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# BRITISH CAVE DIVING ACCIDENTS

by
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## ABSTRACT

A description is given of cave diving accidents to British cave divers between 1946 and 1978. Eleven fatal accidents are described, of which the causes are generally multifactorial. Thirty-four non-fatal accidents are also mentioned and described under causal headings; it is shown that equipment failure or guide-line problems were present in 27 of these. During the 22 year period from 1957 to 1978 there were seven fatal accidents affecting cave divers in cave dives in the British Isles. During the same period it is estimated that 4338 man-cave-dives were undertaken, giving a death rate per man-dive of 0.161%. During 1976 the British Sub-Aqua Club (B.S-A.C.) recorded 5 deaths in a total of 437,863 man-open-water-dives, a death rate of 0.0011%. This difference is highly significant. Some of the methods of preventing accidents, or of correcting them, are discussed.

## INTRODUCTION

In September 1977 an International Cave Diving Camp took place on Mendip, associated with the Seventh Congress of the International Union of Spelaeology (U.I.S.). At this camp one of the authors (R.A.C.) was asked by the Chairman of the Cave Diving Commission, F. T. Piskula, to undertake the reporting of British cave diving accidents. Subsequently this task expanded into the present paper and the co-author (O.C.L.) assisted with research and references.

The material used was initially collected from personal communication and memory but, as the paper developed, we acquired references to all the published incidents and in doing so found further incidents worth consideration. We also tabulated our material and did some statistical work. Certain problems were encountered in collecting information. Many divers are embarrassed by their mistakes and consequently are reluctant to report potential accidents. However, they may sometimes be happier to report equipment malfunctions than more personal errors, so that the proportions between these in the Table may not represent the true state.

No attempt has been made to mention or deal with any of the non-fatal accidents or problems encountered by oxygen divers, because their problems are no longer relevant. Confining the study of non-fatal accidents to divers using open circuit compressed air sets has the advantage of giving a homogeneous group of cases, comparable with others and relevant to today's problems.

## HISTORICAL NOTES

Cave diving in Britain started with improvised surface demand apparatus in Swildon's Hole, Somerset in 1934 (Balcombe 1953) and was

followed in 1936 at Wookey Hole by the use of the 'hard-hat' surface demand suits, with heavy boots and a lot of lead, provided by Siebe-Gorman and Co. World War Two interrupted these operations and the Cave Diving Group (C.D.G.) was formed in 1946, when the equipment used was war-surplus oxygen re-breathing apparatus, with counterlung. Much lead still had to be carried for bottom-walking, as finning is scarcely practicable with such a set. There was some use of nitrogen-oxygen mixtures for diving below -9m. during the late 1950s, but after Waddon's death in 1962 the oxygen rebreathing set was abandoned. Led by Boon's example the Group changed over to open-circuit compressed air diving, using fins and wearing wet-suits (Boon 1966). By 1964 these diving sets were easily available commercially and the practice of cave diving spread rapidly. The cylinder used was generally the 'tadpole', a 750 l. cylinder formerly used by the R.A.F. in the war, but as this became obsolete, so larger cylinders came into use, particularly the 1133 l. cylinder at a working pressure (W.P.) of 150 ats. Details are to be found in the Appendix. By 1971 the carrying of two completely separate sets of breathing apparatus with pressure gauges, knife or cutters, compass, depth gauge, line reels and writing materials had become more usual. Spare lighting in the form of helmet-mounted torches became standard after about 1976, and in 1975 Statham and Yeadon pioneered the use of the neoprene dry suit (Statham 1975). This enables the diver to remain warmer and to carry more air. In the last few years spectacular advances have been made using this type of dress, as freedom from cold enables much further cave penetrations to be made, despite the drag of the suits.

## TABLE OF ACCIDENTS

In this Table the fatal have been separated from the non-fatal accidents because, although they have been studied more carefully, the true causes of the accident can never be certain. In the non-fatal cases, however, a fair degree of certainty exists.

| TYPE OF ACCIDENT | NUMBER OF CASES | |
|---|---|---|
| | 34 Non-fatal | 11 Fatal Cases |
| Equipment failure, total | 15 | 3 |
| Unsuitable apparatus | | 2 |
| Leaks from hoses or taps | 4 | |
| Downstream leaks | 2 | |
| Exhaust valve defects | 5 | |
| Gravel in valves | 1 | |
| Pressure gauge defects | 2 | 1 |
| Fins | 1 | |
| Guide line problems, total | 12 | 6 |
| Junctions | 2 | |
| Pulling line into narrow sections | 4 | |
| Lines cut, broken or missing | 3 | 1 |
| Knots coming undone | 1 | 1 |

| | | |
|---|---|---|
| Tangled lines | | 1 |
| Closed loop | 1 | |
| Losing the line | 1 | 2 |
| Faulty signalling | | 1 |
| Weights | | |
| Underweight | 1 | 1 |
| Overweight | 1 | 1 |
| Air margins overrun | 1 | 8 |
| Tight passages | | 2 |
| Alcohol | 3 | |
| Inexperience | | 3 |
| Cold | 1 | |

## FATAL ACCIDENTS

In the 33 years following the formation of the C.D.G. eleven British cave divers have suffered fatal accidents while diving. Some were not members of the C.D.G. and one was a member diving abroad. The cases are described in chronological order. The sources of information are given in each case. Many of the sources are unpublished.

### 1. JAMES GORDON INGRAM-MARRIOTT

9th April, 1949. Wookey Hole, Somerset. ST 532.480
Sources: Editorial, 1949.

