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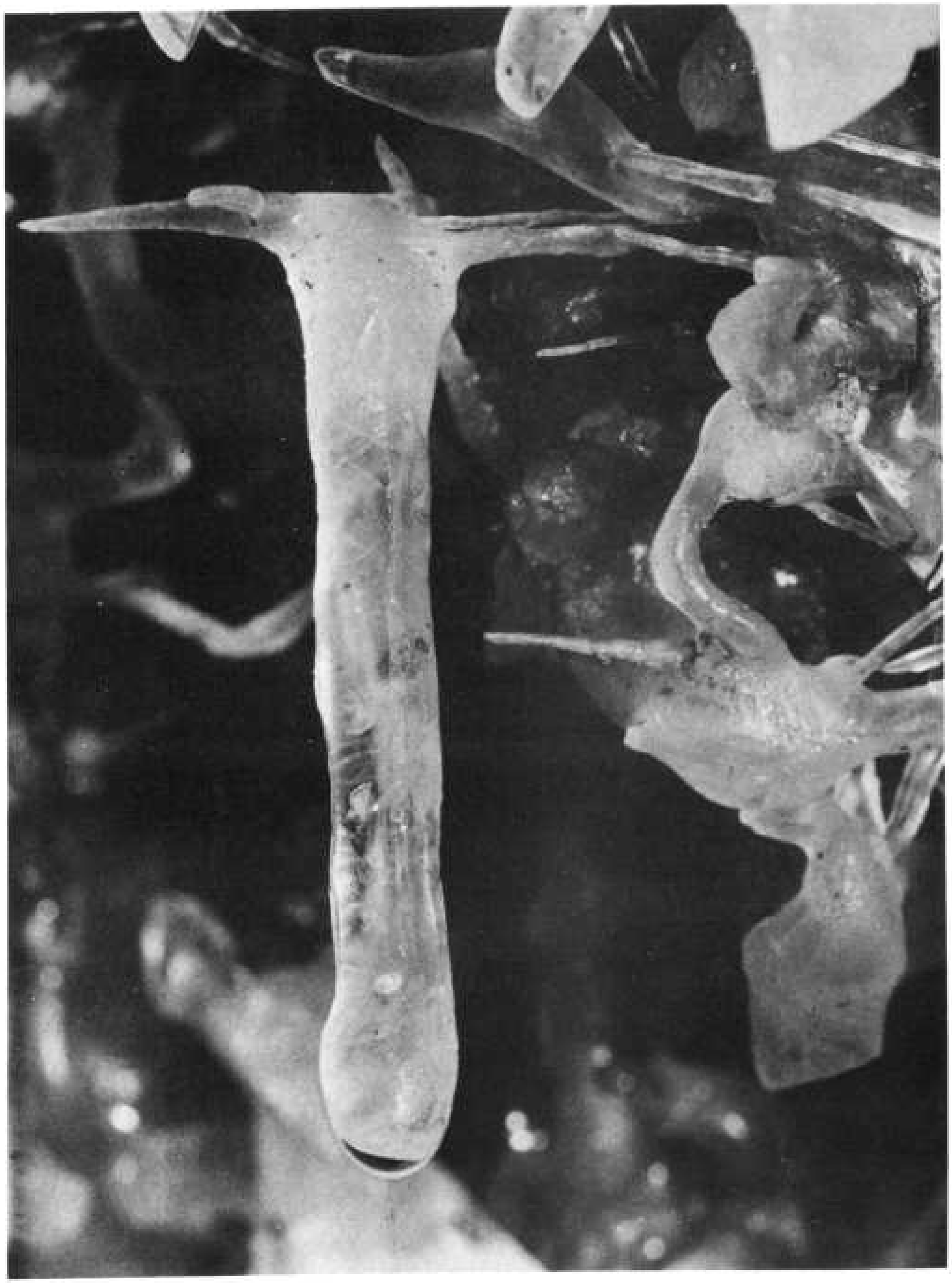

Helictite in Temple of Baal,
Jenolan Caves,
New South Wales.

Unfortunately broken during construction of a new entrance some years ago.

Photo: Anthony Healy

"HELICTITE"

Journal of Australasian Cave Research

Editors

E.A. Lane, Aola M. Richards, J.N. Jennings

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FORTHCOMING PUBLICATION DATE ADJUSTMENTS

For various reasons, some within and some beyond the control of the Editors, production dates have slipped well behind schedule. To bring issues back on line, Volume 12 (1974) will consist of one double-sized issue (about 40 pages) and Volume 13 (1975) will also consist of one double-sized issue. Volume 14 (1976) will revert to normal-sized quarterly issues. For purposes of payment, Volumes 12 and 13 together will rate as a single year's subscription.

NEGOTIATIONS FOR TRANSFERENCE OF OWNERSHIP

Negotiations are now in progress between the publisher of "Helictite" (Mr. E.A. Lane) and the present editorial panel (Mr. E.A. Lane, Dr. Aola M. Richards and Professor J.N. Jennings) and the Speleological Research Council Ltd. to transfer ownership of "Helictite" to the Council. The basic reasons are to ensure the continuity of publication of "Helictite", to increase the number of people working on behalf of the journal, and to help maintain the present high standard of scientific and technical content. The policy set out by the editors of "Helictite" at its inception has been maintained throughout its life and will continue to guide its destiny, though some innovations are being discussed. The present editors will continue and the journal will continue its independent and non-aligned editorial outlook.

"Helictite" is essentially a self-supporting and non-profit journal. However, during the past few issues, members of the Speleological Research Council have given their services freely to help with the production and distribution of "Helictite". The Editors are most grateful for this help. - E. A. Lane.

