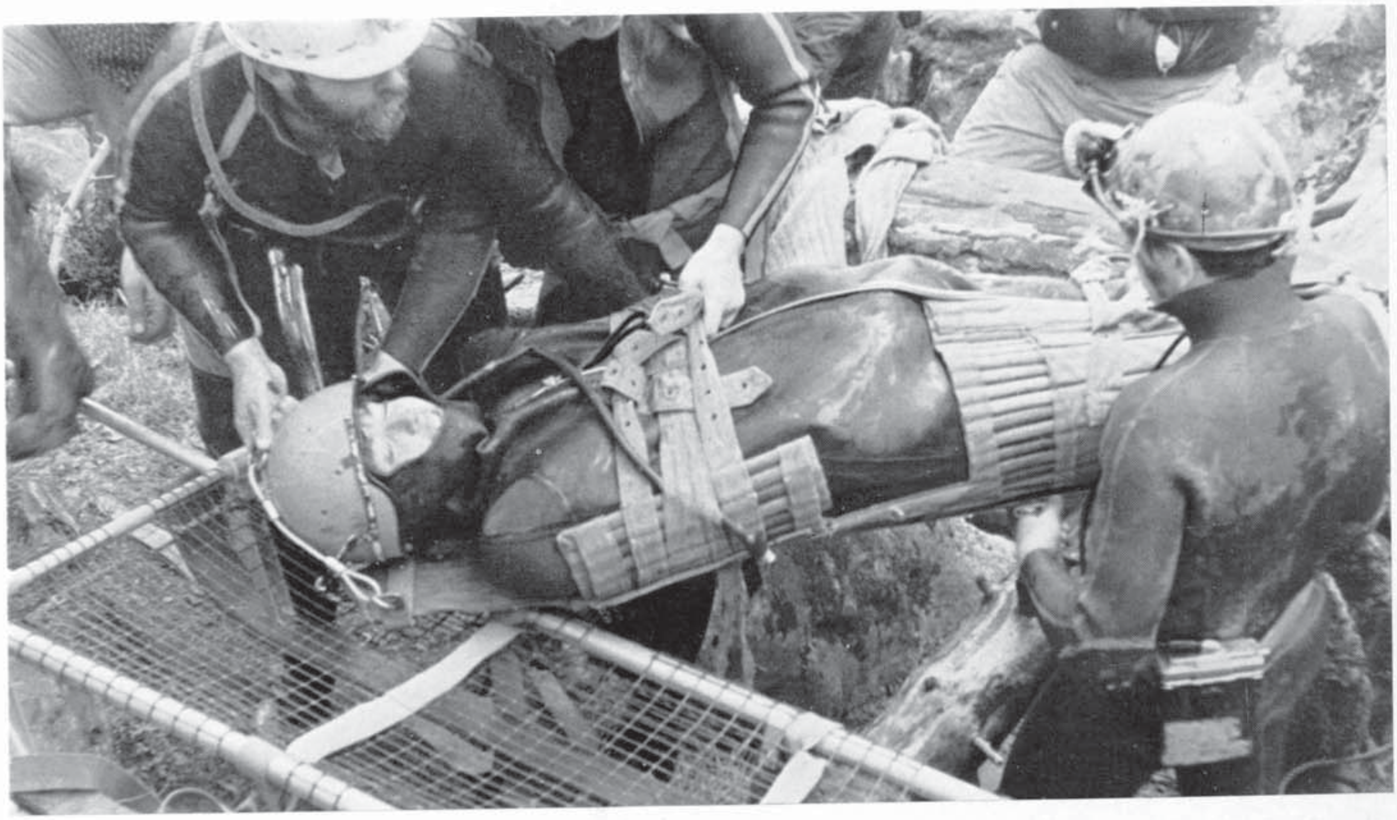
BCRA TRANSACTIONS

BRITISH CAVE RESEARCH ASSOCIATION

Volume 2 Number 2 August 1975



Medical Aspects of Speleology

INSTRUCTIONS TO CONTRIBUTORS

These notes are meant for guidance of contributors in the hope of reducing the amount of labour for both the editor and the contributors! Adherence to the rules is desirable but not absolutely essential.

As far as possible all material submitted for publication in the Transactions should be typed on one side of the paper only with double spacing to allow for editorial corrections where necessary. Paragraph sub-headings should be clearly marked. Metric measurements should be used wherever possible.

A very short summary of the principal conclusions should accompany every contribution.

References to other published work should be cited in the text thus . . . (Bloggs, 1999, p.66) . . . and the full reference with date, publishers, journal, volume number and page numbers, given in alphabetical order of authors at the end, thus . . .
Bloggs, W., 1999. The speleogenesis of Bloggs Hole. Bulletin X Caving Assoc. Vol. 9, pp. 9-99.

Italics are not normally used and only the volume number should be underlined. Periodical titles should be abbreviated in accordance with the World List of Scientific Periodicals, obtainable in any public library.

Illustrations: line diagrams and drawings should be numbered fig. 1, fig. 2, etc., and referred to in the appropriate place in the text. All such illustrations must be drawn in BLACK ink on clean white paper, card or tracing paper. Anaemic grey ink will not reproduce! Illustrations should be designed to make the maximum use of page space. If photo-reduction is contemplated all letters and lines must be of a thickness or size to allow for this. Captions may be typed on a separate sheet if space is left for insertion on the final illustration.

Photographs are welcome. They must be good clear black and white prints with sharp focus, and preferably about 6×4 inches. Captions may be appended by means of adhesive tape on the back.

If illustrations are submitted which have already been published elsewhere, it is up to the author to clear any copyright and acknowledgment matters.

Contributors in Universities and similar institutions are reminded that grants are often available from those which may help towards the costs of publication. The Editor will be pleased to advise.

If you have any problems regarding your material please consult the editor in advance of submission.

Authors may order reprints of their own contribution for their own private use, such as circulation to colleagues or for exchange purposes. The Editor should be notified of the number required at the time of submission of the contribution. Ten reprints are allowed free, if asked for, but the rest will be charged to the author.

ISSN 0305-859X

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

Volume 2 Number 2 August 1975

MEDICAL ASPECTS OF SPELEOLOGY

compiled by Peter Standing

CONTENTS

Cover photo: Patient in Neoprene exposure bag in modified Neil Robertson stretcher being lifted on to McInnes stretcher after evacuation from a cave.

Published by and obtainable from
The British Cave Research Association

Bryan Ellis,
7 School Lane,
Combwich,
Bridgwater,
Somerset. TA5 2QS.

One copy issued free to members
Extra copies to members £1·00
Non-members price £1·50

EDITORIAL

In March 1975 the British Cave Research Association held a symposium in Ingleton on the medical aspects of speleology. This is not a clearly defined discipline and there are few conditions described in the following pages, which do not occur in other sports or situations. Hypothermia, for example, is of interest to mountaineers and water sports enthusiasts and many of the problems of caving expeditions are shared with other forms of exploration. Even histoplasmosis, traditionally thought of as a cavers' disease, is quite common amongst the general population in the southern U.S.A.

Editorially the chief difficulty in compiling the Transactions has been to decide at what level to present the material. I have aimed at a compromise between simplicity and technicality in the hope that both layman and doctor may find something of interest. Although the papers are essentially review articles the reader will notice that the contributors do not always agree on a particular topic. Nowhere is this more so than in the management of accidental hypothermia. An unresolved gulf exists between the scientific approach which favours slow rewarming and the practical approach which encourages speed – the merits of both techniques are fully discussed.

One aspect not covered in this publication is the possible use of the cave microclimate in treating respiratory diseases. Although popular in Eastern Europe this topic has attracted no interest in Britain. It may warrant further study.

Peter Standing
July 1975

Transactions British Cave Research Assoc. Vol.2. No.2. pp.47-52 August 1975.

TEMPERATURE REGULATION IN MAN: THE PROBLEM OF HYPOTHERMIA

by N. Harper

This cold night will turn us all to fools and madmen.

(King Lear)

Normal Temperature Distribution

For temperature regulation purposes the human body can be regarded as consisting of two zones, a central 'core' which is maintained at a constant temperature surrounded by a 'shell' where the temperature is more variable and usually cooler. The core is maintained within the range 36.6-37.1°C, usually towards the warmer limit. It is this core temperature which is meant when people refer loosely to 'body temperature'. The shell in a resting subject is cooler than the core and has a temperature gradient within it from the core to the skin. The skin over the trunk is maintained for comfort at 33-34°C. On exercise the shell temperature distribution is more variable and in the vicinity of working muscles may be higher than the core.

The respective sizes of the core and shell vary with the heat status of the subject (see Fig. 1). When the subject is warm the core is large, including most of the trunk and extending into the limbs. In this situation the usual sites for taking the temperature, armpit and mouth, are within the core. As cooling occurs the size of the core shrinks and, although the temperatures of the core and trunk skin remain normal, the amount of body tissue at a lower temperature than the core increases. In this state it is more difficult to obtain an accurate core temperature as the mouth and armpit are not longer part of the core. In a reasonably steady state the rectal temperature still gives a fair indication of core temperature. In a changing thermal situation, however, the rectal temperature does show a time lag, reading too warm if the subject is cooling and vice versa.

An ordinary clinical thermometer is of no use if you are looking for abnormally low temperatures. It is designed purely to monitor fever. If used very carefully it only reads down to 35°C and if not correctly used will give a false higher reading. Special low-reading thermometers of similar design but reading down to 25°C are available. Electronic thermometers are becoming increasingly cheap, compact and reliable and should in the future replace glass thermometers especially for low temperature measurement.

One effect of the core/shell variation is that there is a large amount of heat stored in the body which can be lost without untoward effect. This stored heat may be as much as one hours resting heat production. People can therefore go for long periods in slightly negative heat balance without loss of core temperature.

Heat Production and Distribution

Heat is produced in the body only as a waste product from other activities; some is produced in the internal organs especially the heart and liver but most, even at rest, is produced in the skeletal muscles. The heat the muscles produce is related to the work they do and increases on physical exercise or shivering. There is in Man no mechanism to increase heat production by burning food solely to warm the body, although such a mechanism does exist in human babies and in most cold climate mammals. Man is really a warm climate animal who survives in temperate regions by virtue of technology rather than physiological adaptation. (In biology one must beware of simple mechanistic thinking, if you shovel more coal on a fire it gets hotter, if you shovel more food into a man he gets fatter but his heat production stays the same.)

Heat in the body is distributed mainly by the blood stream which is so fast that it makes other methods of heat transfer, such as conduction, normally of little consequence. Accordingly the temperature of any part of the body is related to the amount of blood flowing through it. Under cold stress the body constricts the blood vessels to the skin which therefore cools down. Low temperatures of the skin over the limbs is quite usual but if the skin temperature over the trunk falls much below 33°C the subject feels uncomfortable. Only in unpleasantly cold situations when the skin blood supply is very low and conductive losses become important does sub-cutaneous fat have any insulating effect. Fat does not keep you warm subjectively but will prolong your ability to survive in an exposure situation.

If muscles are working they need a high blood flow and, since most of the body musculature is immediately under the skin, exercise will result in increased heat losses although not enough to offset the gain from the muscles themselves.

A further point of importance is that the skin blood vessels become paralysed and dilate at about freezing point. This effect will tend to protect against frostbite but results in very large amounts of heat being lost from the body.

The energy utilised and therefore the heat produced performing various tasks differs considerably between individuals. Further, since in any task most of the energy is consumed in maintaining and moving the body against gravity and inertia, the energy cost of a task does not bear much relation to the amount of useful work done. Table I gives an idea of the average energy cost of some activities. From this it can be seen that shivering is a relatively inefficient form of heat production. The length of time one can maintain a given energy output depends on physical fitness. It is always the least fit who succumb as they cannot maintain sufficiently high energy outputs.

Table 1.

HEAT PRODUCTION

Rest	1.5	Cal/Min
Light Work (Golf, Bowls)	2.5–5.0	Cal/Min
Shivering at Rest	4.0	Cal/Min
Moderate Work (Cycling, Swimming)	5.0–7.5	Cal/Min
Heavy Work (Climbing, Cross Country Running)	7.5–10	Cal/Min

Heat Loss

Heat is lost from the body by conduction, convection and radiation from the skin and by evaporative losses from the skin and lungs. Under cold stress evaporative loss from the skin is relatively small. Since cold air is very dry (i.e. the weight of water it carries is very low) evaporative heat and fluid losses from the lungs are greatly increased in a cold environment however damp it might be. Radiation losses are negligible if the radiant temperature is the same as the ambient temperature. If the radiant temperature is very low, the heat loss may be considerable as under a clear sky at night or in space. It is these radiation losses that the 'space blankets' do most to prevent.

Convective and conductive losses from the body are usually modified by clothing. All heat insulators depend on trapped air for their heat insulating properties so to find the insulating effect all one has to do is measure the thickness. One inch of wool, mink fur and brick all have the same insulation value, but which is chosen will depend on other properties such as weight, cost and strength.

Since it is the trapped air which matters, the insulating effect is destroyed if it is replaced by cold air as in wind or by water if the clothing becomes wet. It is therefore important to keep clothing dry and to wear a windproof outer garment. This is not necessary if the air is completely sealed in as in neoprene and polyurethane foams. Body movement will stir up the air trapped in clothing creating the so called 'internal wind' so the insulating effect of clothing is less whilst working than at rest.

The surrounding air, being a poor conductor, has an insulating effect of its own which is not related to temperature but is dependant on wind speed. This value is equivalent to about 5mm of clothing in very still air reducing to the equivalent of about 1mm of clothing in a wind of about 5 metres/sec. (about Beaufort Force 3).

Now: $$H \quad \alpha \quad \frac{Ts - Ta}{Ia + Ic}$$

Where: H = Heat loss
Ts = Temperature of the skin
Ta = Temperature of the environment
Ia = Insulation of the air
Ic = Insulation of the clothing

This relationship is shown diagrammatically in Figure 2. As more and more clothing is put on the benefit received gets less and less, whereas in the lower temperature range altering the ambient temperature has a big effect. This is why getting into a small space such as a sleeping bag, tent or snow cave which will warm up quickly is so effective at keeping one warm. Additional clothing is no substitute for shelter and fires. Apart from this 1-1½ in. of clothing is about as much as can be worn without interfering with movement because of its bulk.

Temperature Regulation

Temperature regulation in the body seems to be the responsibility of a small area at the base of the brain called the hypothalamus. This is capable of measuring the temperature of the blood reaching it directly. It also receives information about temperature from peripheral receptors, mainly in the skin although there are probably also some in the spinal cord.

The hypothalamus has some sort of reference temperature called the 'set' temperature and it compares this with the temperature of the blood. If the blood is too warm the person feels hot, the blood vessels in his skin dilate and he start sweating. If the blood is too cold relative to the set temperature he feels cold, his skin blood vessels contract and he starts shivering.

Information from the periphery seems to act by altering the set temperature. If a subject is placed in a cold environment the skin relays 'cold' to the hypothalamus and the set temperature alters upwards. The blood temperature is now relatively cold compared to the set temperature and a cold response occurs. The intensity of this response is therefore related not only to the degree of cold to which the subject has been exposed but also to how warm he was at the start. The warmer he was at the start the less cold he will feel in a given environment.

Because of the sensitivity of various parts of this system, in the normal state the body tends to rely on the peripheral receptors for response to cold and central temperature measurement to respond to heat. To illustrate this; if one gets into a cool bath, one that is slightly too cold for thermal balance, there is an immediate feeling of cold and the body reacts to restore thermal balance. If one gets into a bath which is slightly too warm nothing happens until the central temperature has risen over its limit of about 37.2°C and then the central receptors cause a response.

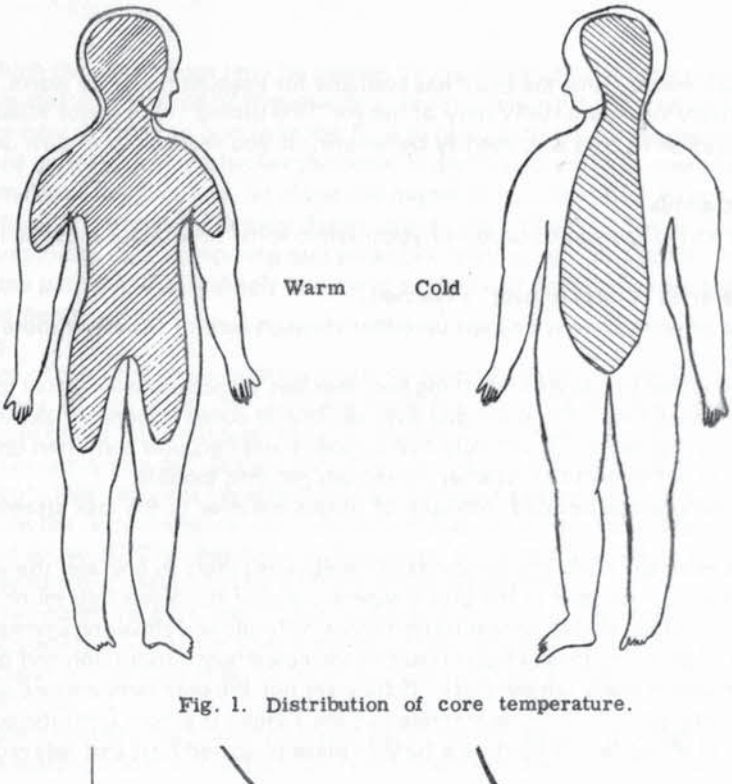


Fig. 1. Distribution of core temperature.

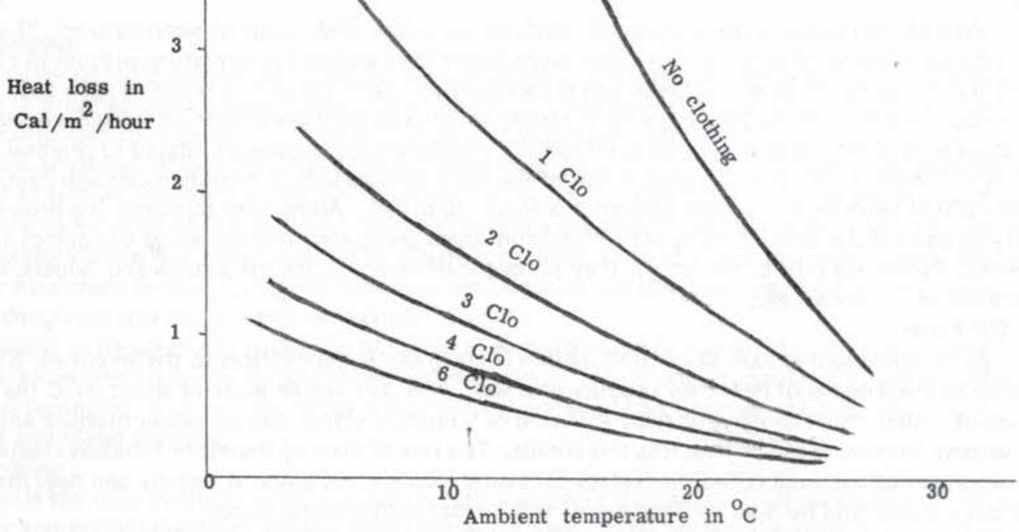


Fig. 2. Effect of clothing on heat loss (1 Clo = 5mm thickness of clothing)

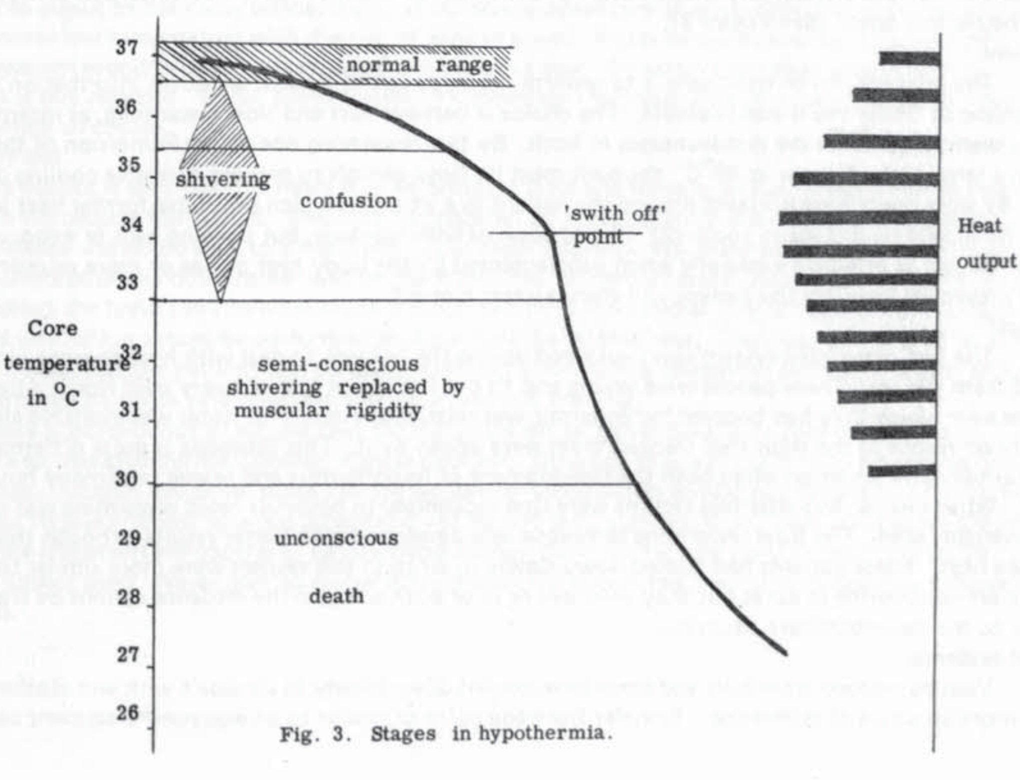


Fig. 3. Stages in hypothermia.

The involuntary mechanisms the brain has available for keeping the body warm, vasoconstriction and shivering, are relatively weak and really only of use for 'fine tuning'. The major effect of the thermoregulatory centre in response to cold is to modify behaviour. If you feel cold you turn on the fire or put on another sweater.

Development of Hypothermia

In order for a normal person to become hypothermic some new factor must be involved, for instance:–

1) The end of the reserves of 'stored heat' is reached.
2) The previous rate of work cannot be kept up either through lack of fitness or more commonly because of injury.
3) Loss of insulation either because the clothing becomes wet or occasionally actual loss of clothing.
4) Change in environmental conditions beyond that which one could reasonably expect. Too much blame is usually placed on this factor; it virtually never applies underground and often on mountains only the people who did not expect the weather conditions get into trouble.

Most hypothermia incidents are associated with lack of fitness (relative to the task attempted), injury or wetting of the clothing.

As heat is lost from the body the involuntary mechanisms start to operate, the skin blood vessels contract and shivering begins. As soon as the skin temperature over the trunk falls much below 33°C one feels uncomfortably cold, which makes concentration more difficult and shivering impedes physical activity. Nevertheless, although unpleasant, these effects result in increased heat production and body insulation and so may be enough to maintain body temperature. If they are not the core temperature begins to fall, the feeling of cold and the intensity of shivering increase but the subject is alright until the core temperature reaches about 35.5°C. In effect he has used up a further piece of stored heat and delayed the onset of trouble.

Most of the organs in the body work satisfactorily over a wide range of temperatures. The muscles in the limbs are often working at temperatures much lower than the core temperature without ill effect, although there is some effect and athletes find it necessary to 'warm up' before reaching their peak performance. The brain is the only organ in the body which is heavily dependant on a finely controlled temperature so it is natural that the first symptoms of low core temperature are related to cerebral function. Below 35.5°C there is a progressive impairment of mental processes with out-of-character and irrational behaviour which becomes more marked until it is frank confusion. Along with this there is a progressive loss of ability to control the limbs starting with slight clumsiness and going on to gross loss of control of movements. People may die at this stage; they jump out of lifeboats, fall off pitches and ladders, take their facepiece off whilst diving, etc.

Switch Off Point

As further cooling takes place the function in the muscles deteriorates so the amplitude of shivering decreases and the amount of heat they produce gets less. At a core temperature of about 34°C the muscles, which are of course much cooler, either by shivering or voluntary effort, can no longer produce enough heat to compensate for the increased heat loss this entails. The rate of cooling therefore increases sharply, a phenomenon which has been called the 'switch off point'. Continued physical activity will now merely exhaust the patient (and by now he is a patient) and further increase heat losses.

Below about 33°C shivering ceases and is replaced by muscular rigidity. Consciousness is progressively impaired and complete unconsciousness occurs at about 30°C. Death, usually due to cardiac arrhythmia occurs below this level. (See Figure 3).

Treatment

The primary aim of treatment is to rewarm the body but at present adequate information on the best method of doing this is not available. The choice is between fast and slow rewarming, as intermediate systems seem to combine the disadvantages of both. By fast rewarming one means immersion of the whole body in a large bath of water at 45°C; the bath must be large enough to prevent excessive cooling of the water. By slow rewarming is meant placing the patient in a situation which precludes further heat loss. Ideally he should be in a warm room (22°C) and covered with blankets, but sleeping bags or exposure bags can be just as effective especially when supplemented by the body heat of one or more rescuers. Having prevented heat loss the patient will then rewarm himself.

Historical

The fast rewarming system was developed during the last war to deal with hypothermia victims rescued from the sea. These people were young and fit but had fallen into the very cold North Atlantic so the time over which they had become hypothermic was relatively short. Hot water was available almost instantly on rescue as the ships that rescued them were driven by it. This timescale is quite different from the mountain/cave situation when both the development of hypothermia and rescue take many hours.

When civilian hypothermia victims were first recognised in hospitals rapid rewarming was used and all the patients died. The slow rewarming technique was developed with better results although the mortality remained high. These patients had cooled down slowly in air so in this respect were more similar to the ones we are considering in caves but they were old or ill or both so again the evidence cannot be transferred directly to the mountain/cave situation.

Lack of evidence

Victims rescued from hills and caves have cooled down slowly in air albeit with wet clothes and one or more episodes of immersion. Transfer from the point of rescue to an equipped treatment centre takes time, time in which the patient can only be treated by insulation, that is slow rewarming. Accordingly hardly anyone has ever treated this type of hypothermia victim solely with rapid rewarming. Accurate core temperatures are extremely difficult to obtain in the field so most patients are treated without knowledge of their temperature. One does not know whether the patients are hypothermic as opposed to merely cold and exhausted with a normal core temperature, let alone the degree of hypothermia. Hospital experience suggests that the results of treatment are heavily dependant on the amount of temperature lowering that exists at the start of treatment so in comparing two series one must adjust for the 'mix' of initial temperatures among the patients. Accordingly anecdotal evidence of practical experience is of no value in deciding between treatments.

Effects of Rewarming

In the absence of direct experimental evidence comparing treatments one must fall back on theoretical considerations. If you warm the periphery there is a danger of dilating the peripheral blood vessels so that warm core blood flows through the still relatively cold periphery resulting in a further fall in core temperature. Certainly you can demonstrate a fall in rectal temperature after the start of rewarming, the so-called 'after-drop'. Not everyone accepts this as a significant phenomenon, however, as it may merely be due to the time lag in the rectal temperature. The skin blood vessels do not dilate on skin warming unless the core temperature is above 35°C so theoretically peripheral rewarming should be possible up to this level unless more deeply placed blood vessels in the shell are acting differently.

In hypothermia occurring over hours there is a loss of fluid from the blood into the tissues. If subjects are rewarmed quickly the vascular spaces could increase in size faster than the blood volume can re-expand causing collapse of the circulation. Alarming drops in blood pressure have been reported in some patients on rapid rewarming.

It is also possible that the cold heart does not warm rapidly enough to meet the increasing demands of the warming tissues causing either circulatory collapse or damage due to insufficient oxygen reaching the tissues.

Rapid Rewarming

The idea of rapid rewarming is that massive amounts of heat are available so that blood coming back from the periphery is hot enough not to cool the core. It has the advantage of getting the patient out of a dangerously cold state quickly. Certainly the after-drop period is shortened but as stated above this may not mean anything. Rapid rewarming has the theoretical risks of circulatory collapse and possibly a short period of further cooling in which cardiac arrest can occur. Having someone immersed in a bath also means that the monitoring of temperature and blood pressure is difficult and the treatment of an emergency such as respiratory or cardiac arrest impossible. There is some evidence that hypothermic patients brought off the hills are already recovering by the time they can be got to hot bath facilities so to expose them to a potentially dangerous treatment seems misguided.

Because of its speed and convenience objective evidence is badly needed about rapid rewarming. At present I do not feel it can be recommended for general use. If it is used it should still be regarded as an experimental technique; a doctor should be present and there should be adequate monitoring of core temperature and blood pressure.

Slow Rewarming

This is the only method available to parties who recognise that one of their members has become hypothermic and the only method initially availa ble to rescuers. It has the advantage of allowing time for the circulatory adjustments to occur and the relative temperatures of various organs (and therefore their work rates) to adjust to the rising temperature. It has the disadvantage of prolonging the time the patient is at a dangerously low temperature with the risk of cardiac arrest. It can be performed by unskilled personnel and allows patient monitoring to be performed with relative ease. Treatment of other injuries and of emergencies is not impeded. In our present state of knowledge I feel that slow rewarming must be regarded as the treatment of choice.

Other Treatment

If a patient is very cold the heart is in an unstable state and there is an ever present risk of cardiac arrest due to ventricular fibrillation. This may be triggered by stimulation of the patient, so movement and other interference should be kept to a minimum. Pain from fractures, etc. must be relieved, by intravenous injection as absorbtion via other routes will be much reduced. If cardiac arrest occurs there is more time to act as the period the brain can survive without a blood supply is increased at low temperatures. Cardiac massage and ventilation should be performed at about half the normal rate. The diagnosis of cardiac arrest is not easy in hypothermic patients and cardiac massage is a potentially dangerous technique which should only be attempted by those who have had adequate previous training.

There is no evidence to suggest that the body is short of either glucose or hydrocortisone in hypothermia so that giving these does not appear necessary although they are unlikely to do any harm in normal dosage. Alcohol and other drugs causing peripheral vasodilation should not be given. The decision as to whether to give antibiotics is not urgent and can be left until a doctor is available and the results of the immediate treatment are apparent. Severe hypothermia slows all the functions of the body so the victim may appear dead. Never give up rescue attempts until a doctor has been able to make an adequate examination.

Conclusions

Control of temperature is confusing and still poorly understood. Man has little physiological ability to withstand cold. Hypothermia is a dangerous condition which should be completely preventable if sensible measures are adopted. When it occurs treatment should be kept to a minimum with slow rewarming and as little interference with the patient as possible. It is human to prefer dramatic active treatments but in slowly developed hypothermia the evidence suggests that at lower temperatures they may be dangerous and at higher temperatures they are unnecessary. Unless reliable core temperatures are known before and during treatment the outcome gives one no indication of the value of that treatment. The ideal treatment has yet to be ascertained so more than in most illnesses prevention is better than cure.

Further Reading

Alexander, L.	Combined Intelligence Objectives Sub-committee, G 2 Division, SHEAF (Rear), APO 413.
Bloch, M.	1965. M.D. Thesis, University of London.
Burton, A.C. & Edholm, O.G.	1955. *Man in a Cold Environment.* Arnold, London.
Durnin. J.V.G.A. & Passmore, R.	1957. *Energy, Work and Leisure.* Heinemann, London.
Hardy, J.D. (Ed.)	1970. *Physiological and Behavioural Temperature Regulation.* Thomas, Springfield.
Keatinge, W.R.	1969. *Survival in Cold Water.* Blackwell, Oxford.
Pugh, L.G.C.E.	1964. Deaths from Exposure on Four Inns Walking Competition, *Lancet, 1210,* (30th May.)
Pugh, L.G.C.E.	1966. Accidental Hypothermia in Walkers, Climbers and Campers, *British Medical Journal, 123,* (15th Jan.)
Starkov, P.M. (Ed.)	1960. *The Problem of Acute Hypothermia,* Pergamon, London.

May 1975.

N.P.A.L. Harper, M.B., B.S., M.R.C.P.,
50 De Villiers Avenue,
Crosby,
Liverpool L23 2TJ.

Transactions British Cave Research Assoc. Vol.2. No.2. pp.53-63 August 1975.

MEDICAL ASPECTS OF CAVE RESCUE

by John Frankland

CAVE RESCUE ORGANIZATION
335 INCIDENTS IN 39 YEARS
641 PEOPLE HELPED

Caving	166
Fell and Mountain	88
Animal Rescue	45
Rock Climbing	12
Diving	6
Disused mines	3
Special	15

Diagnosis

Medical diagnosis underground can rarely be totally accurate. I don't ever expect to be as lucky again as on a recent rescue when I arrived at my patient and asked "How are you?" and obtained the reply "I am alright but I have fractured my left thigh, my pelvis and my left arm!" – a correct assessment apart from the small detail that after x-ray his left elbow was revealed to be dislocated and not fractured! This sort of situation apart, the doctor in the particular circumstances in which we work in cave rescue so often cannot be precise in his diagnosis. We should not miss fractured limbs, although we might well if the patient is unconscious and in a difficult position, but what we can never be sure about is the absence of internal injuries particularly bleeding into the abdomen and chest. If the patient has been immobile for some time and is getting cold it is against his interests to undress him for an adequate examination. It is certainly against his interest to remove his wetsuit unless this is necessary to stop bleeding. The distance he has fallen may bear no relationship to his injuries, for example, we have had a fractured spine from a fall of 15 feet, a death from 40 feet, no real injuries at all from 80 feet and a survival from 150 feet.

