowly to 9 m (30 ft) for 30 minutes and then to 3 m (10 ft) for 60 minutes. Badger suffered as many as 42 episodes of DCS, affecting his hips and elbows. His first experience of DCS was a rash, initially he tried oxygen using an OxyViva on deck, and in his words, "it was a waste of time". He successful treated himself with in water oxygen recompression at 9 m (30 ft). He used a full face mask as he felt the safety of voice communication a necessity. From his experience, he worked out that if pain disappeared within 3 minutes, then 30 minutes of oxygen was adequate. However, if pain lasted longer than 3-5 minutes, then he would need 1 hour of oxygen. None of his divers, who were considerably younger than himself, needed more than an hour of oxygen. Badger himself needed more oxygen and he tried a combination of air and oxygen, with 30 minutes each.

Thus, the diving revolution for pearling started in Broome in 1971, with different developments by the few individuals. Despite the secrecy surrounding the changes, in time, the new techniques were adopted by the industry. From the 1970s to 1990, the techniques of diving were as varied as the number of pearling companies, but most adopted the slow rate of ascent. Decompression technique was variable, especially with the use of oxygen. Various companies used a combination of air and oxygen decompressions. Nonetheless, they shared some common features.

Profiles of the 1980s

The profiles below came from the largest pearling company of the time, therefore could be considered as typical. There were only a few companies, all diving to profiles very similar to the ones described below with only minor variations.

As in the hard hat diving days, pearl diving was still divided into shallow, mid and deep waters. Surface interval was of no consequence being related to the time taken to get into position for the next drift dive. The profiles were determined by shell quantity and availability at the dive sites. Nevertheless, they would still dive from sunrise to sunset.

The profiles below are divided into shallow, mid and deep waters. But the depth range around 21-28 m (70-93 ft) was not covered. This was because the pearlers had learned from experience that there were virutually no shells in that depth range, the shells were either in shallow waters or in deep waters, therefore experience in 21-28 m (70-93 ft) was very limited.

SHALLOW WATERS LESS THAN 40 FEET (12 M).

Bottom time was dependent on the quantity of shells on the seabed. The divers might stay as long as 2 hours. If the bottom time was 2 hours, then there would only be 4 dives per day. If shells were scarce at a particular patch, the divers would surface. The total number of dives and bottom time was therefore dictated by shell availability. They dived fbetween 4 dives and 14 dives a day at this depth. The ascent rate was slow, hand over hand on the shot rope, perhaps at 6-9 m (20-30 ft) a minute. In these shallow waters, no decompression was called for.

The divers also adhered to the rule of no hard physical work after diving. They used to dive for 7 consecutive days during the neap tides.

MID-WATERS AROUND 50-65 FEET (15-20 M).

Again the profiles were dependent on shell quantities. Bottom time was more than 20 minutes and less than 60 minutes. The ascent rate was slower than in shallow waters. They also stopped diving an hour before

sunset in this depth range.

The first decompression stop was before lunch, at 3 m (10 ft) for 10 minutes. This depth of decompression stop was borrowed from the US Navy Tables. The divers would use the pearl diving profiles, but add what they thought was good or appropriate from the USN Tables. If the tides were strong, another 10 minute at 3 m (10 ft) decompression stop would be done in mid-afternoon. At the end of the day, decompression was at 3-5 m (10-15 ft) for 15-20 minutes.

Surface intervals were 10-40 minutes dependent on shell availability and the weather. Visibility was another important factor. A south-westerly wind and rising tides could make conditions rough and another decompression stop would be added in mid-afternoon.

During the decompression stop, if the wind was strong and the tides were large, the boat would rock which would make decompression stops difficult. The divers devised a method to counteract this. They tied a metre long rope to the shot line, the diver either tied the end of this rope around his body, or made a large loop where the diver could sit (Bosun's chair) during decompression. This method minimises the up and down movement of the diver.

DEEP WATERS BETWEEN 29 AND 37 M (97 AND 122 FT), AVERAGE OF 33-34 M (110-113 FT).

This depth range had not been dived since the 1960s because shells were plentiful in the shallower ranges. In 1981 due to a high mortality rate (some 90%) among the oysters, the shell quota was lifted and pearlers were allowed to dive all year. A new patch of oysters was discovered at a depth in excess of 28 m (93 ft), so the deep water range was dived again. Previously, adequate shells had been found in shallower waters. In 1981, oxygen was adopted generally for decompression within the industry and also conventional decompression tables were studied, adopted and modified. Oxygen was first used for decompression in these deep dives (notwithstanding Badger's secret experiments with the use of oxygen since 1976).

