MISCELLANEOUS

BREATHING APPARATUS FOR USE IN FOUL AIR CAVES.

Douglas Irvin.

ABSTRACT.

Some of the lava tunnels of the McBride Volcanic Province, North Queensland contain a lot of carbon-dioxide and cave adapted life. This device was developed to allow the continued safe exploration and study of the tunnels. A safe level for CO_2 and O_2 is proposed. The prototype is described and some preliminary results are given. Some suggestions for further development are made.

INTRODUCTION.

The lava tunnels of interest vary in length between 100 m and 1400+m. They have gently sloping silt or rocky floors and mostly walk-in type entrances. The tunnels are usually damp and sometimes the floor can be slippery. Biological collecting mainly entails crawling around the floor for hours at a time. By normal caving standards it is very easy going. Measurement of the tunnel atmosphere with a Dreager Multigas Detector has shown CO_2 levels of up to 5.7%. As the CO_2 increases the O_2 seems to decrease at a greater rate. Checks for other gases e.g. oxides of nitrogen, carbon monoxide, hydrogen sulphide, methane and ammonia have shown nil or insignificant amounts. This kind of atmosphere is called a Type II (James 1977).

Work in the tunnels has taken place in foul air, luckily without incident. If a caver were to have a problem the extra exertion required by the rest of the party could put everyone at risk. On two occasions climbing a few metres into an upper gallery has produced a panic reaction causing the person to bolt for about 100 m and then rest. Lying down to rest was not a good idea. In fact in coal mines it is against regulations to lie down because of the possible pooling of poisonous gases. This year the most important cave Bayliss was extended by 500 m and contains even worse foul air. As we were all getting older and wanted to continue to do so something had to be done about the foul air problem.

PROPOSED SAFE LEVELS OF CO_2 & O_2.

This apparatus is **solely** for dealing with moderate CO_2 levels. If other poisonous gases e.g. oxides of nitrogen, carbon monoxide, hydrogen sulphide, methane, ammonia etc. are present then self-contained breathing apparatus must be used. We have to consider only two gases:-

- CO_2.

Armstrong and Osborne (1981) proposed a safe CO_2 level in tourist caves of 0.5%. This is in line with the standard set by the American Bureau of Shipping and U.K., U.S., U.S.S.R. and N.S.W. mine regulations. These are industrial standards for day in day out work. James, Pavey and Rogers (1975) proposed a safe level of up to 4% CO_2. I think that with this type of device available a much lower level is acceptable. In anaesthetics the recommended level varies between 0.1% and 1% so that is not much help.

A maximum level of 0.75% in the inhaled air is proposed with a caution range of 0.5-.75% if hard work is involved.

- O_2.

The atmosphere normally contains 21% O_2. The effect of reduced O_2 is called hypoxia. The NSW mine regulations have a lower limit of 19%. The chart on Coal Mine Gases claims that life is threatened below 16% O_2. This is too conservative. Hypoxia can be experienced by mountaineers and in aircraft. Mountaineers are not bound by regulation and are probably not using O_2 much below 6 000 m. The regulations require pilots in unpressurised aircraft to be on O_2 above 10 000 ft. (3 050 m). For passengers O_2 is required above 14 000ft. (4 268 m). (A.N.O. 20.4). I propose a safe level of O_2 equivalent to being at or below 4 000 m with a caution range equivalent of 3 000-4 000 m if heavy work is involved.

Being at 3 000 m and 4 000 m elevation is equivalent to breathing air with 14.2% and 11.9% O_2 at sea level.

The term Sea Level O_2 Equivalent (SLOE) is proposed. It is defined as the percentage of O_2 at sea level equivalent in effect to that being inhaled in the cave. The ambient O_2 level is adjusted for the effect of an absorber (if used) and the elevation above sea level of the cave passage.

For example, in a normal cave at 3000 m measurement of the cave atmosphere with a Draeger would still show 21% O_2. Because the pressure is reduced this is the same as breathing air with only 14.2% O_2 at sea level.

Use the following formula to find if the CO_2 and O_2 levels are within limits. (See appendix for derivation of formula).