Because one cannot guarantee a precise diagnosis underground it follows that rescue teams must still have a first priority in getting the patient out as quickly as possible even though they have got medical support underground. Similarly, any medical care given underground must not cause undue delay in getting the casualty out of a place where he can be examined and assessed properly. I would not suggest that one should not spend time on adequate splintage, on stopping bleeding, or on suturing large cuts but any other measures which delay evacuation must without question be absolutely worthwhile.

Hospitalization Underground

By "Hospitalization Underground" we mean attempting by all practical means to treat and improve the condition of injured cavers underground prior to their removal to the surface (C.R.O. 1970). We appreciate that in certain situations rescue may be virtually impossible by conventional methods, so that underground treatment of casualties may be imperative. We therefore have a responsibility to be prepared for this expediency. It is suggested that hospitalization facilities might be necessary in the following situations:

(a) To allow a constricted exit to be widened.
(b) Where the patient is physically trapped (e.g. fallen rock on leg) until he can be moved.
(c) To improve the general condition of a patient to facilitate his extraction from a difficult system perhaps thereby allowing his removal without a stretcher.

The suggestion is also put forward that the technique may be worthwhile to resuscitate a badly shocked patient who would not otherwise survive extraction from the system. For example a patient with both femurs fractured would be so shocked from the resulting blood loss that he would be unlikely to survive any further buffetting or stress. With intravenous fluid replacement including possibly blood transfusion, splintage, warmth, and painkilling drugs, his general condition could be improved over perhaps four to six hours so that his chances of survival would be increased. This type of situation would present a most difficult decision as to the necessity of treating a patient underground.

Inherent in keeping a patient underground are many risks including (a) the problem of hypothermia, either present initially or developing during treatment. Body temperature must therefore be monitored; (b) deterioration due to undiagnosed injuries not amenable to treatment underground, chiefly internal bleeding which can only be stopped in an operating theatre; (c) the stress on the patient's morale; (d) the inconvenience, risk and extra administrative problems involved in respect of all rescuers by prolonging the rescue; (e) the possibility of criticism or litigation if the patient deteriorates and dies.

Because of these factors it would be negligent to decide to delay any patient underground unnecessarily. These factors must represent inevitable hazards where a patient is treated underground as a necessity. In borderline cases the decision must be taken after due consideration and consultation and with an awareness of the risks involved. Medical supervision should be sought.

Equipment must include dry clothing and sleeping bag for the patient and all relevant camping equipment together with a comprehensive kit of medical supplies and equipment.

The discovery of Pippikin Pot with its tight entrance precipitated these thoughts and on looking further into the question of tight systems in the Yorkshire Dales we found an alarming number where the rescue problems seemed unbelievable. We have never yet in the Dales had a badly injured man in the far reaches of a tight and tough Grade V system. If and when this happens the rescue problems are going to take on a magnitude we have never experienced before and are going to involve prolonged medical support. The Cave Rescue Organisation (C.R.O.) now owns equipment for intravenous resuscitation, intubation and artificial ventilation, suturing and all drugs we think might be relevant. It is certainly not the wish of the writer that we should ever face such a challenge but it would be naive of us to believe it could never happen.

Training of Lay Rescuers

Without doubt it is desirable for all rescue team members to complete a formal course of instruction on first aid and then be prepared to forget some of this, modify other parts, and remember for all time the general principles involved. The cave rescuer may have total responsibility for a badly injured man in extremely hostile circumstances for anything up to twelve hours, well beyond the responsibility of first aiders in almost any other situation with the nationwide efficient ambulance service in the United Kingdom. They should know the priorities for treatment in the injured which are always the treatment of breathing, bleeding, shock and then specific injuries in that order, but be prepared to forget all of these to first get the patient out of a situation where his life is threatened. They should learn how to protect the airway in a drowsy or unconscious patient so that his breathing is not obstructed and how obsessional care is needed to watch this constantly. They should learn how to carry out a full examination for injuries to the limbs, spine, skull, pelvis and chest. They should learn the principles of splintage, namely that it is done to stop pain and to prevent bleeding and by doing both of these to minimise shock and that the joints both above and below the fracture must be immobilised. They must be prepared to improvise with considerable ingenuity to achieve this state. They must never forget hypothermia, must assume that it will always be developing in anyone injured underground and must be familiar with the principles of treatment to prevent and treat it.

Care of the Casualty

One person, either the Doctor or the most experienced first aider should stay with the patient throughout the rescue, to establish rapport, encourage him, observe his condition and provide continuity of care. On a long rescue the stretcher handlers will be changed several times so that continuity of supervision becomes important. A rescue team preoccupied with technical difficulties may at times neglect the object of all their endeavours, namely the patient. One remembers seeing patients put down with drops landing on their face and occasionally ignored when the Kendal Mint Cake is passed round!

The patient's morale is an important factor in his own welfare and perhaps also in the efficiency of the rescue operation. I am constantly amazed at the fortitude injured cavers show. I have only ever seen one case where panic and fear made the victim appear to be in a worse condition than he actually was and I have seen several cases where I was far more worried about patients' well-being than they obviously were. No doubt the arrival of a rescue team is a tremendous boost to morale in victims. I am naive enough to believe also that the presence of a doctor boosts morale. How can one monitor the well-being of a patient during a rescue operation?

Measurement of Temperature

Core temperature is the pertinent factor but practical difficulties arise in the measurement of rectal temperature underground. The writer has never done this, because of practical difficulties involved. What can one do? The measurement of mouth temperature taken under the tongue using a sub-normal thermometer (that is one reading down to 75°F., 24°C.) kept in place for three minutes and not used within approximately 15-20 minutes following a hot drink can provide valuable information. This will not give a true reading of core temperature level but the changes in level which can be observed will give the all important information about whether the patient is getting cooler or maintaining body temperature or even rewarming, which he will do from his own body heat production if the insulation is adequate. The standard clinical thermometer is of no value in these situations. A "Subnormal" thermometer can be obtained from any chemist and comes in a plastic case which is easily carried inside the sleeve of a neoprene wet suit. It is probably adequate to record in a notebook the temperature in this way every 30 to 60 minutes. If this temperature is 95°F. (35°C.) or above one need not worry. If it is dropping the patient is deteriorating, in fact progressing towards death and it is necessary to provide extra insulation and to evacuate him rapidly or both. Evidence that one ignores hypothermia at the patient's peril is illustrated by Lloyd's description of two Mendip cavers dying of cold in 1 and 1½ hours after showing symptoms of exposure, despite help from a rescue team. (Lloyd, 1964).

(b) Count the pulse every hour and again write this down. The radial pulse at the wrist is often difficult to feel in patients with any hypothermia and most injured cavers who have awaited help from a rescue team fit into this category, as the circulation to the hand is reduced to minimise heat loss. This thready radial pulse can be alarming but if one feels the carotid pulse in the neck and it is between 70 and 90 beats per minute this is reassuring information. An increasing pulse rate generally means that either the patient's shock is worsening or that he is bleeding somewhere possibly internally. The treatment for shock is warmth, reassurance and pain relief with drugs, and with adequate splintage. If a patient with a head injury has a pulse which is becoming slower this must be regarded as an ominous sign and evacuation must be carried out as fast as possible, if necessary using a helicopter to transfer him to hospital particularly if the cave entrance is in a remote situation.

(c) The measurement of blood pressure will provide relevant information to the medically qualified although the writer has personally never measured this underground despite having carried an aneroid sphygomanometer. I have always thought that to expose an arm fully, particularly if it meant cutting open a wet suit sleeve, would chill the patient unjustifiably. However, I have recently tried measuring systolic blood pressure by palpation at the radial pulse with a sphygmomanometer cuff applied over a wet suit and obtained exactly the same readings as the systolic blood pressure measured by ausculation at the elbow. Perhaps this technique is worthy of development.

(d) Watch the **rate of respiration** — it will be speeded up with pain, fear and blood loss and may be slowed down with a serious head injury. In this latter category as the respiratory rate becomes inadequate artificial respiration becomes necessary. The standard first aid method of choice for artificial respiration is the mouth to mouth technique or "kiss of life". The feasibility of carrying out this procedure throughout the process of rescue from most caves must be very much open to question. If artificial respiration becomes necessary with a head injury or extensive chest wall injuries the method of choice is tracheal intubation and intermittent positive pressure respiration using equipment such as the Ambu bag. The writer has no experience of this and undoubtedly such patients will be so gravely ill that their survival through a difficult extrication will be unlikely.

(e) Watch the patient's **level of consciousness** particularly after a head injury. Does he respond to questions? Does he respond to shouted commands? Does he respond to painful stimuli? If he is getting increasingly drowsy or becoming comatose, speed becomes very important and the person in charge must watch constantly for airway obstruction and observe whether his respirations are becoming inadequate. To maintain a patient's airway it may be necessary to start carrying him on his side to stop his tongue falling back and obstructing breathing — this, however, presumes that the caving terraine allows it. In the unconscious patient who cannot be carried on his side theperson supervising him should endeavour to keep a constant hold on his chin and pull this upwards away from his body, as this is the optimum position to allow unimpeded air entry to the chest. The rescue team's first aid kit should include a simple anaesthetic airway which is a small tube passing from the mouth to the back of the tongue to stop airway obstruction. Patients who are not deeply unconscious will cough out this simple airway, usually meaning that one need not worry about their respiration.

By monitoring these parameters of temperature, pulse, respiration and level of consciousness the non-medical rescuer can get a very good idea of whether the patient is deteriorating. If he is, medical help should be sought.

Use of Drugs

One should also, of course, record the dosage and time of any drugs given and send this information to hospital with the patient. The use of drugs underground is worthy of mention but no doubt conflicting opinions exist in this sphere. Pain relief following injury is the obvious main demand. Adequate doses of pain killing drugs will make a patient drowsy and unable to co-operate and this can introduce new problems in rescue from a difficult and tight system. With adequate splintage it may not be necessary to give a full dose of Morphia or Pethidine and as a consequence the patient will be more alert and co-operative. He can thus tell you when the stretcher is jamming on a projection or perhaps just give a little sideways push in a crawl and is likely to be out of the system more quickly than an inert drugged patient. In shocked patients subcutaneous injections, ie. those given below the skin, may take up to perhaps one hour to be absorbed as the circulation to the skin is considerably reduced. The most painful time for the patient with fractures underground is generally when one applies splints to his damaged limbs and picks him up to place him in the stretcher. Thus a suggested regime is to give a fairly small dose of Morphia (say 7-10 mgs.) intravenously before these manipulations. It will have a rapid maximal effect which will protect the patient whilst he is being handled initially and will not keep him inert for several hours. Following this small doses of analgesics can be given as necessary via the intramuscular route to control the pain during evacuation. It is wrong to withhold adequate pain relief but equally wrong to overuse powerful analgesics in a cave rescue situation. The writer knows of several patients who have been evacuated from difficult systems with major limb fractures and have only needed 50 mgs. of Pethidine throughout a rescue lasting perhaps 5 or 6 hours and who did not want further pain relief when this was offered. Their alertness and co-operation certainly aided these rescue operations. This is obviously an individual decision depending upon the particular circumstances of the patient and the cave system and presumes optimal splintage, care in handling the patient and an efficient stretcher which adequately protects the patient's injured areas from external buffetting. If the patient is in a full wet suit probably the best place to give intramuscular injections is into the pectoral or chest muscles which can be exposed without cutting the wet suit and are still accessible when the patient is in a stretcher. Intravenous injections can be given if a small transverse cut across the wet suit neoprene in front of the elbow is made. This will expose the antecubital veins and will let in a minimum amount of cold. One of the hazards of Morphia and Pethidine usage is the vomiting it can cause. The writer recalls a salutory experience when after being given Pethidine the victim was lying flat on his back in a Neil Robertson stretcher with his head in the helmet and unable to move a muscle when someone casually mentioned that the patient was vomiting and seemed to be having some difficulty in breathing! He was, of course, all right in a second when he was turned onto his side but we were just about to push him into a bedding plane where he could not have been turned onto his side! One must beware of this hazard shortly after injection of these drugs.

A good painkiller for the non-medical rescuer to use is a drug called Pentazocine (Fortral). This causes less respiratory depression than Morphia so can be used after minor head injuries. It is only available on prescription but is not subject to the provisions of the Dangerous Drugs Act so that difficulties do not arise if the Police find this preparation in your car. In a dose of 100 mg. (4 tablets) every four hours or 30 to 60 mg. by injection it is a reasonably effective painkiller, it doesn't make the patient too drowsy and it doesn't usually provoke vomiting. The law does allow leaders of teams affiliated to the Mountain Rescue

Committee to be issued with Morphia for use by non-medical people. I think all rescue team controllers should undergo a course of what has been called extended first aid which includes instruction in the usage of Morphia. Morphia is certainly a drug which needs handling with great respect in a cave rescue situation. Not many other drugs are often needed. A mild sedative such as diazepam (Valium) may help an anxious patient, may make a small dose of analgesics more effective and a larger dose given intravenously can help control the restless thrashing patient with a severe head injury.

Parenteral antibiotics are probably sound if there is a compound fracture, severe lacerations or if it is going to be a long rescue. "Triplopen" – a delayed release penicillin depot preparation is very suitable. British Oxygen Company market equipment for the relief of pain by breathing an anaesthetic mixture called Entonox. The patient breathes a 50/50 mixture of Nitrous Oxide and pure Oxygen on demand when he feels pain. After a few breaths he gets a short period of good pain relief and the technique is very safe, with no danger of respiratory depression. This sounds ideal but the equipment is fairly heavy and bulky for underground use. Some Mountain Rescue Teams are now using Entonox equipment but a big problem is that below freezing point the Nitrous Oxide starts to liquify in the cylinder so that one can breath an unreliable mixture. I don't think the insulation problem has been fully solved yet. The writer has only used this equipment once on a patient with severe head injuries following a fall of 150 feet and found it to be very effective. Perhaps however, more experience is needed before it can be unequivocally recommended as suitable for cave rescue usage.

Some continental rescue teams are fond of giving 50% Dextrose or strong sugar solution intravenously to hypothermic patients. Hospital experience suggests that in hypothermia the blood sugar is in fact markedly elevated as the tissue enzymes cannot metabolize sugar below normal body temperature. On two occasions I have found hypothermic cavers to have blood sugars elevated to 160 mg.% (8 m.mol./l. in S.I. units). Certainly ketosis or a smell of acetone on the breath from protein and fat breakdown when sugars are not being metabolized is a constant feature of hypothermic cavers. One should always smell the breath to look for this characteristic odour. Everyone of the ten U.L.S.A. cavers who were trapped down Langcliffe Pot for two days had this feature when they came out. Giving intravenous glucose and causing a further elevation in blood sugar can cause a corresponding fall in the Serum Sodium level or hyponatraemia thus disturbing the electrolyte balance. The behaviour of the blood sugar levels during rapid rewarming is inadequately understood. It may possibly overshoot to low levels in which case there may be a place for intravenous glucose during rapid rewarming, but this is only speculation. Evidence exists that during rapid rewarming from hypothermia the use of intravenous plasma expanders such as the high molecular weight dextrans are beneficial both from a point of view of preventing rapid falls in blood pressure and protecting against kidney damage (Craven, 1973).

The corticosteroid drugs such as Hydrocortisone are becoming increasingly used in shock from any cause some would say on tenuous grounds and given merely because it is something one can do. Many experienced mountain rescue doctors, for example with the busy Glencoe Mountain Rescue team claim benefit from their use in traumatic shock and hypothermia (MacInnes, 1971). If their usage is accepted then probably the ultimate preparation is Merck Sharp and Dohme's new "Decadron Shock-pak" which contains 100 mg. of Dexa-Methasone and which costs £20 per injection and may need administering hourly or more frequently. "Solumedrone" (Upjohn) is an alternative preparation in the same category.

The writer cannot find a place for the use of amphetamine preparations in cave rescue. Their benefits of stimulating a tired patient must be weighed against their risks. When the fit and totally healthy British professional cyclist Tommy Simpson died suddenly during extreme exertion in a Tour De France cycle race, his body was found to contain appreciable amounts of amphetamines. Death from sudden heart failure on strenuous exertion in the healthy undrugged athlete is probably not documented in the medical literature.

Blood Volume Restoration

The use of intravenous fluid replacement, i.e. a transfusion of blood or some blood substitute to combat shock from blood loss must be considered. This has never been done in cave rescue in the Yorkshire Dales, although the writer believes it has been done on one occasion in South Wales. As mentioned previously, this technique must be potentially life saving in certain situations. Our own equipment includes high molecular weight dextrans and an infusion kit and we can get Plasma, Group O Rh Negative blood, or even cross-matched blood from local hospitals if necessary. However, every time the writer has carried this underground the patient has been either dead or didn't need it. Setting up an intravenous infusion underground would inevitably delay the rescue as one cannot "drop" a patient and move him along a cave system. The veins are also often collapsed with cold and shock, making the technique of setting up an infusion more difficult. One must weight up the advantages of transfusion against the risks of delay.

Management of Hypothermia

Some aspects of the practical management of hypothermia underground are worth considering (Frankland, 1973). One must assume that all caving casualties who are immobilized will have some degree of hypothermia and that unless measures are taken to protect the patient this may rapidly get worse as rescue can very rarely be near to hand. Undoubtedly neoprene wet suits have saved many lives. Apart from their inclusion benefits, they also provide a slight degree of splintage and also protect against cuts and abrasions during falls. They have probably prevented many caving fractures from being compound fractures and serve to reduce slightly haematoma formation (collection of blood in large bruises) after injury.

Apart from one development to be mentioned later the treatment of hypothermia is **adequate insulation plus rapid evacuation.** As a first aid measure whilst waiting for help the patient's colleagues can do several things to minimise body heat loss, simple measures which are very often neglected. They include wringing out the wet top clothing and replacing it; putting on or covering him with extra clothing from fitter and fatter members of the party; sitting him on coils of rope to keep him off the cold rock. If the patient has no wet suit borrowing one from someone else and putting it over his woollens may be feasible. Don't bother rubbing his limbs – this is a waste of time. Reassure and encourage the patient and feed him with anything available apart from alcohol. If an exposure bag is carried, put the patient in it together with a warmer colleague if possible. Space blankets have had a bad press in caving circles and are almost certainly less efficient than polythene bags, but they are as small as a packet of cigarettes and will fit in anyone's ammunition box. If a patient is put in a survival bag get him to breathe out so that his expired air enters the bag. This will slightly raise the air temperature inside the bag and in this situation every calorie is beneficial. Rest the patient in the most sheltered spot available. This may involve making a wind break if possible if the patient is in a draughty situation as the wind chill factor makes cooling very much more rapid. Alternatively a pit may be dug in sand or shale to provide further protection from draughts. If his injuries allow, sit him fully curled up with his thighs against his chest and calves against the back of his thighs. This measure can reduce the body surface area available for heat loss by approximately 30%. Insulate his head and his hands with anything that can be scrounged. The head contains 9% of the body's surface area and is very vascular thereby allowing considerable heat loss. Insulate him with direct body to body contact with other members of the party. This measure can be extremely beneficial but is very seldom carried out by parties awaiting help with an injured colleague. There is a natural reluctance for most men to hug up against other men but if one is with an injured caver who will have a long wait for a stretcher and exposure bag I would beg cavers to overcome this reluctance.

These measures may seem pathetically inadequate but the patient is facing an insidious drop in body temperature the end result of which is death and every measure must be applied to slow down this inevitable drop. If one can achieve really adequate insulation for an immobilized caver his continuing body heat production will maintain his temperature or even warm him up. Warming him up sufficiently to stop involuntary muscular shivering will considerably reduce the pain from any fractures and thereby reduce the development of shock.

One of the most difficult decisions is what to do with the non-injured caver who develops hypothermia underground. If the hypothermia is mild and he is exercised (assuming that he is not too exhausted to maintain an adequate level of exercise) he will rapidly rewarm so that the problem is fully resolved. If the hypothermia is severe and exercise is forced upon him his body temperature will fall and his deterioration will be accelerated. A severely exhausted caver will not tolerate the degree of exercise needed to rewarm himself and increasing his exhaustion will worsen his general condition.

Freeman and Pugh (1969) suggested that the lowest limit of rectal temperature compatible with continued exercise is 34-35°C. (93-95°F.) – only 2-3°C. (3-5°F.) below normal body temperature. Below this further exercise opens up the circulation in the limb muscles which has been shut down to conserve heat. The blood in this area is below core temperature and as it recirculates to the core it drops the vital core temperature and causes rapid deterioration.

How does one tell underground when this critical core temperature has been reached? It is difficult to be precise in this matter but a good guide is the patient's level of consciousness. If his speech and thoughts are impaired giving confusion or delirium or if he has impairment of muscle function so that simple actions like walking along a cave passage are grossly unco-ordinated then he is probably too cold to move. Each case must be assessed individually. Much will depend on the cave system and its location. If the victim is in the far end of Langcliffe Pot so that it will be perhaps 12 to 14 hours before help can arrive then one would sensibly want to start to encourage him to move out of the system itself. The current teaching that as soon as hypothermia is suspected it is imperative to rest and shelter the victim, comes mainly from mountain rescue circles where victims will generally face a much lower air temperature and certainly much higher wind speeds than are likely underground. In these circumstances the classical teaching of "take shelter at once" for hypothermia is undoubtedly logical (British Mountaineering Council, Handbook of the Mountain Rescue Committee, 1975). If one is in any doubt it is perhaps reasonable to try to get the victim to move out of the cave under his own steam but to watch him very closely, to help him in every way (e.g. using haulage lines on crawls, etc.) and certainly to lifeline him meticulously on even minor hazards. If the patient is deteriorating or getting more exhausted he should then be stopped and be sheltered and be treated with all the measures previously mentioned whilst help from a rescue team is sought. It is likely that in the mild case of exposure with rest, feeding and insulation, the patient's condition will improve so that one can try again to move him but this should not be enforced if the patient cannot manage it.

Traditional medical teaching is that hypothermia is only present when the core temperature (i.e. rectal temperature) has dropped below 35°C. (95°F.) In a caving situation cold individuals who do not meet this strict definition can only be ignored at their peril as their deterioration can still be rapid so that hypothermia as defined can only be a matter of time.

What extra measures can the rescue team supply for the cold patient be he injured or not? He can be helped in five ways:

1. Hot food and drinks can be supplied but never to unconscious patients please or it may be poured directly into their lungs (Lloyd, 1964). If abdominal injuries are suspected this should be withheld but if it is given to these patients inadvertently they will almost certainly reject it by vomiting. Most injured cavers show an apathetic reluctance towards taking food and drinks. They should however be encouraged to take frequent small amounts of these throughout the rescue operation.
2. The boost to the patient's morale when things start happening is undoubtedly beneficial.

3. Patients can be carried out by stretcher instead of having to climb out of the system.
4. Patients can be given extra insulation and clothing. The neoprene exposure bags now used by most teams are most efficient insulators (Plate 1, Fig. 1). The writer prefers a space blanket or a polythene exposure bag inside this neoprene bag. Its use should not be neglected because the patient is already in a wet suit. Using this technique patients often do warm up measurably during an evacuation. If it is not completely enveloping as is the "Sump Rescue" bag then insulation of the head and hands with neoprene helmet and gloves should be routine. The extra bulk given to the patient may preclude its use in some very tight sections but if feasible it should be reapplied after this type of terraine. If its design incorporates a waterproof zip and a facial seal around the helmet it can provide efficient insulation even during sump rescue. There are good grounds for assuming that the neoprene exposure bag should be used routinely on all protracted rescues where the patient has to be carried.
5. The use of warmed inspired air or oxygen. This is an exciting new technique to treat hypothermia by supplying heat by the most beneficial route i.e. via the inspired air to the body core. Developed by an Edinburgh anaesthetist, Dr Evan Lloyd, (Lloyd, 1972) it has been used just once in cave rescue with extremely efficient results.
   The inspired air is heated to 57°C (135°F) by being passed through a container of soda lime which is in turn heated b y having a controlled amount of carbon dioxide passed into it. In absorbing the carbon dioxide the soda lime becomes hot and serves to heat the inspired air or oxygen. An insulated container surrounds the whole equipment and a short insulated tube leads to an anaesthetic face mask. As well as the heat supplied directly to the patient further heat loss in warming the expired air and in evaporation of moisture via the expired air is prevented as the reaction between the CO_2 and soda lime moistens the inspired air in addition to warming it. Our own team's original equipment (Plate 1, Fig. 2) is bulky and heavy, much of the weight comprising an oxygen cylinder and demand valve. We have now replaced this with the "Reviva" equipment recently developed by the Peter Bell Engineering Co. of Ambleside which is lighter (20 lbs. or 8.4 Kg) more compact and designed for rescue purposes (Plate 2, Fig 1). The central rewarming acts directly on the body core, the large blood flow through the lungs efficiently dispersing the heat. Scottish Mountain Rescue teams and the Royal National Lifeboat Institute are carrying out trials with this equipment which may well become the elective on site treatment for hypothermia in the future.

In our own case, the first instance such equipment has been used outside hospital, an inexperienced caver was trapped in a narrow rift in November Hole (Alum Pot Series) partially in water for four to five hours. The terrain was such that he could not be carried and it took two hours for him to crawl out with considerable help. He arrived at the surface ketotic, shivering vigorously and unco-ordinated with a mouth temperature of 33.3°C. (92°F.) He was put in a heated ambulance at the cave entrance, wrapped in blankets and given airway warming with the portable resuscitator. His condition rapidly improved, the shivering stopped and after twenty minutes his mouth temperature was 36.8°C. (98.4°F.) (Lloyd and Frankland, 1974). This rate of rewarming compares favourably with the time required to rewarm by any other method.

Diagnosing Death in Hypothermia

It is worth mentioning how one defines death in the hypothermic state. Experienced forensic pathologists have been proved wrong in declaring as dead, people who are walking around today, much to the delight of the popular press. In the state of suspended animation which results from profound hypothermia definition of death may be extremely difficult as respiration is barely perceptible and the heart beat may be impalpable. Some American research workers have cooled dying cancer patients until there has been electrocardiographic evidence of cessation of heart beat for up to one hour following which they were successfully resuscitated (Niagi & Lewis, 1958). Recovery from profound hypothermia with cardiac arrest following immersion has also recently been documented (Dominguey de Villota, 1973). **The definition of death in hypothermia must only be failure to resuscitate.** This may mean helicopter evacuation to hospital, tracheal intubation and positive pressure respiration with oxygen, cardiac massage, active rewarming, correction of electrolyte and acid base balance and all the technical expertise of modern intensive care therapy. The rescuer should not assume death because he cannot detect breathing or feel a heart beat.

One other possible emergency treatment described but not so far used, on a rescue, may be worth considering. Don Robinson of the Upper Wharfedale team has carried out experiments on himself where he was put inside a neoprene sump rescue exposure bag and had poured into it water heated to 45°C. in a milk church over a bonfire. This caused a dramatic rise in his body temperature to levels of almost dangerous hyperpyrexia in only a few minutes (Robinson 1969a). With a critically cold patient brought out of a remote cave entrance, I would be prepared to try this method.

Management of Hypothermia on the Surface

When a hypothermic patient arrives on the surface further rewarming can be done in one of two contrasting ways:

a) SLOWLY, by providing only dry and adequate insulation with no external heat;
   or
b) RAPIDLY, by immersion in warm water, the temperature of this being maintained as it is cooled by the patient.

In (a) the heat generated by the patient's metabolism rewarms his body if heat loss is prevented. It is slow (possibly up to 48 hours) but safer for infants and the elderly and has been effective on a patient as cold as 18°C. (64°F) (Laufmann, 1951).

Plate 1

Fig. 1. Neoprene exposure bag. Note waterproof zip, hood and facial seal.

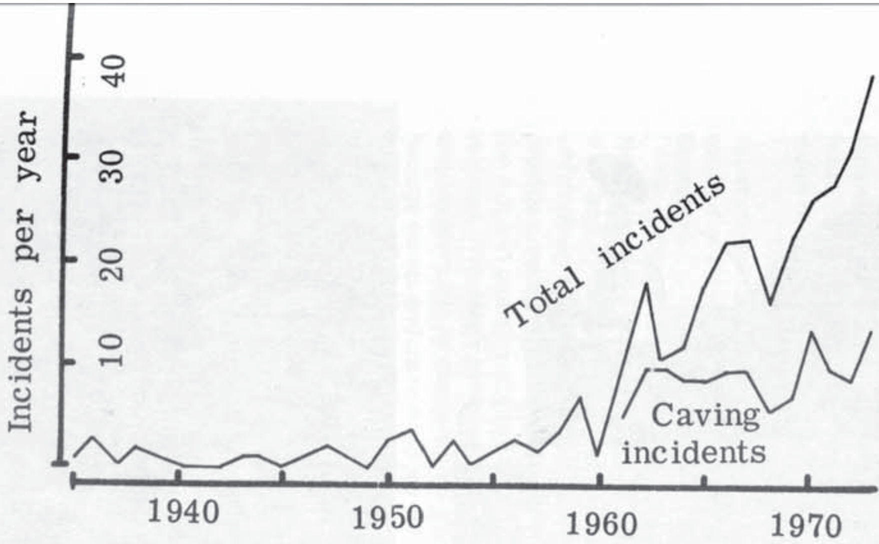


Fig. 4. Cave Rescue Organization call-out record for 39 years. Note the increase in call-outs as the team has become more widely known.

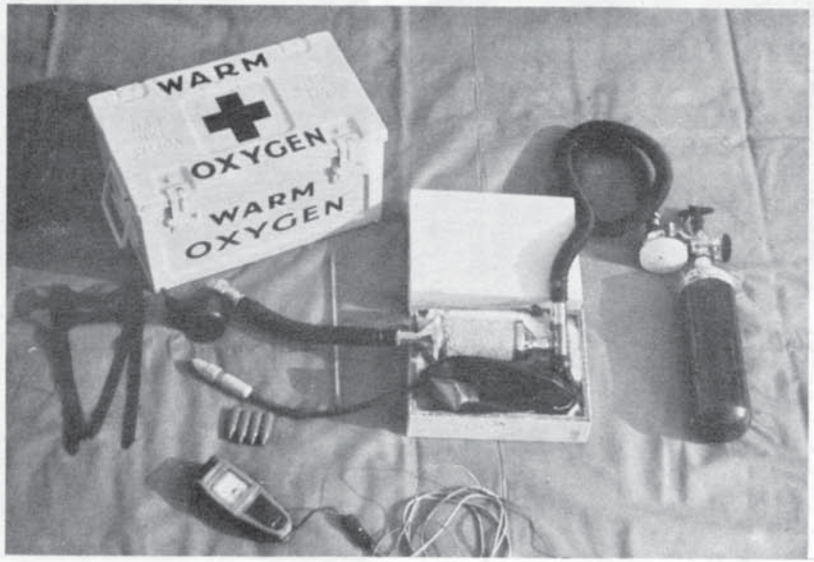


Fig. 2. Original "Warm oxygen kit" for hypothermia treatment. Note thermistor electronic thermometer with rectal probe at bottom.

Fig. 3. Polyurethane foam splintage showing completed long arm and long leg splints.

Plate 2

Fig. 1. "REVIVA" warm air resuscitation equipment for treating hypothermia. Recently marketed by Peter Bell Engineering Co., The Slack, Ambleside, Cumbria.

Fig. 2. Patient in neoprene exposure bag and modified Neil Robertson stretcher being carried on a McInnes stretcher. Note metal support under patient"s feet.

Rewarming by immersion, (b), has become established as the method of choice in young healthy adults who do not have injuries making it inadvisable. However, it is not without hazards if badly supervised, for the following reasons. An inadequate supply of heat to the body surface will merely open up the circulation in the extremities where cold blood is pooled. This cold blood will return to the core causing a fall in core temperature. This 'after drop' in body temperature during rewarming is a real hazard and in the war many survivors from shipwrecks were lost during treatment. It was first beautifully documented by Dr. James Currie of Liverpool in 1798; he immersed conscious human volunteers (his servants!) in water at 9-10°C. and observed the continuing fall in rectal temperature after removal from cold water. Because of the 'after-drop' risk the technique of immersion rewarming demands rapid heating using an adequate volume of hot water. This can supply sufficient heat to the whole body surface and ensure that the pooled blood shut off in the muscles is rewarmed as fast as it is returned to the core.

The technique is as follows: After quickly removing outer clothing (underclothing may be removed underwater) the victim is immersed to the neck in a bath of approximately 40 gallons of hot water at 45°C. (112°F.). A thermometer should be used to check the bath water temperature but if one is not available, use the hottest water in which an immersed elbow can be kept. Beware of the patient splashing violently when first immersed. With cold patients approaching loss of consciousness this can be quite dramatic, convulsion-like states developing briefly. These are helped by keeping the head fairly low, i.e. as near the water surface as is compatible with safety. Try to keep the patient immersed to the neck throughout the rewarming period. Maintain the bath water temperature at 43°C. to 45°C. (108-112°F.) by the continuing addition of further hot water and stir the water around the patient; this topping up to maintain bath water temperature is most important. Remove the patient from the bath when he begins to sweat visibly on the face, indicating that his body temperature has returned to normal, then keep the patient in dry clothes in a warm room until his temperature has stabilized.

This technique should be used on all hypothermic victims whenever practical. If any exposure situation develops or any underground accident occurs then rescue leaders should obtain facilities for this method of treatment at the nearest house in case it is necessary.

