VOL. 10 NO. 2

SOUTHERN CAVER

S.C.S.

PRICE 50 CENTS

"SOUTHERN CAVER"

Published Quarterly by the
Southern Caving Society.

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Registered for posting as a periodical - Category B.

VOLUME 10 NUMBER 2 OCTOBER 1978

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EXTENSION TO JF 211 (SESAME II)

Leigh Gleeson

JF 211 cave was originally discovered and explored by the society at least ten years ago but it had only been 'pushed' to a depth of around 20 metres. Six years ago an exploration team broke through the talus floor of this system and over a period of five trips explored the cave to a depth of 219 m. making it the 5th deepest cave in the country.

The general form of the cave is one of an old abandoned stream cave with only limited side passage development. The system ends abruptly in a long narrow fissure the floor of which is lined in gravel and cobble beds. Two small creeks enter this final fissure, one from each end, and were thought to seep through these gravels, consequently further exploration was not possible. This description of the nature of the bottom of the cave was never really questioned as the original exploration trip had made a thorough search of this final fissure and there seemed no possibility of an extension.

A recent return trip to JF 211 to bottom the cave (there had been no other bottoming attempt since the first one) had the momentary excitement of discovering a new lead through which the small streams were flowing. It is possible that this lead has only become enterable in the last few years due to the gravel being flushed out though more probably it was simply an oversight. The break-through brought home the golden rule of cave exploration; "never assume that exploration is complete".

The lead is a narrow crawl leading to a steeply inclined rock wall that falls away into a small talus chamber. A conservative estimate of the depth of the extension is 10 metres. The possibility for further exploration is still good however the prospective way on is tight, wet and nasty. There is no draught but this should not deter a return team as only an additional 70 metres or so would put this cave in the Khazad - Dum class.

GLACIO-SPELEOLOGY I:

AN INTRODUCTION TO CAVES AND KARST IN SNOW AND ICE

Kevin Kiernan

Most speleologists are aware of the existance of "ice caves" in high altitude karst areas, the Eisriensenwelt and Mammuthole of the Austrian Dachstein being perhaps the best known, although others occur in the Pyrenees, North America and elsewhere. One particularly interesting example is Castleguard Cave, a fossil system extending 3km. under the Columbia Ice Field of the Canadian Rockies. Ice speleothems form up to 400 metres from the entrance during summer, while at the upstream end a passage 4 x 3m. terminates abruptly against a flat wall of ice-the glacier base, 335m. below its surface (Ford 1975). Such caves are essentially normal karst features in which ice accumulates and which are frequently subject to a characteristic alpine regimen involving predominantly summer stream-flow due to melting or ablation of ice.

The object of the present article, however, is discussion of the somewhat embryonic field of caves actually formed in glacial ice, firn or snow, and frequently associated with other pseudo-karst features, through a brief review of some of the contributions to the rather small body of literature presently available. It arises primarily from an initial desire of the writer to place his own interest and observations in some sort of context in his own mind, in terms of previous exploration, research and theory, and some framework in which the matter might be taken further: it is therefore perhaps biased towards those aspects of particular interest to him, and undoubtedly over generous in its bibliographic coverage. However, despite the apparently lengthy bibliography appended, there has been very little actual exploration of such caves. Photographs of such caves are occasionally published for their novelty value, such as that on the cover of Mountain Scene by Breadmore (1977) of a cave in the Andre Glacier of Chilean Patagonia. The earliest records are from speleologists in Europe and geologists in Alaska, after which investigation became almost entirely the realm of glaciologists, often only tangential to broader questions such as the mechanisms of glacier movement, and generally conducted only by speculation from the surface. Rarely have speleologists involved themselves in this potentially rewarding field. The limited speleological material has been rather inbred and stagnant for some years, with the work by speleologists in Washington state perhaps excessively influencing ideas on such caves and their development in other parts of the world. In Australia the only contributions appear to be those of Shannon (1972) Dunkley (1972) and Halbert & Halbert (1972), of which only the latter is related to Australian Caves.

Glacial Pseudo-Karst

Analogy may readily be drawn between caves developed in snow, firn or ice, and those of carbonate karst terrains. As long ago as 1893 Russell described large caves in the Malaspina Glacier of Alaska, while Tarr & Martin (1914) noted pseudo-karst terrain on its margin, but did not use karst terminology. In Europe, Vallot (1898) explored a shaft in the Mer de Glace which branched at a depth of 55-60m. into a horizontal system (reported by Stenborg, 1968). In the same year Forel described the subglacial hydrology of the Rhone Glacier in a speleological publication (Forel 1898). More recently interest has advanced to the stage of water tracing experiments using dye tracers (e.g. Behrens et al 1975 in Austria), while a symposium on the hydrology of glaciers was held in Britain in 1969 under the auspices of the International Association of Scientific Hydrology.

Clayton (1964) suggested karst-like features reach their fullest expression on stagnant, moraine covered parts of glaciers. Citing the Martin River Glacier in South-central Alaska he suggested a glacial karst cycle essentially the same as the limestone karst cycle, proposed by Cvijic including the development of sinkholes, tunnels, caves, sinking streams, blind valleys, large springs, natural bridges, lapies, hums and residual "soils" or ablation tills. Melting of the ice occurs rather than chemical dissolution of soluble rocks. The requirement for dense, highly jointed rocks in carbonate karst is admirably met by dense glacial ice, which is usually jointed. He suggested that as with carbonate karst, development will only occur where water can drain away. Fourthly, the need for at least moderate rainfall still applies.

Clayton considered the ice mass must be stagnant as movement would destroy the karst before it could fully develop. He suggested a cover of morainic debris is necessary to insulate against surface melting and preserve the glacier long enough for full scale features to develop. Cover also increases the irregularity of melting of the surface of nearly homogenous glacier ice. Eyles & Rogers (1977) have suggested that the latter prerequisites are over-emphasised by Clayton and that the main factor is predominantly greatly enhanced basal and englacial melting over rates of supra-glacial ablation. They describe artificially induced pseudokarst from the active ice of the Berendon Glacier in British Columbia, due to discharge of warm (30°C) waste water from a copper concentration plant onto the ice margin.