Marriott was a very competent and experienced diver, having spent some 500 hours under water. His caving record however was almost nil: one dive in Peak Cavern. At this time it was a rule that new divers make at least two trips to the 7th Chamber in Wookey Hole, before proceeding to Nine, but in view of Marriott's exceptional record one trip to Seven was judged enough. After a dive to the Ninth Chamber and an inspection of Eleven by two of the other divers, Bob Davies and Marriott prepared to return to Three. This they did from 9:2 by way of the Second Loop (now called Coase's Loop) to Eight. Here Davies selected the correct guide line and gave it to Marriott and they followed it through the thick mud with Marriott in the lead. At one point near the middle of Eight Davies thought that his light had gone out, but found that it was simply an extra thick patch of mud. He proceeded back to Three assuming that Marriott was still ahead of him but on arriving there it was evident that Marriott was missing. He was found shortly after, lying along the line, head down, facing upstream, three metres upstream of 6:2. His oxygen bottle was empty but still turned on and his counterlung was flat, which meant that he had run out of oxygen. Subsequent inspection of his equipment showed that there was a fault in his test pressure gauge.

### 2. E. JACK WADDON, aged 30.

3rd November, 1962. Mineries Pool, Priddy.
Sources: Lloyd, 1967 and three unpublished reports.

Waddon was using a home-made oxygen rebreathing apparatus made up of components which were designed for other purposes. The details are rather complicated and are no longer relevant to today's problems. In brief he was receiving far less oxygen than he had intended and suffered a carbon dioxide build-up. He tried to release his weight belt but lost consciousness and remained in the water for one hour and ten minutes before being rescued. He was saved from drowning by the use of a full face mask, which was still in position at rescue. Although suffering from pulmonary oedema, resuscitation resulted in a return of spontaneous respiration but he died in hospital an hour later.

3. GARY JOHN McELLIOTT, aged 24.

10th March, 1963. Deep Ecton Copper Mine, Warslow, Staffs. SK 097.584.

Sources: Lloyd 1967 and two unpublished sources.

McElliott was not a caver. He was diving with a local branch of the B.S-A.C. Along the adit to this mine are some deep shafts, which the party were exploring. About 30m. down one of these shafts there was believed to be a side passage. He borrowed a twin-set air-lung which had already been used that afternoon, so that one bottle was empty. It was estimated that the remaining air would last for 10 minutes at -30m., which was perhaps a bit optimistic, but he was an experienced diver. The signalling system arranged was: one pull, alert; 2 pulls, pay out more line; 3 pulls, take in line; 4 pulls, pull me up; 6 pulls, 'I am going to enter the side passage.' This is different from the standard B.S-A.C. code which then, as now, was 1 pull, alert; 2 pulls, stop; 3 pulls, go further from base; 4 pulls, return to base; 6 or more pulls, alarm.

The dive lasted for between 5 and 10 minutes. He went down about 30m. and gave six pulls. He then gave 2 pulls and was given a total of 73m. of line. Two more 'pulls' were received after that, but soon after he failed to respond to signals and was eventually pulled up dead. His gag was not in his mouth, his weight belt was missing and his bottles were empty. At post-mortem death was found to be due to pulmonary oedema, probably due to anoxia or 'squeeze'.

Clearly he had not been allowing a sufficient air margin and it would seem that he removed his weight belt when he ran out of air. Rope signals are at best difficult to interpret but the difficulty is compounded, when an unorthodox signalling system is used.

4. ALLAN CLEGG, aged 35.

29th March, 1964. Lancaster Hole, Casterton Fell. SD 664.807

Sources: Editorial 1965, Lloyd 1967 and two unpublished reports.

Clegg was skilled and experienced both at diving and caving. His last diving operation was in Lancaster Hole at the main downstream sump of the master cave. At the end of the dive some of the diving line got washed back into the sump and Clegg went in to free it. The dive proceeded normally for four minutes but after that his exhaust bubble pattern indicated overbreathing. He was in open water 9m. from base.

Then for half a minute the bubbles came continuously, which indicated that the gag had come out of his mouth, and his light became motionless. The stand-by diver found that Clegg had got stuck in the line but within one and a half minutes he had been freed and brought ashore, when artificial respiration was given, followed after twenty minutes by external cardiac compression. There was never any sign of recovery and at post-mortem death was found to have been due to drowning.

Much of the 1965 report was devoted to criticism of Clegg's apparatus. He was using a side-mounted 'tadpole' containing 740 l. of air and a twin hose regulator with no neck-retaining strap. There were two disadvantages here, one that a regulator designed for symmetrical back-mounted cylinder was being used in an asymmetrical arrangement. This meant that the gag would tend to be pulled from his mouth to one side. The second is that, having no neck-retaining strap, he might well find it difficult to replace the gag in his mouth once lost.

Amongst the C.D.G. Committee's recommendations there are three which stand out:

1. Twin hose regulators must not be used for cave diving.
2. A neck retaining strap for the gag must be worn.
3. The danger of getting tangled in line under water necessitates the carrying of a knife or cutters.

### 5. ROY WILKINSON

13th May, 1967. River Yore, near Hawes.
Sources: Pearce 1967.

Wilkinson had just completed his first open water training dive, wearing a wet suit, mask, small cylinder of compressed air, single hose valve and weight belt. While walking in the river under a bridge he inadvertently stepped off a ledge into deep water, sank and drowned. The body was recovered a few hours later.

The fact that he was over-weighted and had no fins indicates that he was being trained in bottom-walking. The absence of a quick release mechanism on the weight belt was quite normal among cave divers. The emergency which Wilkinson faced was one which any trained diver could have overcome with ease, but he had only just started his training.

### 6. ALAN ERITH, aged 21.

3rd October, 1970. Keld Head, Kingsdale. SD 696.766
Sources: Editorial 1971 and Statham 1975.

Erith's caving experience was six years but his diving experience was nil. He bought all his diving gear on the day before his dive, put it on and went straight into the resurgence, dived for 9m., lost the line and came out very shaken. His cylinder pressure had gone down from 125 to 110 ats. He had a cigarette with his companions and then went in again. Movement on the line was felt for 20 minutes. After 30 minutes the C.R.O. was called. The body was found five years later in the Marble Steps Passage, close to the line, 146m. from base.