Stretchers

Controversy exists over the ideal stretcher for cave rescue purposes. Our own team uses the standard Neil Robertson stretcher with several modifications (Plate 2, Fig. 2). These include a protective helmet with vizor and a metal frame adjustable in length which provides the necessary rigidity for spinal injuries and which serves as a runner when the stretcher is dragged over rough ground. Its lower end is bent round to provide support for the feet during vertical hauls. A feature of this stretcher is the protection afforded to the legs and trunk by the strong flaps which surround the body, important in the inevitable awkward sections. The Hey's splint which will be described later fits firmly onto this lower part of the frame giving very comfortable protection from leg injuries when the victim is both horizontal and vertical. Stronger haulage points and carrying loops are also incorporated. Most alert patients without injuries above the waist prefer to be evacuated with their arms free from the stretcher as this allows more self-protection on vertical pitches and in awkward sections. The arms can, however, be strapped inside the chest flaps on this type of stretcher. The Neil Robertson stretcher could undoubtedly be improved if more modern fabrics and techniques were used in its manufacture. On average our stretcher needs replacing after three rescues. Its main disadvantage is its inherent rigidity which means that in tight winding crawls the patient cannot be passed through in this stretcher and one has the unpleasant task of lifting him out of it, strapping him to a drag stretcher which is a length of thick rubber mining conveyor belt and replacing him in the stretcher after the tight section. Ideally this disadvantage could be overcome if the frame were detachable.

Attempts at redesign reveal many snags mainly centred on efficiently attaching a separate frame to a non-rigid stretcher. Ideally a bag made of durable insulating modern fabric and incorporating the protective flaps of the Neil Robertson stretcher but which could be detached from its rigid metal frame for tight awkward sections would seem desirable. On Mendip the lace-up canvas carrying sheet has long been used and has satisfied rescue personnel. Trials are currently taking place in this area with the Paraguard stretcher. In the Yorkshire Dales we have recently started using an industrial safety harness to support and haul out the weary and the not too badly injured and this seems to have a useful future. It can be a difficult decision whether to use a stretcher or just to help an injured man out if his injuries allow it in which case he may well reach the surface much sooner. The writer agrees with Dave Brook's comments that the only hope for the injured in the far reaches of a Grade V cave is for his colleagues to start to get him out at once (Brook 1970). Two incidents in Simpson's Pot, Kingsdale, illustrate this point. The writer saw a man fall down the bottom pitch and sustain a fractured ankle. A very strong team was down the pothole and after the ankle was strapped the victim was on the surface 2½ hours after the fall (this was before the valley entrance was found). In another incident a man fell and sustained an extremely deep laceration in the buttock on landing on a sharp flake. After suturing and small doses of painkilling drugs he made an uneventful assisted exit without a stretcher. In both these incidents rescue in a stretcher would have been very prolonged due to the nature of the system and serious hypothermia may well have become a problem.

Theoretically shocked or hypothermic patients should be hauled up vertical pitches in a horizontal position in order to maintain the maximal amount of the reduced circulation to the brain (Robinson, 1969b). However such a technique is not feasible on many pitches, particularly those with constricted sections or a difficult finish, often the case. Horizontal hauling also carries extra hazards such as banging the patient against overhangs and increasing the risk of injury from rockfalls. A well organized, speedy, vertical haul probably best serves the patient's interest by accelerating his evacuation.

Splints

For leg fractures the Hey's Splint is excellent for cave rescue purposes. This comprises two wooden strips one reaching from ankle to groin inside the leg, and one from ankle to armpit outside the leg. The leg is supported at the back on a canvas sling which joins the two wooden strips and the splint is tightened with canvas lacing, at the front of the leg. It is suitable for fractures either above or below the knee. It is as comfortable for the victim as a Thomas Splint, is less bulky and is much easier to apply in a confined space. A groove in the bottom of both wooden strips fits nearly on to the foot support on the Neil Robertson stretcher. It is a simple durable and efficient splint.

Pneumatic splints are effective for below knee fractures but puncture easily underground. We have used them for short underground sections where the patient has had to be removed from the stretcher. The most useful is the "Athletic Full Leg" and fits over a climbing boot – on the standard "Long Leg" inflatable splint the boot needs to be removed. These splints are not suitable for fractured femurs as they do not immobilize the hip joint.

The adjustable plastic geriatric cervical collar with velcro fasteners is an excellent splint for suspected neck injuries or to support the head and keep the chin elevated in an unconscious patient.

The Kramer wire splint which resumbles a ladder made of wire which can be bent to shape is ideal for arm injuries but provides considerable extra bulk to the stretcher if it is used under the chest flap of a Neil Robertson stretcher. With the injured arm well supported under the chest flap of a Neil Robertson stretcher no further splintage may be necessary.

The C.R.O. have devised a new form of splintage whereby an expanded polyurethane foam cast is formed around the injured limb (Frankland, 1972). This is aimed at the below knee leg injury in a cave too tight to allow a stretcher to be used. Two polythene bags are placed around the limb and between them is poured a mixture of two chemicals which react to form polyurethane foam which sets within minutes. The resulting cast is extremely durable, is much lighter than plaster of paris and is totally water resistant. It has been used once in Bar Pot where the victim had an ankle injury and was able to walk out with assistance (Plate 1, Fig. 3).

Perhaps the most horrific incident concerning splintage was in the Intestines Route in Marble Steps some years ago when a patient had a nasty fracture of the lower leg. The C.R.O. secretary Brian Boardman crawled in behind him and he was finally evacuated by crawling around the narrow bends with his injured lower leg strapped directly to Brian Boardman's forearm. This is obviously a constant demand for ingenuity in first aid underground!

Single Rope Techniques

In cave rescue we have traditionally had less big falls than in mountain rescue because the sport does not involve as many high risk moves above big drops as does rock climbing (Standing, 1973). With the advent of single rope technique one wonders if this trend will continue. There have been four incidents with single rope technique in the Dales. In the first and second, cavers were too tired or not technically able to prusik out of Lost John's and Flood Entrance, Gaping Ghyll – simple rescues. In the third a karabiner failed with almost 300 feet of space below a man abseiling down Echo Pot on Fountains Fell. Unbelievably he managed to grab the rope as he fell and lower himself safely to a ledge. The fourth incident resulted in a fatality at Gaping Ghyll in December 1974 when a brand new, but unsuitable, polypropylene rope broke during an abseil. One sincerely hopes that this trend is not going to continue but American experience suggests otherwise. A detailed analysis of four years caving accidents showed that 32% (19 out of 59 incidents) involved single rope techniques (N.S.S. Report, 1974). The same report suggests that S.R.T. cavers should use a strong reinforced safety helmet with a stout chin strap, i.e. a climbing helmet as distinct from a caving helmet to protect the head in falls. This is certainly not standard technique at the present.

Foul Air

The presence of foul air in caves is fortunately rare and has only been responsible for one fatality – the Neil Moss tragedy. The C.R.O. now owns gas analysis equipment and has developed a technique to pump bad air out of a confined rift or chamber through a hosepipe for dispersal in a well ventilated section of the cave.

Final Thoughts

When finally the rescue team brings its victim to the surface, having usually surmounted many difficult obstacles it is perhaps provident for the person who has been maintaining rapport with him to suggest that he has a few moments of quiet thought before speaking to the press. Many a victim has been so overcome with relief at reaching the surface that he has made inappropriate comments which reflect on both himself and the sport of caving.

Rescue Teams have, occasionally, the unpleasant task of dealing with a death underground. This is frequently not confirmed until they reach the victim as the story of those seeking help is often far from clear. Medical confirmation of death underground is often appreciated by the Coroner and may make the inquest proceed more smoothly. The unpleasant job of covering the body in stout material by a couple of more experienced members of the team will relieve the distress of the rest of the team during the evacuation. On these occasions there is undoubtedly much wisdom in careful thought before any Press statements are made.

Each Cave Rescue incident seems to provide a unique set of difficulties and to obtain the maximum benefits for the patient ingenuity and careful thought is necessary. Cave Rescue prevents a difficult and challenging aspect of medical care.

Undoubtedly, many opportunities exist for further technical developments in this field and if this paper provokes critical comment then it will have succeeded in its aim.

June 1975

John C. Frankland, B.Sc., M.B., Ch.B.,
M.R.C.G.P., Dip.Obs., R.C.O.G.,
1, Meadowside,
Lancaster.

References

Brook, D. 1970. The Role of the C.R.O., *U.L.S.A. Review* (7), 20-24.

Craven, S. 1973. Some medical aspects of caving accidents, *Injury, 5,* (2), 94-99.

Dominguey de Villota, E. 1973. Recovery from profound hypothermia with cardiac arrest after immersion, *Brit.Med.J., 4,* 394-5.

Frankland, J.C. et al. 1972. Polyurethane foam splintage — a new technique. *Practitioner, 209,* 831-4.

Frankland, J.C. 1973. Hypothermia and its relevance to cave exploration, *Brit. Assn. of Caving Instructors Bull.,* (7), 1-7.

Freeman, J. & Pugh, L.G.C. 1969. Hypothermia in Mountain Accidents, *International Anaesthesiol. Clinics, 7,* 997.

Handbook of the Mountain Rescue Committee 1975. from Mountain Rescue Committee, 9 Milldale Avenue, Temple Meads, Buxton, Derbyshire, SK17 9BE.

Laufmann, H. 1951. Profound Accidental Hypothermia, *Jnl. American Med. Assn., 147,* 1201.

Lloyd, E.H. at al. 1972. Accidental Hypothermia — an apparatus for central rewarming as a first-aid measure, *Scottish Med. Jnl., 3,* 83.

Lloyd, E.H. & Frankland, J.C. 1974. Accidental Hypothermia — Central Re-warming in the field. *Brit. Med. J.,* 4, 717.

Lloyd, O.C. 1964. Cavers Dying of Cold, *Bristol Med. Chirurgical J., 79,* 261.

MacInnes, C. 1971. Plasma — 11 — Hydroxy-corticosteroid and Growth Hormone levels in climbers, *Lancet, 1,* 49-51.

1971. Steroids in Mountain Rescue, *Lancet, 1,* 599.

Mountain Hypothermia Brit. Mountaineering Council pamphlet.

National Speleological Society. 1974. *Report on American Caving Accidents, 1967-70,* Speleobooks Press, Albuquerque, New Mexico, U.S.A.

Niagi, S.A. & Lewis, F.J. 1958. Profound Hypothermia in Man, *Annals. of Surg., 142,* (2), 264-6.

Report of a Sub-committee on Hospitalization Underground. Joint C.R.O. & Upper Wharfedale Fell Rescue Assn. study. 1970.

Robinson, D. 1969(a). Personal communication.

1969(b). Cave rescue, in *Manual of Caving Techniques* (ed. Cullingford, C.H.D.), Routledge & Kegan Paul, p.347.

Standing I.J. 1973. Cave Rescue Incidents in Britain 1935-72, *Cave Science, 50,* 13-20.

Undoubtedly, many opportunities exist for further technical developments in this field. If this paper provokes critical comment then it will have succeeded in its aim.

June 1975

John C. Frankland, B.Sc., M.B., Ch.B.,
M.R.C.G.P., Dip.Obs., R.C.O.G.,
[illegible]
Lancaster.

References

Brook, D. 1976. The Role of the C.R.O. [illegible]

Clevens, [illegible] 1978. Some medical aspects of caving accidents. [illegible]

Dominguez de Villota, [illegible] 1972. [illegible] hypothermia [illegible] Brit.Med.J., 4: 394-5.

Frankland, J.C. et al. 1972. [illegible]

Frankland, J.C. 1973. Hypothermia and its relevance to cave rescue. [illegible]

Freeman, J. & Pugh, L.G.C.E. 1969. Hypothermia in [illegible]

Handbook of the Mountain Rescue Committee 1975. [illegible] Derbyshire, [illegible]

Lautmann, H. 1971. [illegible]

Lloyd, E.Ll. et al. 1972. Accidental Hypothermia [illegible]

Lloyd, E.Ll. & Frankland, J.C. 1974. [illegible] Brit.Med.J., 4: 717.

Lloyd, O.C. 1964. [illegible]

Marchal, C. 1971. [illegible]

Mountain Rescue [illegible] 1971. [illegible]

National Speleological Society [illegible] 1974. [illegible] Albuquerque, New Mexico, U.S.A.

[illegible] & Lewis, [illegible] 1973. [illegible]

Report of a Sub-Committee of [illegible] Hospitalisation Underground [illegible]

Robinson, C. [illegible]

[illegible] 1975. [illegible]

Transactions British Cave Research Assoc. Vol.2. No.2. pp.65-78 August 1975.

SOME MEDICAL ASPECTS OF CAVE DIVING

by Oliver C. Lloyd

INTRODUCTION

The Cave Diving Group

Cave diving in Britain was started by Graham Balcombe. In 1935 his team was active in Wookey Hole and in 1936 he and Sheppard passed Sump 1 in Swildon's Hole. In 1946 the Cave Diving Group was formed, so as to bring together divers from different parts of the country and enable them to concentrate their efforts. Since then some of the achievements of the divers have been spectacular, such as the long dives in Wookey Hole and Keld Head; but the most useful have been those which have opened up further cave passages to ordinary cavers. Among these successes must be counted Swildon's Hole, Stoke Lane Slocker, Langstroth Cave, Ogof Ffynnon Ddu II, and the Little Neath River Cave.

Cave diving in this country, unlike abroad, has always been for cavers who wish to dive rather than for divers who wish to cave. It is an extension of caving and not an end in itself. One of the essential pre-requisities of membership therefore is that the candidate must be known to be a good caver.

The Group also exists for the purpose of setting standards. The standard set is a high one and trainees are expected to work towards qualification. A third objective is the exchange of information and publication of results, and to this end the Group publishes a quarterly newsletter and an annual index of dives. The newsletter, free to members, is on sale to the public and contains complete accounts of all cave dives in which original observations are made. The Group also publishes regional sump indices and occasional publications of a specialist nature.

No drive is ever made for members. Cave diving is far too dangerous an occupation for us to wish to give any encouragement to cavers to take it up. But for those determined to do so the Group tries to provide training facilities. These facilities vary in different parts of the country and are run by the regional sections, of which there are four: Northern, Derbyshire, Welsh and Somerset. The candidate must be known to the members of the regional section, through which he wishes to join the Group. He must be over 18 and in good health, never having suffered from epilepsy. He must be elected by the diving members of the regional section.

Besides diving members the Group includes non-diving members. These valuable people help the divers on their expeditions and receive all publications, but pay a smaller subscription. They are free to attend all meetings and training sessions.

The Group carries insurance policies to protect its members against third party risks and also against loss of equipment. Full information regarding regional representatives, training facilities, rates of subscriptions and price of publications may be obtained from the Hon. Secretary of the Cave Diving Group, Mr. Martin Bishop, Bishop's Cottage, The Batch, Priddy, Wells, Somerset, telephone Priddy 370.

ANATOMY AND PHYSIOLOGY

Air in the body

Air is contained in the body in three sets of places: (a) the para-nasal sinuses and middle ears, (b) the respiratory tract and lungs and (c) the stomach and guts. This air is compressible whereas the body is not. At depth therefore the air in these places will take up less space unless it is replenished with air at the ambient pressure. In the case of (c) this does not matter, since the air is contained in soft bags which can collapse under pressure. The air in the stomach and guts will then take up less space at the higher pressure and the only disturbance experienced is a loss of buoyancy.

This is not true of air in the middle ears or para-nasal sinuses, because they have rigid bony walls and cannot collapse. For this reason they all communicate with the nasal cavity by little tubes, so that air can pass from one to the other along these tubes (see Fig. 1). Air passes from nose to sinuses under pressure at depth and it passes from sinuses to nose when the ascent from depth is made. This passage is usually quite free, so that the diver doesn't have to worry about clearing his sinuses, but when he has a cold or sinusitis the lining of the nose (mucous membrane) becomes congested and the tubes are blocked. A partial vacuum is then created in the sinuses which may be very painful unless relieved. Frontal sinus pain is felt over the eyebrow; maxillary sinus pain over the front of the cheekbone. The vacuum may be relieved by closing the nostrils and blowing into the sinuses. On reascent the sinuses usually clear themselves, but if the ducts are badly blocked the compressed air within them swells and gives the diver a nasty headache, sometimes with nose bleed.

These pages form part of A Cave Diver's Training Manual published by the Cave Diving Group in July 1975 to whom acknowledgement is due. The work started with a lecture to the Bath Medical Chirurgical Society on "Cave Diving Hazards" in 1967, reprints of which were circulated to members of the Cave Research Group. It is however mainly based on a lecture given to the Cave Research Group on Training for Cave Diving. It is fitting, therefore, to offer these extracts to the B.C.R.A., successor to the C.R.G., while the entire work is being published by the Cave Diving Group.

This work, "A Cave Diver's Training Manual" runs to 106 pages (4to) with 16 illustrations in black and white and an index. It can be obtained from The Editor, C.D.G. Publications, Withy House, Withy Close West, Bristol BS9 3SX. Price £1.00 plus 10p for postage. Please make cheques payable to the Cave Diving Group. Commerical outlets are offered 20% commission.

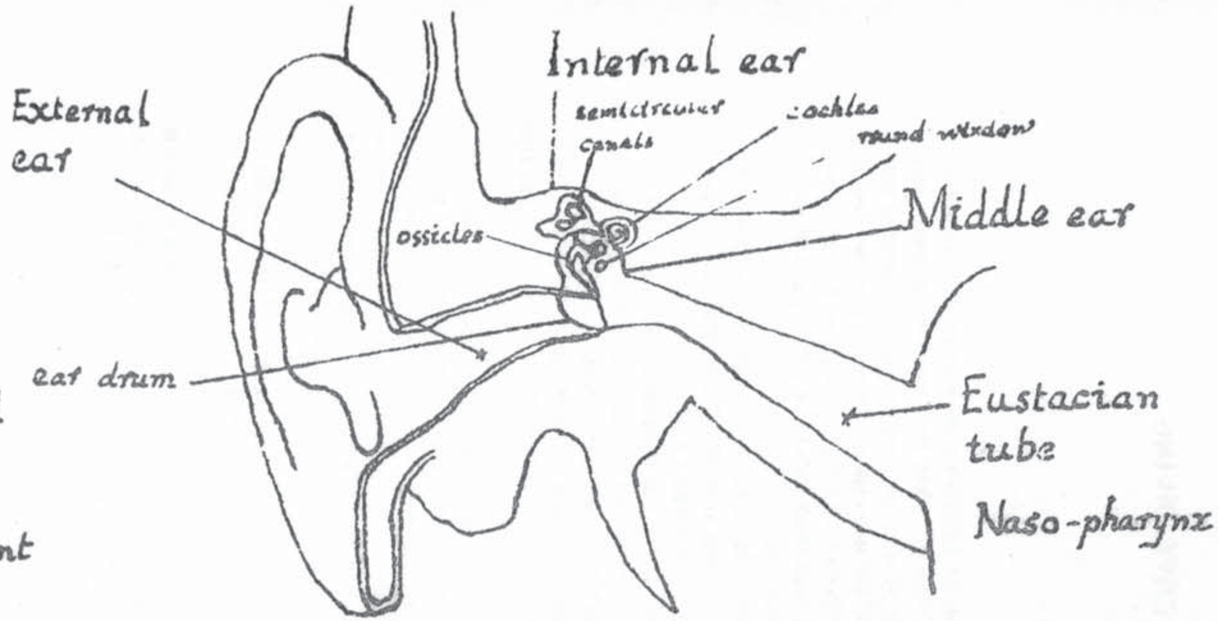


Fig. 2. Right ear viewed from in front.

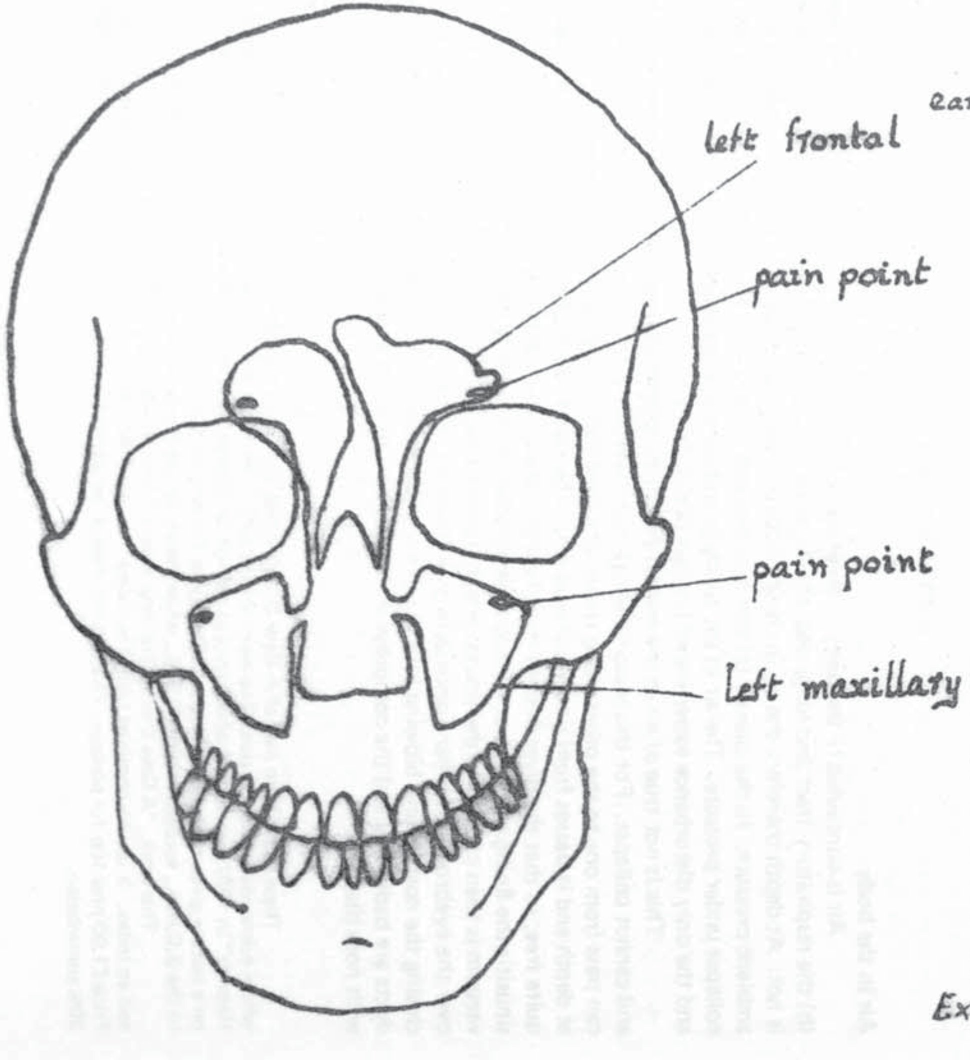


Fig. 1. The para-nasal air sinuses.

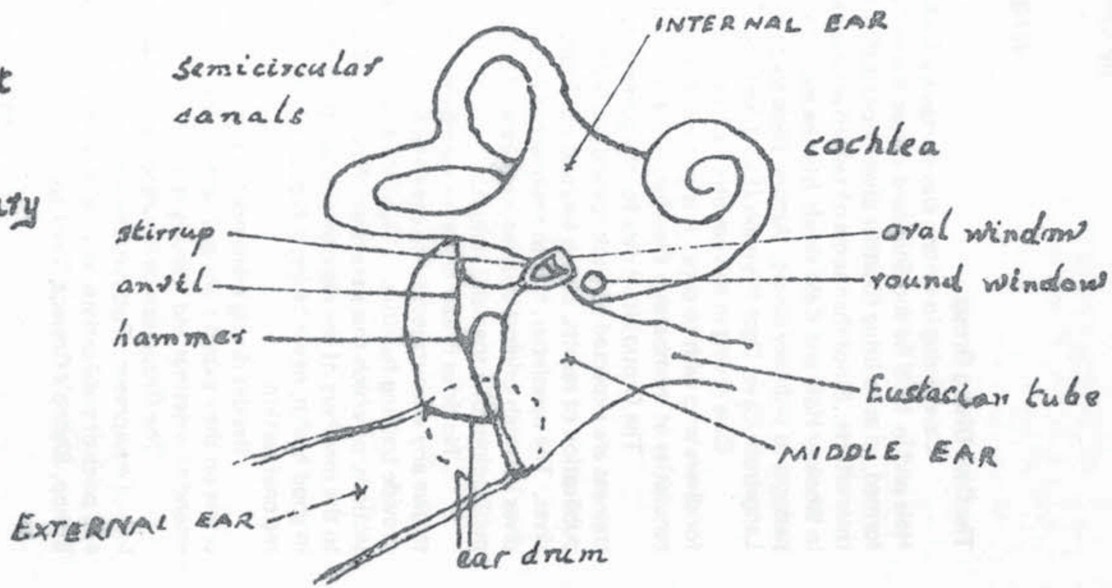


Fig. 3. Enlargement of middle and internal ears.

The ears

Air in the middle ear behaves like air in the sinuses except for two things. (a) The tube which connects it with the nose (Eustacian tube) is slightly valvular at the inner end, so that air travels freely into the nose but not the other way. This means that the ears usually clear automatically when reascending, but not when doing down. They may be cleared by swallowing, yawning or by squeezing the nostrils and blowing. If these fail acute pain is felt in the ear and serious damage may result. (b) The wall of the middle ear is not all of bone. It is closed on the outer side by a thin delicate membrane, the ear drum (see Figs. 2 & 3). This drum may be burst if it is sucked in too far, as by descending without clearing the ears. The consequences are unpleasant.

How the ears work

The ears perform two functions, one is hearing the other is control of balance.

Sound vibrations reach the ear drum and are communicated by three little bones (ossicles), which lie in the middle ear, to the internal ear, where the sensory apparatus lies. Here the sound waves are converted into nervous impulses which travel to the brain. The sound waves reach the ear drum by passing along a rigid tube, the external ear. The ossicles are called the hammer (malleus), anvil (incus) and stirrup (stapes). The hammer is firmly attached to the ear drum by its handle. Its head is jointed to one corner of the anvil. This pivots about a second corner attached to the wall of the middle ear, while its third corner is jointed to the top of the stirrup. The footplate of the stirrup fits neatly into the oval window of the internal ear. All three ossicles are surrounded by air because they are within the middle ear.

The internal ear is entirely surrounded by very hard (petrous) bone. It consists of a number of canals and chambers filled with fluid (endolymph) and is closed on the outer side by the oval and round windows. On the inner side is the acoustic nerve. The balancing apparatus consists of three semicircular canals set at right angles to one another and two little chambers (sacculus and utriculus). All of these contain very delicate cells (hair cells) which can pick up changes of direction of movement in the endolymph and so tell the brain, by way of the vestibular branch of the acoustic nerve, in which direction you are moving and which way up you are. The hearing apparatus consists of a helical tube (cochlea) also lined with hair cells, which sorts out the sound vibrations into those of high or low frequency and communicates its information by the other branch of the acoustic nerve (auditory). The round window is a compensating device. Since endolymph is a liquid it is incompressible. When vibrations communicated to the footplate of the stirrup push the oval window inwards, then the round window is pushed outwards, towards the middle ear.

Things which may go wrong with the ear in relation to diving

The **external ear** is found in all sizes. Some are big and round, others slit shaped, others again so small as scarcely to admit a one millimeter proble. It is the last two sorts which may most easily get blocked.

The external ear is lubricated by a soft wax secreted by special glands. Normally there is a self clearing mechanism for wax and also for the scales formed by the skin which lines the external ear. If you make an ink dot in the middle of the ear drum and watch it for several weeks, you will find that it travels first to the side of the drum and then out to the surface along the walls of the external ear.

When the external ear is too narrow this self-clearing device may be upset. Moreover it becomes increasingly difficult to dry the ears, so that the wax-scales mixture becomes soggy. This provides a perfect culture medium for bacteria and fungi, so that inflammation may result (otitis externa). This produces a vicious circle. The lining swells, the blockage becomes worse, it hurts, inflammatory exudate is added to the natural secretions, the external ear becomes totally blocked and deafness ensues.

In these circumstances it is dangerous to dive for two reasons, (a) it is essential to have a free air passage through the external ear, so that pressure changes may be equalized on **both** sides of the ear drum. For this reason ear plugs should never be worn. (b) The inflammation softens the ear drum so that it is easily ruptured by pressure changes.

When the inflammation dies down the external ear will open up again, but will still contain a lot of debris. Until this is removed the self-cleansing device will not be restored. Its removal is a job for the expert. The diver should never push things into his ears.

The **ear drum** has a thin layer of skin on the outer surface, an even thinner layer of cells lining the inner surface and a layer of fibrous tissue in the middle, like a sandwich. It is remarkably strong but may nevertheless be ruptured by excessive or rapid changes of pressure on one side of it, which are not compensated by similar changes of pressure on the other. It is usually pressure from the outside which ruptures the drum. Pressure from the inside causes bleeding into the external ear ("reversed ear") and may be due to blockage of external ear from tightly fitting hood. But it rarely causes the drum to rupture.

When the ear drum ruptures in a dive, water pours into the middle ear from the outside and causes an acute form of giddiness (vertigo). The diver feels that he is continually falling towards the side where the drum has ruptured. This makes reascent hazardous, because you don't know which way up you are. The balancing apparatus is easily disturbed by cold water. In fact the disturbance can be produced without rupturing the drum, simply by getting cold water into the bottom of the external ear. This does not normally happen when diving, as a little air usually gets imprisoned and protects the drum from cold. The attack of vertigo passes off after a minute, as the water in the middle ear gets warmed up.

The other invariable consequence of getting water into the middle ear is an acute inflammation of its lining (otitis media). The ear aches and throbs and sticky yellow fluid is discharged through the ruptured drum and into the external ear. It is odd that this should happen only with the middle ear, because if you get water into any of the para-nasal sinuses it stings a bit but does not produce sinusitis.

With a perforated or ruptured ear drum diving is impossible, because every time you dive water re-enters the middle ear and sets up the inflammation again. The diver must wait for the ear drum to heal over. This it will do in a few weeks time, provided the hole is not too big and provided the inflammation does not persist owing to some unpleasant bacteria or fungi. The diver's medical attendant will have to identify the offending organisms and prescribe the correct antibiotics. If these fail he can prescribe gentian violet in spirit. This is messy, unsightly and stings horribly, but will kill almost anything.

When the drum has healed it is still very thin and weak for a long time. Diving should be resumed only very cautiously. The diver will find that the healed drum gets tired very easily and aches slightly. He should then stop diving for two or three days. Even when it is completely healed and is behaving itself perfectly the drum will always be weaker than normal. The diver must then never allow rapid changes of pressure on the drum, as by duck-diving, rapid descent, or springboard diving. All descents and ascents must be made very slowly, using swallowing or yawning movements all the time, and listening for the click in the ear that indicates opening of the Eustacian tube. The diver can tell almost to a day when the ear drum has healed up, because he can then feel pressure on the drum, relieved by this clicking, when going up or down long hills in a motor car. Then is the time to be most careful with the drum. Stop going up and down hills for at least a week, and allow no pressure changes whatever.

Internal ear damage is rare, but I have met with three cases. In one of them the balancing apparatus was damaged and vertigo persisted for several weeks. In another the damage resulted in a persistent ringing noise in the ear (tinnitus). This has gone on now for years. In a third, failure to accommodate during ascent resulted in rupture of the round window and the endolymph poured out into the middle ear. This threw the whole of the internal ear out of action and produced vertigo and deafness. Surgical intervention was needed to close the window. The vertigo gradually got better in about three weeks, but the deafness persisted for quite a long time.

The teeth

Front teeth are almost essential to a diver, because he needs to be able to hold the gag in his mouth. If he has any complicated bridgework he wants to make sure during training that it is strong enough for this purpose. Some divers find it best to remove false teeth; others keep them in. It depends on their design, whether they are stable with the gag in position.

A hole in a tooth may contain air. If so it behaves like a para-nasal sinus. If you clear it on descent, well and good, but if not then the partial vacuum may result in tootache. The wise diver will get a dentist to fill the cavities in his teeth.

The lungs

On a free dive, that is without breathing apparatus, the chest will collapse under pressure. At 33 ft. it will contain half the air at the surface, at 99 ft. only a quarter. It will collapse no further without the ribs cracking. A diver taking a deep breath at surface will fill his lungs with about 6 litres of air. If he then breathes out as hard as he can he will expell 4.5 litres of air and 1.5 litres will remain, just one quarter of what he started with. The 1.5 litres is called the residual air, and it will be seen that it is equal in volume to the air remaining in a pearl diver's lungs at a depth of 99 feet. The 4.5 litres of movable air represent a buoyancy of 4.5 Kg or nearly 10 lbs. Such an extreme range of respiration is never used and the tital air with quiet respiration is 0.5 litres, increasing to perhaps 3 litres with extreme exertion. So if you are using respiration for buoyancy-control you will have a range of about 2-3 Kg. or 6 lbs.

When breathing apparatus is used the air is delivered at the ambient pressure. The chest therefore does not collapse and the lungs maintain their normal volume.

In the lungs the air goes along a number of small branching tubes (bronchioles) and enters minute pockets (alveoli) where it comes into intimate contact with the blood in the tiny blood vessels of the lung (capillaries). Here it gives up part of its oxygen and received carbon dioxide from the blood. On expiration the walls of the alveoli, which are elastic, contract and the air is expelled through the wind pipe (trachea).

Composition of air

	Nitrogen	*Oxygen*	*Carbon dioxide*
Inspired air	78.96%	21%	0.04%
Expired air	78.96%	17%	4.04%
Air beyond sumps	63.9%	33.2%	2.9%

This might be an appropriate place to remind cave divers that the air beyond sumps already contains a high proportion of carbon dioxide, unless there is free communication with the surface. When he exerts himself in this atmosphere, therefore, he gets out of breath more quickly.

To return to the lungs, air under pressure is stickier than normal air. At a pressure of four atmospheres (100 ft.) its flow resistance is such that it takes twice the effort to suck it into the lungs and push it out again. This means that at that depth the diver can only work half as hard as at the surface.