C_c	=	Cave CO_2%.
C_i	=	Inhaled CO_2%.
C_a	=	Absorbed CO_2%.
E	=	Absorber Efficiency (%).
O_c	=	Cave O_2%.
O_i	=	Inhaled O_2%.
SLOE	=	Sea Level O_2 Equivalent.
A	=	Cave altitude in meters.

$$C_i = \frac{C_c \times E}{100}$$

Is $C_i < 0.75\%$?
If so, is C_i in the 0.5-.75% caution range?

$$C_a = C_c - C_i.$$

$$O_i = \frac{O_c \times (C_a + 100)}{100}$$

$$SLOE = \frac{O_i \times [1013 - (A \times 0.1093)]}{1013}$$

Is SLOE > 11.9%?
If so, is it in the 11.9-14.2% caution range?

DEVELOPMENT.

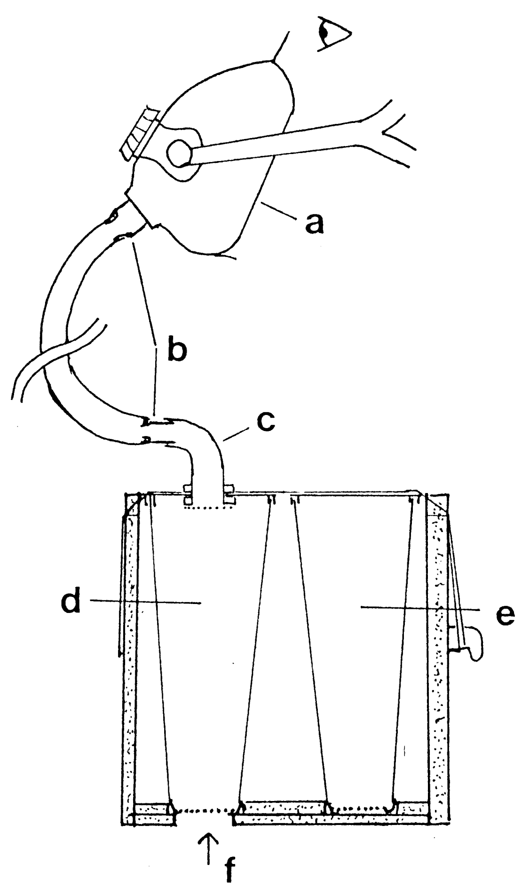
On asking the advice of the NSW Cave Rescue Group I was told "Don't go in". Notwithstanding their good advice there was a pressing need to continue the scientific study. There seem to be three ways of going about it:-

1. Self contained breathing apparatus.
2. A hookah system to feed air from outside.
3. A scrubber to absorb the CO_2.

The latter seemed to be the most practical and cost effective method. I approached Dr. Walter Stark for advice. He developed the ELECTROLUNG, a high-tech scuba system. It uses the product BARALYME to absorb CO_2. This chemical was developed for use in anaesthetics. It is manufactured by National Cylinder Gas of Chicago. It is not known if it is available in Australia. There are other chemicals available. BARALYME is a specially formulated, granulated barium/calcium hydroxide with a dye added (Dorsch 1984). As it is used up it changes color from pink to purple. The ELECTROLUNG is a closed system and BARALYME is used to absorb the 4% CO_2 in the exhaled breath.

CONSTRUCTION.

The canisters are plastic 750ml Decor brand with tight fitting lids. Woolworths sell them for $4.95. Their worst feature is that they come with 6 plastic cups and one ends up with cups to burn. A canister holds 550 g of BARALYME. A ply frame was made for two canisters held in by elastic. Two canisters are carried- one in use called "active" and the other "spare". Air can enter the active canister through the base. The spare canister is sealed. They can be swapped and in use in seconds. The frame



LEGEND.

a. CIG mask
b. Anline fittings
c. PVC fittings
d. Active canister
e. Spare canister
f. Air inlet.

Fig. 1. Mk.II FAD (shown with empty canisters for clarity)

hangs low down below a backpack. The canister has a 50 mm hole in the bottom with fly screen mesh fixed in it. The top has a 28 mm hole with 28 mm I.D. PVC plumbing fittings fixed through it. A piece of lint serves as a filter as Baralyme gives off a stinging dust. Also in unusual attitudes a granule could go along the inlet hose and jam a valve or be inhaled. A length of Anline hose leads to a PVC T-piece. In this are some 25 mm scuba valves to control air flow. A scuba mouth-piece is used. A nose clip completes the outfit. (Figure 1.)

TRIAL.