EVOLUTION OF THE WELLINGTON CAVES LANDSCAPE

G. FRANCIS

Lorengau, Manus Island, Papua New Guinea

Introduction

Wellington Caves, New South Wales (Figure 1), have attracted scientific attention for more than a century, largely through discoveries in the cave sediments of bones from extinct animals. These bone discoveries provided impetus for a number of early speculations about the geomorphology of the caves area and its relationship to the caves. Notable among these was the conjecture of Mitchell (1839) that the valley floor sediments of the Bell River and the cave fills had been deposited during a marine transgression about one million years ago. The first systematic geomorphological work was carried out by Colditz (1943), who argued for two distinct relict erosion levels in the Bell Valley; the older level was assigned to the Lower Pliocene and the younger to the Upper Pliocene. Colditz considered that these levels provided evidence for two phases of uplift in late Tertiary times. More recently, Frank (1971) made detailed studies of the cave sediments, and devoted some attention to landscape evolution. He believed that the Bell River had been captured by Catombal Creek, during the late Pliocene or early Pleistocene.

Geology

The geological basement consists of steeply dipping, folded Palaeozoic rocks which strike slightly east of north. To the east and south of the caves, Ordovician and Silurian volcanic and sedimentary rocks are exposed. The volcanics include both lavas and pyroclastics, ranging from andesites to keratophyres and spilites (Colditz, 1948; Strusz, 1965). The sediments consist of siltstones, shales and limestones. Wellington Caves have developed in limestone of the Devonian Garra Formation, a complex of interbedded biolithites and detrital beds. The stratigraphic section includes algal, pelletal and oolitic calcarenites, calcilutites and some massive biostromal layers (Strusz, 1965). Small-scale folding and faulting have taken place; in Cathedral Cave the limestone is brecciated. Garra Formation limestone also outcrops to the west of the Bell River, immediately east of the vertically dipping sandstones and conglomerates which form the prominent Catombal Range. Basnett and Colditz (1946) postulated a major transverse fault extending from east of Neurea to the area south of the caves. But Strusz (1958) re-interpreted the structure as a sharp pitch depression and small associated fault.

The hills to the north and east of Neurea (Figure 2) are capped with Tertiary basalts and fluvial deposits. These Tertiary rocks are present on hills about 100 m above river level, and extend discontinuously for a distance of at least 10 km parallel to the Bell River. Strusz (1958) has presented petrographic evidence that all six basalt outcrops are remnants of the same flow. The basalt caps are about 6 m thick, and overlie fluvial deposits up to 18 m thick. Both unconsolidated and indurated sediment horizons are present. The unconsolidated deposits consist of rounded quartz gravels and sands. The indurated sediments include shales and mudstones, together with iron oxide cemented sandstones and conglomerates. At some locations, sizeable pieces of silicified wood are present. In the past the deposits have been worked for gold. A ferricrete layer up to 10 cm thick is exposed in a cutting on the Neurea-Dripstone road; smaller concretions are fairly common in the iron cemented deposits. Similar Tertiary ferruginous sediments have been reported from a number of locations in the Wellington district and further south (Colditz, 1943; Stevens, 1948; Walker, 1959; Browne, 1972).

Conflicting explanations have been offered for the ferruginous character of these deposits. Stevens (1948) considered that the iron was derived from residual weathering of underlying limestone. But the sediments in question are often found considerable distances from limestone outcrops. Furthermore, Strusz (1958) has reported magnetite grains in a dark-coloured Tertiary sandstone 2 km northeast of Neurea. This suggests that the iron may be derived from minerals originally present in the sediments.

Colditz (1943), on the other hand, attributed the ferruginous cementation to thermal metamorphism by the overlying basalts. The sediments are not invariably associated with lava flows, though in Tertiary times the basalt cover would have been more extensive. This explanation seems more plausible, but Stephens (1971) has argued that the association of basalts and indurated sediments is just coincidence, and that their cementation is related to groundwater movements. Thermal metamorphism should have greatest effect on the upper sediment horizons in closest proximity to the basalt. But the ferricrete layer is several metres below the contact, and the cementation somewhat selective, generally affecting the lower horizons to a greater degree. Moreover, the ferricrete is laminated, with distinct layers 2-3 mm thick, indicating gradual deposition. The above evidence suggests a relationship to subsurface water movements, in which iron is mobilised and later precipitated. If this analysis is correct, then the changes in the sediments may be incipient laterisation.

Apart from the ferruginous cementation, the most striking feature of the sediments is the overwhelming predominance of quartz in the gravel fraction. Only occasional jasper pebbles and shale fragments are present at some locations. This contrasts sharply with the riffle deposits of the present Bell River, which show substantial variations in lithology over comparatively short distances. The most likely sources for the quartz are veins in the Palaeozoic volcanics (Strusz, 1958). Its predominance is probably a reflection of the palaeoenvironment - under conditions of intense weathering, stream abrasion may

