

BULLETIN

OF THE

NATIONAL SPELEOLOGICAL SOCIETY

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NUMBER 1

Contents

FACTORS IN FATAL EXPOSURE TO COLD

HIGH LATITUDE KARST IN NORWAY

SHORTER CONTRIBUTION

FAUNA OF FRENCHMAN'S CAVE, NOVA SCOTIA

JANUARY 1967

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Papers in any discipline of speleology are considered for publication in the BULLETIN. The upper limit for length is about 10,000 words or approximately 40 pages of manuscript, typed double-spaced. At least one copy but preferably two copies of the manuscript (typed, double-spaced) should be submitted to the Editor, Jerry D. Vineyard, Missouri Geological Survey, Box 250, Rolla, Missouri 65401. Photographs and line drawings, if required, should be submitted with the manuscript. In general, prints and line drawings will be photo-reduced to the size necessary for use in the BULLETIN.

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Physical and Physiological Factors in Fatal Exposures to Cold

By Marlin B. Kreider

ABSTRACT

The deaths of three cave explorers recently from exposure to cold came as a surprise because of the moderate climate of most caves. The special conditions not usually present simultaneously during cave explorations which contributed to these fatalities are: (1) frequent or continuous exposure to cold water, (2) continuation and even intensification of the exposure after the first signs of deterioration from the cold are apparent, (3) the necessity to perform heavy and skilled work in order to make an exit from the cave during this period of increased cold exposure when fatigue from hours of exploring is severe, and (4) wearing of lightweight clothing. When the first signs of deterioration due to cold appeared, rewarming should have begun immediately because this is when body temperature began to drop more rapidly than before. In these cases where death is assumed to be due to hypothermia, it must have dropped very rapidly since death came within 1½ hours of the first signs of deterioration. The personal factors which are favorable to the maintenance of body temperature are good physical fitness which provides a high capacity for exercise and thus for body heat production; good nutritional status; good health; large body size and fat content; abstinence from drugs affecting performance and body function. However, since cooling in water is two to four times faster than in air, the use of protective clothing is necessary. Layered woolen clothing, covered by an outer shell of tight weave which is closed at the cuffs, sleeves and neck to reduce convective cooling, give the next best protection to that of a foam rubber suit during water immersion.

INTRODUCTION

It is not surprising that deaths due to accidental cold exposure frequently occur in the outdoors. However, until recently such fatalities have been unknown among the explorers of limestone caves and their occurrence is especially surprising in view of the mildness of the temperatures generally associated with limestone caves.

Although many cave temperatures in the middle latitudes of the U.S.A. are in the lower 50°F (Davies, 1949) and English caves may average slightly lower, there are some caves where the temperature is below freezing especially near the entrance.

In general, cave temperatures are influenced by the annual ambient air temperature and, therefore, by the latitude and altitude as well as the length and depth of the cave.

ACCOUNT OF CASES OF FATAL EXPOSURE

In order to understand the dangers of this environment, a summary and analysis will be made of the events surrounding three deaths in caves due to accidental hypothermia. The first case occurring in England (Lloyd, 1965) was a 17-year old woman who was making her first cave visit. She is described as being in good health, but lightly clad and thin in body build. At the end of an hour when she was soaked she turned back but became chilled and cold when she was delayed, along with other members of her party, at a rocky overhang. By the time she arrived back at a difficult "S bend" she had been in the cave for 2½ hours but was still experiencing no difficulty in going through. Back at the entrance shaft she was drenched once again by water at about 43°F (6°C). Ten minutes later she tried unsuccessfully to climb

the ladder and became frightened. Members of her party were unable to help her so they went for help. Forty-five minutes later she was found by a rescue party "in a state of stupor, unconscious, curled up and groaning." Fifteen minutes later she appeared to be dead. *One hour had elapsed since the first cause for alarm was detected.* Postmortem examination showed dilatation of the right auricle and ventricle and of the great veins. There was also acute gastric erosion which frequently results from stress.

A second case also occurring in England (Lloyd, 1965) was a 23-year old man described as not robust and with a history of fainting, who was lightly clad and inexperienced in caving. After 3½ hours, the cave began to flood. By 7½ hours when he was tired and cold, he tried unsuccessfully to climb out of a pit. Others in his party finally pulled him out by rope but he became unconscious during the process while water (about 40°F, 4.5°C) was pouring over him. At the top he aroused and was able to stand up with support and to eat some chocolate, but was unable to talk. While being taken out of the cave, he died suddenly, nine hours after entering and *one and one-half hours after the first cause for alarm.* Post-mortem examination showed extreme dilatation of the right auricle, ventricle and great veins.

A third case occurred in eastern New York State in February 1965 and the following details were related to the author by two accompanying explorers. A very robust, enthusiastic and apparently experienced young man 23 years old entered a tight cave where it was necessary to crawl through frequent shallow pools. The next five hours, he and two friends spent laboriously dragging in equipment and setting ropes for a rappel into a pit into which was flowing a small steady stream of cold water (about 38°F) from the icy surface. He then rappelled into the pit, probably getting soaked up to the shoulders and remained in the pit for 15 minutes and spent 10 minutes climbing back until he was stopped by the waterfalls. Here his progress became slower until finally he could not loosen his chest prusik knot to slide it up the main climbing rope partly because of the stiffness of his hands and he remained in the waterfalls for 15-20 minutes before he became unconscious.

His body was never recovered from the cave. *Unconsciousness had come within 30 minutes of the first cause for alarm,* which was detected by the increasing difficulty with his prusik knots. It is not known when death occurred but it is assumed to have occurred in less than one hour after unconsciousness.

Common features of these three accidents are the exposure to cold water, the continuation and even intensification of the exposure after the first signs of deterioration appeared, the obstacle offered by the pit when exiting from the cave and the wearing of very lightweight clothing. Because exposure to cold water was involved in all cases, the cooling effect of water should be discussed.

RATE OF COOLING IN WATER AND IN AIR

The rapid cooling effect of water can be seen by looking at known tolerance times. It has been estimated from the data of the infamous Dachau experiments (Alexander, 1945) and from records of immersion at sea (Molnar, 1946), that a man immersed in water has little chance of survival beyond 30 minutes at 32°F, one hour at 40°F, 3½ hours at 50°F, and six hours at 60°F. The difference in cooling power between air and water can be seen in figure 1. Here it can be seen that exposure to air at 40°F without clothing produced no decrease in rectal temperature, while exposure to water at 40°F for one hour caused the rectal temperature to drop to an average of 85°F which is dangerously low. The actual quantitative difference in heat loss is difficult to determine from this figure, but it was estimated on the basis of skin and rectal temperature changes to be about twofold (or slightly more). Studies using a heated copper manikin wearing lightweight clothing suggest a difference of slightly less than threefold (Breckenridge, 1966) which is strikingly similar to Molnar's estimate for man.

At the same time, once the clothing has become soaked, cooling in air at a temperature of 50°F which is due to evaporation can be as much as 1½ times that of dry clothing according to a regrouping of the data of Hall and Polte (1955), but it would be expected that wind and low humidity would increase the evaporative cooling. Thus, it appears that cooling of the body while wearing

wet clothing takes place almost as fast in air as in water of the same temperature. However, more testing is needed to establish this point.

In addition to the loss of heat by convection and evaporation, heat is lost in a cave by conduction to the rock walls and floors whenever contact is made. This conduction is enhanced by wet clothing. At the same time, the absence of radiated heat from the sun increases the likelihood that even one wetting of clothing in a cave may doom one to coldness for the remainder of the trip. This is due to the fact that much more of the heat of evaporation must be provided by the body for the drying of the clothing than if one were in the sun.

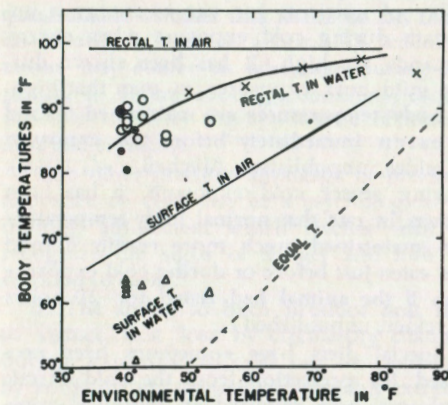


Figure 1.

Rectal and skin temperatures of men immersed in water and in air for one hour (from Molnar, 1946).