Actually the diver ought never to give himself hard work to do. But the cave diver cannot correct for loss of buoyancy at depth in the way that an open water diver can, by means of an inflatable life jacket. He should therefore be unusually cautious about going deep. He may have to pull on the line he has laid, so it must be sound and well belayed. A friend of mine tells the story of how he went down to 110 ft. and then found that, by finning upwards as hard as he could, he was unable to rise at all. He solved the problem by blowing air into his hood. In desperation one could I suppose swallow air, but one must be able to belch it out again on ascent, otherwise one risks a burst stomach.

Respiratory movements, the taking of air into the lungs by the diaphragm and chest muscles, is partly automatic (as in sleep) and partly voluntary. The same applies to the rate of respiration. When you do more work the speed and amplitude of respiration both increase automatically, being controlled by the respiratory centre in the hind brain. But one can alter this speed at will, up to a point, and one can hold one's breath altogether, for a minute or two. The respiratory centre is very sensitive to changes in hydrogen ion concentration and therefore to the level of carbon dioxide in the blood. If this rises too far, due to work or atmospheric conditions, pulmonary ventilation is increased by messages sent from this centre down the nerves to the breathing muscles.

The brain is sensitive to oxygen and carbon dioxide levels in a different way. If the oxygen level rises too high, the brain cells are poisoned. If the oxygen level falls too low the brain cells cease to function and consciousness is lost. If the carbon dioxide level is low the brain is quite happy, but if it rises too high then first of all respiration becomes deep and laboured, the subject is acutely distressed and then loses consciousness. On recovery he has a splitting headache. Loss of consciousness due to oxygen lack is not heralded by any respiratory distress. It may be completely unexpected.

The Heart and Blood Circulation

There are two circulations in the body, one for the lungs (pulmonary) and the other for the rest of the body (systemic) (Fig. 4). The right side of the heart receives blood from the rest of the body and pumps it round the lungs. The left side of the heart receives blood from the lungs and pumps it around the rest of the body. Each side of the heart is a double pump composed of two muscular chambers each with a non-return exit valve. The blood reaches the first chamber (atrium) from the veins and is pumped from there to the second chamber (ventricle). The ventricle has to do much more work than the atrium and is therefore more muscular. It is made more efficient by having a non-return valve at its entrance as well as at its exit. The pressure engendered by the right ventricle is about 30 mm. Hg. but that produced by the left ventricle is much higher (120 mm. Hg.) because it has to do more work.

The heart beat is partly spontaneous, because of the nature of heart muscle, and partly regulated by a cardiac centre in the hind brain. It is this centre which increases the cardiac output, when more work is to be done, and makes the heart beat faster.

The blood owes its red colour to the presence of an iron compound (haemoglobin) which has the capacity of forming a loose combination with oxygen from the air. This compound is enclosed in tiny cells (red blood corpuscles) freely swimming in the blood stream and small enough to pass through the smallest capillary vessel. In the lungs therefore it takes up oxygen and is converted into oxy-haemoglobin, which is a very bright red colour, the most beautiful colour ever invented. This oxygenated blood is pumped by the left ventricle into the arteries, which pulsate with each heart beat. The arteries divide into smaller branches in the tissues until the capillaries are reached. Here the haemoglobin gives up its oxygen and becomes de-oxygenated. The oxygen is used to feed the fires of every bodily activity and the waste product, carbon dioxide, passes into the blood capillaries, where it is dissolved in the blood and carried by the red corpuscles. The capillaries then join together to form veins and carry the blood back to the heart. Venous blood is a deep crimson colour (it looks blue through the skin) because that is the colour of de-oxygenated haemoglobin. The blood in the veins flows smoothly and does not pulsate; the arterial pulse wave has been absorbed by the capillaries. From the right side of the heart the venous blood is pumped into the lungs. The total time taken is about 15 seconds for the whole circulation process.

BLACKOUT

"Blackout" means a temporary loss of consciousness. It has a number of causes and is particularly dangerous for the diver, because he may lose his gag and so drown.

The Valsalva manoeuvre

This is an old parlour trick. You hyperventilate vigorously and then try to breathe out hard against a closed mouth and nose. The result is a rapid diminution in cardiac output, which causes blackout. Recovery is spontaneous. This manoeuvre is a contributory cause of blackout in a number of instances.

Hyperventilation blackout

The sensible swimmer who wishes to swim the length of the bath under water gets into a calm state, takes a fairly deep breath and dives. The foolish swimmer hyperventilates vigorously beforehand. This washes out the carbon dioxide, so that oxygen levels in the blood may reach dangerously low levels before warning of carbon dioxide excess is reached. Not only that, but sudden muscular relaxation at the end of the dive may result in a poor return of blood to the heart. Worse still he may try to prolong his breath holding by "pumping the lungs", which is breathing in and out against a closed windpipe (as in breath holding). This is the same as the Valsalva manoeuvre. A number of deaths have been recorded.

Beating the lung

As already mentioned, breathing is more laboured at depth because the air is denser under pressure and so stickier. In these circumstances, if the diver gives himself too much work to do he is quite unable to get enough air for his needs from his breathing apparatus and so blacks out.

Shallow water blackout

This is a risk peculiar to oxygen divers. If the diver assumes a horizontal position, overbreathes and then stands upright, he may black out if he is using oxygen but not with air.

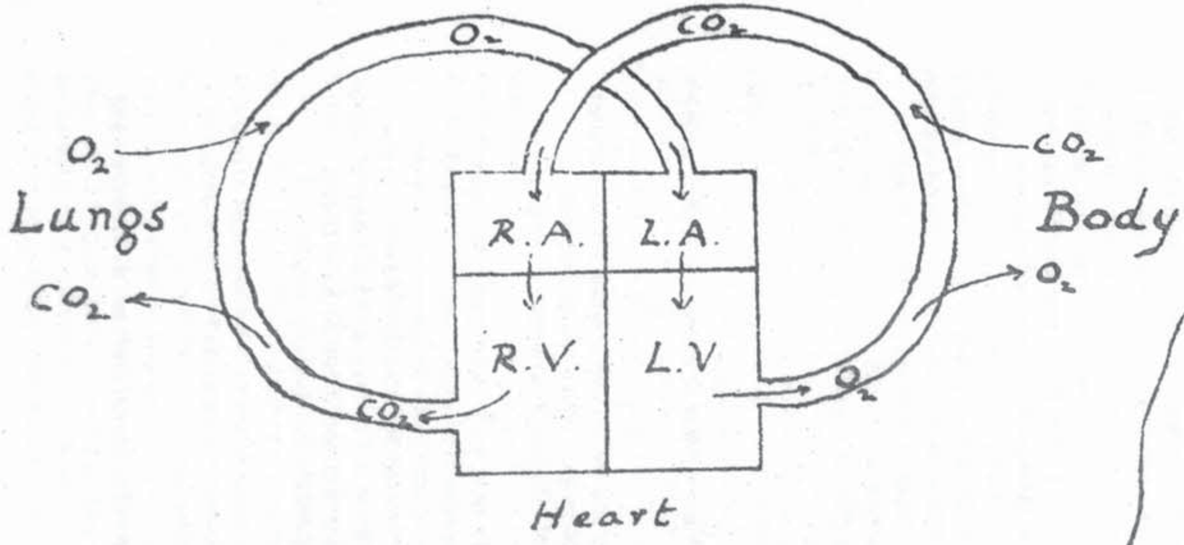


Fig. 4. Diagram of heart and circulation.

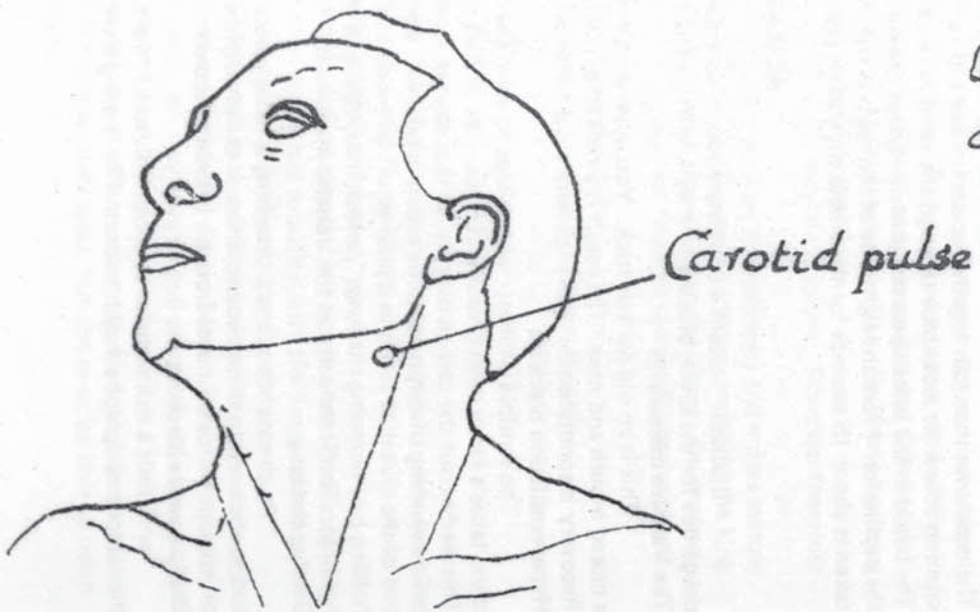


Fig. 5. The carotid pulse point.

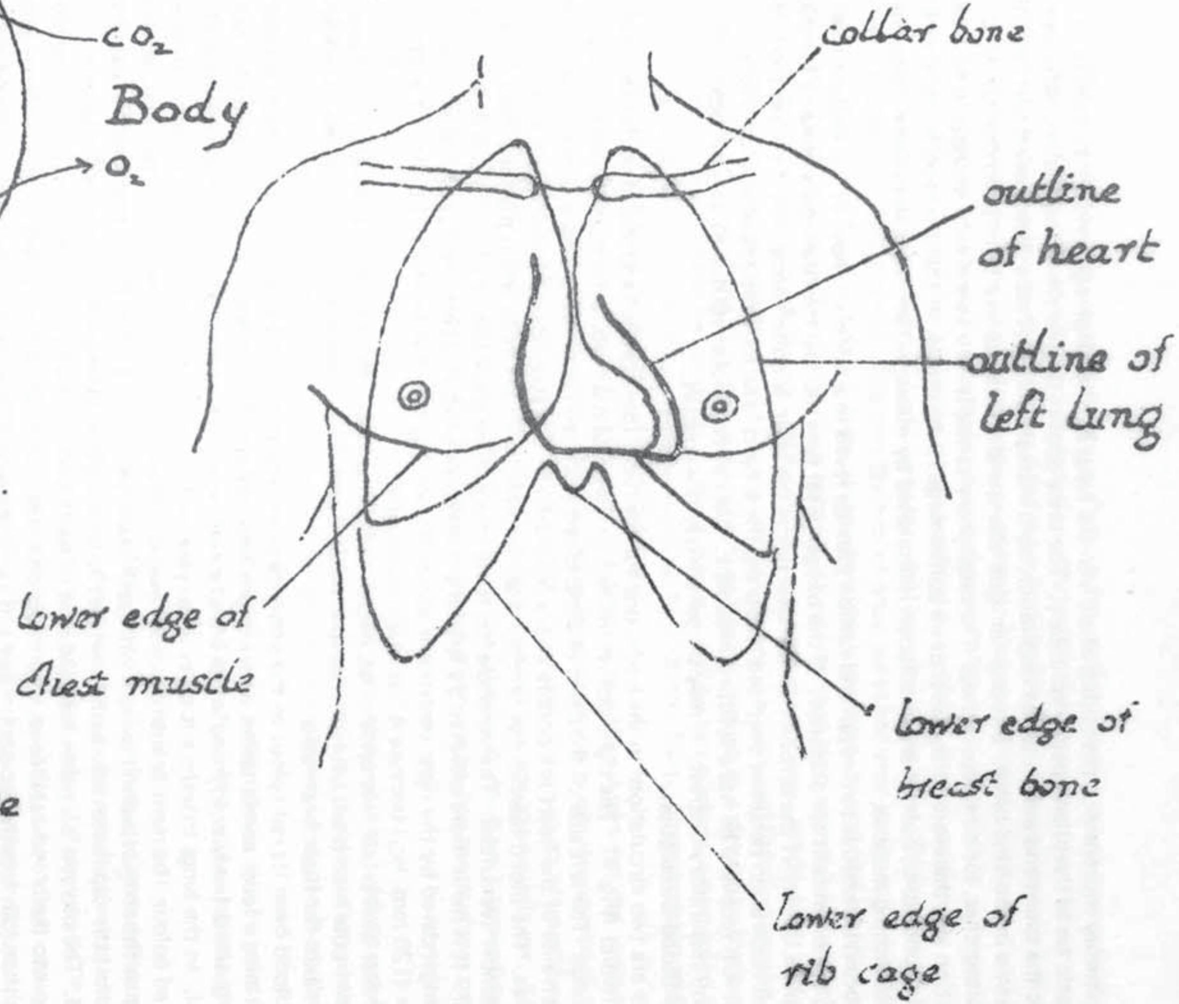


Fig. 6. Chest with heart and lungs.

Running out of air

This should not be allowed to happen. Our rule is that the diver must return to base with a 100% safety margin of air. In practice this means that you use one-third of the air on the way in, one-third on the way back and still have one-third as safety margin. This safety margin is only used if the diver gets into trouble, such as by taking a wrong turning on the way home, or getting tangled in the line. Another cause of running out of air is getting a high pressure leak.

With a closed circuit oxygen set and counterlung lack of air is heralded by "clipping". This means the counterlung is too empty for the diver to get a full breath. With open circuit compressed air and demand valve there is difficulty in sucking air from the set, when the bottle is nearly empty. If this happens at depth and one rises towards the surface, one can suck air more freely and the set may last for as much as another three minutes. Gentle sucking on the mouthpiece may also enable one to get more air from an apparently empty bottle. If the diver fails to gain an air space before the air runs out he is likely toget blackout before losing his gag. The first thing a rescuer has to do is to make sure that the gag is in the subject's mouth and to keep it there.

In planning a dive a useful rule is to think that 1 cu.ft. of air will last 1 minute at 1 atmosphere. This is a generous estimate. It needs to be remembered that at 2 atmospheres (33 ft. depth) air is used up twice as fast, and at 3 atmospheres (66 ft.) three times as fast.

OXYGEN DIVING

When compressed air sets became commercially available members of the Cave Diving Group began to give up the use of oxygen sets. Nobody has qualified on oxygen since about 1963. Nevertheless the cave diver even now should know the principles involved.

The set

Oxygen sets have one great advantage, they are more economical. The bottles are smaller and their contained gas lasts longer. This is because the expired air is rebreathed. It passes first through a canister of soda lime to remove the carbon dioxide. This also has the effect of warming it. It then goes into the bag or counterlung. Here it receives the inflow of oxygen at a rate of about 1 litre per minute and is then rebreathed. There is also a separate bypass for oxygen with a separate tap which feeds oxygen straight to the gag. This is used when additional effort has to be expended and may also be used to maintain buoyancy at depth. The counterlung has a blow-off valve.

The breathing drill

It is essential for the set to contain no nitrogen. To this end a breathing drill is carried out before every dive. The diver fills his counterlung with oxygen, breathes from the bag to fill his lungs, exhales into the open air and repeats this a few times, so as to remove the nitrogen from the residual air in his lungs. The reasons for this is that if there is nitrogen in the bag the diver may run short of oxygen without knowing it. There will be no "clipping", no carbon dioxide excess as a warning, just oxygen lack, either because the flow is too slow or because the diver is beating the lung, followed by blackout.

Oxygen poisoning

The great disadvantage of oxygen is that at a partial pressure of two ats. it is poisonous. For this reason a diver cannot safely go deeper than 30 ft. This is the reason for the name "Oxygen Pot" in Ogof Ffynnon Ddu; it is 30 ft. deep and the oxygen divers could go no further. This was also the main bar to progress in Wookey Hole upstream of the 9th chamber, where the water goes down to a depth of 75 ft. in the 15th chamber.

The expression "partial pressure" needs a word of explanation. In a mixture of gases, such as air, the partial pressure of each of its components is defined as the product of the pressure of that gas and the percentage of its component. In air the percentage of oxygen is 21%, therefore at atmospheric pressure the partial pressure of oxygen is 0.21 ats. In atmosphere of pure oxygen the percentage is 100% and therefore the partial pressure of oxygen is equal to the atmospheric pressure. In 33 ft. of water (2 ats.) the p.p. of pure oxygen is 2 ats. In order to reach such a high p.p. of oxygen with compressed air it would be necessary to go down to 300 ft. of water. Here the pressure is 10 ats. and the partial pressure of oxygen is $10 \times 0.21 =$ 2.1 ats.

Mixtures

Some divers overcame this difficulty by using mixtures of oxygen and nitrogen. This reduces the partial pressure of oxygen at a given depth and so greater depths can be safely reached. The flow rate has to be correspondingly greater. The apparatus is not commercial.

OTHER HAZARDS

Blood shot eyes

A swimmer often wears goggles to protect his eyes from the chlorine in the bath water. He should never dive with these goggles on. If he does the walls of the goggles will tend to collapse under pressure, but being made of rigid material will do no such thing. Instead a partial vacuum will be created and blood will be sucked into the delicate membrane which covers the eyeball and lines the eyelids (conjuctiva). The result is conjunctival haemorrhage, or blood-shot eyes.

The reason why the diver's face mask covers his nose as well as his eyes is to prevent this happening. As he descends he can breathe air into the face mask with his nose, and so equalize the pressure on each side of the mask. Failure to do so may result in blood-shot eyes.

Nitrogen narcosis

All "inert" gases have an anaesthetic effect at high enough partial pressures. Nitrogen begins to have its effect below a depth of about 100 ft. of water. It is rather like getting drunk. The diver feels happy and exhilarated, but fails to carry out his tasks efficiently. At even greater depths (below 300 ft.) it is possible for black-out to result, but at this depth there is in any case a risk of oxygen poisoning, as the partial pressure of oxygen will have reached two atmospheres.

There are one or two stories of cave divers "getting the narks" at depths of less than 100 ft., but these can probably be discounted. Alcohol may bring on nitrogen narcosis earlier and make it worse.

The effects of alcohol

"Don't drink before you dive", is a good motto. Even a small quantity of alcohol before a dive may blunt the finer points in one's discrimination. One may find oneself kitting up in the wrong order, or mislaying items of equipment. In diving you want to be absolutely all there, all the time. In the case of at least two cave divers whom I know it has made them ill enough to be a hazard to themselves and to their comrades.

The effect of getting drunk the night before a dive is variable. The individual with a high alcohol tolerance may be fit for diving the next day, but most divers find diving very uncomfortable with a hangover. There are some cases on record where it has resulted in underwater blackout, so it is in fact dangerous.

Decompression sickness

This has a number of alternative names, such as "the bends" when it produces muscular cramps. It is due mainly to the formation of bubbles of nitrogen in the blood, if decompression is carried out too rapidly. These bubbles may block small blood vessels and so cause death of the tissues supplied by those vessels. It is the shortage of blood supply to the muscles that produces the cramp. A similar shortage of blood to nervous tissue may result in paralysis.

Blood can absorb oxygen and carbon dioxide quite easily, because of its haemoglobin. Nitrogen is not nearly so soluble. On the other hand nitrogen is much more soluble than these gases in fat. If therefore the diver remains at depth for a long time, his fat may absorb a lot of nitrogen. When he reascends the nitrogen comes out of solution in the fat and is dissolved in the blood, but the process is rather a slow one. If therefore the decompression is too rapid, as by ascending too quickly after a long dive, bubbles of nitrogen may form in the blood. The disease can be prevented by slow decompression and can usually be cured or ameliorated by rapid re-compression followed by slow decompression. The re-compression drives the nitrogen bubbles back into solution.

There are two factors which make the absorption of nitrogen by the fat sufficiently great to produce a risk of decompression sickness. One is the depth of the dive and the other is its duration. The deeper you go the more nitrogen can be dissolved in your fat. The longer you stay there, the more nitrogen gets dissolved. Short shallow dives carry no risk of this disease. It has been calculated that a dive to 30 ft. can be maintained indefinitely without this risk. Also that a dive to 120 ft. lasting for less than 15 minutes is safe.

The critical period for gas expansion is near the surface. If therefore it is necessary to decompress slowly the longer stops should be made nearer the surface. For example a dive to 120 ft. for 20 minutes needs a very little decompression. A stop of 5 minutes at a depth of 10 ft. is enough. If, however, the diver stops at 120 ft. for 40 minutes, then on the way up he must stop for 5 minutes at 30 ft., another 5 at 20 ft. and 25 minutes at 10 ft. Making a delay of 35 minutes in all.

Decompression tables have been published which show exactly what stops need to be made. For those who wish to make long dives at great depths it is essential to plan the dives beforehand and take down a reliable watch and depth gauge. Reliance should never be placed on guesswork. Decompression meters are unreliable. There is no substitute for adequate planning before the dive.

The cave diver in the British Isles runs very little risk from decompression sickness, because he does not carry enough air. A dive to 120 ft. for 15 minutes, for which no decompression stops are needed, would use up nearly 100 cu.ft. of air. As his bottle usually only holds 40 cu.ft. and he is unlikely to be carrying more than two of them, it will be seen that he cannot stay down all that time. He must remember however that repeated short dives are cumulative. If he went down to 120 ft. and stayed there 10 minutes, came back to the surface, changed bottles and did it all over again, this would count as 20 minutes at 120 ft., for which a decompression stop is needed. Overseas they do long deep dives for which decompression stops are needed.

Rapid recompression can be done by diving once more, taking more air and more time over the reascent. But if the diver is suffering from the bends or from paralysis he will not want to do this. It then becomes necessary to get the professionals on the job, for example H.M.S. Vernon at Portsmouth (phone 0705-22351, exts. 872366 or 872375). Early medical attention is essential, as great improvement in the subject's condition may result from the giving of anticoagulants. This is because the obstruction to the capillary vessels is produced not so much by the nitrogen bubbles themselves, as by the tiny fibrin clots associated with them. A full list of compression chambers available in emergencies is included in the Cave Diver's Training Manual.

Belching

I have classed this amongst "other hazards" for want of somewhere to put it. It can be uncomfortable and alarming but is harmless and does not indicate that the sufferer is a psychological misfit.

The stomach normally contains a bubble of air (about 100 ccs.) which is replenished from air which is swallowed. A much greater intake of air into the stomach is sometimes made during deep breathing. The reason is that the negative pressure in the chest in inspiration which fills the lungs with air may also draw air into the gullet (oesophagus). This is particularly likely to happen when the body is horizontal and the neck extended. The oesophagus is a very efficient pump with muscular walls, and it promptly conveys the air bubble into the stomach. When the diver reascends this air expands and he is obliged to belch to get rid of it.

One of my correspondents described an unpleasant attack of belching. His valve was leaking and giving him an air-water mixture. He swallowed most of the water and a lot of air with it. Tiring of this he changed gags, having a second bottle and gas, and immediately had a violent attack of wind which threatened to expel the gag at each belch. The changing of gags had allowed relaxation, so that the stomach was encouraged to get rid of its excess of air.

Underwater vomiting

Divers sometimes feel sick under water and occasionally vomit. The drill is to take the gag out of your mouth while vomiting, put it back in and use the purge button, take a breath, remove gag, vomit again and repeat the process until the vomiting stops. You need to be very cool headed to do this correctly and save yourself from drowning.

Cramp

This is a painful contracture of a muscle, generally a calf muscle. It goes into spasm and forms a hard lump. The spasm gradually passes off but the muscle remains sore. Stitch is another form of cramp. The immediate cause for the spasm is generally putting a sudden or unexpected strain on the muscle. When finning the muscle most commonly affected is the calf muscle, but the muscles of the sole of the foot may be affected. At one time I used regularly to get cramp in one of my thigh muscles when driving home after a hard caving trip. The most painful cramp I've had was in the tummy muscles after spending nine exhausting wet cold hours in Dowber Gill Passage; I couldn't get my trousers off.

Conditions which make cramp likely are physical exhaustion, cold, loss of salt through sweating; and then sudden use of the muscle brings it on. The causal mechanism is obscure. The trouble is that no experimental model exists. Nobody wants to be given cramp for research like a guineapig. So no research is done.

The remedy is to put the affected muscle on the stretch. This may be done actively or passively. Actively, you contract the opposite muscle: passively, you bend the joint in the direction which will stretch the cramped muscle. Active stretching is best because it causes relaxation of the antagonist muscles. If for example you have cramp in the calf, then straighten the knee and bend the foot upwards. Messages will then be sent down the nerves to the calf muscle telling it to relax. If you get cramp in the sole of the foot, bend it upwards. If in the tummy muscles straighten out your body. If anywhere else in the leg you may have to walk about on it until the cramp goes away. Slight twinges of cramp should not be ignored; they often means that a big spasm is about to come on. Put the muscle on the stretch.

DROWNING

Death in drowning is due to asphyxia, which means depriving the body tissues of oxygen. Some tissues can withstand deprivation of oxygen far longer than others. The most sensitive is nervous tissue. At normal temperatures the brain can only live for about 5 minutes without receiving oxygenated blood. At very much lower temperatures (hypothermia) it may live for 20-30 minutes. Blackout happens first, and this is followed by depression of the respiratory centre in the hind brain, so that breathing stops. A few minutes later the cardiac centre nearby becomes depressed and the heart stops. These things happen before the brain actually "dies", by which one is referring to irreversible changes in the nervous tissue. For a few minutes the changes are reversible, that is to say the brain may recover if it is perfused with oxygenated blood, but it will take a long time.

Two sorts of drowning are described, wet drowning and dry drowning. In the former case water enters the lungs but in dry drowning it does not. When water enters the windpipe and lungs a severe burning sensation is experienced. Some people seem to manage to avoid this by holding their breath. When they lose consciousness, some of them may inhale water but some do not. The latter are the dry drowners. The importance of the distinction is that in dry drowning resuscitation is much more likely to prove successful than in wet.

The reason for this is that water in the lungs does a great deal of harm to the lining membrane of the alveoli. This membrane has special cells which produce a substance (surfactant) that lowers the surface tension of the alveolar lining. In wet drowning these cells are damaged and the surfactant gets washed away. The result is that the alveoli collapse under their increased surface tension and it becomes impossible to blow air into the lungs (loss of compliance). The surfactant can only be replaced by the special alveolar lining cells, and these may take days to recover.

If fresh water is breathed into the lungs it passes very rapidly into the blood stream. In experimental animals this often upsets the composition of the blood so severely that the red blood corpuscles burst. In man this rarely seems to occur. Nevertheless the surfactant gets washed away and the lungs tend to collapse. The only thing that stops them from collapsing is the leakage of fluid from the blood into the alveoli (pulmonary oedema). This fluid is sticky and easily forms a pink foam, which may be detected around the lips of a drowned subject. The oedema effectively stops any gaseous interchange between alveoli and capillaries.

If salt water is inhaled it does not pass into the blood stream because its salt content is higher than that of the blood. Instead it draws fluid out of the blood into the alveoli (oedema) and washes away the surfactant. There is some myth that sea water does less harm than fresh in the lungs. From what has been said it can be seen that this is not true. The harm done by any water in the lungs is directly proportional to the amount that gets in. So if you find yourself drowning hold your breath and go on holding it until you black out.

An unconscious body in the water is likely to sink, unless the subject has taken off weight belt, and inflated life jacket or taken other such means to become positively buoyant. This should be done in open water, but in cave diving it is not much use. The cave diver must find an air surface. If the body sinks into water of more than 100 ft. depth, then it will get squeezed and the ribs will be broken.

COLD AND EXHAUSTION

If the cave diver, having lost his way or run out of air, manages to find an air space, then he has other problems to face. If the air space is very small he could use up the air and die of asphyxia. If the air space is large he may go on living in it but will have to contend with cold and the kind of exhaustion that results from not having anything to eat. The body needs food to keep warm just as much as a fire needs coal. If he cannot keep warm then the body temperature will fall. The skin temperature will of course have fallen long before that; it normally does on a cave dive. This is part of the body's way of conserving heat. The skin blood vessels shut down, so that the blood does not get cooled by passing near to the body surface. It is the core temperature that matters.

The rate of cooling is greatly accelerated by remaining in the water, so that the subject should try to get out of it, if he can. A subject unprotected by wet suit fully immersed at cave temperature will survive for not more than 5 hours in the south (10°C) or 2 hours in the north (6°C). A wet suit slows down the cooling process very considerably but will not stop it if the subject is unable to exercise. The cooling may take days rather than hours.

When the core temperature drops below its normal level of 37°C shivering begins. This is a normal defence mechanism against cooling. It is much less efficient than taking exercise, which is therefore to be preferred unless the subject is immersed in water. In that case exercise accelerates surface cooling. This is particularly true of an unprotected subject. But with a wet suit it may not be true. At a core temperature of 34°C the pulse slows down. The shivering tends to occur in spasms and there is difficulty in expelling air from the chest, because of this muscular rigidity. At lower temperatures the fall in temperature accelerates, because the defence mechanisms become ineffective. At 31°C there is clouding of consciousness. Between 30° and 29°C auricular fibrillation will set in. This is a reversible irregularity of the heart beat. Death from cardiac arrest (heart stop) or with ventricular fibrillation will occur at between 27° and 24°C. The difference is that with ventricular fibrillation there is a drastic decrease in cardiac output, whereas with auricular fibrillation there is not.

RESCUE

The cave diver who has lost his way or who finds himself in an unknown air bell having run out of air has a difficult decision to make. Should he try and get home or should he await rescue? When Bob Davies got lost in the 13th Chamber of Wookey Hole in 1956 he knew there was no chance of rescue and that, if he waited for the water to clear, he had a fair chance of getting home on a known compass bearing. So he made for home and got there successfully. I think probably that this estimate of the chances of rescue is more likely to carry weight with a lost diver than consideration of the chances of finding the way home. If there is a reasonably good chance of being rescued within a time period, which will not be so long as to incapacitate the subject, then he should stay where he is. If he is unlikely to get rescued then he can be forgiven for making an unsuccessful attempt to g et home.

Search

To find a lost cave diver may be very difficult, sometimes impossible. The burden falls first upon his companion, who will be waiting for him at the diving base. Where is the diver likely to have got lost? Is he likely to be on the line or to have lost it? Are my air safety margins adequate? The emergency is an extreme one, so that these questions have to be answered and decided upon before calling out the cave rescue organization. The only successful one that I can remember took place at Porth yr Ogof, when two divers found themselves short of air and retired to the rawlbolt chamber to await rescue, knowing that a third diver at base would come in for them with a spare bottle, when they became overdue, which he did. He called out the cave rescue organization before doing so, which is the correct thing to do.

Rescue

This is no place to discuss the techniques of cave rescue except in so far as it concerns the extrication of a body from the water. If the water has had time to clear, or if the subject's light is still on, it will make him easier to find. It is generally best for the rescuer to be fully kitted for diving, but this would not be true if for example one was rescuing someone from drowning at the resurgence of Porth yr Ogof. But don't forget to put on a weight belt, when a wet suit is worn, otherwise it may be impossible to reach the subject. A face mask is also needed.