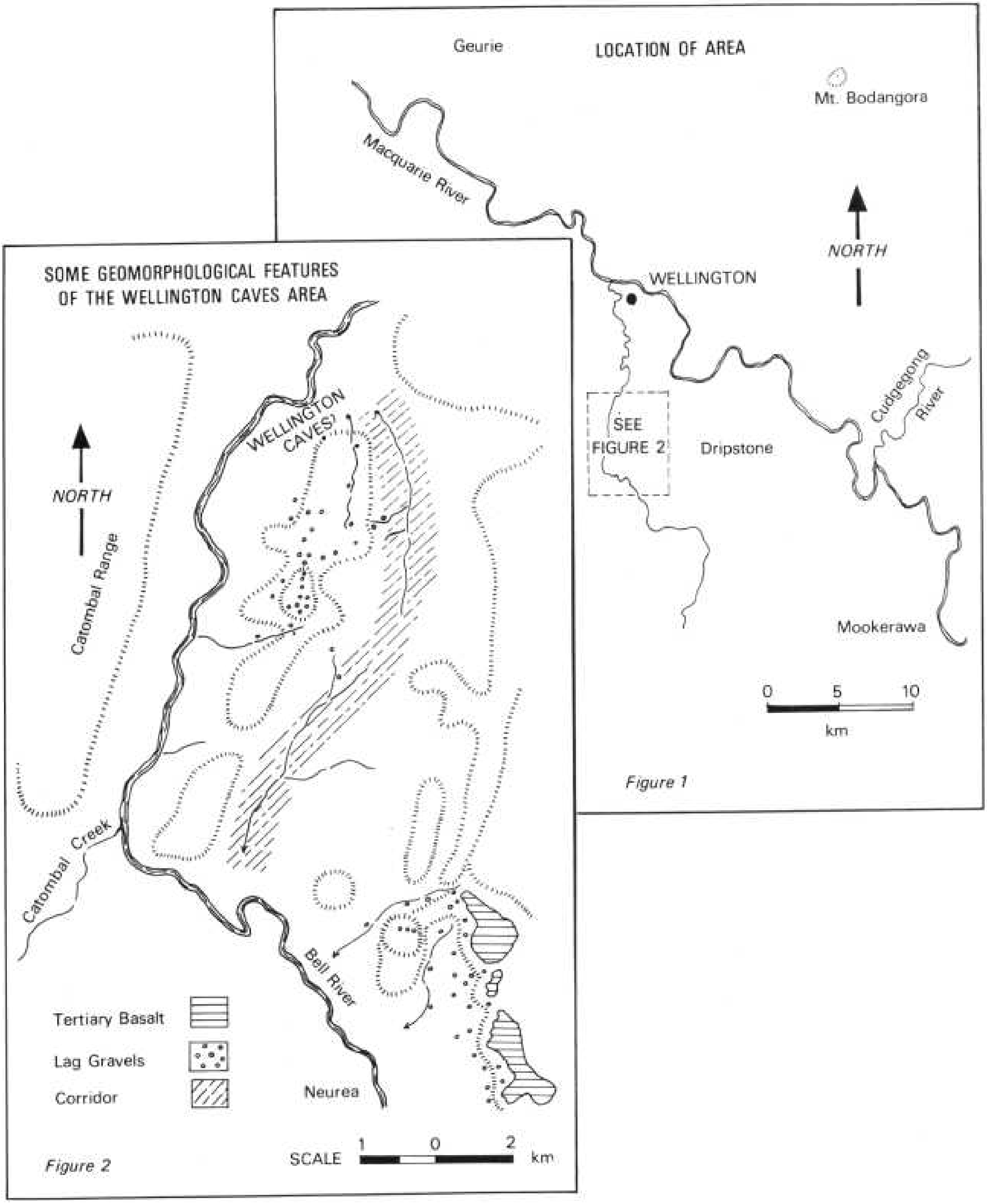

Figure 1

Figure 2

subject gravels to a process of natural selection, in which all but the most resistant lithologies are broken down into finer fractions. The presence of ferricrete provides independent evidence for such conditions.

The basalt-capped stream deposits are remnants of the erosion level to which Colditz (1943) assigned a lower Pliocene age. Potassium-argon dating by Wellman and McDougall (in press), and by Dulhunty (1971; in press) has shown that Colditz' chronology for landscape evolution must be modified considerably. The potassium-argon basalt ages obtained for the lower Macquarie Valley are all middle Miocene *. Dulhunty (1971) has suggested an Eocene or Oligocene age for the basalt cap on Mt Bodangora, a high residual to the northeast of Wellington. However, there is no evidence for post-Miocene vulcanism in the Wellington area. Thus it seems certain that the relict erosion level at Neurea is older than Colditz allowed. Basalt flows lying on the floor of the Macquarie Valley near Dubbo have been dated at 12 million years (Ma) (Wellman and McDougall, in press)and 14Ma (Dulhunty, in press) respectively. Basalts of similar age may be found on the valley floor near Geurie, about 25 km downstream from Wellington. In the Gulgong district, about 75 km upstream from Wellington, basalt flows of 14-15Ma overlie extensive deposits of alluvium on the floor of the present Cudgegong Valley (Dulhunty, 1971). These dates suggest that the Cudgegong and lower Macquarie Valleys had been incised to their present depth by the middle Miocene.

But Wellman and McDougall (in press) obtained ages of about 12Ma for basalts overlying ferruginous sediments on the hills near Mookerawa, about 35 km upstream from Wellington. These deposits are approximately 150 m above the floor of the Macquarie Rivêr. At both Neurea and Mookerawa, the outcrop patterns and underlying fluvial deposits indicate that basalt flowed down the valleys of the ancestral rivers before the present valleys existed. It is difficult to reconcile the Mookerawa dates with the earlier ages obtained for valley floor basalts along the Cudgegong. The former site is only a few kilometres upstream from the Cudgegong confluence, so it seems unlikely that there could have been substantial downcutting of the Macquarie at this point, without any significant incision along the Cudgegong. McDougall (pers. comm.) has pointed out that the Mookerawa basalts are of a type which is vulnerable to radiogenic argon loss, and thus the potassium-argon dates can be regarded as minimum ages only. If significant argon loss has occurred, then the actual eruptions could have taken place somewhat earlier. But at present there is insufficient evidence to resolve these problems. Despite the difficulties of interpretation posed by the potassium-argon dates, it seems clear that the old erosion level is of Miocene rather than Pliocene age. There is some evidence to suggest that the Bell Valley had been incised to its present depth by the middle Miocene.