Erith ran out of air due to some gross miscalculation. Assuming that his was an 1133 l. cylinder with W.P. 150 ats., then 110 ats. would represent 821 l. This might be expected to last, at an average depth of -7.6m., for 16.7 minutes. In fact the story suggests that he made it last for 20 minutes, which fits quite well.

7. PAUL HEINZ ESSER, aged 21.

13th February, 1971. Porth yr Ogof, Powys. SN 927.124
Sources: Editorial 1971 and reports.
An updated plan of the cave is shown in Fig. 61.

The upstream part of the submerged river in Porth yr Ogof is complicated. There are three surface openings: the Top Entrance (A), the Cwmbran Entrance (B) and the 'Tradesman's Entrance' (C). Entrance A is by a tight underwater passage with static water for 22m. which then meets the main streamway at a four way junction. Entrance B reaches the main streamway after 3m. Entrance C is the main diving base for upstream work. Half-way between Entrances C and A is the Rawlbolt Chamber, an air bell where the diving line is belayed.

In 1971 the most recently laid line was a blue tagged one laid by John Parker on 26.9.70 from Entrance A upstream, the total distance being 143m. (Parker 1970). He concealed the belay in a crack under the water inside Entrance A. Besides this line there was another going downstream from the four way junction and many bits of loose line which were impeding exploration.

Esser was a competent open water diver, who had taken to cave diving during the previous autumn and was showing great promise as a trainee. The three other divers present were competent trainees. Esser undertook to enter by Entrance C and proceed upstream to the Rawlbolt, winding in loose line as he went and emerging at Entrance A. The other three were to do a practice dive from Entrance C to the Rawlbolt and back. Esser was fully briefed the night before by Parker, who knew that part of the cave very well. Esser and Lloyd started by going to Entrance A to inspect Parker's belay. They found no line there and assumed that this was because it had been satisfactorily concealed. In fact it had been washed downstream.

Esser entered by Entrance C taking with him a single cylinder of air containing 1200 litres, Spartan Titan II valve with pressure gauge, knife, compass, watch and an empty line reel for taking up loose line. The diving line was broken just inside Entrance C and they mended this with another 3m. of line. A quarter of an hour later the other three entered the same way. In the Rawlbolt Chamber they met Esser, who had collected a lot of line, which he proceeded to wind onto the spare reel. It was thin line without tags, probably from Cobbett's Loop. He then proceeded upstream. The other three waited a bit and then returned. The water temperature was about 6°C, which is very cold.

It now seems evident that what happened to Esser was that on going upstream from the Rawlbolt Chamber, by way of the oxbow with air space, he came across the blue tagged line trailing loose in the

stream. He took this onto his line reel, starting with the end that Parker had belayed just inside Entrance A and winding it up as he went. He then made the mistake of leaving the line he was following, which could have led him back to base, and following the blue tagged line upstream, still reeling it onto his reel. After about 30m. he must have realized that he had cut off his own retreat but, believing that the line ahead led to Entrance A, he dropped the line reel and made a dash for it. His other serious mistake was in not watching his air margins. Had he done so he would have started back much earlier. It is not possible to account for these mistakes.

8. ROGER ANDREW SOLARI, aged 26.

15th June, 1974. Agen Allwedd, Llangattock. SO 189.159
Sources: Farr, 1974.

Solari was very experienced both at caving and cave diving. The diving party consisted of Farr and Solari. Its object was to dive downstream Sump Four in the Mainstream. The support party went as far as Sump 1. Farr dived first closely followed by Solari. Each carried three cylinders, a line reel and a pair of boots. In the air bell between Sumps 2 and 3 they deposited their 'tadpoles', to be used on the dive out, and continued into Sump 3 on full bottles. This went uneventfully and after putting on their boots they made their way down the extension to Sump 4. The going was hard and the 610m. took half an hour. It was decided to dive together, yet independently, if at any point either diver felt uncertain or wished to turn back. They swapped main valves onto the full bottles retaining the others in reserve. Solari had two positively buoyant bottles and was underweight, while Farr's were both negative.

Solari led from base into Sump 4 laying line from a 122m. line reel, while Farr followed with another of 305m. The dip in the sump was of more than 5° and several times Solari had difficulty in clearing. This was not unusual with him. At 122m. from base and at -15m. the empty line reel was cut off and dumped, and Farr tied on his new line reel and took the lead. After about 30m. he came to a steeply ascending gravel bank. He went up this for about 12m. but found no air space. On consulting his pressure gauge he found that he had reached his safe margin, so that it was time to return.

He turned and saw Solari in the distance, reached him and signalled that they had to get out. Solari comprehended but did not actually give a signal to that effect. He looked worried and Farr assumed that this was because of his two difficulties, clearing and excessive buoyancy. Farr then dropped his reel on the gravel bank to one side and led for base. A little beyond the junction of lines (122m. from base) he swapped valves, waited two minutes and then continued out. Solari never returned. After a considerable time, during which he went back to Sump 3 for the Mars bars, carrying his empty cylinder, Farr considered using his air reserve for a dive back into Sump 4. He pulled on the line, found it slack and then pulled in altogether 131m. of it and found that it had been cut at a point 9m. beyond the knot joining the two lines. Low on air, with 131m.

of loose line and no reel, there was nothing further that he could do about it and so he returned.

The body of Solari was never found. What happened to him remains a mystery. It is reasonable to suppose that, if he cut the line, it was because he had got tangled. To do so at 131m. from base he must have got 21m. of the way back.

9. JOHN 'SHAG' SMITH, aged about 25.

28th July, 1974. Merlin's Cave, Eyam. SK 218.759
Sources: Jarratt 1974 and Whatley 1977.

Shag Smith was a good swimmer and an experienced caver but had done little diving. On a solo dive he had decided to push an unexplored static sump downstream of the main sumps of the streamway, now known as 'Shag's Sump'. It was a tight sump and he had accordingly shed his weight belt before entering it feet first. He was using a single 560 l. bottle of the 'fire extinguisher' type and a Kingfisher valve. He was using base fed line tied on to his wrist. After using 4.5m. of line he gave three tugs, which was supposed to mean that he was through, but he did not return.