VARIABILITY IN COOLING RATE AND IN COLD TOLERANCE

There are numerous individual differences which modify the rate of body cooling during exposure to cold and which account largely for the survival of some individuals in the cave, but not of others. These differences fall under two headings: those which decrease heat loss and those which increase heat production. Some of these factors are as follows:

1. Body fat decreases heat loss by serving as insulation against the cold. In figure 2 (Keatinge, 1960) it can be seen that the

greater the fat thickness under the skin (the smaller the reciprocal), the smaller was the fall of rectal temperature by the end of 30 minutes of water immersion at 15°C (59°F). The same relationship was reported between total body fat and rectal temperature drop for men in air at 15°C (59°F) (Baker and Daniels, 1956) and in water at 20°C (68°F) (Carlson *et al.*, 1958). It was also reported that the internal temperature drop of a fat channel swimmer was only one-half that of a thin one while both were floating in water at 16°C (60°F) (Pugh and Edholm, 1955). This knowledge that fat serves as insulation from the cold is not meant as a mandate for explorers in a cold climate to attempt to deposit more fat, but rather that it should

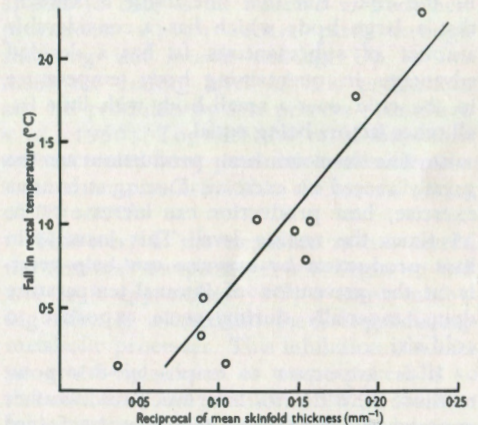


Figure 2.

The relationship between subcutaneous fat thickness and fall in rectal temperature during 30 minutes of immersion in water at 15°C (from Keatinge, 1960).

be a warning that thin individuals are especially susceptible to body cooling.

Closely related to, but separate from the effect of body fat, body size and shape may influence internal temperature during acute cold exposure. On the basis of purely physical law, a small body should have a faster internal temperature drop than a large one, and a tall, thin body should have a faster internal temperature drop than a short fat one of equal weight because of a smaller diameter (Jakob and Hawkins, 1942). In applying this principle to man, it must be assumed that the amount of insulative fat,

the heat production, the degree of peripheral vasoconstriction and other factors, are the same for each man. Most of the studies on animals (Spealman, 1946; Kreider, unpublished) and on man (Blair *et al.*, 1956) in which the authors claimed to demonstrate this concept of a faster internal temperature drop in the thin individual, had the complicating factor of species differences and of differences in the amounts of insulative fat. It frequently happens that the larger individual also has a larger amount of insulative fat. Thus, even though this physical principle should apply to man, it has not yet been adequately demonstrated in man. It is possible that its effect may be smaller than the effect of the other factors that influence body temperatures in the cold. But this one thing is known, that a large body which has a considerable amount of subcutaneous fat has a decided advantage in maintaining body temperature in the cold over a small body with little fat, all other factors being equal.

2. The level of heat production can be greatly altered by exercise. During strenuous exercise, heat production can increase 10 to 15 times the resting level. This increase in heat production by exercise can help greatly in the prevention of internal temperature drop, especially during acute exposure to cold air.

It is important to emphasize this point to those who do not have much cold weather experience, especially if they may be forced into periods of inactivity. At such times, they should perform at frequent intervals exercises such as running in place and isometric contractions. This type of exercise can be done even in restricted situations and is good because it does not involve violent or fast body movements which increase convective and evaporate cooling. The value of exercise during immersion in water is less certain than that of exercise in air because exercise causes a hyperemia of muscles which increases the heat loss to the peripheral tissues and ultimately to the environment. The level of physical fitness of the individual will greatly influence the level and duration of exercise of which he is capable. The importance of this point cannot be overemphasized. For at the point that fatigue sets in, which could be delayed by a higher level of fitness, the level of heat production decreases and the

internal temperature drops more rapidly. Thus, fatigue at a time of cold exposure with inadequate protection can lead to fatal consequences. A fatigued individual can do little, short of a period of rest, to increase heat production volitionally. It is very important for a leader to constantly assess the levels of fatigue and cold exposure of his party and to direct the expedition accordingly to prevent the occurrence of both fatigue and exposure to cold during inadequate protection. Because total available energy is a limiting factor in many types of adventure and outdoor sports, it would be advisable if the activity used to raise the heat production when one is cold could also be beneficial to the objectives of the adventure.

3. The nutritional status as it effects availability of nutrients for use as energy is important during cold exposure when energy demands are high. It has been shown during mild cold exposures in man that higher body temperatures are maintained if food is eaten immediately before the exposure (Kreider, unpublished; Mitchell *et al.*, 1946). During severe cold exposure, it has been shown in rats that normal body temperature was maintained much more readily if food was eaten just before or during cold exposure than if the animal had fasted for 20 hours (Kreider, unpublished).

Special diets have sometimes been proposed for protection from the cold. Arctic explorers have reported an increased appetite for fatty foods and it has been inferred from this that fat is a better food in a cold climate. But when studied in a cold chamber, a diet high in fat did not give any special protection from the cold (Kreider, unpublished) except when eaten at 2-hour intervals (Mitchell *et al.*, 1946). In the latter study, carbohydrates and proteins did not maintain body temperatures as well as fats. Special dietary additives, including vitamins, have been frequently suggested as having special protective value during physical stresses. Vitamin C was believed to give special protection from the cold but there is, at present, no evidence that any dietary additives, including vitamin C, would give added vigor against the cold if diets of normal composition and of adequate quantity are eaten.

4. The general well being of the individual will greatly influence not only the de-

sire to resist the cold but it can also influence the actual capability. An example of this can be seen in the troubles of a woman channel swimmer (Hardwick, 1962). Miss Chadwick developed a digestive upset a day or two before the race and it was not completely cleared up by race time. As a result, she was unable to maintain her normal speed. This resulted in a decrease in the level of heat production and a drop of body temperature so that she had to be removed from the water earlier than usual.

5. Repeated exposure to cold has frequently been credited with the production of an acclimatization to cold which increases the tolerance to cold. Although one of the results of acclimatization seems to be warmer extremities during cold exposure, it is questionable whether this factor or any other one found in man as a result of acclimatization may confer an advantage during exposure to severe cooling conditions, except possibly to delay the appearance of numbness and stiffness.

One other possible advantage of previous exposure to cold may be a psychological or training adjustment which teaches man to recognize the signs of danger and how to respond to them.

6. The ability to both produce heat and to reduce heat loss by circulatory changes during exposure to cold can be decreased by some drugs, disease and possibly extreme age. In many cases the action of drugs may be to slow down or stop voluntary activity rather than to act directly on the metabolism of energy or on circulatory changes. Drugs such as tranquilizers, muscle relaxants, analgesics and sedatives should not be used during a period of potential cold exposure except under special conditions and/or the order of a physician on site. Usual dosages of most common symptomatic remedies for headache, indigestion or the common cold will not affect temperature regulation, and may be taken with discretion although antihistaminic drugs, often included in cold remedies, may make susceptible individuals sleepy, and had best be avoided whenever alertness is desired.

PHYSIOLOGICAL RESPONSE TO COLD

A look at the effects of cold exposure on function and performance of the body may

help one to understand the events preceding the deaths of cave explorers. There are a series of changes that take place when the body is exposed to cold. Constriction of the skin blood vessels occurs very early. This results in a reduction of flow of warm blood to the skin and, thus, in a reduction of heat loss to the surrounding air or water. As a result, the skin temperature will drop, but more so during water immersion than in air, often to within a few degrees of the environmental temperature with little or no change in internal temperature. The result of the blood vessel constriction is the conservation of heat in the body and its entrapment in the core or deep areas including the vital organs. A second physiological response to cold is an increase in body heat production which occurs partly through shivering and muscle tensing. Up to five times the resting level of heat production can be produced by this process (Iampietro *et al.*, 1960). Together the vasoconstriction and increased heat production will keep the internal temperature within the normal range of 97 to 99°F.

However, if the exposure is too severe, the internal temperature will begin to fall, and as it approaches 95°F, a direct inhibiting effect is exerted on the heat-producing-metabolic processes. This inhibition becomes progressively greater as temperature falls so that at a body temperature of 90° F, the five-fold increase due to shivering may be completely eliminated. As cooling continues, somewhere in this temperature range from 95 to 90°F when the heat production decreases rapidly, there is a resulting, more rapid internal temperature drop. Because few measurements are available in man in this temperature range, the change in the rate of internal temperature drop is inferred from animal studies (Spealman, 1946; Kreider, unpublished). Here, such change in the rate of temperature drop is seen only where the initial cooling is slow enough to allow the heat production to compensate at least partially but not indefinitely for the heat loss, so that a slow but steady temperature drop is taking place before the new rate sets in.