Paige (1956) describes semi-circular depressions developed by crescentic crevassing over meander perimeters of subglacial streams in the terminal area of an Alaskan glacier. Loewe (1957) has described similar situations higher in a glacier apparently resulting from stagnation of the ice front and the destructive forces of meltwater behind it, no longer counteracted by fresh ice from higher in the glacier. Odell (1956) has cited evidence that this may be occuring within New Zealand's Tasman Glacier, while Sara (1974) describes features from the Franz Josef glacier which may also be related.

Shannon (1972) notes that a number of karst processes are observable with the time dimension shortened. While this general analogy has some validity the difference between melting which may be inpart due to air currents, (possibly even involving some sublimation from the solid direct to the gaseous phase and removal as such rather than liquid) and carbonate solution with mass removal by running water, is a significant one. Nevertheless, substantial morphological similarities exist, and very sizeable cave systems doubtless await exploration: in fact potential for extensive caves may exceed that in carbonate karst terrains.

A Brief Note on Glacier Hydrology

Development of caves by the melting of ice is dependant upon meltwater, which derives from several sources. Supra-glacial sources are the most important. Particularly in mid latitude situations under maritime influence there is abundant precipitation which may be in the form of rain, particularly in summer and at lower elevations. In early summer it may be frozen into pore spaces in firn such that run-off is delayed. Later in summer only bare ice remains and there is abundant rapid run-off. If surface melting produces more than can be absorbed and ice flow is compressive thus reducing the likelihood of volds to divert run-off "underground," often highly symmetrical meandering channels cross the ice surface, until intersected by swallets called moulins, which exploit vertical weaknesses (Sugden & John 1976).

Run-off from valley sides disappears into entrances produced by it or due to melting by differentially heated dark coloured enclosing rocks, and also contributes to englacial and basal flow. Basal and internal sources produce the remainder. The pressure of ice thickness induces melting at the ice-rock interface, to which the normal geothermal heat release of the earth contributes. Friction produced by the sliding of the ice, and frictional heat from moving meltwater above freezing point from external sources induces melting and is a further source, also there is often some imput from ground water seepage.

There is considerable variation in meltwater output at the glacier snout. Flow tends to be fastest in summer, and somewhat faster than comparable surface streams. There are marked diurnal and seasonal fluctuations which increase in magnitude with improvement of the system. These fluctuations tend to be superimposed on a base-flow which accounts for most of the output (Elliston 1973 - as reported by Sugden & John 1976). Lags between precipitation and run-off occur due to precipitation form and other factors, but rain is particularly effective in autumn when the ice is bare. Maximum flow is derived from the surface in summer, but with the slowing of surface wasting, basal flow dominates in winter and conduits may partially close. Other fluctuations are involved in glacier surges (Sugden & John 1976).

Cave Formation in Snow, Firn and Ice

The host material is an important variable. Snow falls with a density of around 0.1 and porosity of 90%, and may then be compacted into firn (0.5 & 50%) and then ice (≥0.8 & 10%). On the basis of the differences in rheological behaviour and the advantage of emphsising measureable characteristics, Kiver & Steele (1975) adopt a cave classification so based, but note another possibility of a genetic basis, into atmospheric and geothermal ablation caves. The former is the more usual, involving the air temperature being raised sufficiently to promote passage enlargement by melting due to transfer of heat by running water or atmospheric sources, while the latter is a rarity in which raised air temperatures are at least substantially dependant upon geothermal heating.

On the other hand Halliday and Anderson (1970) have suggested the term "ice cave" should be restricted to normal karst caves in which ice speleothems accumulate seasonally, and that the term "glacier cave" should be adopted for caves such as the Paradise system. That also seems unsatisfactory in giving insufficient weight to speleogenesis, host material, and enlargement mechanism.

However, other caves develop due to irregularities of glacier flow, biogenic activity and collapse. The former may occur where a sub-glacial protuberance obstructs glacier flow and a void is left at the ice-rock interface for a short distance downstream, (for which McKenzie 1972 adopts the term "obstruction cave") or where bed irregularities promote crevassing with subsequent roofing by fresher snow bridges (exploration may be inadvertant). Theakstone (1967) suggests large gaps between the glacier and its bed are unlikely when ice thickness exceeds 50m. However, Vivian & Bocquet (1973) describe voids transverse to glacier flow downhill of a rock bar 100m. below the Lognon ice fall in France. These were of quite substantial dimensions with significant air currents present. They were discovered as a result of subglacial tunnelling to divert water for hydro-electric generation. Peterson & McKenzie (1968) and McKenzie & Peterson (1975) report another reached by tunnelling in the Casement glacier, S.E. Alaska. It occurred 10-15m below the ice surface and contained stalactites, stalagmites, draperies, deformed columns, cave coral, sublimation crystals and hair ice.

In alpine areas used for recreation mountaineers may dig sizeable caves for accomodation, and lengthy tunnels have also been dug for research purposes. Where glacial ice is precipitated over a fall in its bed, crevassing and collapse may produce maze-like systems analagous to talus heaps.