About five hours later Tom Brown dived with hand-held bottle and found the body some 4.5m. into the sump. The line was still tied to his wrist. The mask was missing and the gag was not in his mouth. He was lying on his back with his eyes and mouth closed and there were traces of blood coming from his nose. His bottle was empty. It is certain that he did not get through the sump, which has since been passed at 9m. to a large cross-rift air bell (Whatley 1977). It is not known why he was unable to return. He may have lost his light as well as his mask and he used up all his air. A ruptured diaphragm is said to have been found in his valve, but it is not certain how this contributed.

10. DEREK ANTHONY TRINGHAM, aged about 25.

28th August, 1976. Cueve de Vegalonga, Tameza, Asturias, Spain.
Sources: Editorial 1976 and personal account.

Derek Tringham had started training in October 1974 and qualified on the 6th June, 1976. He was therefore only moderately well experienced. He was accompanied by his brother, Mark, who was a trainee doing one of his first cave dives.

Vegalonga is a long cave, about 1.1 km. and at a depth of 180m. there is a downstream sump about 1.2m. high by 3m. wide. Derek Tringham went in for a short dive, meaning to return in ten minutes. Visibility then was about 1m. After about two minutes the line went dead. After 25 minutes Mark Tringham dived and found that the line reel had been dropped 22.5m. into the sump. He then made a dive of 45m. into the sump reaching a depth of -15m. but could find no trace of his brother. Three days later Spanish cave divers searched the sump but could not find anything. It proved to be an underwater maze. It is not

known why Derek dropped his line reel but having done so it was not possible to find his way back to base.

This case has been included since, although it took place abroad, Tringham was a British cave diver using our techniques.

11. MICHAEL FRANK NELSON, aged about 25.

24th September, 1977. Ilam Main Rising, Derbyshire. SK 131.505
Sources: Bishop, 1978 and Brown, 1978.

Ilam Main Rising is a difficult dive, because the passage is narrow and the water flow swift. Nelson was however quite familiar with all this, having dived at this site several times. He was not a very experienced diver; he sometimes made mistakes, but he was a natural pusher and was learning fast. His previous dive at this site was to about 30m. from base at -9m. His objective was to dive to the end of the existing line, tie on his own line and explore the main stream passage beyond the block squeeze at 30m. He was carrying two 1133 l. cylinders, each valved, one with pressure gauge, one line reel of 30m. and two aquaflash lights mounted on his helmet. After he had been gone half an hour large clouds of silt issued from the entrance for two or three minutes. The water then began to clear a little. After thirteen minutes rescue was started, but it was not until five hours later that the body was found, 6m. beyond the end of the diving line, resting sideways in the streamway. The next day after several attempts the body was recovered. Much of the equipment had to be cut off to free the body, which was wedged across the passage.

On 30.10.77 Brown (1978) and Papard removed the rest of Nelson's equipment. Nelson's line was not tied to the old line. Both bottles were empty. Both valves were Kawasakis. The purge buttons jammed two out of three times when tried out of water. On stripping the valves down Brown found sand in both stages on both valves but probably not the cause of any malfunction. Before cleaning, both valves worked on a full cylinder.

It is not quite clear why Nelson got stuck. It may have been simply the nature of the passage and of his equipment. On the other hand he was known to be not very good at tying knots and his knot may have come undone, so that he was unable to find his way back to base. In either case he ran out of air.

## NON-FATAL ACCIDENTS

### EQUIPMENT FAILURE

*Leaks from hoses or taps.*

Popple Hole, Dentdale (Perry 1976). The diver rotated his cylinder several times, while trying to pass a narrow spot with his equipment hand-held. In doing this the second stage hose partially unscrewed from the first stage of the valve. The result was an unpleasant air leak, which he coped with by turning his cylinder valve off until he wanted to breath.

Stoke Lane Slocker, Somerset (Drew 1965). A diver in this cave, which has short restricted sumps, twice knocked his first stage valve partially off his pillar valve, causing O-ring seal failure. He was able to get out quickly.

Personal communication has revealed at least three other cases of O-ring failure on the A-clamp adaptor during the 1970s.

The normal bottle valve now used by the Group is the Draeger-Normalair international thread fitting. This can have either a direct screw fitting to the first stage of the regulator, or can be connected to its A-clamp by means of a Filling Adaptor.

During some of the exploratory dives in the Little Neath River Cave (L.N.R.C.) at least three instances occurred of a backward leak, due to failure to expand of the washer between the gland nut and the spindle. This could be cured by turning the tap full on, which compresses this washer. However, it is then difficult and time consuming to turn the bottle off, should a leak develop in other parts of the apparatus.

Wookey Hole, 1977. A trainee diver found that his bottle tap had jammed solid in the off position. Later, when stripped, it was found that the spindle head had broken up. This is an exaggerated example of the commonest failing of the Draeger-Normalair tap. When turned off too hard the nylon washer on the spindle head is forced into its brass setting, which cracks up, leading to a downstream leak. Bottle taps should never be turned off too hard. If they develop a downstream leak the spindle head needs renewing.

Wookey Hole (Lloyd, 1978). A diver's second stage hose burst near the first stage, where it gets bent. He was only two metres into the sump and exited on his spare set.

Ogof Afon Hepste (Anon. 1970a). A diver got a severe first stage leak in Sump 3, which is long. He returned hastily, turning off his bottle except when breathing. It is probable that his pressure gauge hose had worked loose.

*Downstream leaks.*

White Lady Cave, Ystradfellte (Lloyd, 1968). A diver developed a second stage leak in a restricted muddy sump and had to return by manually controlling his air supply. He gave the alarm signal but the standby diver was unable to get through the constriction.

Ogof Fach, Penderyn (Churcher, 1972a). This cave has a very muddy silted third sump. Somehow mud worked its way into the first stage of the valve, a U.S. Divers Deepstar, jamming it open. The diver returned by turning his cylinder valve on and off.

