Gregory Karst - geology and geomorphology

Preliminary report of field observations in 2005

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(minor corrections, Feb 2006)

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INTRODUCTION

This is a summary of my field observations made during the two week field trip of the Gregory Karst Special Interest Group (GKSIG) of the ASF in July 2005. My intention is to simply record my observations and preliminary thoughts on the geology and geomorphology. This should not be regarded as a formal report. A selection of my photos are included on this CD-ROM, as are the maps and diagrams which I refer to in this text. All photo files are prefixed with "D05", I will generally just quote the following 4 digits. Note that the photos are 5 megapixel and can be usefully zoomed into to look at the fine detail.

Prior to the trip I browsed the literature and did a photo-interpretation of the geology and surface karst and prepared two maps at 1:25,000 scale of the central and far northern areas. These were partly field-checked during the trip, but further checking is needed, especially in the far northern area which remains largely unvisited. Revised versions of the maps accompany this report as the files

* GKC_Geol_21.pdf (central area),
* GKC_Geol_22.cave.pdf (central area with Bullita Cave overlay) and
* GKN_Geol_21.pdf (far northern area)

Field work included studies and photographic documentation of the geology, the surface karst (especially the karren, but also some tufa deposits), and the caves. The cave "studies" were largely a familiarisation exercise and I did not get to see all variations of this complex set of caves. The main contribution to the GKSIG's cave studies was the sketching of four profiles across parts of Bullita Cave, included herewith as the PDF files "Profile-1.pdf" through "Profile-4.pdf".

Sue White and I interviewed many of the GKSIG members during the trip, asking for descriptions of different parts of Bullita Cave. We felt that it was worth getting these descriptions down on paper as people's memories were already growing dusty. Our notes from this are on the CD-ROM as "BullitaCave-descriptions.PDF".

All this in only 11 days fieldwork, so none of the above could be regarded as anywhere near complete. Some of the maps and profiles included on this CD-ROM need additional field checking.

GEOLOGY

The geology of the karst (Skull Creek Formation and Supplejack member) has been documented by others, most recently in an unpublished discussion note by Martini (2005), and I will not repeat that information here. Some comments on Martini's notes are made below.

The main new aspect warranting discussion here is the so-called Bardia Chert in the far northern area, which is in fact a quartz sandstone!

On my geological maps I have picked out some major dolomite beds within the Skull Creek Formation, both above and below the Supplejack member. These beds are thick enough to show significant karren development, including large grikes, and the thicker beds might have some cave potential. They provide useful marker beds for estimating the dip of the rocks. I have used a notation of "s+1, s+2, ..." for beds progressively higher above the Supplejack (in the upper Skull Creek Formation), and "s-1, s-2, ..." for beds below the Supplejack (in the lower Skull Creek Formation).

Dolomite versus limestone

Martini (2005) notes that within Bullta Cave much of the "dolomite" is in fact a fine interbedding of grey limestone (calcite) and light brown dolomitic bands (fine grained dolomite crystals in a calcite matrix). The thin bedding tends to form corrugations and shelves (e.g. photos D051217-1248 in the SOGS area). The colour banding is shown in photo 1233. Photo 1788 shows a less regular colour variation on a surface outcrop of the Skull Creek Formation which might be due to diagenetic replacement of limestone by dolomite. More work is needed to confirm the extent of dolomite against limestone and to compare with other parts of the Supplejack member. It may be that many of the other Proterozoic "dolomites" in the Northern Territory are also partly limestone.

On the surface the thin-bedded zones of the Supplejack tend to disrupt the development of rillenkarren and wandkarren on vertical faces (e.g. the middle of photos 1070 & 1587, and the lower part of 1518, 1672). These thin-bedded areas also tend to have more chert nodules (fine and irregular) than are found in the more massive beds (see photo 1672).

In this report I will use "dolomite" as a general term for all the carbonate rocks, as it is not easy to distinguish dolomite from limestone (calcite) in the field.

Stromatolites

Stromatolites are common in the dolomites. They are particularly spectacular on the upper surface of the Supplejack, where large domes 5-12 m across and 1-2 m high are exposed by the erosion of the brown muds of the upper Skull Creek Formation (Photos D051117, 1203a,). Some earlier workers had mistaken these for exfoliation domes, but the sedimentary bedding is obvious. They form distinctive circular patterns on the low-altitude air-photos (see bottom right corner of the stereo air-photos "Karren.C.L.jpg & Karren.C.R.jpg").

The larger stromatolites have smaller laminated structures within them. These are of two main types. 1: Straight, parallel ribs 10-20 cm wide, several metres long and extending at least 30 cm down into the rock (Photos 1131-32, 1160). In any location these ribs tend to all be aligned parallel to each other, but the direction varies between sites. I suspect they may have been aligned to currents or wave directions. 2: The other type comprises a polygonal pattern of small domes or vertical columns – smaller stroms within the large one (photo 1155).

Elsewhere, within the Supplejack, and in the dolomite beds of the Skull creek, there are many smaller stromatolites, ranging down to polygonal groups with individuals only 10-20 cm across. See photos 1050, 1160, 1162, 1174. There is an excellent cross-section of a medium sized stromatolite in front of the Crystal Cascades lookout, but it is facing away from the viewer so is not obvious (see photo 1050). A sign drawing attention to this could be useful – or relocation of the lookout a few metres forward?

Old land surfaces and denudation rates

The somewhat dissected flat top to the east-west range in the far northern area (shown on my map "GKN_Geol_21.pdf" and at elevations between 220 and 250m ASL) could be an old land surface with associated deep weathering profile. This was the interpretation of Dunster & others (2000) who mapped it as a silcrete duricrust of Cainozoic age and described it as a brecciated chert with silcrete textures. This interpretation differed from the first edition map and notes (Sweet & others, 1974) who regarded it as a member of the Skull Creek Formation, named the Bardia Chert. The nature of the material, which was found to be sandstone in the part visited in 2005, is discussed below. Here I am discussing the old land surface at the top of the range.

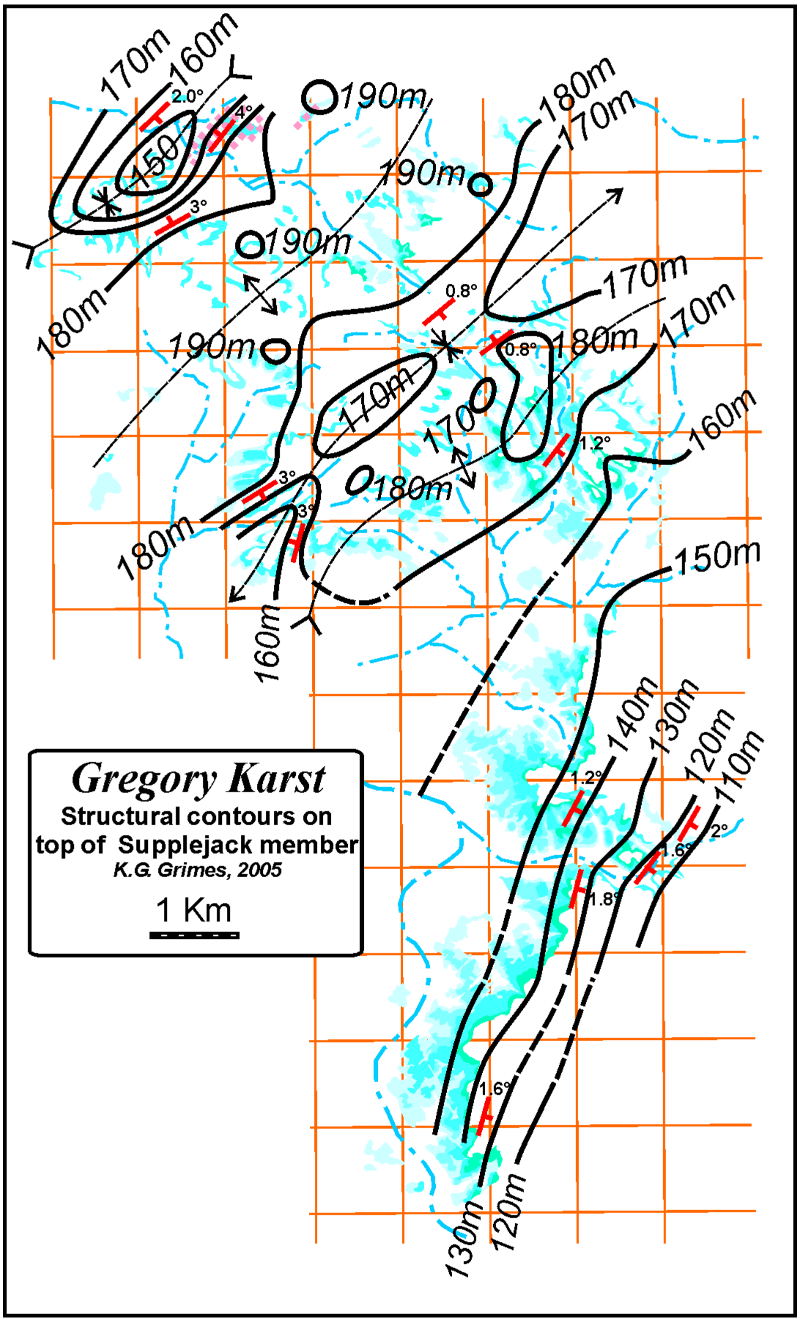
Hayes (1967) in a regional study of old land surfaces in the NT mapped residuals of his late Cretaceous to early or mid Tertiary "Tennant Creek Surface" in this area. He also mapped a lower "Wave Hill Surface" of possible Miocene to Pliocene age, which might correspond to the lower surface seen east of Bullita Cave, at an elevation of 140-150 m ASL. This lower surface predates incision of the present gorges of the river and Limestone Creek to about 100m ASL, and would also predate the cave in its current form. Occasional rounded cobbles and pebbles of hard quartz sandstone were found lying on the surface of the Supplejack in the Bullita cave area. These might be remnants of an old stream channel flowing on the Wave Hill Surface prior to incision. However, similar cobbles were seen at an aboriginal art site, so they may have been carried by the aboriginals as grinding stones.

