Air Quality Measurements in the Undara Lava Tubes

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Abstract

Air quality data for Undara lava tubes is limited with the only gases that have been measured there being carbon dioxide (CO_2), oxygen (O_2) and radon. In Bayliss Cave the CO_2 levels were found to be high and its possible sources, concentrations, distribution and movement both spatially and temporally are discussed. For Bayliss Cave a management strategy for cave visits is in place and is controlled by CO_2 and O_2 measurements. The allowable concentrations of these gases before visitors are permitted to enter Bayliss Cave are presented. The use of oxygen masks, CO_2 scrubbers and SCUBA by lava tube explorers are commented on. Radon measurements made in Wind Tunnel, Barkers, Arch and Road Caves were taken as part of a Worksafe supported study of the occupational exposure to radon in Australian tourist caves, an Australia-wide study. Two important conclusions were reached from the Worksafe study: that the radon flux in the Undara lava tubes shown to tourists and the radiation exposure to the Undara guides from radon is low.

Introduction

The Undara Lava Tubes are located in McBride Volcanic Province in Queensland, Australia. The Undara area is at ~760 m. asl and 18º S. with hot wet summers and warm dry winters. The wet summer is known as the "Green" season; during this period the lava tubes can flood. Major parameters can be measured to define air quality; they are temperature, humidity, carbon dioxide (CO_2), oxygen (O_2), particulates (notably dust and spores), pollutant gases and trace gases, for example, ammonia in bat caves and radon. Portable apparatus for air quality measurements are available to volcano speleologists but are often expensive and need regular calibration for reliable results. Hence, complete air quality analyses are rarely performed and this has been the case at Undara with only relative humidity, temperature, CO_2, O_2 and radon being published. High levels of CO_2 are encountered in both lava tubes and caves in other rocks world-wide and it is often the only gas measured although measurement of O_2 at the same time is becoming more common.

Bayliss Cave – carbon dioxide

Bayliss Cave is 1.3 km long with passages up to 12 m in height and 25 m wide. There is a rock fall forming a constriction at 620 m known as The Wall. Beyond The Wall, roots of surface vegetation hang from the roof. The tree roots house a diverse-specialized fauna (Howarth and Stone 1990). Bayliss Cave is used for nursing and roosting by bats. The dangerously high levels of CO_2 in Bayliss Cave were first recorded by the Chillagoe Caving Club (Atkinson and Atkinson 1995). The air made foul by the high CO_2 was limiting their exploration of the cave beyond the constriction caused by rock fall at The Wall. They measured levels of up to 6% still further into the cave. In order to continue exploration of the cave the cavers used O_2 masks and CO_2 scrubbers. Stone (2010) records air quality data for Bayliss Cave; his data is presented in Table 1 and graphically in Figs 1 and 2.

Site	% volume/ volume CO_2	% volume/ volume O_2
Surface	0.04	21
Entrance	0.2	20.8
Point 2 (225 m)	0.5	20.5
The Duckunder		
Point 3	0.75	20.25
The Wall	3.0	18
Point 5 (650 m)	6.0	15

Table 1. Values of CO_2 % volume/volume with distance into the cave.

The measurements confirm the earlier observations and results of the Chillagoe cavers that the CO_2 concentrations increased with distance from the cave entrance and that they were accompanied by a reduction in O_2 concentrations. This is to be expected as Bayliss Cave has only one known entrance and hence is a barometric breather with airflow controlled by climatic air pressure change and to a lesser extent diurnal air pressure change.

The graph (Fig. 1) shows the relative humidity in Bayliss Cave rapidly increases to close to 100 %. Relative humidity is difficult to measure and experimental errors are known to be large. This pattern is typical for a poorly ventilated cave in the tropics. Even during the dry season in August 2010 the relative humidity in the Undara lava tubes was high with the walls being covered with condensation droplets. The temperature follows the same pattern as relative humidity, increasing with distance into the cave. The temperature close to the entrance may vary with season and may be either below or above temperatures deep in the lava tube.

