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— karst and cave fauna

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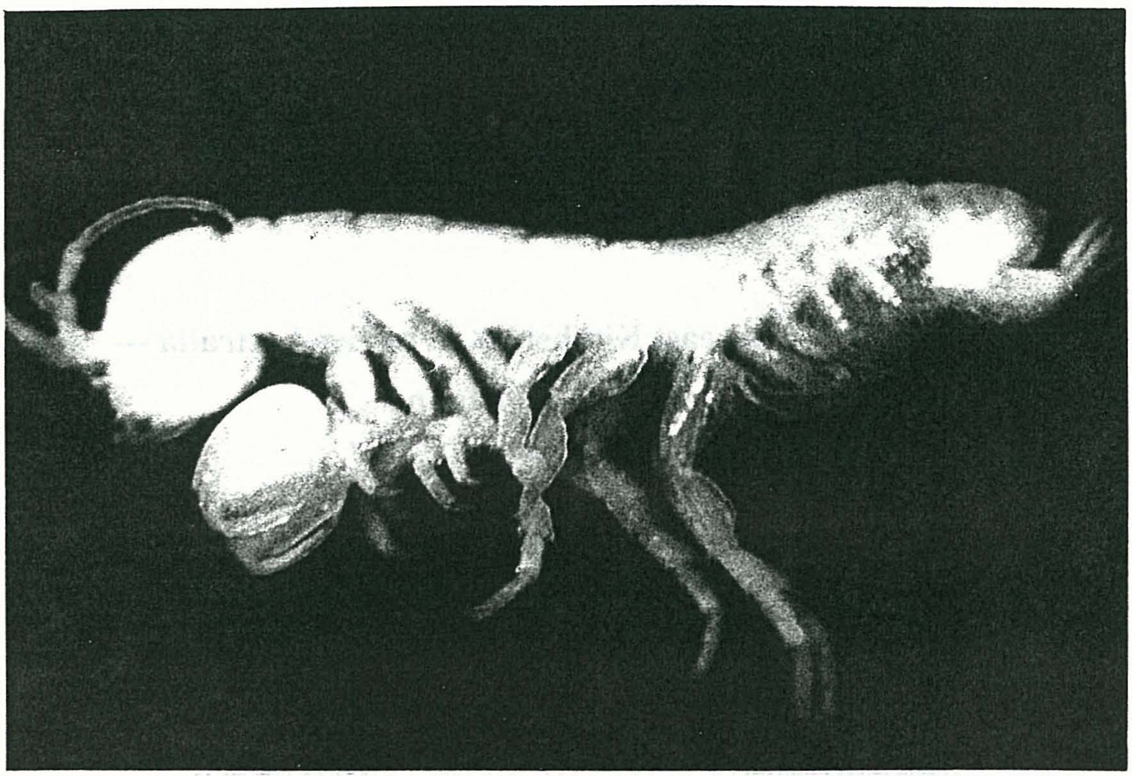

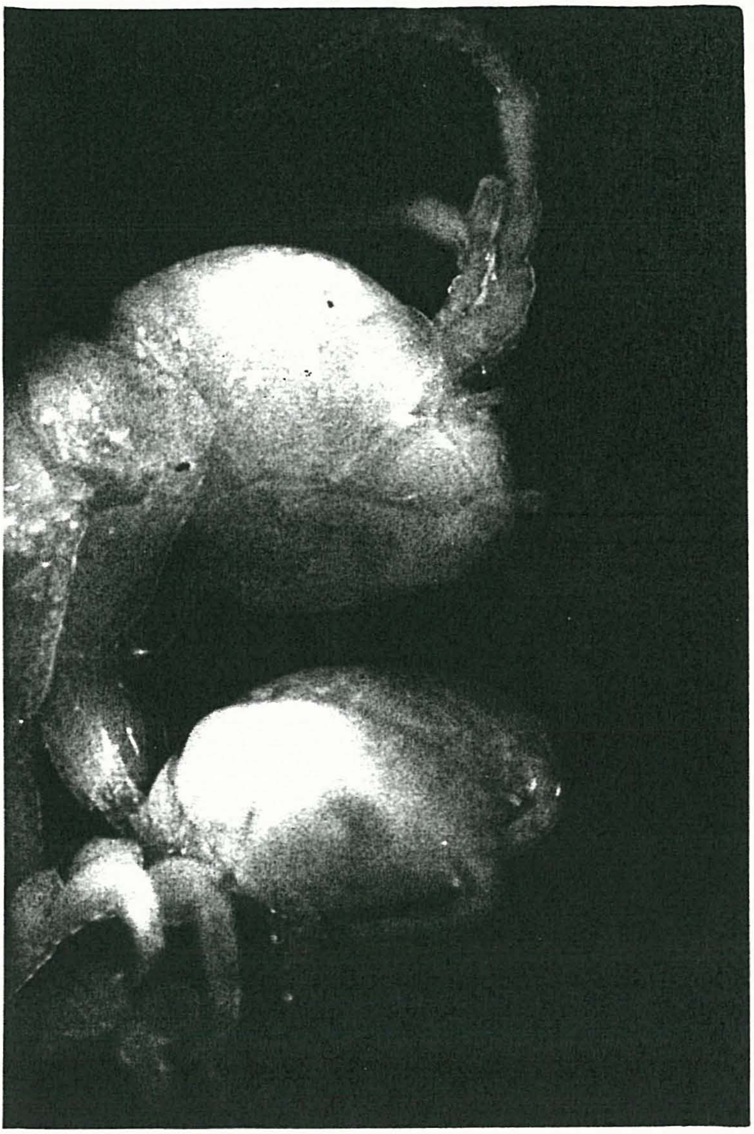

Limestone of the east Kimberley, Western Australia— karst and cave fauna

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Western Australian Museum, Francis Street, Perth, Western Australia 6000

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Front cover: Karren development in the Devonian reef limestones of the central Ningbing Range, east Kimberley. Photo: W.F. Humphreys.

Frontispiece: Adult male phreatoicid isopod from Zebedee Springs, El Questro Station. It is closely related to a South African species belonging to the family Amphisopidae (Mesamphisopinae). The key features of the new isopod are the enlarged distal article on the antennula and the simple pleotelson, lacking a distinct tailpiece, and not highly reflexed (G.D.F. Wilson, pers. comm., 1994). Photo: G.D.F. Wilson.

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Summary

Knowledge of the cave fauna of northern monsoonal Australia, especially the Kimberley because of its remoteness, is very limited. However, the Kimberley is considered likely to contain the nearest relatives of the diverse relictual rainforest fauna found as troglobites (obligatory cave inhabitants) in caves of the arid Cape Range in northwestern Australia.

Research on stygofauna (obligatory inhabitants of groundwater) in Australia is in its infancy but there is an highly disjunct tethyan fauna in northwestern Australia. Not only is this fauna entirely endemic, it contains many higher level taxa (Class, Order, Family and Genera) previously known only in the Canary Islands and the Caribbean region.

The limestone areas of the east Kimberley were examined for karstic development, caves and cavernicolous fauna, both terrestrial (troglobites) and aquatic (stygobites).

Detailed consideration is given to the characteristics of limestone areas of the east Kimberley, including the coastal plain, the Osmond, Carr Boyd, Ningbing, Weaber, Cockburn and Dixon Ranges and the Jeremiah Hills.

Limited consideration is given to the Limestone Ranges of the west Kimberley, namely the Lawford, Pillara Range, Oscar and Napier Ranges.

Certain geological formations that contain significant limestone deposits are considered for their likely cavernous potential, namely the Panton, Olympio, Blatchford and Linnekar Formations, as well as the Headleys Limestone.

The nature of tropical karst systems is described especially the Devonian reef complexes of the east and west Kimberley.

Owing to their relevance to potential stygofauna the hydrogeology of the east Kimberley is considered and described.

At the time of sampling, in the early dry season, the rainfall had been rather better than average.

Consideration of the climate of caves and their nature —predominantly grike developments in the Devonian reef complex— shows that they will dry out early in the dry season making it likely that subsequent sampling for cave fauna—usually requiring high humidity—will be disappointing. However, owing to the however owing to the characteristics of the area it is impractical to sample in the wet season.

The black soil plains surrounding the Devonian reef complex and found in the caves, has properties that preclude movement of water into the ground after the first wetting of the season (owing to its plasticity) and that enhance drying through cracking as the dry season sets in.

The organic carbon content of the cave soils in the Kimberley was much lower than that found in Cape Range but was similarly directly related to the soil water content. Nonetheless, the organic carbon content of the Jeremiah Hills samples was consistently greater (2.5 times) for a given water content than that in the Ningbing Ranges.

Cavernicolous fauna are found where the soil water content is >15% and where the relative humidity is high.

The elevated levels of carbon dioxide that are frequently encountered in tropical caves were not found in the Kimberley owing to the great air exchange that results from the relative openness of the cave systems.

Groundwater in the area is essentially freshwater.

Vertebrate fauna was not specifically examined but ghost bats (*Macroderma gigas*) were widely observed in caves in the Devonian reef complex. Eleven of the 24 species of bats (46%) known from the Kimberley have been recorded from caves and at least seven species of bats are known to occur in the caves of the Devonian reef system.

Banded cat-snake *Boiga fusca ornata* occurred in many caves, as did the tree frog, *Litoria caerula.*

Several species of fish are found in caves containing water and this provides refuge for the fish during the dry season—amongst them are The Common Eel-tail Catfish, *Neosilurus hyrtlii* and the Spangled Perch, *Leiopotherapon unicolor,* fish widespread throughout northern Australia.

Syncarid crustacea were taken in groundwater in the Ord Irrigation Area and belonging to the families Bathynellidae and Parabathynellidae.

Ostracod crustacea were collected from a number of groundwater localities.

Copepods of several families were collected from a number of wells, piezometers, bores, cave pools and springs in both the west and east Kimberley.

The freshwater crab *Holthuisana transversa* (Potamoidea: Sundathelphusidae) is found widely in caves and occurs throughout the monsoonal tropics.

A number of atyids shrimps are known from caves in the Kimberley and the Northern Territory including four obligate stygobites belonging to the genera *Parisia, Pycnisia* and *Pycneus.*

Phreatoicid isopods occur in a spring in sandstone and they are closely related to a South African species belonging to the family Amphisopidae (Mesamphisopinae).

A new family of flabelliferan isopod occurs in the Limestone Ranges of the west Kimberley.

An extraordinarily rich and locally endemic fauna of camaenid land snails is found associated with the Devonian reef complex of both the west and the east Kimberley.

A new genus of terrestrial isopod, *Kimberleydillo* Dalens, 1993 (Armadillidae: Australiodillinae) is known only from one cave in the Oscar Range.

A new species of troglobitic nocticolid cockroach occurs in the limestones of the Kimberley and the Northern Territory (Katherine).
One of the more diverse groups found in the caves of the Australian tropics are plant hoppers (Homoptera) of the fulgoroid families Cixiidae and Meenoplidae. An undescribed species of *Phaconeura* (Homoptera: Meenoplidae) occurs in the

Ningbing Range and it is the first meenoplid known anywhere to be attended by ants, a species of the genus *Paratrechina.*

Four undescribed species of micro whip-scorpion (Schizomida: Chelicerata) occur in caves in the Devonian reef complex.

Pseudoscorpions belonging to the families Chthoniidae, Hyidae and Olpiidae occur in the east Kimberley caves.

Spiders of the families Theridiosomatidae, Filistatidae, Hersiliidae, Pholcidae and Heteropodidae occurred in the caves.

Three orders of millipedes (Myriapoda: Diplopoda) were taken in the caves, namely Siphonophorida, Polyxenida and Polydesmid.

The centipede order Scutigerida is widely seen in caves but is not troglobitic.

The occurrence in the same general massif of congeneric species of chelicerates suggests that the apparent presence of a mesocavernous compartment associated with the Devonian reef complex of the east Kimberley is not, in practice, continuous.

A review is made of the current conservation and heritage status of the karst areas in the Kimberley. Only a few very small areas are currently within conservation areas or listed in the Register of the National Estate.

In the west Kimberley small parts of the Oscar and Napier Ranges have been declared national parks.

Strong recommendations have been made by both the Conservation Through Reserves Committee, the Environmental Protection Authority and the Australian Speleological Federation for a biological survey to be made of the Limestone Ranges. This survey has never been conducted save for the small section covered by this report for the east Kimberley and the associated brief reconnoitring trip through the west Kimberley.

In the east Kimberley a number of reserves of various designations have been implemented or proposed but they do not encompass the Devonian reef system or other limestone areas. No areas of karst have been recommended for inclusion in reserves, although the Ningbing Range (*sensu stricto*) has been recognised as requiring investigation.

In the context of subterranean fauna some areas of sandstone country are relevant both for stygofauna and for non-karst caves—such are known to contain important fauna on the East Alligator River in the Northern Territory.

In contrast to previous work this survey has shown that the Devonian reef system contains a significant fauna of animals adapted to varying degrees to subterranean life. The Devonian reef system of both the west and east Kimberley contain numerous troglobitic and epigean taxa that are endemic at the specific, generic or family level. In addition they contain evidence of inter-continental scale vicariance.

Few caves have previously been reported from the Devonian reef system, however, it is apparent from this survey, although not an aim of it, that there is a large number of caves in the Devonian reef system, that some are substantial and that some contain extensive decoration. In addition there are significant caves in sandstone country.

Springs are of major importance to life in the Kimberley and they are the only conduits to the groundwater fauna in much of the region—the sources need protecting from trampling.

Numerous, impressive and often extensive tufa deposits are associated with limestone areas in both the east and west Kimberley, not solely with the Devonian reef system.

Caves, being relatively stable and of low energy, are important depositories of information on past climates, fauna and vegetation. However, palaeontological and palaeoclimate works associated with caves in the Kimberley are almost non existent.

The heritage values of karst areas are summarised and several general recommendations made.

1. A concerted study of stygofauna should be undertaken in Australia.

2. Waste water from irrigation should be recognised as a potential contaminant of groundwater that has heritage implications.

3. In karst areas the best practice for all development proposal should include detailed awareness of karst and its implications from the earliest stages of conception, not least because it can have major monetary consequences.

The background papers currently in use for karst work are still based on the misconception that troglobites are rare in Australia and especially so in the tropics, whereas the reverse is true. It is now clear that many areas of Australia, especially within the tropics, are exceptionally rich in cave adapted species and that many have very ancient affinities. There needs to be much more awareness of both cave and groundwater fauna.

Recommendations

- The Jeremiah Hills and the Ningbing Range should be included in the Register of the National Estate and much of the area set aside for the protection of landscape, fauna and flora.

- Caves need to be specifically considered when delimiting conservation and heritage areas as they may have special requirements for protection.

- A number of representative tufa deposits should be included in conservation areas.

- The sources of springs should be protected from trampling by stock and people, and springs should be surveyed for stygofauna.

Preamble

Proposal

An examination of the National Estate significance of the limestone areas of the east Kimberley, was proposed as such areas are the foci of important geomorphological and biological diversity. In addition, such areas often contain significant underground fauna and caves that are the repositories for rich information on past temperatures, rainfall, climate and ecosystems—tropical cave systems, in particular, tend to have rich and endemic troglobitic (obligatory cave inhabitants) fauna of major biogeographic significance.

The project is a thematic survey of natural environment (rare and endemic fauna and karst features) in the east Kimberley region.

The project aimed to examine and describe the nature of the karst features and cave fauna of the east Kimberley, to determine their zoogeographic affinities, and to make appropriate recommendations for inclusion in Register of the National Estate.

It was proposed to advance the project as follows.

1. Conduct archival and oral research on known karst features.

2. Locate known features, make standard descriptions of them and survey for fauna, both terrestrial and aquatic.

3. Conduct detailed trapping of certain caves to determine the diversity and nature of the troglobitic fauna.

4. To solicit and encourage formal scientific description of the species.

5. To examine the functioning of the ecosystem where practicable.

6. Describe the geomorphology of the cave systems.

Process

The area has been difficult to work — few caves had been reported from the east Kimberley and of those previously reported few had been accurately positioned, the locations being known from 'mud maps'. Hence, even caves previously known sometimes took a day or more to locate—some were never found.

All the previously identified areas of limestone were examined as well as some non-limestone areas known to have caves or springs were examined (Table 1).

Table 1: The following areas were examined to a greater or lesser extent—areas in the west Kimberley* were visited briefly as the team left the area, namely the Lawford, Oscar and Napier Ranges.

Ningbing Range
Osmond Valley
Cave Springs Range
Jeremiah Hills
'Lost city'
Burt Range
Underground Creek
Dolines in Osmond Range
Bandicoot Range
Cockburn Range
Durack Range
*Lawford Range
*Napier Range
*Oscar Range

The caves were sampled for terrestrial and aquatic fauna and, where possible, groundwater was sampled for specialised groundwater fauna (stygofauna).

Several side trips were made to sample specific habitats not represented in the original target areas, or to obtain comparative regional material otherwise unavailable. These included various sandstone caves and springs (Osmond, Carr Boyd and Cockburn Ranges). Where possible the Ord Irrigation Area was sampled intensively for stygofauna.

In general much of the limestone outcropping in the eastern Kimberley is thinly bedded or is substantially impure (sandy limestones etc.) and has not developed caves or karstic characteristics. The main terrestrial cave fauna occurs in the Devonian reef system of the Ningbing Range and Jeremiah Hills to the north of Kununurra. Many of the caves are grike developments which are open intermittently to the surface. Hence there is considerable air movement in these caves and thus they dry rapidly following the end of the wet season, roughly from March onwards.

The fauna occurs primarily in the more closed caves leading into the sides of the range where the moisture is retained longest into the dry season. The caves rapidly dried during the field work and the fauna was lost from the accessible parts of the systems. To obtain appropriate life stages for the taxonomy of some species it would be necessary to mount a short expedition in the late wet season to the southern Ningbing Range.

Glossary

8K-letter allocated by the Australian Speleological Federation (ASF) to prefix numbers allocated to caves and other karst features in the Katherine karst province, 8 denotes the Northern Territory (see Matthews 1985).

Accidental—species entering caves by chance.

Anchialine — Inland waters affected by marine tides indicating subterranean connection.

Bore — see well.

C- — letter allocated by the Australian Speleological Federation (ASF) to prefix numbers allocated to caves and other karst features in the Cape Range karst province (see Matthews 1985). The full reference would have the prefix 6 denoting Western Australia.

Contamination — to change the water quality so as to produce a noticeable change in its characteristics (Australian Water Resources Council 1992).

Dolerite —(Diabase in the USA; syn. diorite) is an intrusive igneous rock whose main components are labradorite (Labrador spar) and pyroxene and which is characterised by ophitic texture (Gary, McAfee and Wolf 1972).

Dolomites — carbonate sedimentary rocks or limestones rich in magnesium carbonate (41-45.4% (as opposed to calcium carbonate in limestone). They are clearly associated with and often interbedded with limestone and usually represent a post depositional replacement of limestone (Gary, McAfee and Wolf 1972).

Holokarst — karst that is completely developed, characterized by thick limestone bedrock, little or no surface drainage, and a bare surface with well-formed depressions and caves (Gary, McAfee and Wolf 1972).

Karren— in karst topography, a general term for solutional furrows or channels formed on the surface of limestone, ranging in depth from a few millimetres to more than a metre, and usually separated by knifelike ridges. The term is always used in the plural form (Gary, McAfee and Wolf 1972).

Karrenfeld— a karstic surface limestone characterised by karren (Gary, McAfee and Wolf 1972).

Karst— a type of topography that is formed over limestone, dolomite, or gypsum by dissolving or solution, and that is characterized by closed depressions or sinkholes, caves, and underground drainage (Gary, McAfee and Wolf 1972).

KJ-, KL—, KN—, KNI— and KO— —letters allocated by the Australian Speleological Federation (ASF) to prefix numbers allocated to caves and other karst features in, respectively, the Jeremiah Hills, Lawford Range, Napier Range and the Ningbing Ranges karst province (see Matthews 1985). The full reference would have the prefix 6 denoting Western Australia.

Merokarst — karst that is imperfect or incomplete, characterized by thin or impure limestone bedrock and the presence of surface drainage (Gary, McAfee and Wolf 1972).

Piezometer — used loosely for any pipe inserted vertically into the ground to observe the water.

Pollution — state of contamination for which the water quality has deteriorated to a point where the ability of the water to support or maintain the existing or potential beneficial uses is diminished (Australian Water Resources Council 1992), in this case where it affects the potential viability of the stygofauna populations and hence threatens to reduce the biodiversity of Australia and hence its National Estate significance.

Stygobite — true groundwater inhabitants, absent in surface waters, which are adapted to or specialized to the subterranean environment.

Stygofauna — the stygobiont fauna.

Stygophiles — epigean organisms that occur in both surface and ground waters without adaptation to subterranean life.

stygomorphy — see troglomorphy.

Stygoxenes — typical epigean organisms found rarely and at random in ground waters.

Troglobite — obligatory inhabitant of cave, usually with troglomorphies.

Troglofauna — the troglobitic fauna.

Troglomorphy (stygomorphy)— characteristic morphologies found in troglobites (stygobites), often considered adaptive, such as loss of body pigment, reduction or loss of eyes, hypertrophy of non-optic sense organs and relative lengthening of appendages. Physiological changes also occur and these include reduction of metabolic rate, reduction in egg numbers associated with increased size and an increased ability to fast.

Troglophile—facultative cave dwelling species often divided into first level troglophiles, found both in cave and epigean habitats, and second level troglophiles which are found only in caves.

Trogloxene— sporadic cave dwellers (e.g. bats).

Well — well and wellfield are now accepted internationally as meaning both small and large diameter holes independent of the means of construction. In this report the terms bore and well are retained to help distinguish the many sites. The wells are mostly old pastoral wells, whereas the bores are mostly recent water supply and water exploration bores.

Chapter 1

Introduction and methods

Introduction

Until recently troglobites (obligatory inhabitants of caves) were thought to be rare in the tropics, for reasons to do with Pleistocene ice ages (Vandel, 1965; Barr, 1968; 1973; Mitchell, 1970; Sbordoni, 1982), and especially rare in Australia as a whole (Moore, 1964; Hamilton-Smith, 1967; Barr, 1973). Recent finding have not only disproved this thesis (Leleup, 1968; Howarth, 1973, 1981, 1988; Humphreys, 1993b, 1993c) but have demonstrated that Australia contains a great diversity of troglobites in both the humid (Howarth, 1988) and arid tropics (Humphreys, 1993b, 1993c, 1993d, 1994).

Within Western Australia the terrestrial troglobites of Cape Range show both high diversity as well as great generic and specific endemicity (papers in Humphreys, 1993a). Despite the current aridity of Cape Range, the terrestrial cave fauna is derived from the litter communities of wet forests, both tropical and temperate (Harvey *et al.,* 1993; Humphreys, 1993b, 1993c; Humphreys and Shear, 1993; Roth, 1991, in press; Hoffman, 1994).

Amongst the cavernicolous arachnids and myriapods several groups have their closest relatives in northern Australia, while others are clearly representatives of a southern fauna, some having affinities with western Gondwana (Harvey *et al*., 1993). This indicates a temporal series of invasions into the caves from periods when the region was blanketed by northern tropical rainforests and, later, southern temperate rainforests (Truswell, 1990).

With the exception of north Queensland (Hoch, 1988, 1990; Hoch and Asche, 1989; Hoch and Howarth, 1989a, 1989b, 1989c; Howarth, 1988; Howarth and Stone, 1990; Malipatil and Howarth, 1990) knowledge of the cave fauna of northern monsoonal Australia, especially the Kimberley because of its remoteness, is very limited. It is the aim of this study to examine the cave fauna of this remote region and assess the potential of the karst development as a focus of troglobite biodiversity. It has already been established that the Devonian reef system, which is emergent to the north of Kununurra, contains an exceptional diversity of camaenid land snails (Mollusca: Pulmonata)(Solem, 1981a, 1981b, 1984, 1985).

Research worldwide into the stygofauna (obligatory inhabitants of groundwater) is in its infancy and there is a great lag time in the development of Australian work which, considering the importance of groundwater to the Australian economy, is a serious neglect (Humphreys, 1994). Nonetheless, recent work has shown there to be a diverse stygofauna on the Cape Range peninsula (Humphreys, 1993c; Knott, 1993; Humphreys, 1994) and Barrow Island (part of the Cape Range Formation: W.F. Humphreys, unpublished). Not only is this fauna entirely endemic, it contains many higher level taxa (Class, Order, Family and Genera) previously unknown in the southern and eastern hemispheres (Poore and Humphreys, 1992; Bruce and Humphreys, 1993; Humphreys, 1993b; Baltanos, Danielopol and Humphreys, in press). The fauna is clearly and primarily derived (with a sole Gondwanan component: Humphreys,1994b) from the Tethys Sea (Humphreys, 1993; Knott, 1993) that separated the continents of Gondwana and Laurasia and which persisted from the Triassic until the late Eocene (200-40 Ma; Smith and Briden, 1977).

Access

Caves

Knowledge of access points to the underground results from the cumulative efforts of large numbers of people who have found caves, and sometimes explored them, and have passed on information orally or in writing. In Western Australia this information is maintained by various speleological societies—the Western Australian Speleological Group and the Speleological Research Group, and various closed groups who maintain records, such as Plane Cavers. However, expeditions from speleological societies outside the state often explore areas within Western Australia—this has especially been the case in the Kimberley where such incursions have resulted in most of the detailed work in the west Kimberley, especially by the Illawarra Speleological Society of New South Wales. Most such groups are affiliated with the Australian Speleological Federation, the umbrella group representing cavers interests and establishing caving standards and safety protocols.

When a cave is found organised caving groups usually tag it with a physical marker containing the cave number as recorded in the karst index for that area (see Glossary). In areas with a high density of caves this tagging process is invaluable, especially for genetics studies (Humphreys and Shear, 1993; Humphreys and Adams, 1991; Adams and Humphreys, 1993), and will continue to be so despite the availability of the Global Positioning System.

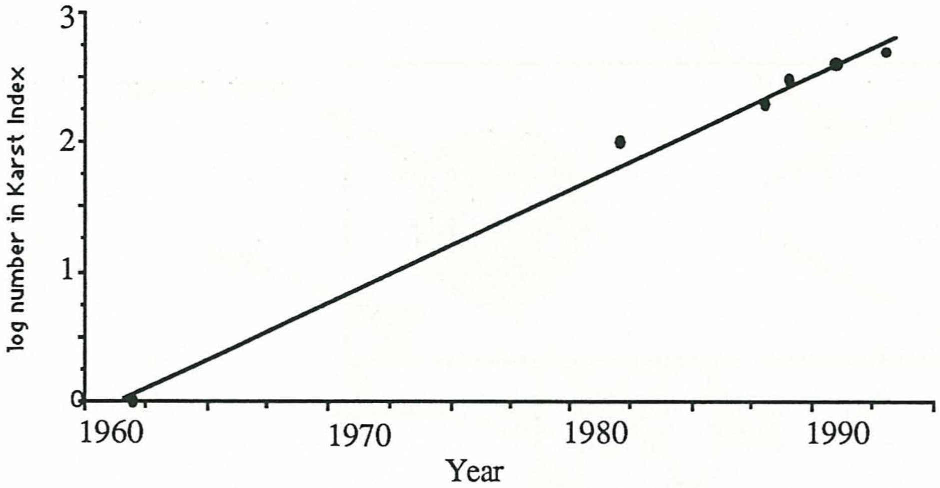
Groundwater

Access to groundwater is though both natural caves and springs and artificial holes (wells, bores and piezometric tubes) which can be sampled using traps and nets (see Humphreys, 1994).

Number of caves

One of the main hindrances to studying the distribution of the terrestrial and aquatic components of subterranean faunas is the lack of access to caves and to groundwater. In the Kimberley this is exacerbated owing to the sparse population and to the minimal cave exploration that has been undertaken. Very few caves have been recorded in the east Kimberley or in the entire Kimberley Region. However, it is clear from even this brief field season, that there is a very large number of caves in the Devonian reef systems of both the east and the west Kimberley. The rate of accumulation of new features during this study means that there will surely be many thousands of caves in the area when it is fully explored. This is especially likely to be the case when the area comprises country as difficult to explore as the Devonian reef systems of the Kimberley— this was well illustrated by the rate of accumulation of new features in the karst index for Cape Range (figure 1).

Figure 1: Regression of the number of features (log Y) in the Karst Index for Cape Range and the year of sampling (X); $r^2 = 0.99$, $Y = 0.088X - 173$.



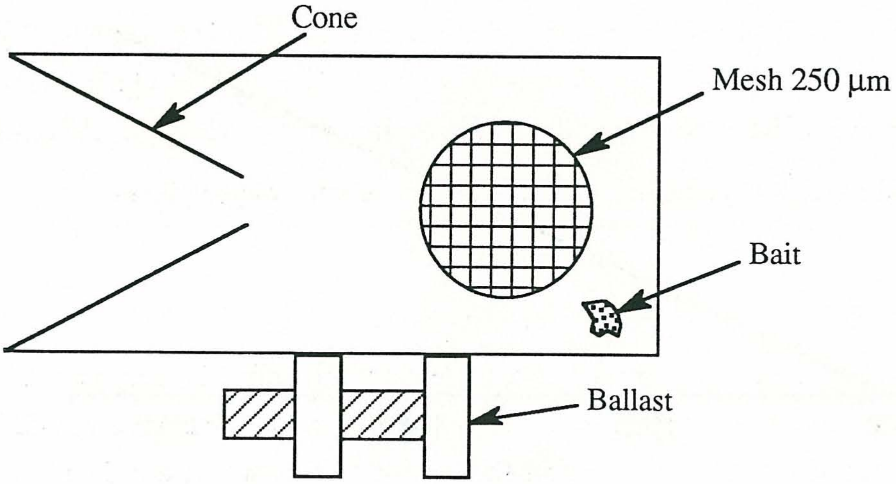
Methods

Fauna

Cave fauna was sampled using detailed visual searching and collecting with a fine brush or forceps— such searching often lasts for hours within a few square metres. Where repeated visits were made baits were laid—parmesan cheese rind or moistened leaf litter—and later examined; they provided little success.

Bores and piezometers were sampled for fauna using a haul plankton net with a 125 µm mesh and of a diameter suitable for the bore— from 30 to 180 mm in diameter. Wells were sampled by hand nets (250 µm mesh) and by Cvetkov (1968) phreatobiological nets (300 mm diameter; 250 µm mesh). Samples were variously taken through the entire water column and from various depths within the water column. Pumped water from bores was filtered through the same nets suspended in a bucket of water to buffer the water pressure—the volume sampled was estimated from the duration of sampling and the time taken to fill the bucket. In addition, where access was suitable, live traps, baited with parmesan cheese rind as used successfully elsewhere (Humphreys, 1994), were employed to sample the water — these were like miniature craypots and could be lowered down bores with a diameter of 50 mm upwards (figure 2).

Figure 2: Diagram of the miniature cray-pots used to sample groundwater. The bait was dried parmesan cheese rind.



Physical factors

Caves were sketched or where necessary were surveyed to Grade 5-3 using standard speleological methods (Ellis, 1976).

Temperature and relative humidity were spot measured using a whirling hygrometer (Brannan, England).

Soil samples were collected and the vials sealed; later the soilwater content (mass of water as a percentage of the mass of dry soil) was determined gravimetrically after drying to constant weight at 65°C.

The organic carbon content was determined by a spectrophotometric modification of the Walkley and Black dichromate oxidation method with glucose as a standard; the presence of $CaCO_3$ up to 50% of the sample volume gives no interference (Walkley, 1947; Allison, 1965; Metson *et al.*, 1979; Raymen and Higginson, 1992).

Conductivity measurements in water, corrected to 25°C, were made using an LC84 meter (TPS Pty. Ltd., Springwood, Brisbane) calibrated against appropriate standards in the laboratory and routinely in the field against a 1.41 $mS\ cm^{-1}$ standard solution.

The carbon dioxide levels in the atmosphere were checked using the physiological reaction of cavers (people are affected physiologically at *c.* 3% CO_2; Williamson, 1975), and sometimes by measuring the atmospheric oxygen levels (MSTox-8600 Gas Monitor: O_2)— biogenic carbon dioxide lowers the oxygen level.

Data lodgement

Data bases have been established in the Western Australian Museum containing the relevant information about more than 2826 specimens included in 642 lots, primarily of fauna, obtained during the course of this work, the details of 96 locations and more than 300 photographs.

Key sites giving access to the subterranean fauna have been documented by description, map and/or photography and located accurately using the Global Positioning System (GPS)(see appendix A).

Chapter 2

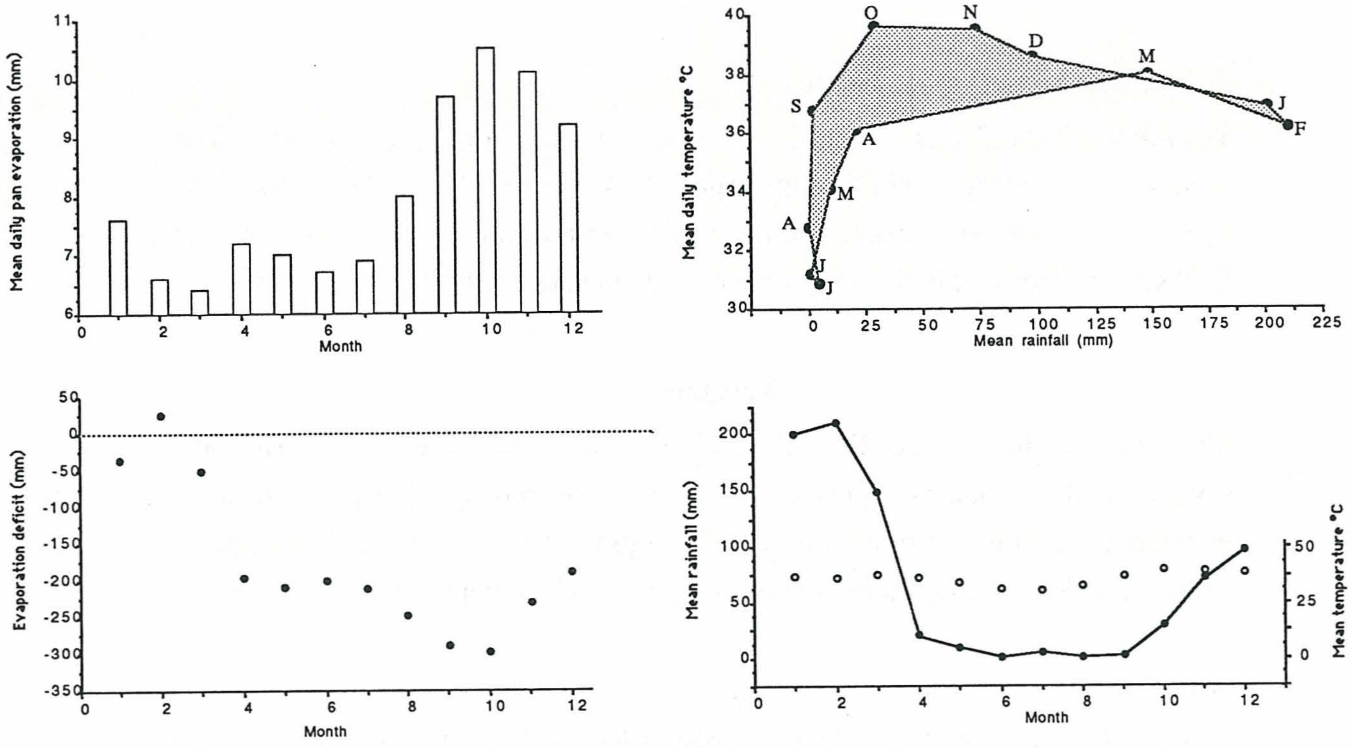
East Kimberley

Chapter 2: East Kimberley contents continued

Climate

The east Kimberley has a monsoonal (wet-dry) tropical climate in which the rainfall of 360-840 mm a^{-1} occurs mainly between December and March. In Kununurra, the main town of the region, the total average rainfall is 809 mm, of which 51% falls in January and February, and 90% falls between November to March inclusive, often in heavy falls (up to 150 mm d^{-1})(figures 3 and 4) (Christian and Stewart, 1953, Slatyer, 1960, Fitzpatrick and Arnold, 1964).

Figure 3: Upper left: mean daily pan evaporation data for Kununurra (Kimberley Research Station, 17-20 years data; Bureau of Meteorology). Lower left: mean evaporation deficit note that on average evaporation exceeds rainfall in all months save February. Upper right: hythergraph of mean monthly rainfall (mm) and mean daily temperature (°C) at Kununurra—data for 1962-1992; Bureau of Meteorology— letters denote month of year. Lower right: ombrothermic diagram for Kununurra—a soil-water deficit is indicated where the temperature line rises above the rainfall curve when the relationship is set such that 20 mm rainfall is equivalent to 10°C. Month 1 is January.