The Two Relict Erosion Levels

In addition to the former erosion level represented by the basalt capped

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* According to the time scale of Berggren (1972)

gravels, Colditz (1943) postulated a more recent level represented by spurs of concordant elevation covered with scattered lag deposits, about 50 m above the present valley floor. The lag gravels on the limestone ridge about 1 km south of the caves were taken to be part of the latter level. These lag deposits consist mainly of rounded quartz gravels, though some ferruginous conglomerate and sandstone floaters are present. The similarities between these sediments and the ones underlying the basalt caps cast some doubt on the existence of two distinct relict erosion levels. Most of the deposits on the spurs east of Neurea are in positions which could be reached by down slope movements from the basalt capped ridges; no sediments in their positions of deposition are evident at the lower levels. The case for a second relict erosion level thus appears to depend very much on the gently sloping spurs of concordant elevation, situated below steeper sided basalt capped residuals. Colditz (1943) interpreted this morphology as valley-in-valley structure, created by two distinct phases of incision.

However, the steep slopes in the upper storey of the landscape are to be expected, since relatively weak Tertiary sediments are overlain by much more resistant basalt. Conditions here are ideal for parallel slope retreat, in which steep slopes maintain their steepness over time. On most of the Palaeozoic basement rocks, the conditions are not quite so favourable for parallel retreat. Consequently, the variations in spur end slopes could well be explained by lithological controls on denudation during a single phase of development, rather than by two phases of incision.

The lag stream deposits on the caves limestone are most numerous on the highest part of the ridge, about 1 km south of Wellington Caves. These deposits extend for about 300 m in a northerly direction from this site. Much of the present distribution undoubtedly results from down-slope movements; Frank (1971) has reported quartz grains, probably derived from Tertiary stream deposits, in the cave deposits. But the gravels and ferruginous floaters on the highest part of the ridge could hardly have reached this position by slope transportation. These deposits are approximately 30 m below the base of the basalt capped sediments, and perhaps provide stronger evidence for a more recent erosion level. The thickness of the basalt capped sediments indicates that the proto-Bell River was flowing over alluvium rather than bedrock; if a gradient similar to that of the present river is assumed, then there would have been a fall of about 10 m between the stream bed north of Neurea and the caves limestone. The problem of correlating lag deposits over distances of this order is quite considerable, especially when the possibility of differential uplift must be admitted. Warping during uplift could well give rise to a discordance between parts of the same erosion level. But this could not be identified without precise elevations for the basalt base on the hills north and east of Neurea.

Even if such movements have not occurred, it seems quite likely that lag stream deposits should remain on limestone during denudation. At Cooleman Plain, lag Tertiary gravels and ferruginous sandstone floaters may be found on limestone knolls 15 m below the level at which these sediments occur in their positions of deposition. In both the Neurea district and the area south of the caves, there appears to be a preferential association of gravels with limestone outcrops. Often the gravels tend to peter out beyond the limestone contacts, even where there is no substantial change in slope. These observations suggest that conditions on the limestone may be more favourable for the preservation of lag deposits than on other adjacent lithologies. Factors which favour the persistence of gravels include:

1. The rugged micro-relief on partially bare karst in the higher topographic positions. Solution pans and grykes provide numerous traps for the gravels.

2. The loss of water due to percolation, which reduces available runoff and slope wash. Other forms of mass movement are impeded by the lack of soil moisture.

3. The relatively greater importance of solutional processes in the denudation of limestone.

The indurated nature of the sediments also contributes to their persistence; numerous gravels are locked up in conglomerate floaters (up to 40 cm diameter), which are not readily removed by slope processes. But their weathering gradually releases gravels to be transported down slope and along drainage lines. It seems likely that this process has been going on since the break up of the Tertiary sediment cover exposed the buried limestone surface.

Thus the possibility that the sediments on the limestone are remnants from a continuation of the basalt filled valley must be considered seriously. If the ferruginous cementation was caused by thermal metamorphism, then a prior basalt cover would be indicated. Since there is no evidence of later vulcanism near the caves, the sediments must be referred in this case to the earlier erosion level. Since the weight of evidence suggests a pedogenetic origin for the iron oxides, the question is more complicated. The nature of the sediments suggests a distinctive depositional environment, similar to that of the basalt capped deposits, and very different from the present one. This provides some evidence for a correlation with the basalt capped erosion level, but the possibility of subsequent sedimentation under similar environmental conditions cannot be ruled out.

The Alluvial Corridor

The caves limestone and the ridges to the north of Neurea are separated by two shallow valleys which rise to a low divide about 30 m above river level. This area was mapped as alluvium by Colditz (1943) and termed an alluvial corridor by Frank (1971). The area is heavily mantled, but has been dissected by erosion gullies. The latter are probably of recent origin, associated with poor land management practices. Gully depths range from 2-4 m, but bedrock is rarely exposed. Much of the corridor is occupied by profiles which would be classified as non-calcic brown soils, according to Stace and others (1968). These soils fall into the Db 2.1 class in Northcote's (1971) classification. They have dark grey-brown upper horizons, giving way fairly abruptly to finer textured, slightly mottled clay subsoils; there is no A_2 horizon. Soil reaction is acid at the surface, becoming neutral with depth. The profiles contain numerous fine andesitic gravels. The area to the west of the corridor is mantled with red-brown earths (Gn 2.1), which extend down into the corridor in places. These soils are brown near the surface, grading into weakly structured red-brown silty clay in the lower horizons. pH values are alkaline at the surface and strongly alkaline in the subsoil, where free carbonates are present.