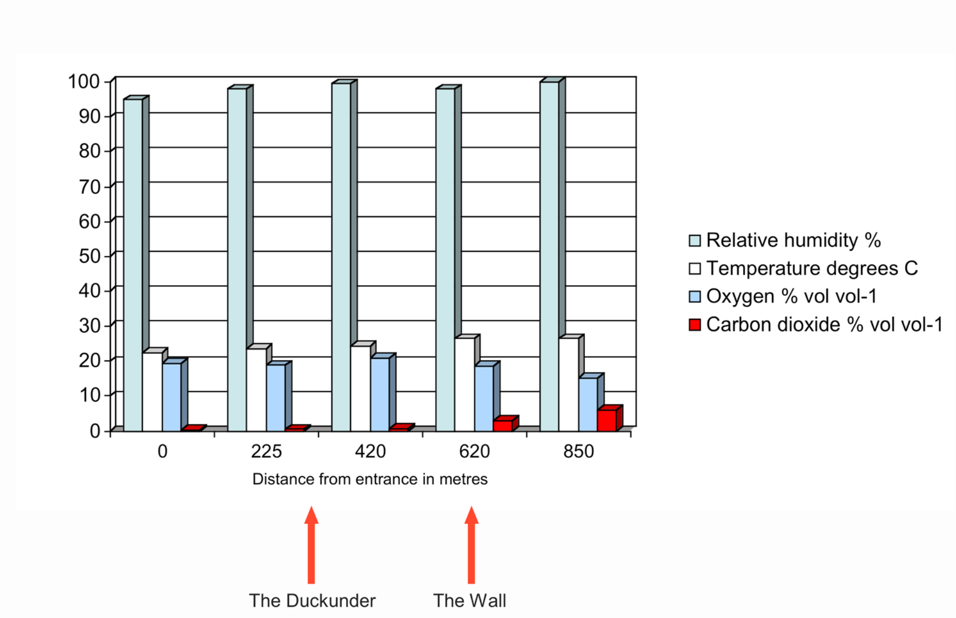

Fig. 1. Air quality measurements for Bayliss Cave, as recorded in Stone (2010).

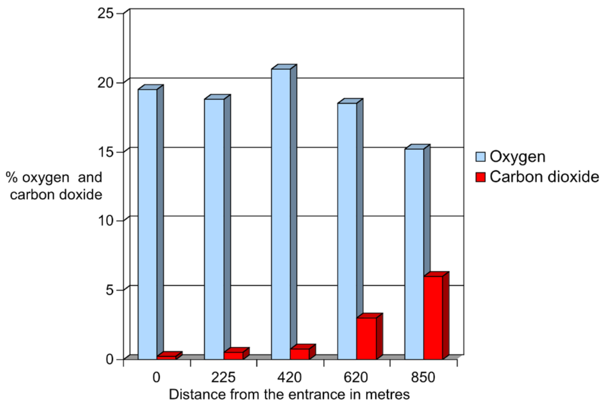

Fig. 2. CO_2 and O_2 measurements from Fig. 1.

The graph in Fig. 2 is expanded to show the relationship between O_2 and CO_2 more clearly. The oxygen levels decrease to first approximation with an increase in CO_2. If the figures are taken for the point 5 and the ideal gas equation is assumed; for 1 molecule of CO_2 generated one molecule O_2 is consumed. This relationship allows the source/s of CO_2 to be identified and characterizes the type of CO_2 enrichment.

James (1977) postulated that there are three distinct types of CO_2 enrichment in cave air. The identification of types of CO_2 sources has been reduced to two and incorrectly attributed in Halliday (2009). The accepted distinct types of CO_2 enrichment and their sources are:

Type I Addition of CO_2; dilution of O_2 and the residual fraction: examples are CO_2 evolution from cave waters and speleothems, anaerobic CO_2 production by microbes and volcanic emissions.

