Cave Science

The Transactions of the British Cave Research Association

BCRA

Volume 12 Number 2 June 1985

Cave Science

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Cave Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

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Karst Development and Cave Formation in the Bocock Peak Area, B.C., Canada

D J LOWE

Abstract: The Bocock Formation of the Rocky Mountain Foothills is a massive, speleogenic limestone, 30 to 60 metres in thickness, of limited lateral extent, which locally forms the uppermost part of the Triassic sequence. Speleological fieldwork in 1984 has led to a new understanding of the structure of the Bocock Formation outcrops in the type area, close to Bocock Peak, British Columbia, and an attempt is made to relate surface karst occurrence and the formation of deep underground drainage systems to this complex tectonic structure. Particular reference is made to the White Hole, the ninth deepest cave so far explored in Canada. The complementary effects of climatic variation and vegetation cover upon karst and cave development are briefly considered.

INTRODUCTION

Speleological expeditions to the Canadian Rocky Mountains in 1983 (Lowe, 1983) and 1984 (ACRMSE, 1985) have concentrated on the reconnaissance of relatively thin limestone sequences in areas where depth potential for cave development was believed to be many times greater than the thickness of the cavernous rocks involved. In the Mount Robson area the total thickness of Mural Formation (in two units separated by impermeable strata) is about 200 m, though depth potential appears to be at least 1 km. In the Bocock Peak-Williston Lake area (Figs 1 and 2) the Upper Triassic Bocock Formation varies between 30 and 60 m in thickness with a depth potential believed to be in excess of 1 km. Geological structure in the Robson area is relatively simple (Lowe, 1983), though dips are generally steep and where the structure reacts favourably with the glacially overdeepened topography, the limestone beds swallow large streams at high level and provide massive, generally scree-choked resurgences at much lower levels.

Near Bocock Peak the geological structure is complex. Major risings to account for the large streams sinking at high altitude have yet to be located, but it seems that resurgences must exist close to Williston Lake, a considerable distance from and much lower than the active caves thus far explored. These caves commence in the massive limestone of the Bocock Formation and the passages linking the sinks to the postulated risings will probably lie predominantly, but not totally, within this one, thin, limestone bed. Detailed observations in the area have shown that the complex geological structure has profoundly affected karst development both above and below ground.

At 1947 m (6388 ft) Bocock Peak is the local high point in an area of gently rolling foothill mountains in many ways reminiscent of the English Yorkshire Dales (Fig 3). Much of the land below about 1500 m (5000 ft) is covered by dense coniferous forest or bush (Fig 4), with thick undergrowth and a profuse deadfall of intact or decaying trees. Above the main treeline are areas of thinner bush, usually where soils are thin or impoverished, and areas free of bush where soil is absent, slopes are steep or, more rarely, where poor drainage has produced waterlogged seasonal swamps. A number of the bush-free areas occur on gentle limestone dip-slopes, along limestone ridges and along scree or debris slopes beneath escarpments.

The major surface drainage route in the area is Eleven Mile Creek (Figs 2 and 3) which flows northeastwards to join Carbon Creek, picking up tributaries from the Bocock area en route. To the southwest and north of this area drainage is westwards towards Ducette Creek and ultimately the Williston Lake-Peace River system (Fig 2). Much precipitation is lost by direct absorption into exposed karst, whilst a number of significant streams gathering on impermeable or drift-armoured ground are swallowed by sinks including White Hole, Short Straw and Bocock's Lesser Sink (Fig 3). No significant resurgences are known in the immediate area of Bocock Peak, but a number of minor springs, probably discharging percolation water, have been recognised in the mixed argillaceous and calcareous Pardonet Formation sequence (Triassic) east of Bocock Peak.

To the east of Bocock Peak and its smaller, un-named satellite peaks is the Bocock Depression (Figs 4 and 8), a predominantly flat-floored alluvial basin, which has been loosely termed a polje. Cols in the surrounding ridges are suggestive of drainage channels and the flat floor which locally encircles relict moraine mounds and rocky knolls probably indicates that the basin supported a shallow lake at some stage. Currently no surface drainage escapes the polje in normal conditions, though the area has not been observed at the time of a heavy spring thaw. Surface drainage flowing into the depression is swallowed by innumerable minor sinks at different levels, but the two major and probably perennial streams are swallowed by the White Hole and Bocock's Lesser Sink. Thick peat overlying morainic and alluvial clay probably stores abundant water.

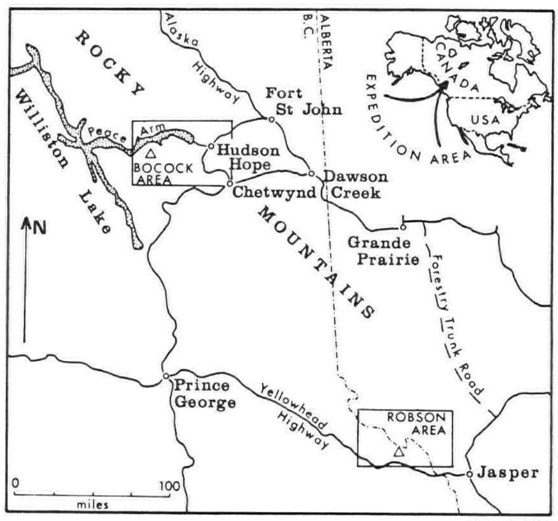


Figure 1 Location of the 1983 and 1984 Anglo-Canadian Rocky Mountains Speleological Expeditions

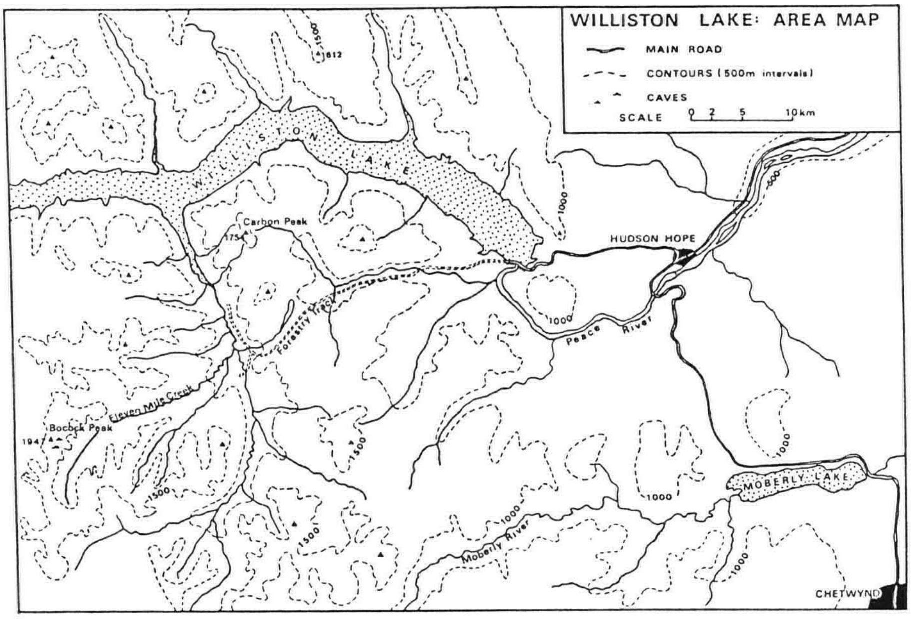


Figure 2

GEOLOGY

The area has been reconnaissance mapped by the Geological Survey of Canada, making abundant use of photogeological interpretation. A small scale map is published and forms the basis of Figure 5. A number of publications deal with the stratigraphy of the area, but the most important stratum in speleological terms, the Bococks Formation, is a minor part of the local sequence and has received relatively little attention (Gibson, 1971 and 1975). Observations during ACRMSE 1984 and subsequent aerial photographic study indicate that whilst the published geological structure is broadly correct, a somewhat more complex fold and fault pattern is required to explain the repeated occurrence of the Bocock Formation (Figs. 6 and 7). The probable local sequence is as in Table 1.

The Bocock Formation, 30 to 60 m in thickness, is exclusively massive, pale limestone. The underlying Pardonet Formation is a mixed sequence of impure limestone and calcareous argillites. No significant pale limestones are recorded in the Pardonet succession, and it is upon the assumption that the Bocock Formation is the only pale limestone present in the area, that the air-photo-derived geological structure (Fig. 6) depends. If significant scarp-forming pale limestones are present in the Pardonet Formation, a simpler structure lacks confirmation by palaeontology or "way-up" criteria and other interpretations are possible.

Those beds younger than the Bocock Formation are entirely non-karstic and effectively impermeable, comprising shale, siltstone and sandstone. The Cretaceous rocks also include typical coal-bearing sequences. As the structural details below point out, these younger beds provide either an impermeable high altitude catchment, or, theoretically, in more extreme circumstances, an impermeable floor to the overturned Bocock rocks.

Impermeable	Gething Formation Beattie Peaks Formation Monteith Formation	Cretaceous
	Fernie Formation	Jurassic
	Bocock Formation	?Triassic
	Pardonet Formation	Triassic

Table 1. Local geological succession

The Pardonet Formation may be locally karstic, though there is no surface evidence to support this. Where encountered underground, in the White Hole, the Pardonet rocks seem to facilitate cavern formation in some circumstances and act as barriers to karst erosion in others (see later).

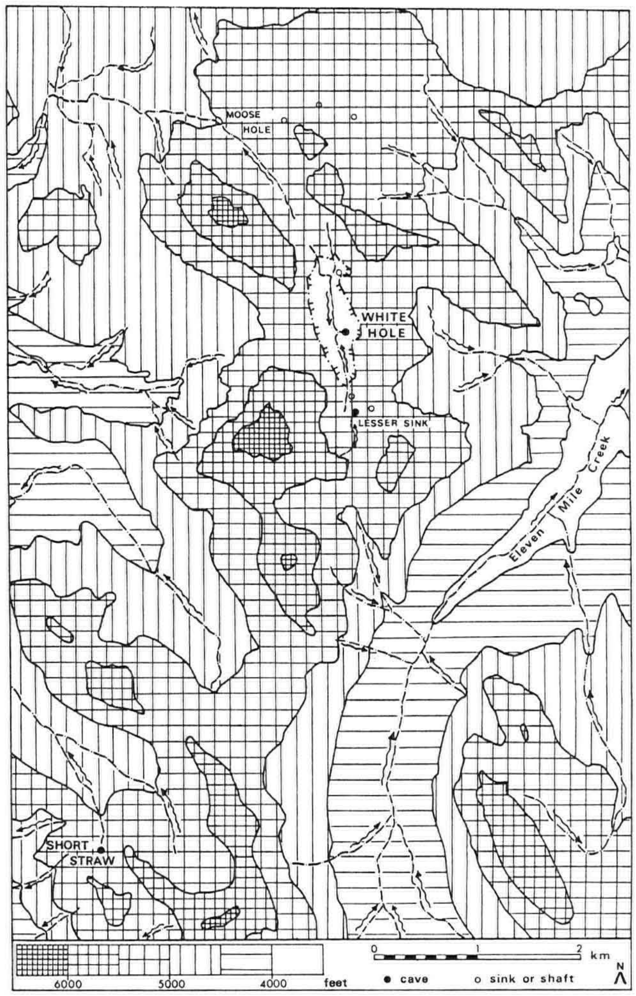
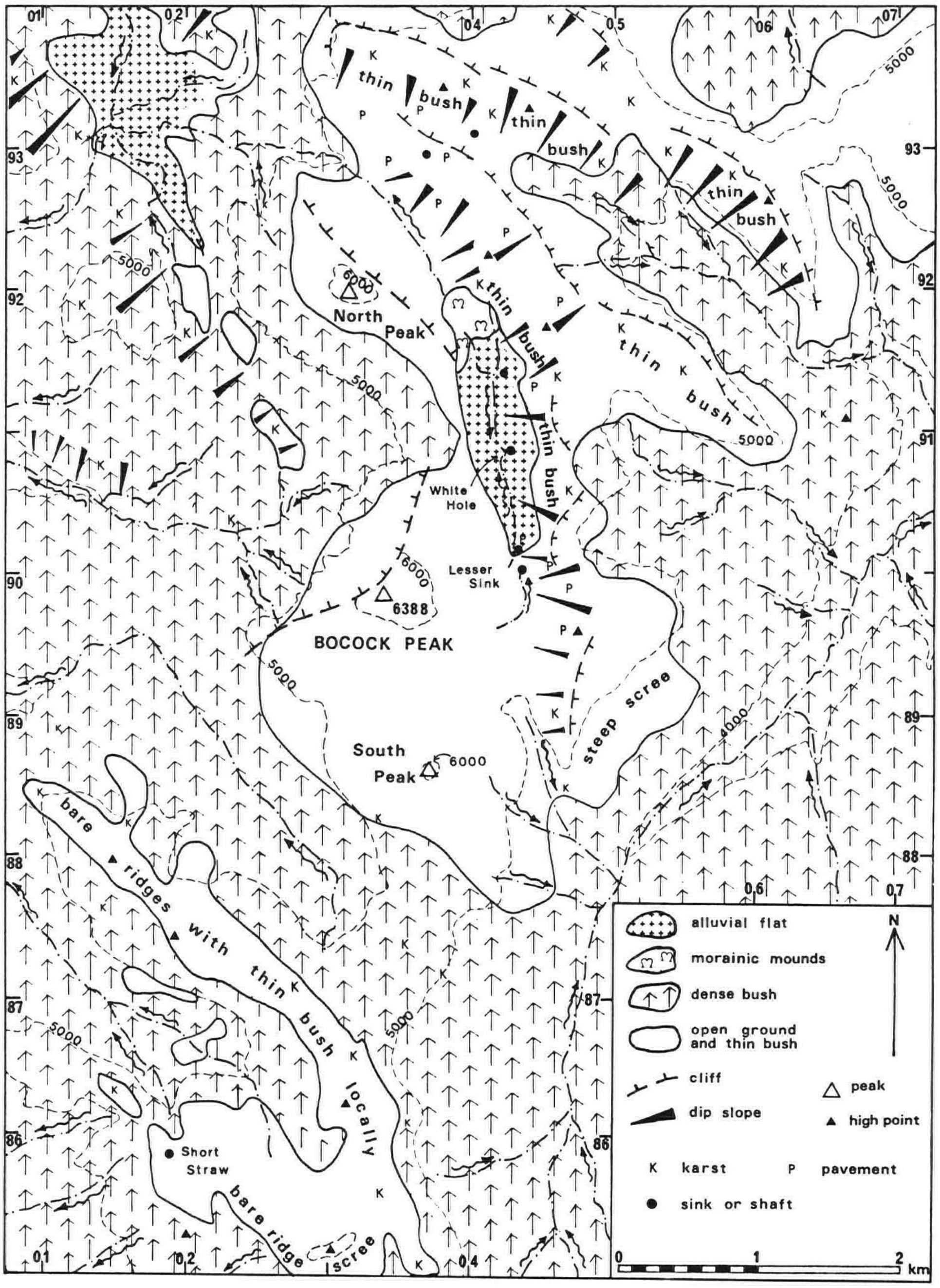


Figure 3 Relief and drainage of the Bocock Peak area. Altitude ornament changes in 500 foot (150 metre) steps

Figure 4 Generalised terrain in Bocock Peak area



The Bocock area lies on the edge of the Rocky Mountains Foothills belt and the main structural trend runs parallel to the long axis of the mountain range, locally NNW-SSE. Compressive stress has been extreme and folding has been locally intense, sometimes leading to overturning. Thrust faulting is also common, though often difficult to recognise, and those fractures which parallel the regional trend tend to be thrusts or high-angle reverse faults, though local accommodation movement might have produced apparently normal faults of small throw. Strike-slip or tear faults have developed quite frequently, being generally more or less perpendicular to the regional trend, and these structures have the effect of dislocating fold axes (Fig. 6). By their nature these faults appear to have highly variable 'throws' and may apparently die out in particularly massive rock sequences, where no marker bands tie down the line of fracture; or they may be limited to one thrust slice.

In general the local topography reflects the geological structure, the higher ground preserving "tight" strata in synclinal cores and the lower ground reflecting the weaker, more open strata, associated with tension in anticlinal folds. In a number of cases anticlines form relatively high ground, but examination shows that here the presence of the massive, resistant, Bocock Formation has been responsible, forming an armoured shell above the Pardonet rocks, often with all the softer, younger rocks scoured from above, probably mainly by glacial action. For instance the major anticline north of Bocock Peak was probably almost completely roofed by the Bocock Formation until, in relatively recent times, the shell was breached by major streams flowing westwards through a gorge, to allow accelerated erosion of the limestone edges just revealed.

A number of folds appear to be overturned (Figs. 6 and 7). It follows that the dipslopes of the Bocock Formation limestone across the area may be normal, with Pardonet rocks below and the Jurassic Fernie Formation above, or inverted, with the Fernie Formation rocks beneath the massive limestone. Various intermediate fold stages are represented, so that, for instance, it is possible to follow a normal limestone dipslope along its outcrop, the dip steepening and eventually becoming vertical or overturned. On Figure 4 only fairly gentle dipslopes are identified since outcrops of Bocock Formation elsewhere, such as near Short Straw in the southwest, are so steeply dipping that their dipslopes are of negligible extent and often only the true thickness of the bed appears at outcrop. Comparison of the relief, morphological and geological maps (Figs. 3, 4 and 6) clarifies the interdependence of these various factors.

Evidence from the caves and deduced from the surface morphology (ACRMSE, 1985) indicates that karst processes were active prior to the last (Late Wisconsin) glaciation in the area, though the current surface morphology and surface drainage, and certain aspects of the underground karst, owe their origins to processes active during and since Late Wisconsin times. It is probable that little major change has occurred in the 10,000 years since the stagnation of the Wisconsin ice.

SURFACE KARST

Surface karst is restricted to outcrops of the massive, pale, Bocock Formation and is developed to some degree wherever these outcrops occur (Figs. 4 and 6) whether in open or bush covered areas. In the bush karstification might well be accelerated due to increased aggressiveness of the soil water. On the other hand the thick vegetation cover would tend to ameliorate extreme climatic variations which must have affected karst development in the open areas. No karst was examined in areas of thick bush. In those areas of thinner bush on the dipslopes east of the Bocock Depression, where progress away from animal tracks is still difficult and the threat of wild animals is perhaps more extreme than in the thick bush, a small amount of time was spent examining classic clint and gryke type karst. The depth and width of the grykes (kluftkarren), though not measured in detail, seemed to correlate with location relative to anticlinal or synclinal structures. On anticlinal folds grykes were common, closely-spaced and generally wide at the surface but rapidly closing down with depth. On synclinal structures grykes were rare and where present were tight. In all areas subsidiary karren forms ran into the major, joint-guided kluftkarren and again, as might be expected from theoretical considerations, these forms were more common in the tensional anticlinal areas and also more pronounced in areas where vegetation cover approached the lip of the major feature. An understandable fear of encountering wild animals precluded an in-depth study of this environment and no entry to cave passage was located in the thin bush.