The slopes at the north-western end of the corridor are occupied by dark red clay soils which Frank (1971) has described as terra rossa. In Australia, "terra rossa" tends to be used as a general term for any red soil formed on calcareous parent material which does not fit readily into any other soil group (see Stace and others, 1968, p.283). But the soils near Wellington Caves would be better described as euchrozems (Gn 3.1). They are red-brown at the surface, with a dark red blocky subsoil; horizon differentiation is rather weak. pH values are slightly acid at the surface, becoming alkaline in the lower horizons. Some free carbonates and a few dark ferromanganiferous concretions are present in the subsoil.

The soils of the corridor are well exposed in the erosion gullies, but no fluvial deposits are evident in the profiles. Scattered surficial quartz gravels extend along a gullied drainage line which runs down from the elevated limestone area to the northern end of the corridor. These gravels are present also along a gully which runs eastward into the main part of the corridor. The distribution of stream gravels suggests transportation down slope and along drainage lines from sources on the highest parts of the limestone ridge. A few angular quartz fragments are present near the saddle in the corridor; but several of the latter exhibit polygonal crystalline form, indicating a derivation from vughs or veins in the adjacent volcanics rather than Tertiary stream deposits.

The paucity of outcrops makes precise delineation of the geological boundaries virtually impossible; thus it is difficult to reach many specific conclusions about the relationships between soil mantles and the geological substratum. But at Wellington Caves, red-brown earths occur as sedentary soils on limestone. This, together with the high pH values, suggests that these soils are derived from calcareous parent material. The andesitic gravels in the non-calcic brown soils indicate a derivation from the volcanics which probably underlie most of the corridor. Boundaries between these two soil types are usually gradational. In one gully on the western side where bedrock is exposed, the change in soil type is located down slope from the contact, suggesting colluviation.

The genesis of the euchrozems is more problematical. Frank (1971) has suggested that they are colluvial in origin, but there is little evidence in the profiles to indicate a specific parent material. At the Wellington Soil Conservation Research Station, 15 km north of the caves, interbedded limestones and andesites are mantled with euchrozems which show little variation over the diverse lithologies (Blandford, pers.comm.). Blandford has attributed this to active colluviation; a similar situation may prevail in the caves area.

Observations during wet weather in August 1973, show that surface wash is effective in the corridor; some higher areas have suffered sheet erosion. Near the saddle in the corridor, lateral through flow was observed in the upper B horizons of non-calcic brown soils. This appeared to be transporting clays into the gully sides. Collectively the evidence from observed processes, profile forms and relations with the geological substratum indicates that the deep soils of the corridor have a colluvial origin. Both surface wash and lateral subsurface movement of finer particles are involved in this development. There is no evidence of any significant contribution from fluvial deposits, so the corridor is not alluvial in nature.

Capture Hypothesis

According to Frank (1971), the Bell River formerly flowed through the corridor. At this time the river had a parallel tributary, Catombal Creek, which joined the Bell just north of the caves area. In the late Pliocene or early Pleistocene, Catombal Creek or one of its tributaries captured the Bell River, which now occupies the valley of the ancestral Catombal Creek. Since there is no evidence of a prior stream course through the corridor, the proposed capture must be re-examined. Frank has offered two other forms of evidence for the capture:

1. The sharp right-angle bend through which the Bell River flows near the Catombal Creek confluence, and the respective alignments of the two valleys.

2. A westerly shift in the confluence between the Bell and Macquarie Rivers, postulated on separate evidence by Matheson (1931) and Colditz (1943).

The shift in the latter confluence seems irrelevant to the hypothesis under consideration, since Frank envisaged a situation in which the ancestral Bell River and Catombal Creek joined just north of the caves. Course changes down at the Macquarie River would only be relevant to a capture hypothesis if the two streams concerned had independent confluences with the Macquarie. But if this were the case, then the capture hypothesis would require the abandonment of one confluence in favour of the other. What Matheson and Colditz have postulated is the gradual westerly migration of the Bell/Macquarie confluence, caused by deposition of alluvium between the two streams.

The right-angle bend in the Bell River appears to reflect structural factors. In the surrounding area, the predominant orientation of geomorphic features is north-south, following the strike of the Palaeozoic rocks. The caves limestone, the corridor and the ridge to the east all run in northerly directions, as do larger-scale features such as the Catombal Range. Major drainage lines like the Bell River tend to follow the beds, only crossing them occasionally where conditions are favourable. After flowing northwards in a strike valley for a considerable distance, the Bell River changes direction about 5 km east of Neurea. From here it follows a meandering course of general west-north-west trend, approximately at right angles to the strike. Near the Catombal Creek confluence, the river swings back to follow the strike again. The reach which crosses the beds runs through an area where Strusz (1958) has postulated a sharp pitch depression; plunging strata are evident at several locations. The abrupt right-angle bend, which Frank has taken as an elbow of capture, occurs where the Bell passes around the nose of a closing fold. This suggests that the abrupt bend is a reflection of structural influences, rather than an elbow of capture.

It could be argued perhaps that the pitch depression has provided a favourable alignment which allowed a headward cutting tributary of Catombal Creek to capture the Bell River. But in this case the elbow of capture would be the bend east of Neurea, and the prior stream course would have flowed near Dripstone, rather than through the corridor. Such a capture would bear little resemblance to the one postulated by Frank. There is no real evidence to support a capture of the former type. The basalt capped fluvial deposits which parallel the Bell River indicate that this stream was flowing westwards past Neurea at the time this relict erosion level was formed. The prior stream course was probably influenced by similar structural factors. The evidence suggests that basalt flowed down the valley of the proto-Bell River, forcing the river to one side of the old valley. Subsequently a new valley has been incised, parallel to and slightly south or west of the earlier one. The present valley has been influenced by structure in the Palaeozoic basement rocks. If the lag gravels on the caves limestone are part of the basalt capped erosion level, then the drainage diversion extended downstream as far as the caves area. Thus, if there was a capture of the Bell River, it must pre-date the basalt capped erosion level. This would put the capture well back in the Tertiary. In view of the degree of dissection which the old erosion level has suffered, it is hardly likely that evidence for an earlier stream course would be preserved. To postulate capture in the absence of such evidence is most uneconomical. The present drainage patterns can be adequately explained in terms of structural influences and evolutionary history, without recourse to a capture hypothesis.