At this core temperature range of 95 to 90°F or occasionally above not only is heat production inhibited, but other central nervous system functions begin to fail. These

may be manifested as violent shivering possibly accompanied by fatigue, poor coordination and stumbling, feeling of generalized deep body cooling and numbness, poor articulation, hallucinations and a disorientation which prevents the recognition of reality — even the physical dangers of the situation. This temperature range is a critical one for it not only will bring on poor performance but it means, at the same time, that the internal temperature is falling rapidly. As the temperature continues to fall, this deterioration will be intensified and at 87 to 86°F unconsciousness may develop. Other outward signs that may appear when the core temperature falls into the 80's are: cyanosis of the skin; collapse of skin veins; dilation and poor response of the pupils to light; rigidity of muscles with exaggerated tendon reflex; irregular heart rate and weak, unpalpable pulse. In the temperature range of 85 to 80°F, respiratory or cardiac arrest with death, could occur due to cold but it is more certain between 80 and 77°F. Other symptoms that may develop are summarized by Kreider (1964) and may vary with the cooling conditions.

TREATMENT OF ACCIDENTAL HYPOTHERMIA

As has been stated already, rewarming should be initiated as soon as the first signs of deterioration from the cold appear. An increase in the exercise level may still be helpful and not harmful at this early stage of hypothermia or general body cooling, although in all probability the victim is already fatigued and cannot increase his exercise. *But drastic steps must be taken to reduce body cooling.* This may include changing the exploration plans in order to leave the cave immediately; removing wet clothing and supplying the victim with all clothing not absolutely needed by others; including rescue blankets; using a heater or food warmer such as a small propane torch; and body heat from other explorers; but by all means remaining out of the water and air currents. A substantial amount of food, especially carbohydrates for immediate energy, should be eaten and, of course, if an open fire or small portable heater is available for rewarming the body externally, the food should also be warmed. In some cases, this must be done in the cave. It is questionable whether any drugs would be of use at this time.

If the hypothermia has progressed to the point of stupor, the first task, as also after cooling of lesser severity, is to reduce and prevent the loss of body heat by supplying more dry clothing and other insulation. The victim should be warmed by application of external heat as soon as possible. Generally, it is agreed that this rewarming should be accomplished as rapidly as possible to reduce the period of time of the "afterdrop" of the core temperature. This "afterdrop" is a decrease of core temperature of as much as 4-7°F after surface rewarming has begun. The process is set off by a peripheral vasodilatation produced reflexly by the touch of warmth to the skin. Immediately, blood flows through and is cooled by the cold shell or peripheral tissues and then returns to the heart, cooling it still more. The ideal then, is immersion in water at about 110 to 112°F whenever a source can be found. Medical assistance is imperative, for even during this rapid rewarming resuscitative techniques may be necessary. If the bath temperature is maintained by the constant addition of hot water, body temperature should soon rise, thus encouraging normal heart action. The value of resuscitative efforts during accidental hypothermia is somewhat questionable, unless there is also rapid rewarming.

The task of rapid rewarming when a hot water bath is not available becomes a problem. Slower rewarming prolongs the time of the "afterdrop" and, thus the time during which the heart or respiration may stop. While such slower rewarming methods with hot canteens, hot blankets, warm human bodies and hot water poured on the clothing are not without danger, there may be no alternative for preventing further heat loss.

A warning should be sounded here concerning forced exercise of one suffering severe hypothermia. Although it has not been proven in man during accidental hypothermia, it is reasonable to conclude on the basis of increased cardiac sensitivity found in clinical hypothermia, that forced exercise during this more severe hypothermia, when the individual is semi-comatose, may bring on cardiac failure at a warmer body temperature. At the same time gravity may have an adverse effect on circulation. For these reasons the victim should not be forced or allowed

to walk but should be carried and maintained in the horizontal position.

POSSIBLE COURSE OF BODY TEMPERATURE

Although no measurements are available, it may be instructive to attempt to describe a hypothetical temperature curve for each case. Here, the assumption is made that cold not only was the important contribution to death, but also was the direct cause. If no other cause intervened, the pattern of body temperature might have resembled figure 3. It is assumed that all cavers had a normal internal temperature of about 99°F upon entering the cave. By the end of one hour, case 1 was soaked through and was only lightly clad so that her temperature probably had fallen a degree or two, but after another hour and one-half, she was still not uncomfortably cold and could move on her own. It must be assumed, however, that her temperature was dropping rapidly. Shortly thereafter she was drenched in the entrance shaft by water of about 43°F (6°C) and she could not climb out. One hour later, when help arrived, she was dead, and it is assumed that her temperature was 80°F or below. Her temperature drop was probably very fast in the last hour due to the cold water pouring over her in the shaft.

In case 2, death occurred nine hours after he entered the cave. If it can be assumed that death occurred close to the temperature of 80°F and that the temperature drop paralleled other known cases, the unconsciousness occurring at 7½ hours could be estimated to have occurred at about 90°F. The pattern of temperature fall above this point is hard to estimate because it could have fallen slowly throughout the first hours or it could have remained high for a few hours and then suddenly fallen, depending on his pattern of activity and amount of exposure.

In case 3, one may assume that his internal temperature remained at a relatively high level for the first five hours since he performed the rather difficult feat at the end of that time of rappelling into a pit and shifting from the rope in the center of the pit to a ledge on the wall. At this time he apparently became soaked by a waterfall and his temperature probably dropped rapidly. One half hour later he was soaked again and became unconscious within 30 minutes. Death prob-

ably occurred within one hour of the onset of unconsciousness.

ANALYSIS

A small body size, modest vigor and lightweight clothing were a handicap to the first two cases. Certainly winter caving, especially where water is involved, is no place for a thin, fragile individual or for a beginner. In all three cases, once it was recognized that they were in trouble, it must be assumed that their body temperatures had already dropped considerably and they were probably in need of external heat.

The metabolic demands can be very high for a cave explorer. Not only is he engaged in strenuous exercise but the exercise may be of a kind for which he has not trained. He is also using a considerable amount of energy for shivering if his clothing is wet. At the same time, it often happens that he has not eaten or rested properly in the last 12 to 24 hours due to lack of time and excessive enthusiasm on a rushed week-end trip. It is possible that if some food had been consumed frequently throughout the exposure period or if a sizable lunch had been eaten in the cave, all three cavers would have been better off. However, there is a point of exposure beyond which no food could help appreciably.

Another factor in the rapid deterioration of these explorers may have been the rapid movement of water over the neck and head. Aside from the more rapid cooling effect of moving water is the special sensitivity of the nape of the neck and head. When the individual was immersed in very cold water so that the back of the head and neck were also submerged, a large quantity of blood was found upon autopsy to have escaped from the vascular system into the cranial cavity (Alexander, 1945) which may have contributed to death.

It is always easier to see in retrospect what should have been done so that some lessons may be learned in the process. In case 1 it is not known whether at the time of the inability to climb the ladder it was obvious that there was deterioration due to cold or whether it was assumed to be due to the lack of experience and weak (female) arm muscles. When it was seen that outside help was needed, she should have been

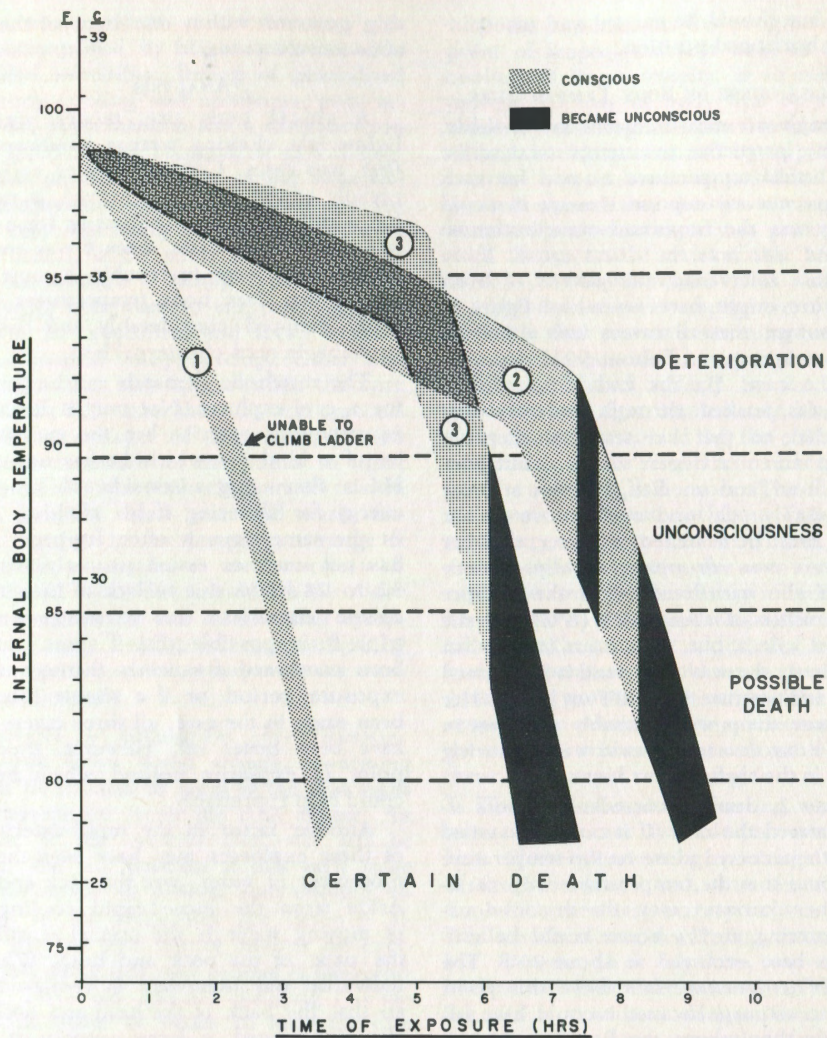


Figure 3.