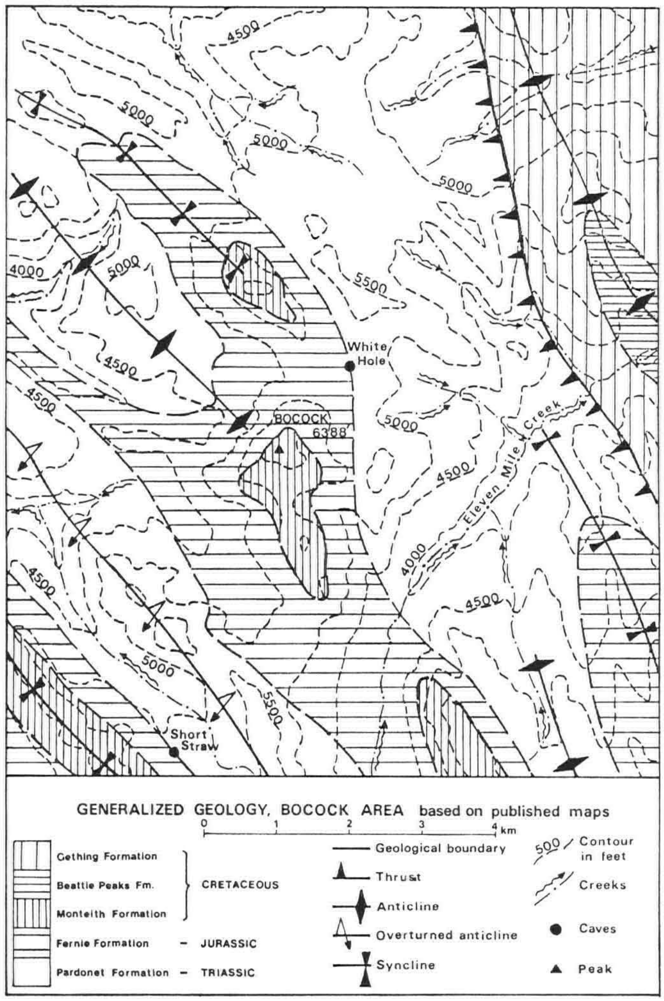
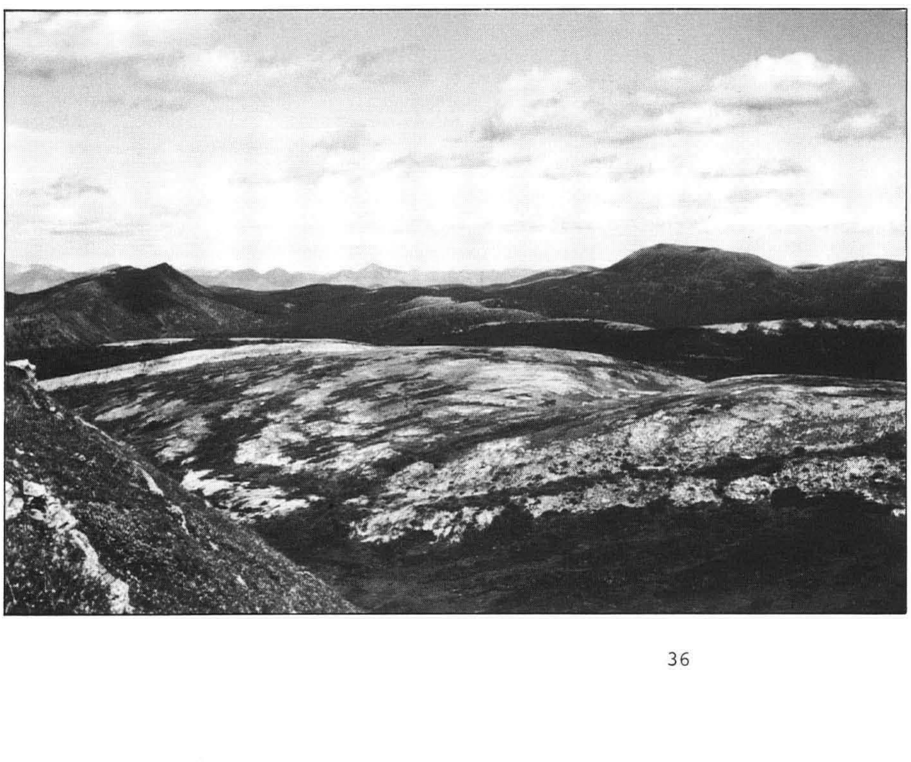


Figure 5

The relatively bush-free areas could be examined in more detail though here again observation was limited and formed part of the general reconnaissance of the areas in search of cave entrances. As in the thin bush kluftkarren were common on the anticlinal structures, particularly the fairly gentle anticline to the northeast of the depression. These features were often of appreciable length and straightness, but



Faulted anticline in Bocock Formation, looking NE from North Bocock Peak ridge Repeated Bocock outcrop in middle distance

Figure 6 Geology of Bocock Peak area, based on the observations of ACRMSE 84. Subject to amendment: some faults omitted for clarity

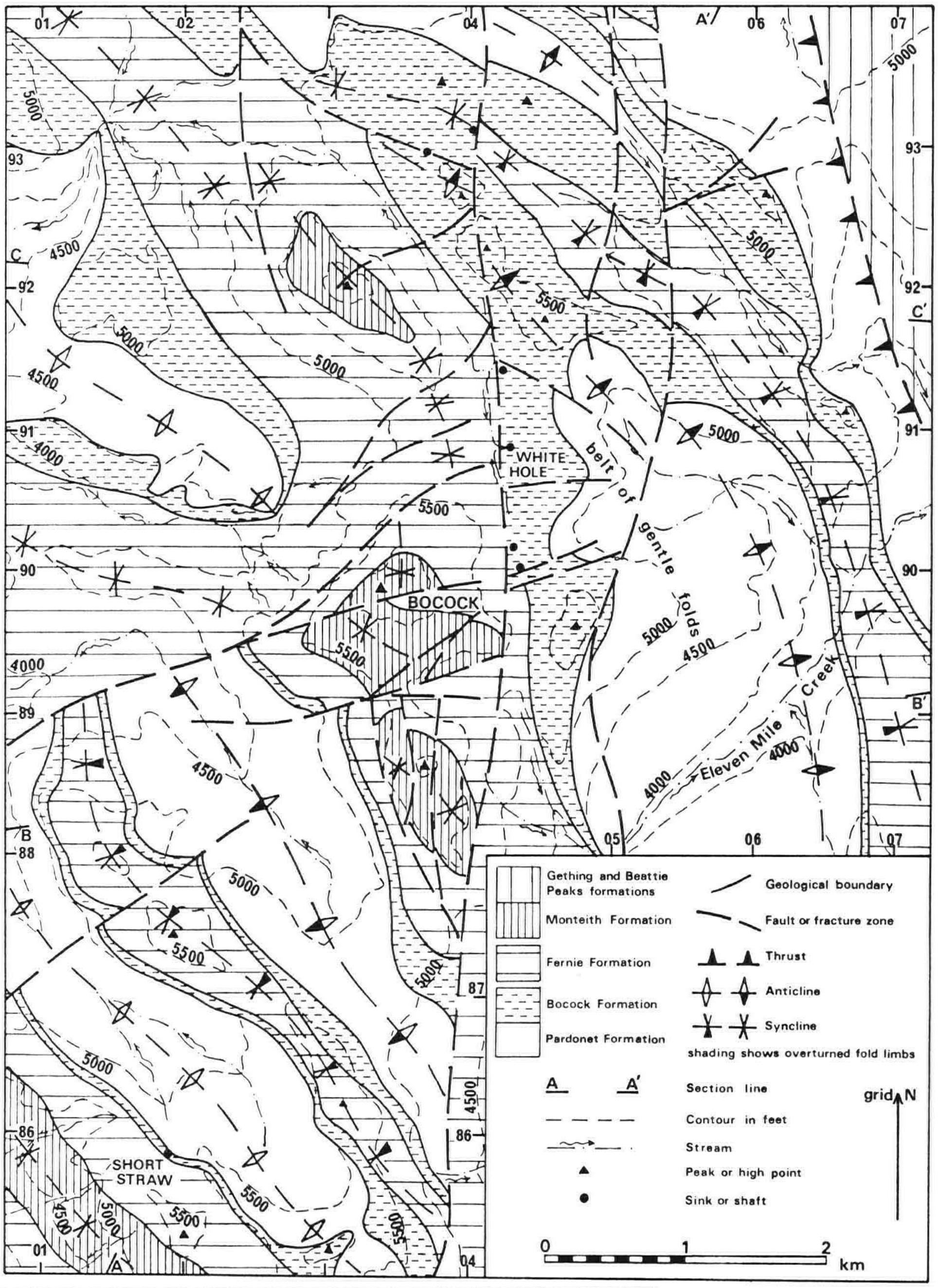
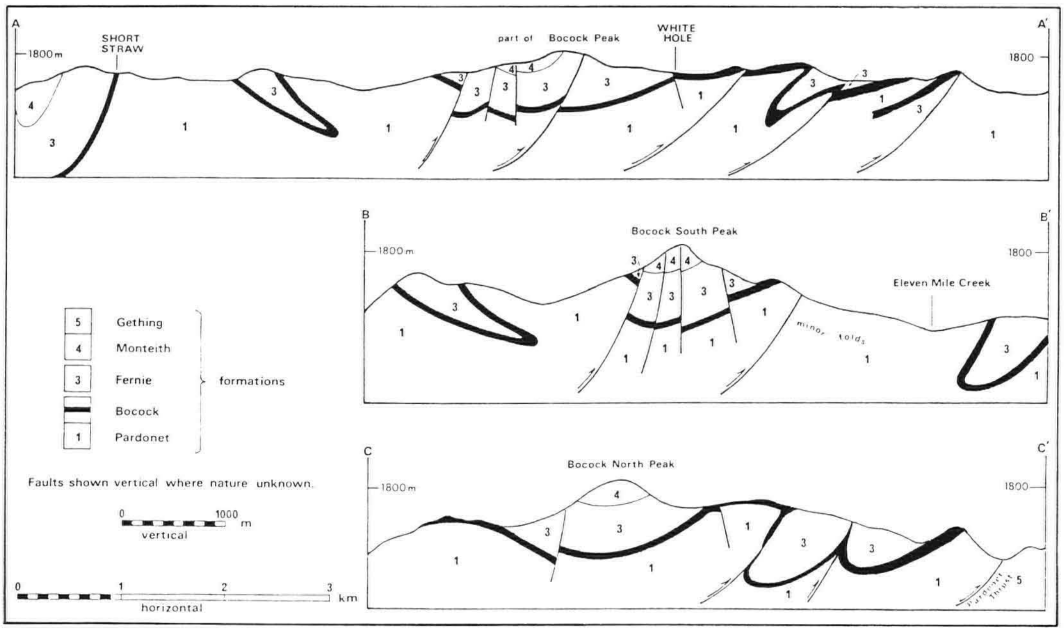


Figure 7 Simplified geological cross sections along the lines shown on figure 6



seldom more than 2 m in depth and only rarely reaching 1 m in width. Generally they become narrower with depth and the evidence suggests that the wider surface expression is due to freeze-thaw weathering as much as to solutional effects. An abundant supply of angular freeze-thaw debris was present in the lower, narrower parts of the karren. Grykes were rarer on the synclinal areas, in accordance with theoretical expectations.

In the open ground it was also possible to examine areas where fractures crossed the limestone outcrop. A number of such lines penetrate the ridges east of the Depression (Fig 8) and they have obviously provided lines of weakness exploited by either ice or surface drainage. Deep and wide kluftkarren were again present in these situations, but here they were generally shorter and sub-parallel to the line of the major structure rather than the regional structural trend, and were en echelon to the major line of movement. A complex interaction of tensional and compressive features was apparent, suggesting that these fractures were probably of strike-slip type, and whilst numerous open grykes were present, there were also areas of compact and unjointed limestone and areas with calcite-healed gashes. As with the fold-guided kluftkarren mentioned above, there was abundant evidence of freeze-thaw modification of these features.

Other karren forms were rare on the open ground, though kamenitza (solution hollows) occurred rarely. This lack of minor solutional forms is probably not a reflection of structure and stratigraphy, but rather the exposure of the rock surfaces to extreme mechanical weathering conditions. The effects of such weathering are visible everywhere and in extreme cases large areas of exposed bedding planes, where normally rillenkarren, rinnenkarren or even trittkarren forms might have been expected, are covered by a thin veneer of angular limestone debris (shillow), reminiscent of frost debris formed on highly cleaved rocks. Again as might be expected this phenomenon was concentrated in tensional areas on anticlinal folds or near fractures whilst in the more compact, compressional areas rare karren forms were visible, though of very gentle aspect. Shallow meanderkarren were probably the most common form.

From the point of view ACRMSE '84 the most significant surface karst features were the sinks, active and abandoned, which were located on the Bocock Formation outcrop. Most of the sinks examined were in fairly gentle dipslopes, 30° or less, but in every case these were associated with major fracture zones. Only one sink, the Short Straw, was found in a steeply-dipping outcrop, and even here a fracture is probably present. The steep outcrops west of Bocock Peak (Fig. 6) have not been examined in detail, with the exception of the Short Straw area, but the evidence of aerial photographs is that other sinks are present where streams run onto these narrow, steep outcrops. Fracture involvement is again indicated, the fractures having guided the surface drainage across impermeable beds, to intersect the Bocock outcrop.

Since the underground karst was not studied in the majority of the sinks and its relation to structural features is unknown, brief mention will be made in this section of the surface features affecting the initiation of these underground drainage routes. The White Hole lies at the intersection or near-intersection of a number of fractures and will be dealt with in detail later. Bocock's Lesser Sink lies adjacent to a notable fault belt, probably of strike-slip type. The major fault line is paralleled by a plexus of smaller fractures and joints and eastwards of the sink a number of abandoned sinks and rifts lie on the same line. The whole belt is highly shattered and loose. Away from the main fault line in the Lesser Sink the rock becomes less shattered and solutional effects become more important. Both phreatic and vadose passage forms are preserved, all lying in Bocock Formation limestone. North of the Lesser Sink are a number of isolated shafts which are apparently fracture guided. One group forms a three dimensional network, much frequented by porcupines, but all choke at quite shallow depth. The strata here are close to horizontal and there is a strong possibility that the wide rifts, which show strong solutional modification, narrow down or pinch out completely at the base of the Bocock Formation. These shafts must certainly carry substantial drainage in wet weather, but the chance of following the drainage to a major conduit or streamway seems slim, except, perhaps, in the case of the Lesser Sink.

North of the White Hole another strike-slip structure crosses the Depression and cuts the eastern ridge. Here again there are a number of shafts and periodic sinks, but all are too tight or are choked at fairly shallow depth. Farther north still a fracture zone is responsible for the Moose Valley, which has numerous inviting shafts in its floor. These too are choked at shallow depth. Only Moose Hole (Fig. 3) seems potentially open, but in 1984 this hole was effectively blocked by an unfortunate, and

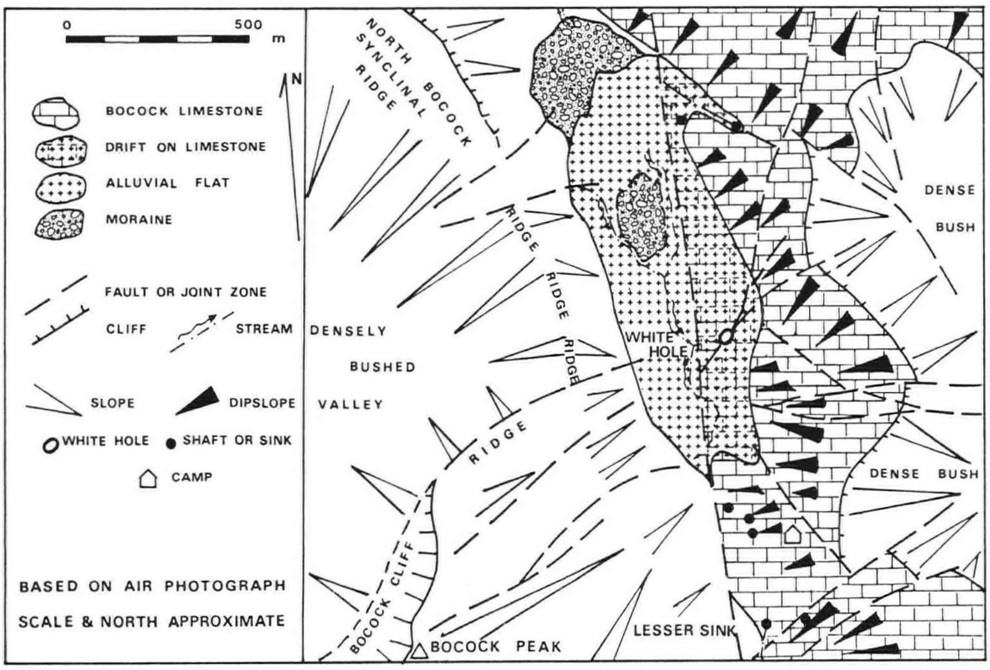


Figure 8 Geology and physiography of the Bocock Depression

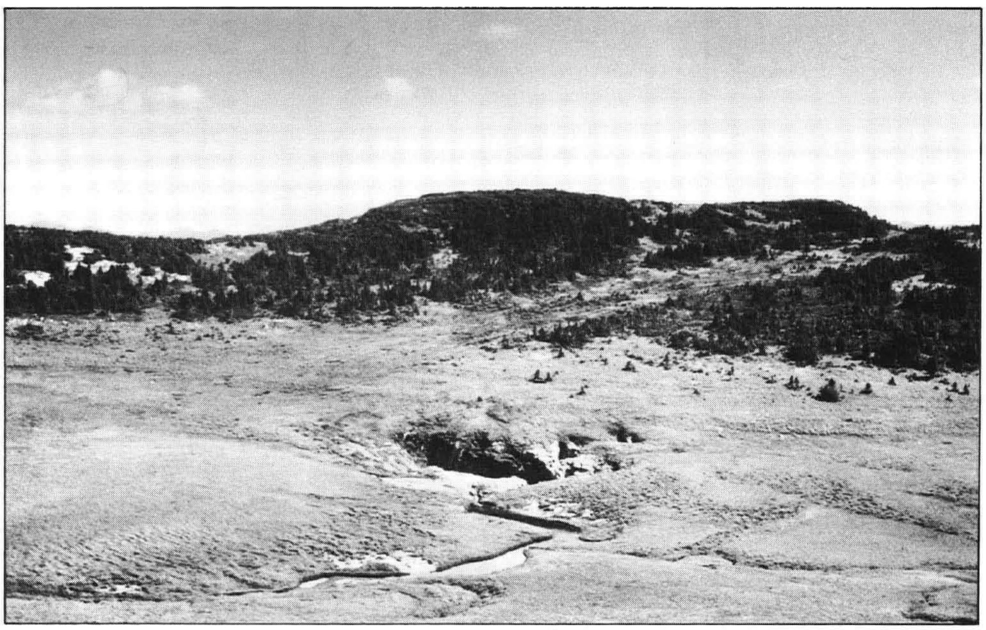
The Bocock Depression

eventually dead, cow moose. On consideration of this potential invitation to grizzly bears and wolves, the site was not revisited. A broad valley to the northeast is structurally complex and has numerous shallow shafts and pavement areas at its northwestern extremity, which is essentially anticlinal, but the floor of the valley, to the southeast, seems to be on a synclinal limb. One significant sink is apparent and was seen to swallow a large stream earlier in the year, before the main team reached the area. This sink is close to a major strike-slip fault which cuts across the valley, but here the way on is blocked by superficial deposits which have crept from the thinly-bushed dipslope above, or been washed in from the alluviated valley floor.

No further sinks were located. What appeared to be a significant closed polje to the northeast turned out to have an outlet at its western extremity, where the Bocock beds dipping eastwards and forming the armoured shell of an anticlinal structure, had been breached by the westward drainage to form a steep gorge. Whether this gorge owes its origin to the collapse and erosion of an earlier underground route is debatable. However several streams cross the polje and exit by the way of the gorge, and the possible presence of abandoned underground routes in this area cannot be ignored - perhaps at a slightly higher level on the Bocock Formation dipslopes.

As pointed out above, the steep, narrow outcrops of Bocock Formation limestone west of the Bocock peaks were not minutely examined. The ridge which holds the Short Straw was reconnoitred where bush-free, but other ridges between here and the peaks remain to be examined. One ridge, essentially free of bush, marks the trace of a steep, overturned syncline and, though only relatively short dipslopes are visible, aerial photographs indicate a well-developed karst with a number of possible sink points. The Short Straw itself is formed entirely within the Bocock Formation, here with an estimated thickness of only 30 m, and brief details of the effects of this stratigraphic control will be included in the next section.

White Hole, seen from the west



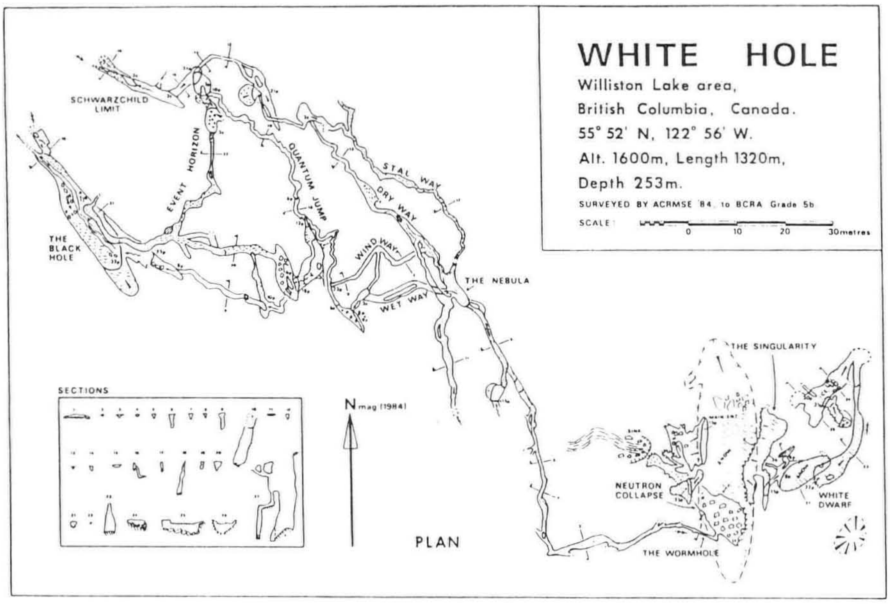


Figure 9

UNDERGROUND KARST

Since much of the Expedition effort in 1984 was concerned with the exploration and survey of the White Hole (Roberts, 1985 and ACRMSE, 1985), this section will deal predominantly with the effects of structure and stratigraphy on the development of this cave (Figs. 9, 10 and 11).

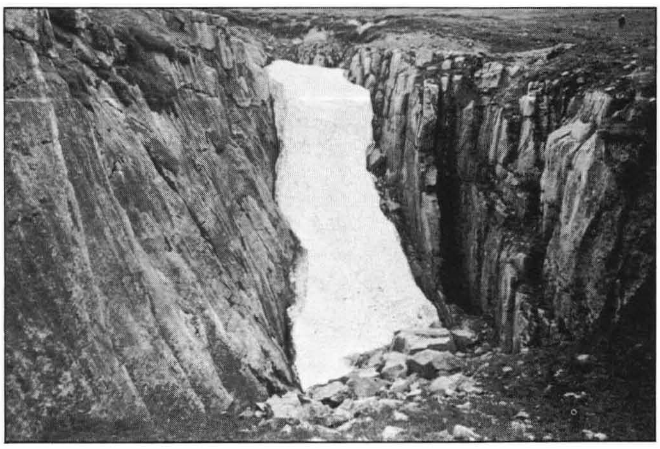
The White Hole is the major sink for the internal drainage of the Bocock Depression, an impressive chasm up to 40m long, 15m wide and 15m deep which lies at the lowest point in the polje. A large stream from the north enters the sink complex throughout the non-frozen part of the year. In very wet conditions additional drainage flows from the north and streams from the south and west also converge on the chasm. At the time of the 1984 Expedition only the major stream from the north was sinking, but aerial photographs reveal traces of a web of stream courses leading across the floor of the depression towards the White Hole.