Wellington Caves

All known caves are located near the northern end of the limestone ridge which separates the corridor from the Bell River. Six caves are usually recognised, but there is evidence of former interconnection. Detailed morphological descriptions of the caves have been given by Frank (1971). Although in many locations bedrock is obscured by sediment, breakdown or speleothems, the caves all appear to be of phreatic origin (Frank 1971). Cathedral Cave is characterised by wall pockets 1-3 m in radius, which are often separated by pendants and other cuspate projections. These solutional forms suggest the injection of strong currents below the watertable (Jennings, 1971, p.164). The main chamber in Cathedral Cave has developed along a fault, which brings together massive calcarenite and thin bedded micrites. The latter extend along the north-eastern wall, exhibiting well-developed, small-scale warping and fracturing. At the northern end of this chamber, and in the lower passage, the limestone is brecciated. This breccia has been effectively rewelded, and forms stable overhangs in places. Recesses around the brecciated areas suggest that they are more resistant to solution than the rest of the bedrock. It is even possible that solution was initiated in small tectonic cavities.

The caves have suffered considerable infilling with a variety of sediments, which have been studied in detail by Frank (1971). He has distinguished three main stratigraphic sub-units and drawn a number of inferences about their depositional environments. At least one phase of entrance sealing and re-opening is indicated. Frank obtained a radiocarbon date of about 30,000 years for bone from the uppermost sub-unit; minimum dates of 35,000 to 40,000 years were obtained for flowstone from the lower half of the basal sub-unit. On the basis of these dates, Frank concluded that the cave sedimentation had taken place during the past 50,000 years.

Small pools in several of the caves and the water level in a nearby well indicate a well-defined watertable which is nearly horizontal (Frank 1971). The groundwater level usually lies between 1 and 2 m below the Bell River, but fluctuates within a zone several metres deep, depending on climatic conditions. According to Frank's calculations, groundwater levels must have been at least 35 m higher to put the caves in the phreatic zone. If a similar relationship between groundwater level and valley floor has prevailed in the past, then the caves would have formed before the valley had been incised to its present depth. There do not appear to be any impervious interbeds or other structural features which could have given rise to a perched watertable in the past. If the limestone had remained relatively impermeable during the earlier stages of karst development, this may have inhibited the development of a single watertable, conformal to the level of the valley floor. But it seems most likely that cave development was initiated before the valley had reached its present depth. Colditz (1943) believed that the caves were formed at the end of the Pliocene. In view of the denudation chronology outlined earlier, it is apparent that the caves are older than this, and may even extend well back into the Miocene.

The present valley floor is heavily mantled with alluvium, and a series of terraces about 5-6 m above the river banks may be traced for considerable distances. Much of the alluvium is undoubtedly Quaternary, though some of the deeper deposits may well be Tertiary. Hunt (1960) has reported partly indurated alluvium of probable Tertiary age underlying the Cudgegong River about 20 km east of Wellington. Since the Bell Valley has been cut down to below its present level and later alluviated, it may be inferred on theoretical grounds that the caves have been drained and partially refilled. The slightly higher erosion level to which the terraces are related may have been associated with the higher groundwater level and more pluvial conditions which Frank has postulated for the deposition of sub-unit 1 about 40,000 B.P. But at present there is insufficient evidence to permit detailed correlation of cave and valley floor sediments.

One of the most striking problems in this interpretation of the caves landscape is the contrast between the inferred antiquity of the caves and the relative youthfulness of the cave fills. Frank (1972) has argued on theoretical grounds that evolution in a purely phreatic cave system is essentially a one way process, in which entrance development and sedimentation lead to the eradication of the system within a few tens of thousands of years. If this is correct, then there is an incipient conflict between the denudation chronology based on potassium-argon basalt dates and the sediment chronology based on radiocarbon dating. Since the ^{14}C dates from the lower part of sub-unit 1 are minimum ages only, it is possible that cave sedimentation has taken place over a longer period than Frank allowed. Slight contamination of the flowstone samples could give rise to radiocarbon dates considerably less than the actual ages (Frank, 1971). Alternatively, it must be admitted that there can be a very considerable interval of time between cave formation, and entrance development to permit infill.

Acknowledgments

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RESULTS OF SURFACE LEVELLING AT BUNGONIA CAVES, N.S.W.

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Introduction

During 1971, members of the University of N.S.W. Speleological Society (UNSWSS) were working on a project to determine watertable levels, as represented by sumps, in some of the Bungonia Caves. It was soon realised that the accuracy of heights determined from the available surface surveys, usually "forestry compass" traverses, was insufficient. The author was asked to provide more-accurate surface levels and, consequently, two trips were organised on 24-25 July and 31 July 1971 with the aim of establishing a differential levelling net in the plateau area. Personnel on the first trip comprised E.G. Anderson and A.J. Watson (Senior Photogrammetrist, N.S.W. Lands Department), surveyors, and A.J. Pavey and M. Caplehorn, UNSWSS, assistants. On the second trip, M. Caplehorn was replaced by A. Culberg, UNSWSS.

The activities on both trips have been reported by Pavey (1971a, b).

Method and Equipment

During a brief reconnaissance, four bench marks (Gate, Junction, 102, and Lookout) were established along the main access road (see Figure 1). A conventional, differential levelling technique was then used to build up a network of one-way loops, incorporating connections to as many caves as possible. A number of additional bench marks were established as necessary. Two parties, each comprising a surveyor and a staff man, operated independently.