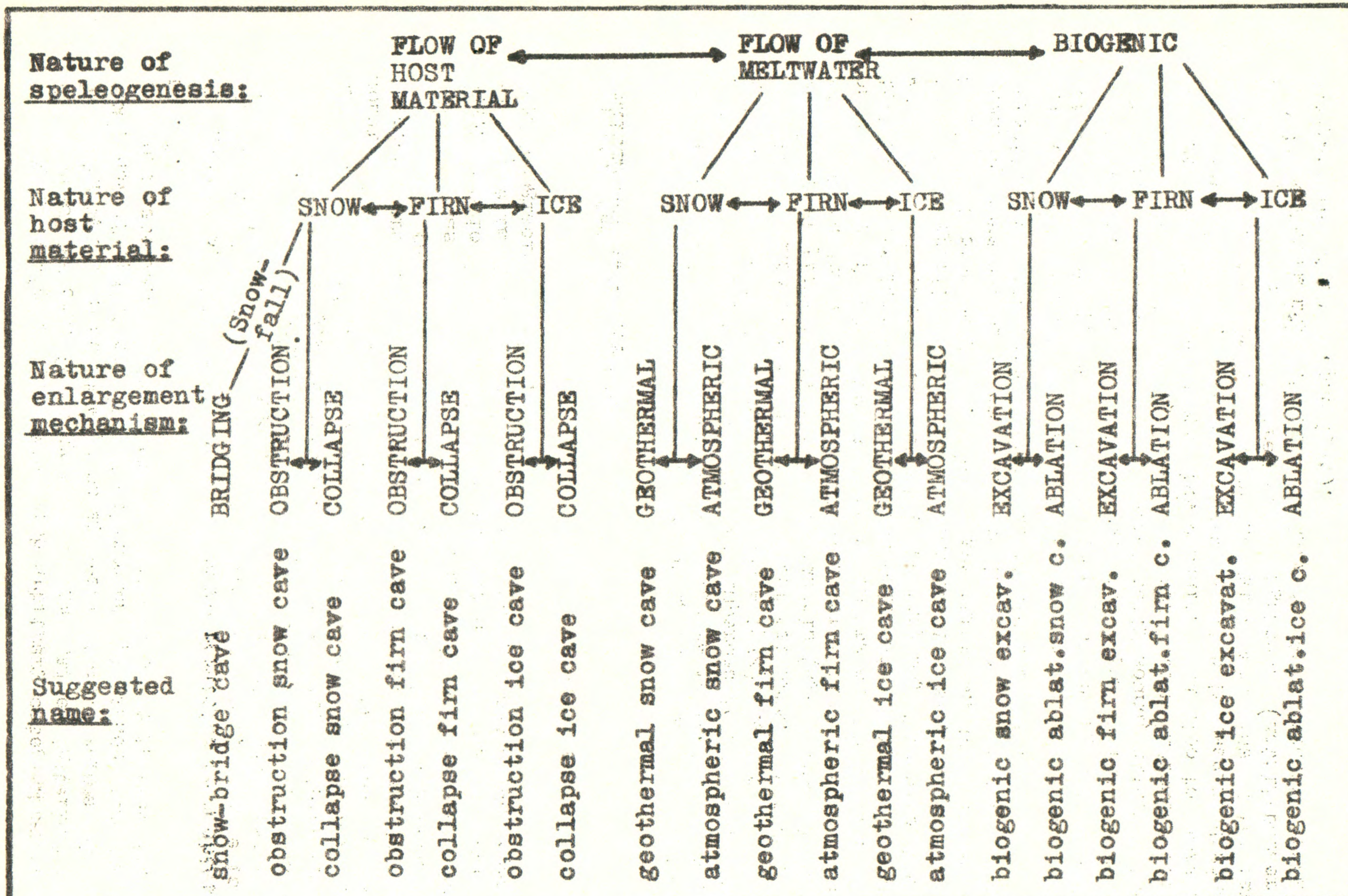

Fig.1 A proposed scheme of descriptive nomenclature for psuedo-karst caves in snow, firn and ice, integrating speleogenesis, host material and enlargement mechanism. Double ended heavy arrows (⟷) signify a continuum. Nomenclature is based upon assessment of dominance in particular circumstances.

To a degree man's preoccupation with arbitrary categorisation and division of the earth's unity to suit his limited intellect is doomed to failure, but in an attempt to at least achieve terms which convey dominance of speleogenetic and enlargement processes, and the nature of the host material, a new schema integrating these is here proposed, in fig. 1.

The largest of these cave forms are those resulting from ablation, discussion of which will form two subsequent items. There is considerable scope for caves of these other forms in virtually any glacial terrain. Most glaciers offer crevasse systems and collapse mazes, often beautifully draped with myriad icicles which glisten and shine in the blue light of the snow. I have seen some very fine examples in the Bonar and Heemskirk glaciers in New Zealand. They tend, of course, to be even more transient than most glacier caves. Obstruction voids in the purest form, must inevitably be innaccessible but others to which ablation has contributed may be accessible if searchers are prepared to brave the ice-falls under which they are most likely to occur. Principle interest however, probably lies in those caves associated with subglacial streams.

Ablation Cave Speleogenesis

Speleogenesis of ablation caves is poorly understood as is their form. Sugden & John (1976) suggest ice temperature is analogous to lithology, a warm ice being permeable and cold ice impermeable due to freezing of melt water. Grain intersections (Shreve 1972) and ice at pressure melting are also permeable, as are joint networks. Secondary permeability is provided by melting of tunnels (Nye & Frank 1973 - as reported by Sugden & John). Temporary water-tables have been postulated on the basis of the nature of some sediments and variations in water levels. Their location depends upon melt water supply and the efficiency of evacuating channels, and they may fluctuate from season to season, spilling out onto the glacier at times, and even water spouts have been reported. Thus there exists an upper vadose zone of downward movement of water under the influence of gravity, and a phreatic zone with water under hydrostatic pressure.

Glenn (1954) notes the greater density of water than ice and the deformability of the latter under stress, observing that a column of water C.150m. exerts sufficient pressure to physically deform the ice and expand the hole. This is theoretically sound, although the rate of operation would be very slow. As percolation increases frictional heat may lead to enlargement, but conduits tend also to close due to overburden pressure. Pressure decreases with increasing discharge therefore smaller conduits close and water must flow in the larger arteries, leading to preferentral enlargement. (Rothlisberger 1968) Glenn's mechanism may maintain the flow of water downward beneath the water-table (Sugden & John 1976).