*Exhaust valves.*

Stonelands Cave, Littondale (Anon, 1974). A diver had smeared his exhaust valve with petroleum jelly during routine maintenance, instead of silicon grease. This caused it to crinkle and leak, causing flooding of the second stage.

Wookey Hole (Anon 1970b). A diver using a Swedish Poseidon valve experienced total collapse of the second stage diaphragm, which tore. It was possible that this was due to excessive use in chlorinated swimming pools, followed by lack of maintenance.

*Gravel in valves.*

L.N.R.C. (Walford 1971). When diving with two sets it is customary to clip the spare second stage gag strap through the one in use. With open valve mouthpieces this allows grit to enter the spare second stage, so that when the diver comes to swap gags grit enters the exhaust valve and may cause a leak.

*Regulator valve defects.*

Kingfisher valve: an English valve made by Submarine and Safety Engineering Ltd. with an international thread adaptor. This valve was initially much favoured (Cobbett, 1971) being cheap and apparently good. In practice the first stage could unscrew itself from the adaptor and pieces fell off, including the mouthpiece and exhaust fins. The purge button could also jam inside the housing, permanently turning the valve on. However, all divers managed to extricate themselves. (Churcher 1972a and Editorial, 1974).

Poseidon valve: a well known Swedish valve. One diver failed to refit a retaining surclip on the exhaust assembly, so that, when diving in Wookey Hole, the whole of the end of his valve fell off. He extricated himself with a second set (Bishop 1979).

Scubapro valve: recently very much favoured in Somerset. Mud can work its way into the purge button housing, causing it to jam on in use (Personal observation of author and Cork 1979).

*Pressure gauges.*

One pressure gauge which achieved popularity in 1969-70 relied on a plunger moving up a scale, so that it could be felt by finger in poor visibility. In use the spring tended to corrode and give falsely high readings (Reynolds, 1970 and Wooding, 1970).

*Fins.*

These are of two general types, the shoe type and the slip-on type, which has a heel retaining strap. Divers occasionally mention in conversation losing a fin temporarily, and usually comment on the difficulty of swimming with only one fin, or of replacing one which has fallen off. Shoe fins are perhaps better from this point of view, especially as fin-retaining straps can be used with them. Slip-on fin heel straps have buckles, which occasionally break or snag the line (Murland, 1980).

## DIVING LINE PROBLEMS

*Junctions of the line.*

Wookey Hole (Anon, 1977). This cave is extensively used by the Somerset Section of the C.D.G. for training dives. On at least two occasions divers have come out of Coase's Loop near 9:2 and have taken

the upstream line instead of that leading to the 9:2 water surface. In Wood's case he ended up in Wookey 20 and had to be rescued. In Nelson's case (Lloyd, 1978a) he returned after realizing his mistake. Similar mistakes have been made in Keld Head, where there are a large number of underwater junctions.

Circular loop (Anon, 1979). In 1975 while attempting to connect two caves the following incident took place. The diver had previously dived in Cave A, leaving the line in. He then attempted to connect with this from Cave B, diving in 100m. to -20m. He found what he believed to be the Cave A line, joined onto it and cut off his line reel. Realizing he was running short of air, he decided to return but found himself returning twice to his own junction. He eventually solved the problem by untying his own junction. Following the line back he eventually realized that he had not connected Cave B to Cave A at all, but had in fact merely made a large oval loop at the end of Cave B. He reached base with no air margin.

*Pulling the line across into cracks.*

Keld Head, Kingsdale (Statham, 1978). During the world record breaking dives made in this cave a visiting German diver got into severe difficulty by accidentally pulling the line a considerable distance across a complicated bedding plane, later named 'Dead Man's Handshake'. He eventually found his way back.

Dub Cote Cave, Horton-in-Ribblesdale (Churcher, 1972b). The 200m. Sump 3 in this cave turns a sharp corner before surfacing and is partially blocked by a black silt bank, which can easily reduce visibility to zero. On two occasions a diver had difficulty returning through this area, having pulled the line across the silt bank. Both times the diver virtually dug his way through on the second or third attempt.

Najdena Jama, Yugoslavia (Churcher, 1972c). This is a massive old phreatic cave containing a number of static sumps. In one of these sumps a British diver returning reeling in his line found it had worked up behind an enormous wall flake and could not be extricated. He was forced to lay a line in the general direction of base, before finding the main line after 10m. or so.

Many other cases have been communicated to the authors.

*Knots.*

Knots have always been a source of danger and though the authors have known instances of a knot coming undone, it is in no case certain that it caused an accident: it may have contributed in Nelson's case. The following case is worth quoting.

Agen Allwedd, Llangattock (Baldock, 1976). While pushing in Turkey Sump a diver had not secured his line to his line reel. He simply reeled off the end and failed to notice. However, visibility was good enough for him to find his way back to it.

*Broken lines.*

Sumps in South Wales are particularly prone to this problem, due to turbulent water and sharp rock.

Porth yr Ogof (Cobbett, 1973). Two divers were stranded, fortunately in an air bell, when they found that the downstream line at base had been broken, cutting them off from return. Fortunately a stand-by diver at the entrance, realizing what had happened, was able to lay a new line up to them.

Ogof Afon Hepste (Lloyd, 1971a). An experienced diver was accompanying some trainees through Sump 2. They went through first and then pulled on the line to signal to him. It broke because it was frayed. Unfortunately they then pulled it in, so that he was unable to join them and had to borrow a line reel from another diving party.

L.N.R.C. (Churcher 1977). On returning from Sump 6 two divers found that the line in Sump 2 had disappeared. Fetching a spare line from the next chamber downstream, they were able to re-lay it.