Observations made here, and deductions made with the benefit of the completed survey, computer derived stick elevations (Bennett, in Roberts, 1985) and with hindsight, are probably applicable to any cave systems which are yet to be located in this area. Study of the White Hole plan and elevation, and of Figure 11 will aid understanding of this account and the nomenclature used. A similar account is included in the report of the 1984 Expedition (ACRMSE, 1984).

The White Hole comprises two almost identical systems, each with its own distinct characteristics. Generally, in the White Dwarf Series vertical shaft development predominates, guided by major joints and sub-vertical faults of small throw, some of which are exposed at the entrance. These shafts and those comprising the Singularity, are large and contain abundant breakdown material, especially close to the base of the Bocock Formation. The stratigraphy in this section is uncertain, but it is possible that these shafts initially formed by water sinking down the weaknesses mentioned in the massive Bocock limestone, to be enlarged at a later stage where this rock was juxtaposed against mechanically weak Pardonet Formation strata. There is no evidence to suggest that the calcareous argillite (or argillaceous limestone) of the Pardonet is capable of supporting primary, solutional, cavern formation, but where brought into contact with an abundant water supply, for instance by faulting, its calcareous matrix is probably removed to produce rottenstone-type lithology, readily removed by corrosion and breakdown. Figure 11 shows the deepest White Dwarf pitch penetrating into the Pardonet Formation, but it must be pointed out that this is only on one wall of the fracture. Passages leading off downdip in the basal Bocock Formation are obscured by Pardonet-derived debris. The initiation of these passages was the earliest recognisable phase in the development of the White Hole and was almost certainly pre Late-Wisconsin. Current surface morphology is not related to the primary sinks and the open entrances to White Dwarf and Singularity must represent glacially unroofed sections of the early cave. It is convenient to consider this phase as pre-glacial, thus allowing for surface modification by glacial activity and the development of additional sinks during interglacial periods.

A precise chronology is impossible to ascertain but the evidence of active and abandoned sinks forming part of the White Hole system indicates a steady westward migration of sinks, from the White Dwarf to the current active sinks. Evidence for an underground link between the White Dwarf and Singularity systems and the current stream route is lacking, a strong possibility being that the early sinks developed lithologically guided dip tubes at a lower level than the present terminal chokes, and due to the geological structure, at a level below the present active route. All this section of the cave lies to the southeast of a reverse fault which runs along the length of the main chasm and throws down to the southeast.

The earliest sink to drain into the limestone block northwest of the reverse fault probably lay



White Hole main rift, with the main entrance right of the snow bank in closely jointed limestone

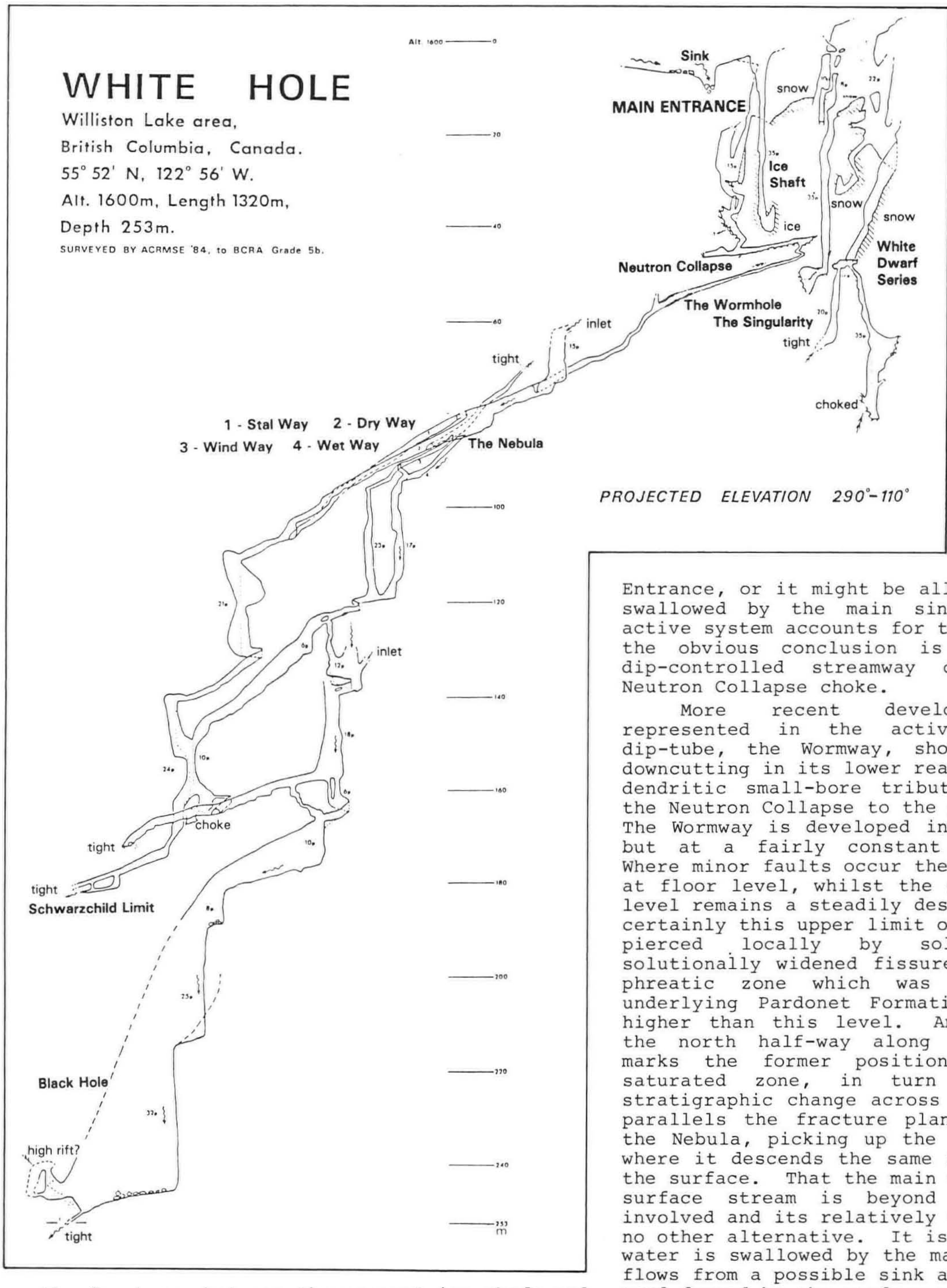


Figure 10

on the fracture, between the present ice shaft and White Dwarf at a site now destroyed by expansion of the main chasm. A set of closely-spaced fault-parallel joints or shears has allowed the main chasm to form, though it is uncertain at what period it developed its present dimensions. Drainage from this hypothetical sink formed the passage known as Neutron Collapse, a huge dip-tube, now largely filled by blocks and rubble from the surface chasm. The ice shaft formed somewhat later and its drainage probably followed the same route, whilst the present Main Entrance also carried drainage at about this time, along tubes which are now choked, to join the Neutron Collapse beyond its current northwestern termination. A high-level joint-guided tube passage, presumed to be a high-stage overflow, is the only open link between the Main Entrance and the Neutron Collapse; its age is uncertain. Beyond the northwest choke in Neutron Collapse a stream can sometimes be heard, which might be the meltwater stream which showers down the Main Entrance, or it might be all or part of the water swallowed by the main sink. No inlet to the active system accounts for this audible stream and the obvious conclusion is that an independent dip-controlled streamway continues beyond the Neutron Collapse choke.

More recent development phases are represented in the active cave. A winding dip-tube, the Wormway, showing signs of vadose downcutting in its lower reaches and with numerous dendritic small-bore tributary tubes leads from the Neutron Collapse to the present active canyon. The Wormway is developed in the Bocock limestone but at a fairly constant stratigraphic level. Where minor faults occur the passage usually drops at floor level, whilst the original phreatic roof level remains a steadily descending plane. Almost certainly this upper limit of passage development, pierced locally by solutional bells and solutionally widened fissures, mirrors an ancient phreatic zone which was sub-parallel to the underlying Pardonet Formation and only slightly higher than this level. An abrupt diversion to the north half-way along the Wormway probably marks the former position of a step in the saturated zone, in turn corresponding to a stratigraphic change across a fault. The passage parallels the fracture plane at least as far as the Nebula, picking up the main stream on route, where it descends the same fracture from close to the surface. That the main water derives from the surface stream is beyond doubt - the volume involved and its relatively warm temperature allow no other alternative. It is uncertain whether the water is swallowed by the main sink or whether it flows from a possible sink at the western end of a pond formed by the surface stream. As pointed out previously, the main sink water could enter an older drainage route beyond the Neutron Collapse.

From the Wormway-Mainstream confluence the passage shows remnant half-tubes locally, though more recent vadose entrenchment has greatly increased the passage size. Speleothem and allogenic deposits are preserved locally, indicating at least one period of predominant depositional rather than erosive activity prior to the vadose initiation. This phase may be associated with short warm phases within the Wisconsin glacial period, whilst the most recent and complex phase of development probably commenced with a lowering of the local phreatic zone in response to the overdeepening of surface valleys postglacially. Remnants of earlier phases are difficult to identify lower in the cave.

As the piezometric surface lowered with the deglaciation of the valleys all round Bocock Peak and conditions of high flow ensued, rapid canyonisation took place. With fairly high,

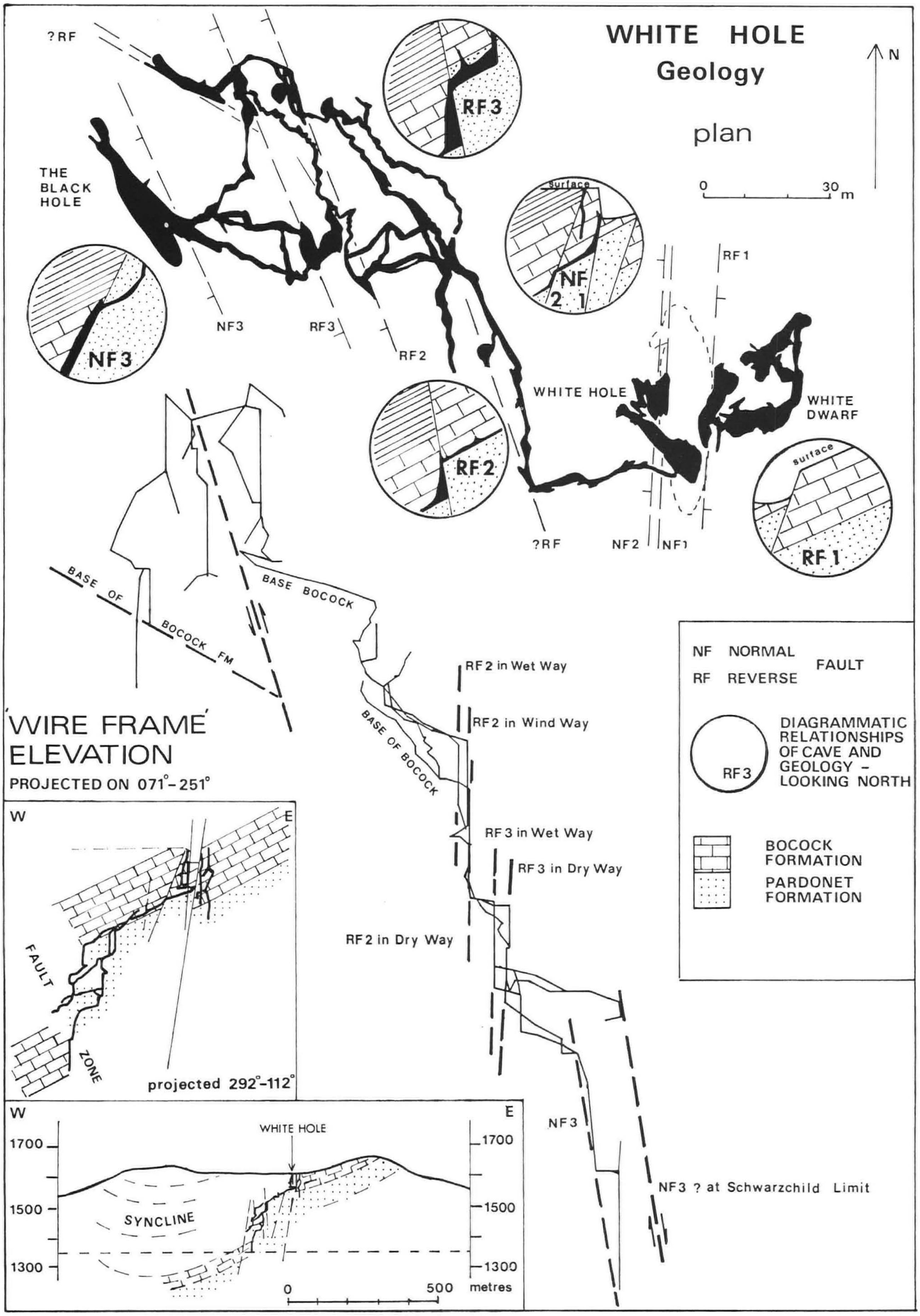


Figure 11 Interpretive geology of White Hole

lithologically or structurally-controlled gradients, passages and shafts were quickly abandoned, leaving sub-parallel fossil routes such as the Stal Way and the Dry Way. Such piracy is common in the system, and without going into detail of each intermediate step, the following sequence is suggested:

Stage 1

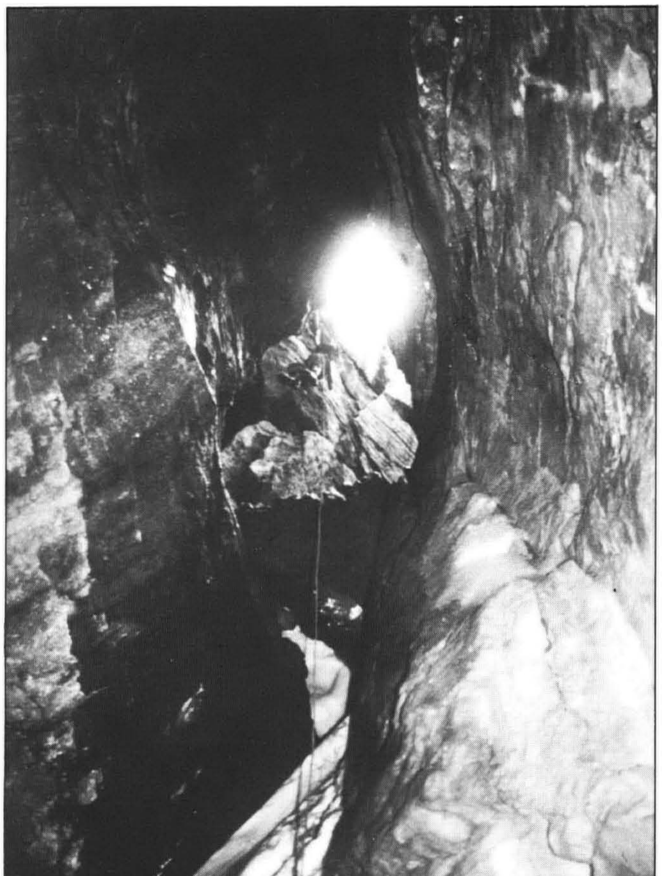
The main stream followed the Stal Way, which was the original phreatic route, and is partly blocked by interglacial deposits. Simultaneously some drainage was flowing along the sub-parallel but slightly down-dip Dry Way. The Dry Way might have formed as a meander off-cut of the Stal Way, leaving the latter high and dry in normal flow, or it might have commenced as an independent streamway fed by a surface sink (now inactive) and flowing through a currently choked and draughting passage upstream of the Nebula. If the latter possibility, then the Stal Way drainage would have been captured by headward erosion of the proto-Dry Way.

Stage 2

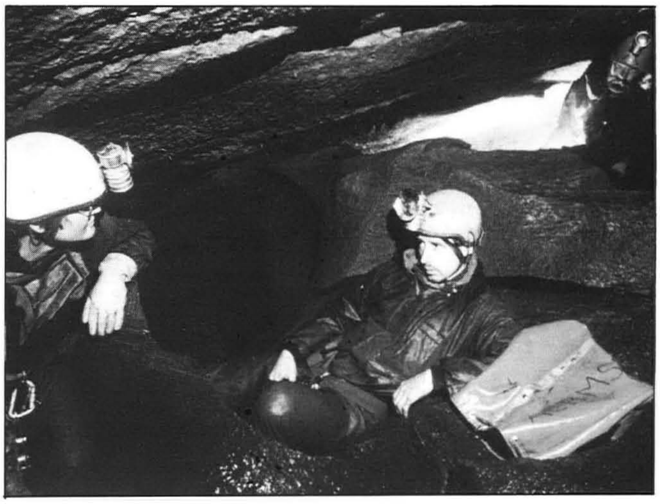
The Wind Way (now a dry by-pass) was probably the next active route, punching through to the lower levels by abandoning its dip-controlled route on top of the Pardonet Formation to drop down a strong fault or joint plexus (which is also responsible for the first pitch in the Dry Way) and then following the same weakness along the top of the Pardonet Formation in an alternately dip- and strike-controlled passage (the Quantum Jump) to rejoin the Dry Way at its second pitch. The eastern (hanging) wall of the Quantum Jump is composed, at least in part, of argillaceous Pardonet Formation strata.

Stage 3

The Quantum Jump was itself abandoned as the stream cut down the same structural weakness to form the dry 12 m pitch and to intersect the



Looking up the White Dwarf entrance pitch, elongated due to fault control



Solutional development in the Bocock Formation, at the Nebula in White Hole. Tubes are stratigraphically controlled and extend down dip

Pardonet Formation at the chamber above Tristal Pitch. Here corrasion of the Pardonet Formation has occurred and the chamber floor is cut well into the argillaceous limestone. Tristal pitch is formed on a major fracture, which could just possibly be the same high-angle fracture responsible for the pitch and passage development previously described. The Pardonet Formation steps down again and the cave took on dip-control 18 m down Tristal, where the Event Horizon led off, again taking the drainage back to the Dry Way. This route involves a number of complex phreatic roof links and lower level passages which are mostly silt or boulder-blocked.

Stage 4

Mechanical erosion continued and water hammering down Tristal pitch cut downwards into the Pardonet Formation, eventually opening up the Black Hole, a 60 m high rift. Close to the top of the Black Hole the argillaceous Pardonet Formation rocks appear to have been penetrated into a band of marbled limestone, but whether another structure is involved or if this is a stratigraphically lower bed is uncertain. The onward route at the foot of the pitch rift is silt choked, the silt being derived largely from the argillaceous rocks. Draughting small-bore tubes lead on, but these might be of recent paragenesis in response to long standing paraphreatic conditions imposed by this, or earlier, silt blocakages.

The above is a very simple outline. Many intermediate piracies can be identified, such as the current wet route (which is conveniently by-passed by the Wind Way Pitch) and the undescended wet route by-passed by the 12 m pitch at the start of Quantum Jump.

Throughout the cave the effects of dip have been important in controlling passage development, but this in turn is merely a reflection of the junction between the Pardonet and Bocock Formations. Even with this control however, the White Hole would not reach its presently explored depth without the superimposition of structural features in such a way as to step the speleogenic Bocock limestone down along the length of the cave. Structural interpretation based on surface and underground exposure suggests that greater depth potential exists beyond the current ends of Black Hole and the Schwarzchild Limit. Unexplored passages might be expected to drop to the level of the downward limit of the North Bocock Peak syncline, or to the level of saturation associated with this structure. The most optimistic scenario is that a major drainage route follows the plunging axis of the syncline generally northwards, ultimately to reach the postulated resurgences close to Williston Lake. Complex structures are probably present on route.

To the west of Bocock Peak, several steeply-dipping outcrops of Bocock Formation limestones are present, but only one significant cave, the Short Straw, has been explored to date (Figs. 6 and 12). The precise age of the Short Straw is unknown, but it is suspected that the major part of the system is pre-Wisconsin. Currently a small, underfit, stream drains into the Short Straw from an adjacent boggy area : the size of the original catchment is unknown. Here the dip of the Bocock Formation is very steep and the stream sinks on meeting the upper surface of the limestone after flowing off the Fernie Formation. Cave development is limited to the Bocock Formation. Cave development is limited to the Bocock Formation, but it seems that at least one fracture is involved. From the sink the cave drops rapidly down into the limestone before taking a fracture guided strike-oriented route along the Ramp. Beyond the Ramp, the Canyon is essentially down-dip, its lower surface probably guided by the effectively impermeable Pardonet rocks below. Beyond, the short length of passage between the Canyon and the big pitch (which glories in the name "In Space No-one Can Hear You Scream") must follow a fracture, possibly juxtaposing Bocock limestone against Pardonet Foramtion rocks, though the latter were not reported by the explorers. The big pitch (37 m) is assumed to drop through the full available thickness of Bocock limestone (this being an apparent thickness due to the effects of dip, and probably equivalent to a true thickness of about 10 m) until diverted by the underlying Pardonet Formation. At the foot of the pitch the cave takes on a horizontal trend again, following the strike of the Bocock/Pardonet junction until choked by cobbles. The dip of these beds is so steep that is seems the choke is of limited extent and a way on could be easily excavated a few metres to where the fracture system, or systems, encountered higher in the cave might be intersected.