Thus there is constant adjustment of conduit diameter to the melt water flow, with direction of flow a product primarily of the slope of the ice surface, with bed topography exerting secondary influences. The passage network becomes dendritic due to preferential enlargement, with a supra-glacial system similar to that of a carbonate karst surface, an englacial system of tree-like systems delivering the water from the surface to the bed, and a subglacial system carrying water and sediments. Abnormally large flows may vastly increase passage dimension within even a few hours. Interconnecting moulins develop on structural weaknesses, their location related to local variations of straining and melt water supply, with frictional and eddy viscosity energy enlarging the conduits (Stenborg 1968). Clearly Glenn's mechanism cannot come into play until a sufficiently deep body of water has developed - again a function of structures in the ice. This situation of structural control of vertical elements, with horizontal development at the foot has been recorded by the early explorations of Vallot 1898 and Carol 1945 (as reported by Stenborg 1968) and by Dewart (1966).

Energy derives from the slope of the water-table. Rothlisberger indicates that where the hydraulic gradient is small the conduit may meander or be braided. In valley glaciers there is frequently a bottom conduit along the deepest part of the valley, and two additional streams at a lesser depth close to the margins. Frequently only these two lateral channels seem to exist in broad flat basins. Stenborg (1969) attributes these lateral passages to the tendency of melt water to run-off towards the margins away from the more rapidly moving and dense central area. In the phreatic zone a rough equilibrium is maintained between flow rate and rate of closure. In the vadose zone gravity maintains flow down moulins bringing in warmer water from external sources and generating frictional melting. Air circulation aids enlargement: Vivian & Bucquet (1973) record such currents in an obstruction void probably due to melt water. With interconnection between such voids, tributaries from the valley walls and water filled crevasses potentially add to the complexity of the system. Where the glacier is still active this whole system is particularly dependant upon melt water for its maintenance, and many elements may proceed downstream, perhaps for short distances in fossil form, with the glacier flow.

Sugden & John speculate on likely passage cross sections based in part on analogy with carbonate karst: circular deep in the phreas, keyhole where the water-table is fluctuating and narrow and deep in the vadose zone. Water-flow avoids areas of high ice pressure, and pressure differences may lead to anastomosing, as found in the Paradise Ice Caves on Mt. Ranier, (Halliday and Anderson 1970).

Much of the foregoing must remain speculative however, until more exploration and direct observation is undertaken.

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GLACIO-SPELEOLOGY II:

GEOTHERMAL ABLATION CAVES

Kevin Kiernan

Geothermal ablation caves are here regarded as those enlarged by water-flow and air movement, in which ablation is consequent upon water or air temperatures being raised due in substantial part at least to geothermal heating. The term is intended to cover a wider range than perhaps envisaged by Kiver & Steele (1975), in paying more attention to the role of ablation by warmed water directly, rather than enlargement only by air currents warmed by it, or raised atmospheric temperatures otherwise consequent upon geothermal activity.

Caves over Fumaroles

Caves formed in snow, firn or ice over fumaroles appear to have been recorded from only five volcanic crater sites: Mt. Wrangell in Alaska; Mts Erebus and Melbourne in Antarctica; and Mts. Ranier and Baker in Washington state, U.S.A., and is here recorded from a probable sixth: Ngauruhoe in the North Island of New Zealand.

At Mt. Wrangell, Bingham (as reported by Kiver & Steele 1975) has noted the formation of small isolated caves above fumaroles along the caldera rim. These consist of discrete openings with little inter-connection at depth. The largest recorded was 100m X 20-30m X 10m high.

The Mt. Erebus caves were first recorded by David & Priestly (1909) and attributed to fumarole activity. They noted ice towers over the entrance, as did Holdsworth & Ugolini (1965). Lyon & Giggenbach (1974) also gave some details, noting others on Mt. Melbourne. Their form is similar to that of the Mt. Ranier caves except for there being only one single entrance, marked by an ice tower 4m. high. The main Mt. Erebus cave is in the form of a figure - 8 and 400m of passage has been surveyed. Air temperatures range from just below freezing point to +1.4°C (Giggenbach 1976). No other evidence of major present day thermal activity has been observed in the area.

The caves of this form par excellence are those in the craters of Mt. Ranier, described by Mitchell (1969), Kiver & Mumma (1971) Kiver, Steele & Mumma (1973), Kiver & Steele (1975) and numerous others. Eruptions from the mountain, possibly the summit craters, occurred up to the mid 1800s, after which they were filled with snow. Cavities formed above the fumaroles and warm ground, elongating, enlarging and coalescing as air rose upslope across the surface.

This produced a relatively horizontal perimeter passage 7 - 9m wide connected to the surface by a number of ascending entrances. Enlargement occurred as circulation became freer, cold air being drawn down some entrances as warm air evacuated from others. Snow becomes firn within two years, with a maximum thickness of 48m accumulated in the west crater and 120m in the east subsiding at 2-3.5m/year to replace that melting in the caves (Kiver & Steele 1975). The caves provided life-saving refuge to the first recorded ascent party of Ranier summit in 1870 although Mitchell (1969) notes that some who have avoided exposure in their shelter subsequently have suffered second degree burns from sleeping too close to the steam! Rime frequently forms on the floor near the entrance.

There are now 2.2km of known passages, the deepest point lying 104m below the ice surface and 16m above the crater floor. Passage size is a product of subsidence rate and heat flow. The largest chamber is 52m x 40m x 8m high, containing a small crater lake 40m x 8m x 4m deep. Sadly, this is already littered -- Snavely (1977) notes that boards and steel rods left on the snow surface overhead in 1959 had worked their way down into its waters by 1977. His article includes some excellent colour photographs.

In glaciers, crevasses close rapidly at depths exceeding 30m, and Kiver & Steele attribute the much greater depth at Mt. Ranier to heat flow, the prescence of firn rather than glacier ice, and its polar temperature. The caves are in apparent equilibrium with current heat release, and Kiver & Steele suggest they may provide early warning of any increased activity of Mt. Ranier. No toxic gases appear to be present (Mitchell 1969).