Hypothetical schema of deep body temperature changes from the time of entrance to the cave.

moved back out of the entrance shaft into which water was pouring and clothing should have been given her from other departing members of her party. In a situation like this, a thin plastic sheet placed over the clothing during rest noticeable reduces evaporative cooling and a small unit heater for

warming food placed inside the plastic sheet would help still more. She should have also been encouraged to eat.

After the rescue team arrived no further emergency treatment was tried because she appeared to be dead. This may have been a mistake, because many people have been re-

wived from this state by rewarming. Wet clothing should have been removed and she should have been wrapped in warm blankets and removed carefully and quickly by litter to a place where she could be rapidly rewarmed.

There is no clear indication that sex *per se* influences the ability to survive severe cold exposure, although on the basis of greater skinfold fat of most females, their tolerance should be greater. The greater sensitivity to cold and colder skin temperatures commonly found in women is due partly to the insulating effect of the skinfold fat which prevents the escape of internal heat to the skin. Thus, the skin temperature may be inversely related to the ability to survive severe cold exposure while the actual sensation of cold on the skin may be directly related under limited conditions or not related at all to survival from severe cold exposure.

In case 2, it is very probable that the first major sign of deterioration was his inability to climb out of the pit. Certainly his unconsciousness while being pulled out should have been a strong warning. From then on, he should have been treated as a serious patient. He should have been made to rest and should have been carried out of the cave. If no litter was immediately available, rewarming should have been attempted in the cave with clothing, food and small heaters. Without these items little else could have been done.

In case 3, very little else could have been done. It has been suggested that he should have been lowered out of the waterfalls to the floor of the pit upon the first signs of trouble, but it is doubtful whether this would have saved his life because cooling of the body would have continued due to evaporation from the wet clothing and conduction to the rocks. Unconsciousness followed so shortly after the first real signs of trouble appeared and the other members of the party, including local would-be rescuers, did not have the strength or technique to pull him out. By the time a competent rescue squad had arrived, many hours had passed and he was long since dead. This case should be a serious warning that even the vigorous and experienced cave explorer can fall to the cold if he does not have adequate protection.

A few unusual deaths have occurred upon initial exposure of the body to cold water. In such cases, cardiac failure may have resulted from reflex stimulation from the skin temperature receptors and not from cooling of the heart or brain (Keatinge, 1962). It is rather unlikely, however, that any of these cave deaths resulted from this etiology since death would have been expected at the beginning of the cave exploration.

Another effect of cold which contributed to the predicament of the stranded cave explorers was the deterioration in manual dexterity. A detailed discussion of this factor will not be considered in this paper, but it is common knowledge that fingers stiffen and become numb and hard to control when they are cooled. Dexterity is first affected at a hand skin temperature of 55 to 65°F. At finger skin temperature below 60°F, hand turning ability begins to deteriorate, and at 40°F the deterioration is considerable (Teichner, 1957). At the finger temperature of 50°F, numbness and a decrease in sensitivity occurs, knot-tying ability decreases by 25% (Gaydos and Dusek, 1958) and grip strength decreases as much as 50%. However, the amount of deterioration will also be influenced by the length of time of exposure. The longer the exposure the greater the deterioration which is due to greater penetration of cold into the fingers. As a guide to finger temperature, it could be stated that finger temperature tends to approach the temperature of the water in which it is immersed, but this is not true for exposure to air. Deterioration in dexterity was first reported in the third case as trouble in manipulating the prusik knots, but it cannot be clearly stated whether total body hypothermia resulted from his loss of dexterity or vice versa. Acclimatization to cold is generally reported to result in warmer hands, but it is doubtful whether it would have been of value in this case because of the deteriorating effect of total body hypothermia.

PROTECTION FROM CLOTHING

It is impossible to construct a chart that would be useful to cave explorers in estimating the length of time of safe exposure or the amount of clothing to be worn because of the great physiological and morphological variability between individuals and

because of the irregular nature of the exposure situation. The amount of protection could be estimated only if the exposure conditions were constant, such as during immersion in water. It goes without saying that if there is going to be exposure to water, some special attention should be given to protection. Many cavers in the past have exposed themselves to water in the caves without any special attention to protective clothing and have survived but they would probably refuse to go into icy water. In recent years, with more winter caving being done, it is apparent (from the examination of trip reports of many caving groups) that numerous exposures have occurred which were close to the fatal level. For example, it was reported that by the time one explorer arrived at the exit of the cave, his legs were so stiff and weak that he could only crawl to the car and to heat.

The average young caver enters a cave with moderately light clothing. Even this may at times be too heavy when he is exercising strenuously at 50°F. in a dry passageway where there is little movement of air. When such lightweight clothing becomes wet, cooling is accelerated by evaporation and it is rarely possible for a caver to sit down to rest comfortably thereafter. This may be of no serious consequence to one in excellent physical condition, as long as his energy holds out, but during forced inactivity such as resting or waiting for someone to climb out of a pit or to repair a lamp, serious body cooling may take place.

The best known protection against cold water is a foam rubber suit. A suit of one-fourth-inch foam rubber can give reasonable, modest protection in water. Such suits have been used occasionally in caves, but they have certain disadvantages which discourage wider use. Among the disadvantages

are their bulkiness and fragility when it is necessary to move out of the water into tight passageways and over sharp rocks. Also when worn out of the water, they would favor excessive overheating by preventing the evaporation of sweat. Their cost is also relatively high. Because such suits are not always available, the next best protection against intermittent exposure to water is clothing of wool or synthetic fabrics worn under an outer shell. For maximum protection, this outer shell must be composed of a tight weave and/or chemically treated to reduce the water penetration. Even a complete vapor barrier, such as a rubber fabric or plastic film should be helpful during intermittent exposures to air and water. Such an outer garment, when closed at the cuffs, neck and sleeves, will reduce cooling due to convective currents under the clothing during water immersion, while in air it will reduce evaporative cooling. The value of such an outer garment, called an anti-exposure suit, has been demonstrated recently in survival at sea (Kreider, 1966).

The advantage of wet wool over wet cotton is related partly to the pattern of evaporative drying. Wool dries from the inside, therefore, evaporation and the accompanying heat loss from the skin will diminish, even though the outer layers are wet, while the wicking action of cotton brings the moisture repeatedly from this outer layer back to the skin again (Breckenridge, 1966). The advantage of synthetic fabrics is due to their draining effect. Water is drawn from the fabric and drops from it more readily than from other fabrics, therefore, less heat of vaporization is lost from the body. As suggested earlier, these physical changes will be diminished by an outer vapor barrier covering such as an anti-exposure suit.

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The Jordbruken Area of Northern Norway-an Example of High Latitude Karst

By Thomas E. Wolfe

ABSTRACT

This report on a high latitude karst area in a metamorphosed limestone near the Arctic Circle considers factors important in the development of the cave system: glaciation, isostatic recovery, and frozen ground. A glacial and post glacial development of the system, Jordbrugrotten, is postulated. Development of a small "paraphreatic" system ends with the deposition of varved clays at the bottom of a lake marginal to a glacier. Postglacial development of the long, shallow vadose passage is related to prolonged uplift due to isostatic readjustment.

INTRODUCTION

In August 1964 the Explorers Club of Haberdashers Askes School, London, England visited northern Norway to extend the survey of a cave first explored two years previously, and to study and map the surrounding area (Poston and Williamson, 1964). The Jordbruken cave system is located along the Plura River, 30 km east of Mo-i-Rana, a post-war iron and steel town on the coast, and 12 km north of the Swedish border*. It lies almost on the Arctic Circle at Long. 4° 06'E., Lat. 66° 17' N. (fig. 1). As a result of the expedition the cave system, Jordbrugrotten, was surveyed at grade 4 for 3,000 m and three entrances were discovered.

GEOLOGY AND TOPOGRAPHY

The Jordbruken area lies in the main Caledonian orogenic belt of the Scandinavian Peninsula. Granitic intrusions are surrounded by gneiss and schist interbedded with occasional thin bands of highly metamorphosed limestone of Cambro-Ordovician age (fig. 2).