Trainees are taught to practice the two British Sub-Aqua Club methods of towing, known as No.1 and No.2. These are particularly suited to open water conditions, but are also useful under cave diving conditions, because the grip on the subject is an efficient one and leaves the legs free for finning. With an inefficient grip you may not only lose hold of the subject but get your legs tangled up in his when finning. The diagram shows the two methods (Fig. 7). No.2 method is the more efficient, as the rescuer is in a natural

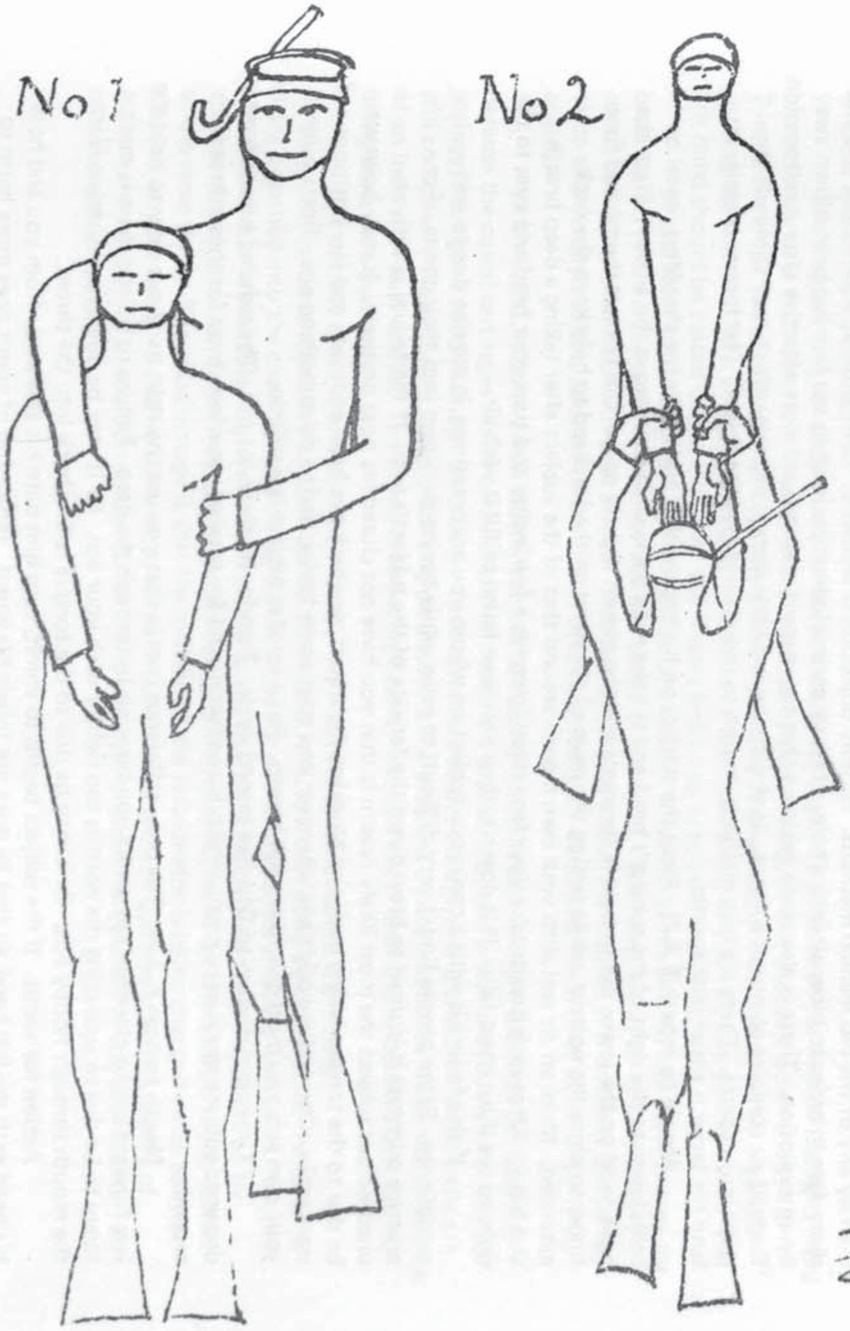
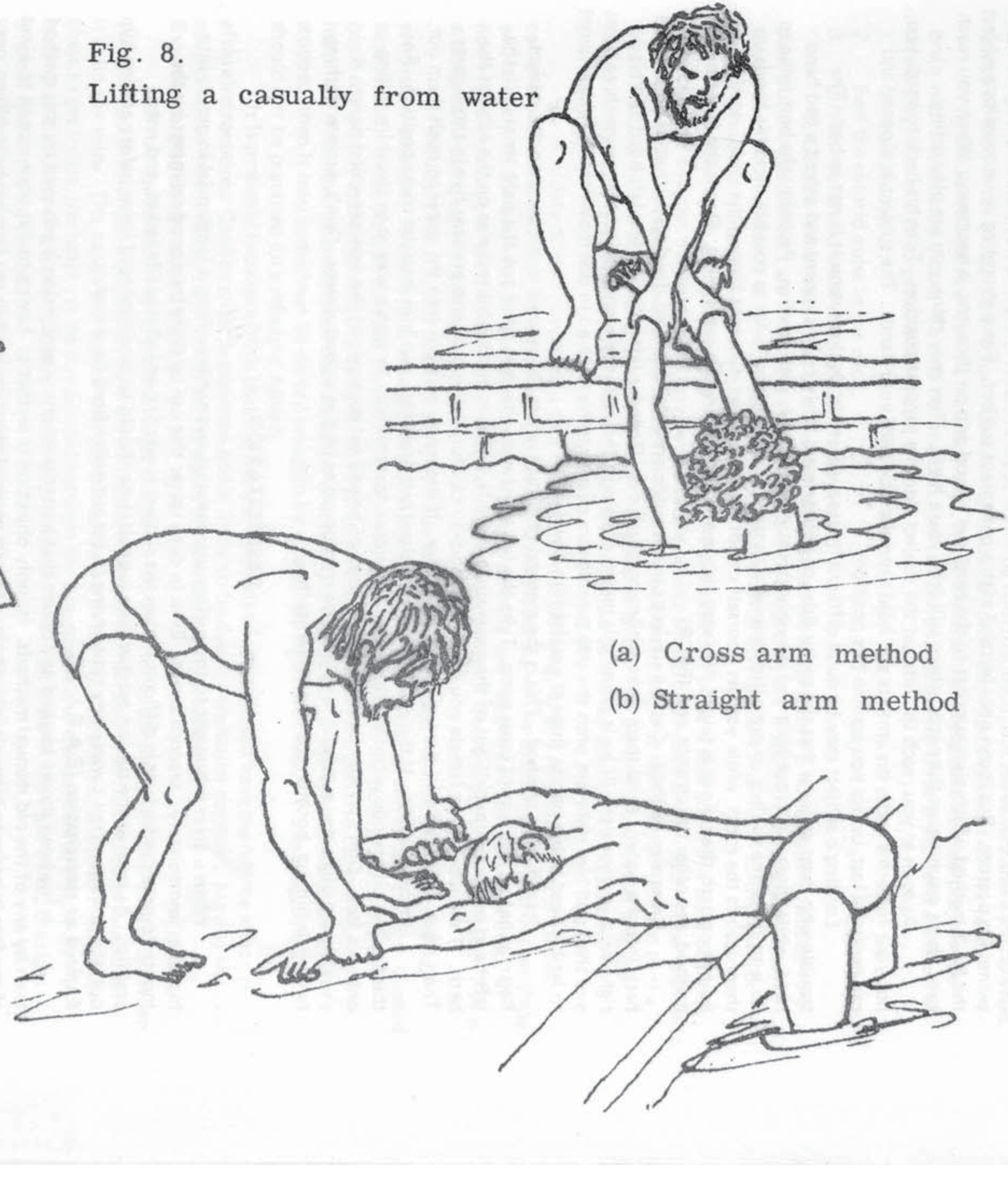


Fig. 7. British Sub-Aqua towing methods.

Fig. 8.
Lifting a casualty from water



(a) Cross arm method
(b) Straight arm method

swimming posture. But it can only be used with a compliant subject. For a struggling or unconscious subject the No.1 method which gives support to the head and a good grip on the arms, is necessary. When you reach base, don't assume that the people there will lend you a hand. They may think you are play acting.

As soon as you reach the side get the subject into the **support position.** Turn his back towards you; put your forearms under his armpits and hold onto the side with your hands. The subject is slippery and can easily be lost, unless you assume this position.

Landing a subject may be quite difficult in deep water. In shallow water it is not so bad. The trouble with deep water is that the rocky sides or boulders are likely to be slippery and afford a bad hand hold, while there is no foot hold and the only thrust one can get is with the fins. Probably the best thing to do is to shove the subject up onto the rocks at a possible landing place, as far as possible, hold his hands up there against the rocks, while you get yourself out of the water, and then pull him up the slope. In the swimming bath the trainee is taught two very tidy methods of doing the same thing. One is the cross arm method, the other the straight arm (Fig. 8).

Cross arm method. Get the subject's hands sufficiently far out onto the side, so that he doesn't fall back into the water. Hold them there while you climb out. Take his left wrist in your left hand and his right wrist in your right (if he is prone this means crossing arms), bounce him in the water two or three times and then pull him right out onto the side turning him over onto his back all in one movement. Take care not to let his head bump on the floor as you let him down.

Straight arm method. This is the method of choice where the rescuer is smaller than the subject. Begin as before but do not cross arms. Take the left wrist with the right hand and the right wrist with the left hand and pull him half out of the water onto the side, without hurting his testicles on the edge of the bath. If the subject is a female you need to be equally careful, for women also are sensitive in those parts. Then reach down and pull the legs out of the water. If necessary get back into the water to push them out.

Coma position. If the subject is unconscious but breathing, put him into the coma position. For this lay him on his side with the upper knee and upper forearm bent in such a way as to stop him rolling onto his face. Don't let him lie on the other arm, or he will get paralysis of the musculo-spiral nerve; it should be straight down behind him. Put the chin up, so as to give a good airway. Don't remove clothing but cover him up, both on top and underneath.

RESUSCITATION

When a diver is brought to the surface unconscious and not breathing it is essential to get air into his lungs immediately: seconds count. Even in deep water this can be done by a good swimmer by the mouth-to-nose method. It is difficult, unless the subject is wearing an inflated life jacket, and needs practice. As soon as the subject reaches base resuscitation should be recommenced, even before getting him out of the water. Don't waste any time trying to tip out water from his throat.

Expired air resuscitation (E.A.R.)

It has been shown beyond any doubt that better pulmonary ventilation is achieved by this method than by any of the old manual methods. Its only objection is aesthetic: having to put your mouth to a wet slimy face in order to blow air into a hole. Its only contra-indication is when the face has been blown away by an explosion. There is also some evidence that the manual methods are more effective after electrocution. Expired air contains plenty of oxygen. It also contains a little carbon dioxide, which may stimulate the respiratory centre. There are two methods, mouth to mouth and mouth to nose. The former is easier on land the latter is easier in the water.

Mouth to mouth E.A.R. Place the subject on his back with a pad under the shoulders, kneel on both knees to the right of the subject's head and tilt the head backwards to improve the airway. Place the right hand on the lower jaw to hold it forwards and the mouth slightly open. Use the left thumb and fore-finger to close the nostrils, while resting the palm of the hand on the forehead to help keep the neck extended. Make an air seal with your own mouth around that of the subject after taking a deep breath and blow. After each breath take your face away from his a few inches and turn your head and eyes to the right to see if his chest falls. If it doesn't, then you have failed to fill it with air.

If this failure is with a conscious subject on whom you are practising, it may be due to non-compliance. Some people find it very difficult to relax while having air blown into their chests. For practice purposes it is usual to blow down the far side of the subject's face. If the failure is with an unconscious subject the most likely reason is that you have not closed his nose properly. It may however be due to the tongue falling back and blocking the throat, so check the head and neck and jaw positions and start again. Check these positions whenever you start again having had to do something else. For a subject your own size you must give him a full breath. For a smaller subject less will do.

Time your rhythm to fit a five second cycle. Two for in, three for out. The exhaled breath from a drowned subject smells very nasty, which is another reason for turning your face away for those three seconds.

Mouth to nose E.A.R. The only difference here is that you use the right hand not only to hold the jaw forward but to close the lips, while you blow air in through the nose. Failure to fill the chest is most likely to be due to squeezing the nostrils too tightly with your lips. Or it may be due to air escaping from the mouth through floppy lips. Or it may be due to the tongue falling back into the throat.

Action for vomit. If the subject begins to vomit, turn him onto his side away from you and hold his head with the left hand, so that he does not inhale his vomit. Inhalation of vomit does more harm to the lungs than inhalation of water. When he stops vomiting turn him back, but make sure there are no solid lumps of food in his mouth before you recommence resuscitation. Also wipe the vomit off his face.

Is the heart beating? E.A.R. is all very well, but if the heart has stopped it will not provide the brain with oxygenated blood. To find out the condition of the circulation do three things, and do them in this order, so as not to forget what they are.

1. Observe his colour.
2. Feel the carotid pulse in the neck.
3. Lift an eyelid and see if the pupil is dilated or not.

1. Colour. When taken out of the water an unconscious subject that is not breathing will be very pale, but the lips and ears are likely to be blue (cyanosis) because they are filled with venous blood (de-oxygenated haemoglobin). If the circulation is all right then after giving a few breaths of E.A.R. the lips and ears should go pink (oxy-haemoglobin).

2. The reason for using the carotid and not the radial (wrist) pulse is that when in a state of shock or circulatory collapse the wrist pulse may be too feeble, whilst the carotid artery being much bigger transmits a stronger pulse. It may be found by placing the finger just below the angle of the jaw, just internal to the sternomastoid muscle andpressing inwards towards the spine (Fig. 5). The sternomastoid is the long big strong neck muscle that goes from behind the ear (mastoid) down to the top edge of the breast bone (sternum).

3. A widely dilated pupil means that the brain is not working. If as a result of external cardiac compression combined with E.A.R. a supply of oxygenated blood is given to the brain then one of two things will happen. If the brain has suffered irreversible damage, nothing will happen and the subject is dead. If however the damage is not irreversible and the brain starts working again then the pupil will contract. This is a very encouraging sign for the resuscitator.

If the heart has stopped beating, it may be due to one of two things: ventricular fibrillation or ventricular asystole. In the former case the ventricle is just wriggling like a bag of worms and no co-ordinated beat results. It can only be stopped by passing a high voltage current through the body. This stops the heart completely and when it starts up again its rhythm may be regular. This operation can only be done in hospital. If however there is ventricular asystole, which simply means that it has contracted down and stopped, then it may sometimes be started up again by a hard slap onto the chest. This is dangerous and should not be practised on a rehearsal subject.

It is probably because of this that the manual methods of resuscitation have been more effective after electrocution. Cardiac arrest is common and is likely to be due to ventricular asystole. Moving the subject about may well start the heart beating again, while simple E.A.R. will not.

External cardiac compression (E.C.C.)

If you squeeze the heart, you will drive out of it into the arteries the blood which it contains. When you let it go the natural elasticity of its walls will restore it to its normal shape, so that blood is sucked into it from the veins. The valves will ensure that the blood travels in the right direction. Without undoing the chest to get inside, the heart can be compressed between the breastbone and the backbone, simply by leaning on the chest of a supine subject. To do this, however, you must press in the right place, the right amount and at the right speed.

The diagram (Fig. 6) shows the heart inside the chest cage. To press with the heel of the right hand immediately over the heart, feel first for the lower edge of the breastbone and choose a point about 1.5 to 2 in. above this. The arm should be kept straight and pressure exerted straight up and down by a gentle rocking movement of the whole body. Don't move more than you need, or you will tire yourself out. The left hand should be placed on the right and the fingers locked so as to even the pressure.

If you want to visualize the size and shape of a subject's heart take his left fist and place it over the breastbone. When clenched it will be the size and shape of his heart. The heart wants to be compressed about half of its thickness with each stroke. This will usually be about 1.5 inches. It is however dangerous to do this on any subject, because of the risk of breaking ribs or of damaging the liver or other underlying organs.

When E.C.C. is done on an elderly subject in hospital the ribs and sternum often do get broken, because the costal cartilages which connect the ribs with the breastbone, and which are normally tough and springy, have gone solid with age (calcified). Cave divers are nearly always young and their chest walls are still compliant. Nevertheless when practising on a subject the pressure should not be for more than a quarter of an inch with each stroke. The Royal Life Saving Society will not allow even this and insists on training being done on a dummy.

The correct speed is one stroke a second. You want to be strict about the timing.

If it is found necessary to combine E.C.C. with E.A.R. it is best done by two people. When air is being breathed into the chest the one doing E.C.C. stops for one or two beats and then continues. If only one resuscitator is available he gives fifteen strokes to the heart followed by two breaths, followed by another fifteen strokes. Some authorities recommend eight strokes followed by one breath, which comes to the same thing. The disadvantage is that theposition of the resuscitator is being changed twice as often and this is more tiring. It has no advantage, as the E.C.C. strokes provide quite an effective degree of pulmonary ventilation in addition to the E.A.R. You can find this out for yourself if you practise for real on a compliant subject.

Resuscitation drill

We now have to prescribe a certain drill for resuscitation which will take into consideration all the things written in the last few pages. This, with suitable modifications for safety's sake, should be practised by the trainee until he has it by heart.

1. Bring the subject to an air surface.
2. Give mouth to nose E.A.R. while still in the water, if indicated.
3. Land the subject by a suitable method.
4. Send any spare person for help.
5. Place the subject on his back, with pad under shoulders if possible, and give 6 breaths of E.A.R. The first two are done quickly, the rest at 5 second intervals.
6. Find out if the heart is still beating by examining
   (a) colour
   (b) carotid pulse
   (c) pupils

7. If the heart is still beating continue with E.A.R. You have a very fair chance of success.
8. If the subject starts vomiting, turn him over.
9. When he begins to breathe on his own, stay by him to render further E.A.R. if he stops.
10. When the breathing becomes deep enough and regular, put him into the coma position and cover him up.

7. If the heart is not beating, give the chest a good hard slap.
8. Feel the carotid pulse to see if you have been lucky enough to re-start the heart. If so continue as before with E.A.R.
9. If no heart beat has been started begin E.C.C. 15 strokes at 1 second intervals followed by two breaths of E.A.R.
10. This should restore the colour at least. If the pupil contracts then the brain is recovering its function.
11. Stop every five minutes or so to feel the carotid pulse and see if a spontaneous heart beat has restarted. If it has, continue with E.A.R. but watch the colour. Proceed as before when breathing restarts.
12. If the pupil remains dilated and no heart beat restarts continue for at least half an hour. After that recovery is extremely unlikely.

Recovery is most likely in cases of dry drowning and least likely if the heart has stopped. In the latter event the chances of survival are about one in seven. These may seem rather long odds, but the chance is well worth offering to the subject. The subject should be got to hospital as quickly as possible. It is only here that ventricular fibrillation and pulmonary oedema can be adequately treated.

Even after recovery the subject is not safe. If there has been any inhalation of dirty water, vomit or loss of surfactant, then a very troublesome pneumonia is likely to follow within two days and be fatal within seven. When this period is past you may begin to heave your sigh of relief.

June 1975

Oliver C. Lloyd, M.D., M.B., B.Chir.,
Withey House,
Withey Close West,
Bristol.

Transactions British Cave Research Assoc. Vol.2. No.2. pp.79-88 August 1975.

FOUL AIR AND THE RESULTING HAZARDS TO CAVERS

by Julia M. James, Andrew J. Pavey and Alan F. Rogers

SUMMARY

A historical introduction and some of the reasons for the study of foul air are put forward. Properties, composition and detection of foul air are discussed. The techniques and instruments available for the analysis of foul air are reviewed. The physiological effects of foul air in terms of its variable components, that is raised CO_2, reduced O_2 and the combination of these in the cave atmosphere are discussed. Advice is given for safe entry to foul air caves and safety when working in poorly ventilated parts of caves. Finally the rescue and treatment of victims of foul air are discussed.

INTRODUCTION

The atmosphere found in a cave is rarely identical to that on the earth's surface. However, in the majority of caves the differences are small and the air can be breathed without discomfort. Unpleasant and dangerous atmospheres such as those occasionally found in wells and mines are sometimes encountered in caves and all the gases which cause hazards to miners have in fact been reported in natural caves. In the British Isles almost all the caves, whether wet or dry, are usually well ventilated, and free from volcanic exhalations and large quantities of decaying organic matter. As a result they rarely produce or accumulate dangerous levels of hazardous gases.

The term "foul air" (Fig. 1) usually means to the caver an above normal concentration of carbon dioxide (CO_2) in the cave atmosphere. However, it is frequently accompanied by the presence of other noxious and foul-smelling gases, for example hydrogen sulphide (H_2S) and ammonia (NH_3). Furthermore there may be a significant reduction in oxygen (O_2) below the normal volume. Only one fifth part of normal air is oxygen, the gas which is vital for life – the rest is inert nitrogen and a variable water vapour content. The exact composition of normal dry air is oxygen 20.95%, nitrogen (with traces of inert gases such as argon etc.) 79.02% and carbon dioxide 0.03% (volume %) and is the same throughout the world.

The first real indication in Great Britain that a cave atmosphere could be lethal was the death of a caver in Peak Cavern, Derbyshire (Lloyd 1961). This caused the Mendip Rescue Organisation (MRO) to appoint a subcommittee to examine the problems of rescue and survival of victims trapped in positions where foul air was found or could accumulate. A survey of potentially dangerous parts of caves was commenced for Mendip and three main types were designated, all having poor ventilation in common. These were chambers near the surface with poor air ventilation and rifts containing rotting vegetation from the surface, such as Banwell Bone Cave (Rogers 1960), cave digs in restricted passages such as the Valentine Passage dig in Lamb Leer, and small passages with heavy traffic such as Paradise Regained in Swildons. Levels of 3% CO_2 were measured in Banwell Bone cave and 1% CO_2 in parts of Goatchurch Cave, Sidcot Swallet and Rods Pot. It is suspected that there are high levels in some parts of Swildons Hole.

In other parts of the world studies of cave atmospheres have been made by speleologists interested in the role of carbon dioxide in cavern development and sediment deposition; these were reviewed by Miotke (1972). In Australia foul air has caused serious problems, by limiting the exploration and exploitation of certain caves in New South Wales. Foul air was first reported in caves there in 1881 when a crevice at Wellington was recorded as being full of foul air. *"The candles and even torches were extinguished on being lowered below the waist of a man sent down".* (Ramsay 1882). In 1900 the full exploration of the Grill Cave at Bungonia was prevented by foul air (Trickett 1901) and in 1931 at the end of a long period of drought the Minister for Lands closed Bungonia Caves to tourists (Nurse 1972).

With the emergence of speleological societies in Australia in the 1950s came the first organised explorations of foul air caves, coinciding with a long period of wet weather, which was probably a time of low CO_2 concentration in these caves (James 1975). In order to explore these tantalising passages disappearing into the depths of the foul air regions of these caves Sydney University Speleological Society (SUSS) commenced a study of foul air in 1958, and since then many other Australian Speleological Societies have contributed to foul air studies.

PROPERTIES OF CARBON DIOXIDE

Carbon dioxide, the major alien component of foul air, is a colourless, odourless, noncombustible gas with a slightly acid taste. It is approximately one and a half times as dense as air and liable to displace normal air and settle in pockets. CO_2 is soluble in water (2-3 ml per 100 ml water) and, depending upon the temperature, about 0.1% of the dissolved CO_2 reacts to form an acid solution. CO_2 will not support animal life.

DETECTION OF CARBON DIOXIDE

When entering a region of foul air, the caver may experience any of the following: an increase in the rate and depth of breathing, increased pulse rate, headache, nausea and a hot clammy feeling. The severity of these symptoms gives an indication of the concentration of CO_2 and the experienced foul air caver can estimate the concentration to within 0.5%. A more reliable indication may be given by flame extinction tests. With a sufficient increase in CO_2 concentration and/or decrease in O_2 concentration, combustion will not be supported, and a burning match, candle or acetylene flame will go out.

Table 1

% CO_2 Causing Flame Extinction

	Burke 1953	Grée 1966	Anon 1969	Renault 1972	Field Test Bungonia 1972	Empirical Bungonia 1972
MATCH	–	–	–	–	1	1
CANDLE	4.3	3	2.3	10	4	3
CARBIDE LAMP	10.0	8.9	8-9	–	6	5

Table 1 shows the variation for flame extinction values given in the literature. Some of these have unfortunately been quoted without experimental details, which are essential in the interpretation of the data. For example, a small carbide cap-lamp will be extinguished at a lower level of CO_2 than will the larger hand-held type. The amount of O_2 present is also critical and a candle may burn in 10% carbon dioxide (Renault 1972) if 21% of oxygen is present in the gas mixture – however in caves a 10% concentration of CO_2 not only would not support a candle flame but would be lethal because the oxygen content would be greatly reduced. A series of field tests carried out at Bungonia gave the results shown in column 5 in Table 1. A small carbide cap-lamp was used and the CO_2 content of the cave was measured with a Draeger gas analyser. These results agree with empirical values reported by the explorers of the foul air caves at Bungonia (column 6) and are probably of most use to foul air cavers.

Carbon dioxide almost exactly replaces oxygen volume for volume in caves as has been shown at Bungonia (James 1975). In most caves carbon dioxide measurements in isolation will establish the safety of the atmosphere. However, rarely "stink damp" occurs in caves (James 1975). It is typified by high CO_2, an unexpectedly low O_2 and a much higher than usual proportion of N_2, for example, CO_2 5%, O_2 9%, N_2 86%. It "stinks" because of trace amounts of H_2S etc. In these special circumstances an isolated measurement of CO_2 is obviously inadequate for safety, and the primitive flame extinction test is probably the best simple indication of danger. **If a candle will not burn it is advisable to leave the cave at once.** If a carbide lamp is extinguished (early warnings are a smoky flame and less light) then the caver is in severe danger as this indicates a level above the safe limit for physiological processes (see Physiological Effects). Note that a match is extinguished before a candle – therefore the candle can only be lit while in good air.

An accurate and critical assessment of a cave atmosphere requires the use of a gas analyser.

Instruments for Field Gas Measurements

In a number of situations it is desirable to measure the composition of foul air rather than merely detect its presence:–

a) for on the spot checks while exploring foul air caves
b) for specification of dangerous or potentially dangerous atmospheres in caves
c) for determining procedures in rescue from foul air
d) in monitoring changes in the cave atmosphere while digging or during rescue operations.

Ideally a full analysis is necessary but at present this is possible only by transferring gas samples to a laboratory. Instruments have been developed by coal boards, mining corporations and safety workers, but most of these are for use in well controlled situations and commonly require mains electricity. As yet no ideal instrument for cave use has been developed and a combined O_2/CO_2 meter is the best compromise within these limitations. A CO_2 meter is adequate in most caves though an O_2 meter would be as good – or indeed preferable in a "stink damp" cave.

In choosing a gas analyser the following points have to be considered:–

1) portability, weight and robustness
2) the degree of accuracy, say ± 0.5%
3) the expected range of values, which may be between 0 and 10% CO_2, and between 21 and 10% O_2
4) the speed of operation
5) the need for special training of the operator
6) the cost

The following instruments have been used:–

A **Multipurpose Instruments**

1) **The Draeger Gas Analyser (Fig. 2)**

This is a lightweight, robust and versatile instrument which can be used to detect a large number of gases of interest to cavers including carbon dioxide, oxygen, carbon monoxide, hydrogen sulphide, ammonia and oxides of nitrogen. The apparatus draws a known quantity of the cave atmosphere through a detector tube containing an absorbent with an indicator which becomes coloured as the gas passes through. The length of the colouration gives the amount of gas present. The accuracy depends on the tube used. For CO_2 in the 0 to 77% range it is ± 0.1% and the method is quick and easy. Unfortunately the tubes for O_2 analysis require the breaking of an inner vial and the mixing of chemicals thereby. A large error results if this manipulation is inexpert. The detector tubes are expensive and not reusable. Similar cheaper devices are available, such as the Kitagawa and Gastec which are both suitable for caving use provided the plunger shaft is kept free from grit.

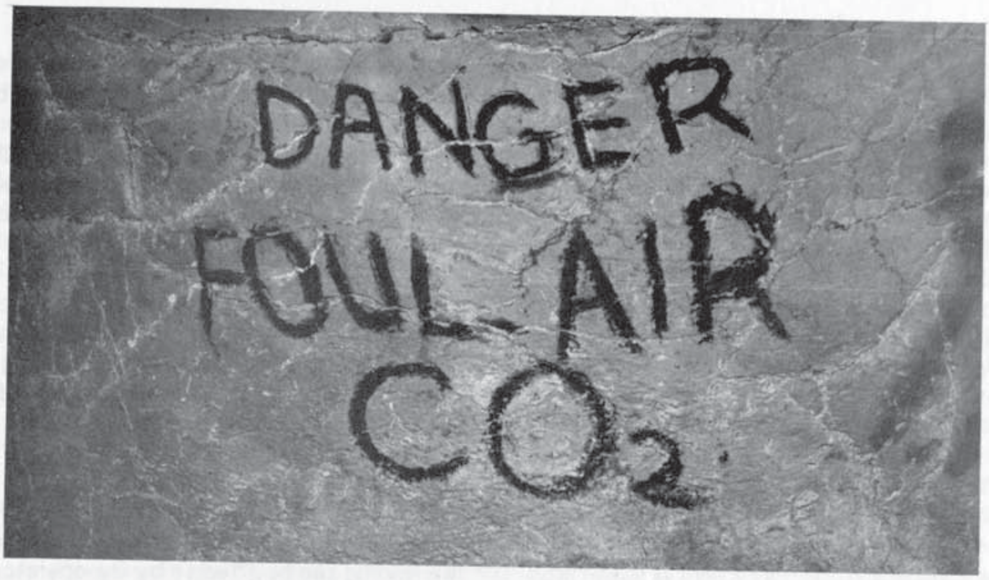


Fig. 1. Foul air warning notice in Bungonia Caves. Photo by Julia James.

Fig. 2. The Draeger Gas Analyzer in use. Photo by G. Montgomery.

Fig. 3. IBC oxygen meter used for aerial and dissolved oxygen. Photo by G. Montgomery.

2) **Fyrite**

This was the first instrument used in field tests in caves (Frazer 1958). The principle of its operation is the measurement of the change in volume caused by the absorption of CO_2 by sodium hydroxide. No training is required for use and multiple readings may be made within a cave. Consistent results for the same gas samples are obtainable but the error involved may be as high as ± 0.75%. By changing the absorbent the instrument can be used for O_2 measurement, but this can be a slow and dangerous procedure underground.

B **Single Gas Analysers**

1) **The GORDON CO_2 Tester**

In 1961 Rogers introduced this instrument for use by the MRO in Mendip Caves. The principle of operation is the absorption of gas by potassium hydroxide solution. The resulting pressure change in the container is registered on a calibrated dial. Atkinson (1970) described the instrument fully, claiming an accuracy of ± 0.05%. This is debatable since it is not expected that an instrument of this type would give readings within 0.2% even under laboratory conditions. For the purposes stated above it fulfils all requirements. However, it does contain strong potassium hydroxide solution which is corrosive.

2) **Electrolytic Field Device**

The electrolytic instrument designed by Delecour *et al* (1968), and quoted by Atkinson (1970) as an accurate method of measuring CO_2, is unsuitable for the above use in caves. It is too heavy (15 kg), the range is inadequate and the instrument is so sensitive that the reading can be affected by the operator breathing (Delecour pers comm).

3) **The Katharometer**

This instrument was designed for use in Australian caves by Michie (1967). The instrument is based on the principle that heat is conducted through different gases at different rates. The thermal conductivities of gases usually examined by cavers are:

N_2 = 6.24 cal sec^{-1} cm^{-1} $degK^{-1}$
O_2 = 6.35 cal sec^{-1} cm^{-1} $degK^{-1}$
CO_2 = 3.96 cal sec^{-1} cm^{-1} $degK^{-1}$ (Hobbs 1963)

The similarity of the thermal conductivities of oxygen and nitrogen is serendipitous, since the rise of CO_2 which parallels the fall in O_2 can be measured directly by the change in thermal conductivity of the gas mixture. The changes in the composition of a cave atmosphere would cause great problems to the calibration of the apparatus if the conductivities of O_2 and N_2 were not so close. The initial design gave inconsistent results (Crawshaw and Moleman 1968), thought to be due to the sample gas not being dry and the apparatus has now been modified to remove this difficulty. Although the change in the thermal conductivity of the gas mixture is small, field apparatus will give measurements accurate to ± 0.5% and laboratory apparatus to ± 0.01%. A small robust unit for field use could probably be built using solid state components.

4) **Nondispersive Infrared Spectrophotometer**

This instrument was used for the first time in an Australian cave by the Metropolitan Speleological Society in 1971 for measuring the changes in CO_2 in tourist caves. The results obtained from this instrument compare well with those from conventional laboratory methods of gas analysis. The apparatus has a heavy current drain, weighs 15 kg and is extremely expensive (Zamberlan pers comm).

5) **Oxygen Meters**

There are many portable instruments available which measure only the oxygen content of a gas mixture (James 1975). Although suitable for cave work this type of instrument is expensive. Fig. 3 shows such a meter from the Biophysics Corporation California (USA), in use at Bungonia.

Collection of samples for laboratory analysis

For calibration of instruments and to confirm field results it may be necessary to collect samples and analyse them in the laboratory by any of the conventional methods such as Haldane's and Orsat's methods (Vogel 1962) or gas chromatography. A recommended way of collecting samples for laboratory analysis is to invert a bottle and empty out a saturated sodium chloride solution (CO_2 is much less soluble in salt solutions than in water at pH7 (Riley 1971). The air which displaces the saline becomes the sample which is then sealed with a firmly inserted stopper. Oil has been suggested as an alternative to saline and it is even better to use any standing water in the region of the air to be sampled as this will already be saturated with CO_2 and traces of water left in the bottle will not absorb more. Various gas sampling pipettes have been used ranging from large plastic syringes to evacuated glass vials with taps or necks sealed by fusion, but their fragility bars most types from extensive cave use.

PHYSIOLOGICAL EFFECTS

The physiological effects of foul air have been studied by a number of interested groups including submariners, astronauts and miners. The symptoms of exposure vary in severity both with the individual and the composition of the foul air, and will be discussed here as those due to a raised carbon dioxide, those due to a reduced oxygen and those due to a combination of these in the atmosphere breathed. However, it is necessary first to discuss breathing in a normal atmosphere.

The body uses oxygen to consume food for energy production and produces carbon dioxide as a waste gas. The oxygen is supplied to the body through the lungs and carried thence by the arterial blood to the tissues where it is used. From the same tissues the waste CO_2 is carried to the lungs in the venous blood and passes from the body in the expired air. The inspired air contains a negligible quantity of carbon dioxide and mixes (by diffusion) with the air in the alveoli (air sacs) where the concentration of CO_2 is a steady 5.6%. The expired air carried 4% CO_2 out with it and the waste gas is thus removed from the body. The actual passage of CO_2 from the blood into the alveolar gas occurs simply because it is present at a slightly higher pressure in the blood. This "partial pressure" difference is the cause of the rapid diffusion across the very thin alveolar membrane. Meanwhile oxygen from the inspired air has passed inwards simultaneously across the same alveolar membrane to saturate the blood with oxygen. The now arterial blood leaves the lungs with the same partial pressure of CO_2 as the alveolar air. Breathing moves fresh air into the lungs and waste air out at such a rate that the amount of CO_2 in the alveoli is kept constant at 5.6%.

The rate and depth of respiration is controlled by a part of the brain called the respiratory centre (situated in the medulla) which is acutely sensitive to the pH (acidity) of the tissue fluids in that region. The acidity in turn depends on the CO_2 content of the arterial blood leaving the lungs and pumped to the brain by the heart. A small increase in the CO_2 brought to the lungs from the tissues will cause a small rise in the alveolar CO_2 and therefore in the CO_2 content of the arterial blood supplying the respiratory centre. Stimulation of the respiratory centre results, and the rate and depth of respiration is increased so that the alveolar gas is more adequately changed. The alveolar CO_2 is restored to 5.6% and respiration returns to normal. Respiration is in fact controlled so as to remove carbon dioxide from the body as fast as it is produced.