Some 800m of passages are developed beneath 60m of snow in the Sherman crater of Mt. Baker. The crater is some 300m. in diameter, and last erupted in 1870 with some 10 events in all in the early part of the 19th century. The caves have been developed by basal melting by many sub-ice fumaroles, melt water flowing under the ice, and warm gases from a big fumarole at the eastern entrance.

One of the four entrances is a 50m. shaft above which a jet of steam rises 10m. The largest chamber is 30m. wide and lies below a surface depression. Other spectacular features include a 10m. melt water rapid in the main passage, and the presence of the largest fumarole in the crater loudly roaring and filling one passage with steam. Objective hazards include toxic gases, some passages not even safe using gas masks due to oxygen shortage. In addition there are hazards of ice blockfall, thin ice crusts over large drops at entrances, rockfall from the crater flank into one entrance, and sediment which liquifies when trodden upon (Kiver 1975)

A brief search in New Zealand

The Tongariro Plateau in New Zealand's North Island consists of three principle volcanoes, Tongariro itself (1970m. - below permanent snowline) Ruapehu (2798m.) and Ngauruhoe, (2290m.) all three remaining active to varying degrees. As an indication of this activity, Ruapehu had recently cast ejecta across the surfaces of the small glaciers encircling its summit, and the village on its western flank had apparently received several substantial tremors in the week prior to my arrival in late 1977.

Ngauruhoe is the most continuously active of New Zealands volcanoes. Its most spectacular known eruption, in 1954-55, saw occasional jets of lava to 300m., while rock, ash, scoria and gas reached heights of 9000m. in February 1975. (Gregg 1975; Johnston 1976). It is a typical strato-volcano, almost perfectly conical, with walls set at 30-40° and rising to a crater 400m. in diameter. Recent aa flows cloak the sides. The main active vent is a small nested cone offset easterly, and much too active for snow accummulation. However snow generally occupies the fosse between the inner cone and crater wall. Long ice couloirs also persist on the flanks, offering an enjoyable ascent on the SE side, (although a quicker route apparently exits on the northern flank).

A certain amount of braille was involved in gaining the final rim of the active vent through the thick vapour and rather overwhelming sulphurous fumes. The presence of snow lying right onto its rim and on rocks around which steam was rising, probably indicative of rapidly increasing unrest was something less than a sedative to the nerves. It is a spectacular place, with colourful sulphurous coatings on rocks. It was impossible to see right across the fosse and only a brief excursion was made onto it due to the increasing influence of the fumes from the vent and the lack of a companion. It was filled with firn. One substantial opening 2m. high was located which appeared to extend for some distance, but it was guarded by one of a number of unstable-looking areas of slightly depressed snow, suggestive of underlying voids. No idea was gained of the depth of the fosse. Some indication is given by an aerial photograph in Ollier (1969) which shows it much reduced after a more active phase, and it may be quite shallow. Thus although caves appear to occur their extent may be limited by the depth of the host material and the excessively high level of this volcano's activity.

Stream Caves

Another form of ablation cave of geothermal origin is present on Ruapehu but I did not have time to visit it in 1977. The summit caldera is some 3 x 1.5km. in extent, usually filled with a lake of warm water which overflows through a tunnel melted in one of the confining ice walls of the Whangaehu Glacier, emerging at its foot as the Whangaehu River. In 1945 a series of eruptions commenced, displacing the crater lake, but by January 1946 its explosive phase had ended and the crater, which had been blasted out to a depth of 300m., began to refill and reached 6-7m. above its old level due to a heavily scoria laden barrier of ice across the normal outlet. On Christmas Eve 1953 the barrier collapsed, sending a wall of water down the valley, which developed into a lahar: a wall of mud, water and rock growing to vast proportions and which reached the Tangiwai railway bridge 20km. to the south minutes before the express from Wellington to Auckland. Of the 285 passengers, 151 were killed and some bodies not found for 12 months (Shadbolt 1973) Odell (1955) includes a photograph of the stream emerging from a large tunnel in the ice-scoria barrier and dropping into a chasm before entering the glacier proper, and another in Gregg (1959) shows the massive lake-side entrance.

In Iceland not dis-similar problems have arisen in the past with very destructive consequences. There the name "jokulhaup" has been applied to the collapse of ice dams blocking lakes. Massive flooding occurs every 10 years or so from a lake developed over the crater of the volcano Grimsvotin, and the stresses sometimes trigger eruption. In 1934 the water-flow reach 40-50,000 cumecs and around 1,000km.^{2} was flooded. (Thorarinson 1953). An ice tunnel 50km. long under the glacier Skeijararjokull produced by water heated by geothermal activity at the base of its ice cap is postulated by Nye (1976).

Of the various types of cave occurring in glacial situation, geothermal ablation caves, while sometimes extensive, are rare. Close to home potential exists for more such features at Heard Island and perhaps Ruapehu. No doubt others will be revealed in due course in alpine volcanoes such as Osorno in Central Chile or Cerro La tero on the Southern Patagonian ice cap. In searching for them it may be worth remembering that more active Volcanoes may be unsuitable sites for adequate snow collection (Ngauruhoe perhaps being one example) and that two members of a party ascending Sangay (5332m.) in Ecuador last year were killed when it erupted unexpectedly: Snailham (1977) provides graphic food for thought.

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GLACIO-SPELEOLOGY III:
ATMOSPHERIC ABLATION CAVES

Kevin Kiernan

Atmospheric ablation caves are here defined as those caves in snow, firn or ice enlarged due to heat transfer or friction by running water or atmospheric sources. Speleogenesis is water dependant, which either stream flow or passage of comparatively warm air is responsible for cave enlargement. This differs slightly from the term as used by Kiver & Steele (1975) in giving more cognisance to enlargement by ablation due to direct stream washing rather than only air currents. Evidence from New Zealand to date suggest the former may be the dominant process in cave enlargement in some areas. The two modes of enlargement form opposite ends of a continuum.