The prevailing south-east trade winds blow from the arid interior bringing dry air with an average relative humidity of 40%. However, in summer the north-west monsoon brings moist air with an average relative humidity of 75%.

The long period with little or no rainfall and the high evapo-transpiration (mean 2919 mm a^{-1}) results in most surface water sources being only semi-permanent and all save spring fed streams and the lower reaches of the Ord River stop flowing in the dry season. However, there is permanent groundwater which is accessible not only through wells but also in some caves (e.g. KNI-19) and which provides a refuge for larger non-stygofauna aquatic species.

Daytime temperatures throughout the year are high, often exceeding 40°C in summer for many consecutive days (figure 4). Temperature extremes generally increase inland giving a range of average summer and winter maxima of 35-38°C and 26-32°C respectively through the region. In winter the inland minimum temperature can be low and occasional frosts are recorded — at Halls Creek, the main settlement in the southern part of the region, the mean minimum temperature is 6°C in July.

Rainfall at the time of sampling

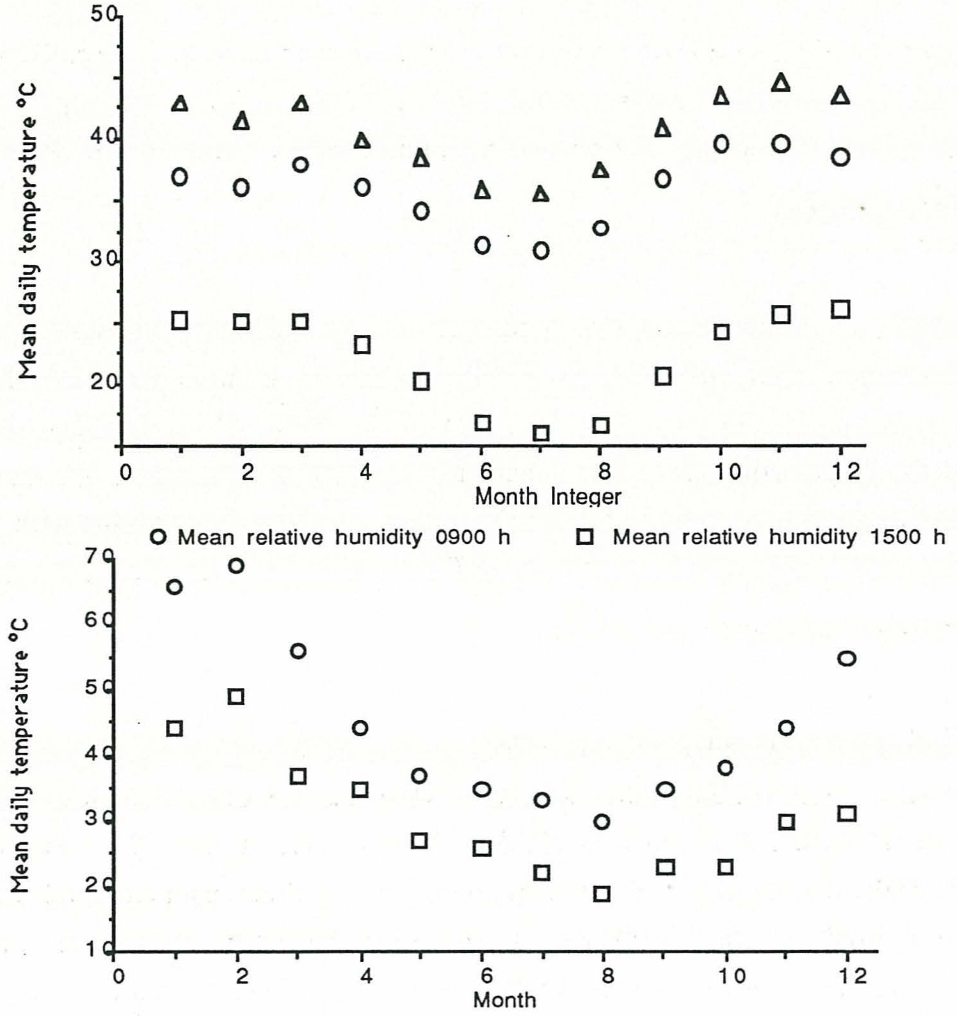
The rainfall in 1993 was 953 mm, 118% of the mean rainfall of 809 mm a^{-1}. The rainfall from October 1993 through April 1994 was 884.4 mm, or 113% of the mean rainfall for this period. Hence, in the period immediately preceding the field season discussed in this report the rainfall had been rather better than average.

Vegetation

The northeast Kimberley lies in the Northern Botanical Province (tropical savanna and scrubland)—most of the area is covered by high grass savanna woodland which to the south merges with regions of short and tall bunch-grass savanna, with or without trees, and semi-desert spinifex steppe (Beard, 1990).

Dry monsoon rainforest elements occur widely in the northern Kimberley (Webb *et al.,* 1984) and the area sampled is within the geographic range of rainforest (McKenzie *et al.,* 1991: Fig. 1). Vine thickets occur in few places in the east Kimberley although elements of the vine thicket flora can be found in places (appendices B-29 and B-35), especially at seepages, in gorges and dolines (e.g. KO-2, the collapse doline

Figure 4: Upper: mean daily mean and minimum temperatures and highest monthly temperature for Kununurra. Bureau of Meteorology. Lower: mean daily relative humidity at 0900 h and 1500 h for Kununurra. Bureau of Meteorology. Month 1 January.



in the middle of the Tunnel, KO-1; W.F. Humphreys, unpublished). The thickets are small patches of mixed tropical evergreen and deciduous species forming forest and shrubland. The canopy is closed 5-10 m above the ground and comprises evergreen species but the emergent crowns reach 10-15 m and are typically deciduous in winter (dry season). The understory consists of low shrubs, trees and vines with a ground flora almost absent (Beard, 1990).

Such vine thickets are found sparsely scattered through a wide area of the northern Kimberley. They are of interest in the present context not only because they are a distinct biome from the eucalypt savannas but because they represent a tropical woodland community, or rainforest, in the broad sense. Rainforest, both temperate and tropical, is the type of vegetation thought to have been associated with the troglobitic fauna of Cape Range but which is now relictual in caves there owing to the present surface aridity (for example see Humphreys, 1993b, 1993c).

The sandstone ranges of the area are covered with high-grass savanna woodland with the main tree species in rugged country, *E. dichromophloia*, being replaced by *E. tetrodonta* on the deeper soils and a ground layer of annual *Sorghum* and *Plectrachne pungens*.

Hilly country on basalt and dolerite is covered by high-grass savanna woodland of the *Eucalyptus tectifica-E. grandifolia* alliance and the groundlayer is mainly the same upland tall grass as on sandstone with *Sorghum* and *Plectrachne*. In contrast the flatter country on basalt and dolerite carries high-grass, low tree savanna (trees <10 m) with *E. terminalis* and *E. argillacea* dominant with a groundlayer of the tippera tall grass type with *Themeda australis*, *Sehima nervosum* and *Chrysopogon fallax* (Beard, 1990).

On the extensive sandy plains that overlie limestone in the region the vegetation tends to be a mixture of the above two types. However, the extensive black soil plains, on which the Ord Irrigation Scheme is based, are typical of the world tropical black soils that are formed on plains of fine-grained calcareous alluvia usually derived from basalt or dolerite. It has a high capacity to absorb and so is extremely plastic when wet and cracks deeply on drying. Such soils are treeless, or almost so, and the blue grass-tall grass community of perennial grasses forms the ground layer (>2 m). There are frequent tall herbs but where sandplains are poorly drained there are stands of teatree, *Melaleuca viridiflora* and *M. nervosa*, over a grass layer of *Plectrachne pungens* and *Sorghum* spp. as occurs, for example, between Kununurra and the coast (Beard, 1990).

Boabs, *Adansonia gregorii*, are frequently found on scree slopes bordering rock ranges, on the bare karst country formed from the limestones of the Devonian reef system, as well as on blacksoil plains that overlie limestone pavements.

Cycads and palms occur widely on the Devonian reef system in rugged country.

Physical landscape context

Physiography

The Kimberley Region is the rugged northern extremity of Western Australia and it comprises mostly Precambrian rocks. This report concerns the area of mainly rough mountainous country that lies between the Kimberley Plateau (to 800 m) to the west and the similar but lower Victoria River Plateau to the east in the Northern Territory. Within this region the oldest rocks are found in the geosynclinal Archaean sedimentary rocks of the Halls Creek Group found throughout the east Kimberley. The area flanking the Halls Creek mobile zone, and where most of the fauna was found, has been tectonically stable since Carpentarian times (>1.3 Ma; Dow and Gemuts, 1969).

In much of the east Kimberley the rivers are superimposed on the rocks they now traverse (e.g. Ord River), cutting through major and minor ranges such as the Carr Boyd and Ningbing Ranges—the latter is part of the Kimberley Devonian reef complex that has been exhumed from a cover of Permian sandstone (Gillieson *et al..*, 1991). Formerly they probably traversed an ancient land surface that now forms the summits of the major ranges (Plumb and Veevers, 1971). The area is drained primarily by rivers flowing north into Cambridge Gulf, principally the Ord River, which in its lower reaches is incised as much as 30 m into the plain.

Detailed descriptions of the geology of the east Kimberley is contained in Dow and Gemuts (1967, 1969), Plumb (1968), Plumb and Perry (1971), and Plumb and Veevers (1971).

Geological history

The Cambridge Gulf area has had a very complex geological history. From the Middle Devonian to the Upper Carboniferous the area was subjected to a complex pattern of subsidence and uplift. Much of the subsidence was local and conditions favoured the growth of large algal and stromatoporoid reefs and their associated facies (Plumb and Veevers, 1971). The limestones formed from these reefs, now exposed, have undergone intensive karstification and its is these limestones that are the main stronghold of the subterranean fauna today. However, the processes occurring at that time laid down a complex series of limestones and dolomites, all of which could be cavernous. Almost the entire area was glaciated on several occasions between 770-600 Ma leaving a residue of tillites over the area that were mostly laid down in a shallow marine environment in the Adelaidean (Proterozoic) (Dow and Gemuts, 1969).

In the east Kimberley glacial rocks are invariably associated with, and overlain by, dolomitic rocks, the dolomite deposition probably being a natural accompaniment of the glacial marine sedimentation due to the decrease in solubility of calcium and magnesium carbonates in the warming post glacial seas (Carey and Ahmad, 1961). The lavas which subsequently overlaid them in the Lower Cambrian preserved this unique record of Precambrian glacial rocks (Dow and Gemuts, 1969).

Immediately above the glacial sediments the carbonate rocks are often thin bedded, probably as a result of seasonal fluctuations in the temperature of the sea water as the sea warmed after the glacial epoch (Dow and Gemuts, 1969), and hence unlikely to be cavernous. However, the upper part of the Egan Formation consists of carbonate sequences up to *c.* 50 m thick mostly dolomite or dolomitic sandstone but they also include a considerable proportion of limestone, some of which is remarkably pure (Dow and Gemuts, 1969), hence these strata are possible cavernous.

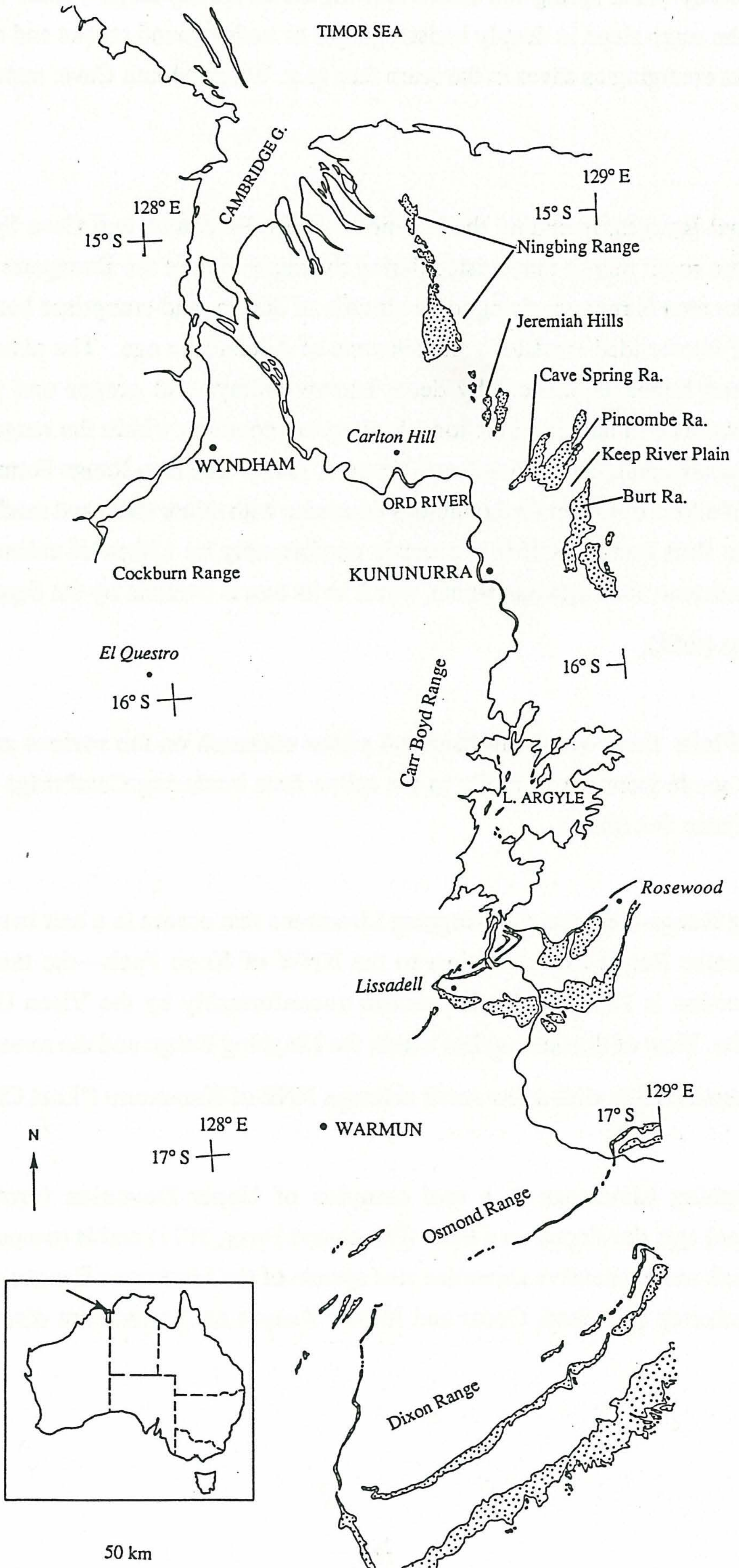
The present landscape was formed, and records of Mesozoic deposition removed, by deep erosion and dissection resulting from a relative drop in sea level of 370 m in Miocene to Pleistocene times (van Andel and Veevers, 1967).

Regional descriptions

The broad distribution and the characteristics of carbonate rocks and of groundwater in limestone areas (figure 5) was examined in the east Kimberley in order to target areas likely to be cavernous and possibly contain troglofauna (obligate cave fauna) and stygofauna (obligate groundwater fauna).

Osmond Range is a broad sandstone massive covered by spinifex growing on a sparse soil cover. It contains a 1270 m section of the Bungle Bungle Dolomite comprising about 525 m of dolomite (4 bands), 25 m dolomite and limestone (1 band) and 75 m of limestone (1 band) and is rich in stromatolite colonies (Dow

Figure 5: The distribution of limestones in the east Kimberley.



and Gemuts, 1969). The gently dipping broad cuestas flanking most of the range are drained by radial spring-fed creeks flowing down the dip slope—some break through the scarp slope in deeply incised gorges or underground creeks and some enter sinks emerging as caves in the scarp face (e.g. Whale Mouth Cave; appendix B-4).

Carr Boyd Ranges, including the Bandicoot, Burt, Pincombe and Cave Spring Ranges, are fossil ranges that existed during the deposition of the Bonaparte Gulf Basin. The area is rugged, rising to an altitude of 300 m, and comprises bedrock mostly of interbedded sandstone and siltstone of Adelaidean age. The plateaux, cuestas and hogbacks are cut by deep, narrow valleys and gorges and some stream terminate in hanging junctions. Springs are common within the range and along large bounding faults (Plumb and Veevers, 1971). The Burt Range Formation consists of 420 m of Lower Carboniferous limestone with minor shale and sandstone and in the Burt Range itself it is overlain conformably by 150 m of calcareous quartz sandstone, the Enga Sandstone, which in its turn is overlain by the Septimus Limestone (*ibid.*).

Coastal Plain these low lying blacksoil plains encroach on the various ranges and they grade from the foothills to the saline flats bordering Cambridge Gulf and the Timor Sea (*ibid.*).

Ningbing Range comprise the Ningbing Limestone that occurs in a belt between the Pincombe Range extending just to the NNW of Knob Peak—the thickest known section is 330 m and it is overlain unconformably by the Visen Utting Calcarenite. Most of the outcrop lies within the Ningbing Range and the remainder in the Jeremiah Hills with a few small outcrops NNE of Kununurra ('Lost City').

The Ningbing Limestone is a reef complex of Upper Devonian (probably Famennian) age, developed on a horst (Plumb and Perry, 1971) and is comparable to the much more extensive Devonian reef system of the Limestone Ranges of the west Kimberley (Lawford, Oscar and Napier Ranges etc.) which are discussed below.

The limestone composition reflects the reef depositional environment with four facies being recognized—reef (massive recrystallized limestone), fore-reef (breccia, conglomerite, calcarenite), back-reef (well bedded calcarenite, birdseye limestone) and inter-reef (platy red and grey limestone) (Plumb and Veevers, 1971). These facies are discussed by Jennings and Sweeting (1963a) in the context of the western Kimberley reefs.

Weaber Range—the Burvill Beds outcrop at the foot of the scarp and these comprise a sequence of sandstone, shale, and interbedded sandy limestone (Plumb and Veevers, 1971). The beds are too thin and sand content too high for cave development, although rounded merokarstification is well developed (appendix B-10).

Cockburn Range is a large monadnock rising well above the general local level of the Kimberley Plateau. It is a large mesa bounded by scarps up to 300 m high and riding to an altitude of 600 m. Numerous springs issue from the sandstones.

Dixon Range sheet (Dow and Gemuts, 1967) area contains a number of surface exposures of limestone and dolomite.

Panton Formation—shale, siltstone, limestone of Middle Cambrian age that outcrops to the north of the Ord River, parallel to the outcrop of Linnekar Limestone lying to the south of the Ord River.

Olympio Formation —comprises Archaean or Proterozoic limestone and dolomite outcropping to the north and south of Osmond Range. At the sites examined north of Osmond Range these strata are thin bedded and dip steeply (appendix B-10) leaving little scope for cavern development.

Lissadell sheet (Plumb, 1968) area contains a number of surface exposures of limestones of Middle and Lower Cambrian age.

Panton Formation—grey shale, siltstone, marl, limestone and a fossiliferous limestone marker bed.

Headleys Limestone broadly outcrops south of Lissadell and fringing the inner rim of the Antrim Plateau Volcanics which surround much of the Hardman Basin. Some small caves have been reported from this formation but they are grike developments that are frequently open to the surface (Shannon, 1969)

Blatchford Formation comprises brown friable sandstone with flaggy calcareous sandstone and siltstone, green-brown crystalline limestone and pelletal limestone outcrop in places in the Lissadell area.

Linnekar Formation —fossiliferous limestone and marl thinly outcrop in the Hardman, Argyle and Rosewood Basins and to the north of Lissadell homestead where it now lies beneath Lake Argyle, the empoundment formed by the Ord Dam.

Karst and limestone

In this section I want to provide a background to the nature of the limestones of the east Kimberley with sufficient general background on karst processes to facilitate the readers understanding of the remainder of the report (see Glossary). For this account I draw heavily on Jennings and Sweeting (1963a), Jennings (1971), Sweeting (1972), Williams (1978) and Ford and Williams (1989).

Karst landforms

Limestone is slightly soluble in ordinary atmospheric water and, as a result of solution of the rock, drainage sinks into the ground and is not integrated into the surface drainage. Hollows and pits form where the water drains into the ground and these become isolated from each other producing a seemingly disordered landscape with underground drainage. These landforms in limestone areas and the processes giving rise to them are so distinctive that they are termed *karst landforms*. *Karst processes* have been studied intensively for centuries (Shaw, 1993) but quite seldom in tropical areas.

Karst is a type of topography with a distinctive hydrology and landforms that have arisen from a combination of high rock solubility and well developed secondary porosity. Rock structure is important in the development of karst—soluble rocks with extremely high primary porosity usually have poorly developed karst and yet soluble rocks with negligible primary porosity that have later evolved a very large secondary porosity support excellent karst. The distinctive landforms above and below ground that are a hallmark of karst result from solution along pathways provided by the structure (Ford and Williams, 1989).

The description of the landforms of limestone country is associated with a complex and confused terminology used to distinguish different types of karst landscapes, and the associated corrosion features at all scales, with many regions having unique terminologies (see Sweeting, 1972: 252 ff)—there is no adequate English language terminology and much of that used is German.

Tropical limestone

Historically differences in karst landscapes were sought from reference to regional climate but such climatogenic geomorphology proved unable to explain the differences (Ford and Williams, 1989). Water is the key climatic factor in karst development (*ibid.*) and less is known about karst in arid and semi-arid areas than anywhere save beneath frozen landscapes (Jennings, 1983). However, present indications are that the processes involved in arid areas are the same as those involved elsewhere.

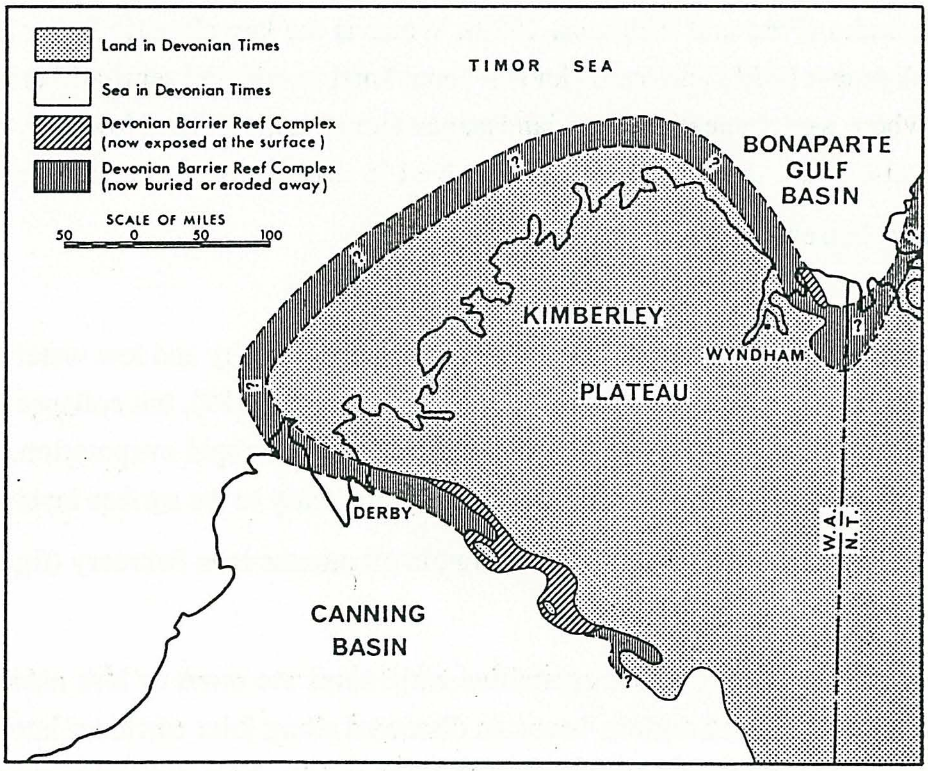
In arid areas solution dolines are rare because high porosity and low water surplus are inimical to their development (Ford and Williams, 1989), but collapse dolines occur associated with caves (e.g. KN-29, KO-2). The rapid evaporation, hence the corrosion of the limestone, is restricted particularly to the surface layers—note that average evaporation exceeds rainfall in all months save February (figure 3).

In dense, massively jointed crystalline carbonates the more or less naked karst characteristic of arid regions becomes dissected along joint corridors into blocks heavily fluted by karren (appendices B-12 to B-14). This dissection eventually penetrates to the level of the neighbouring plain and the karst surface is drained down an open network of grikes or corridors with few draw-down dolines because the detention of water both on the surface or within the carbonate is minimal (Ford and Williams, 1989). However, in areas where the limestone has high primary porosity, conditions favouring karren and joint corridor development are absent because the rainfall soaks into the rock with minimal passage over it. Such differential processes of karstification are likely to have lead to different types of caves systems, with the more porous carbonates tending to form more closed cave systems which would favour the development of specialised cave faunas.

Devonian reef complex

The Devonian reef complex is widely exposed in the west Kimberley, but only in small areas of the east Kimberley (figure 6).

Figure 6: Map showing the form of the Devonian reef system and the current surface exposures of the reef in the west and east Kimberley (from Playford, 1970, by kind permission of the publishers). It is in these exposures of the Devonian reef that the best karst development is found in the Kimberley, a region that otherwise mostly comprises the Kimberley Plateau, consisting of wide, flat sandstone benches with deeply incised rivers.



As so many features conform to those described for the west Kimberley, the overall development of the east Kimberley Devonian reef complex has probably followed closely the pattern identified in the west Kimberley by Jennings and Sweeting (1963a) and which was so clearly summarized by Ford and Williams (1989).

The plateau of Devonian limestone was uplifted above a lower pediment surface and this plateau is reduced to the level of the pediment largely through a process of parallel joint-aligned retreat in interfluvial areas in the following sequence.

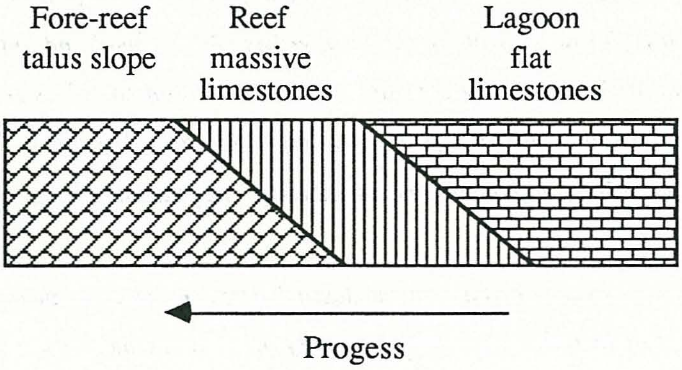
> *1. The plateau surface is stripped of soil and joints are penetrated by corrosion, producing fissure caves which enlarge to become intersecting sets of closed solution corridors or giant grikes that isolated large bedrock blocks. These corridors are up to 3 m wide, 33 m deep and hundreds of metres long. Vertical wall karren flute their sides, and flat caves prolong the open grikes underground and link up joints with different orientations. Intersection points of solution corridors sometimes widen into steep-walled closed depressions. Superimposed allogenic streams cut gorges through the karst, although some pass through the plateau in caves.*
>
> *2. Solution corridors and infrequent closed depressions amalgamate to form integrated valley systems reflecting a joint geometry in plan. Termed box valleys, they have rectangular cross sections with steep walls, flat floors, and plateau like divides. Their long profile grade to adjoining pediment.*
>
> *3. Plateau remnants are consumed by the widening of box valleys, thereby isolating towers that are scattered across bedrock pediments. The landscape is that of a bare fluted tower karst that is sharp and abrupt but of comparatively small relief (<50 m).*
>
> *4. Pediplanation results from continues solution of the towers and from direct scarp recession into the margins of the plateau; scarps are fluted by wall runnels up to 20 m long. Ultimately the upper surface is completely replaced by the lower* (Ford and Williams, 1989: 470-1).

Devonian reef complex: east Kimberley

(Ningbing Ranges and Jeremiah Hills)

The Devonian reef system of the west Kimberley has been described in detail by Jennings and Sweeting (1963a) and has become the type example of a semi-arid karst that is applicable in other seasonally humid karsts in northern Australia (Williams, 1978). This section is written with close reference to, and often by analogy with, their data and discussions, as well as to the subsequent interpretation by Ford and Williams (1989). The exposed limestones are a complex of reef facies that in areas are well displayed (figure 7).

Figure 7: Stylized representation of a section of the barrier reef complex or the Devonian reef system of the Kimberley (from data in Playford and Lowry, 1966). The massive limestones of the barrier reef overgrow the deeply dipping fore-reef talus slope, the dip of which is depositional, and are overlain by the flat bedded lagoonal limestone.



Modern planation surface

The black soil plains which surround the Devonian reef systems (appendix B-3, mid-right) of the east Kimberley appear to be characteristic of limestone areas in northern Australia (Jennings and Sweeting, 1963a: 33). Limestone pavements protrude through these soils close to the range (appendix B-11, lower left) to a greater or lesser extent but they are often deeply covered (appendices B-3, upper right: B-7, upper and lower). Groundwater flows through the buried limestones and in places access to it can be made through small sinkholes in the black soil plains (e.g. Ningbing rockhole). The exposed planation surface is occasionally interrupted by rock outcrops and rock rubble; solution pans are frequent with many crabholes that occasionally expose bedrock. The relief varies from planar to shallow dissected relief with merokarstic or holokarstic development (appendices B-3, 7, 11 and 13).

Dissected karst

Minor surface solution features

The contact between the planation surface and the reef facies is often abrupt such that the boundary has the steepness of a marine cliff—they are not fossil marine cliffs but are actively developing solution features (Jennings and Sweeting, 1963a: 30 ff). The exposed rock exhibits pronounced effects of surface solution on both a small and a large scale with the former often being superimposed on the latter (appendices B-3, 7, 9, 11, 13 and 15).

Steep to near vertical rock surfaces are mostly incised by nearly parallel solution gullies that include solution flutings up to 5 cm across and 2.5 cm deep separated by hollow-ground, razor sharp, partitions (Rillenkarren: appendices B-13 and 15: see profiles in Goudie et al. 1989, fig. 6), solution furrows up to 15 cm wide and deep (Rinnenkarren: appendix B-13); and larger solution gullies up to 1.5 m deep separated by ribs and buttresses that may or may not carry lesser features on the surface (appendices B-13). These small solution features are often subdivided into successive sectors one above the other by small rainpits, tiny hemispherical hollows up to *c.* 2 cm deep (appendices B-12 and B-14).

Flatter surfaces are subdivided by solution slots or grikes (Kluftkarren: appendix B-35) along joints but they are generally pitted by birds nest hollows (Napfkarren: (appendices B-15). The partitions between the pans and flutings are very thin and they break under the weight of people walking on them—there is a tendency for solution effects to work in a horizontal direction thus eliminating intermediate slopes (Jennings and Sweeting, 1963a). Deep circular pits or lapis-wells (Rhrenkaren: appendix B-3) occur in places.

Major landforms

During the evolution of the dissected landscape karst corridors or bogazi develop (Karstgassen: appendices B-7 and 11). Vertical joints, that are widespread in the limestone, are etched by solution to varying widths (generally <5 m), up to 30 m deep and hundreds of metres long with the big corridors continuing underground as cave passages with perpendicular crosslinks these are strikingly developed in KJ-7 and KL-5.

Eventually the fusion of these giant grikes eliminates the intervening ridges producing the box-valley system that are characteristic of the more advanced stages of the dissected karst the later stage of this development is probably marginal amphitheatres.

At a more advanced stage of dissection conical towers, ridges and pinnacles are found on an almost flat rock plain, often thinly and patchily veneered by soil and rock debris. The tower karst (Turmkarst: appendix B-13) is generally on a small scale owing to the low relief.

Large enclosed depressions occur in places in the southern Ningbing (and the northern Napier Range) and the internal drainage emerges at outflow caves on the periphery of the ranges as for example at KN-1 in the Napier Range (Jennings and Sweeting, 1963a) and at KNI-19 in the Ningbing Range.

As found in Kaijende in Papua New Guinea (Williams, 1978: 278), the tops of the range are frequently surmounted by small scale arête and pinnacle karst. As a result the area is characterized by ferociously jagged corrosion surfaces (appendices B-3, 13) although in parts smooth, rounded corrosion surfaces (appendix B-11) develop that are characteristic of below soil weathering; in the west Kimberley these are found particularly in the barrier reef facies (Jennings and Sweeting, 1963a).

As in the west Kimberley (Sweeting, 1972), in places around the periphery of the Ningbing the contact between the limestone and alluvium is the focus of spring sapping and cave formation. Such cliff-foot caves in this dry climate may be relict landforms from a more pluvial climate. They are well developed in algal reef facies at Barnet Spring in the Napier Range, often with relict levels of corrosion represented by raised benches (Jennings and Sweetin, 1963a), or solution notches, and they occur widely around the Ningbing Ranges.

Other features are associated with seasonal flooding of the black soil plains (solution notches and pediments), outflows (often upwellings) peripheral to the range resulting from internal drainage within the range (KNI-19), stream passages cutting through (gorges [the Gap, KN-11M, KL-4, KO-1, KO-4], or penetrating the range as tunnels [KO-1, KL-5]), and from groundwater levels (KN-1).

Watergaps

Tanmurra Creek and Station Creek flow westward, cutting through the Ningbing Range and clearly represent discordant drainage comparable to those seen more dramatically in the west Kimberley (e.g. Geikie, Windjana, and Barker Gorges (Jennings and Sweeting, 1963a) but at a later stage of evolution.

Devonian reef complex: west Kimberley

Despite the extensive nature of the Devonian reef systems of the west Kimberley (figure 6), only 62 features are recorded in the karst index of the area. Many of these features represent springs and gorges or multiple entrances to caves (e.g. KG-4 to KG-8 are all entrances to Homestead North Cave). Hence, in this entire karst region very few caves have been recorded and virtually no collections are known of cave dwelling fauna.

Several areas of the west Kimberley Devonian reefs system were examined briefly in order to determine how cavernous the reef limestones are in that area, whether the fauna was similar to that of the smaller Devonian reef system in the east Kimberley, the feasibility of future work in that area and whether they were as seasonally dry as those to the east.

The Limestone Ranges comprise a belt of Devonian rock running for *c*. 300 km along the northern edge of the Fitzroy Basin. Like parts of the Ningbing Range, they rise abruptly from the surrounding plains and consist of a series of low ridges and plateaux plunging, to the southeast, below Permian strata.

The Napier Range is about 100 km long and mostly <1 km wide, expanding to a width of *c*. 9 km in the northwest. To the southeast the Napier Range merges with the Oscar Plateau, the inner part of the Oscar Range, which includes a substantial inlier of Proterozoic rocks, and together they form the biggest limestone outcrop in the west Kimberley, *c*. 90 km long by 18 km wide. This continues southeast through a lower limestone plateau and the Geikie Range, being separated by the discordant Geikie Gorge. This whole system is a single physiographic unit having been formed from a barrier reef which has remained more or less undisturbed tectonically (Jennings and Sweeting, 1963a).

To the southeast of Geikie Range the Devonian reef system is more complex, with a series of small ranges and plateaux formed from atolls (Playford, 1970) and patch reefs that have subsequently been subject to more tilting and faulting than is the case in the nearly continuous reef forming the Napier to Geikie unit (Jennings and Sweeting, 1963a)—this area encompasses the Pillara, Home, Emanuel, Horse Spring, Lawford, Laidlaw and Hull Ranges.

Erosion rate

Ellaway et al. (1990) examined the water chemistry of the limestone ranges of the west Kimberley including some of the same sites examined in the 1960's by Jennings and Sweeting (1963a). From these data they estimated very roughly the solutional erosion rates for the Devonian reef karst as 10.4 mm ka^{-1}. These rates are low and compare with the rates found in hot and cold arid regions—this is probably due to the high evapotranspiration in the area which results in small effective runoff despite the substantial floods which occur intermittently (Gillieson *et al.*, 1991).

Regional descriptions

Lawford Range— the general area around Cave Springs (KL-1, 2 and 3) and Nardji (KL-6, 7 and 8) and Network Caves (KL-4) was examined for likely cavernous development. Numerous caves and grikes occur in the area, some of considerable extent and with massive decoration. The extensive (14 km+) Mimbi Cave (KL-5) was examined but found to be dry save in one place.