Raised carbon dioxide in the inspired air

Any increase in the CO_2 concentration of the inspired air will decrease the partial pressure gradient available for the outward passage of this gas, resulting in a small increase in the blood CO_2 and stimulation of the respiratory centre. The resulting increase in the volume of air breathed compensates for the smaller amount of CO_2 added to each unit volume with the result that the quantity of CO_2 breathed out is maintained. This compensatory mechanism can continue satisfactorily only until the percentage of CO_2 in the inspired air approaches that normally found in the alveoli (5.6%). Any further rise inevitably increases the CO_2 in the arterial blood to abnormal and increasingly dangerous levels despite extreme activity of the respiratory centre. Atmospheric concentrations of CO_2 above 6% are increasingly intolerable and become narcotic in action thus depressing the activity of the respiratory centre, and causing unconsciousness. Indeed high levels of CO_2 are used in some abbatoirs as an anaesthetic gas preliminary to the slaughter of animals.

All these observations apply to the body at rest. If any exercise or work load is undertaken then further quantities of CO_2 are produced in the exercising muscles and must be got rid of via the blood stream and the lungs, a route whose efficiency is now much decreased. Hence any increase in the CO_2 content of the inspired air automatically causes a proportionate decrease in physical work capacity.

Table 2

Responses for man at rest to atmospheres containing carbon dioxide

The percentage of CO_2 added to dry normal air at a pressure of 1 atmosphere is given in Column 1.

Inspired CO_2	Effect
0.1%	normal
1%	slight increase in rate and depth of respiration
3%	ventilation is doubled slight headache common
4%	ventilation almost trebled, throbbing headache, flushed face, nausea, sweating
5%	ventilation more then trebled, ("off effects" on removal)
6%	ventilation sixfold, can be tolerated for several hours
10%	intolerable to breathe for more than a few minutes
12-15%	unconsciousness within minutes

Table 2 gives the responses for man at rest to differing percentages of carbon dioxide in the air breathed. Reliable data for human responses to increases inspired CO_2 is difficult to obtain because subjective factors are extremely important and both motivation and fear in the subject can produce anomolous results. The measurement of physical parameters such as the partial pressure of CO_2 in arterial blood may be a better indicator of the effect on the subject. The data in Table 2 are for normal subjects at sea level. The first observable effect of increasing the % of CO_2 in the inspired air is an increase in the rate and depth of respiration (Table 2) – but this often goes unnoticed. At about 3% of CO_2 in the inspired air increases in the rate and depth of respiration are subjectively noticeable and physical work capacity is measurably diminished. A rise to 4% produces a flushed face, headache, palpitation and sweating, and these effects are even more marked with 5% CO_2. At this level of CO_2 in the inspired air the level in the alveolar air will of course be even higher and the CO_2 in the arterial blood leaving the lungs will be above the normal amount. Buffering mechanisms in the blood will be involved and if now the subject reverts suddenly to breathing fresh air "off effects" are commonly experienced – headache, nausea and sometimes vomiting. Recovery from such CO_2 levels may be slow and the problem is familiar to anaesthetists. These "off effects" have often been noticed when caving in high CO_2 at Bungonia and in the past have sometimes been attributed to a reduction in tension or fear on leaving the danger area. It seems more likely that the familiar "off effects" result from a rapid emergence from high CO_2 into normal atmosphere and the failure of the buffering processes in the body to revert as rapidly to normal.

The normal lung ventilation is eight to ten litres a minute, but at a 6% concentration of CO_2 in the inspired air this rises to 60 litres/min. which is close to the maximum possible in a healthy young adult. Severe exertion under normal atmospheric conditions will also cause hyperventilation at a similar rate, thus any exercise in 6% CO_2 is virtually impossible. 10% is subjectively intolerable to breathe and slightly higher carbon dioxide levels rapidly produce unconsciousness and eventually death.

Reduced oxygen in the inspired air

By comparison with the effects of breathing a gas mixture containing high carbon dioxide, the visible effects of breathing one deficient in oxygen are hardly noticeable. The physiological effects are trifling until the deficiency is quite large and if the subject is at rest the O_2 may be reduced from the normal 21% to 13% before there is any danger. When the inspired air contains about 13% O_2 the alveolar air is about 8% O_2 and the result of this reduction is that the arterial blood is not completely saturated with O_2. While breathing air the body stores only 1550 ml of oxygen, found mainly in the lungs (29%), the blood (55%), dissolved in tissue fluids (3%), and in combination with myoglobin (13%) (Nunn 1972). The small size of these stores means factors affecting them (such as exercise and reduction in the % O_2 in the inspired air) will produce their full effects very quickly. When the oxygen level in the inspired air reaches 13% then oxygen lack (hypoxia) begins to present a serious threat to the body and in the healthy subject compensatory mechanisms come into play. Hyperventilation occurs although in comparison with the reaction to increased CO_2 it is minor, and moreover the response varies considerably in degree in different normal individuals. The extent of variation in the degree of reaction, and the level at which it occurs is greater than is commonly realised. In some persons a lowering by as little as 5% in the oxygen of the inspired air will increase breathing noticeably, but in most people a lowering of at least 7% is required to produce a noticeable effect, while in others consciousness is lost from hypoxia before any noticeable effect is felt. An increased blood flow to every major organ, particularly the brain, always accompanies hypoxia.

When the reduction in oxygen in the inspired air is gradual, there is little or no preliminary discomfort and the onset of serious hypoxia is very insidious. Reserves of oxygen in the tissues and organs are quickly used up and death can result rapidly. Intermediate stages of oxygen lack cause serious brain damage as nerve cells cannot live for any time without oxygen and do not regrow. Permanent brain damage can therefore result from severe hypoxia.

As the blood becomes less oxygenated it loses its bright red colour and becomes a dusky plum shade. The observable signs are blueing of the lips and mucous membranes, the conjunctiva, the ear lobes and the nail b eds. Again the onset is variable from person to person and other factors such as cold can produce confusion by causing reduced peripheral circulation and local cyanosis.

Powers of judgement are much impaired and muscular co-ordination is steadily affected. Despite fore-knowledge of the certainty of its onset with hypoxia the most harmful and most frequently recorded hazard is a supreme confidence in the ability to continue the experiment or exploration even though the hypoxic investigator is aware that his muscular co-ordination is deteriorating. The off effects are usually negligible on return to fresh air, and there is an immediate return to normal. Loss of memory of the entire event is very common. In a few cases aggressive behaviour occurs with recovery of consciousness and the victim of hypoxia may briefly attack his rescuer.

The combination of raised carbon dioxide and reduced oxygen in the inspired air

When diminution in the oxygen content of the inspired air is accompanied by a corresponding increase in the content of carbon dioxide, then the rise in CO_2 by stimulation of the respiratory centre causes an increased rate and depth of breathing with the result that the oxygen in the alveolar air will remain almost normal within wide limits. Full oxygenation of the blood therefore continues until there is a sufficiently high CO_2 content to depress the respiratory cent re and respiration begins to fail.

It is noticeable that there are considerable discrepancies in the literature concerning the effects of increases in the CO_2% of the inspired air. Many experimenters have omitted to give the full analysis of the gas mixtures used, with the results that fundamentally different mixtures have been regarded as equivalent in composition. The two gas mixtures shown in table 3 are both referred to as 6% CO_2 but differ in their O_2 content. This is important because it has been shown that a reduction in the inspired oxygen content changes the response for a given level of carbon dioxide. For example, if the oxygen in the inspired air is reduced while maintaining a constant level of carbon dioxide the ventilation rate will increase (Nunn 1972) and the subject will exhibit the symptoms normally expected for higher concentrations of carbon dioxide.

Table 3

	Sample 1 Addition of 6 vols CO_2 to 94 vols dry air	Sample 2 Substitution of 6 vols of CO_2 for 6 vols oxygen in 100 vols of dry air
O_2 %	19.7	15.0
CO_2 %	6.0	6.0
N_2 and inert gases %	74.3	79.0

Sample 1 in table 3 can be breathed for several hours, but sample 2 is much more unpleasant and can only be tolerated for a few minutes. While breathing either sample the subject is in danger of respiratory depression from the narcotic action of the high level of CO_2. If such depression occurs then the subject breathing sample 1 is much less likely to show hypoxic signs as the concentration of oxygens entering the lungs is still sufficient to maintain O_2 saturation of the blood even when ventilation is reduced. The subject breathing sample 2 already has a considerably lower alveolar oxygen concentration and under these conditions a reduced ventilation rate will produce serious hypoxia.

Experienced foul air cavers in Australia have observed two types of individual response on exposure to foul air. The common response as might be expected is hyperventilation with some degree of cutaneous vasodilatation, and these subjects are commonly referred to as "pink puffers". A small minority do not hyperventilate, show signs of cyanosis and are called "blue bloaters". Both these terms are commonly used by anaesthetists to describe the reactions of patients under anaesthesia. (Dornhorst, quoted by Cotes 1975).

While the reaction of the "pink puffer" is normal, that of the "blue bloater" is abnormal – or is at any rate a greatly reduced response to a raised CO_2 in the inspired air. Hyperventilation is absent with the result that the alveolar oxygen is low and cyanosis occurs. A blue bloater therefore will be at extreme hazard in foul air caves, in which he will suffer hypoxia and be in danger of unconsciousness without the warming symptoms experienced by most cavers. A known blue bloater should never enter a region of foul air without the warning companionship of a pink puffer.

ADVICE FOR SAFE ENTRY INTO FOUL AIR REGIONS

In Australia the advice given to caving groups is 'if a match will not burn then get out' (Pavey, *et al* 1972). In many caves warning signs are posted and these should not be passed casually (Fig. 1). However, circumstances such as the search for and recovery of victims and the carrying out of exploration and scientific work can require entry into the foul air regions of caves, and in any case enthusiastic excavators may wish to dig in foul places. The following advice is based on the assumption that CO_2 has replaced O_2 volume for volume (7% CO_2 implies 14% O_2). This replacement of O_2 by CO_2 is the worst condition encountered apart from the rare occurrences of stink damp (James 1975). Other research workers may find the situation in the caves they are investigating allows for adjustment of the recommended limits given here.

A. **CO_2 1-4%**

1) A CO_2 tester should be carried – if nothing else is available use a candle. A candle can be recommended as the standard CO_2 test for digs. If the CO_2 rises above 4% (i.e. the candle goes out) – **get out slowly.**

2) Cavers with no experience of foul air should be introduced to it gradually by an experienced leader.

3) A high standard of physical health is essential. A person for example who is suffering from anaemia, asthma or a respiratory infection should not go into any region of foul air.

4) At all times movement should be slow and well co-ordinated.

5) Climbing out of foul air is much more difficult than might at first be expected because of the limited capacity for physical work of the caver in foul air. Special caution is required in undertaking descents – especially pitches.

6) Critical manipulations especially those involving safety must be checked by at least one other person. An example is the tying of bowlines on life lines. Although there have been no deaths in Australian caves directly attributable to foul air, it is possible that the impairment of mental processes contributed to the fatality in Drum Cave, when a caver fell from a ladder and was not saved by his life line because the knot failed to hold. He had just left the foul air region of the cave (Wood 1965).

B. **CO_2 4-6%**

Only experienced foul air cavers should enter these regions. In addition to the recommendations 3 to 6 in section A, –

1) A CO_2 tester must be carried.

2) An "oxygen rebreathing" apparatus should be taken (one kit to four people). Draeger market an ideal apparatus for mines rescue. It is small, robust, easy to operate and can be carried on the belt. It is very suitable for caving but is expensive and only lasts for 30 minutes. The rebreathing set should go down the cave with the first man.

3) Some care is required when leaving a region of high CO_2 to prevent off effects. When some time has been spent in a high CO_2 atmosphere the buffering systems of the body will have adjusted to the new conditions. An instant return to fresh air produces off effects until the buffer systems return to normal. These effects are not dangerous but may be uncomfortable, embarrassing (because they are interpreted as hysteria) and frightening if not understood and anticipated. They include vomiting, extreme hyperventilation, shouting and uncontrollable laughing or crying. They can be prevented by a slow dignified exit if the cave has a CO_2 gradient. In a cave where there is a CO_2 region which finishes abruptly the caver should not rush into fresh air – but take several minutes over the change.

C. **CO_2 6% and above**

Breathing apparatus is necessary and all the precautions against equipment failure taken in mines rescue and caving diving should be followed.

1) The self-contained underwater breathing apparatus (SCUBA) for normal work in CO_2.

2) A line from a compressor (outside the cave) or an air bottle (Hookah) to the explorer if the passage or the way to it is tight.

3) For long periods of work in foul air, relatively lighter oxygen rebreathing equipment may be used and the dangers from high pressures associated with its use under water do not apply.

4) If the caver has passed through a region of foul air and dons breathing apparatus when entering regions with a carbon dioxide concentration above 6%, then he will probably experience off effects on breathing the fresh air in his apparatus. These appear rapidly and there is as yet no routine for avoiding them under these very special circumstances. Any method of making the transition more gradual seems desirable, such as alternate breaths of compressed air and cave air, or leaking the foul air under the side of the face mask. Preferably if feasible the apparatus should be used from 3% CO_2 onwards. Above all it must be certain that off effects are not going to occur and that normal respiratory stability is achieved before continuing into regions of higher CO_2. Vomiting for example would be disastrous. This is especially important when the breathing apparatus is being used for cave diving in foul air caves. Off effects are almost certainly the reason for the comment from foul air cave divers "breathing fresh air makes me feel worse". Underwater off effects would almost certainly be fatal.

TREATMENT

Much of the treatment for foul air narcosis is common sense but success depends upon the ability to assess and adapt rapidly. Hence critical observation by the other members of the party is necessary for immediate treatment of victims. This is difficult because in foul air thinking becomes selfish and survival is one's first priority. Fortunately, the warning symptoms are unpleasant, and this protects the caver.

Mild distress in CO_2

As soon as any minor uncomfortable symptoms (e.g. headache) are felt the victim should return to fresh air **slowly**. Anxiety tends to make victims of foul air move rapidly and hard physical work causes rapid deterioration in the victims' condition. The victim should not be dispatched to return to fresh air alone nor should he be allowed to sit and wait for the party's return. Sickness and headaches may persist on return to fresh air, and are best treated by rest.

Serious distress in CO_2

Serious distress has been reported in concentrations as low as 1% and it is common at 4-5% if working hard. When this occurs check that there is no restriction on breathing such as tight clothes or a prusiking chest harness. Reduce anxiety by soothing and calming the victim. If available administer medical oxygen or compressed air. As soon as the victim is calm start to move him slowly out of the foul air, but no further improvement can be achieved by lingering in it. Victims tend to want to stay still and sleep. They should be given maximum assistance up pitches using a hauling rope and a life-line, and they should be assisted up all climbs.

Collapse

If the victim collapses where there is no oxygen or compressed air available, he should preferably be carried into a region of fresh air. All clothes and other restrictions on breathing should be loosened and mouth to mouth resuscitation should be given if respiration fails. If he recovers organise his removal from the cave. If he does not regain consciousness roll him into the semi-prone position and organise the rescue.

RESCUE

Rescue from Foul Air Caves

The physical effort of carrying a victim in foul air is extreme and will cause the condition of the rescuers to deteriorate rapidly. To assess some of the problems associated with rescue from foul air Sydney Speleological Society organised a practice rescue in the Grill Cave at Bungonia. Unfortunately on the day of the practice the CO_2 was below 1% and no ill effects were felt by the stretcher bearers. It is assumed that rescue from foul air caves with up to 4% CO_2 will be possible without breathing apparatus for the rescuers. Frequent changes of stretcher bearers and stretcher support parties are required because the rescuers have to move slowly and leave immediately any signs of distress are felt, lest further casualties occur.

When the CO_2 level is above 4% removal of the victim to fresh air becomes more urgent, more difficult and less feasible. While it is recognised that normally the only cavers entering such an area will be fully trained and equipped and therefore unlikely to suffer a casualty, the possibility of an accident must be remembered and the rescue of a foolhardy caver can be envisaged. The rescue must be made by a party fully equipped with breathing apparatus. On no occasion should an unequipped person stay with the unconscious caver.

Rescue of a caver trapped in foul air or a place where foul air can accumulate

In the Neil Moss incident in Peak Cavern (Lloyd 1961) the victim had descended a ladder to the bottom of a 12 m tube, where he worked in a boulder choke for 30 minutes. When he came to ascend he could not raise one foot above the other and after 15 minutes of trying felt completely beaten — an indication that his air was already foul. He became light-headed and unconscious within 2 hours indicating further deterioration of the air by O_2 use and CO_2 production. After 24 hours he was dead. The report of the MRO committee set up to examine the possibility of rescue from such situations, stated that the problem of foul air appeared insoluble (Anon 1970). CO_2 levels in small chambers had not been cleared by soda lime absorbers. Laboratory experiments with a large balloon (size of a small room) had confirmed the difficulty of removing CO_2 from a large volume of air. A suggestion by Rogers at the end of the same report gave a clear indication that the problem is far from insoluble, and a victim trapped as Neil Moss was has a definite hope of rescue.

When it is realised a caver is trapped and rescue is required then even if it is not known that foul air will accumulate the following action is wise:—

for the victim

1) Extinguish carbide lamps by turning off the water if possible — if not knock out the flames. H_2S (hydrogen sulphide) and other gases that give acetylene its foul smell will be there in insufficient quantities to be fatal.

2) If possible relax into a position where breathing is easy, loosening belts etc.

3) If possible move the head into a position where breathing apparatus can reach it.

for the caving team

1) Start rescue organisation immediately.

2) Leave one person in voice contact with the victim to keep him calm if conscious. Extinguish all flames.

3) Use the inventiveness of the group to get fresh air to the victim while still conscious, e.g. a hose from a farm, a rebreather set from a fire station.

4) Ensure the victim is supplied with a hauling rope while still conscious.

for the rescue organisation

Any caver trapped in a squeeze may be in danger from foul air, and unless the rescuers are certain that foul air conditions are not present and will not develop then arrangements must be made urgently for a supply of acceptable air. If the victim is near the surface he can be supplied with air from a road drill compressor. However, with the advent of a strong cave diving group and their resulting entourage of sherpas — all qualified for carrying air and oxygen bottles into remote places, the Hookah system of a bottle and pressure tubing or the MRO sump rescue apparatus could be used. A full face mask can be put on while the victim is conscious by which means he can be supplied with air if he collapses. If the victim is unconscious or unable to fit a face mask or demand mouthpiece, then the CO_2 accumulating must be displaced from around his head. The simplest device that may work is a 1 m length of metal pipe firmly attached to the pressure hose so that it can be pushed to the victim's face. Air under pressure would then reach his face. Large volumes of air would be required for this process and an air compressor for refilling bottles at the cave entrance would be essential. If the location is particularly remote, the less easily obtainable oxygen is better than air as the victim will survive much higher levels of CO_2 in oxygen than in air.

In the attempted rescue of Neil Moss (Lloyd 1961) compressed oxygen was released close to him and this may have prolonged life considerably, partly by raising oxygen levels and partly by diluting the carbon dioxide present. Unless oxygen reserves were maintained death would have occurred earlier. The aim must be to keep the victim alive and in good condition while an appropriate extraction and rescue is devised.

CONCLUSION

Many of the practical aspects of foul air caving come from the personal experience of the two Australian authors who for several years have caved regularly in foul air containing up to 6% carbon dioxide. The actual physiological effects of foul air are poorly understood by cavers encountering them and have frequently been misinterpreted. Variation in personality and in tolerance of foul air can allow cavers unwittingly to put themselves at hazard. Medical and physiological literature on foul air is not easily available to the caver and little has been written with the caver in mind. The double danger of a rise in CO_2 associated with a fall in O_2 has rarely been examined and the immense practical problem of working in such an atmosphere lacks the attention it needs. It is hoped to undertake further experimental work in this field.

It is safe to enter and work in foul air containing up to 4% carbon dioxide. At levels above 4% the caver is continuously in increasing danger and above 6% the danger is extreme. Growing interest in foul air caves and improved techniques will lead to further explorations with the increasing probability of an accident. Rescue from foul air caves is possible but success depends on no time being wasted at any stage. Practice rescues from Australian foul air caves will be held in order to provide first hand knowledge of the problems involved. It is hoped that this paper will stimulate thought and discussion of the hazards of foul air.

ACKNOWLEDGEMENTS

The authors would like to thank the MRO committee on foul air, for information especially concerning instruments, the members of both Sydney Speleological Society and University of New South Wales Speleological Society for involuntary assistance as foul air victims, members of the University of Bristol Spelaeological Society for unpublished data concerning foul air in Mendip caves, and N. Montgomery and P. Smart for reading the manuscript critically.

June 1975

Julia M. James, B.Sc., Ph.D.,
Chemistry Dept., University of Sydney
(temporarily Geography Dept., University of Bristol)

Andrew J. Pavey, B.Sc.,
School of Physics, University of New South Wales,

Alan F. Rogers, M.D., M.B., Ch.B.,
Senior Lecturer in Physiology,
University of Bristol.

REFERENCES

Anon. 1969. (Carbon Dioxide). *Descent* Vol. 6(3), pp.15-17.

Anon. 1970. Mendip Rescue Organization. *J.Wessex Cave Club.* Vol.11(129), p.61.

Atkinson, T.C. 1970. Methods of determining carbon dioxide in cave air. *J.Wessex Cave Club.* Vo.11(129),p.63-67.
Burke, D.T. 1953. Foul Air and Bungonia. *Sydney University Speleo Soc. J.* Vol.1(3), pp.7-10.
Crawshaw, R. and Moleman, D. 1968. Bungonia B44 Grill Cave. *Stop Press* Vol.12(9), pp.150-151.
Delecour, F., Weissen, F., and Ek, C. 1968. An electrolytic field device for the titration of CO_2 in air. *Bull Nat. Speleo. Soc.Am.* Vol.30(4), pp.131-6.
Faunce, E.A. 1955. The Physiological Effects of Foul Air. *Sydney University Speleo Soc. J.* Vol.2(2), pp.17-18.
Fraser, N.R. 1958. Foul Air in Caves – Molong and Wellington, N.S.W. *Sydney University Speleo Soc.J.* Vol.5(1), pp.3-10.
Grée, N. 1966. Underground Gases. *The Western Caver* Vol.6(5), p.4.
Hobbs, A.S. 1963. (in) *Handbook of Analytical Chemistry.* L. Meites (Ed.) McGraw-Hill: New York pp.4-11.
James, J.M. 1975. Carbon dioxide in caves. *Trans. British Cave Res. Assoc.* – in preparation.
Lloyd, O.C. 1961. Cave Rescue. *The Medical Journal of the South-West.* Vol.76 (ii)(280), pp.37-49.
Miotke, F.D. 1974. Carbon Dioxide and the soil atmosphere. *Abhandlungen zur Karst-und Höhlenkunde,* Reihe A, (Speläologie) Heft 9, München 1974, pp.44-46.
Nurse, B.S. 1972. Summary of the History of Bungonia Caves and Area; in *Bungonia Caves* by Ellis *et al.* (Eds) (Sydney Speleological Society: Sydney) pp.13-26.
Pavey, A.J., Montgomery, N.R., James, J.M., Dowling, A.J. and Hawkins, L.J. Cave Descriptions; in *Bungonia Caves* by Ellis *et al.* (Eds) (Sydney Speleological Society: Sydney) pp.30-54.
Ramsay, E.P. 1882. Curators' Report on the Exploration of Caves; in Exploration of the Caves and Rivers of N.S.W., (in) *Votes and Proceedings of the Legislative Assembly* 1882: Vol.5, pp.45.
Riley, J.P. and Chester, R. 1971. *Introduction to Marine Chemistry.* Academic Press: London 130p.
Renault, P. 1972. Le gaz des cavernes. *Science Progres Decouverte* No.3443, Paris, pp.12-18.
Rogers, A.F. 1960. Investigators find carbon dioxide in Mendip Caves. *The Guardian* Thursday, October 20th p.7.
Sefton, A. 1967. The Physiology of Foul Air. *Stop Press* Vol.11(6), pp.82-83.
Trickett, O. 1901. Report on Bungonia Caves. *Ann. Rep. Dept. Mines N.S.W.* 1900, pp.198-199.
Vogel, A.L. 1962. *A Textbook of Quantitative Inorganic Analysis.* (3rd Edn) Longmans Green: London, 1054p.
Wood, I. 1965. First Cave Fatality in Australia. *ASF Newsletter.* Vol.28, p.2.

BIBLIOGRAPHY

Cotes, J.E. 1975. *Lung Function* (3rd Edn) Blackwell: London.
Balfour Slonim, N. 1974. *Environmental Physiology* C.V.Mosby: Saint Louis.
Haldane, J.S. and Priestley, J.G. 1935. *Respiration* (2nd Edn) Clarendon: Oxford.
Keele, C.A. and Neil, E. 1971. *Samson Wright's Applied Physiology* (12th Edn) Oxford University Press: London.
Nunn, J. 1969. *Applied Respiratory Physiology* Butterworths: London.

Notes on the Australian Literature

The following publications are Newsletters of Speleological Societies:

ASF Newsletter	Australian Speleological Federation: Sydney.
Descent	Orange Speleological Society: Orange
Stop Press	Sydney Speleological Society: Sydney.
The Western Caver	West Australian Speleological Group: Perth.
SUSS J.	Sydney University Speleological Society: Sydney.

Transactions British Cave Research Assoc. Vol.2. No.2. pp.89-92 August 1975.

HAZARDS OF USING EXPLOSIVES

by Robert M. Williams, M.B., B.Ch., D.P.H. and M. Ann Mason Williams, M.Sc.

There are, of course, the obvious hazards of explosives, substances which have been aptly described as "instantaneously perishable materials". It is to be hoped that anyone who ha s occasion to use "banger" or who is a member of a party using it in a cave or at a dig, appreciates fully the dangers of mis-handling explosives. For those interested, it is worth mentioning that Imperial Chemical Industries have several publications and films on the use of explosives and the techniques of shot firing. In this paper it is intended to point out some of the less spectacular hazards involved; those arising from the toxic effects of explosive mixtures and the fumes which result from their detonation.

Two explosives used frequently by cavers are Nobel Polar Ammon Gelignite and Plaster Gelatine, each of which depends on its trinitroglycerine content for its explosive power. For obvious reasons, it is very difficult to obtain exact formulae for the composition of the various explosives (neither the Home Office nor the industries concerned encourage the Do-it-Yourself idea for making explosives!). It is known, however, that gelignite consists, approximately, of:

60%	nitroglycerine
5%	guncotton
27%	nitrate of some sort
8%	wood meal

Other explosives may contain trinitrotoluene and other aromatic compounds.

Trinitroglycerine is used medically to dilate narrowed blood vessels in the heart in the treatment of Angina. It also causes an increase in pulse rate and dilates the blood vessels supplying the brain thus increasing the blood supply to that area. The consequent rise in intracranial pressure gives rise to headache in many cases: the headache known to cavers as "Banger headache". Medicinally, it is taken by mouth, but it is readily absorbed through the skin and its vapour has an equally powerful effect even when diluted by large volumes of air. The susceptibility of individuals to the action of nitroglycerine is very variable but in all cases is greatly enhanced by heat and by alcohol.

In most cases the headache begins as a severe throbbing in the frontal region and spreads until the whole head aches and it may be associated with a feeling of general weakness, flushing of the face, and, occasionally, vomiting. Little can be done to avoid "Banger headache" other than to avoid using "banger". Rubber gloves afford protection against absorbtion through the skin but it is impossible to avoid inhaling some of the vapour. Once the headache is present the only drugs which are of use are the analgesics such as aspirin and codeine. Drugs such as Ephedrine (a drug used for the treatment of allergic conditions) have been recommended for use before handling explosives. The degree of relief given by such drugs does not appear to be reliable and personal experiments have been disappointing.

The explosives which contain trinitrotoluene may also have an effect on health, through their effect on the blood. Here again they are absorbed through the skin, but in this case continued handling for a longer period of time is required for the symptoms of headache, nausea, vomiting and protration to develop. Cyanosis can appear due to the effect on the blood cells.

It is not only the handling of explosive that can cause discomfort and ill-health; equally dangerous are the products of their combustion. Following detonation, the atmosphere will contain a variety of fumes; carbon dioxide, carbon monoxide, free nitrogen, ammonia, nitric oxide and nitrogen dioxide may all be present. The presence or absence of any particular gas and their relative quantities will depend upon the particular explosive used and the efficiency of the tamping. Carbon monoxide, nitric oxide and nitrogen dioxide are likely to be present in appreciable quantities if:

(i) detonation is not complete
(ii) slow combustion has occurred
(iii) tamping has been poor
(iv) Ventilation is inadequate.

The atmosphere will also contain rock dust which is irritating to the lungs, but the volume of such dust can be assessed visibly and excessive quantities avoided.

Modern explosives are designed to be detonated under well tamped conditions. Small quantities of dangerous fumes may be released but are usually swept away even by small draughts. In the early years of high explosives, manufacturers designed mixtures which were highly "oxygen positive" to ensure complete combustion, or alternatively, mixtures which were highly "oxygen negative" to ensure "cool" explosions, for use in coal mines. Until it was realised, towards the end of the nineteenth century, that many shot-firers were suffering from anaemias and other illnesses, the resultant fume content of such explosives was not studied from a toxicological point of view.

The simplified equations for modern explosives are:

(i) $4C_3H_5(NO_3) \rightarrow 12\,CO_2 + 10\,H_2O + 6\,N_2 + O_2$
(nitroglycerine)

(ii) $4\,C_7H_5N_3O_6 + 21\,O_2 \rightarrow 28\,CO_2 + H_2O + 6N_2$
(trinitrotoluene)

Reproduced from Trans. C.R.G. Vol.6. No.2. 1963

Nitroglycerine and trinitrotoluene are generally used in a mixture with an inorganic nitrate such as ammonium nitrate, NH_4NO_3.

(iii) $$2\,NH_4NO_3 \xrightarrow[\text{detonation}]{} 2N_2 + 4\,H_2O + O_2$$

The combined reactions give equations of the type:

(iv) $$2\,NH_4NO_3 + 4\,C_3H_5(NO_3)_3 \rightarrow 8\,N_2 + 14\,H_2O + 12\,CO_2 + 2O_2$$

(v) $$21\,NH_4NO_3 + 2\,C_7H_5N_3O_6 \rightarrow 24\,N_2 + 47\,H_2O + 14\,CO_2$$

Similar equations can be worked out for mixtures of nitroglycerine with potassium nitrate or sodium nitrate, when the potassium or sodium carbonate will be formed together with water and the gaseous products.

Thus theoretically, no harmful products are released. As has been stated previously, it is difficult to discover the exact composition of plaster gelatine, but in view of its properties it is likely to contain 7-80% nitróglycerine with added inorganic nitrates. This is recognised by the manufacturers to have poorer fume properties than other commonly used explosives such as Polar Ammon Gelignite which consists of 30% nitroglycerine and 60% ammonium nitrate. Confining the fumes in a well-tamped shot-hole will tend to produce a mixture of gases similar to those in the theoretical equations while the use of relatively unconfined explosive will result in an interference with the balance of the theoretical equations, presumably by atmospheric gases.

On burning a small quantity of explosive in air, fumes can be collected and analysed. The conditions are not strictly analogous to those at detonation as the rate of combustion is much slower but the results are interesting and suggestive; large quantities of nitrogen dioxide and its polymer, N_2O_4 are produced.

There are then several harmful substances which may be present following an explosion on limestone, such as carbon monoxide, nitrogen dioxide, ammonia and calcium oxide dust. The latter rarely forms a hazard to cavers as under the wet conditions which prevail in caves, active quicklime is rapidly slaked. In digs on the surface, the dust is visible and can be avoided until the prevailing draughts have blown it away.

Carbon monoxide has been shown to be present following explosions under certain circumstances in concentrations of about 0.02%. The symptoms of poisoning with this gas vary with the concentration in which the gas is present, varying from immediate collapse in high concentrations to the slow development of headache and unconsciousness in lower concentrations. Recovery begins as soon as the victim is removed into fresh air.

Ammonia and nitrogen dioxide are both highly soluble in water. The former rarely constitutes a danger as its characteristic smell is readily noticed together with the effect on the nasal and buccal mucosae well before it affects the bronchial tree or the lungs. Nitrogen dioxide, however, constitutes a very considerable hazard and gives no indication of its presence other than the brown fumes which can be seen only if considerable quantities of the gas have been released.

The dangers of breathing the fumes from an explosion are well illustrated by an incident which occurred in Ogof Ffynnon Ddu in November 1960. A 35 year old caver was seriously ill after he had detonated a charge of Plaster Gelatine in a confined chamber in the cave.

In order to reach the sill on which the charge was to be placed, the man had to swim under water. The object of the blasting was to lower the water level by removing the lip of the rock sill.

The charge used was 1 lb of plaster gelatine which was placed firmly in a crack at "arm's length" beneath water level. No tamping was used beyond that provided by the water over the charge. After diving back out of the chamber the caver detonated the charge electrically. The explosion caused considerable disturbance in the outer chamber, water being thrown some fifty feet up the passage.

About half an hour later the man re-entered the far chamber and on surfacing found that there was a layer of fumes above the surface of the water. On surfacing in another part of the chamber he found that the fumes were present throughout the area and was able to see that they formed a layer eighteen inches thick over the water. The fumes were too thick for him to see the effect of the blast and he returned through the water to the outer chamber. Here he changed into his ordinary caving clothes and made his way out of the cave at his leisure. The explosion had been set off at about 11 a.m. and he left the cave about two hours later.