In this range, the bottom time was strictly adhered to and was to be 30 minutes.

The initial ascent rate from depth was slow, but at a rate faster than 6-9 m (20-30 ft) a minute used in the 12 m (40 ft) dives. The divers used this ascent rate to about 15 m (50 ft) then they slowed the ascent rate to 9 m (30 ft) where they switched to oxygen. They breathed oxygen for 5 minutes after the first dive and, empirically, an extra 5 minutes was added after each dive. Therefore the decompression stops were 5 mins for the first dive, 10 mins for the third, 15 mins for the fourth, 20 mins for the fifth and 30 minutes after the last dive.

Surface interval was again not taken into consideration. However, this depended on who the skipper and head diver were and whether they were diving to the rotational schedules or the non-rotational schedules. Everyone was interested in achieving the maximum bottom time during the daylight hours. They paid attention to the ascent rate which was to be slow. They had learned from experience that a fast rate of ascent caused DCS. Descent to depth was to be fast, as they believed a fast rate of descent would break up bubbles.

Some divers interviewed in the 1980s indicated that it was common to be tired, moody and irritable while at sea. It appeared that "niggles" were more common in the winter months. They were treated with either Panadol or with in-water oxygen recompression. The sites of pain tended to be the elbows and shoulders and hardly ever affected the lower limbs as in the hard hat diving days.

CASE 4

DA worked as a diver in the pearling Industry between 1977-1989. He was taught to dive by friends. Later, he obtained commercial qualifications in Newcastle, so he is also well versed in the conventional mode of diving. DA suffered about 12 to 15 epiosodes of DCS affecting mainly his left knee. Other joints such as shoulders and hip had also been involved. He indicated that all these DCS occurred after diving in deep waters. He never had any incidents from shallow waters diving.

During his diving career, he could not recall any serious incidents of DCS in the industry apart from one grossly obese diver who suffered spinal DCS after diving at the 18 m (60 ft) range. That diver was transferred to Perth for treatment.

Treatment of Decompression Sickness

Virtually all cases have been treated with in-water oxygen recompression since the introduction of oxygen to the industry. Oxygen was used to recompress at 9 m (30 ft) . The patient stayed at 9 m (30 ft) for 30 minutes and if they were improved, they would surface. However, if there were still symptoms, they would stay an extra 15 minutes. The ascent took from 15 to 20 minutes, about 2 m (6.3 ft) a minute. The number of cases so treated are not known as no records were kept. The yearly total was estimated to be around 30 to 40 incidents of niggles.

In the 1980s, a number of cases of DCS were treated in the RAN facilities near Perth. These were more serious cases where either in-water oxygen recompression was unsuitable or did not relieve symptoms. However, they were virtually all from oyster farm divers. Until recently this group of workers was not covered under the Pearling Act and were not required to have a medical examination

Figure 7. Inside the new Broome recompression chamber.

for compressed air diving. Until the late eighties, medical examinations were performed in accordance with the requirements of the Western Australian Pearling Act of 1912. The Medical Form was inadequate for the medical examinations of divers, which were performed largely by practitioners with no training in dfiving medicine.

In 1987, the pearlers formed an association called the Licensed Pearl Producers Association but each company still dived to its own profiles. It was not until 1990 that the new Pearl Producers Association Inc. agreed to dive to a set of profiles produced by the association and printed in their Code of Practice[1] and a recompression chamber was purchased (Figure 7).

Discussion

The pearl diving of bygone days shows that it was possible to do repetitive and multi-day diving, albeit at a high price. The incidence of DCS was not accurately recorded, but the technique used indicated that the following factors were important in avoiding DCS.

1 a slow rate of ascent,
2 the importance of decompression stops,
3 the depth of decompression stops, at 7-8 fathoms (13-14.5 m or 42-48 ft),
4 surface intervals were considered of little importance but have caused many problems in deep dives,
5 avoidance of post-dive exercise,
6 the use of oxygen to aid decompression, which was introduced in 1981 for use within the industry, although experimented with in 1976 by Badger.

These various factors used to improve safety in pearl diving are discussed in another paper.[1]

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Key Words

Deaths, decompression illness, history, hyperbaric facilities, occupational diving, oxygen, tables.

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