Surface studies were carried out along a narrow outcrop of limestone 10 km by 2 km. The eastern rim of a regional dome structure, the limestone strikes N-S, curving NW-SE towards the north, and dips steeply

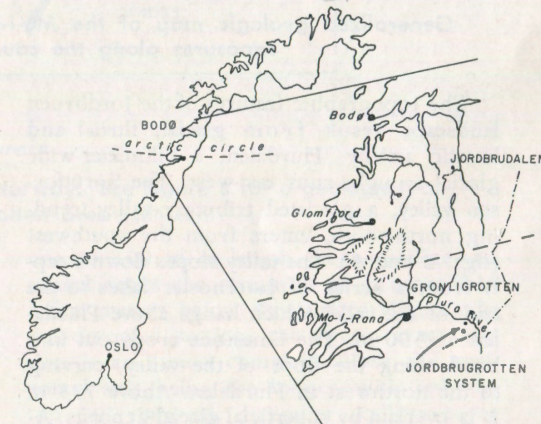


Figure 1.

Location map of the Jordbrugrotten system, Norway.

to the east and north. Thin schist bands and partings occur occasionally within the main mass. Schist interstratified with limestone occurs increasingly toward the edge of the outcrop. The limestone is massive and though of low primary porosity, it is well jointed. Owing to metamorphism bedding planes are not operative. The rock has a marmorised texture, weathering to a light gray. Frost action and solution have widened the joints of the major north-south set to over one meter's width. The minor set, approximately at right angles, has also been widened, but to a lesser extent.

*This area is about 100 km south of Jordbrudalen studied by Horn (1947) and others.

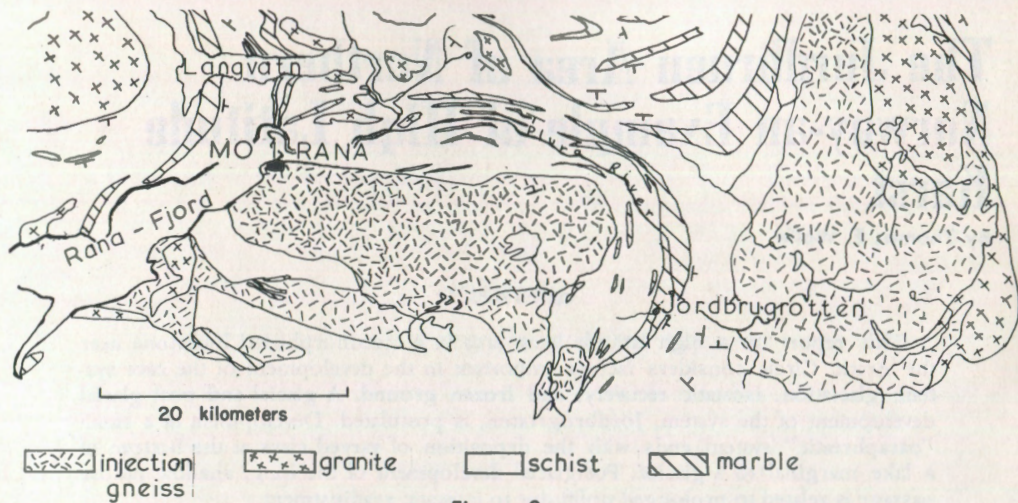


Figure 2.

Generalized geologic map of the Mo-i-Rana area, Norway, showing marble exposures along the course of the Plura River.

The topographic features of the Jordbruen landscape result from glacial, fluvial and karstic activity. Plurdalen, a kilometer-wide glacial trough, runs east-west. The Sprutfossen valley, a glaciated tributary valley trending north-south, enters from the southwest (figs. 3 and 4). The valley slopes down steeply from a series of paternoster lakes to the end of the valley which hangs above Plurdalen at 500 m. The limestone crops out in a band along the floor of the valley, curving to the northwest in Plurdalen. Above 775 m it is overlain by superficial glacial deposits. Above the treeline at approximately 600 m tundra vegetation predominates (fig. 5). Soil is thin; the finely fragmented limestone supports only dwarf trees, mosses and lichens. Where the limestone is exposed it has been subjected to severe frost action. Frost wedging is most active around residual snow patches found frequently above 500 m on the north- and northeast-facing slopes.

The post-glacial River Plura is incised up to 100 m into the floor of the glacial trough. The steep-sided gorge turns sharply north, then west at the schist-limestone contact. The Plura flows against the north side of the valley, apparently in adjustment to the dip of the limestone. The markedly asymmetrical gorge cross profile illustrates the downdip migration of the river.

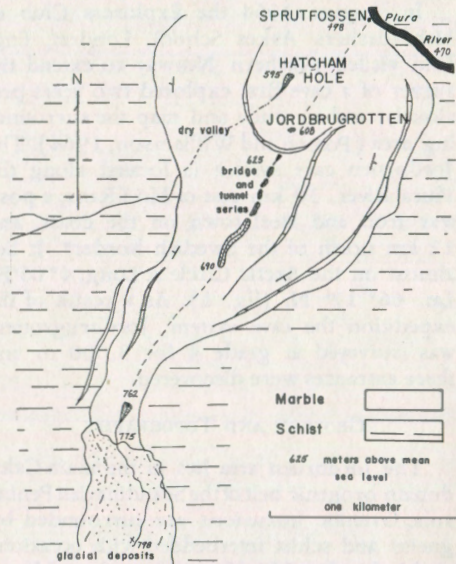


Figure 3.

Geologic map of the Jordbrugrotten area, Norway.

The River Plura flows for 1.5 km over the limestone before sinking at the base of a cliff in a large sinkhole lake 100 m in diameter (fig. 6). A dry valley, the former surface course of the Plura, continues northwest 32 m in elevation above the present

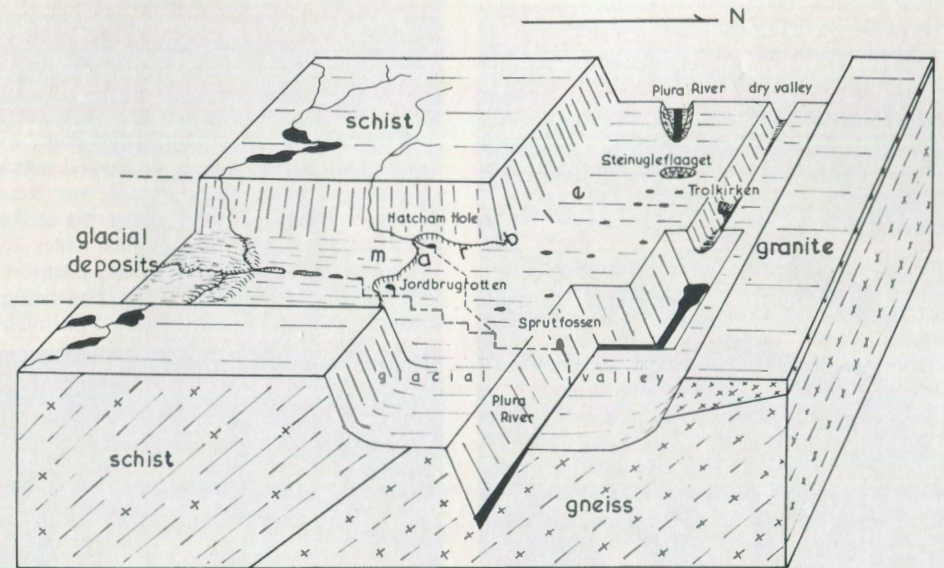


Figure 4.

Block diagram of the Jordbruen area, Norway. See Figure 3 for a geologic map of the Jordbrugrotten area (center).

river level. This dry valley, 100 m below the floor of the glacial trough, cuts through the width of the limestone outcrop, a distance of 2.5 km. Like the 1.5 km of surface flow of the Plura on the limestone, it displays a markedly asymmetrical gorge cross profile. Along the dry valley floor are several dry sinks, showing the progressive upstream sinking of the river. The Plura now rises 150 m south of the lower end of the dry valley. Water from the resurgence backs up into the dry valley filling the lower end for about 200 m depending upon the volume of water resurging.