The mass of accummulated snow, and gravity, causes movement of glacial ice by basal slippage and plastic flow towards the wastage area, the proportion of total flow in water form increasing towards the terminal of the glacier. Deglaciated lanscapes often exhibit a sinuous ridge of sediment, or esker, deposited by subglacial streams. Stokes (1950) describes an esker in formation, including photographs of its cave of origin. Many of the worlds great rivers still originate in this way: the Ganges for instance combines the waters of the Bhagirath R. which issues via two outflows from the Gangotria Glacier in the Central Himalaya at 4200m. and the Alakanada River from a glacier in the next valley. (Holmes 1965). In Australia the Snowy had its origin as a subglacial stream in the Pleistocene, as did the Forth, Mersey and others in Tasmania.

Water is a vital lubricant to the flow of temperate glaciers as much as a product of their movement. Additional water in the form of melt from tributary valleys and run off from valley walls disappears underground at the ice margin, and supra-glacial meltwater may flow across less fractured areas of the glacier's surface to vanish into glacier mills or moulins, eventually joining the main subglacial streams. Where a number of tributary glaciers combine, the subglacial channels of each may be confined by medial moraines such that a number of discrete cave systems occur in parallel in the same valley, as in the case of the Gangotria-one up on most limestone areas! Peterson & McKenzie (1968) suggested ablation caves to be unlikely to contain ice speleothems due to passage of comparatively warm air, but a seasonal factor is involved.

The largest caves of this type presently known are the Paradise Ice Caves in the Stevens-Paradise Glaciers at 1980-2100m. on the flanks of Mt. Ranier (4395m.) in Washington. Part of the system is a tourist cave (as is another cave in the Rhone Glacier of Switzerland). To-date 3.2km. of passage has been mapped and a further 1.6km. is known, (Anderson & Halliday 1970). The glacier gradient is moderately steep. Passage layout is dendritic with some braiding superimposed due to local topography, and constantly changing as the glaciers retreat and change. Some passages are of crawling dimensions but mostly there are "glorious corridors a dozen or more feet in diameter "(Anderson & Halliday 1969). Most of the cave is on the rock floor of the valley but some is floored by ice. Ice helictites are present, and large columns below moulins.

Anderson & Halliday (1969) attributed its formation to initial melting by running water, but initially suggested that passages were too large to have been enlarged by flowing water, even in seasonal peaks. Instead they suggested circulating air above freezing point became responsible for most of the cave volume, with some warming of the air by heat transfer from subglacial streams, but ingress of warm seasonal air, with seasonal reversal due to barometric differentials, is the principle factor in enlargement. A number of other writers have extrapolated this to caves elsewhere (e.g. Dunkley 1972). A subsequent paper (Halliday & Anderson 1970) records the discovery of stream deposits near the roof which the authors regard as indicative of the action of water remaining important much later into the history of the cave than previously thought. They record a number of other caves all but filled by their stream. Theakstone (1967) has noted that air temperature in caves beneath the Osterdalsisen Glacier in Norway is almost constantly below 0°C.

In Australia Halbert & Halbert (1972) have described meltwater cave development in a residual snowbank near Blue Lake at around 2000m. in the Kosciusko National Park. One cave was 45m. long and 1-1.5m. high, with a gradient of some 30°, and large scale wall scalloping due to air movement. Other bergshrund-like entrances 10m. deep in the same area were not explored due to lack of equipment.

In New Zealand small caves occasionally emerge in the Mueller Glacier near the Mt. Cook National Park Headquarters, to which park staff have taken visitors. The thick, moraine covered valley glaciers around Aorangi (Mt. Cook) approach the conditions suggested by Clayton as optimal for development of karst features; they have recently shrunk downwards some 120m. rather than upstream, and collapse over subglacial water has formed cenotes and karst windows. Shannon (1972) has briefly described caves at the snout of the Hooker Glacier from which three streams emerged, two from siphons, a third from a cave into which shingle banks afforded access for a short distance, and another entered via a karst window.

He noted the characteristic general bluish colour inside, a series of deep river niches, and large wall scalloping much bigger than in limestone caves. Dunkley (1972) entered the Franz Josef outflow in Westland for a short distance, and records a major swallet from an adjacent tributary valley. I have looked very briefly at some others. Overall New Zealand offers tremendous potential for ice caves although little has been done to-date.

Caves and Caving

The reports of Dunkley and Shannon from New Zealand have in one way been discouraging. Shannon somewhat colourfully noted: "you are pelted with rocks at the entrance, get exposure and/or drown if you slip into the river, drown if rain melts the ice and virtually drown if its fine and the ice melts" and that at the Franz Josef outflow "additional forms of sudden death" include "the prospect of being skittled by ice-bergs". Dunkley regarded the latter as "the most dangerous cave I have ever set foot in" and exploration of glacier caves generally to be a "death wish". There are definate dangers. Anderson and Halliday's 1970 paper on the Paradise Ice Caves describes coalescence of scallops to produce deeply undercut hanging "flakes" weighing many tons which may fall with the vibration of a person passing underneath. Their aknowledgements include one for rescue en route to the caves during their study: one person died due to the rapid onset of adverse weather. However Dunkley also noted the swallet he saw at Franz Josef "looked no more dangerous than many a limestone cave in Tasmania".

The dangers have frequently been over-stated. Impressions gained from visiting glaciers accessible to tourist areas are predictably unfavourable. Such locations are frequently at the terminal where subglacial flow is at its maximum and final glacier breakdown occurs. Visits are most likely in summer when water volumes are at their maximum, and problems of high flow are often compounded by fluvial tributaries at such elevations where rain is the dominant form of precipitation. The Franz Josef observations of Shannon and Dunkley for instance were at less than 600m. Ice over cave roofs may be thin in the terminal area and differential heating by the sun of dark coloured rocks can cause them to melt a remarkable distance down through the ice leading to entrance rockfall. Larger scale structural failure of cave passages is also more likely there due to ablation close to entrances. Shannon's shortened time dimension occurs here in its most extreme form and if it is disadvantageous that it includes cavern breakdown then such disadvantages must still be accepted along with the advantages.