This area is ripe for caving expeditions as very large numbers of caves occur in the area—only 18 features are recorded in the karst index. Such cave recording would provide an ideal background on which to base future biospeleological work which would best be conducted immediately after the wet season as the open nature of many of the systems causes them to dry out rapidly with the onset of the dry season.

Pillara Range— was examined for groundwater sampling points and Limestone Billy Hills for likely cavernous development—none was found.

Geikie Gorge—the Devonian reef limestone at Geikie Gorge, through which runs the Fitzroy River, is very wide and deeply weathered with extensive box valley development. Only three caves are recorded in the karst index but the area clearly has considerable caving prospects and local informants tell of substantial caves in the area. Access to the central areas would be difficult.

Oscar Range —is a massive exposure of the Devonian reef that is penetrated by Tunnel Creek flowing through the Tunnel. This feature has been described in detail (Jennings and Sweeting (1963a, 1963b). Only two caves (and eight springs) are recorded in the karst index but the area clearly has great caving prospects. The system was examined briefly at the Tunnel (KO-1, 2 and 3) and adjacent area and clearly showed great potential for troglobitic fauna as >14 taxa were found, including troglobitic and endemic species and genera.

Napier Range—the southern (south of the Lennard River) and northern (north of the Barker River Gorge through to the Barnet Spring Gorge) sections of the range were examined. Only seven caves (and one spring) are recorded in the karst index but the area clearly has great caving prospects. It also contain significant sites of human occupation of great antiquity (S. O'Connor; pers. comm.).

A large numbers of rock shelters, caves and tufa deposits were visited through this area—of the features in the karst index they included Old Napier Downs Cave (KN-1: known by the lessees as Lake Cave), Barnet Spring Cave (KN-3 and 4), Bull Cave (KN-8), Barnet Spring Gorge (KN-9M) and Windjana Gorge (KN-11M).

Decoration in the karst landscape

Speleothems—decoration in the caves in the Devonian reef system of both the east and west Kimberley is usually sparse owing to the considerable air flow through the open grike and cave systems. However, where air flow is minimal, such as in blind tunnel caves and avens, substantial decoration may occur.

The decoration may be massive and infilled (appendices B-22 and B-24) showing a number of periods of growth and disturbance (appendix B-22), or may be delicate and clean (appendix B-18) where it is not subjected to seasonal flooding. There is much cave coral from established speleothems (appendices B-18 and B-22) that is indicative of a past more humid phase replaced by a less humid cave environment. The are considerable areas of cyanobacterial growth in the grikes indicated by blue-grey growths often down vertical shaded faces.

The age of speleothems cannot be estimated as they vary substantially in growth rate—by several orders of magnitude (see Humphreys, 1993a)—and impurities. For example from the semi-arid Cape Range large dirty speleothems may be only 25 ka or as old as 172 ka, while delicate, sparkling, and fresh-looking growths may be 99 ka old (dates from D.C. Ford; pers. comm. 1994).

Stegamites—these strange formations (appendix B-27) have only recently been identified (Webb, 1991) and were known previously only from six caves on the arid Nullarbor plains of Western Australia (Webbs, Witches, Gorange, Matilda, Stegamite and Fern Caves)— all are on Mundrabilla station and occur in the same general area (R. Webb, pers. comm., 1994). Stegamites result from water upwelling along a linear crack (Webb, 1991). The central "crack" is characteristic (appendix B-27) and thus they are probably formed in the same way as the ones on the Nullarbor. The surrounds of the stegamite (appendix B-27) appear to be made up of flowstone formed from the stegamite as is the case on the Nullarbor (R. Webb, pers. comm., 1994).

Calcite rafts— form on the surface of still water saturated with $CaCo_3$ owing to surface evaporation. When the water remains undisturbed for a long period they may form a continuous sheet (inner parts of KN-1), but they are usually isolated packed rafts which may become stranded by receding water (appendix B-20). In some caves repeated fluctuations in water level result in the accumulation of deep banks of stranded rafts.

Tufa—flows of white tufa cascade from the side of the Devonian reef system in many places (appendix B-20), being especially common on the northeastern side of the Napier Range (Viles and Goudie, 1990). Stairways of tufa dams occur at irregular intervals up some gorges (appendix B-20).

Hydrogeology— west Kimberley

The deeply incised rivers (e.g. Pentecost River by 300 m) act as groundwater drains and the shape of the groundwater is controlled by the topography. The east Kimberley is divided into six groundwater provinces that comprise Palaeozoic (Ord and Bonaparte Gulf Basins) and Proterozoic sedimentary basins (Ord and Bonaparte Gulf Basins), Proterozoic sedimentary rocks (Kimberley, Musgrave and Osmond Range Provinces), and the Halls Creek Group and Lamboo Complex (Halls Creek Province). Each contains aquifers with characteristic hydrological properties (Dow and Gemuts, 1969). These aquifers are tapped by numerous bores and wells to provide water for domestic stock. Through most of the area the salinity of the groundwater is <1 g L^{-1} and is often of good quality (<0.2 g L^{-1}) although saline water occurs in the alluvium bordering Cambridge Gulf.

Groundwater from jointed siliceous sandstones, such as the Pentacost Sandstone from which issues Zebedee Spring (the location of the phreatoicid isopods), typically contain very fresh water (<0.02 g L^{-1}) and in which concentrations of ions are similar to the proportions found in rainwater (Dow and Gemuts, 1969). The presence of springs (mostly too badly trampled by cattle to sample stygofauna) shows that most of the sandstones contain groundwater. For many reasons there are few bores in these areas (*ibid.*) and hence there is limited access to the groundwater.

Elsewhere, despite the large number of potential access points to the groundwater—at pastoral bores and wells, town water supplies and piezometers—in practice few were available for sampling either because they contained pumping equipment or they were no longer open.

The most intense sampling was undertaken in the Ord Irrigation Area piezometric network. Most of these piezometers are too small to be useful for sampling and many are damaged which precludes sampling. These piezometers range from 25-150 mm in diameter. The nature of these bores is unknown as records are not available to me. Additional bores and wells were sampled opportunistically through the study including the Kununurra water supply bores which takes freshwater (200 ppm total hardness) from the coarse alluvium next to the Ord River, and pastoral bores and wells.

The hydrology of the area below the Ord Dam has been modified by the filling of Lake Argyle, the Diversion Dam at Kununurra and by the associated irrigation areas.

Groundwater Provinces

Bonaparte Gulf Basin Province—contains highly cemented sandstones holding groundwater which supplies several springs (Hart and Point Springs) however, the limestones and dolomite are not known to yield water. Thick alluvial deposits occur along the Ord River but saline water intrudes into the groundwater owing to tidal movements of seawater along the Ord River up to Tarrara Bar, 15 km downstream of Kununurra (Dow and Gemuts, 1969). The extensive black soil plains around the Ord River, the substrate for the Ord Irrigation Area, are alluvial deposits from a time when the river flowed north-east (Carroll, 1947). It is from the groundwater of this alluvium that the syncarid specimens were collected.

Osmond Range Province—the Osmond Range Province contains areas of dolomite and sandstone which maintain numerous waterholes in the gullies cutting through the range (Dow and Gemuts, 1969)—all known water in the province is fresh.

Ord Basin Province— all the subprovinces are drained by the Ord River and the seepage provides a permanent underflow in the alluvium which, in places, maintains water holes (Dow and Gemuts, 1969). Within the area groundwater is obtained from limestone and sandstone—the distribution of cavities within the limestone is variable and often there is no useful water supply for 40 m or more below the first occurrence of water or large quantities may be available at several levels. In general the salinity ranges from 300-850 mg L^{-1} with an extreme of 1130 mg L^{-1}.

Kimberley Province—covers the larger part of the east Kimberley and Carpentarian sedimentary rocks (sandstone, siltstone, and shale), dolerite, and basic volcanic rocks predominate, but there are areas of older crystalline rocks and Cambrian sediments, mainly around the Carr Boyd Range (*ibid.*). While the area lacks limestones, the sandstones do contain groundwater with a mean salinity is 440 mg L^{-1} (range 280-1400 mg L^{-1}). The alluvium is mostly too thin to maintain permanent water but springs maintain the groundwater in places.

Halls Creek Province—comprises crystalline rocks of the Halls Creek Mobile Zone in which the dolomites and marbles of the Halls Creek Group may have cavities containing groundwater but none have been reported (Dow and Gemuts, 1969).

Musgrave Province— the area is characterized by Adelaidean sedimentary rocks, mainly shale and siltstone, with subordinate sandstones and dolomite. Groundwater may be confined or unconfined in joints and fractures in the dolomite and indurated sandstone, and possibly solution cavities in the dolomite (*ibid.*). A wide range of groundwater salinity is found (100->6000 mg L^{-1}) which in places is seasonally variable owing to recharge (*ibid.*).

Chapter 3

Caves and their environment

Nature of the caves

Relevance of cave structure

Cave structure and form is crucial to its microclimate. Within a given climatic zone the quantity of, and frequency with which a cave takes, water and its contained organic matter is directly related to the size of its catchment. Under given conditions of ventilation of the caves the rate at which a cave dries is a function of the ratio of the cave volume to entrance size—a cave with a relatively large entrance and small volume will dry more rapidly than one with a relatively large volume and small entrance (see Humphreys, 1989, 1991a, 1991b).

As many of the caves in the Kimberley are intermittently open to the outside, owing to their origin as grike developments (see section on caves), and they mostly lack large chambers, then their microclimates are especially responsive to both diurnal and seasonal meteorological changes. Caves can be categorized as open if they have a great exchange of air (grikes, cliff-foot caves and rockshelters), and closed if their structure is essentially long and narrow with a single major opening hence restricting air exchange with the outside.

Cave form and structure

The primary process resulting in caves in the Devonian reef system is the development of fissure caves which enlarge to become intersecting sets of closed solution corridors or giant grikes up to 3 m wide, 33 m deep and hundreds of metres long—flat caves prolong the open grikes underground and link up joints with different orientations (appendices E-3, E-4 and E-6). There is much air movement in such open caves and as a result they are exceptionally responsive to conditions outside the cave.

Other open style caves are the cliff-foot caves (Sweeting, 1972) which, however, frequently connect to the drainage from the reef massive, in which case they have elements that are open and closed with the latter being more likely to contain troglobitic fauna.

More closed caves are formed as tunnels (e.g. KO-1, KL-5) and as outflow caves resulting from internal drainage within the range (e.g. KN-1, ?KNI-19: appendices E-5 and E-6), and from upwelling water from springs. However, there are many caves which appear to have developed in part as pressure tubes and from phreatic development (e.g. KNI-41, KN-1) which would warrant examination by a karst geomorphologist.

Cave atmosphere

Temperature and relative humidity

The temperature of a deep cave in which there is restricted air movement will usually approach that of the mean average surface temperature as recorded by meteorologists (Wigley and Brown, 1971, 1976). However, in a cave through which considerable air movement takes place the cave temperature will show some diurnal and marked seasonal fluctuations in both temperature and humidity.

Owing to the frequent opening in the caves in the Devonian reef system of the Kimberley there is often a pronounced gradient in both temperature and humidity along the length of a cave (see below), as well as pronounced diurnal and seasonal variation. This variation results in the mean values for these parameters being associated with high standard deviations (table 1). This indicates that the season variation in both temperature and humidity will be great and that both parameters will be greatly influenced by the prevailing weather conditions and seasonal changes. Hence, the Kimberley caves are often rather different to those encountered elsewhere

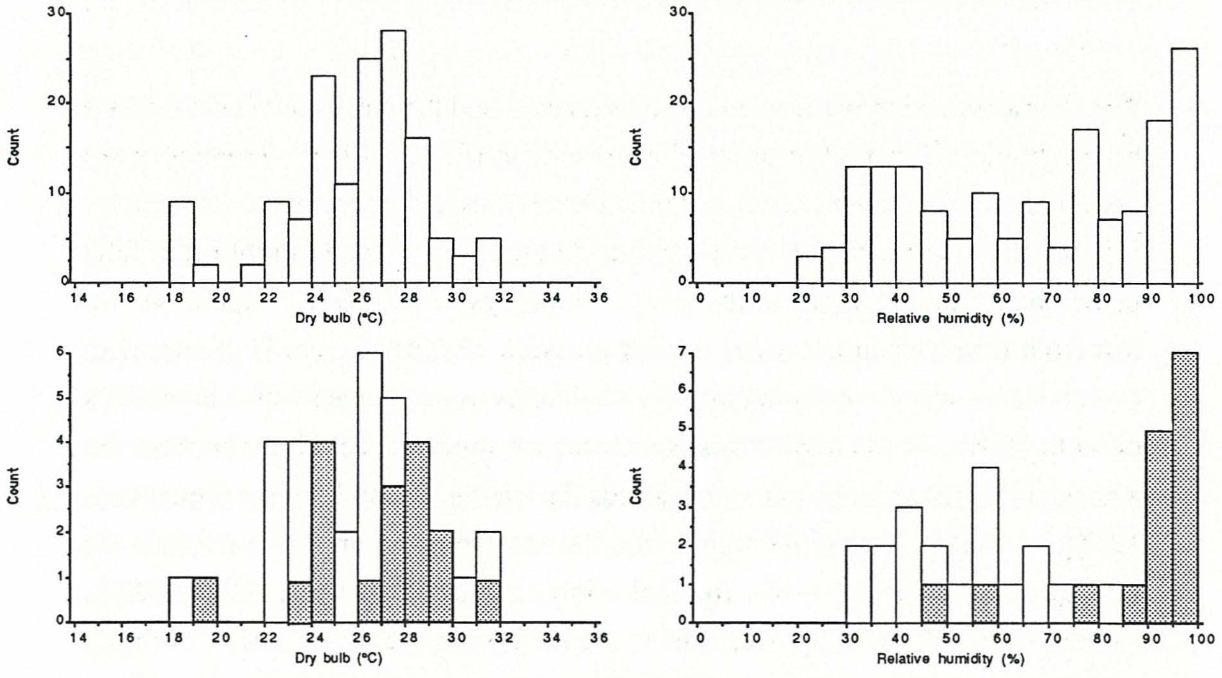
Table 1: The mean air temperature (°C) and relative humidity (%) in some of the caves examined from May through July 1994. Note the high variance (expressed as standard deviation) associated with the means.

Cave	Air C		RH (%)		
	Mean	S.d.	Mean	S.d.	N
KNI-19	21.8	4.56	60.5	27.94	47
KJ-8	21.2	3.31	57.9	14.79	10
KJ-7	22.3	4.71	67.3	14.89	7
KJ-8	21.7	2.77	56.3	14.06	15
KNI-1	26.9	0.55	34.7	1.53	3
KNI-9	25.8	1.82	86.1	15.77	27
KNI-19	27.2	1.19	67.5	24.66	39
KNI-27	24.9	0.91	60.7	19.31	6
KNI-29	28.0	2.25	60.8	21.56	4
KNI-31	23.9	0.73	84.2	5.93	5
KNI-41	27.2	0.21	96.8	1.79	5
40 m N KNI-6	26.5	0.38	33.3	1.53	3
8K-1	26.7	3.95	76.0	24.30	10
KL-5	27.7	4.62	77.8	23.00	6
KO-1	25.3	1.59	79.8	25.17	4

in Western Australia (Humphreys, 1991a) and northern Australia (Howarth and Stone, 1990) in which the lack of air movement permits the accumulation of high levels of carbon dioxide which may have a significant bearing on the nature and distribution of the cave fauna (*ibid.*).

The mean values recorded in table 1 are for the entire data set and values comparable with those recorded elsewhere, for example in Cape Range (Humphreys, 1991a), can be obtained by examining the temperature and humidity of only the deep closed portions of caves and these are shown in the lower histograms in figure 8. These data show that the caves in the north Kimberley are hotter and drier than those in the semi-arid tropical Cape Range—63% of the temperatures are >26°C (cf. 30% for Cape Range; Humphreys, 1991) and 42% of the relative humidity values are >80% (cf. 79% for Cape Range; Humphreys, 1991).

Figure 8: The temperature (°C) and relative humidity (%) in some Kimberley caves in May-July 1994. Upper row—all data; lower row—in the depth of each cave with the shading denoting the occurrence of cave adapted fauna.



Cave climate and fauna

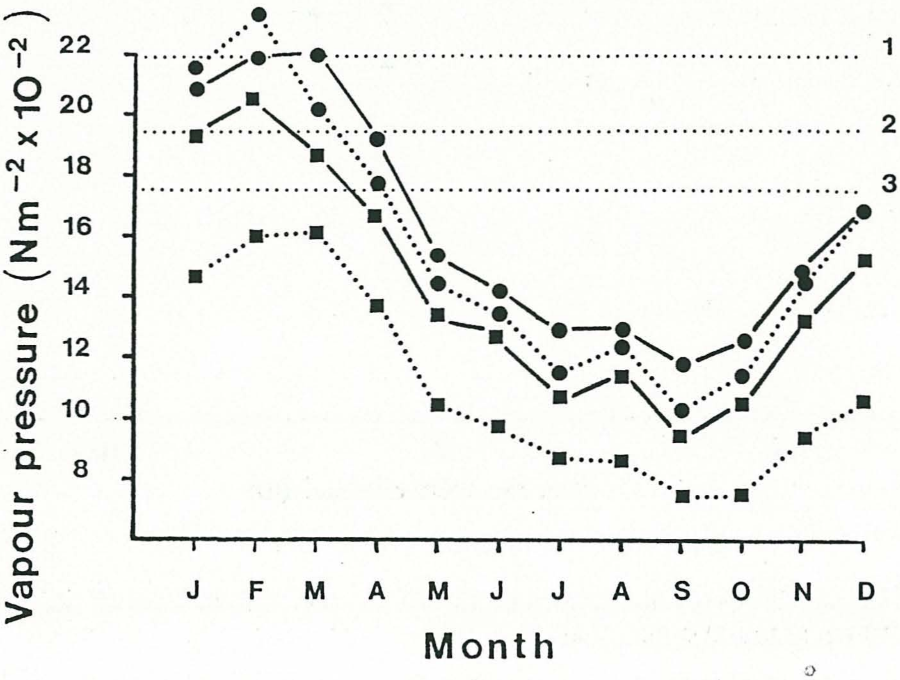
Troglobitic animals are found throughout the temperature range of the caves examined but predominantly at the upper end of the range of temperature found in the caves—the mean temperature at which they occurred was 27.4°C (s.d.=1.87, n=33). The caves containing troglobite fauna were at the upper end of the range of humidity found in the caves. The mean relative humidity was 87.1 (s.d.=13.52, n=33); note that the variance in the relative humidity is much greater than that for temperature. These relationships are depicted in figure 8 (lower histograms) together with the distribution of cave adapted fauna (the occurrence of cave fauna below 80% relative humidity represents meenoplid bugs which, being sap suckers, are less dependent on air and soil humidity). The situation parallels that found in the caves of Cape Range (Humphreys, 1991a, 1991b).

Drying of caves

While temperature *per se* appears to be unimportant in determining the distribution of troglobites in caves, temperature can indirectly have a major influence on the water vapour pressure in the caves and thus the rate at which the caves dry.

The net movement of water vapour between caves and the outside air is determined by the gradient in partial pressure of water vapour (Edney, 1977). Tropical caves dry rapidly in the cooler season, not only because, as is the case of the Kimberley, it is the dry season, but because the outside air temperature at night often falls below that of the cave (Howarth, 1980, Humphreys, 1991). Water vapour will be lost from caves when the water vapour pressure within the cave is greater than that outside— caves containing tropical troglobites usually have relative humidities close to 100%. In the tropics this is the case for much of the winter because the average daily range in temperature exceeds the average monthly range (Petterssen, 1958), as well as during the night when the cave temperature often exceeds the outside air temperature —the tropical winter effect of Howarth (1980, 1983). Conditions on Cape Range are, outside the Kimberley wet season, not dissimilar to those found in the northeast Kimberley. It can be seen from the data above and figure 9 that water vapour will be lost from the cave for much of the year—all else being equal, warm caves will dry more rapidly than cool caves and hence have shorter periods during which they are suitable for troglobites. It is this effect that accounts for the rapid drying of the caves in the Kimberley, a process that is exacerbate by the often open nature of the cave systems themselves.

Figure 9: Annual changes in the partial vapour pressure of water in the semi-arid Cape Range, Western Australia, and the water vapour pressure in caves at various temperatures and humidities. The surface data are for Learmonth and are calculated for 09:00 h (solid line and circles), and 15:00h (solid lines and squares) meteorological readings of temperature and humidity, as well as for the mean monthly maximum (dotted lines and circles) and minimum (dotted lines and squares) temperatures. The horizontal lines show the partial vapour pressures of caves at given temperatures and humidities; if the curve lies below a particular horizontal line then , under the stated conditions of temperature and humidity, water vapour will leave that cave and vice versa. Cave conditions 1) 19°C and 100% R.H.; 2) 17°C and 100% R.H.; 3) 17°C and 90% R.H. The figure is from Humphreys (1991a).



Variability in cave microclimate

The changing nature of the cave environment is seen in the immediate effect of weather on the cave environment where there is air flow but, where airflow is absent no short term effect of weather is detectable (figure 10). Despite the lack of short term effects on the cave microclimate, the relative humidity in the cave gradually decreased as the dry season progressed, despite the lack of overt air movement (figure 11)—similar long term effects are seen in the soil water content (see below) but they are buffered from short term fluctuations by the greater concentration of water and the low exchange rates between soil and air.

Figure 10: Change in relative humidity with distance (m) into KNI-19 from 16 May (open triangles: 1320 h) to 5 June 1994 (solid triangles: 1600 h). This cave has an inflow of air. Note the large effect of the outside humidity up to C. 60 m in from the cave mouth at this point the airflow is diverted down another passage from that in which the humidity was measured and the humidity at the two dates is subsequently indistinguishable.

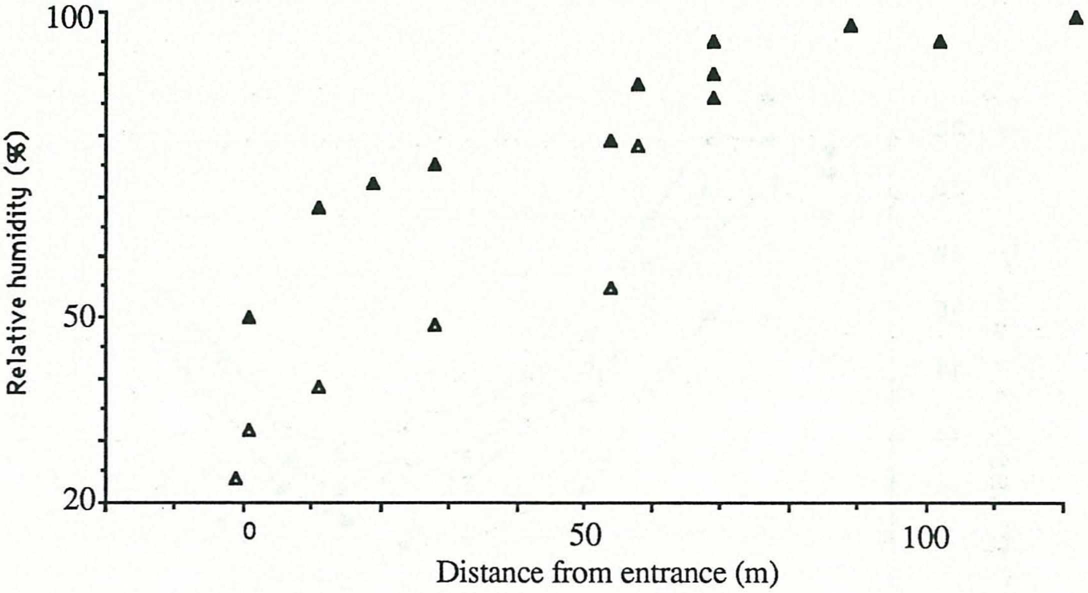
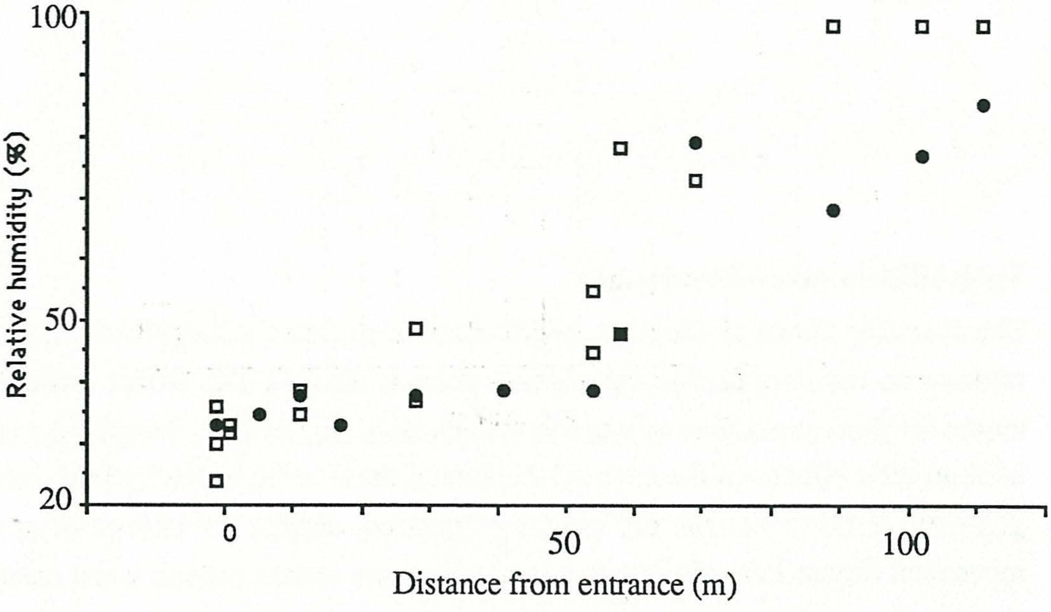


Figure 11: Change in relative humidity with distance (m) into KNI-19 from 10 May (open squares: 0740 h) to 19 June 1994 (solid circles: 1000 h).



Cave soils

Nature of cave soils

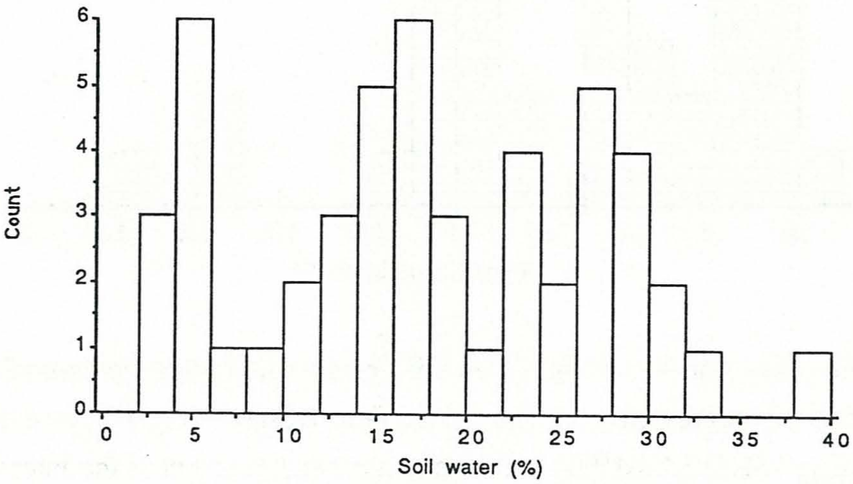
There has been little descriptive work or analysis of cave soils apart from those associated with archaeological remains (Ford, 1976).

The soils in the Kimberley caves are mostly clays that seem to have been weathered from the limestone itself. The high clay content results in substantial shrinkage, and thus deep cracking, of the sediments as they dry out as the dry season progresses—the cracking will increase the drying rate of the soil. The clay banks were once more extensive and numerous false (hanging) floors occur throughout the cave systems; these are speleothems that would have been laid down on former deeper sediment banks that were subsequently eroded.

Soil moisture content

Soil moisture content of the caves in the Kimberley was variable and had a polymodal distribution (figure 12) only 8% of the samples had a soil moisture content >30% compared with 35% of samples in the caves of Cape Range (Humphreys, 1991).

Figure 12: Water content (% dry weight) of caves soils from the Kimberley during 1994. Intervals 2%.

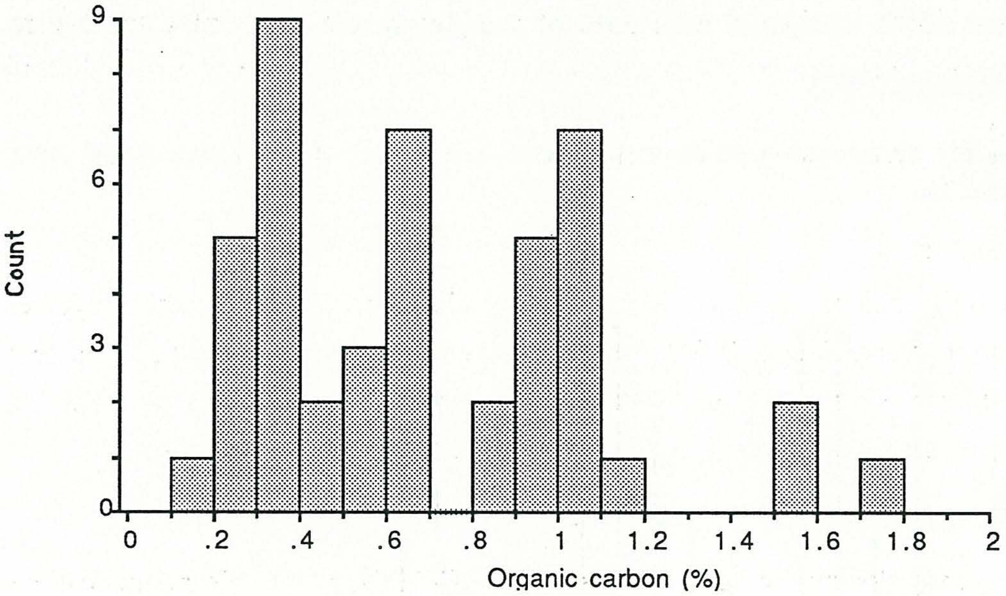


Although soil water content is buffered from short term fluctuations, water is lost from the soil as the dry season advances and this is enhanced by the high clay content of the soils which results in wide cracks opening in the drying soil. To illustrate the drying rate in one cave (KNI-9) the water content of the cave soil fell significantly (t_5=3.85, P=0.012) from 27.8% to 11.9% in the period 15 May to 6 June, 1994. Experience elsewhere has shown that this lower water content will not generally support troglobitic fauna in the accessible parts of caves (Humphreys, 1991a, 1991b).

Organic carbon content

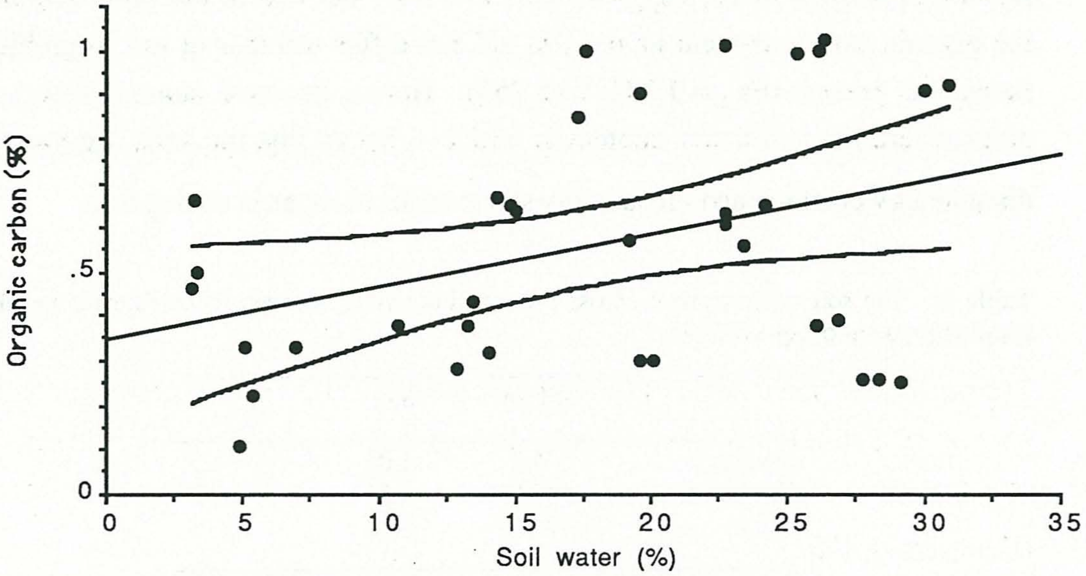
The organic carbon content of the caves in the Kimberley was variable and had a polymodal distribution (figure 13) only 18% of the samples had an organic carbon content >1% compared with 68% of samples in the caves of Cape Range (Humphreys, 1991).

Figure 13: The organic carbon content (%) of cave soils from the Kimberley during 1994. Intervals 0.1%.



In both the Ningbing Ranges and Jeremiah Hill the organic carbon content of the soil is significantly regressed on soilwater content (respectively $Fs_{1,34}$= 4.469, P=0.042 and $Fs_{1,7}$= 31.416, P<0.001) but the organic carbon content of the Jeremiah Hills samples is consistently greater (2.5 times) for a given water content than that in the Ningbing Ranges (figure 14).

Figure 14: Regression of soil organic carbon content on soil water content of cave soils from the Ningbing Range (square) and Jeremiah Hills (), east Kimberley. The biconcave lines represent the 95% confidence intervals of the true mean organic carbon.



The elevated organic carbon levels in the Jeremiah Hills caves may result from them being more open cave system that would facilitate the entry of organic material in contrast to the relatively closed caves sampled in the Ningbing Range.

Soil and fauna

Cave soils contain a rich microflora, especially bacteria and actinomycetes (Rutherford and Huang, 1994), on which the cave community may be dependent for decomposing processes. This part of cave communities was not sampled owing to the problems of obtaining representative samples (*ibid.*) and cost.

In the gently sloping floor a large chamber in KNI-41 there was a clear demarcations between faunate and afaunate regions. Across this transition zone (table 2) there was a clear change in the soil water content ($Fs_{2,6}$= 52.43, P<0.001) but not in the organic carbon content ($Fs_{2,6}$= 2.993, P=0.125) —the transition occurred at *c.* 15% soil water. Drying induces wide and deep cracking of the cave soils in KNI-27 cracked soil contained less water (14.7%) than did non-cracked soil (23.2%; $Fs_{1,4}$= 236.6, P<0.001) but the organic carbon content did not differ ($Fs_{1,4}$= 2.579, P= 0.183).

This is supported by observing that the soil water content of areas containing troglobitic fauna (20.4±7.24%, n=24) is greater overall than in areas lacking such fauna (9.8±6.86%, n=10; $Fs_{1,32}$= 15.427, P<0.001) but that in the same samples the organic carbon content of the soil did not differ whether or not troglobitic fauna was present ($Fs_{1,32}$= 1.341, P=0.255). Hence, the cave fauna is found in areas where the soil water content is >15%— below this the soils are greatly disrupted by cracking and presumably show major changes in drying rate.

Table 2: The soil water content across the transition zone between damp faunate and dry non-faunate areas of cave KNI-41.

	Mean	S.d.	N
No fauna	5.8	1.09	3
Transition	14.5	4.54	3
Fauna	28.4	0.72	3

Carbon dioxide

Elevated levels of carbon dioxide are frequently encountered in caves in which there is little air movement. The enhanced concentrations can result from physical causes but in tropical caves it is usually of biogenic origin and results in an equivalent decrease in the oxygen concentration—in Cape Range the levels may be >>8% CO_2 (W.F. Humphreys, unpublished data).

In the caves of the Kimberley no elevated level of carbon dioxide, sufficient to be detected by the physiological response of cavers, was reported and this is a direct result of the open nature of, hence high air movement within, these caves.

The absence of elevated carbon dioxide levels may restrict the diversity of the troglofauna for it has been shown that the increased concentration of carbon dioxide in stagnant air caves may be a significant factor affecting the distribution and the occurrence of troglobites (Howarth, 1988; Howarth and Stone, 1990). For example, in Bayliss Cave, in northeast Queensland, in which the carbon dioxide concentration range from 0.6-6.0%, of the 24 species of troglobites found there 75% occur only in the foul air zone (*ibid.*).

Water quality

Water quality was not subject to much analysis owing to the remoteness of many of the sampling sites. All water that was monitored was fresh with salinities of *c.* 90 mg L^{-1} (e.g. conductivity: Ningbing rockhole, 0.56 mS cm^{-1}; KNI-19, 0.52 mS cm^{-1}: 0.09 ppt), substantially lower than rainwater in most coastal environments (e.g. Exmouth 1.0 mS cm^{-1} [Humphreys, 1994] and Sydney suburbs 4.5-10.3 mS cm^{-1} [Acworth and Jankowski, 1993]).