Those, admittedly broad, ages are in agreement with the Pleistocene age of the cave suggested by Martini (2005) on the basis of limestone denudation rates in climates similar to the Gregory Karst. However, we must remember that ongoing development and age of the cave is probably more related to rates of horizontal slope retreat (which exposes the contact between the top of the Supplejack and the upper Skull Creek formation) than to vertical incision. However, vertical incision would be a control on the outward drainage of the system and the development of the lower levels.

The present gorges of the river and Limestone Creek suggest that there has been a recent phase of channel incision that might not have had a great deal of associated valley widening (and therefore of retreat of the 'contact zone'). "Recent" must however predate the 8-10,000 BP dates on the older tufa deposits within Limestone Gorge. The period of phreatic preparation within the Supplejack may predate this incision and have been in a broader karrenfield – of which the western part has now been destroyed. However, the lower cave levels probably postdate the gorge incision, as might the mechanical erosion of the shale bed which implies strong flows and efficient drainage of the cave.

Structure

Bedding dips are gentle, and were measured by plotting the intersection of the beds with the contours on the map. In the central area, in the vicinity of Bullita Cave, the beds dip between one and two degrees to the ESE. Further north the dips vary but are still shallow, reaching up to 4 degrees, with several broad gentle anticlines and synclines along NE-SW axies (see diagram: Suppleback.Struct.png). Some previous authors have commented on the possible significance to cave genesis of the dip being into the slope, towards the contact with the overlying Skull Creek formation and away from the gorges. However, on the north side of Limestone Creek the dips are roughly parallel to the contact and cave development there seems similar to that on the south side.



I have shown joints, lineaments and possible faults on my geological maps. This is photo-interpretation, but gives a useful overview of the structures which are controlling the grikes and the cave passage beneath them. The lineaments are simply longer photo-lines than the joints – they may be just long joints or may be faults. The joint (grike) density on the Supplejack karrenfields is denser than can be shown at 1:25,000 scale, I have generalised the patterns and attempted to show the dominant style in each area.

I superimposed the low altitude, 1989, 1:8000 scale, air-photos (Limestone Creek area) onto the cave map to see if there was a correlation between grikes and cave passages. This was simply done visually because of the lack of positional control. Some surface grikes corresponded to cave passages, but there are many additional grikes in the areas between the mapped passages. These might well appear on the cave walls as tight joints, or narrow fissures too small to enter – field work could confirm this. The influence of major lineaments and faults on possible paleokarst brecciated sandstone in the far northern area is discussed below.

Unnamed sandstone and possible paleokarst

The first edition geological map showed the east-west range of the far northern area (see 'qs' areas between AMG 440315 and 500320 on my map "GKN_Geol_21.pdf") as being "Bardia Chert" and interpreted it as a member of the Proterozoic Skull Creek formation (Sweet & others, 1974). The second edition map also described this area as brecciated chert, but interpreted it as being a Cainozoic silcrete (Dunster & others, 2000).

The unit appears on the 1998 air-photos as an area of brown coloured soil. The upper surface is irregular – there is no flat mesa structure such as one might expect from a silcrete cap. The base of the brown unit is very irregular and unconformable on both the underlying Skull Creek Formation and the Supplejack member. However, the basal contact is difficult to map accurately as there seems to be a fair bit of mass-movement of brown soil & scree flowing down over the actual contact and making it hard to pick. Cliffed outcrops of Supplejack member can be seen to cut out abruptly against the steeper edges of this unconformity. The deepest parts of the unconformity are linear trenches, 50-200 m wide and up to 50m deep which seem to be following linear fault traces (WNW to NW trends). These form valleys with normal Skull Creek and Supplejack outcrops on the sides, but interrupted at intervals along their length by saddles of the brown material (Photo D051636p). Given the descriptions of "brecciated chert" on the geological maps, I had tentatively interpreted these as being possible paleokarst fills of brecciated and silicified material due to intense solution along the faults. Isolated knobs of dark brown colour on the top of the ridges I photo-interpreted as ferruginised material ('qsf' on my map).

During the field trip I visited some of these "fault troughs" in the area starting at AMG 493305 and travelling past 484310 to 489316, 485317 and 482315. The brown material was not a brecciated chert, as expected, but rubble of hard quartz sandstone. Photo D051636p is a view along a "fault valley" taken from one sandstone saddle and showing a second brown sandstone saddle in the distance. Note the flat-lying outcrops of Skull Creek and Supplejack units on the valley sides. Photo D051631 shows another saddle of sandstone rubble with undisturbed horizontal Skull Creek outcrops on either side.

There was no solid outcrop of the sandstone anywhere, only loose angular boulders and cobbles. The sandstone is quartzose, brown to grey-brown, fine to medium to coarse grained with scattered rounded pebbles of quartz. The sand grains are moderately to well rounded and moderately to well sorted. Bedding varies from thin (0.5 - 2cm) to thick and a set of small tabular cross-beds, 20 cm thick, was seen in one place. There were a few rippled surfaces and one set of climbing ripples. The rock is hard: a quartzite, but not a silcrete. The lack of solid outcrop prevented measurements of dip, but in two places groups of boulders had apparently consistent dips (e.g. photo D051633), measured at 26° towards 280° and at 42° towards 250°. Neither of these are considered reliable and seem excessively steep for the setting – unless one assumes that we are, in fact, looking at a paleokarst mega-breccia (as concluded below). Where seen, the contact with the dolomite is sharp, linear and steep. Solid outcrops of flat-lying dolomite stop abruptly and are replaced by loose rubble of sandstone (photos 1649, 1668).

I visited only one of the dark brown knobs – it was the same sandstone as elsewhere, but covered by a dense growth of dark-leaved shrubs.

Small areas of Proterozoic Jasper Gorge Sandstone are mapped in a topographically similar setting about 5 km to the NE by Dunster & others (2000). That unit is described as a quartz sandstone that lies unconformably above the Skull Creek Formation (and other units). I am therefor assuming that my sandstone is part of the Jasper Gorge Sandstone, but that the very irregular contact with the older dolomites, the chaotic rubbly outcrop, and the two local steep dips suggest that it was brecciated in a paleokarst situation. The irregular contact might be partly a buried karst surface, but continuing solution in the dolomite after deposition of the sandstone could have caused subsidence and brecciation of the sandstone.

Presumably, elsewhere, the mapped unit really is brecciated chert and silcrete, as described in the geological reports. More field work is needed to check the distribution of the sandstone and to try to find a solid outcrop! The continuation of the Supplejack member along the valley of Spring Creek, south from the East Baines River, which the GKSIG plans to explore in 2006 or later, crosses a saddle at 370100 which may have similar material.

SURFACE KARST

Karren

I spent several days studying the karrenfields north and south of Limestone Gorge. Sue White accompanied me on one day and discussed the karren with me. A summary of my observations appears in a 3-page poster (file "GK-Karren.pdf "on the CD-ROM) and also in a chapter on tropical karren in Australia (Grimes, in prep - see file "KBTK_P05.pdf"). Detailed measurements are in Appendix 1 to this text.