Zeiss Ni 2 automatic levels were chosen for their accuracy, reliability and ease of operation. These instruments depend on a gravity "compensator" to establish a horizontal line of sight and are thus not subject to several sources of error associated with conventional spirit bubble levels. The staffs used were 14 feet, four section, extruded aluminium, and graduated to 0.01 ft. A staff bubble was used to set the staff vertical.

Results

Eleven bench marks were established within an area of approximately

100 hectares and connected by about 11 km of levelling. Levels of five miscellaneous marks and 26 cave tags were determined. (Caves in the Bungonia area are indexed by the letter B followed by a serial number and are physically tagged, near the entrance, by affixing a small metal disc bearing this number. In all cases, the cave levels quoted refer to the centre of the tag.)

Final, reduced levels of the bench marks and miscellaneous marks, and a brief description of each, are presented in Table 1. Table 2 contains the results for the caves. All of the levels are referred to a local datum, B.M. Lookout, the level of which was adopted as 548.64 metres (1800.000 feet). This value refers to N.S.W. "standard datum" and was derived from the 1 : 31680 Bungonia map (N.S.W. Lands Department). The absolute value of the levels (i.e. altitude) must, therefore, be considered approximate and may be subject to an error of + or - 5 m.

The survey was designed as an integrated network of loops, to limit the propagation of errors and provide a reasonable degree of redundancy. Miscloses for the seven loops, indicated by circled numerals in Figure 1, are listed in Table 3. In addition, the misclose resulting from a two-way run between B.M. Junction and B.M. Gate is listed as loop 8. A rigorous, least-squares adjustment by the condition method was applied to the observations, with weight coefficients determined in accordance with the number of readings in each section of levelling. Statistical analysis of the results indicates an overall standard error of the adjusted height differences of + or - 2 cm. However, because of the inaccessibility of many of the cave tags, connection often necessitated indirect measurement and a more realistic estimate of the accuracy of relative levels would be + or - 5 cm.

Acknowledgments

The willing assistance in the field of those named above is gratefully acknowledged. Professor P.V. Angus-Leppan (University of New South Wales) generously permitted use of the equipment. The computer program used in adjustment and analysis of the survey data was developed by the School of Surveying, University of New South Wales.

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TABLE 1 BENCH MARKS AND MISCELLANEOUS MARKS

MARK	RED. LEVEL metres	DESCRIPTION
LOOKOUT	548.6400	Adopted Datum. Nail in base of tree.
TANK	547.94	Bolt in water tank platform.
102	541.85	Bolt in rock near B31, (UNSWSS Origin).
JUNCTION	546.90	Nail in base of tree.
GATE	551.94	Nail in base of tree.
CREEK	538.55	Nail in tree root.
HILL	559.15	Nail in base of large dead tree.
CONGLOMERATE	555.43	Small rock outcrop.
ROCK	544.73	(Temporary).
BECK	544.89	On rock platform near B63.
GREY GUM	540.89	Nail in base of gum tree.
"SSS" ORIGIN	544.62	Painted mark. (Thought to be survey marks
"SSS" No. 5	539.72	Painted mark. of Sydney Speleo. Society.)
POST	547.73	Top of fence post used in UNSWSS survey.
NORTH GATE POST	551.23	Top of gate post at reserve entrance.
SOUTH GATE POST	551.69	Top of gate post at reserve entrance.

TABLE 2 CAVE TAGS

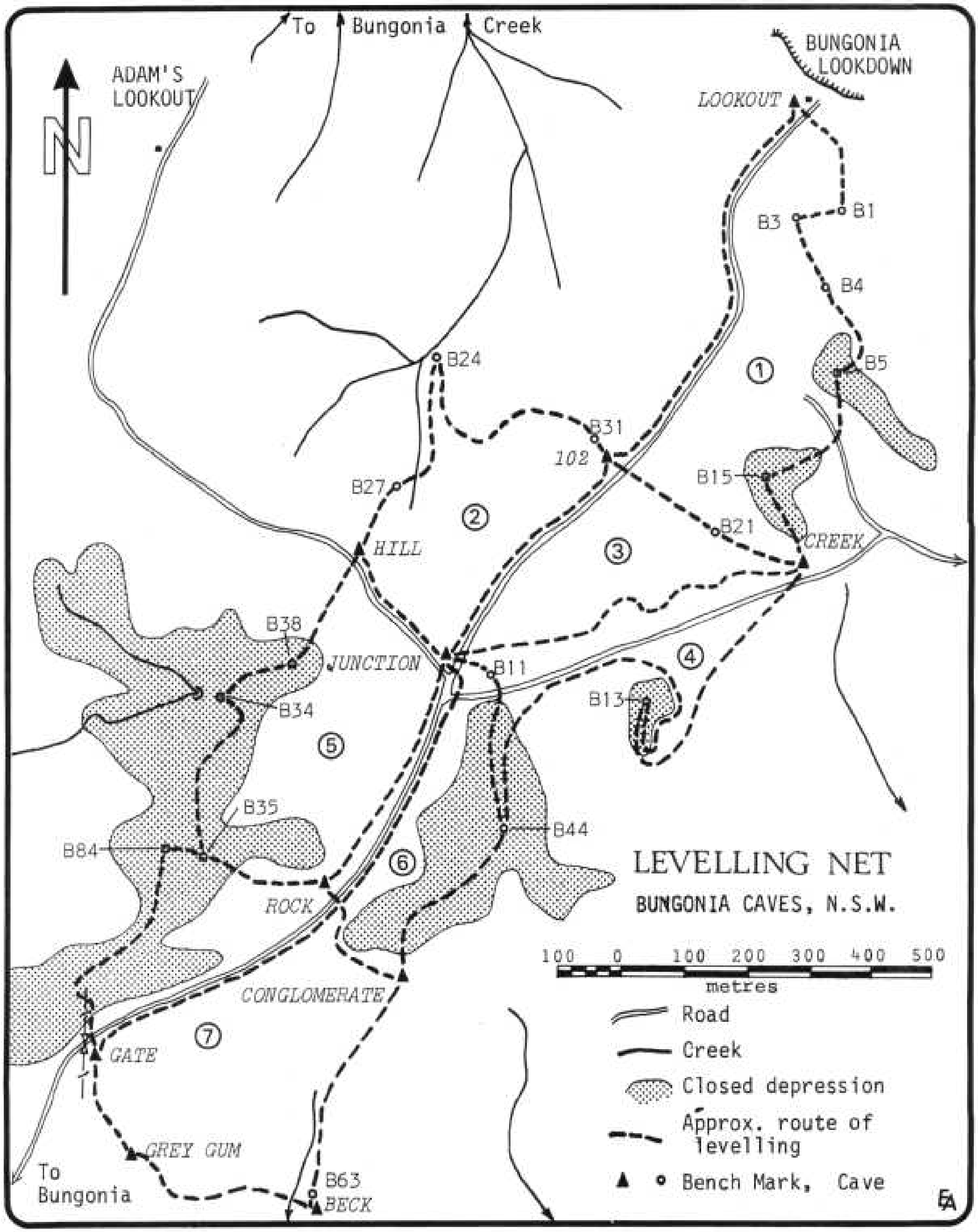
CAVE	RED. LEVEL metres	CAVE	RED. LEVEL metres
B1	539.15	B27	546.37
B2	535.84	B31	531.17
B3	530.25	B32	537.40
B4	521.21	B35	529.88
B5	509.60	B37	538.28
B10	534.65	B38	539.62
B13	513.81	B39	535.29
B15	519.38	B41	536.93
B16	534.40	B44	523.86
B19	524.66	B45	538.56
B22	536.03	B50	533.18
B23	538.61	B51	530.46
B24	529.89	B63	542.75