Water in the Ord Irrigation Area

The Ord Irrigation Area is on blacksoil plains mainly overlying a former channel of the Ord River and underlain in part by gravels which were presumed to act as drainage conduits.

Groundwater levels in the Ord Irrigation Area have been rising since the irrigation started in 1964. The water table has risen by up to 12.3 m and in places in now only 2.7 m below the surface. Overall the water table currently is rising between 20 and 50 cm per year (B. Nelson, personal communication 1994). As the watertable is now 5-10 m above the gravel beds (*ibid.*) it is clear that the gravels are not a continuous stratum but possibly comprise a series of isolated lenses. It is not known in what stratum the stygofauna occurs but it is clear that the rising groundwater in the general area could have implications other than agricultural.

Discussion

Distribution of cave fauna

Background

Troglobitic fauna is found in the main parts of caves only during periods when the water and energy supply is adequate, at other times they leave the cave proper for minor passages. Hence, within the cave proper populations show a pulsed increase in response to outside inputs, followed by a slow decline in population as the conditions within the cave proper become less favourable (Humphreys, 1991b). The periodicity of the changes to energy and water supply has important effects on the fauna. Whereas the supply of both is unpredictable in Cape Range (*ibid.*), in the monsoonal tropical Kimberley there is a marked seasonality in the wet season (although it differs somewhat in timing and intensity). The presence of troglobites and their distribution within caves depends on the availability of food in the form of organic matter, and on the humidity of the cave — in the semi-arid Cape Range of Western Australia the latter can be in the form of very high relative humidity (Humphreys, 1991a, 1991b) or high soil moisture content (Humphreys, 1991b). Owing to the extensive nature of the field work in the Kimberley few repeat samples were possible but it is nevertheless clear that similar processes operate in this more humid part of the semi-arid tropics of Western Australia.

Food resources

The cave fauna depends on allochthonous organic matter for its energy source. Unlike Cape Range, where it is derived principally from water influx following exceptional rainfall, the energy in the Kimberley caves is derived from numerous sources. It is carried into caves by run-off during the wet season, by a rising water table and seasonal flooding of the blacksoil plains. Being shallow and horizontal caves, root penetration and growth on the cave soils is an important food resource for meenoplids (and their attending ants), and bats are an important component of the fauna bringing in quantities of faecal material which accumulates as guano. Although cave crickets are present, there is no evidence of large populations such as are important importers of energy into North American caves (Norton, Kane and Poulson, 1975; Kane, Norton and Poulson, 1975; Kane and Poulson, 1976). Unlike Cape Range, where large amounts of detritus sometimes enter the caves on flooding, there is little evidence of such flooding in the Kimberley caves. The food resources seem to be more evenly distributed through the caves in that when they are moist a fauna is usually present (figure 8).

Troglomorphies

In the Kimberley many areas seem devoid of a typical cave fauna and what is there often has reduced but none the less probably functional eyes. Whereas it is tempting to suggest that this is indicative of relatively recent isolation of the species in caves, it is possible, because they exhibit other marked troglomorphies, that eyes are retained, albeit much reduced, because there is still a selective advantage to eyes owing to the intermittent openings to the surface, and thus to light, in many of the caves.

Chapter 4

Fauna

Fauna contents (continued)

Insecta
    Blattaria: Nocticolidae
    Hemiptera: Reduviidae: Emersinae
    Homoptera: Meenoplidae
    Coleoptera: Scarabaeoidea
    Odonata: Anisoptera: Aeshnoidea: Aeshnidae
Chelicerata
    Schizomida: Hubbardiidae
    Pseudoscorpionida
    Araneae: Theridiosomatidae
    Araneae: Filistatidae
    Araneae: Hersiliidae
    Araneae: Heteropodidae
Myriapoda
    Diplopoda: Siphonophorida
    Diplopoda: Polyxenida
    Diplopoda: Polydesmida
    Chilopoda: Scutigerida

Introduction

Collections resulting from such an examination of cave fauna cover a wide diversity of specimens of which, for the fauna at least, all required examination by an equal diversity of specialists around the world—the involvement of these specialists must be solicited. While some taxonomists are in the process of working on the group in question, and some material is of sufficient interest for the specialist concerned to drop everything to examine it, this is by no means the general case. Much material will await an appropriate time for the specialist to examine it with other collections in the course of their normal schedule—some major groups have no specialist world wide. In consequence, while some material is identified, and described if necessary, very rapidly (within a year or two), much will remain unformalised for some time.

This discussion of the fauna, as a result, does not represent the entire collection, nor is it restricted to collections made on this trip but has included a more comprehensive consideration of the cave and other pertinent fauna of the area.

Mammalia

Chiroptera

Bats were not a target of the field work and were not routinely collected or trapped. However, observations were sometimes made and occasional samples of bat carcasses or skeletal material were collected. Bats are widespread and common in the caves of the Devonian reef systems in both the Western and Northern Kimberley. The geographical distribution of Australian cave-dwelling bats was reviewed by Hamilton-Smith (1966).

Ghost bats (*Macroderma gigas*) are widespread in the caves of both the Northern and Western Kimberley and they often occur in large populations. Observations made on the bats are consistent with those reported by Douglas (1967). The bats seems to be exclusively cave dwellers but they will occupy both shallow and deep caves (as well as artificial caves such as mine shafts, *ibid.*). The bats are easily disturbed and will often leave the cave silently often without the disturber being aware of their presence. They eat a wide variety of vertebrate and invertebrate prey (*ibid.*).

Eleven of the 24 species of bats (46%) known from the Kimberley have been recorded from caves (Hamilton-Smith, 1966 and the data base of the Western

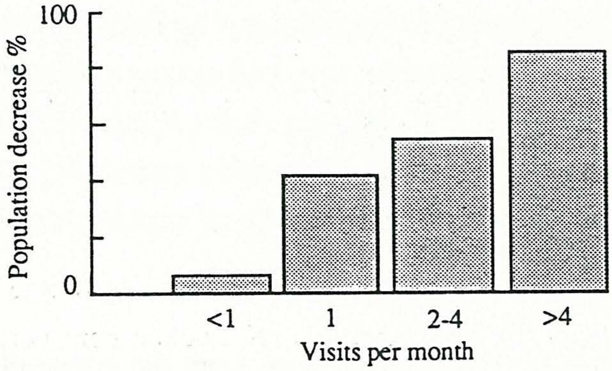
Australian Museum)—this compares with a estimated 39% Australia wide (*ibid.*); namely *Macroderma gigas*, *Eptesicus pumilus*, *E. douglasorum*, *E. caurinus*, *E. finlaysoni* (Vespertilionidae), *Miniopterus schreibersii*, *Taphozous geogianus*, *T. flaviventris* (Emballonuridae), *Pteropus alecto*, *Rhinonycterus aurantius* and *Chalinolobus gouldii*). *Macroderma* and *Rhinonycterus* are both monotypic genera endemic to Australia. M. *gigas* has been added to the International Union for the Conservation of Nature list of endangered species (I.U.C.N., 1978).

At least seven species of bats are known to occur in the caves of the Devonian reef system of the western Kimberley, namely *M. gigas*, *E. pumilus*, *E. douglasi*, *M. schreibersii*, *T. geogianus*, *P. alecto* and *R. aurantius* (Hamilton-Smith, 1966 and pers. comm. in Davey, 1980), with *T. georgianus* and *E. douglasorum* being widespread and common in the Devonian reef limestones.

To that we have to add from the present work *Macroderma gigas* that occurs widely in the caves of the Devonian reef system.

Populations of *Miniopterus schreibersii* are dependent on suitable caves for maternity sites and each uses a specific cave, hence the populations are vulnerable to disturbance (*ibid.*). However, as no information is available on the genetic distance between cave populations, no firm recommendations can be made other than to treat any problems conservatively. There is adequate evidence from other areas that cave populations are easily disrupted by human disturbance, even at very low levels (figure 15).

Figure 15: The effect of human disturbance on the summer colonies of the bat *Myotis griscens* in 20 caves in Alabama and Tennessee. The values are the decrease (%) in the size of summer colonies between 1968-1970 and 1976 at different levels of disturbance (number of visits by people each month). After Tuttle, 1979 from Humphreys, 1993a.



Reptilia

Many caves contained individuals of the banded cat-snake B*oiga fusca ornata* (Macleay)(appendix B-32), a large (up to 2 m), rear fanged snake which inhabits only the far north of Western Australia and the adjacent Victoria River drainage in the Northern territory; *B.o. fusca* replaces it further east and extends as far as northern New South Wales. *B.fusca* lives in caves and hollow trees where it captures small bats.

B.fusca occurred in some caves containing bats and they were especially prevalent in KNI-19, an outflow cave with a long low tunnel leading to the outside (appendix B-32). The inner chamber of this cave is a bat roost and large numbers of bats use the tunnel as a flyway through which they enter and leave the roost. The snakes are adept at moving along the smooth walls typically found in outflow tunnels and, especially when disturbed, retreat into the finer crevices in the limestone where they are no longer visible. The snakes were often observed to hold their body unsupported for a metre or more horizontally across the void of the cave and there remain motionless. Similarly they sometimes hung straight down leaving their head suspended in the middle of the passage. A bat was observed to hit one of these suspended snakes whereupon it was then struck by the snake as it tried to recover its equilibrium (P. Fox, pers. comm.: appendix B-32). The snakes were not seen in the bat chamber itself and would probably not be able to move across the smooth ceiling of the roost chamber. Bats must often move on the ground for the fine sediments in the cave were covered by claw marks.

Amphibia

Anura: Hylidae

Tree frogs, *Litoria caerula*, were widely found in caves from Katherine through the Ningbing Range and Jeremiah Hills area through to the west Kimberley. They were also taken in numbers from open bores (appendices B-30 and B-32).

This large tree frog is widely distributed through northern Australia and southern New Guinea (Tyler and Davies, 1986). It has rapid development (*ibid.*) well suited to breeding in pools of static water.

Anura: Leptodactylidae

Megistolotis lignarius was observed in caves in the Ningbing Range (e.g. KNI-19) from where they have been reported previously (N. Poulter, pers. comm.).

The species is confined to the northern rocky areas of the Northern Territory and the Kimberley where it is found in rock pools at the foot of scree slopes and beneath rocks (Tyler and Davies, 1986) so that it is unsurprising to find it in wet caves.

Pisces

As fish require distinct sampling methods they were not specifically sampled but some observations were made and a few specimens collected opportunistically. A number of species of fish occurred widely in caves and groundwater and water retreating into caves as the dry season advances are clearly important refuges for the fish from which they will emerge with the outflow water at the start of the wet season to recolonise the floodlands. They occurred in water holes, springs, underground streams and isolated pools in caves. No fish were taken in the region by Williams (1979).

Plotosidae

The Common Eel-tail Catfish, *Neosilurus hyrtlii* (Steindachner), appears to be able to survive some desiccation and they have been found in damp debris at bottom of dried pools. The species is widespread throughout northern Australia from the Ashburton River northwards and it is found in a variety of habitats from stagnant water to clear flowing streams. It was collected in an underground stream in Ningbing rockhole.

Teraponidae

The Spangled Perch or grunter, *Leiopotherapon unicolor* (Günther), is probably the most widespread freshwater fish in Australia. It is found from the Greenough River northwards and encompassing the northern three quarters of Australia. The species is well adapted to seasonally dry climates and desert conditions as it can tolerate brackish water and relatively high temperatures and, during drought periods, may be capable of surviving in mud. The biology is poorly known but at Narrandera, New South Wales, they spawned in November at a water temperatures of 26°C hatching occurred in two days giving rise to larvae 1.7-2.5 mm in total length (Llewellyn, 1973). It is thought that it must have some special reproductive biology to be able to restock ephemeral waters, for example it may have specialised eggs or be able to burrow into moist soil and aestivate (Allen, 1982). Observations made in the Kimberley indicate that the fish withdraw into caves and underground water systems and from where they would be able to restock ephemeral waterways at the onset of the next wet season. They were sampled from Siggins Spring and widely seen. They are frequently found with the barred grunter, *Amniatabe percoides* (Günther) (Teraponidae), as at Siggins Spring.

Aquatic invertebrates

Crustacea

Syncarida

Of marine origin, syncarids are one of the oldest groups of freshwater fauna and the two evolutionary lines that independently invaded freshwater were the only ones to survive. The Bathynellacea probably occupied surface freshwater habitats in the Carboniferous and subsequently became restricted to living in the interstitial spaces in subterranean waters—95% of recent syncarids are strictly stygobionts (Schminke, 1986). They have limited dispersal ability and their occurrence in oligohaline and polyhaline waters is secondary (Schminke, 1981), hence their biogeography may provide useful information on past continental connections.

They became adapted to the interstitial stygofaunal habitats by neoteny and the Bathynellacea now attain sexual maturity at a stage that corresponds to the zoea in the development of primitive Decapoda (Schminke, 1981).

The most primitive Bathynellacea are found in southeast Asia and of the Parabathynellidae two lines extend from there, one through Europe, Africa and South America, and the other south via Australia also to South America—along both lines the genera become more and more apomorphic in their characters (Schminke, 1974). Syncarids are considered to be rare but this is probably due to their escaping attention by being subterranean—95% of recent syncarids are strictly stygobionts (Schminke, 1986). The biology of syncarids is virtually unknown.

Two new species of syncarid crustacea (H.K.Schminke, pers. comm.), belonging to two families (Bathynellidae and Parabathynellidae) were taken sympatrically in the groundwater of the Ord River Irrigation Area. One is a species of *Atopobathynella* sp. (Parabathynellidae).

The stygofauna of the Cape Range peninsula has mainly Tethyan affinities (Humphreys, in press, 1993d; Knott, 1993) in that the related taxa occupy tropical regions that would have been underwater prior to the sea level changes of the Miocene and thus correspond with the concept of Tethyan relicts given by Newman (1991). Only two of the described (or being described) taxa do not fit happily with these criteria *Milyeringa veritas* has unknown affinities, and the syncarid

Atopobathynella sp. nov. A (H.K. Schminke, pers. comm.; Parabathynellidae, Bathynellacea). Until recently the latter genus had a clearly Gondwanan distribution, being known only from southeastern Australia, New Zealand and Chile (Schminke, 1986). The recent finding of the genus in the arid (Barrow Island; W.F. Humphreys, unpublished) and monsoonal tropics of Western Australia (Ord River Irrigation Area) suggests that syncarids of the genus *Atopobathynella* may be expected throughout Australia.

Ostracoda

These tiny bivalve-like crustacea were collected from a number of wells, bores, cave pools and springs and are being examined by Professor Danielopol in Austria and Dr A. Baltanos in Spain.

Williams (1979) reported on a collection of ostracods from 13 localities in northwestern Australia—of the 16 species collected all belonged to known genera but six were undescribed; three genera were recorded for the first time in Australia and the range of several species was extended from eastern Victoria. We can expect the subterranean fauna to be less well known (Pesce, De Laurentiis and Humphreys, ms a, ms b).

Copepods

These tiny crustacea were collected from a number of wells, piezometers, bores, cave pools and springs in both the west and east Kimberley. They are being examined by Professor G. L. Pesce at University di l'Aquila, Italy.

Williams (1979) also collected calanoid copepods from northwestern Australia and recorded only four species; major range extensions were made for two species of *Diaptomus* and of *Boeckella triarticulata.* Such is the poor state of knowledge of the surface fauna and we can expect the subterranean fauna to be less well known ((Pesce, De Laurentiis and Humphreys, ms a, ms b).

Decapoda: Sundathelphusidae

The freshwater crab *Holthuisana transversa* (Von Martens, 1868)(Potamoidea: Sundathelphusidae) is found throughout northern Australia from the arid zone through to the monsoonal tropics. As water bodies recede with the onset of the dry season the crabs burrow into the ground maintaining contact with the water table or else the high humidity necessary for them to breath in air. Individuals become active in the wet season and they breed from October through November. The larval stages are suppressed and the young hatch 4-6 weeks later as miniature crabs (Maitland and Maitland, 1985).

The crabs were found widely in caves and they occurred in both free standing and running water, as well as in burrows in cave soils.

Decapoda: Atyidae

Although atyids have an ancient record, being known from the Cretaceous in Brazil, there are no recent marine representatives. When the family in Australia was last reviewed no atyids were recorded from Western Australia (Riek, 1953) but a number of new Australian taxa have since been described, including all the known troglobitic species (e.g. Holthuis, 1959, 1986; Williams, 1964; Bruce, 1992; Short, 1993).

Atyids feed by scraping the surface with specialised brushes on the chelae of the second and third pereiopods but *Pycnisia raptor* Bruce is a predator (Bruce, 1992). The obligate troglobitic shrimp fauna of Australia is found only in northern and Western Australia and includes six species (in the genera *Parisia*, *Pycnisia*, *Pycneus* and *Stygiocaris*). These are found at locations straddling the Kimberley, from the Katherine area, N.T., and the Canning Basin and Cape Range in W.A.

?*Parisia unguius* Williams were collected from 8K-1 where they occur in symaptry with, and are possibly the prey of, *Pycnisia raptor* (Bruc,e 1992).

The genus *Caridina* is found through much of the lowland southwest Pacific region with a few species known from highland areas (Short, 1993). *Caridina* sp. was taken in KN-1 but showed no marked stygomorphies, having well developed and pigmented eyes (L.B. Holthuis, pers. comm.). The genus occurs widely in the Kimberley (Williams, 1981) but was seldom found in caves.

Isopoda: Phreatoicidea (Frontispiece)

Those collected from Zebedee Spring—water temperature 35°C—are closely related to a South African species belonging to the family Amphisopidae (Mesamphisopinae) (G.D.F. Wilson, pers. comm., 1994). Genera within the Mesamphisopidae (*sensu* Bǎnǎrescu 1990) are now found with a disjunct distribution bordering the Indian Ocean and Arafura Sea—South Africa, southwestern Australia, and at two sites in northern Australia, Arhnem Land (Leichhardtian District) in the Northern Territory (Bǎnǎrescu, 1990), and the Kimberley District.

Phreatoicidea are the only group of Peracarida which is confined to freshwaters, although fossils of marine origin are known from the Permian of the U.S.A.—the evidence suggests that they evolved from the marine environment through brackish to fresh water. Phreatoicids are now restricted predominantly to surface freshwaters and are limited in their distribution to fragments of eastern Gondwana (Australia, New Zealand, South Africa and India).

No stygofaunal elements are known from South Africa (Knott, 1986) so can the Kimberley specimens be considered to be stygofauna? Subterranean phreatoicids are characterised by their habitat and morphology—they are blind; white; their body attenuated, vermiform; short abdominal epimera scarcely cover the base of the pleopod. The palm of the gnathopod often develops to massive size and there may be an elongation of the maxilliped portion of the head, especially in large males (*ibid.*). The Kimberley specimens clearly fit this description but the limits of their habitat is unknown as they were collected only from the outflow of a small spring. Phreatoicids are often found in headwater trickles in mountainous areas (Bănărescu, 1990), a description that fits precisely the Kimberley location.

Isopoda: Flabellifera
Tainisopus fontinalis and*T. napierensis* Wilson & Ponder, 1992 were recently described, respectively from the Oscar Range and the Napier Range (cave KN-1), and they represent a new family of flabelliferan isopods (G.D.F Wilson; pers. comm., 1994).

Specimens were collected from cave KO-1 but their identity has yet to be established (W.F. Humphreys; unpublished).

The Oscar Range and Plateau constitute the largest outcrop of limestone in the region and it is separated from the Napier Ranges by the Fairfield Valley (Jennings and Sweeting, 1963) overlain with superficial quaternary deposits (Playford and Lowry, 1966). The type locality of *Tainisopus fontinalis* Wilson & Ponder, 1992 is a spring in Winjana Limestone (reef facies) on the edge of the Oscar Plateau. This watercourse merges with Tunnel Creek *c.* 15 km downstream of the Tunnel where the recent specimens were collected. The two localities are 14 km apart but separated by the Fairfield Valley. The emergent reef from which the spring flows extends 27 km to the southeast where, in the upper reaches of Chestnut Creek, it joins the reef tending northwest towards the Tunnel, a total of *c.*

50 km. However, the narrow (200-500 m) Dingo Gap, filled with Quaternary deposits, completely bisects all elements of the emergent Devonian reef (the Winjana and Pillara Limestones and the Napier Formation) some 3-8 km south of the Tunnel (from maps in Playford and Lowry, 1966). There is no current connection within the emergent Devonian reef system between the two collection sites.

Terrestrial invertebrates

Mollusca

Camaenidae

A diverse assemblage of camaenid land snails occurs in the Ningbing Ranges with considerable microgeographic differentiation even at the generic level (Solem, 1981a, 1981b, 1985). This occurs both because the Ningbing Ranges are a series of limestone islands isolated on black-soil plains and enforced by both the annual wet season flooding and the late dry season burning (Solem, 1981b: 322-3) even within these limestone islands the topography is highly dissected. These factors appear to have a major influences on the patterns of local distribution and variation in the camaenid land snails in the ranges (Solem, 1981a, 1981b, 1985), however, the points of transition between genera do not coincide with the geographical boundaries apparent today (Solem, 1981: 425). This radiation is not only one of the most, if not the most, spectacular among the Australian camaenid land snails, but offers opportunities for the study of speciation and species interaction (Solem, 1981: 425).

The Ningbing Ranges contrast with the Napier Range in the Western Kimberley —that is for the most part it is an unbroken reef with sandstone ranges to the east and south that are basically snail-free (Solem, 1981).

Crustacea

Isopoda: Armadillidae

A new genus of terrestrial isopod, *Kimberleydillo* Dalens, 1993 (Armadillidae: Australiodillinae), was described from KO-1 (The Tunnel) and it is still the only location of the single known species, *K. waldockae* Dalens, 1993. The species has some troglomorphies, namely reduced pigmentation, translucent integument and elongated antennae (Dalens, 1993).

Philosciidae were present in small numbers in both the Ningbing Ranges and Jeremiah Hills. However, while Armadillidae were conspicuously common in the Jeremiah Hills, none was taken in any of the caves in the Ningbing Ranges, part of the same Devonian reef system just 20 km to the north. No reason can be advanced for this marked disparity.

Insecta

Blattaria: Nocticolidae

Cockroaches of the genus *Nocticola* were amongst the most common and widespread troglobitic animals found in the Kimberley caves. They were found in the Devonian reef complex of both the east and west Kimberley as well as in caves near Katherine in the Northern Territory. All are being described as a single new species of *Nocticola* sp. nov. (Roth in press). Three troglobitic species of *Nocticola* are now known from Western Australia; *N. flabella* Roth from Cape Range, and an undescribed species from Barrow Island and the Cape Range coastal plain.

Adult males of *Nocticola* may have fully developed tegmina and wings or their tegmina may be variably reduced and wings variously reduced or completely absent. Adult females are apterous. *N. flabella* males have reduced tegmina and the hind wings and eyes are absent; the females are also apterous and lack eyes.

Nocticola sp. nov. males also has reduced tegmina and the hind wings are absent but the eyes retain a few minute black ommatidia save for those from Cutta Cutta Cave in the Northern Territory in which the eyes are completely absent; the females are apterous and all lack eyes.

Epigean male *Nocticola* have wings but those from caves lack wings so that neither sex has great powers of dispersal. Males of *Nocticola* sp. nov. and *N. flabella* that inhabit deep caves completely lack of eyes, whereas in *Nocticola* sp. nov. that inhabit shallow caves or caves intermittently open to the light a few ommatidia are retained in adult males. It is possible that the retention of some ommatidia (? and light sensitivity) remains a selective advantage in the dispersive males in caves which are open intermittently to the light.

Two groups of *Nocticola* are distinguished by the presence or absence of a male tergal gland (Roth, 1988). All Western Australian species are troglobites and belong to the *simoni*-species group (tergal gland absent) found also in Queensland, the Philippines, Vietnam, Ethiopia, South Africa and Madagascar. The *ueno*-species group (tergal gland present) is known only from Queensland and the Ryukyu Islands.

Hemiptera: Reduviidae: Emersinae

A number of species of emersini are found in caves but they are not necessarily troglomorphic.

The discussion by Kemp (1924 cited in Wygodzinsky, 1966) on two species of emersini found only in caves is instructive.

> *At first site both..., with their narrow bodies and enormously long and slender antennae and legs, present every appearance of adaptation to a cavernicolous existence. This appearance is, however, deceptive, for both belong to a subfamily containing many out-door species, which is characterized by the great length of these appendages.... These two bugs...found themselves at the time of their immigration well suited to existence in the cave.*

Emersinae feed on soft bodies arthropods and their recorded prey include spiders and their eggs (they often inhabit spiders webs), small flies, aphids, bees and psocids, and they may be cannibalistic (Wygodzinsky, 1966).

Ploiaria (Leistarchini) is cosmopolitan, occurring even on oceanic islands.

Homoptera: Meenoplidae

One of the more diverse groups found in the caves of the Australian tropics are plant hoppers (Homoptera) of the fulgoroid families Cixiidae (especially the genus *Solonaima;* Hoch, 1988; Hoch and Howarth, 1989a, 1989b, 1989c) and Meenoplidae (especially the genus *Phaconeura;* Hoch, 1990, 1993). Indeed by 1989 North Queensland alone already had the highest concentration of cave-adapted Fulgoroidea in the world (Hoch and Asche, 1989).

Until 1990 only one cave adapted meenoplid was known in Australia, *Phaconeura pluto* Fennah (1973) from Nambung National Park in Western Australia (Fennah, 1973). Then four new species of *Phaconeura* were described from North Queensland caves (Hoch, 1990) and another (Hoch, 1993) from caves in the Cape Range of Western Australia (Humphreys, 1993a). Since then several more undescribed cavernicolous species of *Phaconeura* (H. Hoch, pers. comm.) have been found in the area of Cape Range and the Kimberley. Cave-adapted meenoplids in Australia have been found exclusively in limestone caves — outside Australia cave-adapted meenoplids are known only from the Canary Islands (Remane and Hoch, 1988) and Western Samoa (Hoch and Asche, 1988) where they are found in lava tubes (Hoch, 1990).

Meenoplids are typically found wandering over the substrate or feeding on fine growing roots of undetermined plants, probably often *Ficus*, usually on soil covered surfaces.

To explain the dispersal of the troglobitic species of *Phaconeura* between different but neighbouring towers of the Chillagoe Karst the nymphs were presumed to be attended by ants (Howarth pers. comm. in Hoch, 1990). This supposition has been confirmed from the Kimberley for in one cave (KNI-9) *Phaconeura* sp. nov. were found in groups on roots in soil cavities with ants of the genus *Paratrechina* sp. in attendance (the genus needs a full revision before species-level identification will be possible—S. Shattuck; pers. comm., 1994)—the ants were observed to become agitated when disturbed, to collect the nymphs, and to transport them both from surface root systems and from underground cells.

The ant genus *Paratrechina* is widely distributed, although they are much more common in eastern and northern areas of Australia (S. Shattuck; pers comm., 1994). *Saccharicoccus sacchari* (Cockerell) (Hemiptera: Pseudococcidae), the sugarcane mealybug, is consistently attended, both above and below ground, by ants including *Paratrechina* prob. *vaga* (Forel) which was observed carrying the mealybugs underground (Carver, Inkerman and Ashbolt, 1987). In addition *Paratrechina obscura* Mayr was involved in behaviour—removing mummies from nodes—which was interpreted as mutualistic (De Barro, 1990).

Coleoptera: Scarabaeoidea

Trox alatus was taken from KN-1 (Davey, 1980)—all Trogidae (Coleoptera: Scarabaeoidea), save for the introduced Holoarctic *Trox scaber* (Lawrence and Britton, 1991) have been transferred to the genus *Omorgus* (Scholtz, 1986a, 1986b). *Omorgus alatus* is known from four localities in northwestern Australia (*ibid.*). *Omorgus alatus* is the most distinctive and unusual of the Australian *Omorgus,* mostly robust, fossorial beetles, in having long, slender legs seemingly unsuited to burrowing; as they have mostly collected in caves and rockshelters the lack of robustness is possibly an adaptation to living in sheltered positions where burrowing is unnecessary (Scholtz, 1986). It has been collected at Katherine (N.T.), Kununurra, Argyle Downs and Napier Range.

The larval and adult beetles are facultative necrophages and are among the last of a succession of insects that invade carcasses. Four species have been recorded in caves or feeding on bat quano in hollow trees (Scholtz, 1986). Moisture and relatively high temperature seems to be necessary for activity.

Trechine beetles, a tribe of the Carabidae, which form such a dominant part of the cave fauna of temperate Australia (Ebberhard *et al.,* 1991), New Zealand (May, 1963), Europe, North America and Japan (Vandel, 1965), are lacking from the Australian tropical cave fauna.

Odonata: Anisoptera: Aeshnoidea: Aeshnidae

Shed larval skins of *Gynacantha nonolangia* (sic!) (= *G. nourlangie*) were reported to have been found in KN-1 which may prove to be the first evidence of breeding by a dragonfly in cave pools (Sands, 1989; Thompson, 1989a, 1989b). Thompson (1989a) considered that the energy source for the dragon fly larvae was undoubtedly bat droppings which also supported the gammarid shrimps (!).

In fact *Gynacantha nourlangie* regularly spend their daylight hours in caves in the Northern Territory (Watson and Abbey, 1980; see also Thompson and Kiauta, 1994) so that their breeding in the fauna rich pools in the twilight zone of KN-1 is not surprising—especially given the vast extent of the water in the cave (unknown to Thompson) and the presence there of a rich fauna including the atyid shrimp *Caridina* sp., the flabelliferan isopod *Tainisopus napierensis*, copepods, gastropods and 'vermes'.

Chelicerata

Schizomida: Hubbardiidae

Four undescribed species of schizomid were collected, belonging to the genus *Apozomus*, one from the Katherine area of the Northern Territory, one from the Oscar Range in the west Kimberley, and two from the Ningbing Ranges. The two species in the Ningbing Range occur in the same block of Ningbing Limestone but in separate promontories 10 km apart.

The Schizomida are represented by 5 genera in Australia of which *Apozomus* is the most speciose containing 14 of the 26 described species (Harvey, 1992; Harvey and Humphreys, 1994). The genus was known previously to extend from southeastern Queensland around the coast to the longitude of Darwin in the Northern Territory—a number of unidentified juveniles have previously been reported from the Kimberley vine thickets in coastal or near coastal areas (Harvey, 1992). The range is here extended across the Kimberley as far west as Tunnel Creek National Park in the west Kimberley. All other *Apozomus* spp. have been collected on the surface, mostly from leaf litter in rainforest.

The relationship between the cavernous (*Apozomus* sp. nov. 1 [cf. *A. mainae*]) and epigean species (*A. rupina* Harvey) from the Katherine karst area may shed some light on the process of evolution of the cavernous taxa.

Schizomid species are mostly known only from their type locality or their distributions are very confined (Harvey, 1992) — a large number of species probably awaits discovery. Only two other species of troglobitic schizomids has been described from Australia, *Draculoides vinei* (Harvey) known from Cape Range, and *D. bramstokeri* Harvey and Humphreys, 1995, known from the coastal plain of the Cape Range peninsula and Barrow Island.

Pseudoscorpionida

A number of pseudoscorpions was collected in the Kimberley from both cave and epigean habitats. they include the families Chthoniidae, Hyidae and Olpiidae. *Lagynochthonius* sp. nov. (Chthoniidae) from KNI-19 has distinct troglomorphies as does *Hyella* sp. nov. (Hyidae) from KNI-41. The status of the Olpiidae from the Oscar Range (KO-1) cannot be decided as it is a nymph.

The Hyidae contains three genera, *Hya* (known from Sri Lanka, Malaysia, Philippines and Indonesia), *Indohya* (known from Madagascar, India and Australia [Kimberley only]) and *Hyella*, the latter erected for a cavernicolous species, *H. humphreysi* Harvey, from Cape Range, Western Australia and by far the largest known hyid (adult body length 2.7 mm; Harvey, 1993).

Araneae: Theridiosomatidae

A small spider was found deep into the Aquarius extension of KN-1 inhabiting webs that were suspended just above the water surface—the webs were loose, flimsy and inverted dome-shaped that hung from the cave roof on few anchor lines. That collected was immature and cannot be placed with accuracy, possibly of the genus *Baalzebub,* but certainly of the family Theridiosomatidae. This family lives almost exclusively in wet or humid, shaded forest habitats. The neotropical genus *Plato* is troglophilic, while the mainly circumtropical genus *Theridiosoma* is common around cave entrances (Coddington, 1986), and in southwestern Australia the genus *Baalzebub*, which is in the same subfamily as *Theridiosoma*, is often found in the twilight zone of caves on webs suspended just above the substratum or stream surface. Web form in the family is diverse, ranging from complete orbs, through forms with anastamosing radii, to sparse networks, or none (*ibid.*).

Araneae: Filistatidae

Filistatid spiders are found only in the warmer regions of the world and include 12 genera, two of which occur in Australia where they are found in habitats as divergent as arid zone rangelands and rainforest. Their biology is poorly known—some species make small, irregular, cribellate sheet webs, with one to four more or less distinct funnel entrances; webs are found under loose bark (notably of *Eucalyptus* spp. associated with water courses), in leaf litter, under rocks and in caves (Gray, 1994).

The monotypic genus *Yardiella* is found only in caves on the Cape Range peninsula and is related to an northeast Indian species. The ancestors of *Yardiella* were presumably widespread in western Gondwana before the 130 million year old separation of India (*ibid.*).

The genus *Wandella*, containing 11 species, occurs throughout Australia, one of which, *W. pallida* Gray, is known only from its type locality, a cave in Devonian reef limestone cave in Jeremiah Hills (KJ-8). They have some troglomorphies being pale with very elongate legs. However, KJ-8 is a very open cave system developed in grikes and in many places is open to the surface.

Only one male was collected (from the type locality!) and so it is not possible to determine whether there is morphological separation between specimens from Jeremiah Hills and the Ningbing Ranges.

In Cape Range it is one of the few families with cave and epigean representatives but this does not suggest parapatric speciation as the species belong to different genera, respectively *Yardiella* and *Wandella*.

Araneae: Hersiliidae

Hersilia mimbi Baehr and Baehr, 1993, was described recently from Mimbi Cave (karst index number KL-5). Discussion with the collector shows that the cave designation is incorrect and should be Cave Spring (KL-1) several kilometers away but also on Mimbi Creek—the two caves are separated by a third, KL-4.

The genus *Hersilia* is a rather recent invader from the Oriental Region and belongs to the same species group as those in New Guinea. *H. mimbi* is known only from the type locality. The cavernicolous status of this species is unknown although it is distinguished from its epigean congener amongst other things by its longer legs and by being much lighter in colour with inconspicuous pattern (Baehr and Baehr, 1993), attributes often considered troglomorphies.

Araneae: Heteropodidae

The huntsman spider *Heteropoda cavernicola* Davies, 1994, has recently been described from the entrance chamber of KN-1—it is known only from the type locality (Davies, 1994).

Of the 38 species of Australian *Heteropoda* only two others have been collected from caves—in eastern Australia—and but one of the eight species of the heteropodid genus *Yiinthi* Davies, 1994.

Myriapoda

Diplopoda: Siphonophorida

Siphonophorid millipedes were taken from 8K-1. They have yet to be determined but will certainly be undescribed species.

Diplopoda: Polyxenida

Polyxenid millipedes in the family Polyxenidae were taken from leaf litter in the doline of KNI-29. They have yet to be determined but will certainly be undescribed species.

Diplopoda: Polydesmida

Polydesmid millipedes were taken from within 8K-1 and KNI-19 and from leaf litter outside KNI-19. They have yet to be determined but will certainly include undescribed species in the families Pyrgodesmidae and Paradoxosomatidae.

Chilopoda: Scutigerida

The long legged centipede *Allothereura lesueurii* was widely seen in caves but seldom collected —they are very fast—specimens were obtained from KJ-7 and KNI-19. This very large and widespread centipede occurs sparsely in caves but is not troglobitic as it is widely found outside caves, especially in the arid zone.

Discussion

The Ningbing Ranges are surrounded by a blacksoil plain overlying, at least in part, a limestone pavement as appears to be characteristic of limestone areas in northern Australia (Jennings and Sweeting, 1963a). On the evidence of the stream in Ningbing rockhole there are, at least in some places, caverns within this pavement. How extensive this system is unknown but it is clear evidence of a mesocavernous rock system (M.S.S., *milieu souterrain superficielle, sensu* Juberthie and Delay, 1981) which potentially could provide passages for truly cavernous species between the different limestone outcrops. It is the lack of such M.S.S. that has contributed to the diversity of the cixiid and meenoplid fauna found in the tower karst at Chillagoe in northeast Queensland (Hoch, 1990). However, the presence of two species of congeneric schizomids within the single southern block of the Ningbing Ranges suggests that the two large promontories within that block are isolated.