Karren are largely restricted to the thin (10-18 m) but extensive Supplejack dolomite member, within the flat-lying late Proterozoic Skull Creek Formation. There the karren can be divided into four zones of increasing dissection (see later). Extensive maze caves underlie the dissected surface. Outside the Supplejack member, the Skull Creek Formation has only poorly developed mesokarren, but it has well-developed microkarren, especially in the upper part.

Types of mesokarren recognised.

Karren are surface sculpturing features, formed by solution of limestone or dolomite. They are divisible into three size ranges, and a host of named forms within those (e.g. Ginés, 2004).

Mesokarren: Normal-sized karren - recognisable within a 1m grid.
Macrokarren: Large-sized karren - recognisable within a 10 m grid.
Microkarren: Small-sized rills & pits - recognisable within a 1cm grid.

Rillenkarren

Rillenkarren are solution flutes – the most common and distinctive of the karren (photos D051012-13, 1711). They are best formed and most common as a component of the spitzkarren (q.v.). But they also occur as simple parallel linear flutes on the sides of the larger grikes and cliffs, though in steep slopes they tend to be modified by cockling (q.v.). Rillenkarren also occur as small shallow incipient flutes on the Skull Creek pavements and on the zone 1 pavements, often with microrills superimposed on them. Dimensions range from 8-30 mm wide, 1-22 mm deep and up to 2 m long (maximum length downslope is generally limited by horizontal bedding notches). The deepest and longest ones are on steep slopes in zones 3 and 4, but there is not a strong correlation between depth and slope.

The diagram (file: RillenKarren.PNG) shows depth profiles on rillenkarren, measured north of Limestone creek (near 487262). The top group are incipient rillenkarren on gentle slopes in zone 1 (corresponding to photos 1710,12, & 13). The bottom group are from steep slopes in zone 4 to the north.

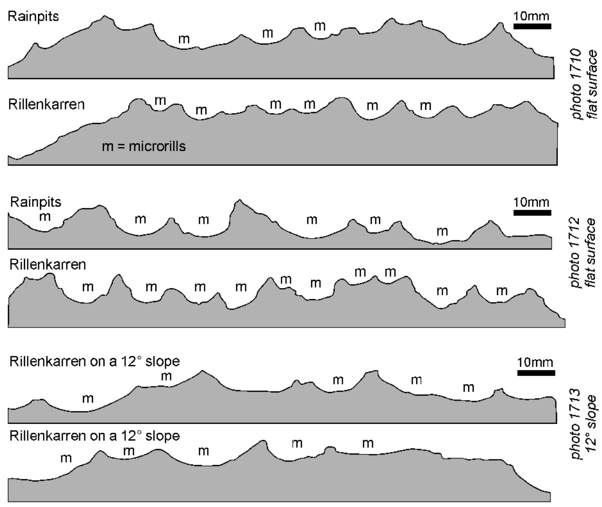


Figure x1: Depth profiles of incipient rillenkarren and rainpits, with microrills (m), on gentle slopes in Zone 1.

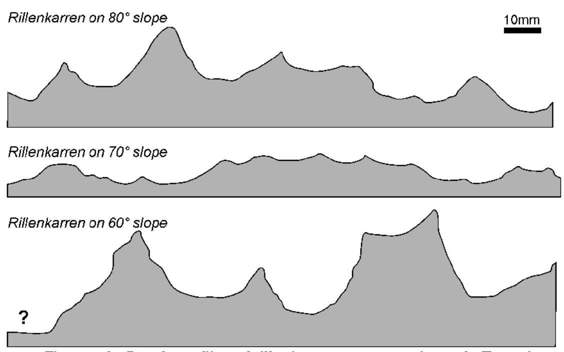


Figure x2: Depth profiles of rillenkarren on steep slopes in Zone 4.

"Rain-pits"

I have put this term in quotes as there is now some doubt as to whether rain impact has a direct effect in their formation (Bernie Smith, pers comm, 2003). These are hemispherical pits with sharp edges, typically 1-3 cm across, but a broad range of sizes occurs (sometimes within a single rock surface) right down to micro-pits only 1mm across (photos 1163-4, photo 1778 shows size variation). See also 'cockling', which occurs on steeper slopes and runnel floors.

"Rain-pits" occur as small clusters on the crests of spitzkarren and grade to rillenkarren on the slopes (photos 1710-11). They are also found on the floors of some kamenitza and flat-floored grikes and on other sub-horizontal surfaces.

As well as on the main Supplejack karrenfield, they also occur (along with incipient rillenkarren and well-developed microkarren) on the pavements of the Skull Creek Formation.

Note that some small but deep pitting may be the result of etching by water seeping along bedding planes that were later exposed at the surface (eg. beneath loose slabs). This is a different thing to the 'true' surface "rain-pits" (see photos 1702 & 1707-8).

Cockling

Cockling is the term for hemispherical pits, similar to "rain-pits" (q.v.), but found on steep to vertical walls and having a larger range of sizes (photo 1716). Cockles may be quite deep and sharp- edged. It also occurs on the twilight zone walls of caves, where it may grade to solution ripples.

Spitzkarren

I use the term spitzkarren **broadly** for all sizes of fluted beehive-shaped pinnacles ranging from a few decimetres up to several metres high and wide. They are composite forms with "rain-pits" on the crest grading down to rillenkarren and then to wandkarren. They form in fields separated by grikes or by runnels (q.v.) in a dendritic pattern, which collect water from the spitzkarren (via rillenkarren) and feed it to a nearby grike (photo 1151, 1773).

In this usage spitzkarren is the most common of the larger (composite) karren forms, but is largely restricted to the Supplejack outcrops. However, there are a few small spitzkarren on the thicker 's+1', 's-1' beds of the Skull Creek Formation.

The spitzkarren range in size from incipient clusters of radiating rillenkarren only 10-20 cm across and a few cm high (photo 1762-3) in zone 1 through groups and fields of fluted pinnacles from a few decimetres to several metres high and wide (photos 1036, 1070, 1139, 1142-3, 1206, 1207, 1384, 1716) to high isolated pinnacles on the outer edges of zone 4 (photos 1464, 1518). Typical dimensions in the spitzkarren fields of zones 3 and 4 are 0.5 - 3 m wide and 0.3 - 2m high (see Appendix 1).

Wall karren (Wandkarren)

Wall karren occur as large vertical channels on vertical or steep slopes (cliffs and grike walls and the largest spitzkarren pinnacles) and extend down the vertical faces from the spitzkarren runnels (photos 1070, 1207, 1730). These can be up to 4 m long (down the wall), and continue across deep bedding notches (e.g. photo 1730). They are from 0.1-0.3m wide (spaced 0.2 - 0.5m) and 0.1-0.3m deep into the wall.

Kamenitza (solution pans)

Solution pans are flat-floored basins, with steep to overhanging walls (photos 1379, 1397, 1742). They have a broad range of depths and widths (up to 2.5 m wide and 0.4 m deep).

Their outline can be roughly circular to very irregular. There is usually an overflow point, and they may form chains joined by short runnels that eventually feed to a grike (photos 1743-4, 1760-61).

The pans in the Gregory Karst have flat floors of two main types: 1: smooth (or with etched polygonal patterns of stromatolite structures) and bare-surfaced with curled flakes of black algae (photos 1383, 1759). 2: Finely pitted with both positive cones and negative pits 2-5 mm wide and 2 mm deep (photos 1033, 1376, 1383, 1752, 1755-6), or with larger hackly 'rain-pits' up to 2 cm wide and deep. These pitted floors have a thin dark-grey algal coating similar to that seen elsewhere in the karrenfield. Occasionally one sees spiky structures (micro-pinnacles) on the floor, e.g. photos 1757-8. There seems to be a correlation between the floor type and the type of algae present.

Kamenitza are mainly found in zones 2 and 3, but are also seen in parts of zones 1 and 4, and occasionally on pavements of the Skull Creek Formation (e.g. photo 1012-13).

Trittkarren (solution steps)

Solution steps (trittkarren) form shallow "paddy-field" terracettes where seepage water has run out from the Supplejack–Skull Creek contact across the slabs of the top of the Supplejack (karren zone 1). The floors are smooth to cockled, and some steps have low rims (photos 1626-7, 1791,2,3). Small tufa rims also occur in this situation (see later).

Runnels

Runnels are small meandering to straight solutional gutters that drain water from the surface into the grikes. They typically form dendritic drainage patterns within fields of Spitzkarren or connecting chains of kamenitza (photos 1142-3, 1151, 1354, 1623-4, 1743-4, 1748-9, 1760-1, 1762-3, 1770-71, 1773). The runnels on the Gregory Karst are not as obvious as in some karst areas as they are not smooth and well-formed, but generally broken by cockling and steps and interrupted by broader kamenitza.