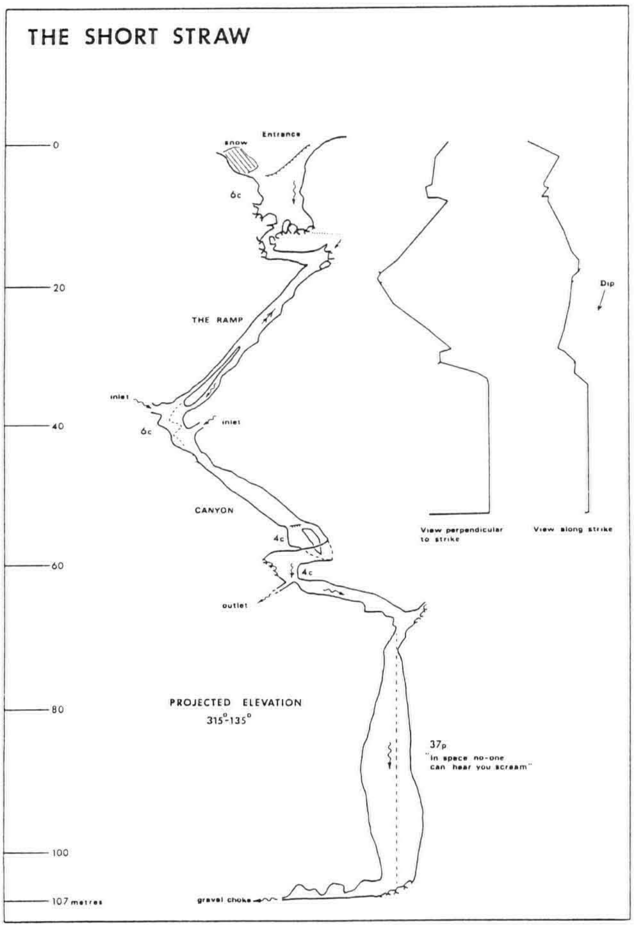


Figure 12

CONCLUSIONS

Though a small thickness and forming only a small proportion of the local stratigraphic succession, the Bocock Formation is highly speleogenic. Complex geological structures including steeply dipping fold limbs, high-angle reverse faults and thrusts have enabled cavern formation to an explored depth of 253 m (theoretical potential more than 1 km) essentially in the single limestone bed which does not exceed 60 m in thickness. East of Bocock Peak the structure has produced a number of gentle dipslopes, some normal, some overturned, where karst development has been influenced by climatic variation and vegetation cover, as well as tectonic setting.

Potential for future research

As pointed out, the depth potential in the Bocock Peak area appears to be in excess of 1 km. The 1984 Expedition explored less than half of the outcropping Bocock Formation, and both major cave finds still hold strong possibilities of extension. That such impressive karst and cave development should occur on a limestone formation varying only up to 60 m in thickness is encouraging. It is obvious that the potential for karst studies in the Canadian Rocky Mountains is vast. Many much thicker limestones sequences in high relief areas remain to be penetrated and seriously explored. Potential vertical cave development up to 3 km has been reported, but remains to be substantiated by future, hopefully well-supported, expeditions.

ACKNOWLEDGEMENTS

The material assistance of all sponsors of the Anglo-Canadian Rocky Mountains Speleogical expeditions is noted, with thanks, in the appropriate reports. All members of the 1984 team provided a measure of inspiration for this paper, though the author claims sole responsibility for the conclusions drawn. The help of Paul Hatherley (some figures), Tony Bennett (computer-derived cave elevations), Pete Robertson (some photographs) and Christine King (typing) has made the paper possible.

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Some Biological Results of the British New Guinea Speleological Expedition 1975

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Abstract : The cave fauna collected during the British New Guinea speleological expedition of 1975 includes a number of highly troglomorphic species. These are mainly non-relictual terrestrial species within locally dominant, endemic taxa, plus a few possibly relictual freshwater species within primarily marine taxa.

INTRODUCTION

The 1975 expedition was one of the largest of its sort to be mounted from Britain. Twenty five cavers spent 5 months exploring an area of over 25,00km² of limestone terrain varying in altidude from 600 to 4,000m (Brook, 1976). The expedition culminated in the discovery and exploration of the 20km long Selminum Tem, at that time the longest cave in the southern hemisphere. Two members of the team conducted biological studies. They were Dr. Petar Beron, of the Bulgarian National Museum in Sofia, and the author.

This paper indicates the state of progress of ongoing taxonomic studies of the biological collections and presents some results.

RESULTS TO DATE

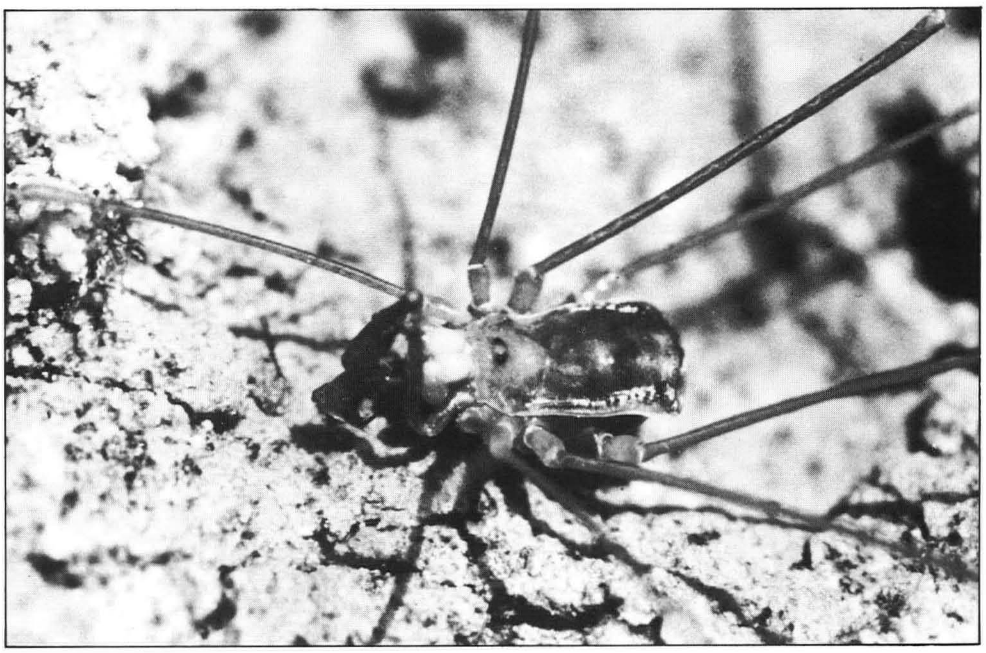
From the small amount of published material on our 1975 collection and later collections made elsewhere in PNG, and from correspondence with the specialists involved in work on these collections, a fascinating picture is starting to emerge. The highland cave fauna of PNG is rich in highly troglomorphic species from a variety of taxa. Some examples are given below:

Collembola

Deharveng (1982) figured the claw structure of an undescribed Pseudosinella from Selminum Tem, which is more troglomorphic (sensu Christiansen, 1961) even than P.carthusiana, the most troglomorphic species known from caves in France. The undescribed PNG species was figured by Chapman (1976), when it was referred to as the "large, white, "hump-backed" Collembola (Entomobridae?)". Deharveng (1983) described a new species of neanurine collembolan, Coecoloba plumleyi, from Selminum Tem and Ok Kaakil Tem (the latter collected by Noel Plumley during the 1978 British Speleological Expedition to Papua New Guinea). This species is characteristically seen on the free water surface of pools, and was referred to (inaccurately!) by Chapman (1976) as the "collembolan with a water-repellant covering (Sminthuridae?)". Like the new Pseudosinella, the new Coecoloba has an exceptionally troglomorphic claw structure, unique among the Neanurinae, and obviously designed to move across and escape from free water surfaces (the mechanism involved is described by Christiansen (1965)), which can trap Collembola whose claws are not so modified. This might be expected in view of the close dependence of the more troglomorphic species of the Finim Tel Plateau on regularly flooded cave habitats (Chapman, 1976).

Beetles

The Carabidae known from PNG caves were listed by Emberson and Moore (1982). They comprise 12 genera and 18 species, all except two of which belong to the regionally dominant tribe, Agonini. Of these, the two new species from Selminum Tem, described by Moore (1978) as Speagonum mirabile and Gastragonum caecum, and three undescribed species from Atea Kananda (Altagonum sp. and two n.gen., n.sp.), are all troglomorphic, having attenuated appendages and



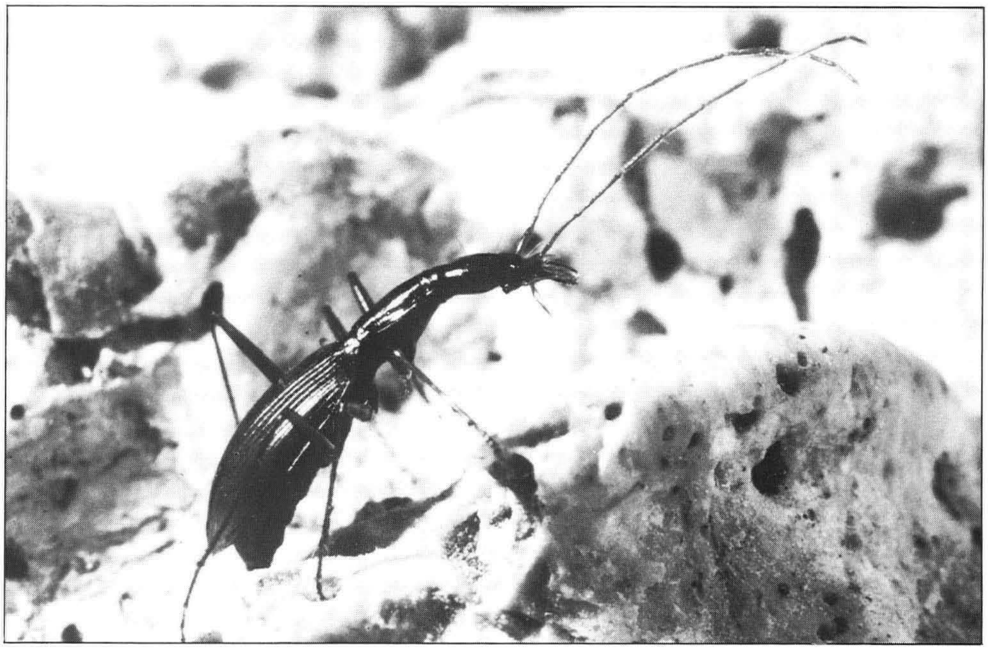
An undescribed harvestman from Selminum Tem

TABLE 1. SUMMARY OF THE STATE OF KNOWLEDGE OF THE INVERTEBRATE CAVERNICOLOUS FAUNA OF THE TELEFOMIN AND FINIM TEL AREAS OF THE UPPER SEPIK REGION, PAPUA NEW GUINEA, BASED ON MATERIAL COLLECTED DURING THE BRITISH NEW GUINEA SPELEOLOGICAL EXPEDITION, 1975.

CLASS	ORDER	FAMILY	GENUS AND SPECIES	REFERENCE*
Turbellaria	Temnocephala	?	?	no specialist
	Tricladida	?	?	no specialist
Polychaeta	Errantia	Nereidae	Namanereis beroni Hartmann-Schroder & Marinov	Hartmann-Schroder and Marinov, 1977
Oligochaeta	Prosopera	?	?	Ziczi, since 1977.
Hirudinea	Gnathobdellida	?	?	no specialist
Gastropoda	Mesogastropoda	Hydrobiidae	2 species indet.	Angelov, since 1978.
Bivalvia	Eulamellibranchia	?	?	no specialist
Crustacea	Cyclopoidea	Cyclopidae	Acanthocyclops viridis	Naidenow det.
	Isopoda	Anthuridae	Cyathura beroni Andreev	Andreev (in press)
		?several	?	Dalens, since 1979.
	Decapoda	Sundathelphusidae	Rouxana phreatica Holthuis	Holthuis, 1982.
Chilopoda	Scolopendromorpha	?	?	Demange, since 1977.
Diplopoda	Polydesmida	Paradoxosomatidae	Eustrongylosoma exiguum Hoffman	
			Astromontosoma jeekeli Hoffman	
			Selminosoma chapmani Hoffman	
			Nothrosoma beroni Hoffman	
			Aschistodesmus sp.	Hoffman, 1978.
		Doratodesmidae	Scolopopyge pholeter Hoffman	
			Selminarchus hispidus Hoffman	
		?	?Opisthoporodesmus sp.	
Arachnida	Pseudoscorpionidea	?	Sternophorellus cavernae Beier	Beier, 1982.
	Araneae	Dipluridae	Masteria sp.	
		Oonopidae	Ischnothyreus sp.nov.	
			Opopaea sp.nov.	
		Pholcidae	Spermophora sp.nov.1	
			Spermophora sp.nov.2	
			Trichocyclus sp.nov.1	
			Trichocyclus sp.nov.2	
			Trichocyclus sp.nov.3	
		Araneidae	gen.et spp.indet.	
		Metidae	Neoprolochus sp.nov.	Brignoli, since 1976.
		Linyphiidae	Afroneta sp.nov.	Brignoli, 1981 and Beron
			"Erigone" sp.nov.	pers. comm.
		Theridiosomatidae	Theridiosoma sp.nov.	
		Mimetidae	"Ero" sp.nov.	
		Nesticidae	Nesticella sp.nov.1	
			Nesticella sp.nov.2	
		Theridiidae	Argyrodes sp.nov.	
			Achaearanea sp.nov.	
		Gnaphosidae	gen.nov.,sp.nov.(Gnaphosinae)	
		Eusparassidae	gen.,sp. indet.	
		Agelenidae	Orepukia sp.nov.	
		Amaurobiidae	Badumna sp.nov.	
		Uloboridae	Daramulunia sp.nov.	
	Opiliones	?	?	Silhavy, since 1976 (no longer answers letters)
	Acari	?	?	Beron, since 1975.
Insecta	Collembola	Neanurinae	Coecoloba plumleyi Deharveng	Deharveng, 1983.
		Entomobryidae	Pseudosinella sp.	Deharveng, 1982.
			Sinella sp. or spp.	Deharveng, 1982.
	Diplura	?	?	Conde, since 1980.
	Trichoptera	Rhyacophilidae	Edpercivalia sp.	
		Polycentropidae	Polycentropus grandis Kimm.	Kumanski, 1979.
			Polycentropus sp.,larva	
	Hemiptera	Cixiidae, etc.	?	no specialist
	Diptera	?	?	Deeming, since 1979.
	Coleoptera	Leiodidae	?	Peck, since 1982.
		Silphidae	?	no specialist
		Staphylinidae	?	Coiffat, since 1977.
		Pselaphidae	?	Besuchet, since 1979.
		Carabidae	Speagonum mirabile Moore	Moore, 1978.
			Gastragonum caecum Moore	Moore, 1978.
			Altagonum misim Darlington	
			Altagonum sphodrum Darlington	
			Notagonum altum Darlington	Emberson & Moore, 1982.
			Notagonum margaritum Darlington	
		Dytiscidae	Copelatus nomax Balfour-Browne	Gueorguiev, 1978.
			Platynectes (Metaplatynectes) beroni Gueorguiev	Gueorguiev, 1978.

* or specialist who holds material for study, with date it was sent for study (Beron, pers.comm.).

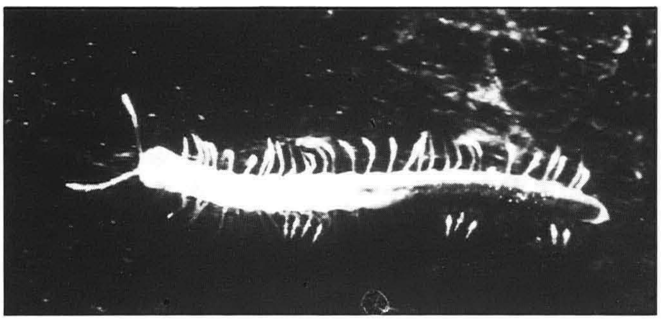
Speagonum mirabile
from Selminum Tem



lacking eyes and wings. S. mirabile was referred to by Chapman (1976) as ""Rhadine-like" carabid beetles" and G. caecum, as ""Neaphaenops-like" carabid beetles". Indeed there is a remarkable superficial resemblance between the PNG species and these American "counterparts" which betokens a certain degree of convergent evolution, perhaps suggesting similarities in the cave environments of the PNG highlands and the southern USA. Rossi (1978) described an interesting parasitic ascomycete, Rhachomyces beronii which infests the beetle S. mirabile.

Millipedes

Hoffman (1978) described 4 new genera and 8 new species of Polydesmidae from the highland caves (Table 1). Of these, Selminosoma Chapmani is the first troglomorphic species in the family Paradoxosomatidae, and the two doratodesmid species extend the known range of this family eastwards across the Wallace's Line from West Java (Hoffman, 1978).



Selminosoma chapmani from Selminum Tem

Spiders

Brignoli (1981) gave a generalised account of the PNG collection (Table 1). He commented that tropical caves have a characteristic spider fauna which is more or less the same (at family or even genus level) all over the world. The cave collection shows biogeographical affinities with New Zealand, Australia and the Oriental regions, so that the spiders, like the millipedes, show scant regard to Wallace's Line in their distributions.

Polychaete worms

Hartmand-Schroder and Marinov (1977) described Namanereis beroni from Bem Tem, near Telefomin. The species was referred to by Chapman (1976) as "errant nereid polychaetes", with some speculation on how a "marine" worm might have come to colonize freshwater pools in caves at 1600m above sea level! There are only three other species known in this genus at present. The closest to N.beroni may be N.quadraticeps which lives in the south of Chile and in S.W. Africa in marine intertidal, brackish and freshwater biotopes of estuaries. In many ways N.beroni was the most exciting and enigmatic discovery of the 1975 expedition.

Crustacea

The marine relicit anthurid isopod, Cyathura beroni Andreev (in press), belongs to a genus with a scattered pantropical distribution, with cavernicolous species in Borneo (Andreev, 1982), Mexico, Cuba, Curacao and Reunion Island.

Three variably troglomorphic crabs are known from the PNG highlands. The crabs found in caves on Finim Tel and referred to by Chapman (1976) simply as "freshwater crabs", belong to the long-legged, microphthalmic species Ruxana phreatica Holthuis (1982). It is related to the riverine crab R. papuana Bott (family Sundathelphusidae) and looks similar to a second undescribed species of troglomorphic crabs found in Atea Kananda by the 1978 Australian Expedition (Smith, 1980). The third cavernicolous species is the highly troglomorphic, white, eyeless Holthuisana alba Holthuis (1980), found in 1978, by Noel Plumley, in a cave near Tabubil, below the Hindenburg Wall, PNG. This latter crab also a sundathelphusid, is the first known blind, white member of the Gecarinucoidea and is only the sixth known blind white freshwater crab (2 from Mexico, 2 from Guatemala, 1 from Sarawak).

"RELICTUALNESS" OF THE FAUNA

As in other tropical caves visited by this author in Borneo, Hawaii and Venezuela, the troglomorphic fauna of the PNG caves was found to consist mainly of close relatives of the endemic surface fauna, plus some relicit species. Examples of the former are beetles of the tribe Agonini, millipedes of the family Paradoxosomatidae and crabs of the family Sundathelphusidae, all locally dominant taxa.

Examples of the latter are the two supposed "marine relicits" Namanereis beroni and Cyathura beroni. But as virtually nothing is presently known about the hyporheic or interstitial littoral fauna of PNG, even these latter species may prove to have close living relatives in the area.

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Anglo-Australian Speleological Expedition to Java 1984

Sheena STODDARD, Editor

Abstract : The Anglo-Australian expedition to Java in 1984 comprised six cavers from Britain and six from Western Australia. They were joined in the field by a number of Indonesian cavers from FINSPAC. Fifty five cave entrances were located in the spectacular cone karst of East Gunung Sewu. The major discovery, Luweng Jaran, was explored for over 11 km and is currently the longest cave in Indonesia.

INTRODUCTION

Gunung Sewu is an area of over 1000 km² of cone karst in Central Java. Caves in West Sewu were explored in 1982 and 1983 (Waltham et al. 1983; Willis et al. 1984) as part of a groundwater exploration project. Readers are referred to Waltham et al. (1983) for a succinct description of the Gunung Sewu karst.

The Anglo-Australian expedition was mainly a sporting venture and little scientific work was attempted. West Sewu had been briefly visited in 1983 (Willis et al. 1984, p.151) and obviously had a similar potential for cave exploration to West Sewu, so six cavers from the UK and six from Western Australia joined forces to investigate the area. Three small areas were ultimately explored and much work remains to be done (Fig 1).

The team arrived in Jakarta on Sunday August 12 and finally departed a month later. Two mini-buses with drivers were hired in Bogor, 60km outside the capital, to take us to Gunung Sewu, some 500km and 15 hours drive away. We were joined in the field by a number of cavers from FINSPAC (Federation of Indonesian Speleologic Activities) who provided essential help in dealing with Javanese bureaucracy and the uncomfortably vigilant police.