Chapter 5

National Estate significance

Current status of karst areas in the Kimberley

I provide a brief outline of the current status and/or recommendations that have been made for the karst areas of the Kimberley as part of a wide ranging review of nature conservation reserves in the Kimberley as a whole (Burbidge, McKenzie and Kenneally, 1991).

West Kimberley

Small areas of the Oscar and Napier Ranges have been declared national parks and are vested in the National Parks and Nature Conservation Authority, namely Geikie Gorge (3136 ha), Windjana Gorge (2134 ha) and Tunnel Creek (91 ha) National Parks.

The Conservation Through Reserves Committee (CTRC) recommended that-

> ... (a) *the W.A. Museum be requested to make a survey of caves with the objective of proposing a conservation programme for important sites, and (b) that a survey be made of springs with the objectives of designing small reserves and reconciling conservation requirements and pastoral usage.*

The Environmental Protection Authority (EPA) recommended

> ... *that the W.A. Museum, in conjunction with the Australian Speleological Federation, make a survey of caves in the Oscar Range and report to the EPA on their consideration* (sic) *and anthropological value, with a view to reservation.*

Additional karst areas have been recognised as requiring investigation. These are the Chedda Cliffs in the northern Napier Range:

> ... *that the Department of Conservation and Land Management investigate the conservation and recreation values of the Chedda Cliffs sector of the fossil reef and, after consultation with local Aboriginal people and the pastoral lease owners, make recommendations concerning its future status,*

and the Lawford Range at the southeastern end of the Devonian reef complex:

> ... *that the Department of Conservation and Land Management investigate the conservation and recreation values of the Lawford Range and surrounds and make recommendations as to its future status.*

East Kimberley

In the east Kimberley a number of reserves of various designations have been implemented or proposed. These are:

- Bungle Bungle National Park and Conservation Reserve (in place).
- Mirima (Hidden Valley) National Park (in place).
- Lake Argyle and Carr Boyd Range (proposed).
- Ord River Nature Reserve and False Mouths of the Ord (in place and proposed).
- Packsaddle Swamps (proposed).
- Parrys Lagoons Nature Reserve (proposed).
- Pelican Island Nature Reserve (proposed).
- Point Spring Nature Reserve (in place).

No areas of karst have been recommended for inclusion in reserves although the Ningbing Range (*sensu stricto*) has been recognised as requiring investigation—

> *... that the Department of Conservation and Land Management investigate the conservation and recreation values of the Ningbing Range and surrounding area and make recommendations as to its future status.*

In addition, some areas of sandstone country are relevant. Deeply incised rivers (e.g. Pentecost River by 300 m) act as groundwater drains and thus the topography controls the shape of the groundwater (Dow and Gemuts, 1969). Hence the fauna, such as phreatoicids, typically found at surface seepages, is likely to be isolated from adjacent sections of the ranges by the form of the groundwater. As such one can expect to find a species swarm of phreatoicids in the isolated sandstone massives of the east Kimberley, especially in the Cockburn Range. To this end the following recommendation is here pertinent—

> *... that the Department of Conservation and Land Management investigate the conservation and recreation values of the Cockburn Range and surrounds and make recommendations as to its future status.*

A recommendation for the conservation of many areas of the Devonian reef system of the west Kimberley was made in a submission by the Australian Speleological Federation (A.S.F.) in July 1978 to the then Western Australian Department of Conservation and Environment in the *Report of the Conservation Through Reserves Committee on System 7: the Kimberley*. An edited version of this submission was published without the maps (Davey, 1980).

I present below the verbatim summary of this submission (with its original numbering) because the submission was addressed specifically, and primarily, to the conservation of geological and geomorphological aspects of the Devonian reef system of the west Kimberley—as such little has changed in this context and no additional work has been conducted.

> *1. SUMMARY*
>
> *1.1 The caves and karst of the West Kimberley are of considerable international significance.*
>
> *1.2 The karst is of special interest because it occurs in an unusual geological context in the seasonally humid tropics. It exhibits many features which are found in very few other places in Australia and which are of international interest because of the mode of their occurrence and the clarity of their expression.*
>
> *1.3 Of all the outstanding karst features of the West Kimberley, the Conservation Through Reserves Committee appears to have recognized only a few key areas (Windjana Gorge, The Tunnel, Brooking Gorge, Geikie Gorge and Bungle Gap) and recommended reserves of only moderate size.*
>
> *1.4 The recommendations of the* Conservation Through Reserves Committee *do not adequately provide for the reservation and protection of many other important karst features, nor do they recognize outstanding opportunities to incorporate into existing reserves features nearby which would considerably enhance the value of those reserves.*
>
> *1.5 The recommendations of the Submission can be implemented without prejudice to the pastoral industry, and would not inhibit mineral exploration except at a few outstanding karst features of such small extent as to be quite insignificant from an economic standpoint.*
>
> *1.6 Several substantial additions to the existing Windjana Gorge, Tunnel Creek and Geikie Gorge National Parks, and a total of nine other reserves is proposed.*
>
> *1.7 All of the Reserves in the Limestone Ranges should be vested in and managed by the National Parks Authority.*
>
> *1.8 It is recommended that there be a thorough integrated survey of all the cave and karst features in the Limestone Ranges of the West Kimberley and that such a survey should examine geomorphological and biological attributes as well as aboriginal relicts.*

The Committee had recommended that the Western Australian Museum be requested to make a survey of caves and springs in the Oscar Range. The Australian Speleological Federation submission strongly endorsed this recommendation but added the proviso that the Western Australian Museum would then have needed considerable assistance in this complex task and also recommended that the survey be extended to cover the entire Limestone Ranges as well as the east Kimberley.

This survey has never been conducted save for the small section covered by this report for the east Kimberley and the associated brief reconnoitring trip through the west Kimberley.

The basic tenet of this submission applies also to the Devonian reef system of the east Kimberley—the Ningbing Ranges, Jeremiah Hills and sundry small outcrops. However, I would like to take up several points from this submission which need amplifying or which simply are incorrect. These concern the supposed lack of troglobite fauna, the sparsity and small size of the caves, and the protection of the springs.

Cave fauna

In contradiction of Davey (1980) the current work has shown that the Devonian reef system contains a significant fauna of animals adapted to varying degrees to subterranean life, either trogloxenes or troglobites. Overall the Devonian reef system of both the west and east Kimberley contain numerous troglobitic and epigean taxa that are endemic at the specific, generic or family level—some have been described but most await formal description.

West Kimberley

An endemic genus of terrestrial isopod *Kimberleydillo* Dalens, 1993; two species of a new family of flabelliferan isopods (G.D.F Wilson; pers. comm., 1994), *Tainisopus fontinalis* Wilson & Ponder, 1992 and *T. napierensis* Wilson & Ponder, 1992, respectively from the Oscar Range (also taken from cave KO-1, W.F. Humphreys; unpublished) and the Napier Range (cave KN-1).

Several genera and 36 species of camaenid (plus one pupillid) landsnails are endemic to the Napier Range, namely:- *Amplirhagada percita* Solem, 1981a, *A. napierana* Solem, 1981a, *A. burnerensis burnerensis* (Smith, 1894) and *A.. b. umbilicata* Solem, 1981a; the genus *Westraltrachia* Iredale is confined to the long, narrow curved strip that is the Devonian reef system of the west Kimberley—it is found from the extreme northwest tip of the Napier Range through to the Lawford Range, a distance of 245 km; none is known from even abutting non-limestone ranges. The genus includes 21 species which, with three exceptions, are allopatric with often narrow zones of species transition (Solem, 1984); *Mouldingia occidentalis* Solem, 1984 has a range of only 2.2 km on the eastern side of the Napier Range. The monotypic genus *Kendrichia* Solem, 1985 and three species of the genus *Kimboraga* (*K. mccorryi* Solem, 1985; *K. yammerana* Solem, 1985 and *K. micromphala* Solem, 1985) are endemic to small patches of the Napier Range (Solem, 1985). Five species in the genus *Rhagada* are endemic to the Napier (*R. mimika* Iredale, 1939 and *R. basedowana* Iredale, 1939) or the Oscar-Napier Ranges (*R. gatta* Iredale, 1939; *R. construa* Iredale, 1939; *R. sutra* Iredale, 1939: Solem, 1985). *Quistrachia monogramma* Ancey, 1898 is confined to the Oscar Range and the pupillid land snail *Gyliotrachela napierana* to the Napier Range (Solem, 1985).

East Kimberley

New species in the genera *Phaconeura* sp. nov. (Meenoplidae) and the cockroach *Nocticola* (Blattaria: Nocticolidae) are known from caves in the Ningbing area. Two undescribed species each of micro-whip scorpions (belonging to the genus *Apozomus* [Schizomida]) and pseudoscorpions (belonging to the genera *Lagynochthonius* [Chthoniidae] and *Hyella* [Hyidae]) are known from the Ningbing caves each with distinct troglomorphies. In addition the spider *Wandella pallida* Gray (Filistatidae) is known only from its type locality (KJ-8).

Three genera comprising 26 species of camaenid molluscs are endemic to the Devonian reef system (*Ningbingia* containing 6 species, *Turgenitubulus* containing 8 species and *Cristilabrum* containing 12 species; Solem, 1981, 1985) and numerous additional genera can be expected (Solem, 1985)—*Xanthomelon obliquirugosa* (Smith, 1894) is endemic to the Ningbing Ranges; *Mouldingia orientalis* Solem has a range of <0.5 km on limestone outcrops on Lissadell Station related populations were probably drowned by Lake Argyle on the many adjacent limestone outcrops (Solem, 1984); the genus *Ordtrachia* Solem, which includes four species, and the monotypic genera *Exiligada* Solem and *Prototrachia* Solem have only been taken from limestones within the Ord River catchment, mainly to the east of Lake Argyle and the latter in the Northern Territory (Solem, 1984).

Although the camaenid distribution includes many species isolated on islands of limestone scattered over camaenid free plains, many species distributional limits are in the middle of continuous cliffs and are thus biologically rather than geographically limited (Solem, 1984). The camaenid snails of the Devonian reefs of the Kimberley are remarkably diverse at both the species and generic levels— their small ranges and narrow zones of species transition make them exemplary for ecological and evolutionary research.

Caves

The report (Davey, 1980) details various overt and/or large karst features (surface solution sculpture, karst corridors and giant grikeland, marginal amphitheatres, tower karst, pediments, gorges and caves) and, as they are similar in the east Kimberley, these descriptions will not be repeated here with the exception of the less visible features, the caves, on which the report gives quite the wrong impression.

Several joint developed caves now have an horizontal extent of >10 km (KJ-8, KL-5), one outflow cave extends for the better part of one kilometer (KN-1) and numerous caves were visited that had substantial internal chambers and fine decoration. Clearly, detailed exploration of any of the Devonian reef systems will yield numerous caves, some of substantial dimensions and highly ornamented.

Springs

Protection of springs was proposed to safeguard the water while allowing carefully controlled access for stock (Davey, 1980).

Cliff foot caves are the most common caves in the Limestone Ranges and they are usually developed at or near spring outflows—their enlargement, or elongation along the cliff line, may result from cliff collapse and diversion of the springs which are themselves important sites for flora and fauna and often support rainforest elements. But, in addition, they are now known to be access points to a stygofauna, as yet barely known, of relict taxa including a new family of flabelliferan isopod, and, on the sandstones, a Gondwanan relic as represented by the phreatoicid isopod.

Tufa

Tufa deposits, including impressive tufa dams, are widespread on the Devonian reef systems of the Kimberley, being especially well developed on the eastern aspect of the Napier Range (Viles and Goudie, 1990). Tufas contain valuable palaeoclimatic information but they are soft and friable and so are exceptionally vulnerable to disruption by stock and people. Recommendations have been made (Viles and Goudie, 1990) to undertake studies of these valuable palaeoclimatic resources (W.F. Humphreys, S.M. Awramik and M.H.P. Jebb, unpublished).

Palaeontology

Caves, being relatively stable and of low energy, are important depositories of information on past climates, fauna and vegetation

Little palaeontological work has been conducted in the Kimberley caves (Glauert, 1921; Gorter and Nicoll, 1978; Hardman, 1884; McKenzie, 1981), although collections of fossil and subfossil bones have been made from caves in both the west and east Kimberley.

Fossil reptiles (?Pleistocene), now unknown in Australia, were collected from conglomerates *c*. 40 m above the Lennard River in Windjana Gorge (Gorter and Nicoll, 1978) from what would then have been a cliff foot cave.

There are of course more extensive studies of marine fossils in the limestones themselves (see references in Dow and Gemuts, 1969).

Palaeoclimatology

Caves provide protected repositories of the worlds natural and cultural history. Caves contain irreplaceable and datable records of biological, climatic and landscape history (e.g. table 3) and, not included in this report, cultural information from contemporary and prehistoric art and archaeological deposits.

Table 3: Palaeoclimate information obtainable from caves.

Temperature	Oxygen ^{18} of water trapped in speleothems
Rainfall	Speleothem growth rate
Age	Uranium series
	Palaeomagnetism etc.
Vegetation	Pollen trapped in speleothems
	Composition of troglobite fauna
Periodicity	Dated speleothem rings
Tectonic events	Composition and relations of troglobite fauna
Sea level changes	Age of drowned speleothems
	Composition of troglobite fauna

The heritage values of karst areas

The heritage values of karst are so numerous and varied (see Ford and Williams, 1989) that it may seem obvious that karst areas should be listed in the Register of the National Estate. However, to do so would not necessarily be judicious and it may be reasonable to balance the heritage values with the processes likely to lead to the degradation of karst heritage values to see if there is a subset of attributes more needing of protection.

However, as outlined below, karst landscapes have peculiar properties that require, above all other landscapes, an integrated approach to conservation and, if necessary, management. As such one may recommend without hesitation the incorporation of entire natural areas into heritage areas for the purpose of promoting their integrated conservation.

Karst areas are are exceptionally complex and integrated pieces of landscape where the surface geomorphology may be unrelated to the drainage patterns. Actions in one part frequently impinge on distant locations within the karst region and on unexpected targets—the hydrogeological factors are delicately balanced. This landscape integration and the problems that may be associated with it have been ably addressed recently by Kiernan (1988), in an Australian context, and in general by Ford and Williams (1989). In essence the landscapes are fragile and the structure and processes are easily disrupted—I echo entirely Kiernan's (1988) conclusions:

> - *Karst is a complex phenomenon.*
> - *Maintaining the hydrological system in a natural condition is the foundation of karst management.*
> - *Individual caves will still need management.*
> - *When in doubt apply first principles.*
> - *Karst is an important consideration for land managers.*
> - *Knowledge of the impact on karst of various forms of development remains inadequate.*
> - *The geography of Australian karst remains inadequately known.*
> - *Ad hoc development should be replaced by a moratorium on the non-essential development of Australias karst.*
> - *Important heritage values should be rigorously defended.*
> - *Despite limited study, it is already evident that the heritage significance of much of Australias karst is very high.*
> - *Australia's karst heritage should be a top priority.*

To which I would add the recommendations (Humphreys, 1994) that:-

1. A concerted study of stygofauna should be undertaken in Australia—the Australian stygofauna is barely known and they are an important component of

biodiversity and important indicators of, and contributors to, groundwater health. Indeed a recent major conference on groundwater pollution failed to mention groundwater fauna (AGSO 1993).

2. Waste water from irrigation should be recognised as a potential contaminant of groundwater that has heritage implications.

3. Development proposal on karst landscapes should be required to include consultation with appropriate specialist in karst terrain—these should include those with special knowledge of karst hydrology, biology, and waste and water management, as well as in engineering and landscape. Such expertise is uncommon in Australia. This should be considered at the earliest stages not least because karst landscape *per se* may have major financial implications to the project. There is a consistent failure of development projects to take cognizance of the implications of karstic landforms and their contained fauna (see the examples cited in Humphreys, 1994). Consultants should at least be familiar with, and take cognizance of, Kiernan's (1988) treatise.

It is not the purpose of this report to address the management of the karst areas examined, as has been done for some of the better studied karst areas (e.g. Davey, 1978)—indeed too little relevant land information is available from the east Kimberley. Kiernan (1988) recently addressed generally the management of Australian karst regions (soluble rock landscapes) and developed in some detail especially those factors likely to lead to the degradation of karst heritage values. While it is not the purpose if this report to identify factors threatening the structure of, or the processes necessary to maintain the integrity of, the karst areas examined, it is necessary that some comment be made on threatening processes clearly present in the area.

The Australian Speleological Federation considered evaluation criteria for the cave and karst heritage of Australia (Davey, 1984) and identified many key characteristics of caves and karst (table 4), with the scientific and recreational values placed in an international setting by Ford and Williams (1989). The criteria considered in table 4 do, to some extent, reflect the interests of the main contributors to the study (*ibid.*)—predominantly of an earth sciences and landscape management background—and reflects the period in which the work was produced (the body of the work was completed in 1978). In consequence there is rather little consideration of cave fauna, other than bats. Since that time the oft repeated

Table 4: Key characteristics of caves and karst—the heritage value may be derived from any combination of these or other attributes (from Davey, 1984).

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1. Rock type: age, stratigraphy/petrology, structure

e.g. aeolian calcarenites (dune limestones), various marine limestones bioherms, marbles calcretes, dolomites, basalt, acid volcanics, granite, evaporites, sandstone, quartzite, laterite alluvium etc.

2. Regional context

a) climate, past and present. b) relationship of cave or karst/pseudokarst area to surrounding rocks: stratigraphic, tectonic, structural. c) the nature of the karst e.g. impounded/free, bare/covered (subsoil/mantled), subjacent, relict, buried/exhumed, syngenetic/postgenetic. d) topography, available relief. e) surface ecology: soils, vegetation associations, etc.

3. Surface features

a) landscape features (a few metres to several kilometres in scale) e.g. gorges, natural bridges & arches, dry valleys, semiblind & blind valleys, steepheads, solution pipes, solution dolines, subsidence dolines, collapse dolines, cenotes, uvalas, poljes, streamsinks, springs, estavelles, tufa barriers & dams, hums, towerkarst, cockpit karst, conekarst, "tombstones", corridor karst; lava blisters, tumuli, barriers, lava canals, sinkholes, spatter cones, scoria cones, vents, etc. b) smallscale features (millimetres to several metres) e.g. ripples, fluting, bevels, runnels, grikes, pavements, wells, solution pans, rockholes, blowholes, etc.

4. Types and stages of cave genesis and modification

e.g. vadose seepage, vadose flow, nothephreatic and dynamic phreatic; subsidence, collapse breakdown; various combinations of these

5. Controls on cave morphology

e.g. bedding, lithology, stylolites; jointing, faults; dykes; successive water table levels; successive lava flows, relationship to point of eruption; weathering

6. Present cave morphology

e.g. streams, lakes, gours, siphons/water traps, passages, domed chambers, rockfalls, flat roofs, potholes, blind shafts, fissures, flatteners, scallops, wallchannel grooves, boxwork, spongework, anastamoses, deckenkarren, cave wall fluting, bellholes, wall pockets, mazes, rock pendants, volcanic vents, layered lava, lava stalactites and drips, lava level lines, ledges, benches

7. Hydrology, geochemistry and meteorology

physical and chemical state and dynamics of cave waters and atmosphere; e.g. crossing over of surface and underground drainage; differences between surface and underground catchments; breaching of surface divides by underground drainage; water chemistry: variation of streams/lakes and between streams, etc; air movements; co$_2$ concentrations; variations in humidity and atmospheric condensation; tidal variations.

8. Cave contents

a) clastic sediments e.g. entrance deposits; fluvial, lacustrine, cryogenic and exsudation deposits
b) biogenic deposits e.g. rockmilk, guano. c) speleothems e.g. columns, stalactites, stalagmites, helictites, flowstone, shawls, cave pearls, etc. d) aragonite, gypsum, halite, guano minerals and other noncalcite mineral deposits. e) flora and microorganisms. f) fauna (chiefly invertebrates and bats) e.g. trogloxene/troglophile/troglobite; species composition, abundance and life history; food chains; distribution; ecology. g) palaeontology— exposure of fossils in host rock—deposits of fossil & subfossil animal and plant remains.

9. Human use of caves

a) art: prehistoric/historic/contemporary. b) occupation: prehistoric historic contemporary. c) recreation, including wilderness. d) tourism. e) education. f) research. g) other special uses; e.g. religious, ceremonial, defence. h) other factors of cultural, historical or social significance.

10. Aesthetic attributes

a) of surface landscape and features. b) of cave: size, shapes, spaces, sounds, silence, colours, textures, contrasts. c) of speleothems and other features: size, shapes, forms, abundance, distribution, diversity, colours, contrasts.

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view that troglobites are uncommon in Australia (e.g. Moore, 1964; Hamilton-Smith, 1967) has been found to be so manifestly incorrect that a paper could, quite legitimately, be entitled *Environmental ecology of north Queensland caves: or why are there so many troglobites in Australia* (Howarth, 1988). The main areas that have been examined for cavernicolous fauna are Tasmania (Eberhard *et al.*, 1991), northeast Queensland (Chillagoe karst and Undara lava tubes e.g. Hoch and Howarth, 1989a, 1989b, 1989c; Howarth 1988), the Nullarbor (e.g. Richards, 1971) and Cape Range (e.g. Humphreys, 1993a, 1994).

It is now clear that many areas of Australia, especially within the tropics, are exceptionaly rich in cave adapted species and that many have very ancient affinities (papers in Humphreys, 1993a).

Cave conservation

The discovery of a cave starts a long process of degradation of the cave which is directly related to the number of visitors. The degradation of the cave may be subtle or gross, fast or barely perceptible but, even if the cave is accessed only by researchers, some decline in cave quality will occur (Spate and Hamilton-Smith, 1991).

Despite the remoteness of the east Kimberley and the sparse population of cavers, there has been significant degradation of some caves. This has resulted partly due to a lack of awareness of cavers not affiliated with caving clubs, as well as an attitude that caves belong to the finder. Such independent cavers often show considerable concern about 'their' caves—indeed the intent of their secrecy is to protect the cave—but they may have little specific awareness of the fragility of the systems they explore and do not profit from the exchange of information that is an integral part of membership of caving clubs, whether or not they are affiliated with the Australian Speleological Federation. Indeed the heritage value of a cave may be destroyed even before anything is recorded.

Recommendations

- The Jeremiah Hills and the Ningbing Range should be included in the Register of the National Estate and much of the area set aside for the protection of landscape, fauna and flora.

For karst scenery, recreation (caves and topography), aesthetic (spectacular scenery and fine surface micro- and macro-topography), cave fauna, epigean fauna (especially molluscs) flora (appendices B-29 and B-35)—it is clear from the evidence of artefact scatters and rock art that the area has major cultural significance but this attribute is not considered in this report.

- Caves need to be specifically considered when delimiting conservation and heritage areas as they may have special requirements for protection.

- A number of representative tufa deposits of each depositional type (see Goudie et al. 1990, figure 6) should be included in conservation areas.

- The sources of springs should be protected from trampling by stock and people, and springs should be surveyed for stygofauna.

The finding of phreatoicid isopods and a new family of flabelliferan isopods in the Kimberley stygofauna is a discovery of major biogeographic significance. It is likely that different sandstone and limestone massifs respectively contain different taxa and these should be surveyed to ensure adequate representation in conservation areas.

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The following includes the references cited in both the main body of the report and in the appendices.

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Appendix A

Locations visited

Locations visited

The locations sampled are listed below. Locations that are in the karst index have a code, such as KNI-5, in which the first letter denotes the geographical region, the second (and sometimes third) letter denotes the karst area followed by the cave number. All numbers in Western Australia would be prefixed by the state code of 6, hence 6KNI-5 is cave number five (5) in the Ningbing Ranges (NI) of the Kimberley District (K) of Western Australia (6). The 6 is left out for brevity—8 is the state code for the Northern Territory, L, O and N are the Lawford, Oscar and Napier Ranges respectively and J the Jeremiah Hills. The protocols involved are given in Matthews (1985).

Most features in the karst index are not named and in some cases the names used are simply fabricated or descriptive for ease of use.

The coordinates were determined to the nearest second but are here degraded to the nearest minute of arc to protect the sites. The full data are retained at the Western Australian Museum.

Karst index	Name	Latitude	Longitude
8K- 1	Cutta Cutta Cave	14° 35' S;	132° 25' E
KJ- 7		15° 27' S;	128° 44' E
KJ- 8		15° 26' S;	128° 44' E
KL- 1	Cave Spring	18° 44' S;	126° 04' E
KL- 5	Mimbi	18° 45' S;	126° 05' E
KN- 1	Old Napier Downs Cave	17° 14' S;	124° 39' E
KN- 3	Barnet Spring Cave	17° 06' S;	124° 33' E
KN- 8	Bull Cave	17° 26' S;	124° 58' E
KN- 9	Barnet Spring Gorge	17° 06' S;	124° 27' E
KNI- 7		15° 06' S;	128° 38' E
KNI- 9	Green Ant Grovel	15° 17' S;	128° 37' E
KNI- 13		15° 07'S;	128° 38' E
KNI- 19		15° 18' S;	128° 37' E
KNI- 21		15° 01' S;	128° 35' E
KNI- 27		15° 17' S;	128° 41' E

Karst index	Name	Latitude	Longitude
KNI- 29		15° 16’ S;	128° 39’ E
KNI- 30		15° 17’ S;	128° 39’ E
KNI- 31		15° 11’ S;	128° 37’ E
KNI- 32		15° 11’ S;	128° 37’ E
KNI- 33		15° 11’ S;	128° 38’ E
KNI- 34		15° 10’ S;	128° 37’ E
KNI- 35		15° 10’ S;	128° 21’ E
KNI- 36		15° 11’ S;	128° 38’ E
KNI- 37		15° 11’ S;	128° 38’ E
KNI- 38		15° 11’ S;	128° 38’ E
KNI- 39		15° 11’ S;	128° 38’ E
KNI- 40		15° 11’ S;	128° 38’ E
KNI- 41	Nefertitis Palace	15° 11’ S;	128° 38’ E
KO- 1	The Tunnel	17° 37’ S;	125° 08’ E
	‘Lost city’ Devonian reef	15° 26’ S;	128° 50’ E
	Big tufa	17° 35’ S;	125° 07’ E
	Black Rock Pool	15° 48’ S;	128° 40’ E
	Blowing tube	15° 28’ S;	128° 45’ E
	Bow River Production Bore #2	16° 37’ S;	128° 38’ E
	Bow River Production Bore #3	16° 37’ S;	128° 38’ E
	Bow River Production Bore #4	16° 37’ S;	128° 38’ E
	Bream Gorge	17° 15’ S;	128° 18’ E
	Bream Gorge	17o 16’ S;	128° 16’ E
	Brolga Spring Bore	14° 54’ S;	128° 34’ E
	Camp at KNI-19	15° 18’ S;	128° 39’ E
	Camp South Ningbing	15° 17’ S;	128° 39’ E
	Cattle Creek Well	16° 57’ S;	128° 29’ E
	Cave	16° 40’ S;	128° 31’ E
	Cave	15° 01’ S;	128° 35’ E
	Cave below rockshelter	17° 25’ S;	124° 59’ E
	Cave Spring	15° 32’ S;	128° 50’ E
	Daintree (Pilbara)		
	Dry bore	15° 33’ S;	128° 43’ E
	Eight Mile Well	15° 19’ S;	128° 39’ E
	Frank Wise Institute	15° 39’ S;	128° 42’ E

Karst index	Name	Latitude	Longitude
	Golf Course Bore	15° 47' S;	128° 43' E
	Killarney Bore	16° 06' S;	128° 16' E
	Limestone Well	14° 29' S;	128° 44' E
	Lissadell #2 bore	16° 46' S;	128° 30' E
	Mataranka Spring	14° 55' S;	133° 08' E
	Middle Springs	15° 38' S;	128° 40' E
	Mimosa? site	15° 17' S;	128° 41' E
	Ningbing camp	15° 02' S;	128° 36' E
	Ningbing Rockhole	15° 17' S;	128° 38' E
	Number 8 Bore	14° 58' S;	128° 36' E
	Old Lissadell Bore #5	16° 37' S;	128° 36' E
	Palm Well	17° 59' S;	127° 48' E
	Piezometer HI 3/78	15° 42' S;	128° 41' E
	Piezometer PN6D	15° 39' S;	128° 45' E
	Piezometer #11 RDB	15° 37' S;	128° 42' E
	Piezometer #64	15° 38' S;	128° 44' E
	Piezometer #81	15° 41' S;	128° 44' E
	Piezometer #82	15° 41' S;	128° 44' E
	Piezometer #83	15° 41' S;	128° 44' E
	Piezometer #84a	15° 41' S;	128° 44' E
	Piezometer Boschamber deep #103	15° 37' S;	128° 45' E
	Piezometer Boschamber shallow #104	15° 37' S;	128° 45' E
	Piezometer PB1	15° 38' S;	128° 45' E
	Piezometer PB1M1-1	15° 38' S;	128° 45' E
	Piezometer PN5D #65	15° 38' S;	128° 44' E
	Piezometer VEPL deep #106	15° 37' S;	128° 45' E
	Piezometer VEPL shallow #105	15° 37' S;	128° 45' E
	Piezometer, new DOME	15° 33' S;	128° 48' E
	Pillara Bore	18° 19' S;	125° 47' E
	Pinbilly Well	18° 44' S;	126° 04' E
	Rockshelter	17° 27' S;	125° 00' E
	Sandstone cave	15° 57' S;	128° 43' E
	Siggins Spring	15° 17' S;	128° 39' E
	Tanmura Bore	15° 06' S;	128° 38' E
	Tickalara Well	17° 24' S;	127° 46' E

Karst index	Name	Latitude	Longitude
	Tufa waterfall cave	17° 26' S;	125° 00' E
	West of production bores	15° 47' S;	128° 43' E
	Whale Mouth Cave	17° 16' S;	128° 16' E
	White waterfall	16° 46' S;	128° 44' E
	Zebedee Springs	16° 00' S;	128° 01' E

Appendix B

Photographs

Photographs are by Bill Humphreys unless otherwise credited.

Figure 1:	Karst terrain.
Figures 2 and 3:	Cave entrances.
Figure 4:	Cave entrance and terrain.
Figures 5 to 7:	Karst features.
Figure 8:	Cave chambers.
Figure 9:	Speleothems.
Figure 10:	Tufa deposits, calcite rafts and bedding planes.
Figures 11 to 13:	Speleothems.
Figure 14:	Plants.
Figure 15:	Sampling animals.
Figure 16:	Animals.
Figure 17:	Caves.

Figure 1:

Upper left— View towards the Onslow Hills from the top of the southern Ningbing Range: Bill Humphreys in foreground. Photo— Darren Brooks.

Middle right— Vertical face of the Ningbing Range rising abruptly from the planation surface covered by black soils.

Lower left— Karst features on top of the Ningbing Ranges.

Lower right— Spitzkarren, rillenkarren and solution basins, Ningbing Range.

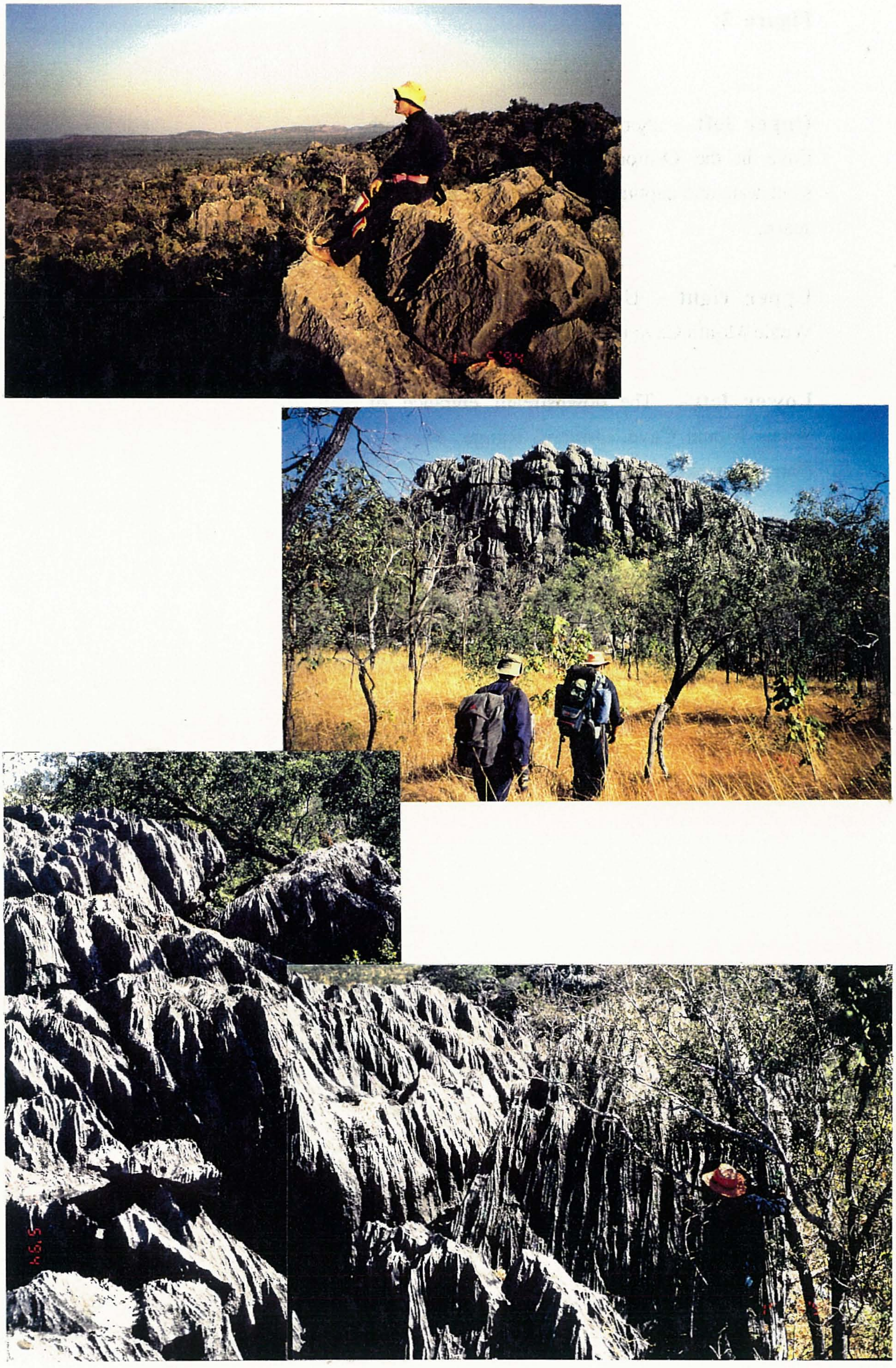
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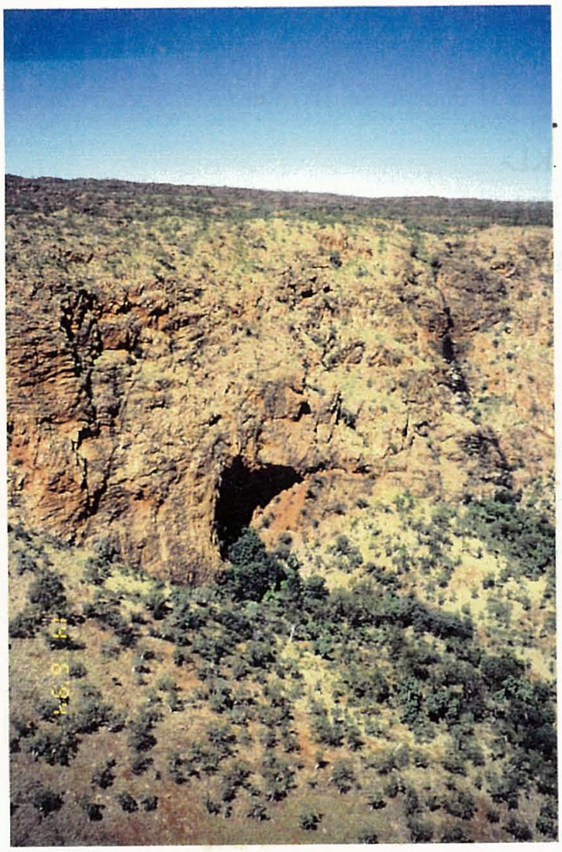
Figure 2:

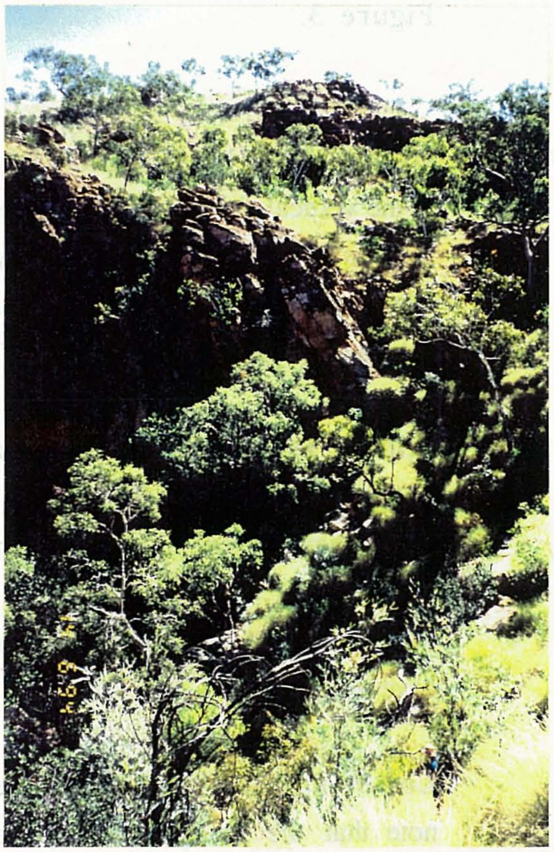
Upper left— Aerial view of Whale Mouth Cave in the Osmond Range: the cave is in sandstone and captures a stream at the top of the scarp.