Grikes (Kluftkarren)

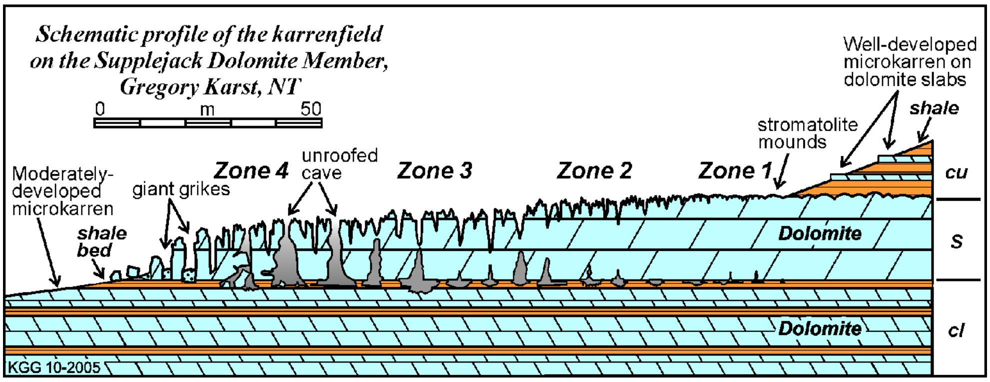
Grikes are linear trenches formed by enlargement of vertical joints. They come in a large size range, up to "giant grikes' 5 or more metres wide and 10-20 m deep (photos 1207, 1536sbj). At the small end of the size range they grade to splitkarren (photo 1532 and see below). The larger ones have walls that are sculptured by rillenkarren, wandkarren and cockles (photo 1716). They may connect with underlying cave passages.

Splitkarren (v-notches)

Splitkarren are small V- or U-section notches formed by the solutional enlargement of cracks (photos 0992, 0997, 1163-4, 1372, 1402, 1899). They can have any orientation. The size varies from one mm (microkarren) up to several cm wide and deep. Larger ones would be called grikes if vertical.

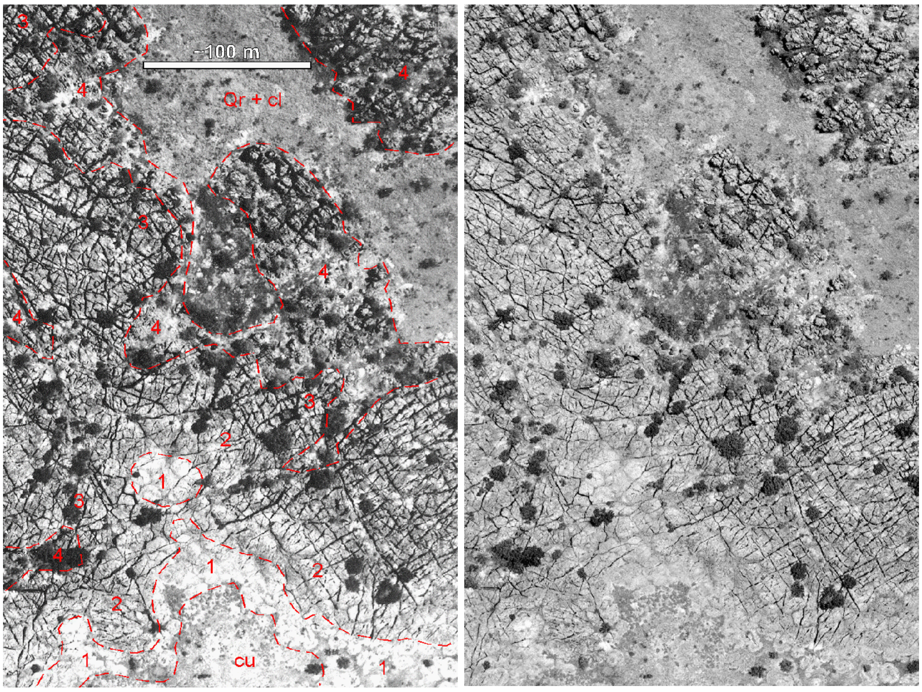
Karren zones

The karrenfields on the Supplejack show a zonation which results from progressively longer periods of exposure at the surface after removal of the overlying beds by erosion. This starts with incipient karren development on recently exposed surfaces and continues through progressively deeper dissected karren to a final stage of "ruined cities" of isolated blocks and pinnacles at the outer edge (Zones 1 to 4 on the diagram, "TK-Fig12.png"). The changes from one zone to the next are gradational. See the stereo pair of low-altitude air-photos "Karren.C.L.jpg & Karren.C.R.jpg" – the pixel size in these is about 0.3m.



Zone 1 has well-preserved stromatolite mounds (up to 12 m wide and 2 m high - photos D051117, & 1203a) exposed by stripping of the overlying Skull Creek Formation. The surfaces are smooth or sculptured by incipient rillenkarren and "rain-pits" with superimposed microkarren (photos D051039, 1402-3, 1408). Etching of joints and bedding forms splitkarren. There are scattered kamenitza and small grikes. See photos 1372, 1373p, 1710, 1711. In places where seepage water from the Skull Creek Formation contact flows across the Supplejack surface one finds small solution steps (trittkarren) and small tufa dams which produce a "paddy-field" pattern of shallow terracettes.

Away from the contact, increasing dissection produces small spitzkarren up to 0.3 m high, and grades to zone 2.



Stereo air-photos of karren field above the northern part of Dingo Cave. The karren zones are shown in red. Note the stromatolite domes at southern edge.

In **Zone 2** the stromatolite domes are still recognisable locally (photo 1750p), but are strongly dissected by a variety of mesokarren, including numerous kamenitza (up to 2 m wide and 0.4 m deep) and spitzkarren up to 1 m high. Grikes are wider and deeper; averaging 2 m deep, but with considerable variation, including occasional narrow connections to the cave passages below. See photos 1116, 1132, 1151, 1163, 1379, 1384, etc.

The transition to zone 3 is quite gradual.

Zone 3 has wider and deeper grikes, and connections to the cave become more common, though still narrow. Traversing the surface becomes difficult. Spitzkarren are dominant and up to 2 m high (photos 1036, 1206). Wandkarren and cockles appear on the grike walls and the sides of the larger spitzkarren (photos 1207, 1716).

In **Zone 4** the surface has become completely dissected. Giant grikes 1-5 m wide penetrate to the cave floors 10-15 m below and separate blocks of rock with strong spitzkarren on the tops and wandkarren, rillenkarren and cockles on the walls (photos 1070, 1144, 1146, 1207, 1730). As the grikes widen, one gets a "ruined city" topography of isolated blocks, many of which are tilted (photos 1011, 1461, 1464, 1518, 1587). and finally an abrupt change to a broad flat floored valley on the lower Skull Creek Formation with only scattered blocks and sculptured pinnacles (photos 1599, 1605a, 1726, 1728).

In one area of stone city in the northern area (AMG 491287), erosion of the grey mud soil has exposed a pediment (smooth flat rock surface) and soil notch at the base of stone city blocks (photo D051602-3 stereo).

Twilight zone sculpturing

In the twilight zone of the caves – entrances and daylight holes – there are solutional (and depositional) features that differ from those seen in the surface karren or in the dark zone of the cave. These generally have a coating of algal material, similar to that found on the surface karren.

Phototropic Spikes

These are grooves, sticks and spines oriented towards the light and found in the twilight zone of the caves and deep grikes (photo 1320, 1531). They are a type of phytokarst eroded by algae which dissolve the rock beneath them but avoid shaded areas. Individual spikes and grooves are between 2-10 mm across, but can be up to 20 mm long. They may also have (secondary?) coralloid growths on them. Some are capped by chert nodules.

Cockling

This is the same as the cockling seen on the surface. It is particularly common on cave walls beneath roof holes that admit light and rainwater.

Solution ripples

On cave walls beneath daylight holes the cockling patterns may become organised into small horizontal ripples, with or without serrations (photos 1316-17).

Microkarren

Microkarren are finely-sculptured forms, typically recognisable within a one cm grid, that appear to occur mainly in arid climates (but not necessarily hot-arid as they have been reported from Greenland and Tibet). In Australia they have been found in the monsoon (seasonally dry) and arid areas. However, these cryptic forms are poorly documented and it is too early to make definite statements about their distribution. Microkarren are best developed on gentle slopes, but can form on the vertical sides of cobbles and even on the under-side! Solution by thin films of water, dew or light rain, with surface-tension effects, may be their most likely origin (e.g. Ginés, 2004). However, Rhys Arnott (ranger, pers. comm. 2005) says that dew is rare in the Gregory Karst area. Photo D050992, of a surface pavement, is reminiscent of pitting and etching effects seen on cave walls in temperate Australia that have been attributed to condensation corrosion (James & others, 1982 & see photo B760111 from the Border Rivers Karst of southern Queensland). There is some local lithological control – on the laminated stromatolite outcrops one can see better development of microrills on the finergrained paler laminae than on adjoining darker (organic rich?) and coarser laminae (see photos D050997, 1166). More work is needed on these lithological factors.