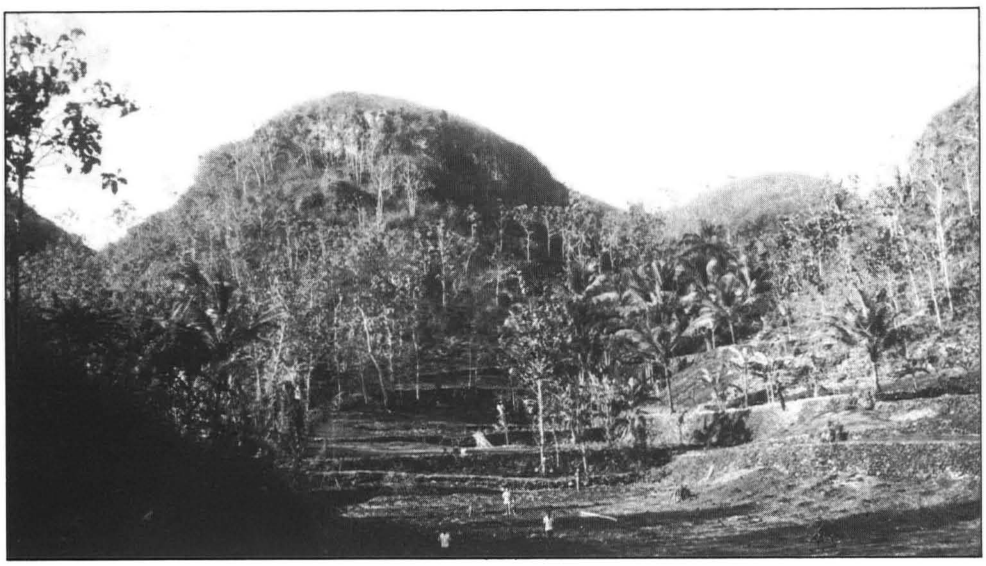
Twenty days were spent in the field, and over 20km of cave passage were surveyed in that time. The expedition spent its first week based at Wonogiri, which was unfortunately a considerable distance from the area chosen for investigation. Pracimantoro would have been an ideal base but there was no official accommodation available; we had considered renting a house (camping is virtually unknown in Java) but ultimately spent every night in lodgings (losmen). Renting a house poses considerable bureaucratic problems as one person is required to report to the police every day - in lodgings the proprietor performs this onerous task on behalf of his guests.

During our time at Wonogiri the expedition split into two with one vehicle covering the cone karst near Giritontro and the other the area around Sumberagung where entrances of interest had been noted in 1983. Wonogiri to Sumberagung was a two hour drive on bad roads and the group working there also wasted their first day and a half sorting out access problems with the local head men and police. A large group of white people indulging in an incomprehensible activity obviously attracts a great deal of attention, but once our credentials had been verified the local people were unfailingly helpful and hospitable.

Four caves of significance were explored during this first week: Luweng Demplo, Luweng Pace, Luweng Telaga Pilah and Luweng Seban. The team working near Giritontro encountered bad air on several occasions, presumably caused by the disturbance of the highly organic mud in the caves. One incident was particularly unnerving and the exploration of Luweng Kucing was abandoned.

The long drive to the caving area each day was an appalling waste of time so, although many sites were left unvisited or not fully explored, we changed our base to Pacitan some 50km to the southeast near the coast. This move proved to be a great success as our chosen caving area was a mere half hour's drive on good roads from the losmen. Two attractive stream caves, Gua Batuh and Luweng Ombo were explored in the first couple of days and the main discovery of the expedition, Luweng Jaran, was entered on the second day at Pacitan. Exploration of Jaran absorbed most of the team for nearly a fortnight although a number of other entrances were investigated. It was hoped another entrance into the far reaches of the system could be found but this was not achieved.

The potential for further exploration in East Sewu and a return is planned in 1986 to conclude exploration of Luweng Jaran and the surrounding area.



Cone karst near Sumberagung

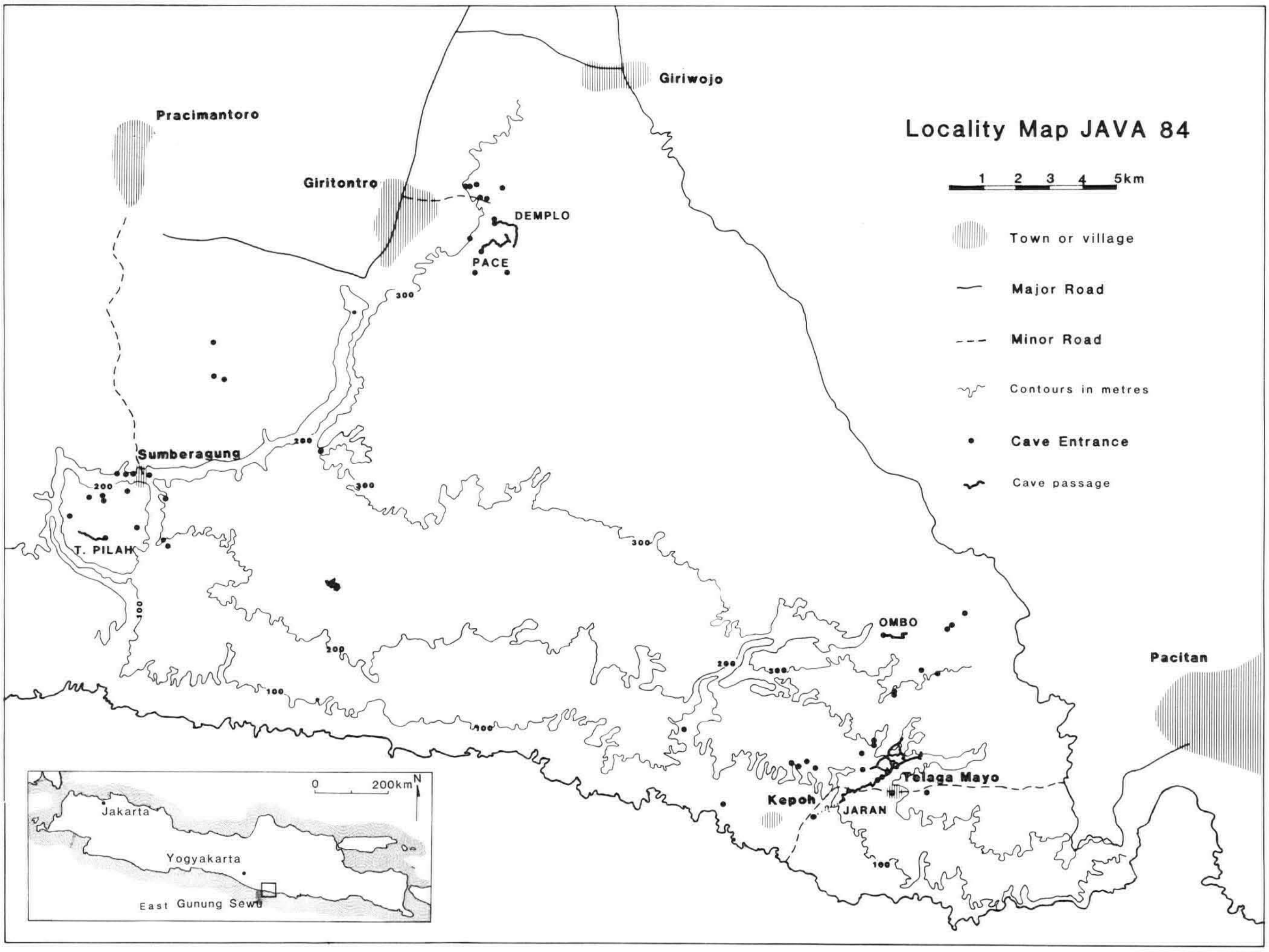


Figure 1

Cave descriptions

Each description starts with a number, name and grid reference. Numbers have an AA prefix to differentiate the cave from those of the Luwang (sic) Register (Waltham et al. 1983).
G = Gua (cave entrance).
L = Luweng (entrance shaft).
Sirah = spring or resurgence.
Song = a dialect word used for Gua.

Local names were determined for the entrances, but they are often the name of a village and may refer to more than one entrance.

Topographical maps used were 1:50,000 U.S. Army Map, Series T725, based on early Dutch surveys. Grid references in the following list of caves are from sheets 5118 I (Giritontro), 5218 III (Pacitan), and 5118 II (Kalak).

THE CAVES

AA/1 L. PUGERAN. 810045. 30m choked shaft in hillside.

AA/2 G. KUNIRAN. 813035. Small, blind hole 10m deep.

AA/3 G. MBUBUT. 810035. 30m blind cave at the foot of a cliff.

AA/4 L. NGALURAN (a). 850052. Main entrance is a hole in the floor of a large dry valley, although there are at least two other entrances. A 10m climb to a stream and about 100m of passage to a mud choke.

AA/5 L. NGALURAN (b). 887067. Entrance above the village of Ngaluran. 20m shaft to a small crawl and choke.

AA/6 L. NGANTAP. 896067. A 30m by 20m entrance near the village of Ngantap, with a variety of local legends, has a large flat mud floor with no way on. A large doline 200m to the east of this cave entrance has a 40m slope to a mud floor which floods in rain.

AA/7 L. GEMPLO. 888088. 12m shaft to a trench which becomes too tight after some 30m.

AA/8 L. POTRO. 895091. Depth 37m. A large entrance in the end of a dry valley leads into a narrow steadily descending rift passage with a small stream. After crossing a small pool a chamber is reached with a bat colony. A hole in the floor leads to the top of a 20m pitch, into a rift passage blocked by calcite and mud.

AA/9 L. KUCING. 887092. A 2m wide entrance in a dry valley leads to a narrow rift. Muddy, phreatic tubes were pushed for 50m in the top of this rift. A series of tight climbs down the rift lead to an undescended 20m pitch. Exploration was abandoned due to bad air.

AA/10 L. SAPI. 885091. A 20m shaft to a small stream. Downstream impenetrable, upstream quickly sumps.

AA/11 L. SOCA. 884091. A 20m slope to a trench which soon chokes.

AA/12 L. SADI. 889087. Undescended shaft.

AA/13 L. PITAK. 892082. A 3m climb down through boulders to the head of an undescended 10m pitch.

AA/14 L. SONGO. 886076. A complex of nine entrance shafts in a large doline. The shafts, 20m-30m deep, were not descended.

AA/15 L DEMPLO. 981081. Length 1538m, depth 61m. Survey, Figure 2. The entrance pitch of 11m is at the bottom of a 4m deep scrub filled shaft and it leads immediately to two further pitches of 7m and 3m into a stream passage. Downstream, a 4m wide phreatic passage continues until an inlet is reached, where the passage becomes vadose and gours are well developed. The passage continues past a number of unexplored inlets until the final sump. Bats were found throughout the length of a cave.

AA/16 L. PACE. 888072. Length 2173, depth 82m. Survey, Figure 4. A climb down to an entrance passage shortly reaches a 5m pitch, into a narrow inlet which is followed, in tedious walking-size passage, for 1700m to where it joins a large river passage. Upstream a spacious boulder-filled passage with several short cascades ends in a deep sump pool in a very large domed chamber. A steep mud slope up from the right bank of the sump reaches pools where water enters from above in wet weather. Downstream from the junction with the entrance inlet was explored as far as deep water.

Exploration of this promising system was not continued as the expedition moved to Pacitan. Luweng Pace would repay another visit, with lifejackets.

AA/17 SONG GEMBRUNG. 791006. The water supply for the village of Sumberagung; the name means 'something you do without thinking'. A steep boulder slope in a big depression leads to a passage which sumps after 100m.

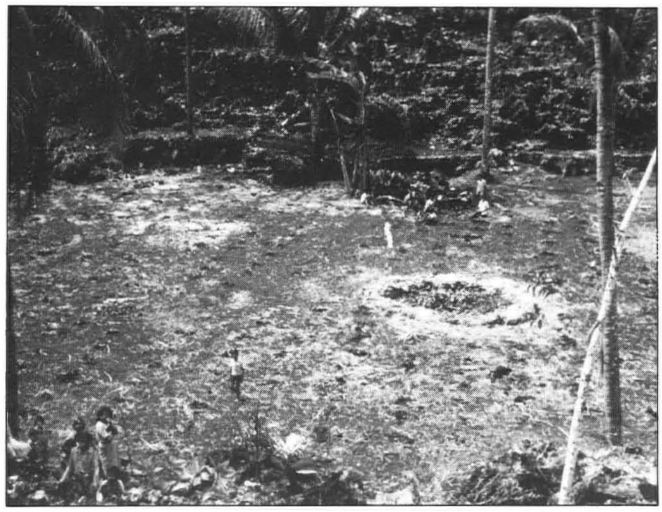
AA/18 L SAMBIN. 786006. The entrance is in the middle of the large dry valley which is the dominant feature of this area. A 30m vegetated entrance pitch is followed by a 2m climb, and the way on soon becomes too tight.

AA/19 L. SONGO. 784006. The entrance is down the dry valley from AA/18. A 25m entrance pitch lands in a small perched pool. A 4m pitch into a rift passage was not descended. A high level tube at the top of the rift was followed for 30m and not further explored.

AA/20 L. KANDIL. 781006. Down valley of AA/19 in a depression next to one of the largest telagas in the area. Unexplored.

AA/21 L. JATI. 784002. Entrance is a window into a shaft with a 30m pitch to a short, low passage with a duck. A squeeze leads to the head of an undescended 30m pitch.

Entrance to Luweng Songo, a shaft in the centre of a depression with walling built up to match the sediment level



Walled and filled sinkhole entrance near Pacitan

AA/22 L. KENDIL. 767994. A 20m shaft which is fortunately choked (as it is situated in someone's garden and only 10m from their lavatory).

AA/23 L. TELAGA PILAH. 777988. Length 1266m, depth 139m. Survey, Figure 5. The entrance is in the corner of a field about 100m below a telaga dam. An entrance shaft of 36m is broken by ledges and is followed by a 2m climb down to the head of the second pitch, 10m into a small chamber, and the obvious hole in the floor is pitch 3, 5m. At the bottom of the narrow third pitch is a rift to the right to a short length of canal and sump. To the left is pitch 4, 6m, into a large rift passage and another winding rift which emerges into a canal with water up to 1.5m deep. It rapidly becomes a duck almost 50m long with 15cm of airspace. Where the roof finally lifts, a stooping passage with a boulder floor leads to pitch 5, 4m into a canyon. Upstream was not explored, and downstream this tortuous canyon, often less than half a metre wide, continues for a tedious kilometre with one pitch of 6m. Towards the end it abruptly becomes a large phreatic tube. Progress becomes difficult because of thigh deep mud under the water and thankfully the passage soon sumps.

AA/24 Unnamed Luweng. 795999. Not descended.

AA/25 G. SONO. 793986. A large fossil entrance in the base of a cone. A rubble slope descends very steeply for 60m to an unstable pitch of 5m, not descended.

AA/26 G. KALIANYAR. 795985. The name means 'a new river' and it is used as a water supply. The entrance is small, descending over rubble to a short pitch, which is conveniently rigged with a fixed bamboo ladder. Walking-size passage reaches a 3m duck, and a second duck which is too tight.

AA/27 L. MLOKO. 844012. Shaft in the side of a cone with an undescended 35m pitch.

AA/28 L. SEBAN. 786989. Length 295m (surveyed), 450m (total); depth 98m. Survey, Figure 3. There is a pump installed in the large entrance which supplies water for twenty seven villages. The entrance passage leads to a 3m climb down to a deep and winding canal. The local people have been to the head of the first pitch at the end of the canal which is why it is a luweng and not a gua - from the entrance one would have thought it would have been a gua. The storage capacity of the canal could be increased by raising the lip of the first pitch, which is 8.5m over the flowstone and drops into a pool and canyon passage. Upstream was not explored through the deep, black mud. Downstream descends quickly in a narrow trench to a series of pitches in a very large rift. The last, wet, pitch drops into a pool and

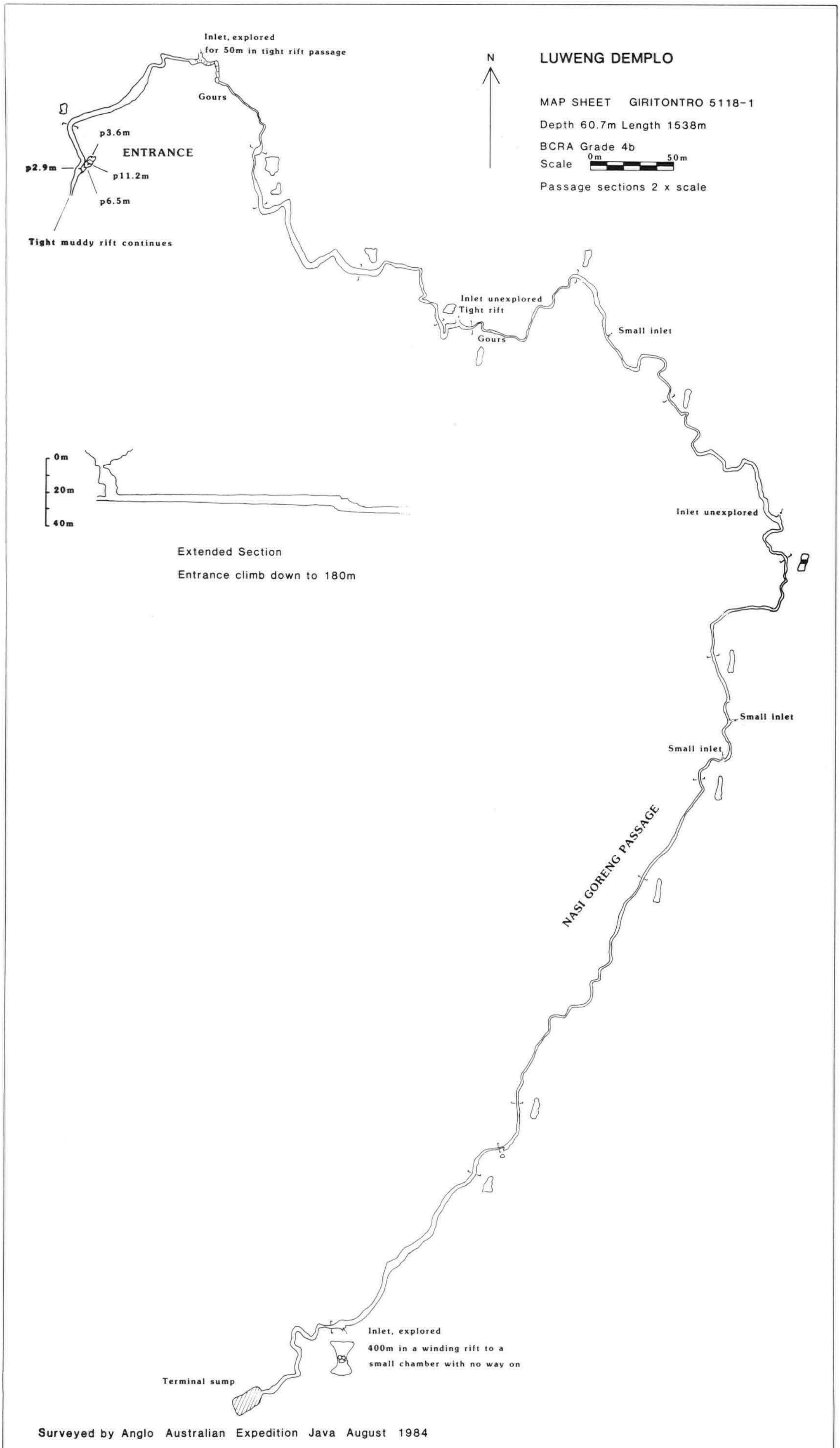
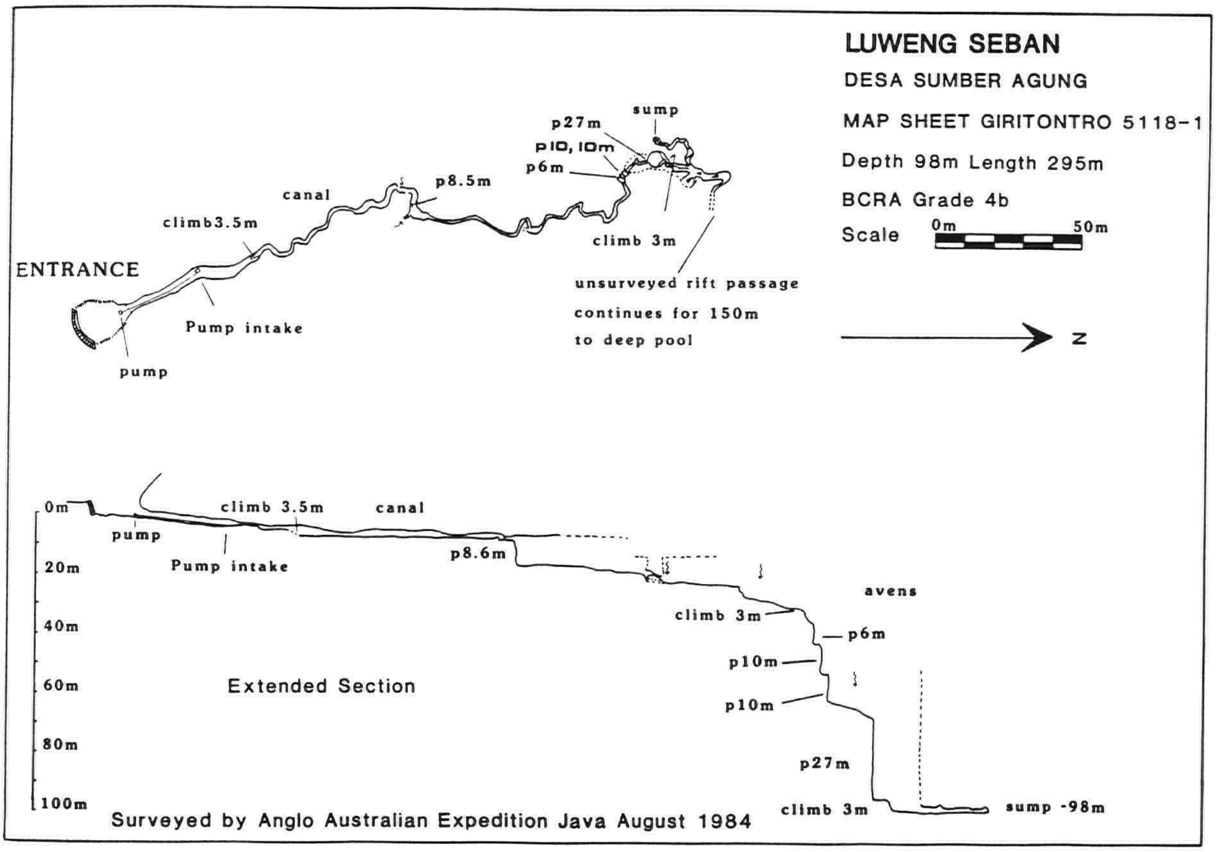

LUWENG DEMPLO
MAP SHEET GIRITONTRO 5118-1
Depth 60.7m Length 1538m
BCRA Grade 4b
Scale 0m 50m
Passage sections 2 x scale
N
Inlet, explored for 50m in tight rift passage
Gours
ENTRANCE
p3.6m
p2.9m
p11.2m
p6.5m
Tight muddy rift continues
Inlet unexplored
Tight rift
Gours
Small inlet
0m
20m
40m
Extended Section
Entrance climb down to 180m
Inlet unexplored
Small inlet
Small inlet
NASI GORENG PASSAGE
Inlet, explored
400m in a winding rift to a
small chamber with no way on
Terminal sump
Surveyed by Anglo Australian Expedition Java August 1984

Figure 2

Figure 3



climb down to a short section of streamway to a junction. Left is a deep canal sump. Right is a climb up a muddy slope to a chamber and 150m of unpleasant low passage through unstable areas, ending in a deep, static pool.