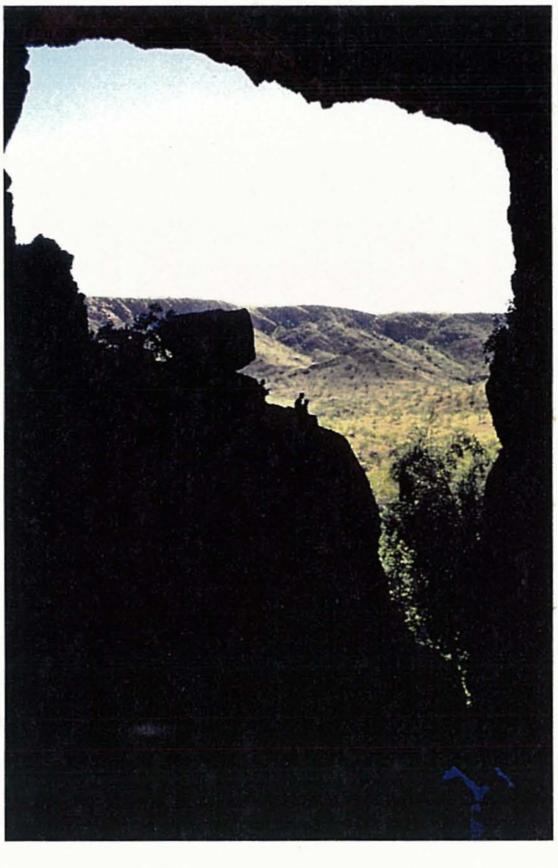
Upper right— Upper (inflow) entrance to Whale Mouth Cave in the Osmond Range.

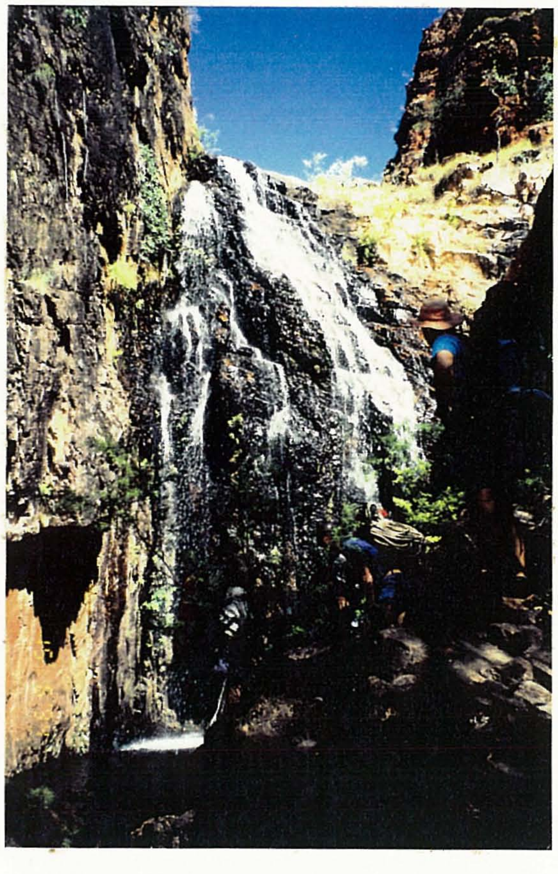
Lower left— The downstream entrance of Whale Mouth Cave, Osmond Range. Photo— Darren Brooks.

Lower right— Waterfall in Bream Gorge, Osmond Range covering a small cave; (L to R) Darren Brooks, Brian Vine and Wendy Binks.









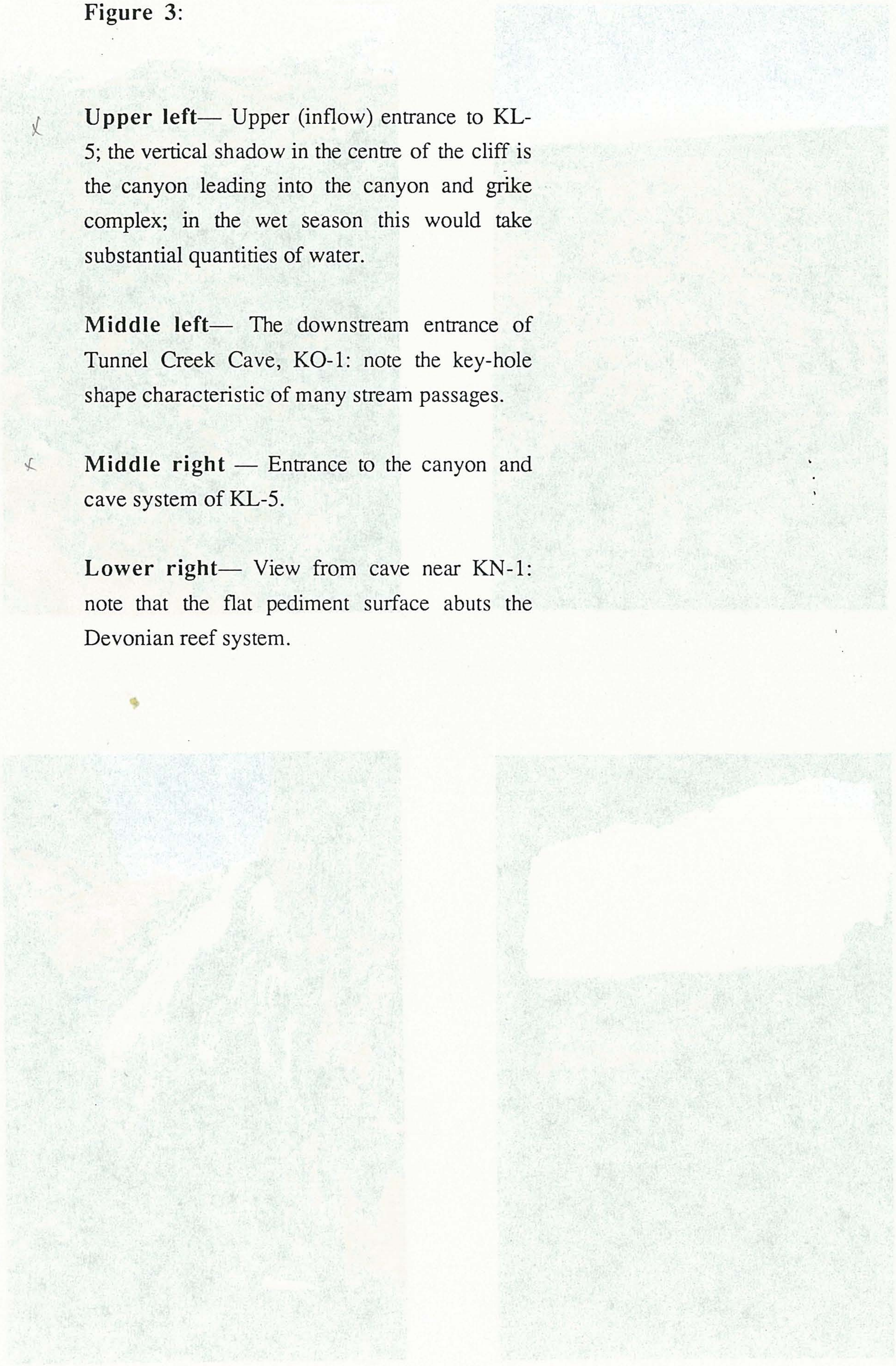


Figure 3:

Upper left— Upper (inflow) entrance to KL-5; the vertical shadow in the centre of the cliff is the canyon leading into the canyon and grike complex; in the wet season this would take substantial quantities of water.

Middle left— The downstream entrance of Tunnel Creek Cave, KO-1: note the key-hole shape characteristic of many stream passages.

Middle right — Entrance to the canyon and cave system of KL-5.

Lower right— View from cave near KN-1: note that the flat pediment surface abuts the Devonian reef system.

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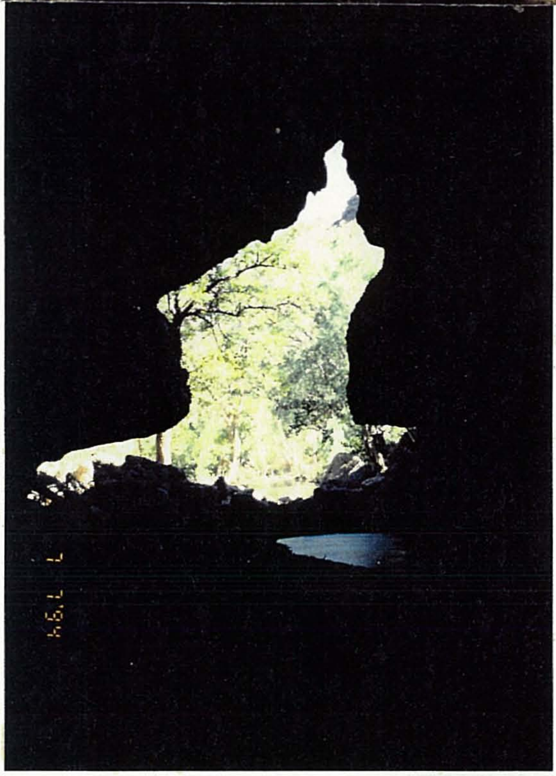

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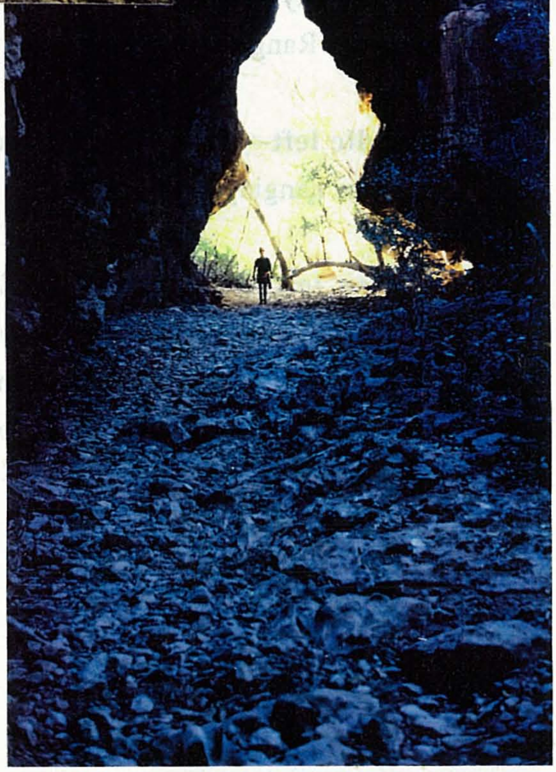


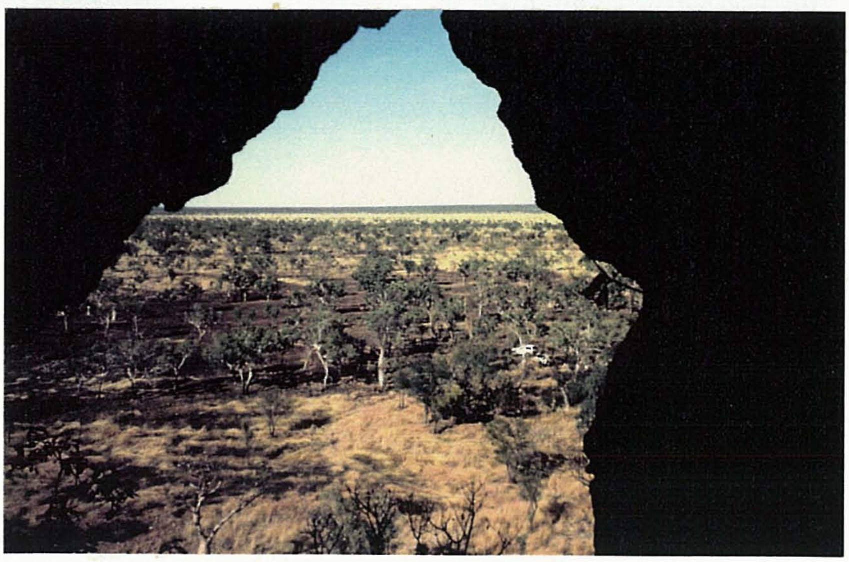


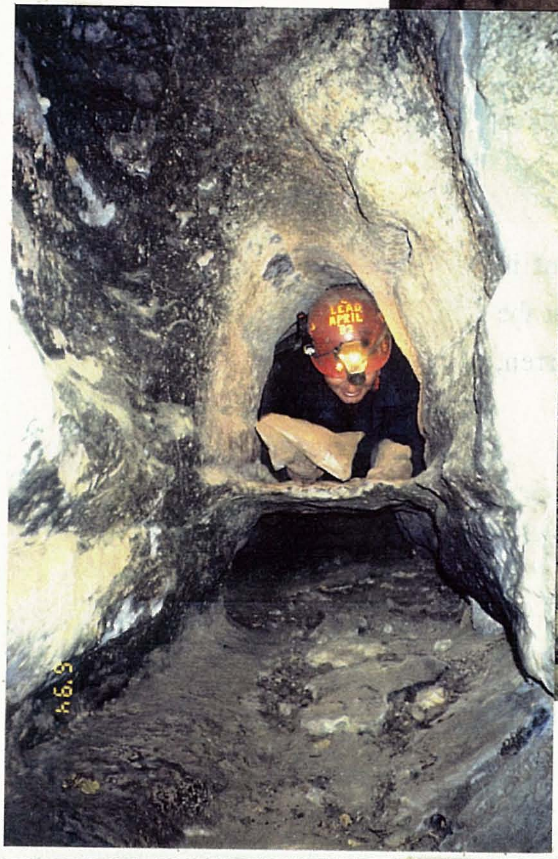
Figure 4:

Upper right— Osmond Range from camp site showing the richly coloured sandstones; this is the view to the south of the previous photograph. Photo—Brian Vine.

Middle right— Aerial view of the thinly bedded steeply dipping outcrops of the Archaean or Proterozoic limestone and dolomite of the Olympio Formation to the north of Osmond Range.

Middle left— Horizontal entrance of KNI-41; note the hanging floor.

Lower left— Entrance of KJ-8 showing the reflective cave number tag to the left of the photograph; Brian Vine (right) and Bill Humphreys. Photo—Darren Brooks.



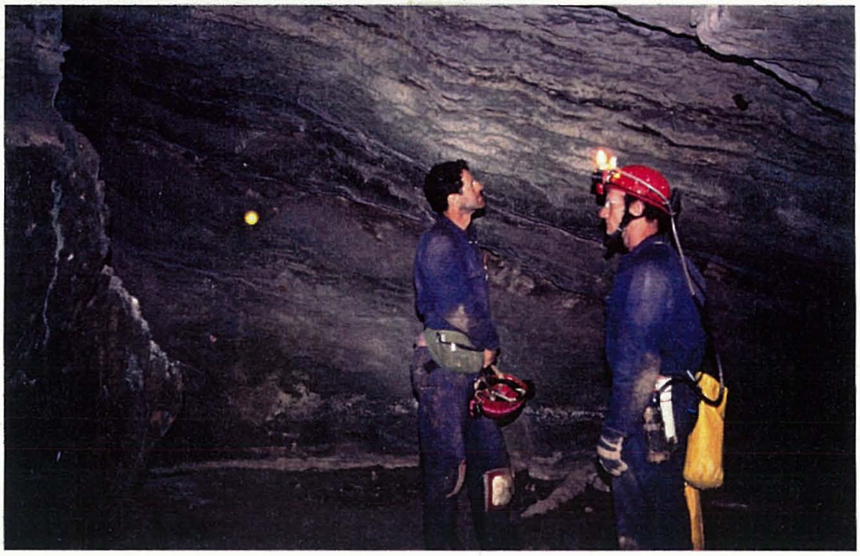


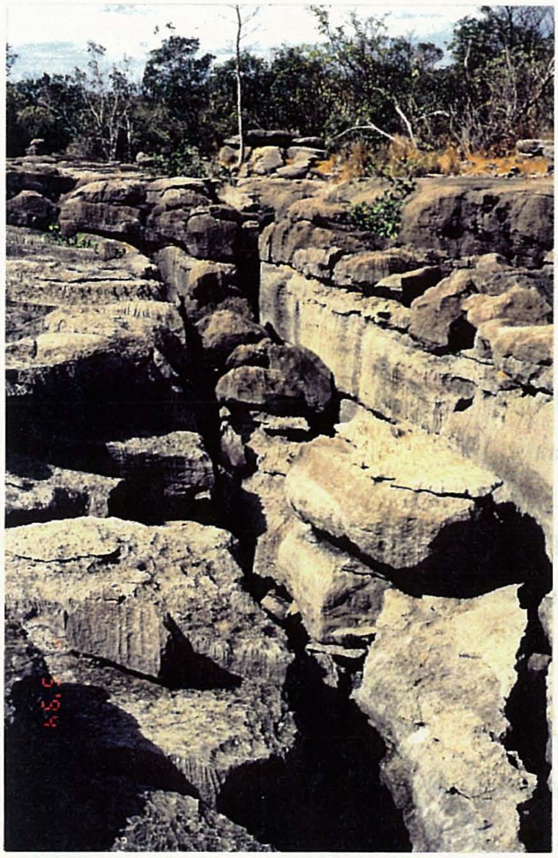
Figure 5:

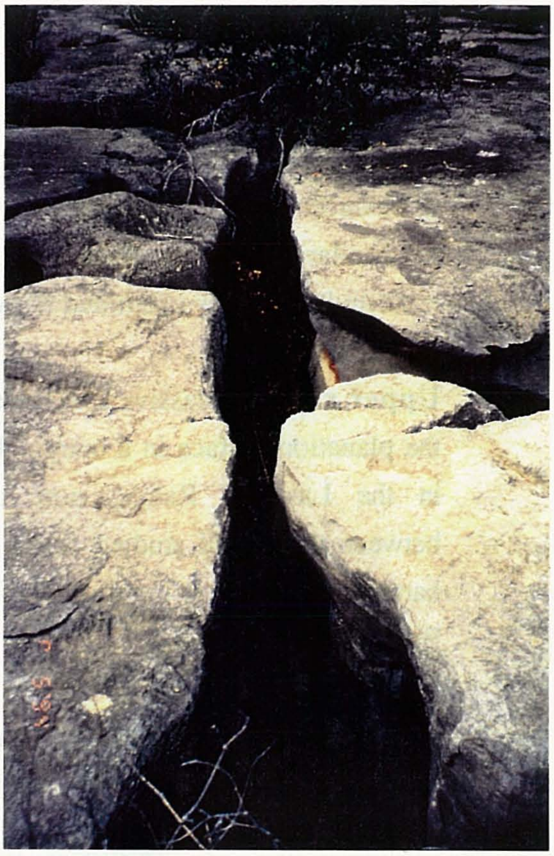
Upper left— Giant grike (bogaz) development in the Ningbing Range; these crevices are several metre across and up to 40 m deep.

Upper right— Giant grike (bogaz) development in the Ningbing Range; these crevices are several metre across and up to 40 m deep.

Middle left— Limestone pavement and grikes in marginal amphitheatre, Ningbing Range.

Lower right— Detail of karst development in the Septimus Limestone (sandy limestone) at the foot of the Burt Range; note the rundkarren, typically a subsoil development.





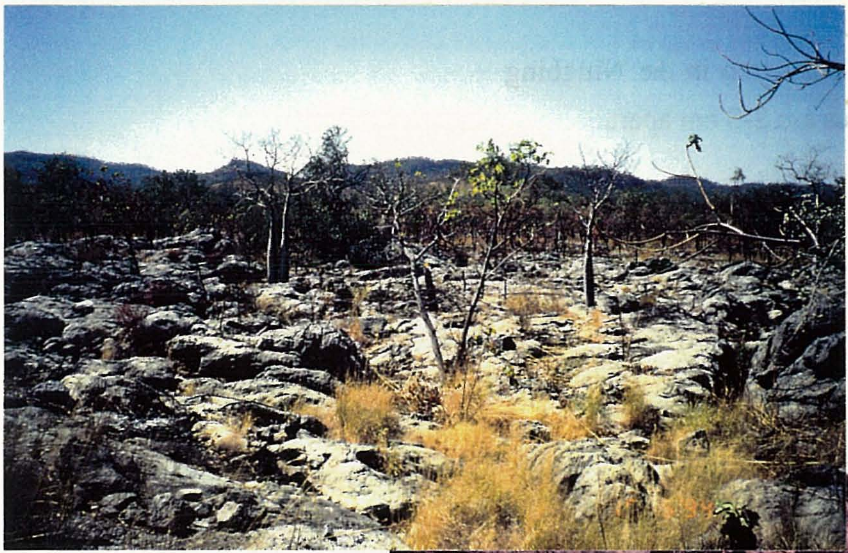


Figure 6:

Upper left— Tower karst with spitzkarren and rillenkarren on Napier Range above KN-1; note the similarity between these well studied fossil reefs and the barely examined Ningbing Range.

Upper right— Massive limestones rising from the planation surface in a marginal amphitheatre in the Lawford Range; note the similarity between these well studied fossil reefs and the barely examined Ningbing Range. Photo— Brian Vine.

Lower left— Rillenkarrren on the vertical faces and rainpits on the horizontal faces; Ningbing Range.

Middle right— Rillenkarrren in the Ningbing Range; the sharp flutes are 2-3 cm apart.

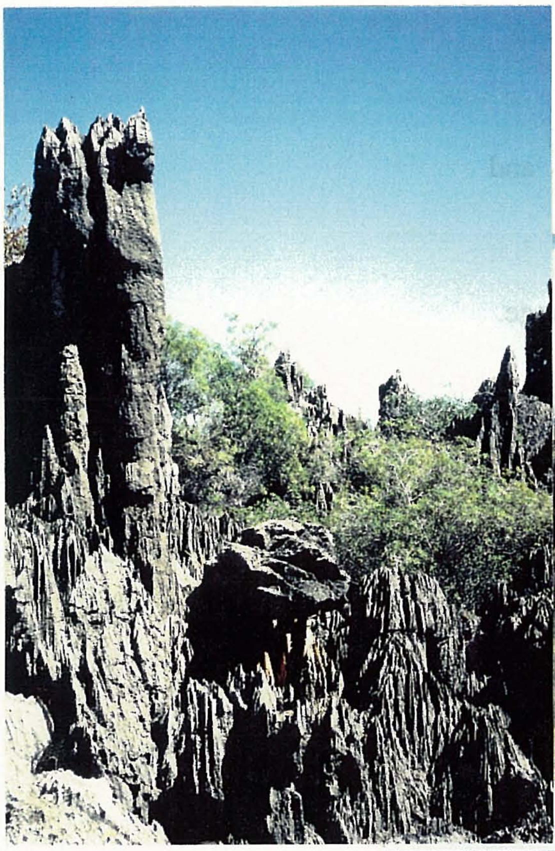


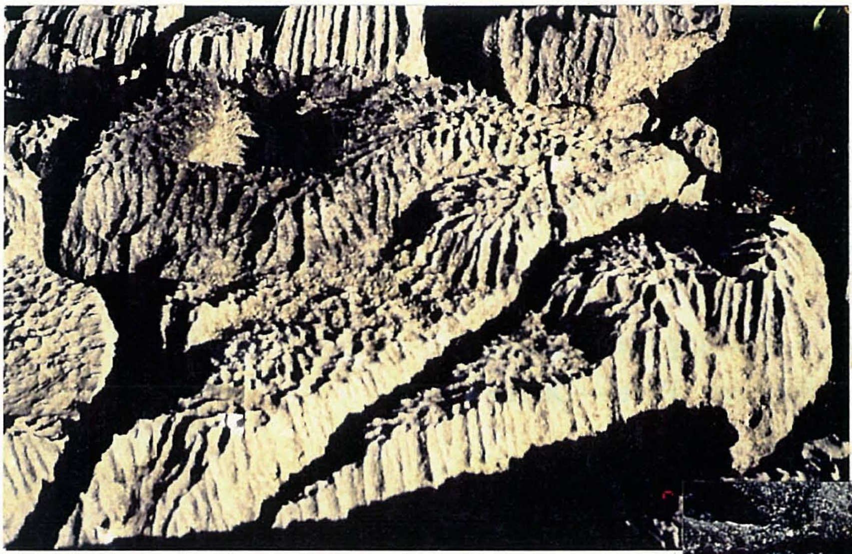
Figure 7:

Upper left— Rillenkarrren, rainpits and grikes; Ningbing Range.

Middle left— Rillenkarrren; Ningbing Range.

Middle right— Rillenkarrren and rainpits; Ningbing Range.

Lower— Rillenkarrren and rainpits; Ningbing Range.



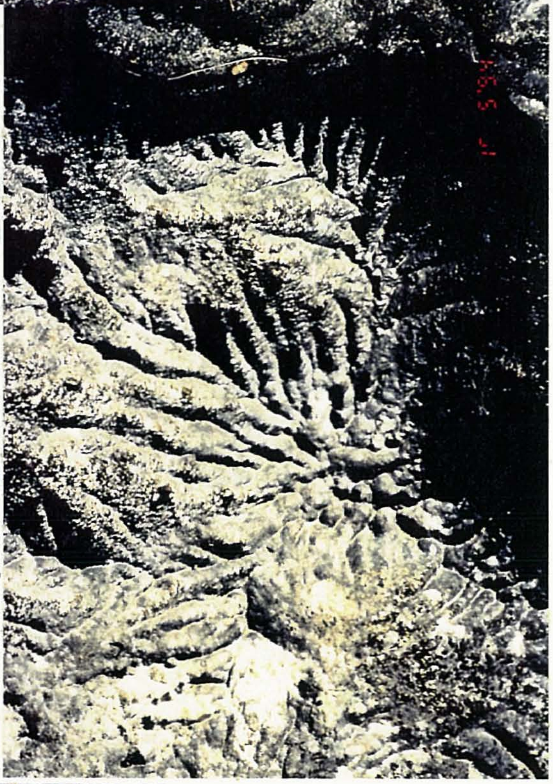


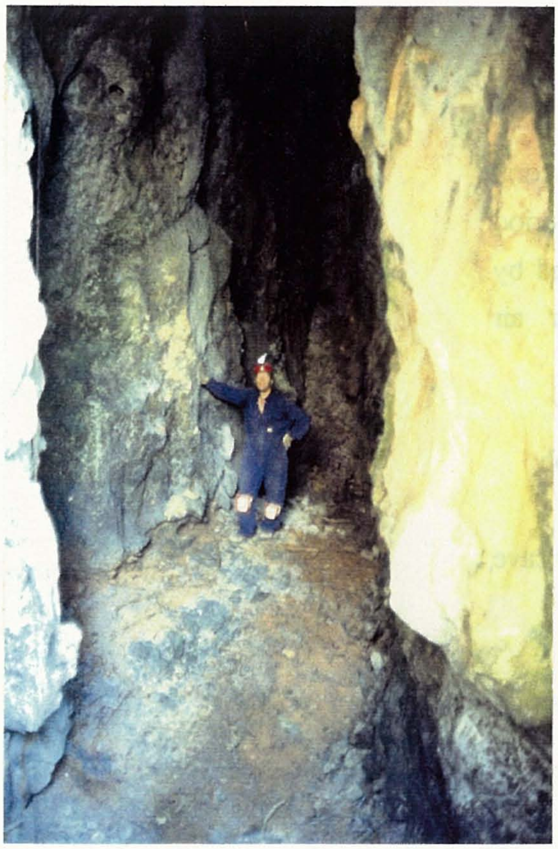
Figure 8:

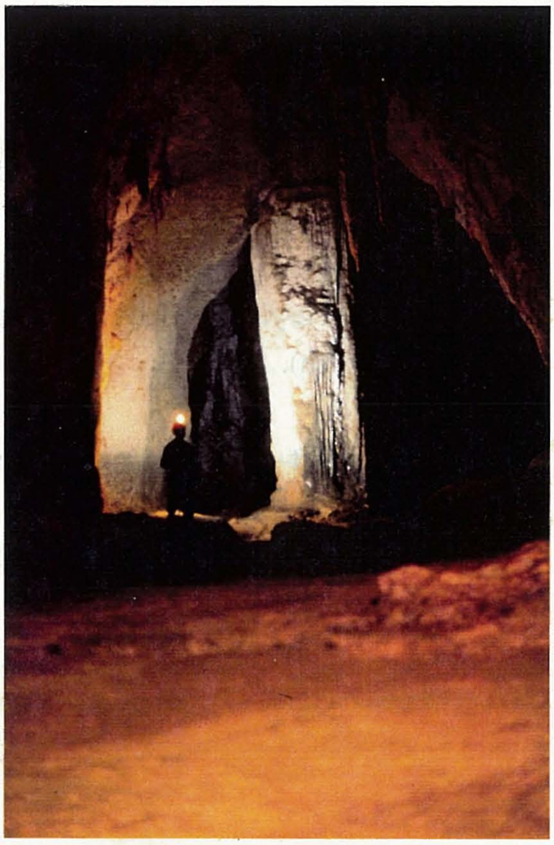
Upper left— Bill Humphreys in unnumbered cave on the top of the central Ningbing Range. Photo—Darren Brooks.

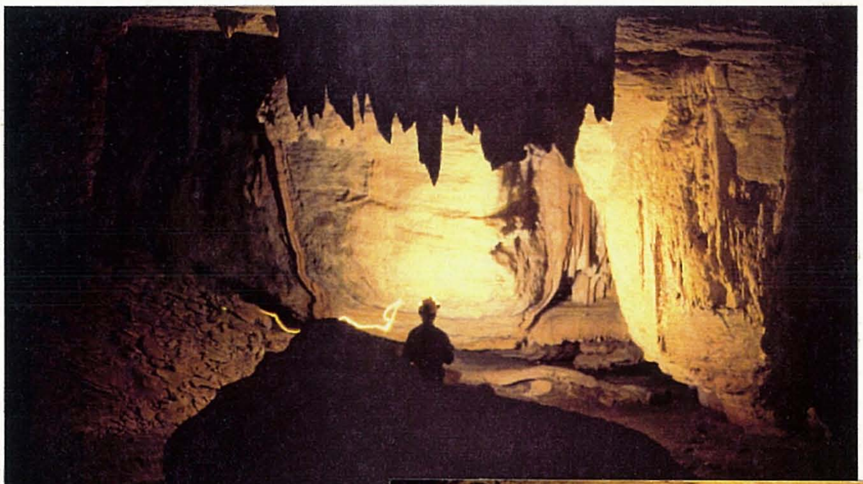
Upper right— KL-5 showing the massive rectilinear structure of the cave. Photo—Darren Brooks.

Lower left— Brian Vine in the main chamber of KJ-8. Photo—Darren Brooks.

Lower right— Brian Vine in the main chamber of KJ-8; this is contiguous with the previous view. Photo—Darren Brooks.







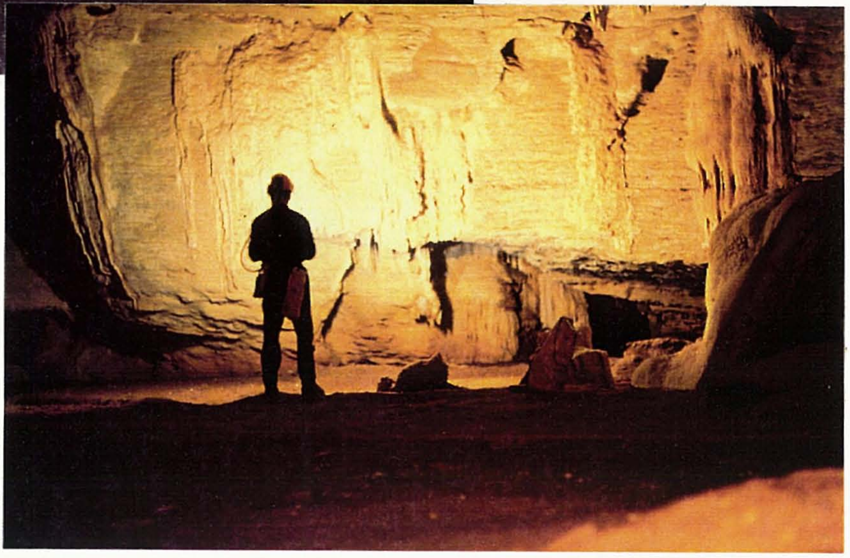


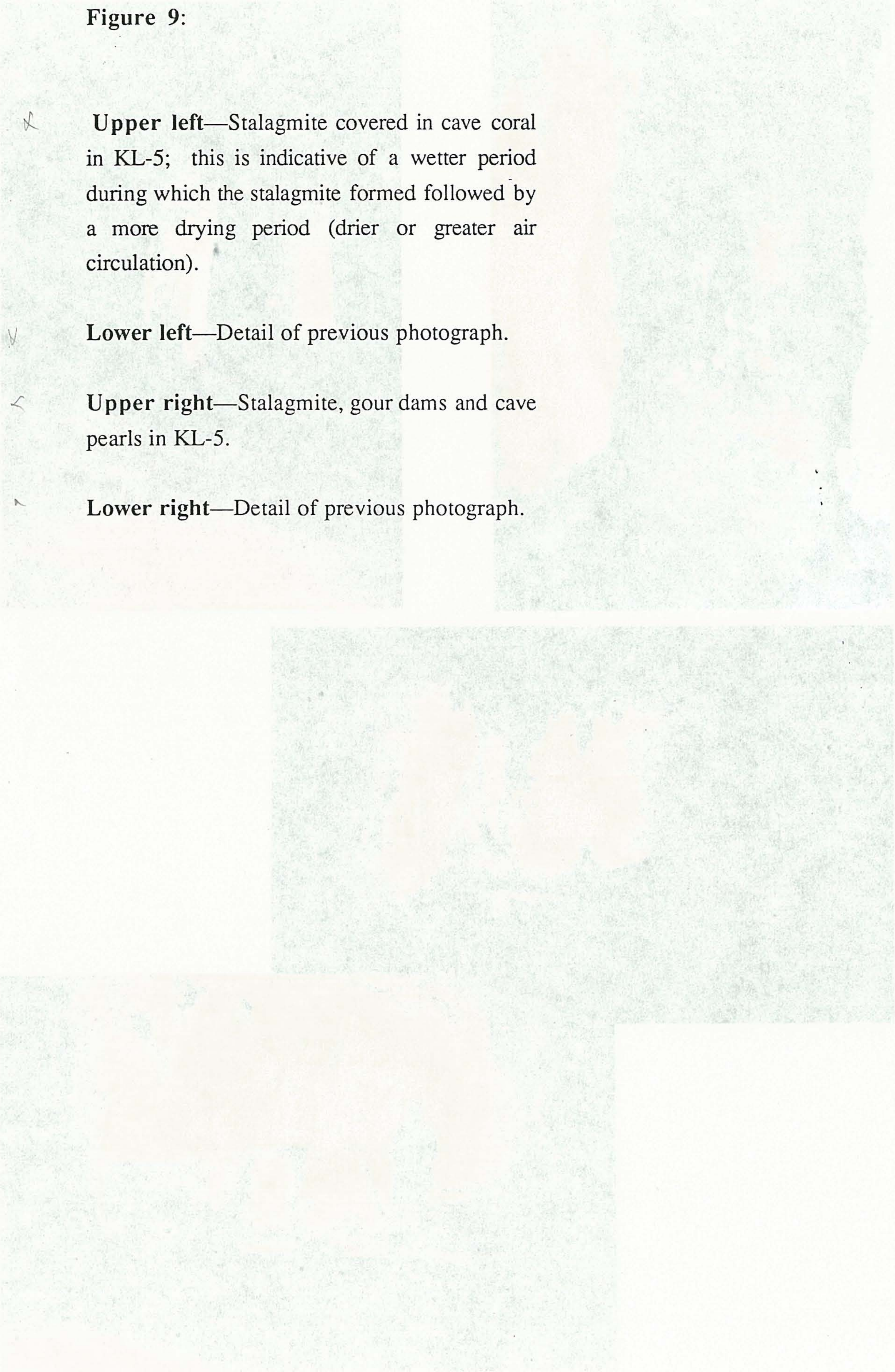
Figure 9:

Upper left—Stalagmite covered in cave coral in KL-5; this is indicative of a wetter period during which the stalagmite formed followed by a more drying period (drier or greater air circulation).