The Gregory Karst has the best examples of microkarren I have seen (so far) in Australia (Grimes, in prep). Within the area the best development of microkarren is on the flaggy to slabby outcrops of dolomite in the upper Skull Creek Formation, where there is little competition from mesokarren. However, microkarren do occur within the main karrenfield of the Supplejack member. They are common in zone 1, but also occur in the other, more dissected, zones, usually at the tops of spitzkarren and associated with rillenkarren and "rain-pits" on gentle slopes.

Microkarren Types.

Note that, apart from *microrills*, these terms are my own unofficial ones invented to assist in my study.

Microrills: Narrow grooves, running down gentle slopes. Typically 1 mm wide, and less than1 mm deep, but can be up to a 60 cm long. They vary from straight, to sinuous to tightly meandering. There are two sub-types: The most common type are regular in width, sharp-ridged, with parallel sides, and can be straight, sinuous or meandering (photos 1039, 1166, 1695, 1705, 2446). Less common, and mainly found on the gently domed surfaces of cobbles, are variable in width (tending to widen downslope) with either sharp or rounded ridges (photos 1361, 1393, 1877). Microrills grade to ...

Micro-networks are similar to microrills, but form an irregular network rather than long linear runs (photos 1703-4, 1705-6, 1780, 1781, 1783, 2446). They grade to...

Micro-teeth are sharp, rasp-like, conical or faceted teeth about 1 mm wide and less than 1mm high. See photos 1124, 1403, 1785.

Micro-pits: Hemispherical to conical pits occur in a wide range of sizes from 1mm wide and deep up to 20 mm (i.e. to normal "rain-pits"). Possibly there are several modes of formation for these (see also discussion of "rain-pits"). A broad range of sizes can occur within a single outcrop (photo 1778, 1789, 1408). On gently-domed surfaces micro-pits occur on the crest and grade to microrills on the slopes (photo 1361, 1877).

Micro-pans: Shallow pits, 5-10 mm wide, but only 1-2 mm deep. They have flat to slightly concave floors with fine micro-pits or teeth. They are commonly superimposed as scattered clusters on other microkarren (photos 1123, 1696, 1699, 1701, 1703-4, 1781, 1783, 1790?). This superimposition suggests that they form after the other types. A possible origin might be concentrated solution beneath pellets of wallaby dung - but this has not been confirmed.

Micro-notches: Irregular v-section notches that follow cracks in the rock (a micro-version of splitkarren). See photo 1884. Other microkarren may be superimposed on the larger v-notches (photo 2446).

Micro-grikes: Perhaps not the best term, but these are U-section notches in lines or networks. They commonly disrupt other pre-existing microkarren and appear to be following a cracking pattern. See photo 1909.

Micro-decantation rills: These run down the vertical side of a cobble, becoming smaller as they descend – implying a loss of aggressiveness as they descend from their source at the top (photo 0998, 1049).

Etched rock structures: Various structures of fossils, crystals or bedding may be etched out.

Relationships

The micro-rills, -networks, -teeth and -pits are forms that grade into each other. It is common to find on undulating surfaces that the crests have micro-pits or micro-nets that grade to linear or meandering microrills on the slopes. In the hollows, networks and pits may reappear or there may just be a smooth surface. Micro-teeth are an extreme case of micro-nets where the grooves of the network overlap to leave only small faceted teeth in place of longer ridges. The micro-pans and micro-grikes appear to always be late-stage features that are superimposed on other microkarren. Microrills can co-exist with shallow, incipient rillenkarren and "rain-pits" (e.g. photo 1039).

Some observed successions of types are:

* Shallow incipient rillenkarren and "rain-pits" underlie microrills, micro-teeth, etchings & v-notches. But the micro-rills etc may be peni-contemporaneous in the early stage of incipient rillenkarren development. Photo 1039, 1402
* Microrills predate some v-notches. Photo 1701, 1703-4.
* Some microrills are continuous across pre-existing v-notches. Photo 1705, 2446.
* Some microrills appear to be continuous across the sharp crests of rain-pits and rillenkarren. Photo 1039a.
* Microrills etc predate micro-grikes (nets of u-notches). Photo 1909
* Microrills etc predate shallow micro-pans. This is moderately common. Photo 1696, 1709.
* Microrills occasionally predate "rain-pits". Photo 1031.

Tufas

The tufa deposits of Limestone Creek have been described and mapped by Canaris (1993). Canaris reports that the relict tufas in Limestone Gorge have been radiocarbon dated at 8 - 10,000 BP. This would have been a period of wetter climate. The modern tufas began growing about 1600 BP.

The "Crystal Cascade" is a water fall with tufa deposits – it was dry when visited, but would be active during the wet season. See photo D051347pa. The colour is due to a thin coating of finely crystalline calcite which coats greyer algal and carbonate material that in turn coats the rock. This sparkly white coating looks fresh, and possibly reforms at the end of each wet season. The algal crust material beneath the crust forms curls 5-10 mm thick (photo 1337a). Leaves and other organic material are incorporated. There are also some tufa rims and pools. Above the falls the tufa is all a dull grey colour, not white.

In several places I saw where seepage water had run out from the Supplejack - Skull Creek contact across the slabs at the top of the Supplejack (karren zone 1). This formed small "paddy-field" terracettes of two types. A constructional form had small rounded tufa ridges a few cm high and wide damming the terraces (photos 1630, 1794-5). The other type appeared to be wholly solutional in form and comprised shallow steps with or without low rims (photos 1626-7, 1791,2,3 and see Trittkarren in the Karren section above).

During a long walk into the far northern area, we found a set of good tufa dams, falls and pools between 471275 and 478278 along the main eastern creek that drains south from the northern area. The following description is given moving downstream from the stream junction at 484303. There was a pond near the junction, the northernmost one seen, then a dry stream bed with thin coatings of grey to light grey tufa. The first falls, at 478278, were dry and formed as a 5m high cascade on dolomite slabs with no tufa. This would seem to be a structural bench. Downstream from there was a series of shallow pools dammed by low tufa walls. In one place, numerous small tufa walls (0.3m wide, 0.2m high and 1-2m long) formed a pattern of rimstone pools. The south bank here is a 6m cliff of dolomite with tufa coatings. No actual springs were seen but the amount of water increased as we moved downstream.

This is a pleasant area (photo D051678), about an hours walk from the Limestone Creek campground, and could make a good fly camp for trips running into the far northern area.

The second, and main, waterfall was at 471275 (photos 1685-93). This was flowing at about 5L/sec (rough visual estimate) over a 5 m high tufa wall into a deep pool. The pool sides are coated with soft, crumbly, bubbly, white tufa (photo 1690). An overhang of the dam wall on the north side has tufa stalactites beneath it.

HYDROLOGY

A float experiment within Bullita Cave was planned but I did not have time to install these. The park rangers offered to do this after we left, prior to the wet season, in a cave beside Limestone Creek (BAA-22?). This will involve leaving a series of small, labelled, polystyrene floats attached to the rock by string at different heights above the floor in hydrologically interesting parts of the cave and returning after the wet season to observe any displacement by flood waters. The highest displaced float would indicate the maximum wet season flooding level at each site and the strings might give clues to the water flow direction. The indicated directions of water flow would probably be the final flows at the end of the wet season, when the cave was draining.

For what it's worth – electrical conductivity (EC) & temperature of water in the swimming pool in Limestone Creek at AMG ~ 512256 was:

4-7-2005, 5:30 pm: EC 740 µS, 27.5°C.
5-7-2005, evening: EC 746 µS, 26.4°C.

CAVES

Although I visited several parts of Bullita Cave, and a number of other caves in the area I do not feel that I have seen enough to start pontificating about their genesis. The ideas on speleogenesis presented by Bannink & others (1995) and Martini (2005) seem reasonable, and are summarised below. In this report I will concentrate on my own observations of specific parts of the caves. Photos of various features in the caves are on the CD-ROM, along with a set of four measured profiles and sections as PDF files ("Profile-1.pdf" etc.). A brief summary and map of Bullita cave appears in the poster "GK-Poster.pdf".

Extensive horizontal maze caves underlie the dissected surface of the Supplejack member, being best developed under karren zones 2 & 3. The largest, Bullita Cave, is an extensive horizontal, multi-level, joint-controlled, maze system with a total passage length of 103 km(± 5) in 2005. Its overall extent is 4-5 km north-south and 400-600m east-west. Passage junctions are typically every 15-30 m. It is divisible into sectors, separated by narrow connections (often a single tight passage). The individual sectors have distinctive properties. Dingo Cave, on the north side of Limestone Gorge, is also large (~50 km of passage) and possibly more complex than Bullita cave, with multiple levels.