In a hastily prepared trial the unit was able to support five cavers in fairly foul air. They were very happy to have it along and would not have been able to go into the Bayliss extension without it. The Firemans breathing apparatus they had taken in was just too bulky to use. As there was no Draeger available no readings of CO_2 levels were possible. The unit got hot and the incoming air was warm. This may be a good feature in cold caves but a drawback in the Tropics.

GENERAL CONSIDERATIONS.

In anaesthetics CO_2 absorbers are found to be 90-95% efficient. Let us assume that our unit is 90% efficient. Take the case of Nasty Cave at Undara in June 1986 where the following readings were made:-

	CO_2 %	O_2 %	CO_2+O_2 %	N_2* %
Station 1	3.6	14.8	18.4	81.6
Station 2	5.1	13.7	18.8	81.2

* N_2 not measured.

(Note that if CO_2 were replacing O_2 exactly the sum of their percentages would be about 21%). If we used our device at Station 2, 90% of the CO_2 would be absorbed leaving .51% to be inhaled. With some CO_2 absorbed the O_2 proportion would increase from 13.7% to about 14.3%. Adjusting for the 650 m elevation of the cave, the SLOE is 13.2% (or the same as being at 3530 m). In this case both the CO_2 and O_2 would be in the caution range and one shouldn't be doing heavy work.

PHYSIOLOGICAL CONSIDERATIONS.

The article by James, Pavey and Rogers (1975) gives a good explanation of respiration in foul air. The medical aspects of trekking/mountaineering are applicable to our problem i.e low O_2 sometimes combined with strenuous activity.

Cavers with heart/lung problems should not go where the SLOE level is in the "caution" range. They probably should seek medical advice before going into any foul air cave.

People who live at high altitudes are adapted to the low O_2 conditions. It has been found that trekkers and mountaineers can acclimatize as well. A daily cycle of high altitude during the day and lower altitude at night is an ideal acclimatization method. It is strongly recommended that trekkers go to altitude slowly. e.g. 5 days to reach 3350 m (Bezruchka 1981). We could be doing that in minutes. This could be a problem. It will probably inhibit acclimatization of anyone doing sustained caving.

Hypoxia's first effect is on vision. Below 18.25% O_2 (4 000 ft. or 1 220 m equivalent) vision starts to be impaired and eventually one gets tunnel vision. Cavers should take care in low light conditions as one's judgment of distance is impaired. Smokers will be more susceptible.

Mental ability is one of the first effects that can be checked. Cavers particularly doing vertical work need all their facilities. A prepared set of simple sums should be done by all the party and checked on leaving the cave. Checking them in the cave is not necessarily effective. Hypoxia is so insidious that gross errors can be accepted as perfectly normal.

In extreme hypoxia a person will sink into a blissful sleep and not wake up. Hypoxia can kill. Cavers should also watch out for Acute Mountain Sickness (AMS) some of whose symptoms range from nausea, dizziness, weakness, headaches to bubbily breathing, vomiting, staggering, confusion and coma. If anyone has any abnormal symptoms the whole party **must** immediately leave the cave. AMS too can kill. It is not related to age or fitness. Surprisingly the latest treatment for AMS is to administer CO_2.

FURTHER DEVELOPMENT.

It is hoped that other cavers will do more work with this type of absorber. From the collected data a proper design can be made and hopefully would be standardized across Australia.

An important feature is the "active" and "spare" canister system. This allows a quick change no matter where the caver is, on a rope, in a squeeze or on a stretcher. One does not want to be filling a canister from a packet in these cases. The units should be standardized in the party for added safety. Naturally all spent absorbent is taken from the cave.

I look forward to getting feedback from other cavers and by next Conference it should be properly refined. Other points to consider for development are:-

1. Cavers should be careful about foul air caves. It would be unwise to charge off with this device into foul air without knowing if it is safe. The cave atmosphere should be checked with a Draeger or similar instrument for O_2, CO_2 and poisonous gases. Trials also have to be made to measure the efficiency of the absorber over a range of CO_2 levels. The larger the canister the higher the efficiency.

2. BARALYME can absorb 270 litres of CO_2 per kg. In 5% CO_2 and with 90% efficiency 1kg should last a resting person about 16.6 hours.

3. The temperature in the canister and inhaled air has to be measured to see that it is acceptable.

4. In anaesthetics it is found that the air flow tends to go along the side of the canister leaving unused chemical in the middle (Dorsch, 1984). It could be worth while lining the canister with sandpaper to break up the laminar flow.