Lower left—Detail of previous photograph.

Upper right—Stalagmite, gour dams and cave pearls in KL-5.

Lower right—Detail of previous photograph.



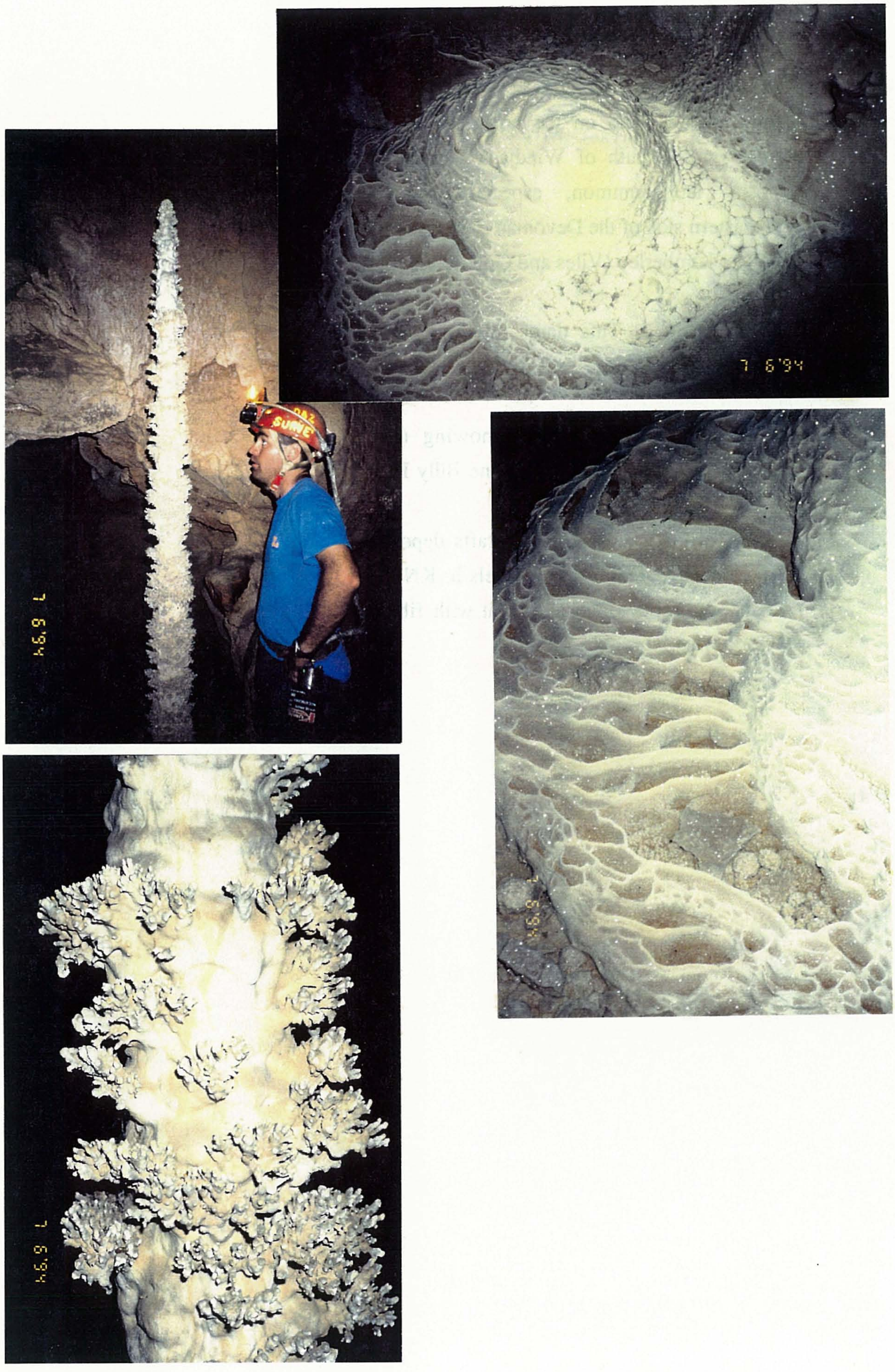

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Figure 10:

Upper left— Tufa on the north side of the Napier range, south of Windjana Gorge; tufa deposits are common, especially on the northeastern side of the Devonian reef system of the West Kimberley (Viles and Goudie 1990).

Upper right — Tufa dams in gorge at the north of Napier Range.

Lower right— Quarry face showing thinly bedded limestones in the Limestone Billy Hills.

Lower left— Bands of calcite rafts deposited on mud bank by falling water levels in KNI-19; note the tree roots to left and right with fibrous network of aerial roots.

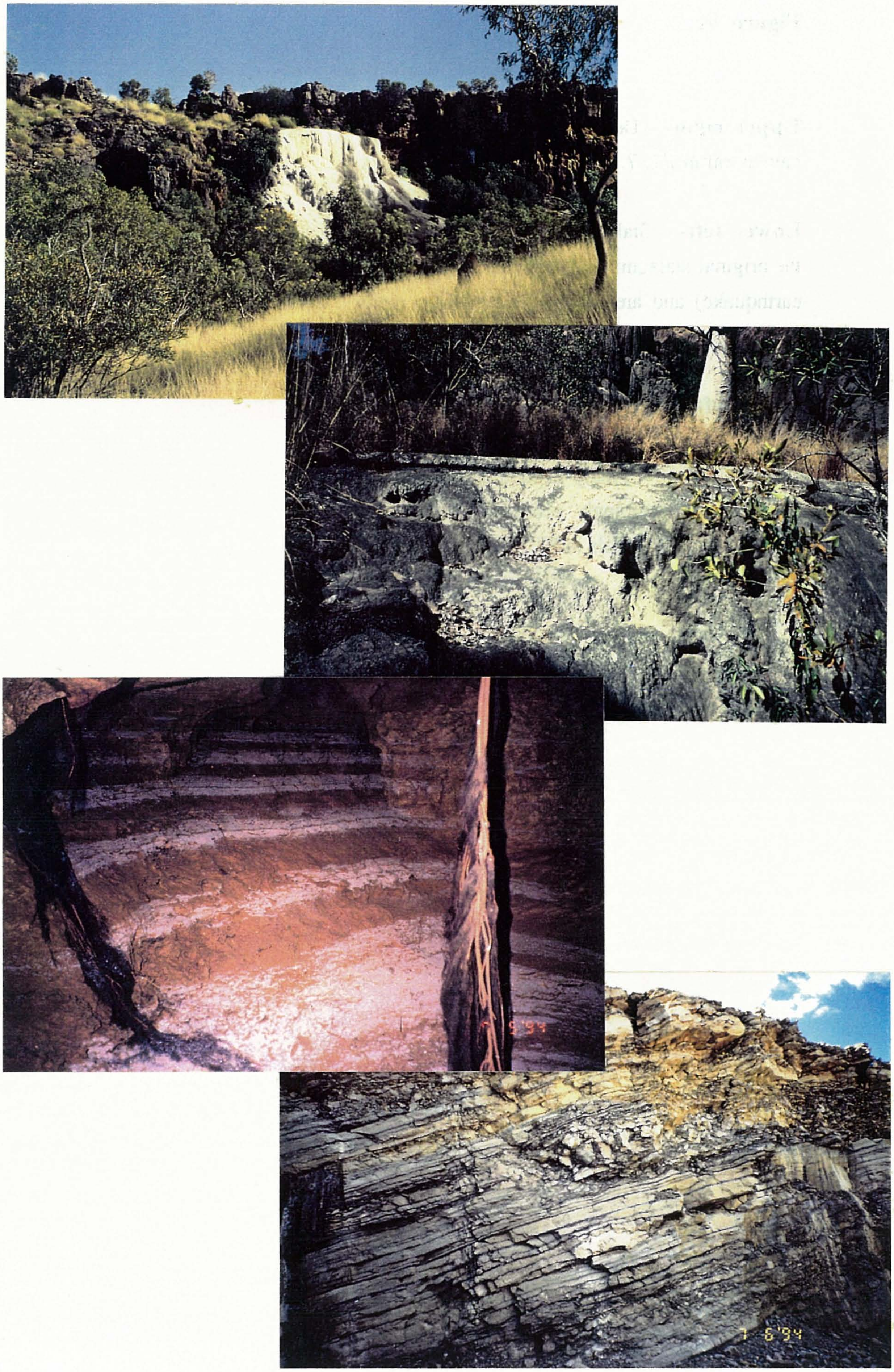
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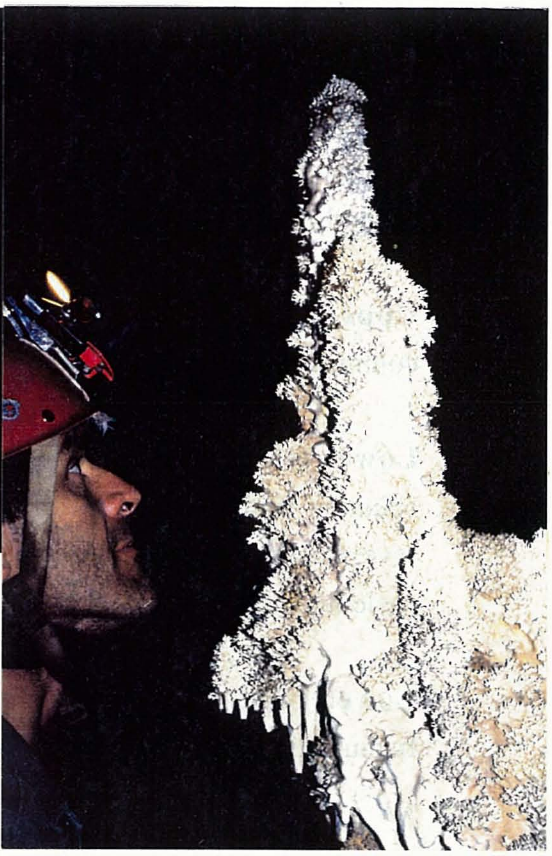
Figure 11:

Upper right— Detail of stalagmite covered in cave coral in KL-7. Photo—Darren Brooks.

Lower left— Stalagmites in KL-5; note how the original stalagmites have sheared (? from an earthquake) and are growing again from many foci.

Upper left— Flowstone in KNI-9.

Lower right— Finely eroded edge (? of a speleothem) seemingly formed from two intersecting swirl pools in ~~KL-5~~. Photo—Darren Brooks.
KN1-41

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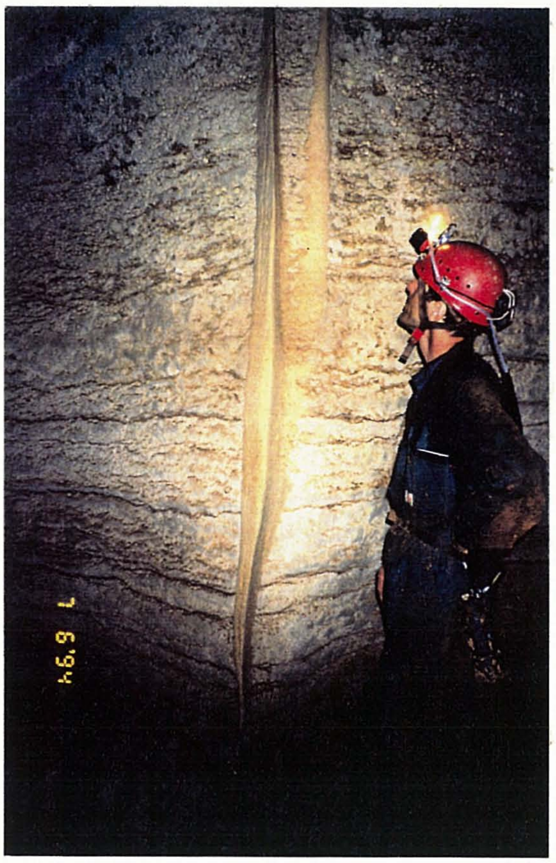
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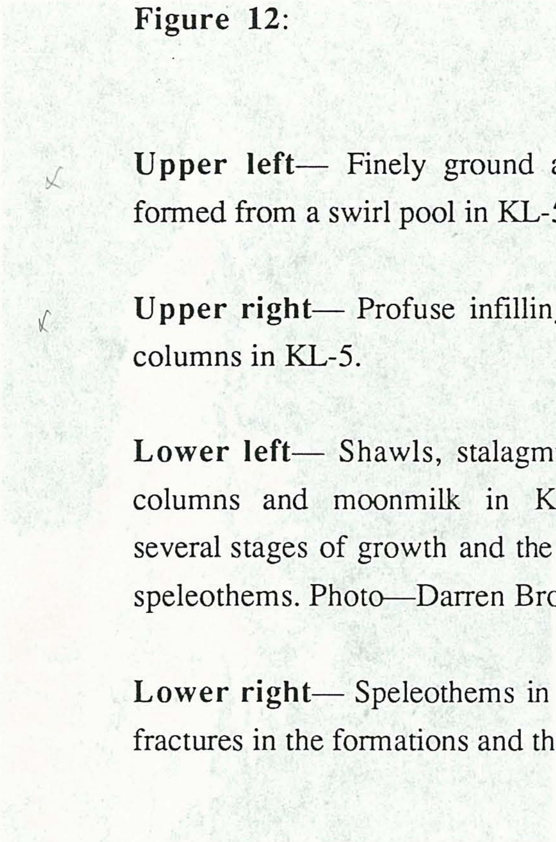
Figure 12:

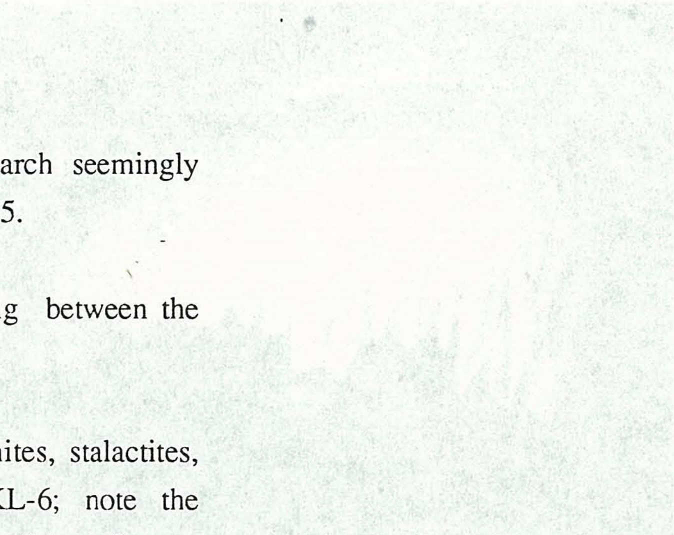
Upper left— Finely ground arch seemingly formed from a swirl pool in KL-5.

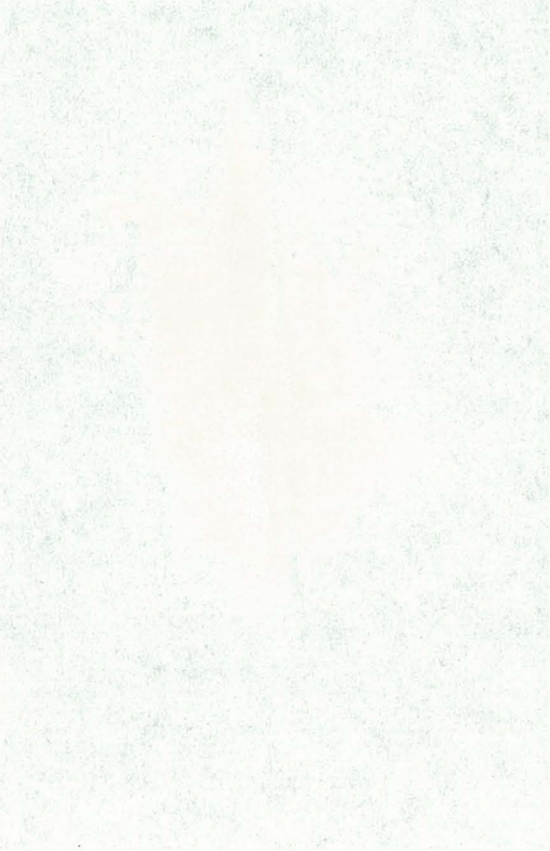
Upper right— Profuse infilling between the columns in KL-5.

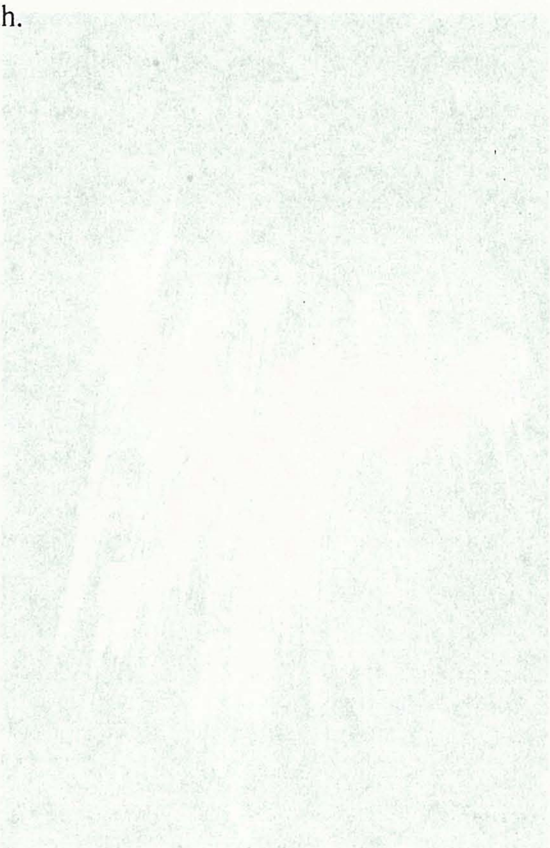
Lower left— Shawls, stalagmites, stalactites, columns and moonmilk in KL-6; note the several stages of growth and the tilting of some speleothems. Photo—Darren Brooks.

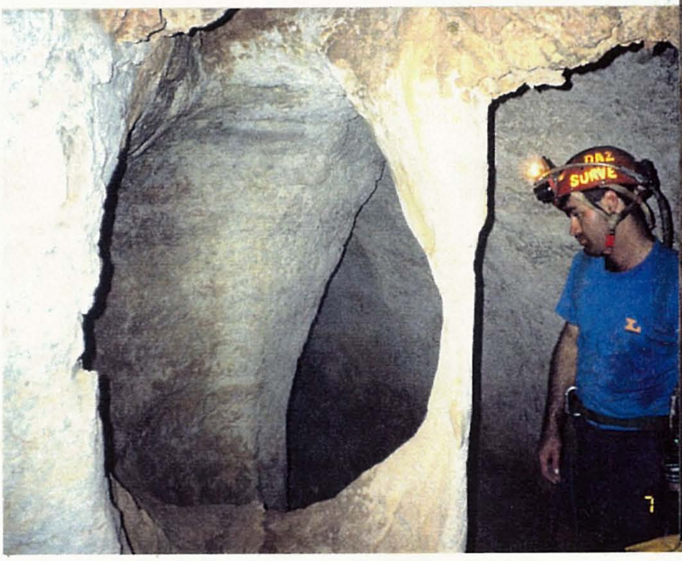
Lower right— Speleothems in KL-8; note the fractures in the formations and the regrowth.

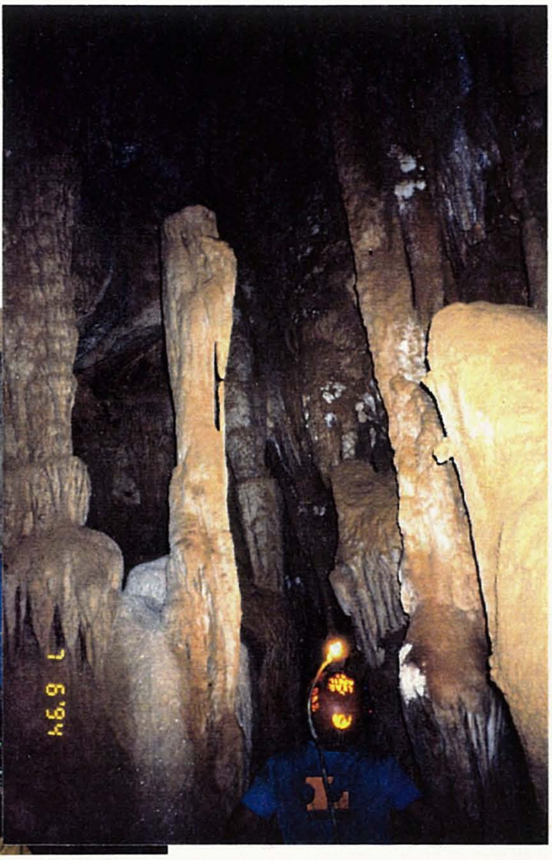


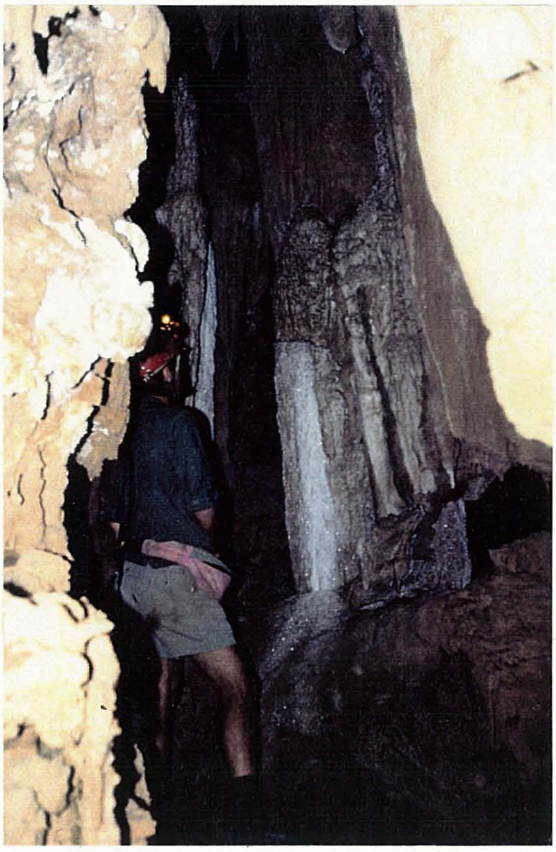












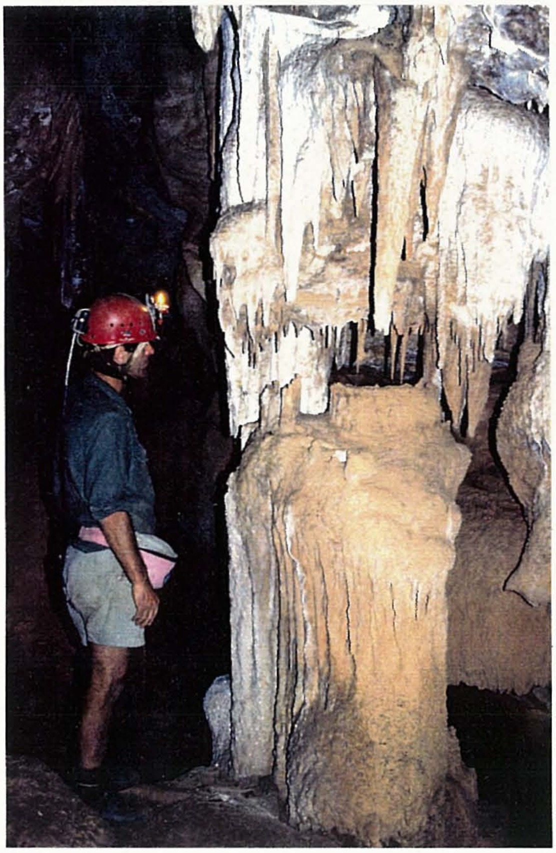


Figure 13:

Upper left—Stegamite in cave on cliff top of Napier range near KN-1. This formation has previously been described only from a few caves in the Nullarbor and result from water upwelling along a linear crack (Webb 1991).

Upper right—Stegamite (lateral view).

Lower left—Stegamite (inclined end view).

Lower right—Shawl with banding and natural fracture in KNI-9.

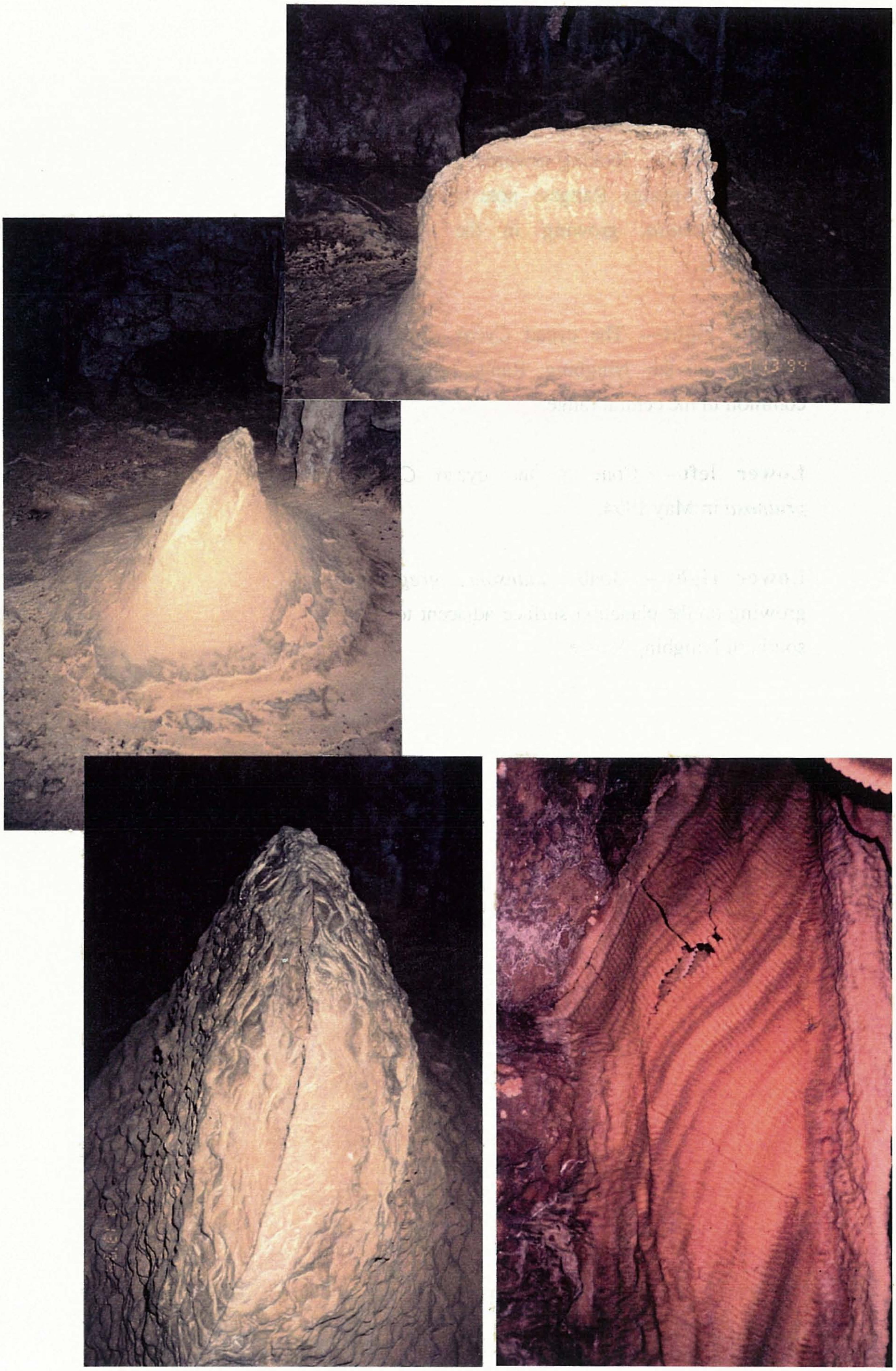


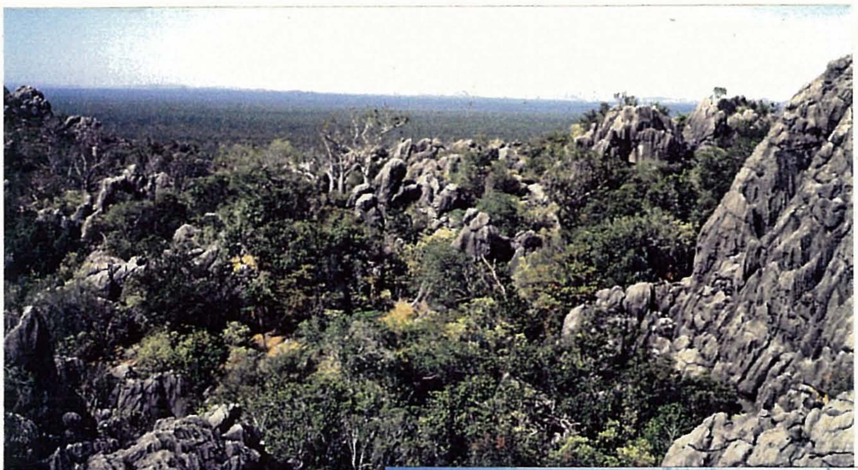
Figure 14:

Upper left— View from top of the central Ningbing Range, looking towards the Weaber and Cave Springs Ranges; note the cycad, *Cycas pruinosa*, growing in the mid-left foreground.

Middle right— The cycad *Cycas pruinosa* growing in the Ningbing Range; they are common in the central range.

Lower left— Cone of the cycad *Cycas pruinosa* in May 1994.

Lower right— Boab, *Adansonia gregorii*, growing on the planation surface adjacent to the southern Ningbing Range.

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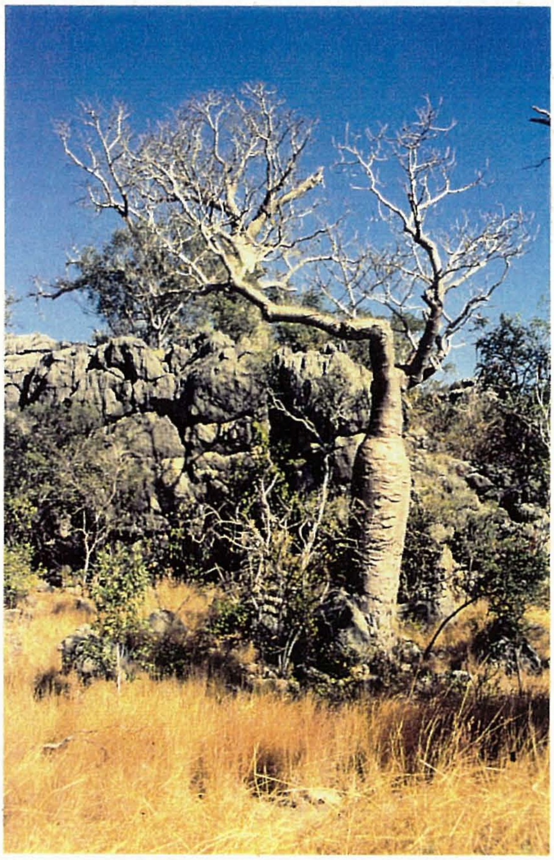


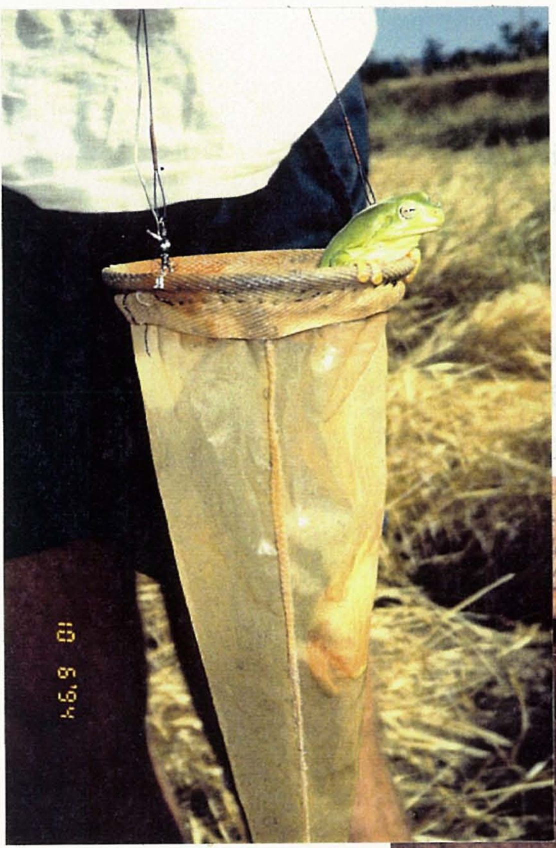
Figure 15:

Upper left— Net full of tree frogs, *Litoria caerula*, from a piezometer in the Ord Irrigation Area; the bore also contained syncarid crustaceans.

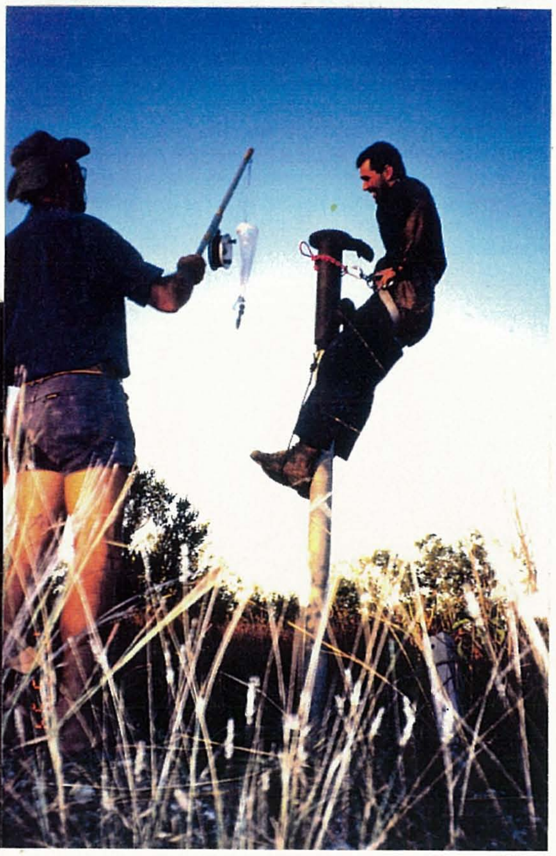
Upper right — Darren Brooks collecting in KNI-19; this is a small outflow tunnel containing a rich fauna.

Lower left— Brian Vine collecting in KJ-8.

Lower right— Brian Vine passing Darren Brooks a stygofauna net to sample a collapsed well to the north of Kununurra.


10 6'94


5'94



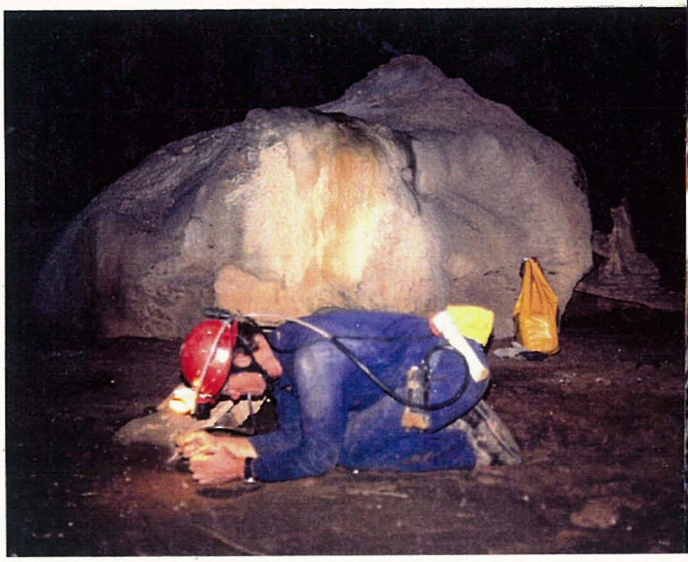


Figure 16:

Upper— A banded cat-snake, *Boiga fusca ornata* (Macleay) in cave 8K-1 . Photo—Brian Vine.