After an initial encounter under terminal conditions the likelihood of a second is much reduced, but considerable potential for much safer caving exists at higher levels, and at some risk even the lower caves may be explored: Shannon, and Dunkley certainly lived long enough to write their papers. At higher elevations most precipitation is in the form of snow, and glacial stream caves may probably be more safely entered. Bedrock floors and steep gradients make hanging glaciers a better possibility, but the risk of ice-cliff collapse and avalanche around outflows needs to be borne in mind. Crevasse systems may be a safer means of entry, but moulins are unfortunately often poorly developed if present on the higher glaciers. Early morning after a good freeze would be the optimum time. Standard caving gear would need to be supplemented by ice climbing equipment, and perhaps wet suits if moulin descent was involved. Higher elevation retreating glaciers are likely to be the driest. Fluvial tributaries are likely to be more important to cave development and maintenance where the ice is more active.

One of the problems is simply deciding what entrances are worth looking at: retreating down to the head of the Mueller Glacier in heavy rain last summer, I was amazed at the extent to which the whole valley-side was totally awash, with vast amounts of water disappearing from butresses down bergschrunds and under avalanche cones. Under such conditions the overwhelming number of holes becomes very evident, and in fact can be a quite demoralising thought. Anywhere even late season avalanche debris remains it is likely to be riddled with passages formed along the streams. On the higher neves one could spend a lifetime probing crevasses, probably with little result as far as reaching stream level is concerned, but access is likely to be easier lower down.

The big Westland glaciers show this vertical zonation of horror, promise and frustration very well. The Franz Josef outflow as described by Dunkley in 1972 and when I saw it in 1976 was of much the same form: "30ft. high, 50ft. wide with a turbulent milky torrent of the order of 50 cusecs issuing forth". Inside, fairly deep river niches and exaggerated scalloping similar to that described by Shannon from the Hooker are present. The Fox Glacier is of similar dimensions: In 1978 a serac complex was present 500m. upstream of its outflow above which supra-glacial meltwater ran in sinuous channels across smooth white ice to disappear down moulins towards the subglacial system. Where the glacier changes direction slightly upstream of this, morainic material covered the inside margin, with contorted ice and large crevasses on the outside from some of which subglacial waters were clearly audible. Just below the upper ice fall is a massive swallet where the stream from the Victoria Glacier plunges under the ice margin. The flow was enormous, and access could perhaps be most easily gained via holes on the glacier surface.

Distance from the Victoria swallet to the outflow is about 3km. Above the upper ice-fall and across the neve for several kilometres is a sea of crevasses that doesn't bear thinking about.

Dunkley suggests the Malte Brun Glacier may be a likely prospect, but comparable (or perhaps slightly larger) glaciers on the Sealy Range, such as the Sladden and Melville, seem to produce compartively small meltwater outflows. Caves are doubtless present, the question is what is optimal for large caves. Beaty (1975) suggest 50-80% of total spring snow in the White Mts. of California and Nevada goes by sublimation or evaporation rather than meltwater, high, dry and windy conditions with intense direct and indirect solar radiation providing suitable conditions. That may have some relevance.

Cave Development in New Zealand

Despite the discovery that stream action may have played a larger role in the development of the Paradise caves than initially thought, there is generally considerable evidence for cave enlargement by aerogenic mechanisms. There are likely to be differentials in its significance related for instance, to altitude, : Halbert & Halbert (1972) describe the rapid destruction of meltwater caves developed well below permanent snow-line in Australia, whereas at higher elevation (or latitude) sites where there is sufficient snowfall for firn or ice, that material is not only slower to respond to atmospheric melting, but air temperatures are likely to be correspondingly lower. That is not to say that it is irrelevant there of course, but even if one were to concede that aerogenic enlargement is generally dominant, water is still fundamental to speleogenesis.

Many of the New Zealand outflow streams do not appear to be anywhere near as underfit as those of the Paradise system (at the present state of knowledge). The Fox and Franz Josef outflow entrances, for instance, although of very large size, would probably not be far off adjustment to contemporary peak flow conditions, even allowing for any entrance area subsidence due to terminal ablation. River niches are also present at higher levels on the cave walls, a situation Shannon (1972) also records from the Hooker on the eastern side of the main divide at 910m. It seems likely that fluvial tributaries are important, and fluvial action and heat transfer from subglacial streams is dominant over seasonal barometric airflow in their case, with the role of the latter commonly over-emphasised and under-qualified. Theakstones finding that air temperature is almost always below 0°C. in caves beneath a Norwegian glacier lends some support for this suggestion. It may be that more precipitation in the form of rain at lower elevations in New Zealand, and consequent flooding, removes the evidence of enlargement by air currents.

Sara (1974) gives some indication of just how much water may be involved. As the Franz Josef glacier has retreated substantial entrances have been revealed at the snout, their position dependant upon where the Waiho R. emerges. It is frequently in flood, and large caves form under the ice which occasionally collapse and block the flow, the obstruction usually being gradually removed. After some days of rain in December 1965 the pressure so increased that a section of the terminal face 30m. wide and a strip 300m. long up the western edge blew out. Ice reached the Tasman Sea 19km. distant, was piled up on roads and caught in trees. Rock debris raised the bed of the river downstream by 18m. initially and successive floods increased this to 30m. Some 750,000m^3. of ice, and as much rock debris, was involved. Sara also records the exposure of an apparent collapsed cave at the foot of the main ice-fall in January, 1967, observers in an aeroplane claiming to have been able to see the gravel bed. This closed with continued glacier movement but reappeared after more rain in March, 1967, at which time it was estimated to be 0.4km. in diameter.