TABLE 3 LOOP MISCLOSES

LOOP NUMBER	MISCLOSE mm
1	+9
2	-14
3	-12
4	-9
5	+11
6	+29
7	+11
8	-6

<u>Add Table 2</u> -
B80 - 540.60
B84 - 532.70

FIGURE 1


To Bungonia Creek
BUNGONIA LOOKDOWN
ADAM'S LOOKOUT
N
LOOKOUT
B1
B3
B4
B5
①
B24
B31
102
B27
②
B15
B21
CREEK
③
HILL
B38
JUNCTION
B11
④
B13
B34
⑤
B35
B84
B44
⑥
ROCK
LEVELLING NET
BUNGONIA CAVES, N.S.W.
100 0 100 200 300 400 500
metres
CONGLOMERATE
Road
Creek
Closed depression
Approx. route of levelling
▲ ○ Bench Mark, Cave
GATE
⑦
GREY GUM
To Bungonia
B63
BECK
EA

ABSTRACTS AND REVIEWS

GEOLOGY OF THE SOUTH SEPIK REGION, NEW GUINEA. By D.B. Dow, J.A.J. Smit, J.H.C. Bain and R.J. Ryburn. Bureau of Mineral Resources, Geology and Geophysics Bulletin 133, 1972 : 88 pp + folded map in pocket (Geological map of South Sepik region).

Until 1965, the mountains south of the Sepik River, New Guinea, had remained largely unexplored, mainly because of the difficulty of access and the inhospitable nature of the country. It is rugged, wet, and has an unrelieved cover of tropical rain forest. The area supports only a few semi-nomadic people and tracks are almost non-existent. The BMR mapped the area using Hamilton jet-boats in 1966-67 for access to the mountains, and a helicopter in 1967 to position field parties within the mountains. An area of about 10,000 km^2 was geologically mapped, covering the northern fall of the Central Range between the Yuat River in the east and the Frieda River in the west.

The main area of speleological interest is the Tibinini Limestone which occurs as very thick limestone forming spectacular cliffs on the south side of Lagaip Valley between Porgera and Kepilam. Thickness is estimated to be between 900 and 1200 m. A photograph (Plate 8) shows a line of cliffs 600 m high, with Mount Kaijende (3261 m = 10,700 ft) in the background. Kaijende is also composed of Tibinini Limestone. Though caves are not referred to, the authors say the elevated surface of the limestone is weathered into karst topography on a gigantic scale - spires and aretes of limestone up to 100 m high being common on Mount Kaijende.

After reading this Bulletin, I can only conclude that the Tibinini Limestone (roughly surrounding 143 deg. 15 min. E, 5 deg. 30 min. S) must rank as one of the world's most "impossible", though potential, caving areas. - E.A.L.

CAVERNICOLOUS SPIDERS FROM THE NULLARBOR PLAIN AND SOUTH-WEST AUSTRALIA. By M.R. Gray. J. Aust. ent. Soc., 12 , 1973 : 207 - 221.

Three cavernicolous spiders are described from caves on the Nullarbor Plain, Southern Australia - two troglobites, *Janusia muiri* n. gen., n. sp. (family Miturgidae) and *Tartarus mullamullangensis* n. gen., n. sp. (family Amaurobiidae), and a troglophile, *Epimecinus alkirna* n. sp. (Amaurobiidae). Both troglobites are blind and depigmented and *T. mullamullangensis* has much attenuated appendages. *T. mullamullangensis* is closely related to a species inhabiting the moist South-West of Western Australia and its presence on the Nullarbor suggests the occurrence of at least one phase of wetter, cooler conditions in the past than are now prevailing. The web of *T. mullamullangensis* is illustrated and described. - G.S. Hunt.