*Losing the line.*

Ogof Tarddiant Hepste (Churcher, 1971). The line was very loosely laid in upstream Sump 1. On one occasion a diver was jumping the line from one loose coil to the next. He snagged his kit on a roof pendant in mid-jump and paused to free himself. Behind him another diver was being more cautious, collecting the line up and passing it under him. While the leading diver was freeing himself the second pulled the line away from him. Looking for the line the first diver swam around in his silt and found an air bell. Just at that moment diver number two appeared and was summarily grabbed by one fin.

WEIGHT

*Underweight.*

Keld Head, Kingsdale (Fletcher 1979 and Pickles 1979). Fletcher, wearing a new dry suit, had reached the jump line which goes up into the air bell at 213m. Proceeding up the main line he decided to inflate his suit to compensate for a slight increase in depth. The direct feed button stuck open causing the suit to overinflate, so that the diver went up to the roof. The direct feed had then become free but, when he tried to fin downwards, all the air from the chest went unto his legs, so that he was stuck against the roof upside down. By bending his legs he was able to resume an upright position and so could dump some air out of his suit.

*Overweight.*

Wookey Hole. A number of divers have reported having difficulty and overbreathing, when attempting to ascend the 12m. pitch on the Shallow Route to Wookey 20. Others have reported the results of descending this pitch overweighted, crashing head first onto the floor (Lloyd, 1970).

Dan yr Ogof (Lloyd, 1965). On this occasion a diver was crossing Lake Three on the return from having dived further inside the cave. Still weighted and carrying equipment in both hands he inadvertently stepped off the underwater ledge into deep water. His efforts to keep his nose above water were not very successful, until someone lent him a hand.

Reports of similar accidents have been received. The only really unlucky diver was Wilkinson.

## AIR MARGINS

Eight out of the eleven fatalities occurred finally from running out of air, though this was not their primary cause. Not many divers are willing to admit that they made such an apparently elementary error, as diving on inadequate air margins, but a few cases have come to light.

L.N.R.C. (Wilkins, 1975). A diver pushing Sump 8 realized too late, that he had gone down too deep for the air he was carrying. Although he surfaced safely, he then had an insufficient margin to return through Sumps 7 to 2. Fortunately the party was able to bleed air from another diver's set via the pressure gauge hose.

There have also been a number of cases, in which the diver has returned to base with no air margin, generally after experiencing unforeseen difficulties with route finding or line problems.

## TIGHT PASSAGES

Actually squeezing through very tight passages or gaps is not a pastime that appeals to many cave divers. The authors have not received any reports of non-fatal accidents from this cause, though there may have been some. It was probably an aggravating cause in the fatal cases of Smith and of Nelson.

## ALCOHOL

Wookey Hole (Wilkins, 1973). A diver had a small quantity of brandy during lunch. Diving after lunch he started to vomit just inside Sump 9 but was able to remove his gag and replace it at correct intervals, in synchrony with his vomiting.

Another diver in Wookey Hole dived one afternoon still suffering from a severe hangover. Diving from Sump 3 to 9 he suffered giddiness, sickness and disorientation when approaching -7m. at the Bear Pit. He returned safely, a relief of symptoms being apparent in shallower water. A third similar case in another cave is on record.

## NITROGEN NARCOSIS

Although not an uncommon problem in sea diving, nitrogen narcosis has hardly ever been recorded on a cave dive. Pridhamsleigh Cavern, Devon, in 1971 seems to be the exception, when narcosis was reported by a group unattached to the C.D.G. The report is open to doubt, as the maximum depth of -25m. is unlikely to have caused such a problem.

## DECOMPRESSION SICKNESS

As yet there have been no recorded cases of a British cave diver getting the bends following a cave dive.

### INEXPERIENCE

It is rather invidious to be using this heading at all, since all cave divers are inexperienced to start with. However this factor seems to stand out clearly as a contributory cause in three of the fatal accident cases, Wilkinson, Erith and Smith.

### COLD

Although cold may occasionally interfere with a diver's judgement (the case of Esser may be an example of this) there have been no accidents attributable to hypothermia. The only case in which cold was a major factor was that of Warren in Sell Gill Holes (Jeffreys, 1979) who suffered vertigo and disorientation due to cold water in the ear.

## ACCIDENT RATES

### NON-FATAL ACCIDENT RATE

Early on in this study we decided to try to compare our accident rates with those of open-water divers but in the case of non-fatal accidents this proved impossible. For one thing an accident, if not fatal, is difficult to define and for another the non-fatal accidents reported to us are probably nowhere near the total. The British Sub-Aqua Club (B.S-A.C.) defines an accident as an incident involving illness or injury. For us an accident is any case in which the diver is upset by something going wrong. A comparability study is therefore not possible.

### FATAL ACCIDENT RATE

Here a comparability study is possible, because all of the cases have been reported. The first step was to define the parameters and the second to estimate the size of the population at risk. Because the figures were readily available, a study period of 22 years was taken from 1957 to 1978 and an estimate was made of the number of man-cave-dives which took place in the British Isles during that period. We first studied the cave dives of 1978 which had been reported in the C.D.G. Newsletters and Reviews and found that the number of reported man-cave-dives was 375. This clearly was not the total, as many dives go unreported. So we wrote round to all the divers who had the highest totals to find out what their totals really were. We found that the unreported dives were almost exactly one third of those reported, so that the figure 375 for 1978 had to be raised to 500.

The C.D.G. has always reported dives by non-members equally with those of members, so that this figure is probably quite near the total for the study area. It does not include dives in open water or outside the British Isles.

The next question was, is it reasonable to add this figure of one-third of the reported dives to the total of reported dives during every year of the study period? We think it reasonable. In this study period

therefore of 22 years there has been an estimated total of 4338 man-cave-dives. Of the 11 fatal accidents under consideration four have to be excluded in calculating the case rate. These are Marriott 1949, which is outside the study period, Waddon and Wilkinson, both in open water and Tringham (Spain). This leaves us with seven fatal cases, which gives a case rate of 0.161% deaths per man-cave-dive.