From my own limited observations to-date in New Zealand and Patagonia I suspect it may be the case that in the absence of fluvial tributaries glacier catchments and neves need to be fairly extensive in their upper reaches and their lower channels elongate so as to concentrate drainage for substantial caves to be likely. The steep Hochstetter Glacier draining from the Grand Plateau below Aorangi (Mt. Cook) is a good example, with a strong flow issuing from a rather innaccesible outflow cave at the ice-fall. Small glaciers in other areas seem to follow the same pattern. In Patagonia those glaciers draining from the Cuernos del Paine into the Rio Pingo, and those on the flanks of Paine Principal and the peaks on the margin of the southern ice cap west of the Grey Glacier, seem to have somewhat less potential than the lower level, elongate ice mass between the Torres del Paine and Paine Chico, which has fluvial tributaries and a considerable outflow.

On the other hand, really large glaciers may be disappointing. Just as those limestone areas where karst is well advanced may no longer offer the best caving, so may those glaciers optimal for pseudo-karst development in Clayton's (1964) terms not be of most interest to cavers. Moraine covered glaciers with low gradients such as the Hooker, Tasman or Mueller in New Zealand often have holes choked with debris (although on the latter the big swallet of the Ngaroimata waterfall, which falls hundreds of metres from the mountain wall into the ice, would be worth a closer look, as would the Mueller's upstream fluvial tributaries). Apart from the enormous thicknesses of ice the really big Patagonian glaciers often enter the sea or proglacial lakes, (including many of those in the Balmaceda Mts. of Chile and those draining the south Patagonian ice cap). Outflows may be partly or wholly under water with massive unstable ice cliffs hundreds of feet high which collapse to form huge icebergs.

Some Potential Sites for Glacier Caving in New Zealand

Finally some places which look promising:

In the Darrans, the Madelaine has surprisingly little flowing from it, but contributes to a sizeable flow from the Age: the latter however is constantly bombarded by enormous ice avalanches off the south face of Tutoko which don't even stop at night. The Donne looks a good prospect, extending fairly low but of easterly aspect and steep gradient. Further north, a considerable amount of meltwater emerges from glaciers on the Five Fingers Range such as the Whitehead, and others on the Olivines. Some of the larger Olivine glaciers, such as the Andy, have very broken terminal areas. The Joe may be worth a look.

On the Barrier Range, a very large stream emerges from the Blue Duck and also from the Margaret and Dredge Burn Glaciers. These are readily accessible from the Dart Valley. Considerable water seems to flow from the Marion Plateau. In the Snowdrift Range the Snowball Glaciers may be of interest. The Dart Glacier itself may have some potential and a very substantial stream flows from the Whitbourn. The Snow White Glacier which debouches a lot of water towards the Arawata is a fairy-tale place with a special magic, but the stream seems to fall almost immediately into a deep canyon and there were no adequately sized moulins for access in 1978. It is nevertheless very promising and the one of which I would personally most like to have a closer look.

The major glaciers around Mt. Aspiring, such as the Bonar and Volta, terminate high into sizeable streams which frequently emerges from nasty looking ice-falls. Further north in the Westland National Park smaller glaciers such as the Stauchon and Copland are probably worth a look. Both are dead ice masses disconnected from the valley head snowfields and maintained by avalanche and have fluvial tributaries.

The foregoing list has been confined to the most promising of the comparatively small number of New Zealand's many glaciers of which I have some first hand knowledge: there are doubtless many, many more sites of promise, the Whymper and those draining into the Callery among those which look particularly interesting on the map. But virtually every patch of ice offers something. The Westland National Park alone contains 57 glaciers.

One really is left wondering, as Shannon was, "whether the potential of the ice karst in New Zealand might dwarf the tremendous potential of the limestone caves".

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A PLEA FOR INFORMATION

Glacial psuedokarst

Kevin Kiernan is anxious to hear from any persons with information on caves in snow and ice, and would particularly like to make contact with anyone who would like to pursue the matter further. Please write C/- 10 Meath Avenue, Taroona, Tasmania. 7006.

AREA REPORTS

By Ron Mann

This report covers the period 13th July to 8th October 1978, when the Society only managed to field four trips.

JUNEE/FLORENTINE (2 trips)

Two parties of five, consisting mainly of Ambulance Board members and led by Leigh Gleeson and Steve Harris explored Sesame 2 (JF211) over the weekend 5th and 6th August 1978.

The first team led by Leigh Gleeson rigged the ladders through the cave. Leigh explored a lead at the bottom which he pushed for an estimated ten metres downwards but he did not continue because the passage was narrowing and the party was anxious to start back to the surface.

The team led by Steve Harris entered the cave some hours after Leigh's party and de-rigged the cave on their way out. This team also bottomed the cave. At the entrance pitch on the way out, one of Steve's party, Colin Ransley, fell ten metres off the ladder when has hand slipped from his glove. Fortunately Col only suffered shock and muscular injury as his fall was apparently broken by hitting the wall many times and bouncing off a log at the base of the pitch.

On September 18th Leigh Gleeson and four others walked to Satan's Lair to check on the amount of water flowing into the cave in preparation for a future surveying trip. It is hoped that the survey will reveal that the present estimated depth of 470 ft. is conservative.

MOLE CREEK (2 trips)

A general tourist trip led by Steve Harris in September introduced two visitors to Caving. The party spent about two hours wandering in and out of the entrances of Honeycomb.

Georgies Cave was visited on the Sunday and the visitors were impressed with Georgies Hall and Root Hall.

Late in September a party of five spent a beautiful Saturday surface surveying in the Honeycomb - Cow Cave area. The survey began at Honeycomb 2 and took in the entrances of Spider Cave, Roaring Hole and Cow Cave. The survey was closed back to Spider Cave but unfortunately it was found that the tripod used for the survey affected the compass and when the survey was drawn an error of 50 metres was evident. On the Sunday the party looked for a cave that was reported to be in the small quarry near Cheops Pyramid on Scott's property. The entrance had been blocked according to information, and they could only find a narrow tunnel blocked by large rocks. Water divining was attempted near Cow Cave with some success as three of the party obtained indications of a stream below, which is known to be the Mole Creek,