AA/29 L. NGOROCUIT. 772999. A shaft with a rock bridge with a tree on it. A 25m pitch onto a sloping boulder floor which ends against a solid wall after 15m.

AA/30 L. LEGUNDES. 776998. An 11m shaft in the valley floor, partially walled up.

AA/31 G. WORA WARI. 776999. Fossil entrance in the side of a cone with decaying formations. A roomy passage runs N.W. for 64m into a muddy chamber 20m long. A 17m pitch drops to a second chamber with a steep muddy slope up to an inaccessible slot. The villagers excavate phosphate from this cave.

AA/32 G. GEDE. 027963. A small hole in the side of a cone leads into a well decorated horizontal passage. Unexplored.

AA/33 L. JABERAN. 020950. A blind tunnel in the side of a large depression.

AA/34 L. SEROPAN. 024949. A rock bridge between two large depressions which are used as a water hole. No passage.

AA/35 Unnamed Gua. 012943. A muddy hole in the side of a cone continues for 50m in a small passage. Small tubes off the final chamber were not explored.

AA/36 Unnamed Gua. 013944. Short 10m cave in the side of a cone.

AA/37 L. OMBO. 008960. Length 1122m, depth 60m. Survey, Figure 6. The entrance is in a saddle between cones and descends a slippery 50m slope to a large stream. Upstream sumps after 30m. Downstream crosses 100m of large gour dams and is followed by a deep vadose trench to an area of breakdown and a 5m pitch. The water flows down a series of cascades and follows a canyon to the terminal sump. This very attractive stream cave contains eels, fish, river prawns and a population of bats.

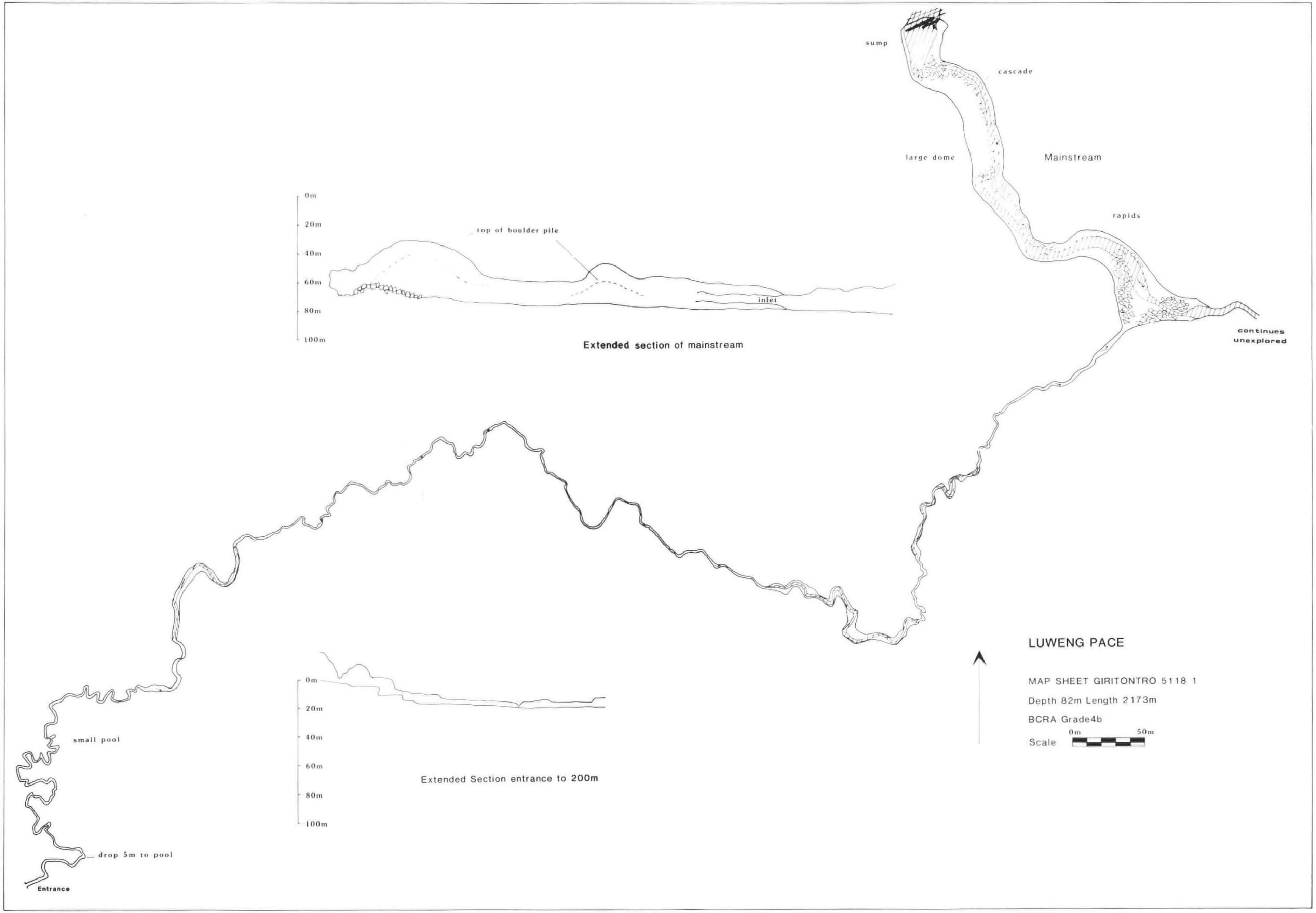
AA/38 G. BATUH. 032967. Length 1473m. A small stream enters a fine phreatic, onion-shaped, passage. After 200m a 3.5m climb down to a deep pool can be avoided by non-swimmers via an overhead route. A small muddy inlet enters on the right. This was surveyed for 150m and continues very muddy and was not explored further. The main stream passage soon reaches a 5.4m climb (handline) to a final section of large, well-decorated passage which ends in a sump.

AA/39 Unnamed Luweng. 029962. 12m walled shaft to a rift passage, shortly too tight.

AA/40 L. JARAN. 006916. Length 11,249, depth 158m. Survey, figure 7.

The entrance to Luweng Jaran is in a river bed, shown on the old Dutch map as a sink for the Kali Barong river which has cut its course through the cone karst. The river bed was dry in August but is obviously the main sink in the wet season. When we were exploring Jaran the river was sinking (impenetrably) about 2 km upstream. The river bed continues downstream from the entrance but then peters out amongst fields between the cones and there is no further downstream sink.

Jaran is a fine cave system with large passages and chambers, sporting stream passage and canals plus beautifully decorated high level fossil passage. The main stream was not fully explored and continues upstream, the major objective for 1986. It is fed by two large inlets, Slappity Slurp and Dire Straits, which also have a number of leads. The obvious way on was always chosen and the numerous small inlets left for another time. At over 11 km Jaran is, at the time of writing, the longest cave in Indonesia and at least another kilometer was explored in a number of directions without time for surveying. The expedition had to return home when the rains started early, making muddy sections like Kerbau



sump
cascade
large dome
Mainstream
rapids
continues unexplored
0m
20m
40m
60m
80m
100m
top of boulder pile
inlet
Extended section of mainstream
0m
20m
40m
60m
80m
100m
Extended Section entrance to 200m
small pool
drop 5m to pool
Entrance
LUWENG PACE
MAP SHEET GIRITONTRO 5118 1
Depth 82m Length 2173m
BCRA Grade4b
Scale
0m
50m

Figure 4

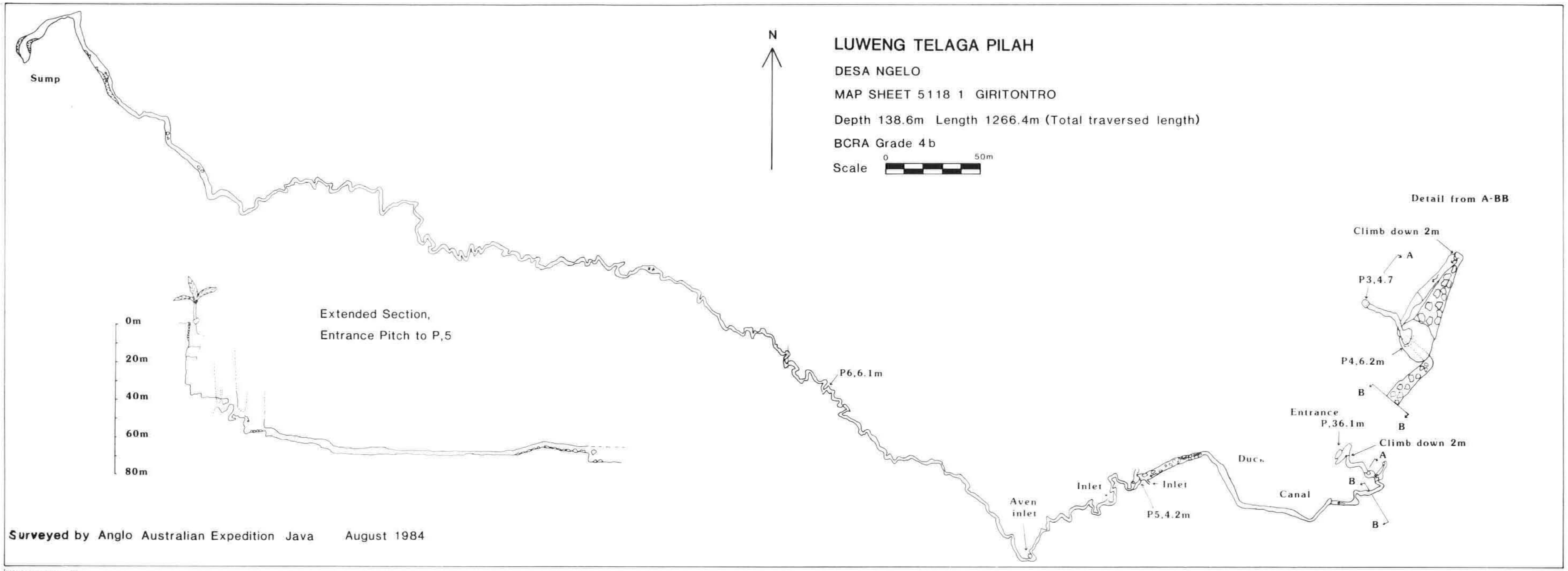
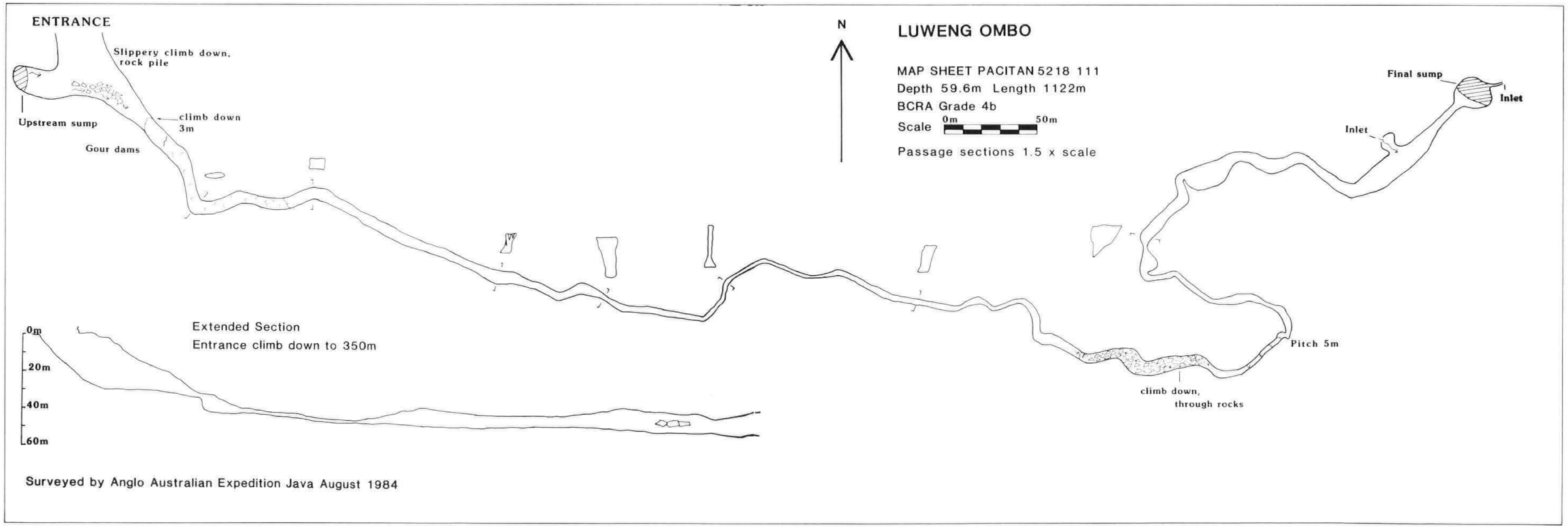
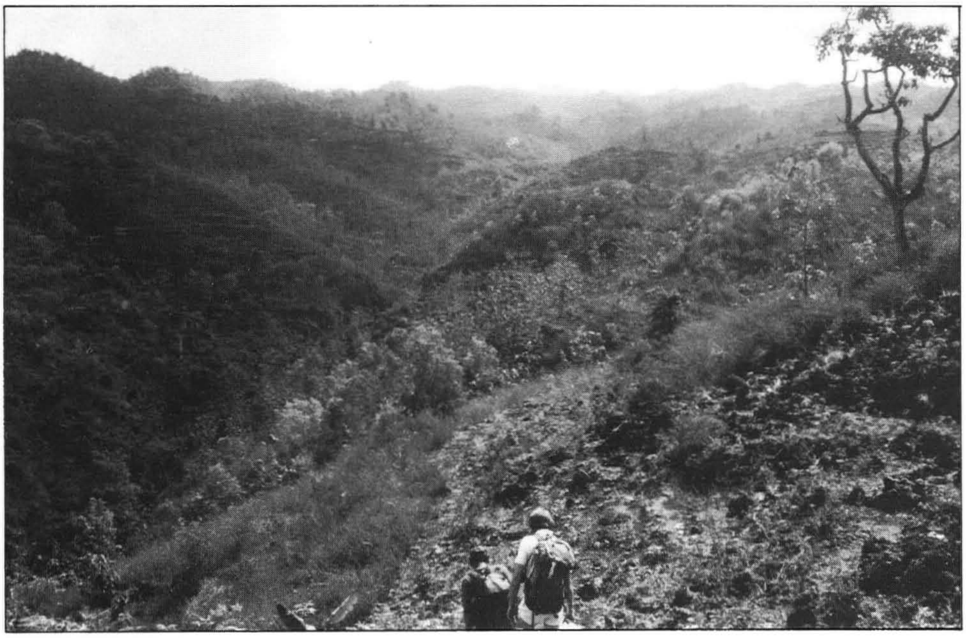


Figure 5

Figure 6





The Kali Barong Valley cut through cone karst, with the Luweng Jaran entrance in the river bed at bottom left

increasingly heavy going, and on the last day water began to come down the entrance pitches. Much work remains to be done in the system to tie up loose ends, and hopefully find more passage.

The entrance is a 13m shaft to a short section of passage and a climb. A large platform slopes down to the head of a pitch overhanging the space of the Main Chamber. The first excited caver at the edge of this black void, convinced it was a lake, called for a lifejacket; in fact a free hanging 17m pitch lands on a pile of boulders in the middle of the chamber. Climbing up the boulder slope away from the pitch reaches a dismal area with stalagmite bosses covered with mud. There is the usual Javanese flood debris of coconuts and sandals, and the Main Chamber obviously floods in the wet season. There are two large tunnels leading out of the chamber, the west to Dead Dam Passage and the east to Nylon Junction.

Downstream Series

The beginning of Dead Dam Passage is reached by scrambling over boulders to a wide and sandy section. This leads to the first of many enormous black gour dams, up to 6m high, some holding back deep pools of water. After this gloomy section there are two routes down to a lower level and wading through deep pools towards the roar of the main stream.

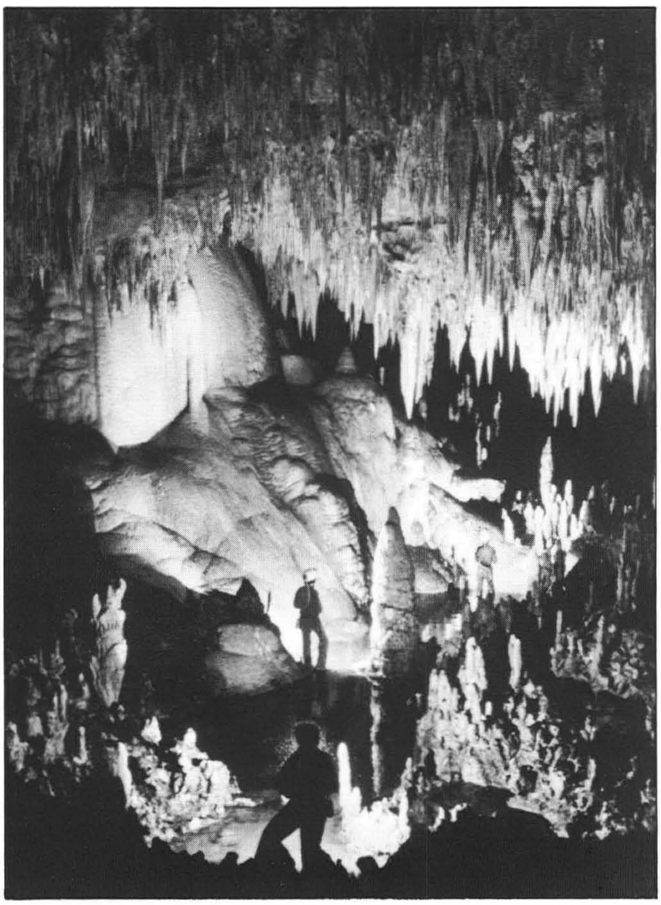
The passage enters the stream at a wide, boulder-strewn section. Upstream, along fine stream passage, ends in a boulder choke. Downstream is good caving through boulder-filled canyon and deep pools - where the expedition's non-swimmer practised drowning - and a decorated section. The stream then plunges down a small waterfall and descends to Sump I. A climb up on the right 100m before the sump leads to a phreatic overflow, the Gondola, with a swim through another deep pool. A climb down regains the main stream and easy walking to Sump II. A bypass on the left is virtually all swimming in deep canals to Sump III.

Although we did not have the facility to dye test, the most obvious resurgence is AA/55 near the coast, about a kilometre from the terminal sump in Jaran.

Upstream - Doddy Series

The other large passage leading off the Main Chamber is easy going with a level mud floor to Nylon Junction. A short climb down at the junction reaches a section of perched streamway, which must flow soon after the rains start. The stream itself can be heard in both directions. Downstream has a series of static pools before joining the main stream once again. This can be followed with little difficulty down small cascades, passing Slappity Slurp inlet, and finally along easy walking passage to a deep sump.