For comparison the B.S-A.C. has reports of five fatal accidents to their own members in 1976, when the membership was 25,310 (Skuse, 1980). The diving rate was reckoned to be 17.3 dives per member per annum, which gives us a total of 437,863 man dives for that year. This gives a death rate of only 0.0011%, of the order of one hundredth of ours. Statistical analysis shows this difference to be highly significant ($P = 0.007$).

A comparison may also be made with some American figures. The number of cave diving deaths which took place in Florida in the ten year period 1970 to 1979 was 130. The estimated number of man-cave-dives per annum was 500,000 (Exley 1980). This gives a death rate of 0.0026%, which is much nearer the B.S-A.C. figures than ours.

## DISCUSSION

Examination of the Table of Accidents shows that there is but a single recorded factor in each of the non-fatal accidents, but that the fatal cases are multifactorial. This illustrates the fact, well known to cave divers, that if only one thing goes wrong, you can usually put it right; but that if two or more things go wrong at once, you are in serious trouble.

*Equipment failures.*

It is rather surprising to find equipment failures so high on the list of non-fatal cases and so low on that of fatal accidents. General opinion in the Group has been that they were rare. Most members tend to keep such problems to themselves, unless observed by others at the time, and to dismiss them as isolated incidents resulting from their own carelessness. Because most divers now carry two independent sets, total equipment failure is usually avoided. In the three fatal cases only one set was being carried.

Unsuitable apparatus ought to be a thing of the past. All air leaks can be controlled immediately by turning off the bottle. The second set is then brought into use. If no second set is carried, then it is possible to turn the bottle on and off each time a breath is needed, make a speedy return and hope for the best. All known cases so far have got home safely. A broken second stage hose can empty a bottle very quickly; a first stage leak even more quickly. An addition restrictor valve can be made with a disc of hard plastic, according to Hasenmayer. The disc needs to fit at the base of the socket for the pressure gauge hose in the first stage. The restrictor is screwed in afterwards. The valve needs to be scored on the outer (restrictor) surface, so as to allow air to escape

smoothly from the pressure gauge, while the pressure in the bottle is falling. It will slow down high pressure leaks from the gauge or its hose.

Exhaust valve defects can be very troublesome, as it is difficult to cope with an air-water intake approaching 50 - 50. Much air (and water) tends to be swallowed in these circumstances, giving rise to belching afterwards. However, the water intake can be almost completely stopped by using the purge button just before or during inhalation. This of course uses up a lot more air. Defects in the exhaust valve can be prevented by proper maintenance. Gravel can be excluded with a little care, or by spreading some nylon stocking over or inside the mouthpiece. Care should be taken when re-tightening the mouthpiece, as one diver found out when his mouthpiece slid off the valve.

Our experience with Kingfisher valves shows that they are best avoided. Poseidon valves are good, if properly maintained. The basic defect of the Subapro valve is the open-work around the purge button, through which mud can be forced. When this happens the button jams inwards and the second stage will leak. As this is most likely to happen to spare valves, when going through muddy squeezes, use the Scubapro as the main valve but not as the spare.

The joints on the set which are most likely to come undone are those to the pressure gauge and to the second stage hoses. These should be spanner tight. The only joints for which thumb tightness is appropriate are those with O-rings. An important potential leak is eliminated by the use of the international direct thread take-off, as with the Poseidon. The place where the second stage hose is most likely to burst is just distal to its take-off from the first stage. A sleeve designed specially to protect this spot is worse than useless, as it slips down the hose, thus rendering the weak spot even more prone to bending and damage.

Always check the performance of the pressure gauge before the start of a dive. Make sure that the liquid filling the dial chamber has not been lost and that its hose is connected with the high pressure outlet on the first stage and not with the low.

Prefer the shoe-type fin to the one with buckles. Make sure that it is a good fit before starting the dive and wear fin-retaining straps. A new fin with buckles, straight from the shop, has the strap ends directed outwards. This comes undone easily. Turn the straps in the buckles so that the ends of the straps point inwards. Also secure the buckle to the ankle with a lanyard. If you lose a fin in a sump, stop and look for it and refit it, if you can. Experience shows that finning with one blade is tiring and may lead to cramp.

*Guide line problems.*

Skill in the use of guide lines is the most important attribute of the cave diver. Correctly used they are the guarantee of his safe return; misused they are the source of his greatest danger. They account for one third of the non-fatal accidents and one half of the fatal ones. A detailed monograph on how to lay lines and follow them has been prepared by Yeadon (1980). Meanwhile here are some points which occur to the authors.

1. Know the lines in the sump in question. Find out about them.

2. The number of junctions should be kept to a minimum. Many of the divers who turn the wrong way at junctions could have eliminated this problem by using a compass. Where a junction leaves a main line it should be marked with a tag on the home side of the main line. For this reason fixed loops are better than sliding loops at junctions. Line should only be joined by the interlinked loop method. When this is used all knots may be tied beforehand. One loop must always be big enough for the diver to pass the reel through it.

3. Parallel lines are best avoided, unless one is weighted well away from the other, as they may become intertwined. If a diver gets snagged by the other line and cuts it, he may conceivably cut another diver off, literally.

4. As a long term aim there must be a better colour for line than the orange-brown used at present. This becomes difficult to see when dropped in the usual orange-brown limited visibility of many British sumps.

5. If the line is lost it may be found again by carrying out a circular search with a spare piece of line. Such a spare line will in any case be useful for exploring side passages off the main line and so should be carried. If the search leads into clear water that is the wrong way. If the line cannot be found the diver must try to exit on a compass bearing, as Davies did in Wookey Hole in 1955 (Editorial, 1956).

6. Before following a line make sure it is belayed at base. The Porth yr Ogof incident of 1973 would not have occurred, if this had been done.

7. Tangles usually occur with bottle taps, harnesses or fin straps. Never pull a tangle tight. Always stop and carefully undo it. If as a last resort you are compelled to cut the tangle, make a loop in the home line and put an arm through before you start cutting. Secateurs have advantages over knives.