The tributary Sprutfossen stream flows along the strike of the limestone, alternating surface and subsurface flow. After leaving the superficial glacial deposits the stream flows over the limestone for 200 m before sinking in a blind valley cut 20 m below the surface. The entrance is graded, inclined at an angle of only a few degrees. After a shallow subterranean course of some 800 m the stream alternates surface and subsurface flow for another 600 m. Both subterranean and surface sections of the stream range from

one to 100 m in length. In the bridge and tunnel series the stream is never more than a few meters below the surface (fig. 3). In the deroofed sections the stream cross section is an almost complete ellipse, the horizontal axis being the longer, with only the top 90° removed. Irregular scallops cover the entire rock surface of the stream bed. The stream sinks for the last time, 20 m back from the edge of a cliff, down a steeply inclined shaft (fig. 7). The dry entrance to the cave is located at the foot of the cliff, which is the head wall of a small cirque. From the cirque a narrow, steep-sided valley approximates the subterranean stream course down to the Plura gorge. At the effluence in the Plura gorge 150 m below the glacial floor, the stream forms a 20 m high waterfall, Sprutfossen (fig. 8). Below the fall the stream immediately resumes an underground course, to emerge only a few meters from the river. It appears that Sprutfossen originally joined the Plura at the foot of the falls, but the downdip migration of the river at a faster rate than the downcutting at the foot of the fall resulted in the stream again seeking



Figure 5.

Sprutfossen stream above Jordbrugrotten. This photo, taken from a rock span, looking north, shows the overhanging sides and elliptical cross section of the stream.

Note the tree line in the upper left of the photo.

England, and attributed their development to localized snow patch solution intensified by freeze and thaw action. Snow patch solution is intensified by localization of CO_2 (Williams, 1949).

The cave system, Jordbrugrotten, consists of an upper, poorly developed network of passages and a lower, single wet passage 1,500 m long, oriented along the strike of the limestone. Several waterfalls enter from the west, the updip side of the passage. One tributary cave, Hatcham Hole, consisting of a single passage approximately 500 m long,



Figure 6.

The sink of the Plura River. Note steep, v-shaped valley sides and the dry valley 32m above the far side of the sink. The small ridge in the top center of the photo represents the floor of the glacial trough above.



Figure 7.

Upper entrance of the Jordbrugrotten system, Norway. After several kilometers of alternate subsurface and surface flow, the stream sinks deeper here just above the tree line, to form the main passage of Jordbrugrotten. Photo by H. Williamson.

an underground course before joining the river.

Several small sinks are in the main glacial trough floor. At 500 m these sinks contain snow patches even in August. A large sink, Steinugleflaaget, lies above the estimated course of the subterranean Plura. The sink walls are steep-sided. The floor, 80 m lower than the surrounding terrain and an estimated 10 m in elevation above the underground river, is covered with large curving slabs of breakdown. Another large sink, Trolkirken, is located in the Plura dry valley, at the foot of the north facing wall. Frost wedging along the joints of the metamorphosed limestone has caused breakdown of huge blocks, leaving conchoidal hollows. Sweeting (1950) noted the existence of similar, but smaller pits on hill slopes in northern



Figure 8.

Sprutfossen: the resurgence of cave water from the Jordbrugrotten system along the valley wall of the Plura River, Norway.

running from west to east and containing a small stream, enters the main passage not from the west but from the east. The stream passes over the main passage and enters as a waterfall from the east. The passages show a slight downdip migration. Occasionally they abut against the schist on the east side. This appears to have been the case with the Hatcham Hole stream, which was thrown back into the limestone at the schist-limestone contact.

The upper passage network is developed along the strike at two levels 15 m apart, with small, interconnecting joint-controlled passages, approximately at right angles. The influent Sprutfossen stream sinks above these dry passages and reappears in the lowest passage 30 m below the sink. Two small, sinuous sewer passages, which have been truncated by erosion in the cirque, lead back to the subterranean stream. The larger passages display an elliptical cross section with

a longer horizontal axis when entirely within the limestone (fig. 9Ba). The small sewer passages are circular in the limestone (fig. 9Ba). Some elongation of the passage cross-section downdip occurs when the floor contacts one of the thin schist bands (fig. 9Bc). This is particularly noticeable in the stream bed. The water is carried to lower elevations by the steeply dipping schist bands. Large scallops, up to 40 cm in diameter cover the walls, floor and ceilings of these upper passages. Though they are slightly asymmetrical, it is difficult to ascertain a definite flow direction (Bretz, 1942). Very small scallops are found in a circular ceiling tube with a vertical development of 2 m (Thraillkill, 1960). Thin flowstone and several small stalactites up to 10 cm long are found in a small side passage, developed on cave fill which has subsequently been removed, leaving the flowstone suspended some 50 cm from the wall.

Although breakdown and fill occupy less than one sixth of the cave, both are best developed in the upper passages. The floor of the dry entrance is littered with large blocks of breakdown and fine rock fragments, covered with a thin coating of mud. Probably due to frost action and inwashing of mud, this effect is noticeable only in the first 200 m of passage. Several of the passages terminate in mud and fine micaceous sand. The most significant deposit is a series of varved clays overlain by sand and gravel preserved in a side passage at the uppermost level. The varves lie immediately on the limestone floor. Total thickness is approximately 76 cm. Toward the bottom the varves are very thin, six to eight pairs per 0.5 cm, increasing in size upwards to one pair per 0.5 cm at the top; 606 pairs were counted. The clay is overlain by gray sand, 7-14 cm thick, topped by large pebbles averaging 7 cm in diameter. This layer, 4-25 meters thick, comes to within 7 cm of the ceiling.

In the remaining 1,200 m of lower passage there is no breakdown. The walls are clean washed and covered throughout with small irregular scallops up to 5cm across. Banding in the marble varies from white through all shades of gray to black. Occasional small schist bands 3 cm or less in width form small sharp ledges. There are three main types of passage cross section: smooth

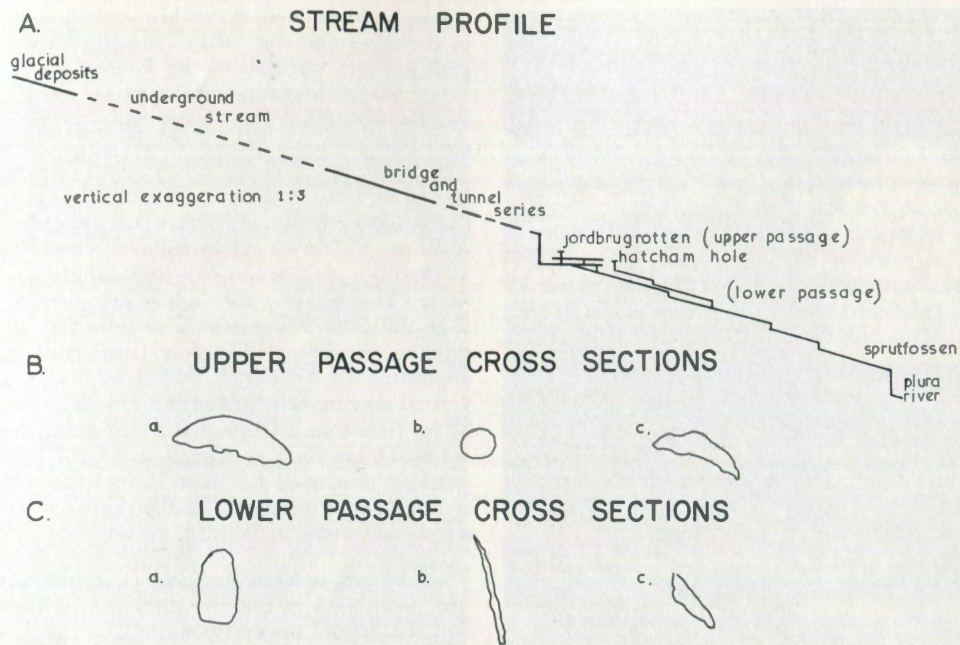


Figure 9.

Profile of the surface-subsurface stream flowing through the Jordbrugrotten system, Norway, with passage cross sections in the upper and lower passages.

elliptical with long axis vertical (fig. 9Ca), high rectangular fissure with schist controlled ledges in the walls (fig. 9Cb), and elliptical with downdip elongation (fig. 9Ca). Stream gradient is high throughout the entire length of the lower cave, which descends at a gradient of approximately one in 10. Steeply sloping passages alternate with waterfalls up to 20 m in height. Circular potholes have formed at the foot of several falls. Depth of the potholes appears related to the height of the falls. One is 3 m deep and only 50 cm in diameter. Though their formation may generally be attributed to solution (Ford, 1965a) mechanical abrasion is evident in one pothole where a circular trough has been cut to a depth of 1 m. Small pebbles were found swirling around a central peak of limestone. Though the passages are generally clean washed, there are some localized deposits of coarse material consisting of gneiss and schist pebbles and micaceous sands. These have filled the cave almost to the roof at a point where a large tributary waterfall enters from the west.

ORIGIN AND DEVELOPMENT

Both phreatic and vadose features are found in the cave. Generally, however, phreatic and vadose features are not found in the same section; nor are the passage profiles the composite type such as was found by other workers in the area to the north (Horn, 1947, and Jenkins, 1959).