5. The product SODA-LIME is also used in anaesthetics. It is available from CIG under the brand name VIVALIME . It costs $29.00 for 4.5kg. SODA-LIME should not be wet as it very reactive to water. As well it is hygroscopic and in very humid conditions may lose its ability to absorb CO_2. SODA-LIME will absorb about 250 litres of CO_2 per 1kg. These chemicals have to handled with care as they are caustic.

6. SODA-LIME has the ability to "regenerate" (Dorsch 1984). Using the "active" and "spare" system, a canister may be able to be rested and reused. This would make it more economical on absorber chemical. The literature is vague on how long it should rest. Field tests will have to be made.

7. Canisters should always be completely filled. If not, in unusual attitudes a channel may form along one side by-passing the absorber.

8. A Metal canister could be used to suit more strenuous caving conditions.

9. The system could be made more water resistant to suit wetter conditions.

10. A transparent window in the canister would allow the color of the chemical to be monitored.

11. A face mask rather than a scuba mouthpiece is probably more practical. The Mk.ll model uses a CIG Respirator Mask (type 55456) which has valves built into it. The Anline fittings are a good tight fit into the mask. It is much more comfortable. In a rescue situation a mask would be easier to put on a patient. The fit around beard, glasses and chin strap has to be considered. Small leaks would not be critical.

12. The King Systems 8600B 08 (60") hose used in anaesthetics in hospitals is far more flexible than that used in the prototype. Your local hospital will probably donate some used hose if asked nicely.

13. The hose could be attached to the chin strap if coming around over the shoulder. This would stop the twisting action on the mask or mouthpiece. The hose could also go around the waist and come up the front.

14. Before taking a system underground it should be tested by going jogging with it. This may show up some deficiencies.

15. The thing has been called a Fad (Foul Air Device) until now. Is this a suitable name?

16. Graphs or tables will be developed to determine safety levels.

CONCLUSION.

This type of device should allow safer caving and more scientific work to be done. If the Greenhouse Effect goes exponential we might all be using one. There could even be designer devices.

ACKNOWLEDGEMENTS.

I would like to thank Dr.Walter Stark of Daintree and Dr. Phil King and his colleagues at the Cairns Base Hospital for their practical advice. Dr. Stark also donated 40lb of Baralyme. My thanks to members of the Chillagoe Caving Club Inc. who conducted the preliminary trial for me.

REFERENCES.

DEPARTMENT OF AVIATION, **Air Navigation Orders**. 20.4.5.1 & 2.

ARMSTRONG, R. and OSBORNE, L. 1981 Towards an Air Quality Standard for Tourist Caves: Studies of Carbon Dioxide Enriched Atmospheres in Gaden-Coral Cave, Wellington Caves, N.S.W. **Helictite** 19(2): 48

BEZRUCHKA, S. 1981 **A Guide to Trekking in Nepal.** Cordee, England. pp 82-87

DORSCH J. and S. 1984 **Understanding Anaesthetic Equipment Construction Care and Complications.** Williams & Wilkins. USA. pp 212-218.

JAMES, J.M., PAVEY, A.J. and ROGERS, A.F. 1975 Foul Air and the Resulting Hazard to Cavers. **Trans. Brit. Cave Res. Assoc.** 2(2): 19-88.

JAMES, J.M., 1977 Carbon Dioxide in the Cave Atmosphere. **Trans. Brit. Cave Res. Assoc.** 4(4): 417-429.

APPENDIX

The composition of the atmosphere stays fairly constant as altitude increases. Therefore the availability of O_2 is proportional to the atmospheric pressure.

Derivation of the SLOE formula:-

Atmospheric pressure is 1013 hectopascals (hp).
Atmospheric pressure drops at 1hp per 30ft. altitude gain.
To convert metres to feet use, A x 3.28

$$\text{The drop in pressure at altitude A} = \frac{A \times 3.28}{30} = A \times 0.1093$$

$$\text{The pressure at altitude A} = 1013 - (A \times 0.1093)$$

$$\text{Proportionate drop in pressure} = \frac{1013 - (A \times 0.1093)}{1013}$$

To find the SLOE of being at altitude A the O_i has to be reduced by the proportional drop in pressure i.e.

$$\text{SLOE} = \frac{O_i \times [1013 - (A \times 0.1093)]}{1013}$$

Douglas Irvin,
P.O. Box 916,
Cairns, 4870.