A theory of speleogenesis is being evolved by members of the Gregory Karst Special Interest Group (GKSIG) of the ASF – who have been mapping the system for 15 years. A preliminary report appeared in Bannink & others (1995) and that model is being developed further (Martini, 2005). This model will probably involve progressive exposure of the Supplejack Member by slope retreat and broad-scale water input via the karrenfield. The age of the passages would be youngest beneath the contact (karren zone 1) and progressively older to the west until they become unroofed and destroyed in zone 4. Lithological control by a shale bed that is easily eroded by flood waters is an important part of the story. The shale bed may also have controlled the level of initial phreatic speleogenesis by providing a perched watertable. Wet season flooding may be significant, particularly in the mechanical erosion of the shale bed. One suggestion is that this is a type of epikarst cave.

No one caver has seen all parts of Bullita Cave. In an effort to compile an overall description of the system Sue White and I interviewed various members of the GKSIG during the field trip, asking them for descriptions of various sectors of the cave. Our notes from the interviews are included here in the file "BullitaCave-descriptions.pdf".

A float experiment was planned to record water movements in the 2005-6 wet season - see Hydrology section.

Passage types

Martini (2005) grouped the cave passages into three types: The uppermost are within the Supplejack member, the second group lies within the "shale bed" at the base of the Supplejack, and a third group lies deeper within the lower Skull Creek Formation – this last group is restricted to a few parts of Bullita Cave, but is extensive in Dingo Cave where Bannink & others (1995) recognised several lower levels.

Supplejack passages

The first group, within the Supplejack, comprises two sub-types: firstly the phreatic tubes and avens which lie wholly within the Supplejack and secondly the fissure and "tented" passages which may extend down into the shale bed. The phreatic tubes include horizontal tubes running just above the shale bed, commonly as inverted-U or omega (Ω) tubes in the roof of the shale chambers (photos D051283k2, 1830,32.), and higher up there are other rounded or elliptical tubes (1110, 1254), alcoves (1482), vertical pipes (1495) and bell-holes (1265, 1543) – which are exposed in the walls of the fissure or tented passages (photo 1488-89) or form passages in their own right (photo 1500j, 1507-8, 1510j). Water stains below some of these indicate outflow during the wet season (photo 1100).

The fissure and tented passages follow obvious joints. Those that terminate at or above the shale bed have a simple A-form (photos 1217a, 1821), but those that extend down into the shale are usually undercut in the shale to form a tented (1480r,) or inverted-T form (1287, 1291, 98a, and see also the Profiles) – the latter are perhaps better classed as passages or chambers within the shale bed but extending above it. Martini (2005) described two detailed wall morphologies: thinly corrugated surfaces (possibly my photos 1275j, 1450 and 1814?) and ledges at decimetric intervals (photos from 1217 to 1248). Some ledges had secondary pits (photo 1234). Larger cuspate or scalloped forms also occur (photos 1815-16)

Shale bed passages & chambers

The second group of passages and chambers are formed mainly within the shale bed. The shale bed (photos D051074p, 1861) is a distinctive lithology and forms a useful marker bed for correlating cave levels – provided one allows for its gentle dip. The four measured profiles make use of this. Martini (2005) describes the "shale bed" as being a "2-3m thick layer of well stratified silty carbonate flags and platelets, with interstratified thin shale". In many places the top 40 -50 cm is a thicker-bedded dolomitic mudstone (Bannink & others, 1995) – this bed is visible in the upper half of photo 1074p, with the thinner-bedded material below.

Passages within the shale bed tend to be rectangular in section (photo 1420), possibly with a triangular roof extending upwards along a joint into the Supplejack (photos 1421, 1435,37). Widening of these passages produces large, flat-roofed, rooms with scattered remnant shale pillars (photos 1840-1, 1849, 1851j, 1859r). Roof fissures in these mark the location of the original passages (photo 1840-1). The broader ceilings become unstable and breakdown commences (photos 1867,68).

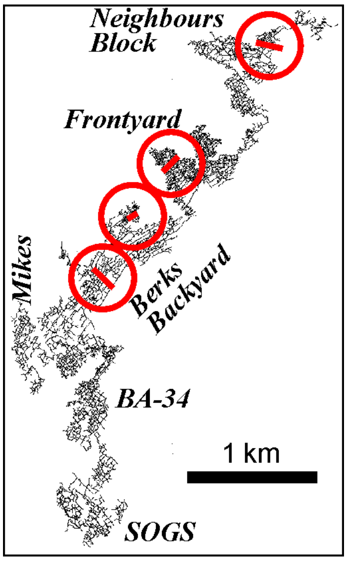
The ceilings of shale chambers may be flat – following the dolomite/shale contact (photo 1861, 1416pr, 1428p) and these may show preserved casts of mudcracks that formed on the ancient muddy sea floor (photo 1440). Alternatively, the ceiling may show a variety of "phreatic" sculpturing features: Ω-half-tubes (1830, 1832a), pendants (1236, 1859r) and joint-controlled fissures (1082, 1287, 1829j, 1840-1).

The influence of erosion of the shale bed has a possible analogy with a system in Spain described by Calaforra & Pulido-Bosch (2000). This is a gypsum system, but has interbeds of marl & clay which have eroded mechanically to dominate the form of many passages. Their description of a 'first stage' of phreatic evolution of protoconduits just above the clay, followed by a 'second stage' in which the predominant process became vadose mechanical erosion of the beds of marl and clay resembles the situation above and within the shale beds at Bullita.

Speleothems

Martini (2005) describes the speleothems, which are sparse. Coralloid speleothems are the most common, particularly adjacent to fissures and roof holes which would be a source of saturated water (photos 1082, 1277k, 1543, 1830, 1868). A new discovery in 2005 was of curled crystal "flowers" of gypsum(?) in Claymore Cave on the wall of a passage between the Catacombs and the Telegraph Line section (photo 1300x).

Cave Profiles



My main contribution to the cave studies in 2005 was the sketching of four profiles across parts of Bullita Cave, included on this CD-ROM as the PDF files "Profile-1.pdf" through "Profile-4.pdf". In this I was assisted by Susan White, Carolyn Redpath, Nicholas White and Bob Kershaw. The supplied draft versions of the profiles need some additions and field checking. A list of problems and specific field checks needed for each profile is in Appendix 2.

Profile 1, Three Presidents area, Neighbours Block.

This profile starts in the east beneath karren zone 1 (near the surface contact between the Supplejack and the overlying Skull

Creek) and runs west to a large box valley at the edge of the karrenfield (see location map in "Profile-1.pdf"). The easternmost part is a small tight triangular-section passage that follows the top of the shale bed. As it runs west it quickly widens by expanding down and sideways into the shale (photo 1411). There is an obvious stream channel in the muddy floor here, implying significant wet season flows. At the first junction (station 6829) there is a flat roof at the supplejack/shale boundary and the floor is muddy with stream channels and banks (photo 1416pr).

Continuing west, the passages follow the shale bed and are small with either flat ceilings or with roof slots following joints (photos 1420,21,28p). The floor is either soft mud or flaggy rubble derived from the shale bed. Continuing west the passages enlarge with the floor dropping further down into the shale and the walls widening (photos 1435, 37). Roof slots continue. Sue White thought she could recognise riffle and pool structures along here (mounds of gravel alternating with hollows of muddier material, which would indicate a strong stream flow in the wet). I was uncertain - the gravel mounds might just be localised breakdown?

At Three Presidents Pitch the first daylight hole is seen. Here the floor has cut through the shale and a short distance into the massive dolomite of the lower Skull Creek Formation. To the west the floor rises. The walls here showed solutional cockles, or possibly vadose scallops in a thin bedded dolomite (photo 1451). The final section is a crawl and tight squeeze to the surface at the base of a high cliff in the box valley.

Profile 2, NW Frontyard

This is a NE to SW profile across the northwest part of the Frontyard (see location map in "Profile-2.pdf"). We entered at station 5418, west of the profile line. This involved a climb from the broad valley up a rise between widespread stone city blocks, then a steep descent down a rubble slope into the cave. This seems to be typical of most entrances from the valley in this area.