*Weights.*

Lack of proper buoyancy control rarely contributes towards accidents, particularly now that bottom-walking has been given up and the diver is always striving after neutral buoyancy. There is still the problem of loss of buoyancy at depth. With a wet suit the simplest solution is to try to achieve neutral buoyancy at half the maximum depth contemplated. With an inflatable dry suit a constant volume can be maintained, but this needs practice beforehand, if you wish to avoid ending up standing upside down on the roof.

*Air margins.*

The rule is: one third for entry, one third for exit and one third in reserve. This should always be the diver's aim and he should never get so engrossed in his task, that he forgets to look at his pressure gauge. When doing a through dive, he should have enough air to make the return journey, in case the far end be blocked or the line broken. Air margins are not sacrosanct. A diver must use his air margin, if he gets into trouble.

One empty and one full diving bottle may be equalized on the far side of a sump as follows. No special tools are required, if the hoses are screwed on hand tight only, but a spanner is needed, if they are spanner tight.

1. Turn off both bottles.
2. Remove valve 2 from bottle 2.
3. Remove pressure gauge and hose from valve 2.
4. Remove gauge only from pressure gauge hose 1.
5. Screw on valve 2 in its place (hope the threads mate).
6. Refit valve 2 to bottle 2.
7. Turn both taps on full. The grub screw restrictor prevents too rapid equalization.

*Cold.*

There have been no instances of a cave diving accident due to hypothermia. Frequently a report will finish with a remark such as, 'cold, miserable and browned-off, the diver returned to base', but the changes have always proved reversible. More interesting was the vertigo experienced by Warren in Sell Gill Holes. When cold water reaches the innermost part of the external ear it produces a reflex called the 'cold caloric response', which consists of nystagmus towards the affected ear and vertigo with a sense of falling towards that side. The fact that it hardly ever occurs to a diver is because there is nearly always a pocket of air in the deepest part of the external ear, so that the cold water does not reach the sensitive spot. If however the drum is perforated, then the air pocket disappears and vertigo will result. This happened to a diver well known to the authors, when snorkel diving in the sea.

*Experience.*

After a cave diver has done his pool and open water training his real experience comes with sump diving in caves. It is not the number of years that makes a diver experienced, it is a combination of two other things, first the number of cave dives carried out and second the number of sump kilometres covered. It has been argued that the latter is the more important; one of our leading cave divers has already totalled eighty sump kilometres. But to the novice in particular the experience of kitting up and dekitting is of great importance and its value increases with the number of cave dives carried out.

It is almost certainly true that the more experienced you become, the safer is your diving, because you are better able to anticipate problems and to deal with them. A word of warning is needed for those who are unfamiliar with the laws of probability. If the death rate is once in every 620 man-cave-dives, this does not mean that the 621st dive a man does is more likely to be fatal. The chances are still 1:620 for every single dive. But the odds lengthen with experience.

## CONCLUSIONS

This study has shown that, while line problems are still the most important causal factor in cave diving accidents, equipment failures are commoner than was thought. A recent study by Brandt (1980) has born this out in 25 non-fatal cases, where half had line trouble and one quarter equipment failure. Our study has also shown that there is an unacceptably higher rate of fatalities amongst cave divers, as compared with open water divers. Much of the difference may be attributed to the fact that theirs is a different sort of diving and the same may be said of the Florida cave diving. It would be nice to be able to say that experience was a defence against accidents but the facts do not bear this out. Technical innovations might be expected to help but they bring new problems with them. The role of anxiety and of other psychological problems is one that cannot be measured and they have been omitted from this study. Brandt claims that they affected the issue in 12% of the non-fatal cases.

The good cave diver is the one that has the inward driving force suitably modified by care of equipment and training in the art. The best cave diver is the one who has not only this but is able to impart his knowledge and enthusiasm to others. But we are still losing our best cave divers and the hard truth is that they sometimes will not use their full experience in preparation for the dive or during its course. As one of them has admitted to the authors: 'In every dive that I have experienced problems I have done something naughty'.

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Two special abbreviations have been used:
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2. Cave Diving Group Newsletter New Series becomes C.D.G. NL.


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## APPENDIX

A note on the open circuit compressed air apparatus used by cave divers. For a more detailed description with illustrations see Lloyd (1975).

Two types of cylinder tap are in use: the pillar valve, which has the tap at the end and the Draeger-Normalair valve, which has the tap at the side. The pillar valve outlet is provided with an O-ring for attachment to the A-clamp on the first stage of the regulator. The O-ring does not behave like a washer; it closes the gap between two metal fittings by being blown into it by the force of the air pressure. If the gap between the metal fittings is too wide, the O-ring can get blown through it. The Draeger-Normalair valve has an international screw thread outlet into which some types of regulator first stages (e.g. Poseidon) may be directly screwed. Types which only have the A-clamp need a filling adaptor. The taps in both cases work like any domestic tap. The handle which is turned is connected to a spindle which fits into the spindle head. When the tap is turned off this spindle head is screwed firmly down, so that its terminal nylon washer is against the seating. This closes the air outlet. The spindle passes through the gland nut, which is screwed firmly into the body of the tap.

The regulator (demand valve) has a two stage reduction and single hose. The first stage reduction is sometimes accomplished by a piston and sometimes by a diaphragm, but in either case the piston or diaphragm closes the air inlet against the force of a spring, which regulates the pressure in the hose leading to the second stage. There are two outlets to the first stage, one is a low pressure outlet to the second stage, the other is a high pressure outlet to the pressure gauge, which records the bottle pressure and works on the Bourdon tube principle. The second stage reduction is a downstream valve operated by a lever. This lever can be depressed either by a diaphragm operated by inspiration or by a purge button. Expiration forces air out through a mushroom valve. It should be noted that downstream leaks are not always caused by second stage defects. The downstream valve in the second stage also acts as a blow-off valve for the first stage. An apparent second stage leak is therefore often due to a first stage leak.