Type II Replacement of O_2 by CO_2: respiration and combustion.

Type III O_2 depleted significantly more than in Type II Characterized by presence of gases associated with low oxygen levels – e.g. H_2S and CH_4. Examples of limestone caves containing Type III atmospheres are given in James (1995), Table 1.

All three types are expected to be found in lava tubes.

Experimental results for air quality represented in a Gibbs Triangle can further be used to identify types of CO_2 enriched air (Halbert 1982).

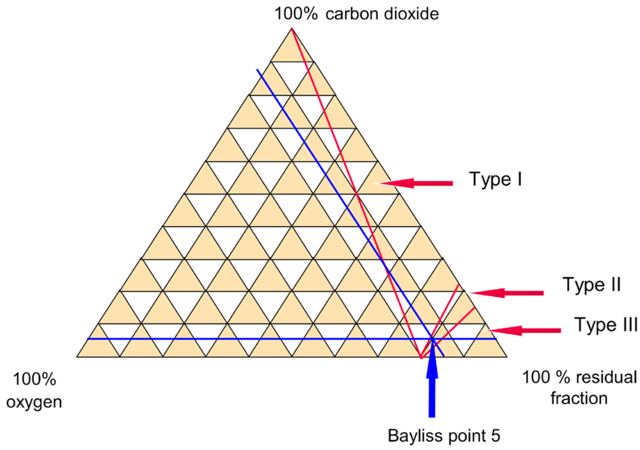

Fig. 3. Types of CO_2 as defined by a Gibbs Triangle for dry air (after Halbert 1982).

Using the Gibbs Triangle and plotting the results at Bayliss Cave point 5 from Table 1, the blue lines at 6% CO_2 and 15% O_2 intersect in the area designated as Type II enrichment. That is, the replacement of O_2 by CO_2. Thus, the possible CO_2 sources are the respiration of tree roots and cave fauna – notably the bats and microbes in Bayliss Cave. The conditions in the lava tube are perfect for continuous microbial CO_2 production, that is warm, wet and with a nutrient supply brought into the lava tube by floods and bats. CO_2 generated by the respiration of microbes and roots in the surface soils and descending through cracks into the lava tube is unlikely as such low concentrations of CO_2 do not separate out of the lava tube air by gravity (Badino 2005). However, in some circumstances – notably if there is a direct connection with the surface – CO_2 enriched air can be dragged into the tube from the surface soil as the lava tube ventilates.

Type I CO_2 enrichment will be present in some of the Undara lava tubes as some contain calcium carbonate deposits. However, calcium carbonate deposits are not present in the high CO_2 areas of Bayliss Cave. Bayliss

Cave is in a relict lava flow in which volcanic activity that formed it stopped many tens of thousands of years ago. Thus, Type I CO_2 enrichment is not expected from volcanic emissions. Type III CO_2 enrichment is also unlikely because the catchments of the lava tubes are protected from pollution as they are in a national park.

The conclusion that the CO_2 enrichment is Type II from respiration can be further confirmed by the carbon stable isotopes analyses. Such analysis is not able to identify which of the specific respiration sources is dominant in Bayliss Cave.

In conclusion, the modest experimental studies carried out in Bayliss Cave have defined:

- the extent of CO_2 enrichment in the lava tube
- the type of cave air produced and its possible sources
- the distribution of CO_2 in the cave system.

The diurnal and seasonal movement of CO_2 enriched air has not been established for Bayliss Cave. To comment on this would require further research as in tropical lava tubes the gas may not move in the manner established for temperate limestone caves (James 1977).