During the afternoon, the caver sat enjoying the late autumn sunshine and did nothing energetic. At dusk he returned to the Club headquarters where he prepared an evening meal and retired to bed at 10 p.m. During this period of time no changes had been observed in his appearance and he had made no complaints.

At midnight he woke one of his friends, and asked to be taken to see a doctor. He was breathless and as preparations were being made to take him to the local hospital, his condition deteriorated and he started to cough up quantities of loose grey-green fluid. On reaching the local hospital, he was found to be much worse and required oxygen to prevent cyanosis. An X-ray revealed dense opacities in both lung fields due to acute pulmonary oaedema. By the time that he reached the nearest general hospital in an ambulance, he was comatose and oxygen was being administered continuously.

Treatment following his admission to hospital was by sedation, diuretics, postural drainage and suction, with oxygen being administered as necessary. Within twenty-four hours, his condition had improved considerably and following a short course of antibiotics he was discharged for convalescence. For the following six months he felt a lack of his normal vigour but then returned rapidly to normal health and strength.

The patient's own impressions of his illness are of interest. After leaving the cave he felt well in himself except for a certain weariness and lethargy. He had not exerted himself unduly during the rest of the day and had gone to bed at his usual time. He awoke to find his breathing tight and coughing produced loose, frothy sputum. As fresh air did not seem to help he called his friends. He remembered being carried to an ambulance following his X-ray at the local hospital and feeling at that stage that his time had come and that as he had neither the strength nor the will to struggle, gradually sank under this feeling. His next memory was of resenting the fact that someone was slapping his back and sitting him up for an X-ray. This incident seems to have taken place after he had been at the second hospital for about twenty-four hours.

Some months after this accident, a second and larger charge was placed near the site of the first charge which had not succeeded in removing the lip of rock. On this occasion the charge was tamped with sandbags and was fired from a greater distance away. When the party who had laid the charge returned to the edge of the water in the outer chamber some thirty minutes after firing the charge, a dense layer of brown fumes was observed over the surface of the water in the outer chamber. The colour of the fumes was typical of the fumes of nitrogen dioxide, confirming that such fumes are likely to be present after the detonation of poorly tamped explosive. Wearing breathing apparatus, one member of the party entered the further chamber and found that the fumes in there were equally dense. The explosion had been successful in removing the lip of rock on this occasion, thus lowering the water level and allowing some of the fumes to escape into the outer chamber. The party of cavers left the area as quickly as possible after making these observations and no ill-effects were felt by any member of the party.

For some time the cause of the illness of the caver who laid the first charge was uncertain but the general clinical picture seems to lay the blame on the oxides of nitrogen contained in the fumes released by the explosion. Although nitrogen dioxide is soluble in water, such large quantities of it had been produced that a considerable time was required for them to be washed away. The observations of the second party tended to confirm this view, for the brown fumes were still noticeable up to an hour after the explosion despite the fact that the charge had been tamped and that there was a perceptible draught once the water level had been lowered. It is permissible to assume that in the case of the caver who laid the first charge, he took a deep breath on surfacing in the inner chamber when he went to inspect the results of the explosion and thus took a considerable quantity of the fumes into his lungs.

Expert opinion on the circumstances of the explosion which resulted in the illness, suggests that the tamping resulting from two feet of water over the charge was insufficient.

One of the chief dangers of nitrogen dioxide poisoning is that there is no warning level at which the victim will perceive the danger in time to remove himself without further damage. Concentrations of more than 1 in 1,000 are likely to cause coughing, but even a few minutes exposure at this level will cause death. Lower concentrations, which can cause severe illness, are unlikely to cause any immediate symptoms. According to Hunter (1957) the major symptoms of "nitrous fume" poisoning are delayed for 12-36 hours after exposure. Apart from a slight cough and a feeling of lassitude during the latest period, the victim has no warning. It seems that the greater the exposure, the earlier the symptoms will appear and the more severe the course of the illness.

The symptoms vary from a mild dyspnoea (like mild asthma) to extreme dyspnoea with cyanosis and coma. Death may result in severe cases. The symptoms are said to regress within 24-36 hours so that if the patient can be kept alive for that period of time, the danger is passed and the patient will recover. Recovery is complete, no scarring of the lungs result unless there is repeated exposure when chronic dyspnoea develops, as was the case with the early miners.

Thus the general picture of nitrous fume poisoning with recovery following expectant and symptomatic treatment is well illustrated by the case described. There are but few similar cases described in the literature, the two most recent being those of Rafii and Godwin (1961) who describe "Silo Filler's Disease" believed to be caused by the presence of nitrogen dioxide in maize silos and Kronenberger (1959) who reports two cases of bronchiolitis in shot-firers in collieries.

It is possible, therefore, to conclude that there are dangers to health both in handling explosives and in respiring the gases produced by explosions. The former hazards can be reduced to a minimum by careful handling and by adequate ventilation during the preparation of charges. The latter hazards need never be encountered provided that the danger is borne in mind and sufficient time is allowed to elapse before re-visiting the site of an explosion. No absolute time can be given for this time interval because the amount and type of fume will depend on the explosive used and on the adequacy of the tamping and the rate at which the fumes clear will depend on the ventilation of the site. A guide to the amount of time required for fumes to clear from a confined space can be found in the regulations imposed by certain commercial undertakings on their employees which do not allow shot-firers or drillers to return to the site of an explosion in a confined space for several hours.

If, despite precautions, exposure to fumes is suspected certain first aid measures can be taken.

(i) **Carbon monoxide poisoning:** the victim shows symptoms progressively of headache, giddiness, loss of power in legs and, sooner or later, unconsciousness, but characteristically remains a good colour with a pink complexion. The treatment consists of removing the patient to fresh air and applying artificial respiration if necessary.

(ii) **Nitrous fume poisoning:** Any case where the victim is thought to have been exposed to such fumes, should be kept under close observation for 36 hours for the development of the symptoms outlined above and should any wheeziness develop the patient should be kept still in either a sitting or lying position. If available, oxygen should be administered. If the symptoms develop beyond a mild degree of wheeziness, medical aid should be sought immediately. In any case where there is doubt seek medical aid sooner rather than later.

Acknowledgements

The assistance given by the victim of the nitrous fume poisoning in relating the circumstances of the accident and the course of his illness, and by the Nobel Division of Imperial Chemical Industries Limited in the preparation of this paper, is gratefully acknowledged.

Cardiff, June, 1962.

References

Aslett, E.	1960.	*South Wales Caving Club Newsletter, 34.*
Hunter, D.	1957.	*Diseases of Occupations.*
Kronenberger, F.L.	1959.	*Brit. Jour. Dis. Chest. 53*, pp.308-313.
McAdam, R. and Westwater, R.	1958.	*Mining Explosives.* Oliver and Boyd.
Rafii, S. and Godwin, M.C.	1961.	*Arch. Path., 72.* pp.424-433.
Taylor, J. and Gay, P.F.	1958.	*British Coalmining Explosives.* Newnes.
Williams, R.M.	1961.	*South Wales Caving Club Newsletter, 37.*

Personal communications from Imperial Chemical Industries Ltd., Nobel Division.

R.M. Williams, M.B., Ch.B., D.P.H., M.F.C.M.,
Hafod,
Edwards Terrace,
Pentwyn,
Quakers Yard,
Treharris,
Glamorgan.

Transactions British Cave Research Assoc. Vol.2. No.2. p.93 August 1975.

MISCELLANEOUS MEDICAL PROBLEMS

by Peter Standing

Acetylene Explosions

The inflammable properties of the gas acetylene have been put to good use in the oxy-acetylene flame and the acetylene lamp. The principle of the latter is to achieve a small jet flow of the gas by carefully regulating the quantity of water allowed to mix with calcium carbide in the lamp base. Minor explosions due to blocked jets and leaking rubber washers are quite frequent and add somewhat to the enjoyment of caving with this particular form of lighting.

There have, however, been reports of much more serious explosions involving transported carbide underground. In 1962 a member of the British Gouffre Berger expedition was carrying a kit bag containing a 7 lb. can of carbide. Somehow during its passage through the cave the tin lid became partially disloged and water leaked in. The person involved noticed a strange hissing sound and bent down to investigate, whereupon the flame on his lamp sparked off a large explosion. He was thrown several feet across the passage and had his eyebrows and beard burnt but otherwise escaped serious injury.

Another incident occured in Agen Allwedd. In the interests of cave conservation, a caver was carrying out his spend carbide in an ammunition box. Unfortunately the carbide was not entirely spent and the box was not completely watertight. As he was crawling along the constricted entrance passages he heard gas hissing from the box. His reaction was immediately to release the pressure by opening the box but he forgot to put out his lamp first. The resulting explosion was heard in the Main Chamber, several hundred feet away, and caused superficial burns to the face and eyes and removal of eyebrows and lashes.

The prevention of acetylene explosions is self-evident!

Electrolyte Burns

Other forms of lighting are even more frequent cause of burns amongst cavers. They include nickel iron, nickel cadmium and lead acid batteries. Alkali burns from the first two are the more serious.

Standing (1967) reported a case in a young female caver in Stoke Lane Slocker. She had carried her Nife cell to the cave in the same bag as her underground clothing and alkali had leaked over her wet suit. She noticed pain in her thigh after putting on her wet suit but it took a few minutes to get to the stream and wash the burn thoroughly. She then continued with the trip and it wasn't until several hours later that she became worried by the ugly appearance of the burn. She spent three weeks in hospital requiring a skin graft after the burnt area had sloughed off.

Numerous other,less serious burns have occurred. The moral is clear. Use leak-proof steel vents in Nife cells, store the battery separately from underground clothing and wash any burns IMMEDIATELY.

Your editor (TDF) carries the scars of alkali burns from 1949 on his shoulder. He donned his caving clothes on a warm sunny day, and noticed they were still 'damp' from the previous week's trip; he also noticed a mild burning sensation after a while but put it down to an insect bite. After several hours caving with a caustic alkali compress you can imagine the results! They took 6 months to heal.

Problems with Wet Suits

Some cavers have been known to develop an allergic dermatitis in response to neoprene. Occasionally this is serious enough to require avoidance of wet suits altogether. More often, however, the dermatitis is a minor complaint, probably multi-factorial in origin and associated with exposure to neoprene, excessive sweating and urinating inside the suit.

Overheating in both wet and dry suits can be a problem in the dry upper reaches of a cave and sweat loss is frequently underestimated. Indeed inadequate fluid intake on a long trip is a contributory factor to overall exhaustion and merits more consideration than it usually gets.

Weil's Disease (Leptospirosis)

This disease is caused by a relative of the syphylitic spirochaete, *Leptospira Icterohaemorrhagiae,* which is excreted in the urine of infected rats. Man acquires the infection by either ingesting food or drink contaminated by rats or by immersion in contaminated water. In Britain Weil's Disease is uncommon, occurring mainly as an industrial illness amongst those who work in rat infested places e.g. sewer workers. In 1964 a Mendip caver contracted the disease in Stoke Lane Slocker and the source of the infection was traced to rats contaminating the stream as it ran through a farmyard, someway above the swallet.

Leptospirosis can be a very serious illness with a mortality of 15%. After an incubation period of 1-2 weeks the commonest presenting symptoms are fever, headache, lethargy and pain in the back and limbs, all coming on rapidly. The conjunctivae are injected and jaundice occurs in 75% of people. Bleeding from the gut and elsewhere can occur and the patient may go into renal and/or hepatic failure.

July 1975.

P.A. Standing, M.B., Ch.B., D.A., D.Obs.R.C.O.G.,
34 Greenway Lane,
Charlton Kings,
Cheltenham.

Transactions British Cave Research Assoc. Vol.2. No.2. p.93 August 1975.

MISCELLANEOUS MEDICAL PROBLEMS

by Peter Standing

Acetylene Explosions

The inflammable properties of the gas acetylene have been put to good use in the oxy-acetylene flame and the acetylene lamp. The principle of the latter is to achieve a small jet flow of the gas by carefully regulating the quantity of water allowed to mix with calcium carbide in the lamp base. Minor explosions due to blocked jets and leaking rubber washers are quite frequent and add excitement to the enjoyment associated with this particular form of lighting.

There have, however, been reports of much more serious explosions involving transported carbide underground. In 1962 a member of the British Guatemala Expedition was carrying a tin box containing a 7 lb. can of carbide. Somehow during its passage through the cave the tin lid became partially dislodged and water leaked in. The person involved noticed a strange hissing sound and bent down to investigate, whereupon the flame on his lamp sparked off a large explosion. He was thrown several feet across the passage and had his eyebrows and beard burnt but otherwise escaped serious injury.

Another incident occured in Agen Allwedd. In the interests of cave conservation, a caver was carrying out his spend carbide in an ammunition box. Unfortunately the carbide was not entirely spent and the box was not completely watertight. As he was crawling along the constricted entrance passages he heard gas hissing from the box. His reaction was immediately to release the pressure by opening the box but he forgot to put out his lamp first. The resulting explosion was heard in the Main Chamber, several hundred feet away, and caused superficial burns to the face and eyes and removal of eyebrows and lashes.

The prevention of acetylene explosions is self-evident!

Electrolyte Burns

Other forms of lighting are even more frequent cases of burns amongst cavers. They include nickel iron, nickel cadmium and lead acid batteries. Alkali burns from the first two are the most serious.

Standing (1967) reported a case in a young female caver in Stoke Lane Slocker. She had carried her Nife cell to the cave in the same bag as her underground clothing and alkali had leaked over her wet suit. She noticed pain in her thigh after putting on her wet suit but it took a few minutes to get to the stream and wash the burn thoroughly. She then continued with the trip and it wasn't until about 48 hours later that she became worried by the ugly appearance of the burn. She spent three weeks in hospital requiring a skin graft after the burnt area had sloughed off.

Numerous other, less serious burns have occurred. The moral is clear. Use leak-proof alkali vents in Nife cells, store the battery separately from underground clothing and wash any burns IMMEDIATELY.

Your editor (TDF) carries the scars of alkali burns from 1949 on his shoulder. He donned his caving clothes on a warm sunny day, and noticed they were still 'damp' from the previous week's trip. He also noticed a mild burning sensation after a while but put it down to an insect bite. After several hours caving with a caustic alkali compress you can imagine the results! They took 6 months to heal.

Problems with Wet Suits

Some cavers have been known to develop an allergic dermatitis in response to neoprene. Occasionally this is serious enough to require avoidance of wet suits altogether. More often, however, the dermatitis is a minor complaint, probably multi-factorial in origin and associated with exposure to moisture, excessive sweating and urinating inside the suit.

Overheating in both wet and dry suits can be a problem in the dry upper reaches of a cave and sweat loss is frequently underestimated. Indeed inadequate fluid intake on a long trip is a contributory factor to overall exhaustion and merits more consideration than it usually gets.

Weil's Disease (Leptospirosis)

This disease is caused by a relative of the syphilis-like spirochaete, Leptospira icterohaemorrhagiae, which is excreted in the urine of infected rats. Man acquires the infection by either ingesting food or drink contaminated by rats or by immersion in contaminated water. In Britain Weil's Disease is uncommon, occurring mainly as an industrial illness amongst those who work in rat infested places e.g. sewer workers. In 1961 a Mendip caver contracted the disease in Stoke Lane Slocker and the source of the infection was traced to rats contaminating the stream as it ran through a farmyard, someway above the swallet.

Leptospirosis can be a very serious illness with a mortality of 15%. After an incubation period of 1-2 weeks the commonest presenting symptoms are fever, headache, lethargy and pain in the back and limbs, all coming on rapidly. The conjunctivae are injected and jaundice occurs in 75% of people. Bleeding from the gut and elsewhere can occur and the patient may go into renal and/or hepatic failure.

July 1975.

P.A. Standing, M.B., Ch.B., D.A., D.Obs.R.C.O.G.,
26 Greenway Lane,
Charlton Kings,
Cheltenham.

Transactions British Cave Research Assoc. Vol.2. No.2. pp.95-97 August 1975.

SPELEOLOGY AND CIRCADIAN RHYTHMS

by J.N. Mills

The values of medical science to speleology are evident enough. The values of speleology to medical science are, however, less evident, and consist largely of the isolation which caves provide, an isolation from any indication of the alternation of day and night, which is very helpful in the study of human biological rhythms. This is a subject which has attracted a lot of publicity of late, as well as some unjustifiable commercial exploitation. Human circadian rhythms in particular have been of considerable practical importance ever since night work and shift work became common, but the publicity they have recently attracted has been rather in association with what the press likes to call 'jet lag'. Most of us will appreciate, if we pause to think of it, that there is an inherent rhythmicity in our sleepiness and wakefulness as well as in our ability to perform any exacting task, and this is not solely dependent upon the fact that we normally have a refreshing sleep every night. If sleep were the sole cause then everyone would be at their best soon after they awoke every morning and would steadily deteriorate, reaching their lowest point of ability and performance by bed-time. This is not the experience of most people. Many indeed complain that they are not really awake properly until an hour or two after breakfast or even until mid-day, while some reckon that they can do their best work late at night, when by all reason one should be tired or exhausted. This alternation of sleepiness and wakefulness can perhaps be demonstrated most clearly when a person stays awake all night. Usually after a time of extreme sleepiness somewhere in the small hours of the morning he feels distinctly better later on in the morning even though, in fact, he has had no sleep. A careful investigation of this point carried out on a group of Swedish soldiers who were kept awake for seventy-two hours showed that their increasing fatigue was punctuated each morning by a few hours when they felt distinctly less fatigued, before their progressive fatigue deepened again in the afternoon.

This rhythmicity may be appropriate for those people who follow regular and conventional times of work and leisure, though the difficulty of some people over getting started in the morning, and the tendency of others to work late in the evening, does not always fit in with the habits of their colleagues. So as soon as anyone is expected to work and to sleep at unfamiliar hours these rhythms are liable to become inappropriate. Ability and performance are not easy to measure, particularly when one is trying to define a regular repeated pattern which involves taking a series of measurements every day for many days.

Circadian rhythmicity, however, extends to almost every bodily function one can measure, including quantities whose practical importance is not immediately obvious, such as the rate of excretion of different salts in the urine, as well as quantities which can well have a practical importance, such as the rate of secretion of various hormones; and perhaps most commonly measured is the body temperature. There is, in fact, some indication that the timing of the body temperature peak, whether early in the morning or later in the day, as well as the timing of some of the behaviour of the kidneys, varies with the person's temperament, the peaks coming earlier in 'morning' types and later in 'evening' types. There is also some evidence that one's performance at a variety of essentially mental tests is better at the time when one's body temperature is highest and worse when the temperature is low.

The most notably rhythmic hormone is the principal secretion of the adrenal gland, cortisol, which is produced very largely in the early morning and which has been described as an alerting hormone. Whether or not we accept this description, there seems little doubt that it is of importance in assisting the body to meet a great variety of stresses and strains which are much more likely to be encountered during the active part of the day than during rest and sleep in the evening and in the night.

The greatest difficulty in the study of these rhythms consists in the multiplicity of rhythmic influences outside us. Daylight, for instance, conduces to wakefulness, darkness to sleepiness. The noise and bustle of people busy around us, or the relative silence that descends when others depart for their rest or sleep, are influences which are all too obvious to anyone who has worked systematically through twenty-four hours in a laboratory. Even in factories where plant is operated throughout the twenty-four hours there tends to be much more activity during the conventional daylight hours than at night. These various external influences, social and climatic, can powerfully affect the rhythmic functions which we would like to measure; but were they the only determining influence on, for instance, our wakefulness or our performance level, then no serious problems would arise for anyone who flies a long distance around the world into a new time zone and has to reset his watch by perhaps eight hours or more. If we want to study the operation of the postulated internal clock we must somehow screen a subject from all these outside influences, and on the surface of the earth this is surprisingly difficult. Even in the Arctic the sun still goes round the horizon, and anywhere short of the Pole its elevation varies somewhat, and this in turn can produce a rhythm in environmental temperature even though there is no gross alternation of light and darkness such as is encountered at lower latitudes. This is why caves have proved particularly useful for study since they are mostly at uniform temperature, dark, and well insulated from external noise; and, apart from their depth, most of them are situated reasonably far from cities and heavy industries with the rumbles and low-frequency vibration which are very difficult to exclude by conventional methods of sound-proofing.

The study of human biological rhythms by speleologists began with Michel Siffre, whose book "Hors du Temps" appeared in 1963 and, in an English translation, "Beyond Time", in 1964. This work is a curious mixture of adventure story and scientific record, recalling the activities of Victorian mountaineers who carried barometers and other heavy pieces of physical apparatus up their mountains and recorded measurements, apparently feeling the need to justify their ascents by contributions to scientific knowledge. Times of retiring, rising, taking meals and so forth were recorded in his diary by Siffre as he imagined the time to be, though he had no watch, and they were also recorded at the surface by telephonic communication. He stayed for 63 days following a cycle of waking and sleeping which averaged close to 24.5 hours, but he himself thought he had been underground for only 38 days, since by his own estimation he was sleeping for less than an ordinary eight hours and up and active for considerably below the usual sixteen hours; and he thought that the time lapse from one rising to the next was about fifteen or sixteen instead of 24.5 hours. He also attempted to estimate a period of 2 minutes and was nearly always in error, often grossly so. During the first few weeks his estimates were not grossly in error, averaging around 150 seconds, but they became both more erroneous and more erratic in the second month, nearly always exceeding 3 minutes and twice exceeding 5 minutes. The errors were thus much greater in estimating such short intervals than in estimating a day.

The following year we had the opportunity to study Geoffrey Workman, who spoke with scorn about Siffre's 63 days and reckoned that he co uld happily stay underground for 100 days. To be fair he had a much more comfortable cave, a side branch off Stump Cross Cavern which is a show cave open to visitors. He was not primarily interested in biological research and took a watch with him, having every intention of living on normal time, though we took the opportunity of arranging for him to produce urine samples at intervals which would be sent to us in Manchester for analysis. Remarkably, however, he found that he had considerable difficulty in living on ordinary time, wanting to go to bed progressively later every night and to get up later in the morning, so after the first 3 weeks he abandoned any attempt to live by the clock and started going to bed and getting up when it seemed to him to be right. As a result, though perfectly aware of the time outside as registered on his watch, he drifted successively later day by day in his bed-time, following a day whose average length over the remainder of his stay was 24.7 hours, so that by the time he had completed 105 days alone underground he had lost about 2½ days. The urine samples which he collected suggested that his kidneys also were following a day of rather longer than 24 hours, in fairly close accordance with his habits of waking and sleeping.

Either through emulation or scientific curiosity, another Frenchman, Toni Senni, in the following year, spent 125 days alone down a cave and he, as well as recording his times of waking, sleeping and collecting urine samples, recorded his body temperature. His 'day' was prolonged to a mean of 24.7 hours, very similar to that of Siffre and Workman, and this prolonged day seems to have operated equally for all measured functions: his body temperature, his urinary excretion of adrenal steroids, as well as his habits of waking and sleeping. The peak value of body temperature, however, which usually occurs in the late afternoon, had moved forward into the morning, and the peak value of urinary excretion of steroids, which probably lags a few hours behind the peak production of these hormones by the adrenal gland, had also moved much earlier in the day.

The following year we had the opportunity of studying David Lafferty, who, in a cave in Cheddar, planned to beat Senni's record for solitary confinement. This was primarily a publicity stunt organised by the owners of the cave, and they were quite pleased to find that some useful scientific results could be obtained which added a certain respectability to their efforts. He, like Siffre and Senni, had no watch with him, but indicated his habits by means of a telephone line to the surface. These were extremely irregular since he lived on a 'day' whose duration varied between 19 and 66 hours, but nevertheless a variety of techniques indicates that there was an underlying rhythm of close to 25 hours in his waking and sleeping habits, and in this respect his observations confirmed those of earlier workers that men in isolation live on a day slightly beyond 24 hours. Urine samples were not collected continuously, but from those which were collected and sent to us in Manchester for analysis there is a suggestion that his kidney was following a 'day' slightly shorter than his waking and sleeping habits; close, in fact, to 24.6 hours. As a result, during his 127 days of solitude, the time of his peak excretion of salt (sodium) drifted backwards from early in his sleep period to his waking period and then further back into his sleeping period again. This raises the possibility that his biological rhythms were governed not by a single clock which would have accounted for the findings on earlier workers in caves, but by two independent clocks keeping slightly different times. Even more striking evidence was obtained when, after he had satisfactorily broken the record for solitude underground, he consented to remain for a few days further without knowledge of the time. This enabled us to visit him and collect a series of blood samples; and during these last three days, when in fact we visited him about every four hours, he thought we were visiting him roughly every two hours. His adrenals, as reflected in the concentration of corticosteroids in his blood, and his kidneys, as reflected in the excretion of potassium, followed during these three days a rhythm close to 16 hours, very far from the 25 hours of his sleep habits. There is a striking contrast between the length of his 'day' as assessed from his habits, around 25 hours, the rhythm of his adrenals and his kidneys at the end, 16 instead of 24 hours, and the gross error in his subjective estimation of the time, since he thought that our four-hourly visits were recurring every two hours.

The French next regained the record when Jean Maretaet, who had been one of the surface team looking after Siffre, remained alone in a cave for 174 days. The conclusions drawn from his stay were broadly confirmatory of those from earlier subjects, as well as from subjects studied in more comfortable isolation units by Professor Aschoff and his colleagues near Munich and by ourselves at Risley near Manchester. Maretaet frequently adopted a 'day' of around 48 hours, and such doubling of the normal day length had also been seen occasionally in our study on Lafferty; he was also at times so far out in his subjective estimate that he lay down for what he took to be a brief siesta after lunch but was in fact a full night's sleep of as much as 10 hours after a full day of wakefulness and activity.

The French have continued to study subjects in caves, and in fact equipped a pair of adjacent caves with transmission lines to huts at the surface so that electrical recordings could be made while the subjects slept. Of two further subjects who spent 20 weeks alone, one settled down to a fairly regular 'bicircadian' cycle of approximately 48 hours, as Maretaet had done; after he had settled down in this routine, he was deliberately exposed to a lighting system giving him 34 hours of light alternating with 14 hours of darkness, and he lived satisfactorily on this routine, imagining the 48-hour 'days' to be only 24 hours. The other, though much more irregular, followed some similar cycles of up to 48 hours. On both these two, satisfactory records were obtained from which their sleep stages could be assessed on more than half of their 'nights', as had been done for part of the time on Maretaet. Perhaps the most remarkable finding was that, despite such gross variation in the length of their 'days' and 'nights', the proportion of their sleep spent in paradoxical, Rapid Eye Movement (R.E.M.), or 'dreaming' sleep remained roughly as normal, and the recurrent cycles of REM sleep had a period of around 1½ hours, just as in subjects sleeping under more or less normal conditions above ground.

More recently Siffre, in a cave in Texas, has beaten Maretaet's record and spent 177 days alone underground. A popular account appeared in the March 1975 issue of the National Geographic Magazine, but the scientific data have not yet been published. He followed for most of the time a 'day' of more conventional length, slightly over 24 hours, though he had a few days of around twice this length. Both his memory and his manual dexterity were severely impaired by the end of his stay, but it is not clear how relevant this may be to the problems of long submarine voyages or space flights: men are unlikely to be alone on such journeys, and it is always rash to generalize from the experience of one man.

The use of specially constructed isolation units has permitted the study of a much larger number of subjects, especially in Professor Aschoff's unit but also in our own. Bicircadian rhythms have been observed occasionally, but much less often than in subjects in caves. These studies have, however, revealed a few other striking exceptions to the usual appearance of a 'day' slightly over 24 hours for all functions investigated. Perhaps the most notable has been in subjects who have followed a 'day' of around 33 hours, so far as their habits of waking and sleeping were concerned, but whose body temperature and/or renal excretion followed a more conventional rhythm of only slightly over 24 hours. It seems that at least two different internal 'clocks' can run independently, and there may be many more controlling different bodily functions. This possibility of the existence of several independent internal clocks offers one of the most intriguing aspects of current investigation.

Acknowledgements

These observations could never have been collected without the willing collaboration of Geoffrey Workman and David Lafferty, and of the managers of their respective caves. The study on David Lafferty also rested heavily upon the help of my former colleague Dr. [now Professor] R.T.W.L. Conroy who, though he had never before been down a pothole, accompanied me on 18 descents. We were equally dependent upon Mrs. Ann Elliott who received and analysed the samples which we despatched to Manchester each day.

Further Reading

The accounts of the different subjects who have spent long periods of solitude in caves have been published in a number of papers in scientific journals, the only popular account being Siffre (1964). A brief summary will be found in Conroy & Mills' book covering human circadian rhythms generally. The particular topic of performance, sleep and rhythms is considered from several aspects in Colquhoun's conference report (1972) which includes a short account of the observations on Maretaet. Some of the wider aspects of biological clocks, including their presence in Plants and in insects, and their use by birds for navigation, may be found in the writer's own book (Mills, 1973).

Colquhoun, W.P. (ed.) 1972. *Aspects of Human Efficiency: Diurnal Rhythms and Loss of Sleep.* English Universities Press.

Conroy, R.T.W.L. & Mills, J.N. 1970. *Human Circadian Rhythms.* Churchill.

Mills, J.N. (ed.) 1973. *Biological Aspects of Circadian Rhythms.* Plenum Press.

Siffre, M. 1964. *Beyond Time.* Chatto & Windus.

May 1975

Prof. J.N. Mills, M.D., B.M., B.Ch.,
Physiology Dept.,
University of Manchester.

slept. Of two further subjects who spent 20 weeks alone, one settled down to a fairly regular (but [illegible]) cycle of approximately 48 hours, as Mairetet had done; after he had settled down in this routine, he was deliberately exposed to a lighting system giving him 24 hours of light alternating with 24 hours of darkness, and he lived satisfactorily on this routine, imagining the 48-hour 'days' to be only 24 hours. The other, though much more irregular, followed some similar cycles of up to 48 hours. On both these men, satisfactory records were obtained from which their sleep stages could be assessed on more than half of their 'nights', as had been done for part of the time on Mairetet. Perhaps the most remarkable finding was that, despite the gross variation in the length of their 'days' and 'nights', the proportion of sleep spent in Rapid Eye Movement (R.E.M.) or 'dreaming' sleep remained roughly as normal, and the recurring cycles of REM sleep had a period of around 1½ hours, just as in subjects sleeping under more normal conditions above ground.

More recently Siffre, in a cave in Texas, has broken Mairetet's record and spent 177 days alone underground. A popular account appeared in the March 1975 issue of the National Geographic Magazine, but the scientific data have not yet been published. He followed for most of the time a 'day' of rather conventional length, slightly over 24 hours, though he had a few days of around twice this length. Both his memory and his manual dexterity were severely impaired by the end of his stay, but it is not clear how relevant this may be to the problems of long submarine voyages or space flights; men are unlikely to be alone on such journeys, and it is always rash to generalise from the experience of one man.

The use of specially constructed isolation units has permitted the study of a much larger number of subjects, especially in Professor Aschoff's unit but also in our own. Bicircadian rhythms have been observed occasionally, but much less often than in subjects in caves. These studies have, however, revealed a few other striking exceptions to the usual appearance of a 'day' slightly over 24 hours in length in isolation. Perhaps the most notable has been in subjects who have followed a 'day' of around 33 hours so far as their habits of waking and sleeping were concerned, but whose body temperature and many other rhythms followed a more conventional rhythm of only slightly over 24 hours. It seems that at least two different internal 'clocks' can run independently, and there may be many more controlling different body functions. The possibility of the existence of several independent internal clocks offers one of the most fascinating aspects of current investigation.

Acknowledgements

These observations could never have been collected without the willing endurance of [illegible] Mairetet and David Lafferty, and of the [illegible] of their respective caves. The study on David Lafferty [illegible] help of my former colleague Dr [illegible], though he has never [illegible] the [illegible] on 48 [illegible]. We were equally [illegible] which were despatched to Manchester each day.

Further Reading

The accounts of the different subjects who have spent long periods of isolation underground have been published in a number of papers in scientific journals, but only popular accounts by Siffre (1964). A [illegible] Conroy & Mills' book covering human circadian rhythms in general. The particular topic of [illegible] is considered [illegible] several authors [illegible] Mills (1973) which includes a [illegible] of the observations on Mairetet. General [illegible] biological clocks, [illegible] and their use by birds for navigation, may be found in [illegible] book (Ward, 1972).

Colquhoun, W.P. (ed.) 1972. *Aspects of Human Efficiency: Diurnal Rhythm and Loss of Sleep.* London: English Universities Press.

Conroy, R.T.W.L. & Mills, J.N. 1970. *Human Circadian Rhythms.* Churchill.

Mills, J.N. (ed.) 1973. *Biological Aspects of Circadian Rhythms.* Plenum Press.

Siffre, M. 1964. *Beyond Time.* Chatto & Windus.

May 1976

Prof. J.N. Mills, M.D., D.M., B.Ch.,
Physiology Dept.,
University of Manchester.

Transactions British Cave Research Assoc. Vol.2. No.2. pp. 99-105 August 1975.

MEDICAL CARE ON CAVING EXPEDITIONS

by Peter Standing

Expedition Doctors

Before 1970 very few British caving expeditions visited regions remote enough to render the inclusion of a doctor in the party a necessity. The last 6 years however, have taken parties to many parts of the globe including Peru, Venezuela, Turkey, Iran, India, Nepal, Ethiopia and Papua, New Guinea. With cheap travel and diminishing possibilities for cave discovery in Britain this trend towards exploration in exotic areas is likely to continue and the need for expedition doctors increase.