The only unquestionable phreatic features are confined to the upper cave: the three dimensional passage network, the circular to elliptical passage cross section, and the circular ceiling tube. This type of passage is known variously as a "bore" (Ford, 1965b) or a "sewer" (Turner, 1959) passage, a "tubular conduit" (Thraillkill, 1960), or "trykkledning" (Horn, 1947). Though considered to be of shallow phreatic origin (White and Longyear, 1962), the elliptical form with the long axis vertical most characteristic of Norwegian caves is considered by Horn to have been produced under pipefull conditions by water under hydrostatic

head, but bearing an unknown relationship to the regional water table. Such conditions have been described by Tratman (1957) as "paraphreatic."

By contrast the long stream passage seems to be vadose in origin. The strike-controlled passage is either elliptical with a long vertical axis, or rectangular fissure type. Unlike the cave passages investigated by Horn in the area to the north there is no evidence of a composite profile. The characteristic features of this part of the cave, the stream and passage gradient, which closely approximates that of the land surface above, and the falls and plunge pools, are vadose.

The variation in the size and regularity of the scallops found in both the upper and the lower cave passages is an additional indication of differing modes of development. The size of the scallops ranges from up to 40 cm, well developed and evenly distributed in the upper cave, to up to 5 cm, small and irregular in the lower cave. Though scallops may be developed under both pipefull conditions and in free surface streams (Maxson, 1940), their size is some indication of flow velocity. The scallop sizes would indicate flow velocities of 0.03 - 0.09 m per second in upper cave and 0.3 - 0.6 m per second in the lower passage (White, 1966, personal communication). This would suggest that the upper cave was developed under conditions of turbulent flow at a low velocity and low gradient, which prevailed for a long period, whereas the lower passage was developed under conditions of high water velocity of inconstant turbulence, either pipefull or by a free surface stream.

AGE OF DEVELOPMENT

There are several periods when cavern development may have occurred: the pre-glacial period; a glacial or inter-glacial period; the post-glacial period; or a combination of any of these.

Pre-glacial. Horn dismisses a pre-glacial development of the caves of north Norway by referring to the small dimensions of the caves, and to the fact that the pre-glacial land surface may have stood as much as 500 m above the present surface, so that the caves would have had to have been developed in a very deep phreatic zone.

The small size of the caves raises the difficult question of the rate of limestone solution, particularly in high latitudes and at high altitudes. Corbel (1959), reasoning that water at low temperatures can hold more CO₂ in solution than at higher temperatures, suggests a relatively high rate of limestone solution in Arctic areas. It is now felt, however, that Corbel's formulae "refer to potential aggressivity, rather than to actual solution rates" (Sweeting, 1964). High values of calcium carbonate carried off in solution are generally attributed to a high CO₂ content of the soil atmosphere produced by microorganisms in the soil (Moore, 1962). As the region has been recently glaciated, soils are poorly developed, especially in the tundra region, above 500 m, so that the soil probably has a low microorganism content and low CO₂ content. The concentration of CO₂ in the snow patches (Williams, 1949) will be insufficient compensation, though it may cause a concentration of solution in small areas. An additional important factor is the volume of water involved. Sweeting (1964) states that maximum denudation is likely to occur at or near maximum discharge, due to the large volume of water involved, and Groom and Williams (1965) also found that a high proportion of solution activity was by flood waters. In the Jordbruen area precipitation is over 100 cm per annum. Spring and summer melt waters flood the cave so that many parts of the stream passages run full. There is a coarse and abrasive stream load. It would appear, therefore, that the rate of erosion by solution and abrasion cannot be discounted, large scale pre-glacial cavern development is unlikely.

Glacial period. The caves may, therefore, have been formed beneath a glacier or during an interglacial period of ice recession. Both Horn and Jenkins favor development of the caves by subglacial meltwater streams. Reference is made to the fact that the temperature of rock at the base of the glacier is at or above 0°C even though the surrounding ice-free rock may be frozen to a considerable depth (Werenskjold and Sverdrup, 1922). Moreover, there is meltwater at the base of the glacier because the melting temperature is lowered owing to the great pressure at depth (Sharp, 1954). But no direct evidence



Figure 10.

A typical vadose section of Jordbrugrotten cave system, Norway. Note the fine scalloping and the potholes in an elliptical passage with long axis vertical. A small limestone pinnacle capped by thin schist bands can be seen in the center of the photo. Photo by Fotohuset, Mo-i-Rana, Norway.

is offered by Horn or Jenkins in support of this subglacial theory. Conflicting evidence is offered by Warwick (1956) who found that in the Pennines cavern entrances were not conduits for subglacial water, but were overridden by ice and only later used to take meltwater. The Horn theory does, however, fulfill the requirement for paraphreatic turbulent flow under pressure. Somewhat similar paraphreatic conditions could be produced by a pro-glacial or marginal lake (Railton, 1954). Again, development under these conditions is difficult to prove or disprove. However, the development of the upper cave must predate settlement of the varves found there, probably in a lake (De Geer, 1912) marginal to the trunk valley

glacier. A count of the pairs gives a period of at least 600 years for their formation. Although the truncation of the upper passages may be due to erosion in a glacial cirque or in a post-glacial nivation cirque, the de-roofing of the upper bridge and tunnel section of the stream is probably attributable to glacial erosion during the most recent ice advance.

Post-glacial period. Several features of fluvial erosion are developed on the glaciated landscape. If the upper cavern was developed during the glacial period, re-establishment of surface drainage must be examined. The sinks may have been blocked by glacial fill, although now there is little evidence of glacial fill around or at the bottom of the sinks.

The existence of frozen ground may have prevented subsurface flow. The region is now

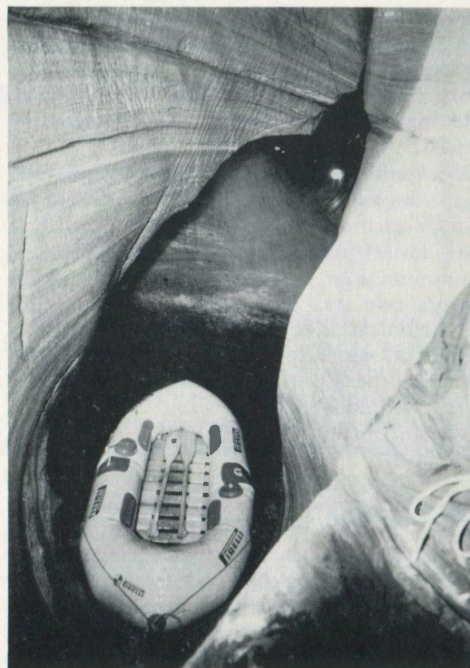


Figure 11.

Another section of the lower cave, Jordbrugrotten. Note the profile and scalloping. The raft was used to cross a deep plunge pool at the base of a large waterfall, seen in the background. Photo by Fotohuset, Mo-i-Rana, Norway.

in the area of sporadic permafrost (Black, 1954), but morphological evidence suggests that permafrost has been considerably more extensive in the recent past.

Thawing of permafrost at progressively higher elevations must then have allowed the re-establishment of underground drainage. The long lower cave passage of Jordbrugrotten and the tributary Hatcham Hole show primarily youthful vadose features. The passage is developed along the strike, and is generally of the high fissure type, or elliptical with some downdip elongation. Only at the confluence of the two underground streams does the passage become a crawlway, where inwashed coarse sands and pebbles fill it nearly to the ceiling. The ubiquitous scallops are small and irregular. Waterfalls and associated potholes are not structurally determined. Control of vadose development by permafrost is advocated by Corbel (1957), and it does offer a plausible explanation for the accordance of the Jordbrugrotten effluence and the Plura dry valley, giving allowance for a few meters downcutting by the Sprutfossen stream. Deeper water circulation may have been temporarily prevented by the existence of frozen ground at this elevation.

Because so little is known about the former extent of permafrost at depth and its effect on ground water circulation an alternate explanation is offered for this accordance. Horn (1947) discusses regional uplift due to isostatic readjustment at a rate greater than the eustatic rise in sea level, but does not apply it to his theory of cavern development in the area. Though the exact degree of regional uplift is not known, uplift would account for the increase in hydrostatic head which changed the solutional regime of the cave from phreatic to vadose. Such uplift would also account for the steep profile of the vadose section of Jordbrugrotten and the accordance of the cave effluence with the Plura dry valley. The succession of sinks in the Plura dry valley indicate progressively headward sinking of the river. Renewed uplift after a period of standstill would then account for the downcutting of the Plura 32 m below the blind valley wall.

CONCLUSIONS

In general terms the development of the

cave is in accord with the "invasion" theory of Malott (1937). Halliday (1960) offers a similar explanation for certain high altitude caves in the western United States: initial phreatic origin and the development of a small phreatic system, followed by vadose development when a large trunk stream, in this case the Plura River, has cut down deeply enough for tributary water to be drained from the adjacent hillsides.