The cave here is a maze of large joint-controlled passages with mostly flat gravel floors. At each end of the profile the passages are lost in large breakdown blocks of karren zone 4, or else one can enter/exit via a steep rubble slope. Occasional blocks of breakdown occur within the system (photo 1484). The shale bed is a horizontal undercut at or just above floor level and most of the large passage is in the Supplejack. The big passages are mainly high 'tent' passages or A-section fissures (photos 1480, 1484, 1486). Daylight holes and tree roots are common. A distinctive feature of this profile is the abundance of phreatic forms. Smoothly sculptured alcoves (1482) and large irregular tubes run into the dolomite walls at various levels above the shale bed's undercut (1488-9). In one place a vertical tube has been intersected by the wall (1495). In one part at the SW end of the profile the large fissure passage shrank to a smaller size that was distinctively phreatic, with cusps, hollows and bridges (photos 1500j, 1507-8, 1510j).

Profile 3, Golden Arches, Backyard.

The Golden Arches (Photo 1525a) are a set of daylight chambers at the NW edge of Berks Backyard. This is an area of partly unroofed cave beneath karren zones 4 and 3. Stone city terrain at the edges (photos 1518, 1587) leads into the cave, where giant grikes (photos 1535, 36sbj) alternate with partly or wholly roofed large fissure passages (1568a). The cave map here does not adequately distinguish between roofed and unroofed sections. Much of the cave is twilight zone with greenish tinges on many walls (1563) and phototropic spikes(1531). Phreatic tubes, alcoves and bell-holes are fairly common in the walls (1543,45). At the eastern end of the profile the entrance to the partly unroofed passage is down a ramp of rubble, soil and leaf litter (photo 1568a) – this is common for entrances in zone 4. The western end of the profile is in large collapse blocks.

Profile 4, Hermitage Grange area, Berks Backyard.

This long profile runs SE-NW, starting at Bruce Ruxton Way (BRW) beneath the contact (zone 1) in the east and ending in the big chamber of Hermitage Grange (see location map in "Profile-4.pdf"). West from the chamber is a short section of open giant grikes (zone 4) which was not included in the profile, and then the edge of the karst.

The BRW is a relatively straight fissure passage that "goes on and on" along the eastern edge of the mapped cave. The map showed no passages east of BRW, but a bit south of the profile we mapped a set of low triangular crawlways (photo 1807j) that continued east for about 20 metres before becoming too tight. A bit further south, an unmapped head-height passage also ran to the east but we did not explore it – our job was to sketch the main profile! The BRW itself is a high, but narrow, fissure with, in places, a low undercut into the shale right at the floor level. The walls are thin bedded dolomite with minor chert that has small ledges and larger cusps sculptured into it (photos 1815-6). In places the wall hangs in thick pendant blades with hollows dissolved behind them – reminiscent of the case-hardened outer wall of a tafoni (see photo 1814, and the lower parts of 1815-6 (stereo)). Further north the passage has dry rimstone pools (photo 1821).

Moving NW from the BRW the profile follows a set of small passages. These are wide at the base, in the shale bed, and taper upwards into roof slots in the Supplejack (photo 1826j). There is little daylight here. The passages become bigger to the NW, cutting down into the shale and widening beneath a flat ceiling with fissures (photo 1829j).

Hermitage Grange is a large chamber with numerous shale pillars holding up the roof (see location map in "Profile-4.pdf", which does not show all the pillars; photos 1840-1, 49, 51j, 59r). It was named for its resemblance to a wine cellar (?). The floor rises and falls with a surface of mud or flaggy shale fragments. Where the high points reach the roof they form shale pillars (photo 1861). The ceiling is flat (at the dolomite/shale boundary) with joint fissures and phreatic Ω half tubes (typically 0.5 - 1 m wide and high, photos 1830, 32a) rising above it, and also has many less-regular pockets and pendants (1859r, 1830). The fissures reach to the surface in places allowing entry of light and tree roots. Thick roots (both alive and dead) wander across the floor (1841). In spite of the daylight holes, the light levels are quite low. White corraloid deposits coat many parts of the ceiling - especially close to the fissures (1830 etc).

Towards the entrance (BAA-65E, the Bier Garden) which is north of the profile, there was an increase in breakdown with large slabs (1867, 68a) and more daylight. Near the entrance the passages become partly unroofed and giant grikes appear. The entrance is a climb over rubble and then a drop back down to the valley outside.

RECOMMENDATIONS FOR FURTHER WORK

Profiles

More measured profiles are needed to give a visual description of the caves, especially in the multi-level cave areas (e.g. Dingo Cave, the Efflux area of SOGS, and the western Neighbours Block). The aim should be to draw profiles (with cross-sections), photograph and write descriptions of all the representative variants of the cave morphology. This needs people with sketching skills, as against surveying, and some understanding of cave geomorphology will be an asset. They should keep in mind that the existing maps have errors, especially in the wall details, which may need correction. This will take time – we managed only one full profile per day in 2005 (including photography and arguments/confusion about both navigation and the geology), and they all need additional work.

We got into trouble by assuming the maps were right! It might be best in future to actually re-survey the profile base-line (distances and bearings), tying into any station tags that are found. Rather than trying to measure vertical angles with a hand-held suunto, it is probably better to use the 'top of shale / base of dolomite' marker for vertical control (adjusting it at the drafting stage to allow for the local apparent dip in the direction of the profile, see my structural map "Suppleback.Struct.png" for dips). But note that the half metre thick, massive, mudstone bed that sits between the thin-bedded shale and the true dolomite above may confuse you in places. Sometimes the flat ceiling is above this bed (against the dolomite) and sometimes below it. A "Disto" or other laser rangefinder is invaluable for ceiling heights, and also for getting quick passage widths. It can also be used, with a target, for the survey legs. In small passages do your sketching of cross-sections at 1:250 or bigger, even though the final plot will be at 1:500 (which seems to be the optimum if printing onto A3 paper).

The four profiles supplied on the CD-ROM should be regarded as only first drafts. They need field checks and additions. Details of the needed checks are in Appendix 2.

Geomorphic studies

There is a lot of documenting and thinking still to do here. Towards the end of the trip Bruce Swain showed us the latest map of Dingo Cave. This 50 km multi-level system appears more varied and interesting than Bullita – the descriptions in Bannink & others, 1995, refer to this cave and others on the north side of Limestone Creek. I suggest that future studies of cave form and genesis should dedicate a significant proportion of time to Dingo Cave. For example, the passage that runs under the ridge of upper Skull Creek Formation at ~485261 could provide a unique opportunity to see what happens beyond the contact line.

Geology

More work is needed to confirm the extent of dolomite against limestone (calcite) in the cave area and to compare with other parts of the Supplejack member in the region. It may be that many of the other Proterozoic "dolomites" in the Northern Territory are also partly calcite limestone.

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APPENDIX 1: KARREN MEASUREMENTS

Summary of karren measurements during 2005 field work.
Observations are arranged by Karren Zone (1-4). NB these zones grade into each other.

Site codes & locations are:

Neigh1	Neighbours Block, site 1, AMG 48.92kmE, 24.84kmN.		= zone 1
Neigh2	" "	, site 2, 23m west of 1.	= zone 1-2
Neigh3	" "	, site 3, 43m west of 1.	= zone 2
Neigh4	" "	, site 4, 60m west of 1.	= zone 3
Neigh5	" "	, site 5, 70m west of 1.	= zone 3+
T-valley	Top of the T-shaped box valley north from Limestone creek (AMG ~491259)		
North1	Northern Dingo	, site 1, 48.68mE, 26.32mN	= zone 4
North2	" "	, site 2, 25mSW of 1 (48.66,26.30)	= zone 3
North3	" "	, site 3, 43mSSW of 1 (48.66, 26.27)	= zone 2-3
North4	" "	, site 4, 60mSSW of 1 (48.64,26.27)	= zone 2
North5	" "	, site 5, 86mSW of 1 (48.62,26.26)	= zone 1
North6	" "	, site 6, 48.91,26.07 basal Skull Ck. just above stroms.	

(NB, the area containing these northern sites is shown on the air-photos "Karren.C.L.jpg & Karren.C.R.jpg")

FarN1	Far North	, site 1, AMG ~492298.	zones 1-2-3
FarN2	" "	, site 2, AMG ~496300,	zone 1

Karren Zone-1

Strom Domes:	Common (5-6m W (T-valley), 10-12m(Neigh1), 7-8m, 5-12 m W on air-photo) North5 = dominant. 2m H.
V-cracks	Neigh1 = 0-10cm W, 1-20 cm D
Rain-Pits	Neigh1,2 = Patchy, 1-5,2-5 cm W, < 1cm D, mainly <0.5c D North5 = common. W=1-3cm.
RillenK	Neigh2 = Short (<20cmL), + Cockling, 1-5cmW, 0.5-2cm D. North6 = see depth gauge on p 2.20+22 (pits & RillenK) North5 = small, on SpitzK & incipient elsewhere. L<= 0.2m
SpitzK	Neigh1, None - incipient at outer edge North5 = rare (in hollows & lower strom surfaces). W=0.3-0.5. H=0.2-0.3m.
Kams	Neigh1 = None Neigh2 = Some (5-15cmD, 20-80 cm W) North5 = mainly in hollows, and common there. W=0.2-0.5m, D=0.1-0.2m.
Grikes	Neigh1 = Rare, small, (5-15cmD, 20-80 cm W) Neigh2 = 10-50cmW, 20-00 cmD, spaced 5-10m) North5 = space=3-10m, W=0.1-0.4-1m, D=0.3-0.5-3m.
microK	Neigh1 = Good, mod-common (up to 60 cm L microrills). Lithol control (laminae in stroms) North5 = present but not common. rills on gentle slopes, within RillenK
Tufas	FarN2 & North6 = thin, small tufa dams & terracets. also solution steps with small rims.