Upstream from Nylon Junction through pools of the perched streamway the passage emerges over a shingle bank into a large chamber. (A short climb up to the left into a passage which is noticeably colder passes through static water to the base of an aven. There are leaves and debris, but no draught. Underneath is the end of the duck



High level passage in the Doddy Series of Luweng Jaran

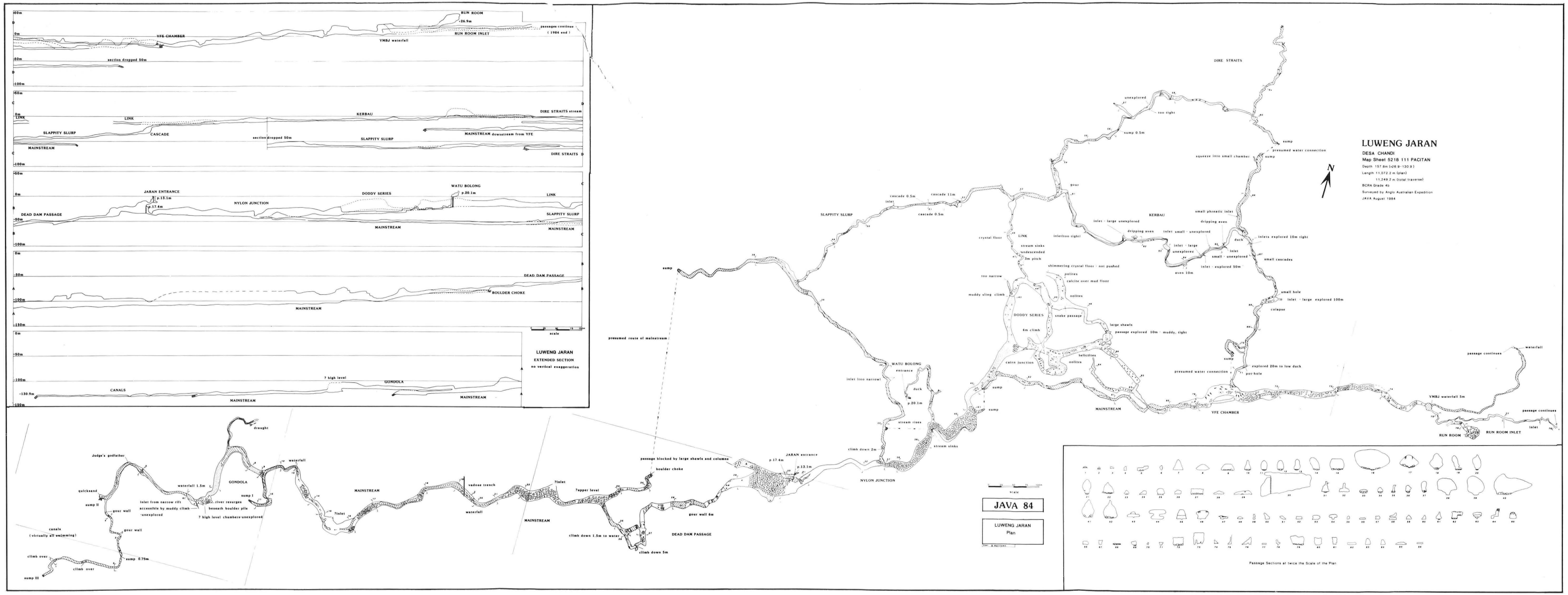

LUWENG JARAN
DESA CHANDI
Map Sheet 5218 111 PACITAN
Depth 157.8m (+26.9-130.9)
Length 11,072.2 m (plan)
11,249.2 m (total traverse)
BCRA Grade 4b
Surveyed by Anglo Australian Expedition
JAVA August 1984
N
JAVA 84
LUWENG JARAN
Plan
LUWENG JARAN
EXTENDED SECTION
no vertical exaggeration
Passage Sections at twice the Scale of the Plan
DIRE STRAITS
KERBAU
SLAPPITY SLURP
LINK
DODDY SERIES
WATU BOLONG
JARAN entrance
NYLON JUNCTION
MAINSTREAM
YFE CHAMBER
RUN ROOM
RUN ROOM INLET
YMBJ waterfall 5m
DEAD DAM PASSAGE
GONDOLA
CANALS
VFE CHAMBER
CASCADE
BOULDER CHOKE
JARAN ENTRANCE
presumed route of mainstream
presumed water connection
passage continues
waterfall
sump

Figure 7

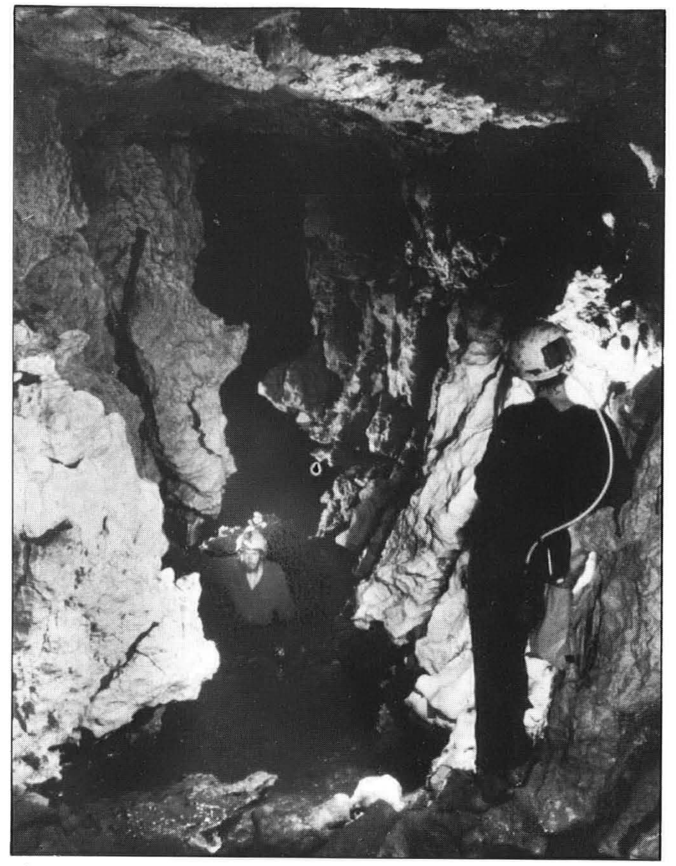
into L. Watu Bolong, AA/41). Back on the main route is a large chamber with the main stream sinking into a fissure. The stream can be followed along the right wall of the chamber to where it rises from a deep sump.

After scrambling across boulders the passage continues large and decorated with a smooth floor. To the right is a climb up to Cairn Junction (the best route to the Link) and the main passage continues over filthy climbs before degenerating into a muddy tube which fortunately becomes too tight. An awkward and muddy 3m climb leads up through a gap in false floor to an upper series. Above a calcite slope is Snake Passage, a wide mud-floored passage incised with a narrow trench. After a blind 8m pitch on the left a passage over muddy gours on the left is the Link, the best route to the far upstream passages. Snake Passage ends in mud fill near the end of the upper level downstream from YFE Chamber, though there is no connection yet.

Before Snake Passage becomes small there is a slope up to the right into the most beautiful section of the cave. Deep, static pools reflect the copius formations, large numbers of cave pearls have to be carefully skirted, there are helictites in the roof, and to either side of the main passage are two further chambers with white crystal floors. The larger of these has enormous crystals and a stunning curtain. Because of the decorations the perimeter of this chamber was not pushed.

The main passage drops to Cairn Junction. Immediately ahead an obscure opening behind stalagmite columns leads back to the large passages, and to the right well-decorated passage and a climb down lands in Snake Passage near the Link.

After muddy gours the Link joins an inlet passage with the stream sinking down a narrow undescended hole to the right. The passage has a fine nest of cave pearls. A shallow, calcite-lined vadose trench is incised into the sediment floor; rapid progress along it connects with the streamway of Slappity Slurp inlet.



Dire Straits Inlet in Luweng Jaran

Slappity Slurp and Dire Straits

Slappity Slurp is a main inlet of the system and begins with several 3m high mud banks and deep mud in the stream which slows progress. In this section there are stalagmites consisting of mud - presumably formed on an annual basis. Small cascades are climbed over before reaching the spectacular 11m flowstone cascade, best climbed on the left with the aid of a hand-line. Where the passage abruptly enlarges, the Link enters up a bank to the right; further upstream through decorated passage the obvious inlet on the right, by a broken calcite dam, is Kerbau. Slappity Slurp narrows and a few metres after passing another inlet it sumps. The inlet is low and muddy; another unexplored inlet on the left may offer a bypass to the Slappity Slurp sump. After some fine decorations a climb down joins the Dire Straits stream which sumps both upstream and down.

The small Kerbau inlet is followed in increasingly muddy conditions (a 'kerbau' is a water-buffalo and these animals are seen working deep in the mud of the paddy fields; it was also the nickname given to the most portly of our group by the Indonesian cavers!). Kerbau is a cross-over passage which connects the Slappity Slurp inlet with the equally large Dire Straits streamway. Just 10m before reaching Dire Straits,

The main stream in Luweng Jaran below Nylon Junction water rises and flows towards Slappity Slurp, making the last few metres of Kerbau an underground watershed.

Dire Straits sumps upstream, only 35m from its most northerly section. Downstream a duck is passed into an attractive stream passage. Immediately before an area of collapse related to a dripping aven is a large inlet explored, but not surveyed, in winding rift passage for several hundred metres. Dire Straits stream turns sharply to the right and sumps; a passage which probably acts as a flood bypass is the continuation to YFE Chamber.

The far upstream passages

YFE Chamber (Yesterday's Far End - named when imagination was running dry) is large and boulder filled with the main streamway regained and flowing beneath the boulders. Downstream is very large and decorated, and a climb up an inlet on the left enters a high level, decorated passage. This is obviously a continuation of the Doddy Series, but no route was found to provide a short cut into the far streamway. The main stream meanders past mud banks to a sump, only 30m from where the water rises in the Doddy Series.

Upstream from YFE Chamber is tedious going in loose and confusing collapse. Impressive decorations include a large, pure white phallus. After much boulder scrambling, a 7m overhanging waterfall and yet another inlet passage is reached. After a serious climb up YMBJ Waterfall ("You must be joking", said an Aussie to the Pom who climbed it) a sporting streamway was surveyed for 300m and a similar distance again explored to another waterfall with an obvious continuing passage. There was surface debris including coconuts in this section and it is very near where the Kali Barong river was sinking on the surface.

The inlet stream at YMBJ Waterfall leads to the Run Room, a large domed chamber with much loose rubble building up to a cone in the centre. A flowstone climb to an enticing black hole led to a well-decorated grotto; the inlet itself was surveyed a little further and continues unexplored.

In 1986 work will continue in Jaran and on the surface to try and find another way into the system. Sites such as AA/45 and AA/46 are probably part of the same system.

AA/41 L. WATU BOLONG. 007917. The entrance is 200m north east of the entrance to L. Jaran and is also in the river bed. A descending tube passes through a squeeze to a 4m climb down to a rift passage. Upstream chokes. Downstream is a tight rift with boulders to the head of a 20m free-hanging pitch. A slot in the floor drops into a pool and a 5m duck. Low awkward crawling through flood debris and loose rock leads to a swim through a deep water duck into Luweng Jaran. L. Watu Bolong is another sink for the Kali Barong river in the wet season and feeds the main stream of L. Jaran at the start of the Doddy Series. It is an awkward and loose way into the main system.

AA/42 L. KETO. 021914. Large entrance shaft 100m from the road. A superb 50m entrance pitch drops into a chamber with a stream flowing into a sump. A decorated dry passage degenerates into a crawl and ends at a sump pool; upstream is stooping amongst bats to a short duck and a sump after 50m. The stream can be followed another 30m to a sump.

AA/43 L. NGELO. 011912. There are at least three holes close together which share this name; they are all interconnect and are choked with mud.

AA/44 L. GUNDONG. 003925. A 9m deep walled depression at the end of a gully in a dry valley, west of the road to Desa Gundong. Three pitches of 7m, 13m, 6m followed by a 3m climb down to a 10m long pool ending in a choke. Two chickens were rescued from the bottom of the second and final pitches, much to the amazement of the local people.

AA/45 L. PAGAR DERSONO. 002920. Rift entrance at a high level with a small stream in the bottom; this soon became too tight.

AA/46 L. KALEN. 002920. An open walled shaft with a dangerous take-off point at Pagar Dersono. 17m descent into a pool. A small inlet into the same rift as in AA/45, becomes too tight after 30m.

AA/47 L. PELENGAN. 006928. A large open shaft at Jelubang in a depression. After a sloping loose descent a free-hanging 16m pitch lands on a mud choked floor.

AA/48 L. GOTONG. 986922. A large, partly walled open shaft, 15m by 8m, 6m north of the road between Desa Sumur and Desa Watu Karung. (An eye-hole 15m to the west connects to the main shaft). A free descent of 68m reaches a mud floor with no way on.

AA/49 L. BANTENG MATI. 988921. An oval walled shaft in a field 30m north of the Sumur to Watu Karung road. 50m pitch to a boulder choked floor.

AA/50 L. NGLODO. 984921. 150m east of Kampung Karang Nongko. A partly walled shaft in a field with a mud choked floor, 35m deep.

AA/51 L. LUNG BANYU. 983921. Half a kilometre south of Kampung Karang Nongko. A vegetated shaft at the base of a valley with a 20m pitch to water.

AA/52 L. SURUH WATU. 006927. An open shaft in a small field on the right hand side of a dry water course. 27m pitch broken by a ledge 5m from the bottom. A passage descends for 15m to flowstone, and a crawl on the right becomes too tight.

AA/53 SIRAH SUNGLOW. 962911. Coastal resurgence. A 2m climb down through boulders into a lake 10m across. In the left hand corner a 20m rift with loose boulders forming the left wall leads to

YFE Chamber in Luweng Jaran

another lake, 20m by 10m. A small duck to the right becomes too low after 3m. The water has little perceptible flow.

AA/54 SIRAH MARON. 949931. A resurgence 1km south of Maron on the east side of the river. The river rises in a large deep sump pool. It is possible to swim for about 5m under an overhang before it became impassable.

AA/55 Unnamed Sirah. 985904. A resurgence 1500m from the coast, and the most likely resurgence for Luweng Jaran. A flat-out crawl after a duck becomes too tight.

Further entrances in the Giritontro area

Before leaving the Giritontro area and moving to Pacitan on the coast one of our FINSPAC colleagues identified the following entrances for us, which were not visited. We do not have their co-ordinates, but they could easily be found with the help of the local people.

L. PETRAH. Near AA/15, L. Demplo.

L. NELGO. Near AA/5, L. Ngaluran (b).

G. GUO 7km from L. Demplo.

L. GBROMO. Near the village of the same name.

G. SONG MUBENG. Near L. Demplo.

L. TELENG. Near L. Demplo.

G. SONG PARI. Near L. Demplo.

G. SONG. TERAS. Near L. Demplo.

G. SONG MACAN. Near L. Demplo.

G. PARING. Near L. Gbromo.

L. DERO. One kilometre west of Giritontro.

L. PAGUTAN. Near L. Gbromo.

L. GIGEM. Near L. Demplo.

ACKNOWLEDGEMENTS

Our first thanks must go to Dr. R. Ko, chairman of FINSPAC in Java, for all of his help. Any group who want to visit Indonesia are advised to contact him at P.O. Box 55, Bogor, Indonesia. We were accompanied by a number of FINSPAC friends to whom we are most grateful for translating and other help both above and below ground. The Director General of Tourism in Jakarta gave us permission to visit Gunung Sewu and was most supportive.

In Australia, Western Collieries, Perth, gave such computing and draughting assistance. The expedition's nurse was given invaluable advice and assistance by Dr. Richard Sallie, QE II Medical Centre, Perth and also Dr. Gofar Bain, Indonesian Embassy, Canberra.

In addition, the British contingent would like to thank the Sports Council for a grant, Dick Willis and Colin Boothroyd for thier advice and enthusiasm, Dr Tony Waltham for a copy of a rather vital map, and Phil Chapman for biological nomenclature.

In Java the people were unfailingly hospitable; our drivers and their assistants developed an enthusiasm for cave-hunting, and in Pacitan, Elsje Martini provided good food and converted her shop into a restaurant for us.

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APPENDIX 1 TEAM MEMBERS

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Australian: M. Arnold, J. Campbell, R. and B. Matthews, M. Millard, W. Tyson.

APPENDIX 2 CAVE SURVEY, by K. Daykin

The surveys were made using Suunto compasses and clinometers and fibron tapes. The instruments were read to the nearest degree and the tape to the nearest 0.1m. Unfortunately on many occasions the instruments became unreadable due to mud or condensation on the lens. In these cases a hand held silva compass was used and clinometer was read by an assistant from the side. Reading from the side in this way gives an estimated error +2° on clinometer readings. Passage widths and heights were estimated and noted at each survey station as was the height of the station. Cross sections were drawn whenever the profile of the passage changed significantly. The BCRA survey grade is therefore 4b. The north point on the surevys is magnetic.

Surveys were plotted using co-ordinates derived from a programmable calculator, though the amount of work each evening would have made a second calculator welcome. The Luweng Jaran survey was drawn up in the field, but on return to Australia was replotted after closure errors had been computer distributed.

APPENDIX 3 CAVE BIOLOGY

The following notes were prepared in the absence of an expedition biologist. Only one snake was encountered: a short, slender and bright green specimen which lived on the entrance pitch of Luweng Jaran (which it free-climbed). It may have fed on swiftlets, many of which flew into the cave at dusk, or on the variety of small frogs which were common underground. Precise identification of the swiftlets, which used echo-location, is virtually impossible in the field, and we did not see their nests.

Bats were often seen, but there were no large colonies. However, guano was seen in the upper chambers of the Doddy Series in Luweng Jaran.

Large eels were common in the stream passaged of Luweng Jaran, Luweng Ombo and Gua Batuh. Despite abortive attempts to inspect their teeth they were not found to be of the aggressive character of those reported previously.

Crickets were common as were the so-called tail-less whip scorpions (Arachnida Amblypygi). There were also fish, white crabs, river prawns and shrimps, and the latter were frequently observed climbing waterfalls.

APPENDIX 4 MEDICAL REPORT, by Marcia Millard

Being a small expedition with limited resources, (including lack of doctor) our medical facilities were geared mainly towards the treatment of non-emergency type conditions to be expected in the tropical/underground environment, with an emphasis on prevention. For major rescue or emergency we relied on ability to improvise with local materials and resources. All members of the expedition had practiced SRT self rescue techniques and all parties carried sufficient gear for the same. Our safety margins were hopefully extended by the warm underground conditions.

Prior to the expedition, all members were immunized for tetanus, cholera, typhoid and polio. We all took prophylactic anti-malarials. About half of us had hepatitis immunoglobulins. Nobody, unfortunately, had rabies vaccine. This would have been worthwhile as rabies is endemic to Java, and one member was actually bitten by a dog.

First aid kits were always carried, but after the first minor accident we realised that not everybody know how or when it was appropriate to use the various pre-packaged dressings etc. with their meaningless trade names. A familiarisation session helped to overcome this problem. Perhaps a waterproof instruction sheet would have been advisable. We also found it necessary to have a revision class on constrictive bandaging technique for snakebite. Exploration parties consisting of 2-4 persons carried individual first aid kits. The contents were kept to a minimum because if too big, they tended to be 'forgotten'. A variety of containers (plastic bags, lunch boxes) were tried, none of which were particularly waterproof.

Numerous cuts, scratches and bruises were mainly treated with Betadine. Anything which was likely to become infected was covered with Op-site waterproof dressing before going underground. This seemed to work well and stay intact. One scalp laceration (sustained when the person concerned removed his helmet at the base of a pitch to wipe his sweaty brow) required suturing and a course of antibiotics.

Only three of us had anything worth calling diarrhoea despite the fact that we all ate local food and disobeyed quite a few of the 'rules for travellers' such as not having ice in drinks and peeling all fruit.

We had one case of moderate heat exhaustion. This can easily occur when surrounded by water, especially water which one is reluctant to drink. Pre-packaged fruit juices were found to be a convenient and robust form in which to carry fluids underground. Some drank from the cleaner looking inlets with no ill effects, and much more pleasant than the smoky-tasting pre-boiled water from the losmen.

Many of the medical items we took were available in Java relatively cheaply and over the counter. The things most likely to be unavailable are sterile items. It could be very easy to run out of these if someone needs to have regular dressings or a lot of surturing.

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Factors Controlling Micro-solutional Karren on Carbonate Rocks of the Griqualand West Sequence

Margaret E. MARKER

Abstract : Rillen karren, micro-solution grooves, are restricted to specific beds in the Griqualand West Sequence exposed on the Ghaap Plateau escarpment. In a measured transect up the escarpment at Kloof, 60 km west of Kimberley, pronounced rillen karren were found to be associated with fine grained, dense, homogeneous carbonate rocks of the Campbell Group. Where rocks were less homogeneous or contained a range of impurities, micro-solutional development was restricted. However neither porosity nor total solubility were strong controls. Variability in the Campbell Group of the Griqualand West Sequence appears to be as great as in the Malmani Subgroup of the Transvaal Sequence.

INTRODUCTION

The characteristics of karst development on carbonate rocks at different localities is a basic topic for karst research. Detailed studies focus on micro-solutional forms or karren, in relation to their host beds. Few such detailed studies are, however, available for the karst rocks of southern Africa. This paper offers a further contribution, reporting an investigation into karren incidence on the central part of the Ghaap Plateau escarpment.

Karst is a term applied by geomorphologists to encompass surface and subsurface landforms developed chiefly by chemical processes and largely on carbonate rocks. Since solution processes are dominant in karst development, karst incidence is closely allied to the susceptibility of the carbonate rock to solution and to climatic factors controlling the availability of chemically aggresive waters. In southern Africa, karst landforms are hosted by a wide variety of carbonate rocks of which the most significant are the hard Proterozoic (Precambrian) dolomitic limestones of the Transvaal and Griqualand West and the soft, poorly cemented Tertiary calcarenites, informally grouped as the Coastal Limestones. Although the Proterozoic dolomitic limestones were deposited in two separate sedimentary basins, the two sequences show close lithological similarities (Brink, 1979). In the Transvaal, the Chuniespoort Group of the Transvaal Sequence is dominated by carbonate beds of varying lithology and calcium/magnesium ratio, within the Malmani Subgroup and to a lesser extent in the Duitschland Formation (SACS, 1980). Beds in these rocks demonstrate the variability in karst development (Marker, 1971). In Griquland West,the Campbell group has similar characteristics to the Malmani Subgroup (Brink, 1979). Varability in karst incidence was anticipated.