Though two types of cavern development – phreatic in the upper section and vadose in the lower – have been distinguished, dating of the system and explanation of the mechanism of development is hypothetical. The relative importance of subglacial meltwater, marginal lake, frozen ground and regional uplift cannot yet be fully determined, due to inadequate understanding of these morphological influences. Several questions, therefore, remain unsolved: the cause of the perching of the upper natural bridge section of the Sprutfossen stream; and the reason for the very limited headward extent of the phreatic section, though the limestone runs the length of the valley.

At best it may be said that the greater part of the cave is a youthful system developed during the post-glacial period whereas the upper part of the cave was formed either during the last major glaciation or the most recent inter-glacial period; that mechanical abrasion as well as solution has played an important part in the development of the lower cave passage; that the effect of frozen ground is not precisely known though it does retard cavern development, and may contribute to the existence of surface and near-surface flow; and that isostatic readjustment appears to be a satisfactory explanation for the increase in hydrostatic head which changed the regime of the cave from phreatic to vadose.

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Observations on Frenchman's Cave, Nova Scotia, and Its Fauna

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ABSTRACT

Caves have received little attention in Nova Scotia until recently, although several are known, particularly in the gypsum and anhydrite of the Windsor group. Frenchman's Cave at St. Croix, Hants County, was examined in 1963-1964 during investigations on microarthropods and bats. A total of 37 species of animals have been identified to date from the cave, including 19 insects, 10 arachnids, three diplopods, and five mammals. The only possible troglobite is a staphylinid beetle, *Quedius spelaeus*. Although the cave was probably formed by rapid solution in geologically recent times, presently stoping is the major factor shaping its topography.

INTRODUCTION

Caves have received little attention in Nova Scotia, possibly because the majority are small in size and relatively prosaic. The first speleological study in Nova Scotia was conducted by Prest (1912), who investigated Five Mile River Cave, Frenchman's Cave, and Miller's Creek Cave for possible anthropological significance. Prest discussed the general topography of the caves, and included maps and measurements, but did not remark on their biota. Nothing was written again until Taschereau (1963) compared his observations with those of Prest and discussed the structural changes that occurred in the 51-year interval. The only biological investigation of these caves to date is that of Calder and Bleakney (1965), who studied the microarthropod ecology of Frenchman's Cave. Except for studies on bats by Bleakney (1965), the fauna of the others has been neglected.

Most caves in Nova Scotia are located in gypsum and anhydrite of the Windsor group of Mississippian age (Taschereau, 1963). Taschereau noted that glaciation probably collapsed earlier caves, or filled them with glacial fluvial, lacustrine clays, sands, and gravels. Because most biospeleological studies

in North America have been conducted south of the maximum extent of glaciation, detailed studies on the biota of recently formed northern caves could contribute to the understanding of cave community development and speciation of cavernicoles. The present fauna in Frenchman's Cave consists primarily of pre-adapted epigeal species, rather than the highly adapted and modified troglobites frequently encountered in older caves south of glacial action.

The assistance of the following taxonomists, who examined our collections, is sincerely appreciated: E. C. Becker (Coleoptera), J. G. Chilcott (Diptera), C. D. Dondale (Araneae), E. E. Lindquist (Acarina), D. R. Oliver (Diptera), B. V. Peterson (Diptera), and W. R. Richards (Collembola) of the Canada Department of Agriculture; T. C. Barr, Jr. (Coleoptera), University of Kentucky; Nell B. Causey (Diplopoda), Louisiana State University; K. Christiansen (Collembola), Grinnell College; and M. W. Sanderson (Coleoptera), Illinois Natural History Survey. This study was supported in part by National Research Council of Canada Grant A-2009.

OBSERVATIONS

Frenchman's Cave at St. Croix, Hants County, has been studied more than any other cave in Nova Scotia. The entrance lies 35 feet from the top of a 55 foot deep sinkhole. The sinkhole has a diameter of 86 feet at the top, but a talus slope reduces this to 40 feet at the bottom. The vertical

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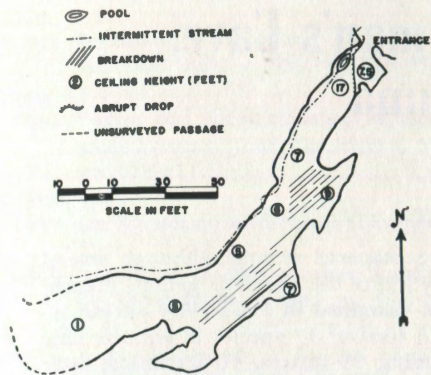


Figure 1.

Map showing the general topographic features of Frenchman's Cave, St. Croix, Nova Scotia.

walls of gypsum on two sides of the sinkhole suggest that it may have once formed part of the cave proper. A small stream runs into the cave in a westerly to southwesterly direction, undercutting the west wall (fig. 1). According to Prest (1912), this stream became a torrent in rainy weather. No evidence of this was observed in any of the visits by us, several of which were made during heavy rains. No doubt the stream is largest in spring when it is swelled by melt-water.

The location, size, and shape of the cave suggests rapid solution in geologically recent times. It is presently above the water table for the most part, and stoping has replaced solution as the predominant shaping force. The gypsum walls of the cave are soft and wet, and breakdown litters the floor. During the 1964 study, a large block fell from the ceiling 145 feet from the entrance. Water seeps through fissures in the ceiling even in dry weather. Wet weather increases the seepage and danger of cave-ins. The spring thaw is undoubtedly the most critical period for rockfalls in the cave.

The cave can be readily penetrated to a length of 145 feet. By crawling in the stream bed one can reach 165 feet, but at this point the ceiling, less than a foot high, decreases progressively inward and laterally. The cave ends with a wall of gypsum to the west, but the stream turns northwest and continues on.

The ceiling becomes too low to permit further exploration. Mr. Gordon Allen, a farmer in the vicinity, told us that passage to deeper regions was once feasible, but the mud and gravel carried in by the stream has now made this impossible.

Records indicate that temperature fluctuations in the deeper regions of the cave are less marked than those near the entrance. A range from 32° F to 44° F was recorded at a station 145 feet from the entrance, while a range from 28° F to 51° F was recorded at a station 28 feet from the entrance during 1964. Relative humidity rarely falls below 85% anywhere in the cave.

In winter, deep snow accumulates at the bottom of the sinkhole and ice makes the entrance to the cave hazardous. Hoarfrost forms on the rocks and ceiling about the entrance due to freezing of outward moving moist air from within the cave. Ice stalactites and stalagmites form in the cave from the entrance to a depth of approximately 70 feet, decreasing progressively in size with increasing distance from the outside. The stalactites are fewer and smaller than the stalagmites because the warm air moving out of the cave is buoyed up by cold air from outside. Warmer temperatures prevent ice formation deeper in the cave. It is not known when ice first forms in the cave. Well developed ice formations were observed on 18 January 1964, indicating that ice had been present for some time. Ice was present in the cave until 9 June 1964.

A temperature cline exists from top to bottom of the sinkhole outside the cave. This is particularly noticeable on hot days in summer, when the colder air lies at the bottom of the sinkhole. On 28 July 1964, a range from 85° F at the top to 57° F at the bottom was recorded.

To date, 37 species have been identified from faunal collections in Frenchman's Cave (table 1). Perhaps the most interesting of these is the staphylinid beetle *Quedius spelaeus*, a widespread species known only from caves (M. W. Sanderson, personal communication). Collections of several taxa, including Oligochaeta, Isopoda, Chilopoda, Corrodentia, Pauropoda, and Symphyla, have not been examined. Identification of the Acarina collection is incomplete.

Table 1.
Fauna identified from Frenchman's Cave,
Nova Scotia.

ARTHROPODA

Insecta

Collembola

Onychiurus armatus
Tullbergia iowensis
Folsomia fimetaria
Isotoma notabilis
Entomobrya nivalis
Pseudosinella alba
Heteromurus nitidus
Megalothorax minimus
Arrhopalites pygmaeus
Ptenothrix marmorata

Diptera

Smittia sp.
Trichocera sp.
Scolioecentra fraterna
Leptocera (Limosina) sp.
Bradysia sp.
Megaselia (Aphiochaeta) meconicera

Coleoptera

Quedius spelaeus
Brathinus nitidus
Aphodius leopardus

Arachnida

Araneae
Meta menardi

Acarina

Alliphis sp.
Geholaspis sp.
Zerconopsis sp.
Parasitus sp.
Veigaia sp.
Bryobia praetiosa
Pygmephorus sp.
Eugamasus sp.
Arctoseius sp.

Diplopoda

Proteroiulus fuscus
Ophiulus pilosus
Diploiuulus latestriatus

CHORDATA

Mammalia

Chiroptera

Myotis lucifugus
Myotis keeni
Pipistrellus subflavus

Rodentia

Erethizon dorsatum

Carnivora

Procyon lotor

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