Karren zone 2

Strom Domes:	Neigh3 = nill
	FarN1 = have RPits, small RillenK, microK
	North4 = locally common
V-cracks	Neigh3 = rare (3cmW, 2cmD, neigh3)
R-Pits	North4 = common, esp on stroms. W=2-1-0.5cm
RillenK	North4 = Common, on Spitz & edges of kams.
	Neigh3 = 2-3cmW, 0.5- 0.9 mL (on grike walls)
SpitzK	Neigh3 = Small (0.2-0.5mH, 0.4-0.6mW)
	FarN1 = small Spitz at outer edge
	North4 = Locally common. W=0.5m, H=0.2-0.6-1m.
Kams	Neigh3 = v common but varies (0.2-2 m W, 10-25-40cmD)
	farN1 = up to 1.5m W, 20 cm D
	North4 = common. W=0.2-0.5-2.5m, D=0.1-0.2-0.3m.
Runnels	Link Kams & between SpitzK as a dendritic drainage feeding to grikes
Grikes	Neigh3 = Spaced 10-20m, 0.2-1.5mW; 0.4- 2 - 10+m D.
	Neigh3 = Sides = vert RillenK + vague cockles
	FarN1 = 0.2-1.5m W, 0.5-3m D
	North4 = common. space=2-4-6m, W=0.1-0.4-1m, D=0.3-2-5m.
microK	Neigh3 = rare & only on bare rock (rills within RillenK)
	North4 = Common on strom surfaces (flat to gentle slopes). = rills & some small pits.

Karren zones 2-3 (North3, p.2.26))

Strom Domes:	absent
V-cracks	?
R-Pits	On crests (W=1-2cm, D=1-1.5cm) & on one gentle slope. W=0.2-1cm (photo 1741)
RillenK	Dominant (on Spitz & grike walls). W=1.5-2-3cm, D=0.5-1.5cm, L <= 1.5m
SpitzK	Dominant. W= 0.5-1m, H= 0.5-1m
Kams	Mod common. W=0.2-0.5-2m, D=0.1-0.3m. linked into drain nets (Photo 1742)
Runnels	
Grikes	Dominant. spaced 2-4-10m, W= 0.2-0.5-2m, D= 0.5-2-10m
WandK	On grike walls. spaced 0.2-0.4m, D=0.2-0.5, L= 2-3+m
microK	mod comon on flatter surfaces & crests of Spitz (in rillenK)

Karren zone 3

Strom Domes:	absent
V-cracks	?
R-Pits	North2 = on crest of Spitz
RillenK	North2 = Dominant, on Spitz & grike walls. W= 1.5-2-2.5cm, L= <=2m in grikes.
SpitzK	Neigh4 = Well-dev. (1-3mW, 0.5 - 1m H.) + good RillenK, cockles & WandK
	Neigh5 = (1-3mW, 0.5-2m H)
	North2 = Dominant. W = 0.5-1-2m, H=0.3-1-2m.
Kams	Neigh5 = Mod common, 0.2 - 2m W, 10-40cm D

	North2 = a few. W=0.1-0.5m, D= 5-20 cm
Grikes	Neigh5 = (Spaced 3-10m, 0.3 - 2 -3m W, 0.5 - 1 - 4 - 10+ mD)
	Neigh5 = largest Grikes (<=4mW) have a pavement floor of Kams, RPits, smaller grikes & small Spitz
	North2 = spaced 3-5-8m, W= 0.2-1-2.5 m, D= 1-2-10m. walls = RillenK, cockels, WandK
WandK	Neigh5 = (grike walls & Spitz) 10-20 cm W, 10-20 cm D, 3-4 m L on grike walls
	North2 = on walls. space = 20-40-100cm, D= 10-20cm, L= >=3m
microK	Neigh4 = rare, on bare surfs (on RillenK)
	Neigh5 = also on tops of SpitzK
	North2 = rare rills on clean crests
Dolines	Neigh4 = Some collapse dolines (5-8mW, 5-6mD).

Karren zone 4

Strom Domes:	absent
V-cracks	?
R-Pits	North1 = on crests of Spitz. 10-20-30mm W.
RillenK	North1 = dominant, W= 2-4cm, D= (see guage, p2.21-25, 2mm-11mm D), L <= 2m (where uninterrupted)
SpitzK	North1 = 1-1.5mW, 0.3 - 2m H, dissected by RillenK, Pits, cockles, kams.
Kams	North1 = common. W= 20-40-100cm, D= 20-40cm
Grikes	North1 = spaced 2-15m (av 3m), W = 0.1 - 2 - 5+m, D = 1-3-10m. Walls have RillenK, cockles & WandK
WandK	North1 = on grike walls and edge walls. spaced 20-30-50cm, W= 10-30cm, D = 10cm, L <= 3m
microK:	some locally (superimposed on RillenK)
ALSO:	
'Runiform' towers	(small <5mH ?) & pinnacles (composites of SpitzK, bedding notches, grikes, WandK, etc.
Blocks	North1 = Blocks (some with chaotic dips), 2-15m W, 1-5m H. edges = grikes. Tops = SpitzK, RillenK, Kams etc...
Pediments	FarNorth = one stone city had pediment & notch beneath thin grey soil
Cliffs:	T-valley = have SpitzK (on top), RillenK, Grikes & Kams, only minor microK

Upper Skull Ck:

Flaggy lstn	common pavements - tessellated cobbles or solid
little mesoK,	some small rillenK & Rainpits
lots of microK =	rills, pits, teeth, etc ... very well developed.

Lower Skull Ck:

Pavements	scattered, more solid than Upper SCk
MesoK	Some Kams, rillenK, ...
microK =	rills, etchings, minor teeth & pits. Less abundant than upper SC

APPENDIX 2: FIELD CHECKS AND ADDITIONAL DATA NEEDED FOR PROFILES 1-4

Profile 1 Neighbours Block

* The western end of the profile was poorly surveyed on the cave map and we were rather bushed. The location of the profile line may be incorrect in places. The low crawl and entrance we found is not shown at all. This area needs some (re)-surveying and wall sketching.

* I did not go out the west entrance - the shape of the cliff above this is just guess-work and needs to be sketched on site.

* There are two missing cross-sections of passages running away from the profile line (the grey ones):
- Passage NW from 3-Presidents pitch
- Passage NW from 6829

Profile 2: NW Frontyard

* I was a bit confused as to location at the NE end of the profile, due to a lack of survey tags: we may have been near 5810 (as shown) or may have been in the next passage to NW (near 5823?). Field check needed.

* Because of this confusion, the location of the side-passage sections may be wrong (I tried to match them to the map, but they did not fit very well). There seemed to be more side passages than shown on the map!

* Check the wall detail on map, adjust my side passage locations and sketch any additional side passages as needed.

* The SW end is also confusing - the sketched walls here did not match what we saw. There does not seem to be direct connection between 5420 (which ends to west in small phreatic alcoves) and 5415. We detoured to the north, past 5417.

Profile 3: Golden Arches, NW Backyard

* The stone city outside the eastern end was not accurately drawn. Check height, width and density of blocks here.

* We found a number of labelled stations, but the cave map did not match well with what we saw, some cross-passages shown on the map did not seem to exist. Station 8150 (or 8160?) is shown on the map in the middle of a large intersection, but the tag was found on the side against the wall.

Profile 4: Hermitage Grange, Backyard.

* The Cross-section of the passage running NE from 633 should be sketched and added (in grey).

* In the big chamber of Hermitage Grange the map does not show all pillars correctly. There are more pillars than shown and their size and location does not match well with the map. We could not find many survey tapes here, and had trouble working out where we were. My best guess for the location of the profile line is shown (dotted) on the location map, but it might have been more westerly in direction (Yes, I know, I should have dug out the compass, but at the time I thought I knew where I was, and only got confused later). Neither alternative matches well with what we saw in the cave!