Once the type of CO_2 enrichment has been established, a management strategy for cave visits can be put in place and entry can be made subject to CO_2 and O_2 measurements. The aim of management strategies should be to increase the comfort, protect the health and ensure the safety of visitors and employees without damaging the cave or its ecosystems. The concentrations of these gases that need to be reached before visitors should be excluded from these caves are open to debate. In the modern work place, health and safety regulations must be evoked and a definition of the lava tube as a work place is required and the period that can spent in the Type II CO_2 enriched air. In New South Wales it is recommended that visitors and guides must/should not be exposed to cave air that fails to meet statutory conditions for mines (CO_2 > 1.25% and O_2< 19%). The expected time in air with these characteristics for a miner is a shift of 8 hours. It is not desirable that tourists or guides should develop symptoms or signs of hypercarpnapia in caves where significant exercise is required. Halliday (2009) discuses in detail the health and safety requirements pertinent to the lava tubes in the United States.

The Queensland National Parks Service permit for Bayliss Cave requires that CO_2 concentrations be less than 0.5% and O_2 more than 19.5% for entry to the cave to be permitted. Bayliss Cave is a wild cave and access is now only granted for scientific purposes. During the exploration of the cave by Chillagoe Caving Club members used oxygen masks and CO_2 scrubbers to enter the areas of high CO_2 and reached 1.3 km into the cave. With the present knowledge of the composition of the lava tube air, they should have been using SCUBA equipment and breathing and expelling fresh air. For the lava tube explorer who encounters CO_2 enriched air, essential reading is James *et al.* 1975. Alan Rogers, one of the authors, is a medical respiratory physiologist and in that paper the authors detail the synergistic physiological effects encountered in Type II CO_2 enriched air.

Undara Lava Tubes - Radon

A 12-month study of radon commenced in March 1994 (Solomon *et al.* 1996). At Undara, radon monitors were placed in 4 lava tubes: in Arch Cave, 2 sites in Road Cave, 4 sites in Wind Tunnel and 14 sites in Bakers Cave.

At each site a pair of passive integrating radon monitors based on CR-39 detectors was used to measure both 3-monthly seasonal and 12 monthly annual radon levels.

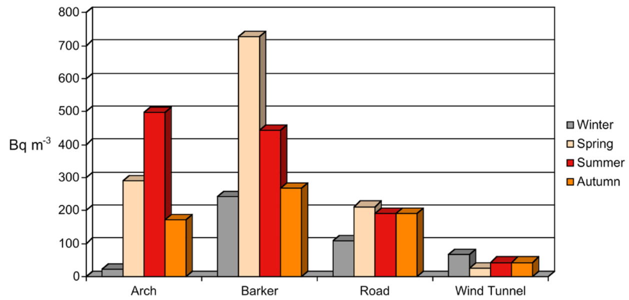

Fig. 4. Seasonal radon levels in Undara lava tubes.

The results do not show any consistent trends from lava tube to lava tube with season, indicating that the lava tubes are ventilating differently with season. A year-long meteorological study of the individual lava tubes in association with air quality measurements is much needed.

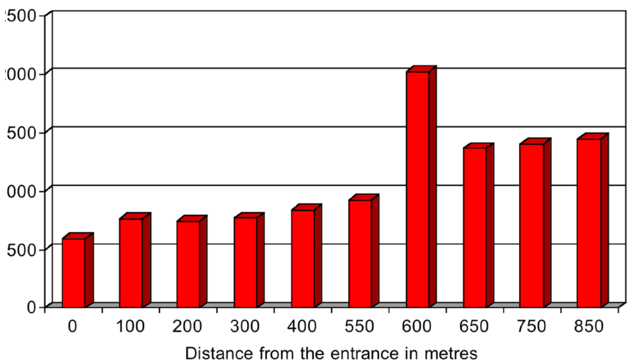

Fig. 5. Annual radon levels in Barkers Cave with distance from the entrance.