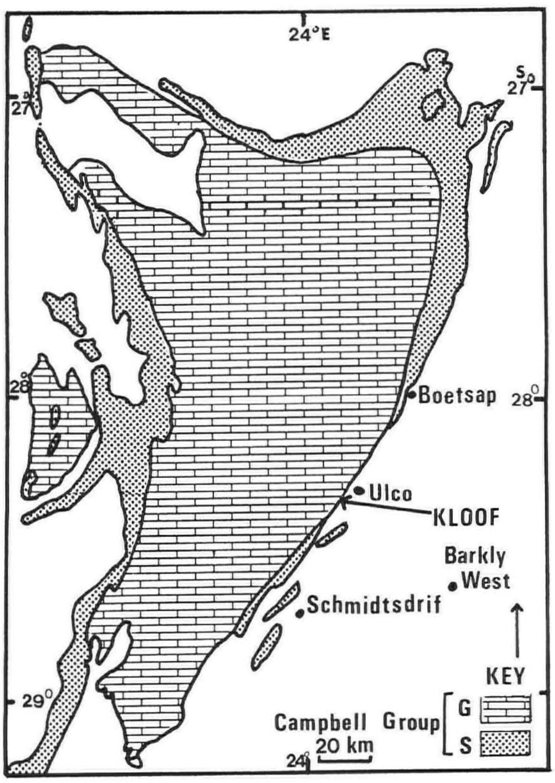

Figure 1 The Ghaap Plateau showing the distribution of Campbell Group strata of the Griqualand West Sequence and the locations of sites mentioned in the text (G = Ghaap Plateau Formation, S = Schmidtsdrif Formation).

The investigation reported here is based on a transect taken across the basal portion of the Campbell Group strata exposed on the Ghaap Plateau escarpment at Kloof, 7 km south of Ulco and 60 km west of Kimberley (Fig. 1). Campbell Group strata form the Ghaap Plateau but exposures are scarce owing to veneers of surface rubble and calcrete, the low relief and low angle dip to the northwest. Macro karst forms are restricted to small caves, shallow solution dolines and tufa mounds aligned along dykes. Along the actual eastern escarpment relief is sufficient to expose rocks across the succession except where masked by large carapace tufa deposits. The virtual limitation of surface rock exposures to the escarpment enhances the significance of the sites exhibiting variable development of micro-solutional forms.

THE STUDY SITE

In January 1984 fieldwork along the escarpment south of Ulco between Kloof and a new lime quarry at Gorrokop suggested that this area was particularly suitable for an investigation of variability in solution susceptibility. karren forms there vary from pronounced rillen karren, through incipient poorly defined rills, to solution enlargment of micro-structural weaknesses, known as olifantklip weathering, to no noticeable solution forms at all. The subvertical face of the Ghaap Escarpment clearly demonstrates that susceptibility to karst solution is markedly variable from bed to bed. Well developed rillen karren are confined to specific zones.

Rillen karren, the most marked micro-solutional form at this site, are parallel solution grooves aligned down the maximum angle of the exposed rock face. The divides normally intersect sharply as ridges. Rillen karren development is governed by the length of bare rock

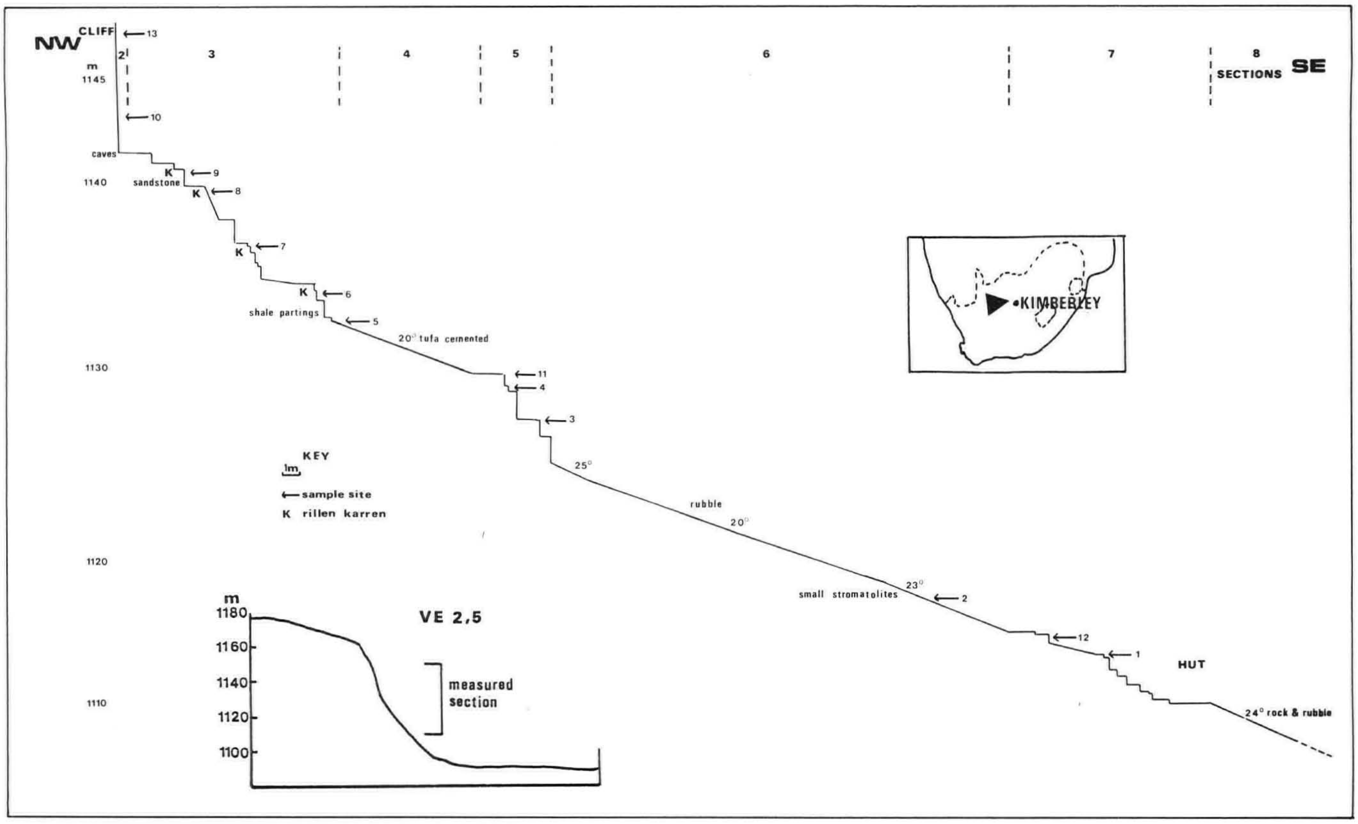

Figure 2 Measured transect at Kloof drawn to scale. Sample sites designated and slope sections included. Insert shows location of transect of the Ghaap Escarpment drawn to scale from 1:5000 ortho photo map.

face,intensity of runoff and suitable substrate. They therefore occur commonly on bare sloping rock in areas of convectional rain storms. Rill width is related to length of rill, to water volume and rock solubility. Rillen karren are virtually absent when rainfall intensity is low. Other forms of karren may include pit karren, caused often by mist or drip, pool forms (kamenitza), common on horizontal surfaces and often fed by rillen karren, and rund karren, rounded smooth forms developed in a subsoil situation. The characteristic olifantklip weathering may be classed as a particular form where solution is insufficient to do more than to etch innate rock weaknesses.

At Kloof, the site chosen for this investigation, the Ghaap Escarpment rises steeply from 1092 m altitude on the sand veneered basal footslope to a maximum plateau altitude of 1200 m (Fig. 2). The actual escarpment is some 70 m high and has a general gradient of 24 degrees at the base, increasing to 30 degrees midslope and is capped from about 1140 m by a 20 m near vertical cliff developed in massive beds. Above the cliff summit the rise is gradually convex. The escarpment is essentially a stepped rock slope partially covered in rubble, whose configuration is governed by bed thickness and resistance. Only in one section isthe rock masked to very shallow depth by a fine scree cemented by indurated tufa.

FIELD INVESTIGATION

A transect was accurately measured from 1110 m to 1155 m altitude, rock samples being selected from well exposed vertical rock faces. The lower 20 m of the escarpment was excluded since it is formed of brown carbonaceous shale and siltstone of the Schmitsdrif Formation. Solution forms along the transect consist of caves at the base of the summit cliff associated with large intraformational algal domes, pronounced rillen karren immediately below the cave level and more generally distributed micro-solutional fissures and ripples, typical of olifantklip weathering (Fig 2). The entire escarpment zone can be subdivided into 8 components, 6 of which were covered by the transect (Table 1). Excluded were the rubble veneered footslope composed of the non carbonate Schmitsdrif Formation and the summit convexity which also hosts pronounced rillen karren.

The measured transect demonstrates the great variability in bed thickness with little consistency even within specific slope components (Fig 2.). Steeper stepped sections within incipient cliffs tend to develop in more massive beds. Joint spacing is positively associated with bed thickness. Straight slope segments develop at 24° angles on beds with numerous thin stromatolite partings and small joint spacing. The summit cliff is constructed of massive beds up to 2 m in thickness with joint distances exceeding 2 to 3 m.

The presence of pronounced rillen karren was accepted as indicative of suitable water availability and storm intensity over the entire transect. Although recipient rill development can be found on many beds, pronounced rillen karren occur only on selected beds of the upper cliff, Section 2, and immediately below the cliff in Section 2 (Fig. 2). Karren rill width was measured for the beds in Section 3 associated with

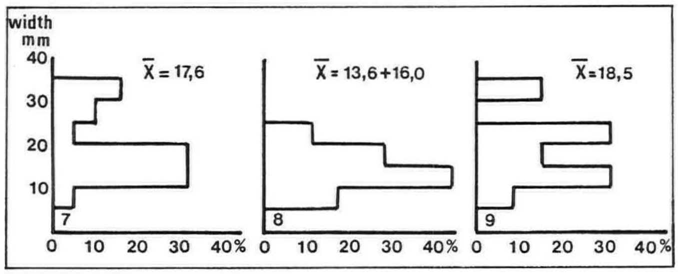

Figure 3 Histograms of rillen karren width frequency at sample sites 7, 8, and 9. Average widths in millimetres

Table 1 Kloof section slope components

SECTION	CHARACTERISTICS	SAMPLES	GRADIENT	ALTITUDE (m)	BED THICKNESS (m)
8 Summit convex	Dark blue dolomite with large algal domes. Marked karren.	-	Slight	1160 - 1200	-
7 Cliff	Large algal dome structures with massive beds. Marked karren.	13,10	Near vertical	1142 - 1160	1.00 - 2.00
6 Stepped	Some sandstone and shale. Marked Karren.	6,7 8,9	30 - 35^0	1132 - 1142	top 0.72 base 0.23
5 Rock slope	Tufa cemented small scree overlain by large boulders.	5	20^0	±1130 - 1132	?
4 Stepped	In part massive beds liable to fracture.	11,4,3		1124 - 1130	0.96
3 Rock slope	Rock gradient overlain by rubble veneer. Stromatolite partings.	2	25 - 20^0	1114 - 1124	-
2 Stepped	Brown dolomite, mainly small beds with micro solution effects.	1,12		1110 - 1114	0.35
1 Basal slope	Rock with rubble veneer. Dominantly shale.	-	24^0	1090 - 1110	

rock samples 7, 8, 9. All measurements were taken 50 mm below the top of the block being measured. Although considerable variation occurs, two major groups of widths recur (Fig. 3). Their modal distribution lies between 10 mm and 25 mm and between 30mm and 35 mm, the latter grouping also being reflected in beds associated with sample 7.

LABORATORY INVESTIGATION

A series of rock samples was taken from the transect to test the hypothesis that rillen karren development is closely associated with rock porosity and rock solubility. All rock samples were examined first in hand specimen and then thin-sectioned for examination microscopically. Porosity was calculated. Samples were also treated with concentrated hydochloric acid to determine solubility and to enable calculation of the amount of insoluble residue which was also examined under the microscope (Table 2)

Microscopic examination showed that these rocks are variable. Samples from the lower slopes where karren solution is virtually absent are all dense rocks with variable grain size and show considerable microstructural distortion with impurities in the form of iron, manganese and carbonaceous material. Where pronounced rillen karren occur, as associated with samples 6, 7, 8, 9, 13, the rocks are all dense with close packed small consistent crystal structure. Colour is uniform and less impurity is present than in other samples. Olifantklip weathering is characteristic of samples 3 and 11. Sample 3 is a coarse micro-conglomerate with patches of homogeneous sparite. Sample 11 consists of evenly packed dense small crystals with strong iron staining.

Porosity is also variable. The tufa scree cement (sample 5), as might be expected, is far more porous than any dolomite sample (Table 2). Samples with olifantklip weathering range from 0.24% to 0.54% porosity from zero to 1.24% porosity, but rillen karren samples exhibit a wide range. No relationship between porosity and solution forms could be detected.

Speed of reaction to hydrochloric acid and total solubility within 42 hours (the duration of the experiment) are also variable. The most reactive sample, again as expected, was the tufa. Vigorous reactions were also recorded by sample 3 (olifantklip) and samples 6, 8, and 9. The latter was as reactive as the tufa sample. Complete solubility within the 42 hour sampling period was achieved by 7 of the 12 samples. Although there is slight indication that solubility has some bearing on the presence of surface karst features, some samples that dissolved completely support little or no karst solution forms.

The insoluble residue was investigated microscopically. Most samples contain considerable amounts of manganese (wad) and iron within the residuum. Granular silica is also a common constituent of many samples (Table 2). Two samples exhibited silica as microsheets. In hand specimen these infill micro joints and fissures and are variably orientated. They are present in samples 3 and 11, both characterised by olifantklip weathering. Most other samples contain black wad dust. The residue from samples 6 and 8, however, differed in being finer, paler grey in colour and had fewer silica grains. Sample 5 from the indurated tufa differs from all the others. Contrary to expectation, the volume of insoluble residue is not clearly inversely associated with the incidence of micro-solutional forms. Nevertheless all rillen karren samples contain only very fine residual material.

DISCUSSION

The presence of pronounced rillen karren, even if restricted to slope components 2 and 3, indicates that climatic conditions at the site are suitable for the development of micro-solutional forms. The closest first order weather station at Barkly West shows a semi-arid, markedly summer seasonal rainfall regime with an average total annual rainfall of 417 mm only, falling as high intensity convectional storms (Fig 4). Evaporation is high. Although the climatic regime is adequate for the formation of karren, development is enhanced where susceptible beds are exposed.

The hypothesis was posed that the incidence of micro-solutional forms as shown by the various types of karren is related to rock porosity and rock solubility. The laboratory analyses have

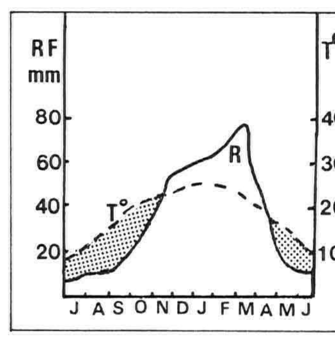

Figure 4 Climatic hythergraph for Barkly West. (Weather Bureau 1954).

Altitude (m)	Sample number	Unit	Karst character	Av karren (mm)	Av joint (m)	Microscopic features	Porosity (%)	Rate of reaction with HCl	% impurity in HCl	Solubility (%)
1113	UD1	7	Brownish massive		.45	Marked distortion & lamination. Fractures infilled with micritic cement. Brown staining.	Lost sample			
1116	UD2	6	Stepped stromatolite with rippling		<1.08	Laminar streaky densely crystalline. Fe & other impurity.	0.99	1	1.6	98.4
1127	UD3	5	Massive olifantklip weathering		2.57	Variable coarse conglomerate in opaque micritic field. Some fine grained homogenous grey matrix altered to sparite. Round cryst inclusions.	0.24	3	4.4	64.4
1129	UD4	5	Messy uneven solution, not olifantklip, fissured and stressed.		0.70	High crystalline grey with inclusions. Irreg brown Fe staining. Large crystals in open structure.	0.41	2	1.6	98.4
1132	UD5	4	Indurated tufa below stromatolite caves,ang breccia tufa cemented		0.80	Disordered with reworking and crys on all rounded, varied size inclusions and iron staining.	3.68	4	22.7	70.2
1134	UD6	3	Rillen karren. Well developed solution effects.		1.13	Close pack small-medium dol crystals in dense dol ground. Some signs alteration & Fe streaking.	1.24	3	17.5	30.1
1137	UD7	3	Karren pinnacle.	17.6	3.95	Even dense grey ground with white crys streaks and patches. Highly cryst dense.	0.14	2	2.8	97.2
1140	UD8	3	Karren.	14.8	3.70	Dense cryst in dol ground with re-cryst rims in crystalline areas.	0.44	3	6.0	94
1141	UD9	3	Karren.	18.5	0.60	Dense dark homogenous, some alteration & distortion less than samples 1 & 2.	0.44	4	3.2	72.5
1144	UD10	2	Stromatolite Cliff. Planar jointing. Massive.		3.35	Disordered Cryst structure with chunky structure consisting of densely packed small crystals. Much Fe staining.	0.86	2	9.2	09.8
1130	UD11	5	Lower cliff olifantklip.			Densely packed small white cryst. With patched Fe stain.	0.54	2	1.2	72.1
1114	UD12	7	1st cliff bluff			Dense crystalline with random Fe staining Medium grain & no alignment clear sparite	0.17	3	0.9	99.1
1155	UD13	2	Top of kloof & stromatolite Ripple pitted - crystalline			Very small grains with marked recrystallisation rims. Little original dark ground left.	0	3	2.2	97.8

Table 2 Laboratory results on Kloof samples

shown that no clear relationship exists between rock porosity and rock solubility, at least at this site. The range of porosity shown by the karren samples suggest that porosity alone is not a critical control.

Rock solubility is dependent on lithology, in particular granular density and texture, degree of alteration from micrite to sparite, degree of subsequent alteration as shown by the development of re-solution rims, micro-structural distortion, and the inclusion of insoluble materials. Micro-structural distortion is visible in many hand specimens and is more common in the lower part of the transect. Many samples also show considerable staining and the incorporation of variable grain sizes within the sparite matrix. It is noteworthy that those samples hosting pronounced rillen karren, samples, 7, 8, 9 and 13, are all lithologically similar, consisting of closely packed homogeneous small crystals. Colour is a uniform pale grey, probably indicating a percentage of wad.

Most samples contain considerable volumes of insoluble residue. There is evidence of wad (amorphous manganese dioxide) a common constituent of the basal portions of the dolomite succession in the Transvaal (Erikssen, 1975), iron and sliica. A considerable range in residue size is evident from some samples, notably those with little or no karren development. Although the actual volume of the insoluble residue does not appear to be inversely related to the presence of karren, all pronounced rillen karren, samples contain a low volume of very fine, even-textured residue. It may be surmised that a wide range of non-soluble material may inhibit the formation of karren. The tufa sample is anomalous in this set. It shows a surprisingly high degree of alteration of the cement to sparite with the development of calcite angularity and size as is typical of colluvial sites. The powerful reaction to acid suggests that a considerable proportion of the interstitial cement may yet remain as micrite rather than as sparite. The residuum contains a high percentage of larger subangular silica grains which retain traces of the red patina typical of Namib and Kalahari blown sands. Similar sand grains have been identified from the interbedded sands within the tufa series at Ulco quarry (Marker, 1974), further reinforcing the view of the age of this segment of the transect.

A further point of significance is that with the exception of sample 13, no evidence for the development of re-solution rims was found. This is in complete contrast to the Malmani Subgroup carbonate rocks of the Trasnvaal where re-solution rims are almost ubiquitous (Marker, 1981). Pronounced rillen karren development appears to be favoured by fine-grained, densely packed homogeneous lithologies but no evidence was found that porosity or solubility were strong controls.

Residue colour	Solution after 42 hours OR solution time	Residue after HCl
N3/0	18 hours	Fine black dust + uniform small Si grains.
N3/0	32.7%	Si sheet fragments impregnate in rock. Micro karren solubility. Si yellow silt and ang Si fragements.
N3/0	21 hours	Grey dust + unsorted ang Si grains dom small but variable.
7.5YR7/4	9.2%	Ang sand grains with red "Namib" stainings. Few dark grains in calcite dust.
2.5Y4/1	63.6%	Grey/black dust & fine yellow white Si sand. Soft with high wad content.
N2/0	42 hours	Fine uniform black wad dust.
N4/0	18 hours	Pale grey dust & clay/silt Si grains.
N3/0	25.1%	Grey dust + fine Si grains. Rock surface v worn. Yellow fine silt.
N4/0	18 hours	Fine uniform grey dust.
N4/0	27.0%	Sand and paper size. Si sheet & grains Si brown sand lumps Si recementation Si sand in rock with soln features.
5B2/1	21 hours	Black soot-like dust & small Si ang fragments dome small but variable.
N4/0	18 hours	Limited black dust.

CONCLUSION

Detailed investigation of transect across the beds transitional from the Schmitsdrif Formation into the Campbell Group of the Griqualand West Sequence has shown that micro-solutional karren are preferentially located. That they are not ubiquitous on exposed rock surfaces indicates that rainfall intensity is not the critical control.

The hypothesis was posed that porosity and solubility governs the distribution of karren forms. This hypothesis remains not proven. Indications are that even-grained texture and a low proportion of included impurities are of greater significance. It has also been demonstrated that variation in susceptibility to solution is as great in the Campbell Group of the Griqualand West Sequence as in the Malmani Subgroup of the Chuniespoort Group of the Transvaal Sequence.

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Errata

Corrections to references: The World's Earliest Underground Cave Photograph by Alfred Brothers, FRAS. Cave Science, 12, (1), March 1985

Owing to a number of errors at the production stage, several of the references to Chris Howes' article were wrongly or incompletely cited.

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The last date in Chris Howes' abstract should be 1867.