Even for the less glamorous Europe-based expedition however, the presence of a qualified medical officer does offer advantages. His specialist knowledge is useful in selecting and obtaining medical equipment, and in countries not having reciprocal rights with the National Health Service he can save the expedition members money by treating minor ailments. Should more serious illness occur he can provide useful liaison with the local hospital and in the event of an accident underground he can give medical care to the casualty.

In other continents a British doctor may find much interesting medicine amongst the local people and any therapy he gives them can benefit the expedition by promoting goodwill. If possible he should confine himself to purposeful treatment and avoid the pitfall of prescribing ephemeral placebos for diseases that he cannot cure. The latter practice may not only antagonize the people against expeditions but also hinder the development of local medical services.

Pre-expedition Matters

1. **Assessment of the team.** By a process of natural selection the members of caving expeditions are usually fit, healthy, young individuals. Routine medical examination before departure, other than as a baseline for research purposes, is superfluous. It is worthwhile sending each person a questionnaire regarding past and present illness and recent drug therapy. Dental fitness should be mandatory. For very remote regions expedition members should have a blood sample grouped and cross matched against other members of the party. In an emergency they can then be transfused with another team member's blood, providing he is a suitable donor. Parties visiting high altitudes should be examined and treated for piles before departure.

2. **Insurance.** Regardless of whether the expedition has its own doctor medical insurance is essential. It should be for at least £1000 and provide for emergency evacuation by air to Britain. Several firms offer cheap, comprehensive travel insurance, policies provided for the National Union of Students being very suitable and widely available (details from Endsleigh House, Ambrose Street, Cheltenham, Glos. CL50 3NR).

British nationals are now entitled to free treatment in other E.E.C. countries but there are complications. The unemployed and self-employed are not at present covered and also travellers must obtain in advance a certificate of entitlement to benefits (Form E.III). Application forms (CMI) for this are available from the Department of Health and Social Security or any employment exchange. The D.H.S.S. also provide form SA 28 giving details of medical facilities in E.E.C. countries. Despite all this, most travellers still prefer medical insurance because of its simplicity or through ignorance of the new arrangements.

3. **Vaccinations.** These can prevent many of the communicable diseases endemic in parts of Africa, Asia and South America. They are obtainable from General Practitioners and Local Authority Vaccination clinics, usually at a price. Information on the vaccination requirements for different countries is available from travel agents, embassies and the D.H.S.S. leaflet 'Notice to Travellers'. Vaccinations should be booked up 3 months before departure, particularly if a multiple protection programme is planned.

International vaccination certificates are provided for only 3 diseases – smallpox, yellow fever and cholera (the latter is soon to be dropped). Quite apart from the desirability of protecting oneself against these diseases, failure to obtain certificates can play havoc with travel plans both in entering other countries and re-entering Britain.

Even though certification is not required by law for other communicable diseases, travellers would be foolish to ignore vaccination. Protection against typhoid, paratyphoid, tetanus, poliomyelitis and tuberculosis should be standard practice. Other diseases to be considered according to destination might be plague, typhus, meningococcal meningitis, infective hepatitis and rabies.

An injection of pooled human gamma globulin provides some degree of passive immunity against infective hepatitis for 3-6 months. American evidence (Conrad 1971), suggests that it is a worthwhile prophylactic although there are many sceptics in Britain. Gamma globulin is stocked by Public Health Laboratories and if used should be given shortly before departure.

Rabies vaccination would seemadvisable for speleobiological expeditions handling bats.

Further details of communicable diseases and vaccination programmes are widely available in textbooks of public health and elsewhere (Edholm & Bacharach 1965; D.H.S.S. 1972; Roodyn 1974).

4. **Medical Equipment.** Exactly what supplies to take on an expedition depends on many factors – the size of the party, remoteness of the area, whether a doctor is present and if he intends any treatment of the local people. The choice will be influenced by the doctor's experience and his preference for different brands of drugs. Since the supplies may be subject to a weight budget it is better to take tablets and powders rather than syrups and suspensions wherever possible.

If the expedition has a doctor it should not be necessary to spend anything on medical supplies. Pharmaceutical firms are usually extremely generous in donating their products, often to the extend of sending whatever is requested by return of post.

Several expeditions have published useful lists of medical equipment, including the Annapurna South Face Expedition 1970 (Lambert 1971), the Speleological Expedition to Ghar Parau 1972 (Judson 1973) and the Papua New Guinea Speleological Expedition 1973 (James 1974). The following inventory is a composite one based on the experience of the 1971 and 1972 British Iranian expeditions. It would be suitable for a party of 15 people for 6-8 weeks. Drugs are listed in most cases under their more familiar trade names and rough quantities are given according to the following key; A — ampoule, C — capsule, D — drops, G — granules, L — lozenge, O — ointment (no. of tubes), S — syrup, Sp. — suppository, T — tablet.

	Quantity	*Uses*
Alimentary System		
*Actal	T 100	dyspepsia, hangovers, heartburn
*Fentazin	T 50, A 10	nausea and vomiting
*Lomotil	T 500	)traveller's diarrhoea
*Streptotriad	T 500	)bacillary dysentery
*Dulcodos	T 20	constipation
*Xyloproct	SP. 30, O 2	piles, pruritus ani
*Flagyl	T 200	amoebiasis, giardiasis
*Antepar	T 100	threadworms, acariasis
Alcopar	G 5 gm. x 10	hookworm
Ear, Nose and Throat		
*Merocets	L 200	sore throats
*Actifed Linctus	250 ml.	cough and nasal congestion
*Soluble Aspirin	T 500	)common cold, headaches
*Paracetamol	T 200	)toothache, etc.
*Benylin Expectorant	S 250 ml.	expectorant
*Ephedrine 1%	D 10 ml.	sinusitis
Sod. Bicarb. 1%	D 5 ml.	softening hard wax
Genticin H.C.	O 1	otitis externa
Ribbon gauze	½-inch	nasal packs and aural wicks
Jobson Horne W.C.	1	aural toilet
Ophthalmic		
*Chloromycetin 1%	O 2, D 10 ml.	conjunctivitis
Atropine 1%	D 5 ml.	acute iritis
Hydrocortisone ¼%	D 5 ml.	
Fluorescein	D 5 ml.	)diagnosis and removal of corneal
Amethocaine 1%	D 5 ml.	)foreign bodies
Idoxuridine 0.1%	D 10 ml.	Herpes keratitis
Eye pad and pipettes		
Dermatology		
*Histofax	O 20	sunburn, insect bites
*Oily calamine	100 ml.	sunburn
*Nivea Creme	O 450 gm.	cracked hands and lips
*Brulidene	O 5	burns, general antiseptic ointment
*Polyfax	O 2	minor skin infections
*Tineafax	O 5	athlete's foot
Betnovate	O 2	psoriasis, dermatitis
Phenergan	T 50 x 10 mg.	itchy allergic rashes
*Lorexane	O 3	lice
Antibiotics		
*Penicillin V	C 250	)
Benzylpenicillin	A 20	)Infections where systemic antibiotic
Ampicillin	C 250, A 20	)therapy is indicated
*Tetracycline	C 250	)
Septrin	T 100	)
Lincomycin	C 100	deep penetrating wounds
*Triplopen	A 20	long-acting penicillin
*[Nivaquine]	T 2 weekly	malaria prophylaxis when necessary
Hypnotics		
*Mogadon	T 200	sleeping pills

Emergency Drugs	*Quantity*	*Uses*
Xylocaine 1%	100 ml.	local anaesthetic
Sterile water	25 ml.	diluent for injections
Adrenaline 1/1000	A 2	collapse due to anaphylaxis
Piriton 10 mg.	A 5	acute allergy
Hydrocortisone 100 mg.	A 10	collapse
Aminophylline 250 mg.	A 5	asthma, acute LVF
Morphine 15 mg.	A 5	severe pain, acute LVF
Lasix 20 mg.	A 5	acute LVF, acute mountain sickness
*Fortral	C 100, A 20	moderate to severe pain (non DDA)
Dextrose 50%	50 ml.	hypoglycaemia
Valium 10 mg.	A 10	fits, minor surgery
Largastil 100 mgs.	A 3	acute psychosis

General

thermometer, sphygmomanometer, auro-ophthalmoscope, stethoscope; needles, syringes, Mediswabs (30 of each); velcro tourniquet.

Resuscitation Equipment

Laryngoscope, endotracheal tube, mask and Ambu bag, airways
Intravenous cannulac and giving sets — 2
I.V. fluids — Normal Saline, Dextrose 10%, Dextran 70

Trauma

Gauze swabs and cotton wool in sterile packs
Assorted Elastoplast dressings
Melolin dressings, Carbonet and Sofratulle
Crepe bandages, triangular bandages
Plaster bandages and orthopaedic wool
Antiseptic lotion (e.g., Savlon concentrate)
Assorted sutures
Instruments — scissors, needle holder, artery forceps, scalpel and blades, toothed dissecting forceps.

* can be used by informed lay personnel.

Clearly if the expedition has no doctor, a less comprehensive inventory will suffice. If lay personnel are trained how to perform simple suturing and are educated in first aid techniques, they could also usefully take all the items listed under trauma. Medical kits are available from B.C.B. Ltd., 2 Moorland Road, Cardiff, CF2 2YL and more details of suitable equipment for groups without a doctor are contained in Steele (1974).

Patterns of Illness

The percentage of time actually spent underground on caving expeditions is usually small. For example during the 1971 Reconnaissance Expedition to Iran, I spent only 50 hours underground, out of 6 weeks and in 1972 only 47 hours out of 4 weeks. It follows that most medical problems occur on the surface and have little to do with caves. They are associated instead with extremes of environment and climate, with locally endemic diseases transmitted to the party through food and water and with interpersonal contact within the group. The pattern of this surface illness can have wide ranging consequences from simply reducing individual enjoyment to causing shortage of manpower or more seriously total disruption and abandonment of the expedition. Preventive medicine and the early treatment of minor ailments is highly desirable and may be the deciding factor controlling the success or failure of the expedition.

Base Camp Problems

Water. Polluted water supplies are common in parts of Asia, Africa and South America. Ideally expeditions should site their base camps well away from villages and try to obtain their drinking water direct from resurgences, having established that the sink is unpolluted. In practice this may be difficult becuase the location of the villages themselves is often determined by available water supplies. Sterilization of water is commonly necessary. Three methods are available.

a) **Boiling** is the most effective one, killing all known bacterial, viral and parasitic pathogens. It is however, a time consuming procedure and may not be feasible where fuel is expensive, in short supply or has to be carried long distances to the base camp.

b) **Chemical Methods.** Many commercial products are available e.g. Halazone tablets (marketed by Boots as Sterotabs). These kill bacterial and viral pathogens but may be ineffective against amoebic cysts.

c) **Filtration.** Lightweight portable water filters.

— are very effective in removing particulate matter, amoebic cysts and probably most bacterial pathogens but they do not filter out the infective hepatitis or other viruses. Filters are helpful in alpine regions where glacial melt water is drunk. This usually contains a lot of particulate matter including mica which can cause unpleasant gastritis.

There is then, no perfect way of sterilizing water combining reliability with ease of operation. The expeditioner will probably end up using a combination of techniques to suit the particular requirements of his area. For example, boiling all cooking fluids and adding Halazone to cold drinking water would be a reasonable compromise.

Food. Standards of food handling abroad are often sadly below those in Europe and the U.S.A. Fresh fruit and vegetables should be washed thoroughly and either peeled or soaked in some sterilizing solution. All uncooked foodstuffs should be regarded with suspicion.

Sanitary Arrangements. Several diseases which are endemic in developing countries, such as bacillary dysentery, typhoid, cholera, amoebiasis, and infective hepatitis, are spread by the faeco-oral route. This means that the organisms causing them are excreted in the faeces of a patient or a symptomless carrier of the disease. Either can transmit the disease to a third person by polluting food or water consumed by him. Altneratively, flies who have been in contact with the infected faeces, can effect the pollution. The dangers of local water and food supplies being infected have already been stressed. If an expedition member does succumb it is vital that he does not infect other members of the party and he should not take part in communal food preparation. All too often such a person, while not feeling well enough to go underground, is left to attend to the basecamp kitchen.

Faeco-oral spread can be minimised by meticulous attention to personal and communal hygiene. For short camps of a day or two's duration cat-type sanitation (burying faeces in a shallow hole) is adequate. For longer camps a permanent deep trench should be dug at least 100 yards away and suitably sited according to the prevailing winds. A disinfecting solution such as Jeyes Fluid added daily to the contents will discourage habitation by flies. Asian style toilets are a good deal more hygienic than European ones and squatting is to be recommended on expeditions rather than constructing a toilet seat. Facilities for hand-washing should be provided.

Much the same principles apply to the disposal of garbage as to the disposal of faeces.

Gastro-Intestinal Infection

Travellers' Diarrhoea. This is the commonest pattern of diarrhoeal illness in travellers, usually occurring soon after arrival at their destination and coinciding with the consumption of local food. Many causes have been postulated including change in bowel flora, infection with unusual E. Coli serotypes, enteroviruses and Yersinia — indeed the condition may well be multifactorial in origin.

Clinically there is sudden onset of diarrhoea with loose stools but rarely blood, abdominal cramps, pain during defaecation, nausea and, less commonly vomiting. Untreated, the illness usually settles within a few days. Symptomatic medication with Lomotil (4 tablets loading dose followed by 2 tablets 6 hourly) and an anti-emetic (e.g. Fentazin 4 mgs.) is beneficial.

Other causes of diarrhoea. Bacillary dysentary is caused by the Shigellae group of bacteria. More than one member of the party may be affected and the picture is similar to, but much worse than, travellers' diarrhoea with severe malaise and pus, mucus and sometimes blood in the stools. With this picture the treatment is again Lomotil and an anti-emetic with the possibility of adding an antibiotic. In hospital practice antibiotics are now generally not used in the treatment of Shigella and Salmonella infections since they probably do not influence the overall course of the illness and may encourage the persistence of resistant strains. In the field however, without the backup of laboratory facilities, it is seldom possible to be precise about diagnosis. Treatment necessarily has to be blind. Because antibiotic preparations such as Streptotriad or Lomotil with Neomycin may shorten the course of the acute illness, their use is justified.

If the patient has persistent diarrhoea which has not cleared up with Lomotil and antibiotics, other possible causes are giardiasis and amoebiasis. The first usually gives a mild dysentery like picture with foul smelling stools but no blood. In amoebic dysentery blood is nearly always present. The treatment of the two conditions is the same, namely metronidazole (Flagyl) 600 mgs., three times a day for 7-10 days which could be given blindly on an expedition.

Other more exotic causes of gastro-intestinal upset are cholera, typhoid, infective hepatitis and even falciparum malaria (Paton 1974). Medical help will be needed to diagnose these.

Respiratory Infections

Simple illnesses such as the common cold coming on top of heat, altitude, and excessive physical exertion can prove incapacitating. It is important to take plenty of drugs for the symptomatic relief of coughs and colds. People debilitated by chronic diarrhoea have an increased risk of getting infections and bronchopneumonia is not at all uncommon.

High Altitudes

It may seem incongruous for speleologists, whose aims are more often going down deep, to dwell upon the problems of going high. However reconnaissance expeditions are becoming more and more ambitious in searching high mountain regions for deep caves — for example the 1972 Imperial College Expedition to the Peruvian Karst (Imperial College 1972) and the 1970 Karst Research Expedition to the Himalayas (Waltham 1970) both went well above 15000 ft. The medical problems of high altitudes are serious and sometimes fatal and parties going above 12000 ft. must be acquainted with them (see Edholm & Bacharach 1965; Steele 1971; and the Mountaineering Medicine Symposium in the Himalayan Journal, vol. 30, pp.3-85. 1970).

Table 1 — High Mountain Air

Advantages (few)	*Disadvantages* (many)
low density — work of breathing less	hypoxia (shortage of oxygen)
	low ambient temperature
purity	low humidity
	increased radiation

Hypoxia. The barometric pressure varies inversely with altitude so that at 1800 ft. it has dropped to 380 Torr (mms. Hg.) half its normal sea level value. Since the air still contains the same percentage of oxygen (about 21%) it follows that the partial pressure of inspired oxygen also drops — from a normal sea level value of 150 Torr to 70-75 Torr at 18000 ft This lack of oxygen is the most important single problem posed by high altitudes

Temperature and Humidity Temperatures at high altitude are commonly sub zero. Although heat loss from the skin can be minimised by adequate clothing there is no way of reducing heat lost from the lungs in warming up cold inspired air In addition cold air contains no water vapour and has to be humidified in the lungs Respiration thus becomes the major route for fluid loss - a situation worsened by the continual hyperventilation (overbreathing) that occurs at altitude. The partial pressure of water vapour in the lung alveoli remains constant at 47 Torr (the Saturated Vapour Pressure of water at 37°C) and this fraction becomes increasingly important the higher one goes - competing with oxygen for a place in the alveolar air

Acclimatization. These are the changes that occur in low altitude residents who go high

Up to about 12000 ft. the most noticeable effect of hypoxia in a fit subject is breathlessness during exercise Above 12000 ft however the oxygen level in arterial blood becomes sufficiently low to cause hyperventilation at rest. This results in carbon dioxide being blown off from the lungs, and the blood and brain fluids (C.S.F) become more alkaline — a state called respiratory alkalosis. Over 3 or 4 days at 12000 ft the C S.F. pH is gradually restored to normal and this is thought to be a very important facet of acclimatization the symptoms of mountain sickness coinciding with it

Longer term changes occur in the blood, where more red cells are formed (polycythaemia) and in the kidney, where more bicarbonate is excreted in an attempt to correct the respiratory alkalosis.

In summary, acclimatization is aimed at getting used to chronic respiratory alkalosis and at using what little oxygen there is to best advantage. By hyperventilating, more oxygen gets into the lungs and blood and the polycythaemia and consequent increase in Haemoglobin allows more oxygen to be transported to the tissues.

Mountain Sickness. All unacclimatized people get this to some degree, the unfit and the elderly who ascend rapidly being worst affected. People do however vary tremendously in their response to altitude Symptoms include lethargy, headache, insomnia and irritability and more seriously nausea, vomiting and muscle weakness. The onset can be from 6 hours to 3 days

The illness can be prevented by SLOW ASCENT and it is best to camp at 12000 ft. for a week, going higher only during the day Camps can be moved up in 3000 ft. stages with similar time intervals at each A course of acetazolamide (Diamox) 250 mgs. daily for 2 weeks before going high may aid acclimatization by producing a metabolic acidosis and hence simulating the normal renal compensatory action.

Mountain sickness can be treated symptomatically with analgesics anti-emetics etc. and descent to lower altitude for a few days if necessary

High altitude Pulmonary Oedema. The cause of this insidious and very dangerous condition is not fully understood. It occurs usually above 12000 ft. and often, but not always, in poorly acclimatized subjects who have suffered from mountain sickness. Its onset is rapid, sometimes at night, the clinical picture being similar to acute left ventricular failure, with symptoms of breathlessness, gurgling respirations, pink frothy sputum and cough The lungs become waterlogged with oedema fluid, giving rise to widespread crepitations, heard with a stethoscope or ear on the chest The patient may also suffer from cerebral oedema and become increasingly delirious

Pulmonary and/or cerebral oedema can rapidly be fatal and there have been numerous deaths amongst mountaineers, casual trekkers in the Himalayas and Andes and soldiers involved in the 1962 Sino-Indian conflict The key to preventing both conditions is not to engage in heroic, high speed ascents. The treatment is

1. Rest the patient he will use up less oxygen
2. Arrange urgent evacuation to lower altitude
3. Oxygen is life saving. 6-8 litres/minute It should be carried for medical purposes by all parties going above 20,000 ft
4. Other measures If a doctor is present Morphine and Frusemide may be used and if facilities permit intermittent positive pressure ventilation with oxygen

Other Conditions. High altitude visitors may suffer from numerous other ailments:—

1. Dehydration caused by continual loss of water vapour in expired air and lethargy in preparing adequate meals.
2. Respiratory Problems the cold air and dry mucus predispose to cough, colds, sinusitis. pneumonia and cough fractures
3. Thrombo-embolic disease With polycythaemia and dehydration the blood becomes more viscous. Add to this forced immobilization in a tent through bad weather and conditions become ideal for the development of thromboses in the legs, brain and elsewhere
4. Frostbite and snow-blindness
5. Piles. Because of raised venous pressure, these can become very troublesome.
6. Mental problems. With the higher altitudes, impairment of will, slowness of thought, blunting of emotion and poor judgement can occur.

Problems of Heat. Heat and humidity can prove a great hindrance to reconnaissance expeditions in tropical and sub-tropical regions. Indeed it may be necessary to date the visit to coincide with the cooler season

In the field loose fitting clothing, a wide brimmed safari hat and a large water container are essential items of equipment for reconnaissance. Sunburn is an entirely preventable condition which Britons, new to hot climates, are prone to because of ignorance and vanity. Liberal supplies of calamine cream and lotion should be taken.

The disorders resulting from excessive exposure to heat are well covered in *Exploration Medicine* which is an invaluable source of information on this and many other problems relevant to expeditions (Edholm & Bacharach 1965).

Insects, Snakes and Game. Apart from their nuisance-value insects may transmit disease to man. It is therefore desirable to prevent bites by using a repellent if necessary during the daytime, and by sleeping in an insect-proof tent at night. Lorexane cream or powder is effective in treating lice and fleas on clothing, sleeping bags and skin. In malarial areas a prophylactic should be taken — local advice is best sought on the most suitable.

The risk of snakebite varies very much in different countries but in general the chances of being bitten in mountainous terraine are small and the majority of bites are non-fatal. If a bite does occur the most useful things to do are to wash it thoroughly and to prevent panic in the patient, sedating him if necessary. Hoechst market anti-snake-venom serums for the Near and Middle East and Central and North Africa which cover a wide variety of species. However, many authorities are opposed to the use of serum unless the user is able to identify the snake concerned and has the means of treating anaphylactic shock, a dangerous and sometimes fatal complication of administration. Hoechst recommend a conjunctival test with a 1-in-10 dilution of serum before use to select out people likely to suffer anaphylaxis.

The dangers of attack by game, like snakebite, are overrated and can be greatly diminished by common sense. Most big game will move away from the path of a walker long before he is aware of its presence. Accidents are most likely to occur at night when many wild animals are active and may be disturbed unexpectedly. In East Africa a mountaineer descending after dusk was killed by elephants, and members of the 1972 Ghar Parau expedition came face to face with an adult male leopard at dusk. (Fortunately the outcome was not fatal). Rambling after dark in mountains known to be inhabited by big game is foolhardy.

Histoplasmosis

This disease is caused by the fungus *Histoplasma Capsulatum* which usually infects the lungs following inhalation. It occurs mainly in Africa, Central and South America and the fungus thrives in deposits of bat guano in the caves of these areas. Numerous cases have been recorded amongst cavers (e.g. Beck 1974; Murray 1957) and Frankland has recently, in these transactions, reviewed the literature and described his own studies on members of the 1973 British Karst Research Expedition to Venezuela (Frankland 1974).

The clinical picture of pulmonary histoplasmosis is usually one of a mild atypical pneumonia, with cough, slight fever and shortness of breath, tiredness and sometimes chest pain. There is a dearth of physical signs and the chest X-Ray shows scattered patchy opacities sometimes with hilar lymphadenopathy. The disease commonly resolves spontaneously within a few weeks, the only longstanding evidence of it being a positive histoplasmin skin test. Frankland found 5 out of 8 members of the Venezuelan expedition to have positive tests on return to Britain, but none of them could recall suffering from the symptoms above. It is possible that asymptomatic infection is common. He suggests the following programme for investigating future expeditions visiting risk areas.

1. Routine histoplasmin skin tests before and after.
2. Records of all caves visited by each member to be kept.
3. Records of all illness during and up to 1 month after return from the expedition.
4. Routine chest X-Ray on return.
5. Publication of results.

Underground Problems

Expeditions usually only include experienced devotees of the sport and the incidence of accidents is low. With the possible exception of some recent high flood risk discoveries in New Guinea, the intrinsic objective dangers of caves abroad are not much greater than in Britain. However since rescue facilities may be limited or non-existent the expedition should be self sufficient as far as underground rescue is concerned. The members should be well versed in the techniques of cave rescue and ideally the doctor should have experience in casualty medicine and of work in a British Cave Rescue Organization. With a little ingenuity rescue equipment can be improvised; for example, a stretcher can be made from pack frames. A carrying sheet and possibly an exposure bag would be worth taking on a major expedition.

One underground problem involving parties engaged in lengthy explorations of major cave systems has earned the name *Berger hands.* It has been reported from the Gouffre Berger and Ghar Parau, and it is due to the abrasive effects of rough limestone on continually wet hands. The explorers of Ghar Parau suffered from it so badly that they were unable to grip anything tightly for several days. The condition can be treated with Nivea or, better still, prevented by the use of lightweight industrial gloves.

Interpersonal Problems

From the old-style expedition accounts where everybody was considered to be "a jolly, good chap", we have emerged into an era where it is commonplace to disect expedition members' personalities in print and to highlight interpersonal rivalries. Certainly some mountaineering and caving expeditions have been ruined by unimaginative leadership and conflicts within the ranks. Pozner (noted in Edholm & Bacharach 1965) considers that an explorer's mental agility and emotional stability are at their best between 25 and 35, and that a happily married man is more likely to make a reliable expedition member than a divorced or unattached man. Judson (1973) holds the view that cavers are at their prime at 19 or 20 and that youthful enthusiasm can be a great asset to an expedition.

Caving, like kindred activities, attracts its fair share of egocentric prima donnas, and such people, who may be very successful in British caving circles, may not necessarily make good expedition members. It is when things are going badly that the benefits of wise team selection become most evident.

Returning Home

The poor state of health of some overland travellers to Nepal has attracted attention recently in the medical literature with colourful descriptions of the 'Overlander Syndrome' and 'Drop-outs diarrhoea' (Knight, 1972; Anon 1974).

Follow-up medical care for returning cavers may be necessary, and if so, it is essential to inform the doctor of exactly where one has travelled. Persistent diarrhoea is the commonest problem and microscopic examination of a fresh stool for ova, cysts and parasites may reveal the culprit. Giardia is the most frequent cause found at the Hospital for Tropical Diseases in London. Some unfortunate people develop a malabsorbtion syndrome along with their diarrhoea and they will require more extensive investigation and treatment with tetracycline (Tomkins 1974). Britain has two specialist hospitals for the treatment of tropical diseases (in London and Liverpool) but medical referral to these is normally required.

Finally, it is to be hoped that all caving expeditions will include medical notes in their published reports. Details of what medical equipment and drugs were actually used, in addition to taken, will benefit future ventures.

July 1975

Peter Standing, M.B., Ch.B., D.A., D.Obs.R.C.O.G.,
34 Greenway Lane,
Charlton Kings,
Cheltenham.

References

Anon. 1974. Editorial 'Drop-outs Diarrhoea', *British Medical Jnl., 3,* 373.

Beck, B.F. 1974. 'Some additional comments on histoplasmosis and the Aguas Buenas Caves, Puerto Rico, *Nat. Speleo. Soc. News, 32,* (2), 31.

Conrad, M.E. 1971. *Archives of Internal Med.,* 128, 723.

Dept. of Health & Social Security 1972. *Communicable Diseases contracted outside Great Britain* – obtainable from the D.H.S.S., Alexander Fleming House, Elephant and Castle, London SE1 6BY. The D.H.S.S. *Notice to Travellers* is reproduced in this or is obtainable separately from the same address.

Edholm, O.G. & Bacharach, A.L. 1965. *Exploration Medicine,* John Wright, Bristol.

Frankland, J.C. 1974. 'Studies on the Response of Healthy English Speleologists to exposure to histoplasmosis infection', *Trans. British Cave Research Assoc., 1,* (3), 153-7.

Imperial College Expedition Imperial College Expedition to the Karst of Peru 1972, Report 1973, *Cave Science (52).*

James, J.M. (Ed.) 1974. *Report of the Papua, New Guinea Speleological Expedition 1973,* published by the Speleological Research Council Ltd., P.O. Box 235, Kingsford, N.S.W. 2032, Australia.

Judson, D.M. 1973. *Ghar Parau,* Cassell, London.

Knight, R. 1972. 'The Overlander Syndrome', *Practitioner, 209,* 665-72.

Lambert, D. 1971. Medical Appendix in *Annapurna South Face* (Bonington, C.J.S.), Cassell, London.

Murray, J.F. 1957. *South African Med. Jnl., 31,* 245.

Paton, A. 1974. 'Gastrointestinal Disorders', *Brit. Med. Jnl., 4,* 522-4.

Roodyn, L. 1974. 'Immunization and other prophylactic measures', *Brit. Med. Jnl., 4,* 648-650.

Steele, P.R. 1971. 'Medicine on Mount Everest 1971', *Lancet,* July 3rd, 32-39.

1974. *Expedition Travel and your Health,* 18pp published by and obtainable from University of Bristol.

Tomkins, A.M. et al. 1974. 'Malabsorbtion in Overland Travellers to India'. *Brit. Med. Jnl., 3,* 380-4.

Waltham, A.C. 1970. *British Karst Research Expedition to the Himalaya.* Nottingham.

and that a happily married man is more likely to make a reliable expedition member than a dim-wit or unattached romp. Judson (1973) holds the view that cavers are at their prime at 19 or 20 and that youthful enthusiasm can be a great asset to an expedition.

Caving, like kindred activities, attracts its fair share of eccentric prima donnas, and such people who may be very successful in British caving circles, may not necessarily make good expedition members. It is when things are going badly that the benefits of wise team selection become most evident.

Returning Home

The poor state of health of some overland travellers to Nepal has attracted attention recently in the medical literature with colourful descriptions of the 'Overlander Syndrome' and 'Dropouts diarrhoea' (Knight, 1972; Anon 1974).

Follow up medical care for returning cavers may be necessary, and if so, it is essential to inform the doctor of exactly where one has travelled. Persistent diarrhoea is the commonest problem and in these the examination of a fresh stool for ova, cysts and parasites may reveal the culprit. Giardia is the most common cause found at the Hospital for Tropical Diseases in London. Some patients have a true malabsorption syndrome along with their diarrhoea and they will require more extensive investigation and treatment with tetracycline (Tomkins, 1974). Britain has two specialist hospitals for the treatment of tropical diseases, (in London and Liverpool) but referral to these is not usually required.

Finally, it is to be hoped that all caving expeditions will include practical notes in their published reports. Details of what medical equipment and drugs were actually used, in addition to advice, will help future ventures.

July 1976

Peter Standing, M.B., Ch.B., B.A., D.Obst. R.C.O.G.
34 Greenway Lane,
Charlton Kings,
Cheltenham.

References

Anon, 1974. Editorial 'Drop-outs Diarrhoea', British Medical Journal, 3, 173.
Bach, B.P. 1974. 'Some additional comments on histoplasmosis and the newly found ...', Speleological Jour. 24(2).
Conrad, M.B. 1957. Medical Journal of Australia, vol. 1, 1.
Dept. of Health & Social Security 1972. Communicable diseases contracted outside Great Britain.
D.H.S.S. Advice on Avoiding Mosquitos, Scorpions and Snakes, London HMSO.
D.H.S.S. Advice to travellers ... the tropics.
Edholm, O.G. & Bacharach, 1965. Exploration Medicine, John Wright, Bristol.
Gaskell, I.C. 1975. Studies on the Epidemiology of Histoplasmosis ... Histoplasma infection'. Trans. British Cave Research Assoc.
Imperial College Expedition Imperial College Expedition to the Sierra ... 1973. Report.
James, J.M. (Ed.) Report of the ... New Guinea ... Speleological Research Council Ltd. P.O. Box ... Australia.
Judson, D.M. 1973. Ghar Parau, Cassell, London.
Knight, R. 1972. 'The Overlander Syndrome', Practitioner, 208, ...
Lambert, D. 1971. Medical Appendix in 'Innocents ... South Face ...', Cassell, London.
Murray, J.F. 1957. South African Med. Journal, 31, 245.
Peters, A. 1974. 'Gastro-intestinal Diseases', Brit. Med. J., vol. 4, 272-4.
Roodyn, L. 1974. 'Immunisation and other precautions for travellers', Brit. Med. J., 4, 627-630.
Steele, P.R. 1971. 'Medicine on Mount Everest 1971', Lancet, July 3rd, 32-39.
1974. Expedition Travel and your Health. Published by and obtainable from University of Bristol.
Tomkins, A.M. et al. 1976. 'Malabsorption in Overland Travellers to India', Brit. Med. Journal, ...
Waltham, A.C. 1970. British Karst Research Expedition to the Himalaya 1970. Nottingham.

The TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION covers all aspects of speleological science, including geology, geomorphology, hydrology, chemistry, physics, archaeology, and biology in their application to caves, as well as technological matters such as exploration, equipment, surveying, photography and documentation. Papers may be read at General Meetings held in various parts of Britain, but they may be submitted for publication without being read. Manuscripts should be sent to the Editor, Dr. T. D. Ford, Geology Dept., University of Leicester, Leicester LE1 7RH, who will be pleased to advise in cases of doubt about the preparation of manuscripts. The Transactions is normally issued four times a year to paid-up members of the British Cave Research Association. Subscriptions are due on January 1st annually.

Full Members £3 per annum or U.S. $8.50

Corporate Members Clubs £3 per annum or U.S. $8.50

Institutional Members £4 per annum or U.S. $11.00

Back numbers of the Transactions and other publications can be obtained from Bryan Ellis, 7 School Lane, Combwich, Bridgwater, Somerset TA5 2QS

Printed by Hawthornes of Nottingham Ltd.