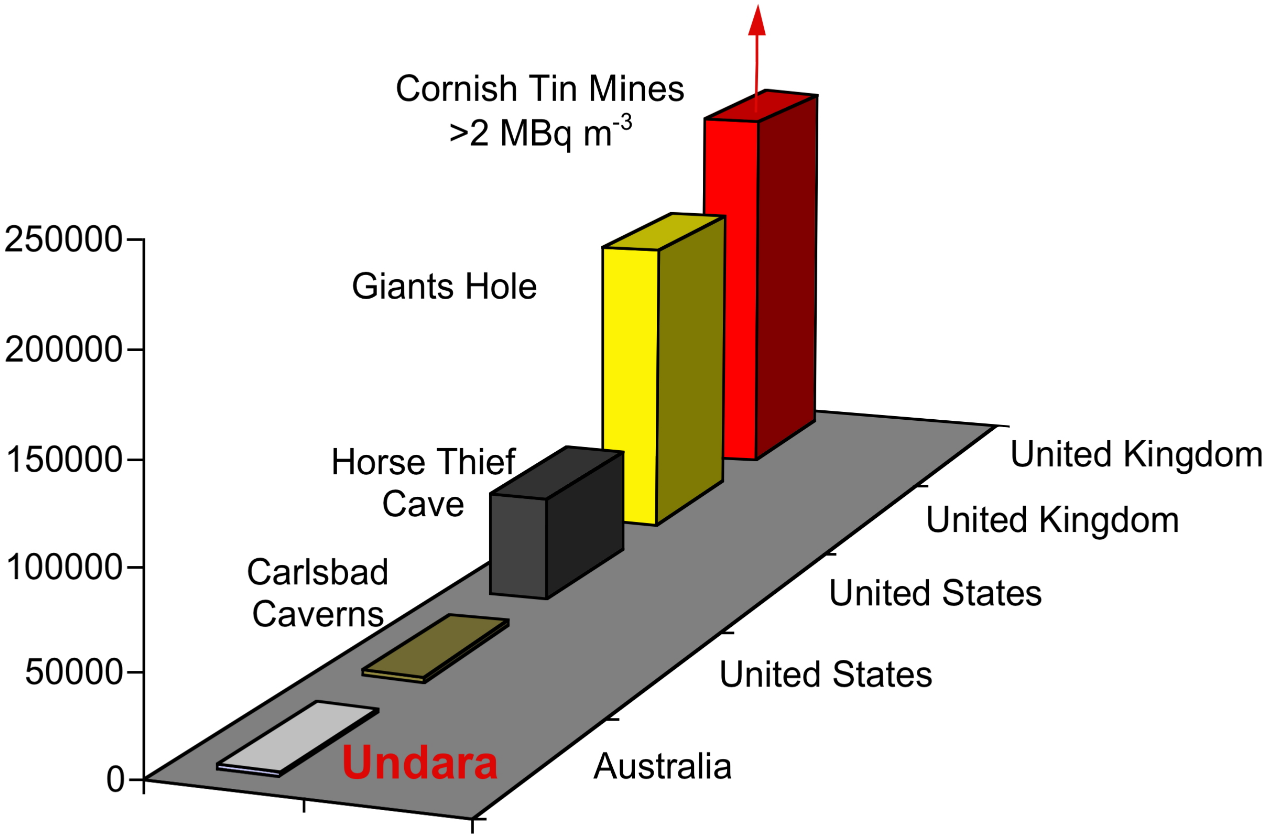

Fig. 6. Comparison of highest radon levels measured in world caves and mines, with those at Undara.

Radon shows the same trend as CO_2 in that its concentrations increase deeper into the lava tube.

The Undara radon flux is exceptionally low when compared with some limestone caves and considerably lower than those encountered in some mines. Work records for six guides were supplied by the Undara management and allowed yearly radiation doses for each guide from taking cave tours to be calculated. The annual radiation dose received by the Undara Guides in 1994 as a consequence of taking cave tours was less than 0.5 mSv per year and thus not considered to be an occupational hazard.

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