Middle— A banded cat-snake, *Boiga fusca ornata* (Macleay), stretched out across the flight path of bats in cave KNI-19; they are most often stretched out horizontally. Note the tide marks on the floor of deposited calcite rafts. Photo—Peter Fox.

Lower—Tree frog, *Litoria caerula*, in KNI-33 closing in on a cricket.

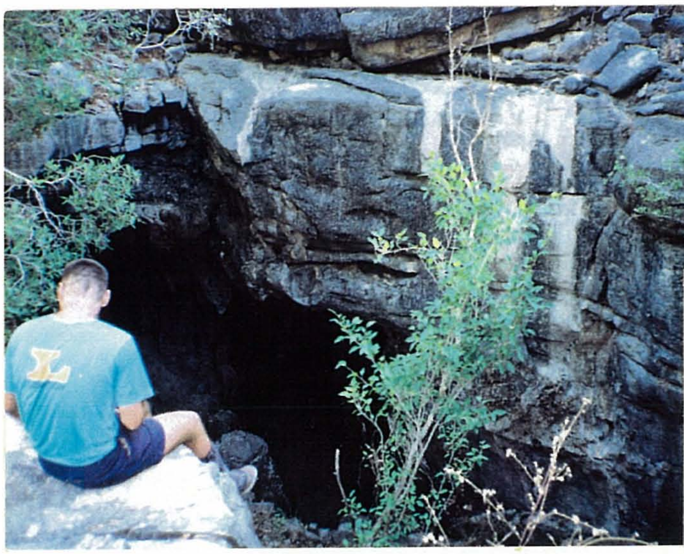
Figure 17:

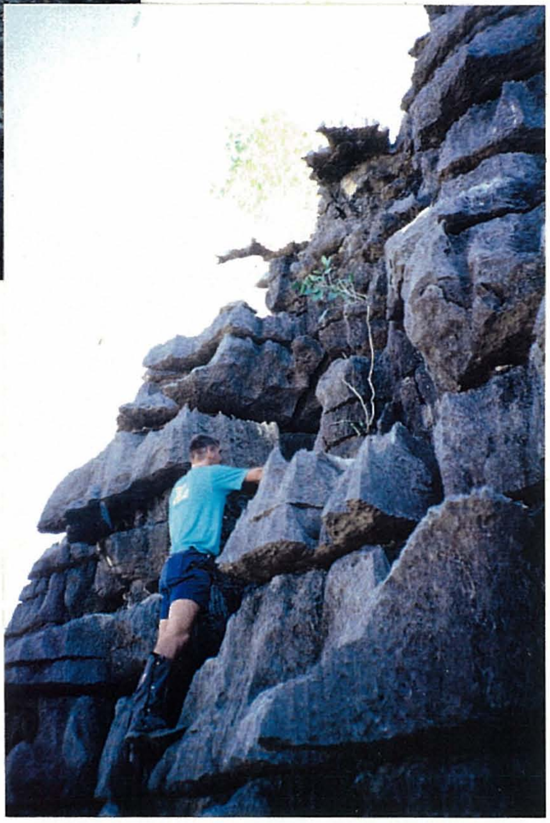
Upper left—Darren Brooks at the entrance to KNI-31. Photo—Brian Vine.

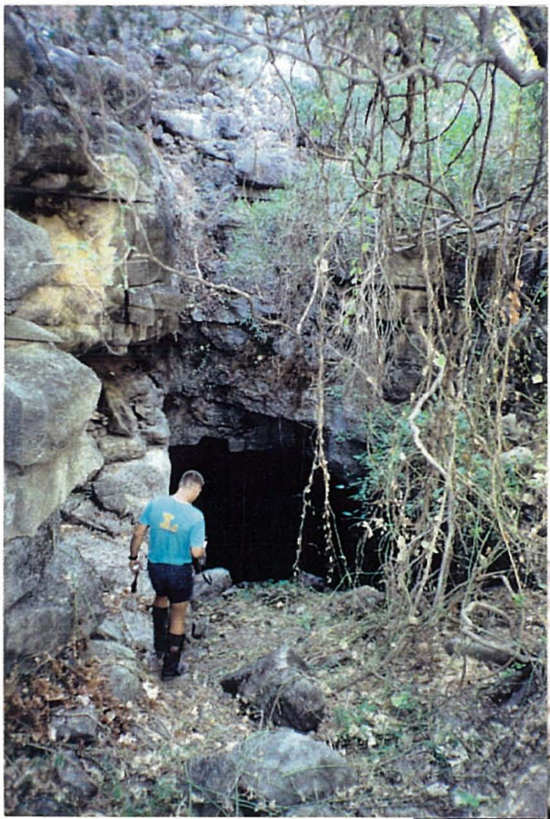
Upper right—Darren Brooks searching for caves in the Gorge, Ningbing Range. Note the horizontal and vertical weathering along the bedding planes and faults. Photo—Brian Vine.

Lower left—Darren Brooks at the entrance to KNI-32. Note the vines which are elements of monsoonal rainforest that is widely associated with depressions in the karst terrain. Photo—Brian Vine.

Lower right—Ascending from the water level in 8K-1. Photo—Brian Vine.







Appendix C

Collection

Collection

With the exception of cave fauna (since 1988) and terrestrial invertebrates other than insects and crustacea, the invertebrate collections at the Western Australian Museum are not available on computerized databases. In consequence complete searches of the collections at the Western Australian Museum, as well as those of other institutions is impractical. Where material has been referred to in the literature this has been included where possible in chapter 4 (Fauna) and chapter 5 (National Estate significance).

A number of specimens from early collections are in the Western Australian Museum or have been recorded elsewhere.

Microvelia sp. (Coleoptera) collected by A.M. Douglas & G.W. Kendrick in 1966; KN-1.

Myrmeleontidae (Neuroptera) larvae collected from calcite sand by A.M. Douglas & G.W. Kendrick in 1966; KN-1.

Myrmeleontidae (Neuroptera) from Window Cave above KN-1

Laccotrephes tristis (Stal)(Hemiptera) collected by A.M. Douglas & G.W. Kendrick in 1966; Cave Spring, Pincombe Range

Sandracottus bakewelli Clk. (Coleoptera) collected from water by A.M. Douglas & G.W. Kendrick in 1966; Cave Spring, Pincombe Range

Odonata s/f Libellulinae collected by A.M. Douglas & G.W. Kendrick in 1966

The following groups are being actively examined.

Ants	Dr S. Shattuck	Canberra
Atyid shrimps	Dr S.C. Choy	Brisbane
Cockroaches	Dr L.M. Roth	USA
Coleoptera	Dr J.F. Lawrence	Canberra
Coleoptera	Dr B.P. Moore	Canberra
Coleoptera	Dr E.C. Zimmerman,	Canberra
Copepoda	Prof. G. Pesce	Italy
Diplura: Campodeidae	Professor B. Condé	France
Diplura: Japygidae	Professor J. Pagés	France
Diptera: Chironomidae	Dr P. Cranston	Canberra
Fish	Dr G. Allen	Perth
Hemiptera	Dr H. Hoch	Germany
Hemiptera	Dr M. Malipatil	Melbourne
Isopoda—aquatic	Dr G.D.F. Wilson	Sydney
Isopods—terrestrial	Dr H. Dalens	France
Diplopoda	Dr D.G. Black	Melbourne
Mollusca	Mrs S. Slack-Smith	Perth
Orthoptera	Dr D.C.F. Rentz	Canberra
Plants	Herbarium of WA	Perth
Pseudoscorpions	Dr M.S. Harvey	Perth
Psocidae	Dr T.R. New	Melbourne
Schizomids	Dr M.S. Harvey	Perth
Spiders	Dr M.S. Harvey	Perth
Spiders	Dr M.S. Gray	Sydney
Syncarids	Prof. H.K. Schminke	Germany
Thysanura	Dr J. Irish	South Africa
Thysanura	G. Smith	Sydney

Much of the collection from the Kimberley is described briefly in the following pages. The level of classification ranges from merely a higher level classification to specific level classification depending on the involvement of specialists and the status of their work on the collections.

Karst	Class	Order	Family	Genus	Species
8K 1	Decapoda				
8K 1	Crustacea	Copepoda			
8K 1	Malacostraca	Isopoda: Oniscoidea			
8K 1	Insecta	Blattodea			
8K 1	Insecta	Blattodea	Nocticolidae	*Nocticola*	sp. nov.
8K 1	Insecta	Hemiptera	Meenoplidae		
8K 1	Arachnida	Araneae	Pholcidae		
8K 1	Insecta	Hemiptera			
8K 1	Diplopoda	Siphonophorida			
8K 1	Diplopoda	Polydesmida			
8K 1	Insecta	Hymenoptera	Formicidae		
8K 1	Arachnida	Acarina			
8K 1	Insecta	Coleoptera	Carabidae: Pterostichini	*Lecanomerus*	*speluncarius* (Moore)
8K 1	Insecta	Coleoptera	Tenebrionidae: Heleini	*Brises*	
8K 1	Diplopoda	Siphonophorida			
8K 1	Insecta	Hemiptera	Meenoplidae		
8K 1	Arachnida	Schizomida	Hubbardiidae	*Apozomus*	sp. nov. 1 (cf *A.mainae*)
8K 1	Arachnida	Araneae			
8K 1	Malacostraca	Isopoda: Oniscoidea			
8K 1	Arachnida	Araneae	Pholcidae		
8K 1	Insecta	Diplura			
8K 1	Insecta	Coleoptera	Curculionidae: Entiminae		
8K 1	Insecta	Blattodea	Nocticolidae	*Nocticola*	sp. nov.
8K 1	Insecta	Thysanura	Nicoletiidae: Atelurinae	*Gastrotheus?*	sp.
8K 1	Insecta	Hymenoptera	Formicidae		
8K 1	Arachnida	Acarina			
8K 1	Insecta	Collembola			
8K 1	Insecta	Collembola			
8K 1	Insecta	Hymenoptera	Formicidae		
8K 1	Insecta	Blattodea	Nocticolidae	*Nocticola*	sp. nov.
8K 1	Diplopoda	Siphonophorida?			
8K 1	Insecta	Hymenoptera	Formicidae		
8K 1	Insecta	Hemiptera	Meenoplidae		
8K 1	Insecta	Thysanura	Nicoletiidae: Atelurinae	*Gastrotheus*?	sp.
8K 1	Arachnida	Araneae	Pholcidae		
8K 1	Malacostraca	Isopoda: Oniscoidea			
8K 1	Insecta	Blattodea	Nocticolidae	*Nocticola*	sp. nov.
8K 1	Arachnida	Araneae	Pholcidae		
8K 1	Arachnida	Araneae			
8K 1	Insecta	Hemiptera	Meenoplidae		
8K 1	Diplopoda	Polydesmida			
8K 1	Insecta	Collembola?			
8K 1	Crustacea	Copepoda			

8K	1	Decapoda			
8K	1	Decapoda			
8K	1	Diplopoda	Polydesmida		
8K	1	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
8K	1	Insecta	Hemiptera	Meenoplidae	
8K	1	Insecta	Hymenoptera	Formicidae	
8K	1	Arachnida	Araneae	Pholcidae	
8K	1	Malacostraca	Isopoda: Oniscoidea		
8K	1	Insecta	Coleoptera	Ptiliidae	
8K	1	Vertebrata	Mammalia: Chiroptera		
8K	1	Vertebrata			
8K	1	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
8K	1	Diplopoda	Siphonophorida?		
8K	1	Diplopoda	Polydesmida		
8K	1	Decapoda			
	Ningbing Range				*Cycas pruinosa*
	Ningbing Range				*Cycas pruinosa*
KJ	7	Insecta	Diptera		
KJ	7	Arachnida	Araneae	Filistatidae	
KJ	7	Arachnida	Araneae	Theridiidae	
KJ	7	Arachnida	Araneae	Theridiidae?	
KJ	7	Insecta	Orthoptera		
KJ	7	Insecta	Coleoptera	Staphylinidae	
KJ	7	Chilopoda	Scutigerida		*Allothereura lesueurii*
KJ	7	Arachnida	Araneae	Ctenidae	
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Insecta	Hemiptera	Meenoplidae	
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Insecta	Diplura	Japygidae	
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Insecta	Hemiptera		
KJ	8	Insecta	Hemiptera		
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Insecta	Hymenoptera	Formicidae	
KJ	8	Arachnida	Araneae	Pholcidae	
KJ	8	Insecta	Psocidae		
KJ	8	Arachnida	Acarina		
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Arachnida	Araneae	Uloboridae	*Uloborus*
KJ	8	Arachnida	Araneae	Linyphiidae	
KJ	8	Arachnida	Araneae	Lycosidae	
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Arachnida	Araneae	Ctenidae?	
KJ	8	Arachnida	Araneae	Lycosidae	
KJ	8	Insecta	Diptera		
KJ	8	Arachnida	Acarina		
KJ	8	Arachnida	Araneae	Linyphiidae?	
KJ	8	Insecta	Insecta	Psocidae	
KJ	8	Arachnida	Araneae	Pholcidae	
KJ	8	Insecta	Coleoptera	Staphylinidae: Paederinae	
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Mollusca			
KJ	8	Arachnida	Araneae	Pholcidae	
KJ	8	Insecta	Hemiptera	Meenoplidae	

KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Insecta	Coleoptera		
KJ	8	Arachnida	Araneae		
KJ	8	Insecta	Diptera		
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Arachnida	Acarina		*Amblyomma* sp.
KJ	8	Insecta	Lepidoptera		
KJ	8	Arachnida	Araneae	Filistatidae	
KJ	8	Arachnida	Araneae	Linyphiidae	
KJ	8	Insecta	Hymenoptera	Formicidae	
KJ	8	Arachnida	Araneae	Filistatidae	
KJ	8	Arachnida	Acarina		
KJ	8	Insecta	Hemiptera	Meenoplidae	
KJ	8	Insecta	Coleoptera		
KJ	8	Arachnida	Araneae	Theridiidae	
KJ	8	Mollusca			
KJ	8	Mollusca			
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Insecta	Coleoptera	Curculionidae: Entiminae	
KJ	8	Arachnida	Araneae	Ctenidae	
KJ	8	Mollusca			
KJ	8	Insecta	Hemiptera	Meenoplidae	
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Insecta	Hymenoptera	Formicidae	
KJ	8	Arachnida	Araneae	Pholcidae	
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Mollusca	Gastropoda		
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Insecta	Orthoptera		
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Mollusca	Gastropoda		
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Insecta	Lepidoptera	Noctuidae	*Speiredonia*? sp.
KJ	8	Arachnida	Araneae	Filistatidae	
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Arachnida	Araneae	Filistatidae	
KJ	8	Arachnida	Araneae	Linyphiidae	
KJ	8	Insecta	Hemiptera	Meenoplidae	
KJ	8	Insecta	Diptera		
KJ	8	Insecta	Coleoptera	Carabidae: Bembidiini	
KJ	8	Insecta	Coleoptera	Curculionidae: Cryptorhynchinae	
KJ	8	Insecta	Pscoptera		
KJ	8	Insecta	Hemiptera		
KJ	8	Malacostraca	Isopoda: Oniscoidea		
KJ	8	Insecta	Hemiptera	Meenoplidae	
KJ	8	Mollusca			
KJ	12	Insecta	Orthoptera		
KJ	12	Arachnida	Araneae	Araneidae?	
KJ	12	Arachnida	Araneae	Ctenidae	
KJ	12	Malacostraca	Isopoda: Oniscoidea		
KL	5	Vertebrata	Chiroptera	Macrodermidae	*Macroderma gigas*
KL	5	Mollusca	Gastropoda		

KL	5	Mineral			
KL	5	Insecta	Orthoptera		
KL	5	Mineral			
KL	5	Arachnida	Araneae	Heteropodidae	?*Heteropoda* sp.
KL	5	Insecta	Blattodea		
KL	5	Arachnida	Araneae	Heteropodidae	?*Heteropoda* sp.
KL	5	Arachnida	Araneae	Oonopidae	
KL	5	Insecta	Blattodea		
KL	5	Insecta	Lepidoptera		
KL	5	Arachnida	Araneae		
KL	5	Insecta	Hemiptera		
KL	5	Insecta	Lepidoptera		
KL	5	Arachnida	Araneae	Hersiliidae	*Hersilia mimbi* B.Baehr & M.Baehr, 1993
KL	5	Mollusca	Gastropoda		
KN	1	Decapoda			
KN	1	Crustacea	Copepoda		
KN	1	Vermes			
KN	1	Mollusca	Gastropoda		
KN	1	Decapoda			
KN	1	Insecta	Lepidoptera		
KN	1	Arachnida	Araneae	Theridiosomatatidae	
KN	3	Insecta	Hemiptera	Reduviidae: Emesinae	
KN	3	Insecta	Hemiptera	Meenoplidae	
KN	3	Arachnida	Araneae: Amaurobioidea		
KN	3	Arachnida	Araneae	Araneidae	*Cyrtophora* sp.
KN	3	Mollusca	Gastropoda		
KN	3	Insecta	Orthoptera		
KN	3	Arachnida	Araneae	Uloboridae	*Uloborus* sp.
KN	3	Insecta	Hemiptera	Reduviidae	
KN	3	Insecta	Coleoptera	Trogidae	
KN	3	Insecta	Hemiptera		
KN	3	Arachnida	Araneae	Pholcidae	
KN	3	Insecta	Diptera		
KN	3	Insecta	Orthoptera		
KNI	7	Arachnida	Araneae	Araneidae	*Cyrtophora*?
KNI	9	Insecta	Hemiptera	Meenoplidae	
KNI	9	Insecta	Hemiptera	Meenoplidae	
KNI	9	Insecta	Hymenoptera	Formicidae	*Paratrechina* sp.
KNI	9	Mollusca			
KNI	9	Mollusca			
KNI	9	Insecta	Hemiptera	Meenoplidae	
KNI	9	Insecta	Isoptera		
KNI	9	Malacostraca	Isopoda: Oniscoidea		
KNI	9		?		
KNI	9	Insecta	Hemiptera	Meenoplidae	
KNI	9	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	9	Arachnida	Araneae	Ctenidae	
KNI	9	Arachnida	Araneae	Ctenidae	
KNI	9	Malacostraca	Isopoda: Oniscoidea		
KNI	9	Insecta	Hemiptera	Meenoplidae	
KNI	9	Arachnida	Araneae	Pholcidae	
KNI	9	Insecta	Hemiptera	Reduviidae: Emesinae	
KNI	9	Arachnida	Araneae	Filistatidae	
KNI	9	Insecta	Hemiptera	Meenoplidae	

KNI	9	Malacostraca	Isopoda: Oniscoidea		
KNI	9	Insecta	Hemiptera	Reduviidae: Emesinae	
KNI	9	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	9	Insecta	Coleoptera	Pselaphidae	
KNI	9	Insecta	Hemiptera	Meenoplidae	
KNI	9	Malacostraca	Isopoda: Oniscoidea		
KNI	9	Insecta	Hemiptera	Meenoplidae	
KNI	9	Insecta	Hemiptera	Reduviidae: Emesinae	
KNI	9	Insecta	Hemiptera	Meenoplidae	
KNI	9	Arachnida	Araneae	Linyphiidae?	
KNI	9	Malacostraca	Isopoda: Oniscoidea		
KNI	9	Arachnida	Araneae	Filistatidae	
KNI	9	Arachnida	Araneae	Pholcidae	
KNI	9	Insecta	Lepidoptera		
KNI	9	Arachnida	Araneae	Filistatidae	
KNI	9	Insecta	Diptera		
KNI	9	Insecta	Coleoptera	Staphilinidae: Aleocharinae	
KNI	9	Arachnida	Araneae	Ctenidae	
KNI	9	Vertebrata	Mammalia		
KNI	9	Insecta	Coleoptera		
KNI	9	Mollusca			
KNI	9	Arachnida	Araneae	Filistatidae	
KNI	9	Arachnida	Araneae	Uloboridae	*Uloborus* sp.
KNI	9	Mineral			
KNI	9	Vertebrata	Mammalia		
KNI	9	Vertebrata	Mammalia		
KNI	9	Vertebrata	Mammalia		
KNI	9	Diplopoda			
KNI	9	Insecta	Hemiptera	Meenoplidae	
KNI	9	Malacostraca	Isopoda: Oniscoidea		
KNI	9	Arachnida	Araneae	Pholcidae	
KNI	9	Insecta	Diptera		
KNI	9	Insecta	Diptera		
KNI	9	Insecta	Hemiptera	Meenoplidae	
KNI	9	Insecta	Hemiptera	Meenoplidae	
KNI	9	Malacostraca	Isopoda: Oniscoidea		
KNI	19	Mollusca			
KNI	19	Crustacea	Copepoda		
KNI	19	Crustacea	Copepoda		
KNI	19	Crustacea	Copepoda		
KNI	19	Crustacea	Copepoda		
KNI	19	Arachnida	Araneae	Ctenidae	
KNI	19	Arachnida	Araneae	Ctenidae	
KNI	19	Mollusca			
KNI	19	Malacostraca	Isopoda: Oniscoidea		
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta	Coleoptera	Trogidae	
KNI	19	Insecta			
KNI	19	Insecta	Hemiptera		
KNI	19	Vertebrata	Mammalia: Chiroptera		
KNI	19	Acarina	Chelicerata	Acarina	
KNI	19	Insecta	Hymenoptera	Formicidae	

KNI	19	Insecta	Hemiptera		
KNI	19	Crustacea	Decapoda		
KNI	19	Chilopoda	Scutigerida	*Allothereura lesueurii*	
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta	Diptera		
KNI	19	Insecta	Hymenoptera	Formicidae	
KNI	19	Arachnida	Opilionida	Assamiidae	?*Anjolus* sp. nov.
KNI	19	Diplopoda			
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta	Lepidoptera		
KNI	19	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	19	Insecta	Lepidoptera		
KNI	19	Insecta	Diptera		
KNI	19	Insecta	Hemiptera	Meenoplidae	
KNI	19	Insecta	Coleoptera	Pselaphidae	
KNI	19	Chilopoda	Scutigerida		
KNI	19	Insecta	Hymenoptera	Formicidae	
KNI	19	Mollusca			
KNI	19	Arachnida	Araneae	Salticidae	
KNI	19	Insecta	Hymenoptera	Apidae	*Trigona*
KNI	19	Arachnida	Araneae	Araneidae	*Argiope* sp.
KNI	19	Insecta	Coleoptera	Trogidae	
KNI	19	Insecta	Lepidoptera		
KNI	19	Insecta	Orthoptera		
KNI	19	Arachnida	Araneae	Ctenidae	
KNI	19	Crustacea	Copepoda		
KNI	19	Molusca			
KNI	19	Crustacea	Copepoda		
KNI	19	Diplopoda			
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta	Diptera		
KNI	19	Insecta	Hemiptera	Meenoplidae	
KNI	19	Insecta	Coleoptera	Pselaphidae	
KNI	19	Insecta	Diptera		
KNI	19	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	19	Insecta	Blattodea		
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta	Coleoptera	Trogidae	
KNI	19	Insecta	Lepidoptera		
KNI	19	Insecta	Hemiptera		
KNI	19	Insecta	Diptera		
KNI	19	Insecta	Coleoptera	Pselaphidae	
KNI	19	Insecta	Diptera	Streblidae	
KNI	19	Insecta	Orthoptera		
KNI	19	Insecta	Lepidoptera		
KNI	19	Insecta	Hymenoptera	Formicidae	
KNI	19	Insecta	Hymenoptera	Formicidae	
KNI	19	Mollusca			
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	19	Insecta	Coleoptera	Pselaphidae	
KNI	19	Insecta	Diptera		
KNI	19	Arachnida	Acarina		

KNI	19	Arachnida	Schizomida	Hubbardiidae	*Apozomus* sp. nov. 4
KNI	19	Diplopoda			
KNI	19	Arachnida	Araneae	Linyphiidae?	
KNI	19	Insecta	Hemiptera	Meenoplidae	
KNI	19	Insecta	Diptera		
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta	Lepidoptera		
KNI	19	Insecta	Coleoptera	Trogidae	
KNI	19	Arachnida	Araneae	Gnaphosidae	
KNI	19	Arachnida	Acarina		
KNI	19	Diplopoda			
KNI	19	Arachnida	Opilionida	Assamiidae	?*Anjolus* sp. nov.
KNI	19	Arachnida	Opilionida	Assamiidae	?*Anjolus* sp. nov.
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta	Hemiptera	Meenoplidae	
KNI	19	Insecta	Diptera		
KNI	19	Mineral			
KNI	19	Vertebrata	Mammalia: Chiroptera		
KNI	19	Crustacea	Decapoda		
KNI	19	Arachnida	Pseudoscorpionida	Hyidae	*Hyella* sp. nov.
KNI	19	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta	Lepidoptera		
KNI	19	Arachnida	Pseudoscorpionida	Chthoniidae	*Lagynochthonius* sp. nov.
KNI	19	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	19	Insecta	Diptera		
KNI	19	Insecta	Diptera	Nycteribiidae	
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Diplopoda			
KNI	19	Insecta	Coleoptera	Pselaphidae	
KNI	19	Insecta	Coleoptera	Ptiliidae	
KNI	19	Insecta	Diptera		
KNI	19	Insecta	Hymenoptera	Formicidae	
KNI	19	Diplopoda			
KNI	19	Insecta	Hymenoptera	Formicidae	
KNI	19	Diplopoda			
KNI	19	Arachnida	Araneae	Uloboridae	*Uloborus* sp.
KNI	19	Arachnida	Araneae	Oonopidae	
KNI	19	Crustacea	Copepoda		
KNI	19	Arachnida	Araneae	Ctenidae	
KNI	19	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	19	Diplopoda			
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta	Hemiptera	Meenoplidae	
KNI	19	Arachnida	Pseudoscorpionida	Chthoniidae	*Lagynochthonius* sp. nov.
KNI	19	Insecta	Diptera		
KNI	19	Insecta	Lepidoptera		
KNI	19	Insecta	Lepidoptera		
KNI	19	Arachnida	Acarina: Oribatida		
KNI	19	Insecta	Coleoptera	Pselaphidae	
KNI	19	Insecta	Coleoptera	Ptiliidae	
KNI	19	Arachnida	Opilionida	Assamiidae	?*Anjolus* sp. nov.
KNI	19	Arachnida	Acarina		
KNI	19	Insecta	Coleoptera	Pselaphidae	

KNI	19	Insecta	Lepidoptera		
KNI	19	Arachnida	Acarina		
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta	Diptera		
KNI	19	Insecta	Coleoptera	Trogidae	
KNI	19	Malacostraca	Isopoda: Oniscoidea		
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta	Coleoptera	Trogidae	
KNI	19	Arachnida	Pseudoscorpionida	Chthoniidae	*Lagynochthonius* sp. nov.
KNI	19	Diplopoda	Polydesmida		
KNI	19	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta			
KNI	19	Insecta	Coleoptera	Pselaphidae	
KNI	19	Arachnida	Opilionida	Assamiidae	?*Anjolus* sp. nov.
KNI	19	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	19	Diplopoda	Polydesmida		
KNI	19	Malacostraca	Isopoda: Oniscoidea		
KNI	19	Insecta	Coleoptera	Pselaphidae	
KNI	19	Arachnida	Acarina: Oribatida		
KNI	19	Arachnida	Acarina		
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Insecta	Diptera		
KNI	19	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	19	Insecta	Coleoptera	Pselaphidae	
KNI	19	Arachnida	Acarina: Oribatida		
KNI	19	Arachnida	Opilionida	Assamiidae	?*Anjolus* sp. nov.
KNI	19	Arachnida	Araneae	Pholcidae	
KNI	19	Arachnida	Araneae	Ctenidae?	
KNI	19	Arachnida	Araneae	Ctenidae	
KNI	19	Arachnida	Araneae	Ctenidae	
KNI	19	Arachnida	Araneae	Ctenidae	
KNI	19	Arachnida	Araneae	Ctenidae	
KNI	19	Arachnida	Araneae	Ctenidae	
KNI	19	Arachnida	Araneae	Ctenidae	
KNI	19	Arachnida	Opilionida	Assamiidae	?*Anjolus* sp. nov.
KNI	19	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	19	Insecta	Coleoptera	Trogidae	*Omorgus alatus*
KNI	19	Insecta	Coleoptera	Trogidae	*Omorgus dilaticollis* (Macl.)
KNI	19	Arachnida	Pseudoscorpionida	Chthoniidae	*Lagynochthonius* sp. nov.
KNI	19	Insecta	?		
KNI	19	Arachnida	Araneae	Ctenidae	
KNI	19	Arachnida	Araneae	Ctenidae	
KNI	27	Mollusca			
KNI	27	Mollusca			
KNI	27	Insecta	Hemiptera	Meenoplidae	
KNI	27	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	27	Malacostraca	Isopoda: Oniscoidea		
KNI	27	Insecta	Diptera		
KNI	27	Arachnida	Araneae	Pholcidae	
KNI	27	Arachnida	Araneae	Linyphiidae	
KNI	27	Arachnida	Araneae	Pholcidae	
KNI	27	Arachnida	Araneae	Theridiidae	
KNI	27	Arachnida	Araneae	Oonopidae	

KNI	27	Insecta	Blattodea		
KNI	27	Insecta	Hemiptera	Meenoplidae	
KNI	27	Insecta	Diptera		
KNI	27	Mollusca	Gastropoda		
KNI	27	Insecta	Coleoptera	Carabidae: Odacanthini	?genus
KNI	27	Vertebrata	Mammalia		
KNI	27	Vertebrata	Mammalia		
KNI	27	Malacostraca	Isopoda: Oniscoidea		
KNI	27	Insecta	Blattodea		
KNI	27	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	27	Arachnida	Araneae	Pholcidae	
KNI	27	Insecta	Hemiptera	Meenoplidae	
KNI	27	Insecta	Diptera		
KNI	27	Diplopoda			
KNI	27	Vertebrata	Mammalia		
KNI	27	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	27	Malacostraca	Isopoda: Oniscoidea		
KNI	27	Arachnida	Araneae	Filistatidae	
KNI	29	Insecta	Hymenoptera	Apidae	*Trigona* sp.
KNI	29	Mollusca			
KNI	29	Insecta	Coleoptera	Chrysomelidae: Galerucinae	
KNI	29	Insecta	Orthoptera		
KNI	29	Arachnida	Araneae	Ctenidae	
KNI	29	Insecta	Hemiptera	Meenoplidae	
KNI	29	Mollusca			
KNI	29	Arachnida	Araneae	Araneidae	*Argiope* cf. *dietrichae*
KNI	29	Arachnida	Araneae	Oxyopidae	
KNI	29	Arachnida	Araneae	Salticidae	
KNI	29	Insecta	Coleoptera	Trogidae	
KNI	29	Insecta	Orthoptera		
KNI	29	Insecta	Isoptera		
KNI	29	Insecta	Hemiptera	Meenoplidae	
KNI	29	Insecta	Hymenoptera	Formicidae	
KNI	29	Insecta	Coleoptera		
KNI	29	Arachnida	Araneae	Pholcidae	
KNI	29	Insecta	Hemiptera	Meenoplidae	
KNI	29	Arachnida	Araneae	Pholcidae	
KNI	29	Insecta	Hemiptera	Meenoplidae	
KNI	29	Insecta	Hemiptera		
KNI	29	Arachnida	Araneae	Pholcidae	
KNI	29	Arachnida	Araneae	Oxyopidae	
KNI	29	Arachnida	Araneae	Salticidae	
KNI	29	Arachnida	Araneae	Uloboridae	*Uloborus*
KNI	29	Insecta	Hemiptera	Meenoplidae	
KNI	29	Arachnida	Araneae	Ctenidae	
KNI	29	Arachnida	Araneae	Ctenidae	
KNI	30	Insecta	Hemiptera	Meenoplidae	
KNI	31	Mollusca	Gastropoda		
KNI	31	Arachnida	Araneae	Pholcidae	
KNI	31	Insecta	Diptera		
KNI	31	Insecta	Coleoptera	Chrysomelidae: Galerucinae	
KNI	31	Insecta	Diptera		
KNI	31	Arachnida	Acarina		
KNI	31	Arachnida	Araneae	Desidae?	

KNI	31	Malacostraca	Isopoda: Oniscoidea		
KNI	31	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	31	Insecta	Plecoptera		
KNI	31	Arachnida	Araneae	Pholcidae	
KNI	31	Insecta	Diptera		
KNI	31	Arachnida	Araneae	Ctenidae	
KNI	31	Mineral			
KNI	31	Mineral			
KNI	34	Insecta	Hemiptera	Reduviidae	
KNI	35		Mammalia		
KNI	38	Arachnida	Araneae: Amaurobioidea		
KNI	40	Insecta	Hemiptera	Reduviidae: Emesinae	
KNI	41	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	41	Vertebrata	Mammalia		
KNI	41	Vertebrata	Mammalia		
KNI	41	Vertebrata	Mammalia		
KNI	41	Vertebrata	Mammalia		
KNI	41	Insecta	Lepidoptera		
KNI	41	Insecta	Coleoptera	Trogidae	
KNI	41	Vertebrata	Mammalia		
KNI	41	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	41	Arachnida	Pseudoscorpionida	Hyidae	*Hyella* sp. nov.
KNI	41	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	41	Malacostraca	Isopoda: Oniscoidea		
KNI	41	Arachnida	Araneae	Ctenidae+Oxyopidae	
KNI	41	Vertebrata	Mammalia: Chiroptera		
KNI	41	Arachnida	Pseudoscorpionida	Hyidae	*Hyella* sp. nov.
KNI	41	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	41	Malacostraca	Isopoda: Oniscoidea		
KNI	41	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	41	Vertebrata	Mammalia		
KNI	41	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	41	Malacostraca	Isopoda: Oniscoidea		
KNI	41	Arachnida	Pseudoscorpionida	Hyidae	*Hyella* sp. nov.
KNI	41	Insecta	Diptera		
KNI	41	Mineral			
KNI	41	Insecta	Coleoptera	Pselaphidae	
KNI	41	Arachnida	Pseudoscorpionida	Hyidae	*Hyella* sp. nov.
KNI	41	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	41	Malacostraca	Isopoda: Oniscoidea		
KNI	41	Insecta	Collembola		
KNI	41	Arachnida	Pseudoscorpionida	Hyidae	*Hyella* sp. nov.
KNI	41	Arachnida	Schizomida	Hubbardiidae	*Apozomus* sp. nov. 3
KNI	41	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	41	Insecta	Coleoptera	Pselaphidae	
KNI	41	Arachnida	Araneae	Oxyopidae	
KNI	41	Arachnida	Acarina		
KNI	41	Arachnida	Araneae	Ctenidae	cf. *Janusia*
KNI	41	Arachnida	Araneae	Ctenidae	cf. *Janusia*
KNI	41	Arachnida	Araneae	Ctenidae	cf. *Janusia*
KNI	41	Arachnida	Araneae	Ctenidae	cf. *Janusia*
KNI	41	Insecta	Coleoptera	Trogidae	
KNI	41	Insecta	Hemiptera	Reduviidae	
KNI	41	Arachnida	Araneae	Ctenidae	cf. *Janusia*

KNI	41	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KNI	41	Arachnida	Araneae	Pholcidae	
KNI	41	Arachnida	Pseudoscorpionida	Hyidae	*Hyella* sp. nov.
KNI	9	Echinodermata: Crinoidea		Echinodermata: Crinoidea	
KNI	9	Echinodermata: Crinoidea		Echinodermata: Crinoidea	
KO	1	Arachnida	Schizomida	Hubbardiidae	*Apozomus* sp. nov. 2
KO	1	Malacostraca	Isopoda: Oniscoidea		
KO	1	Malacostraca	Isopoda: Flabellifera new family		*Tainisopus fontinalis*?
KO	1	Insecta	Hemiptera	Reduviidae: Emesinae	
KO	1	Arachnida	Araneae		Ceryerda
KO	1	Insecta	Coleoptera	Trogidae	
KO	1	Insecta	Orthoptera		
KO	1	Arachnida	Araneae	Pholcidae	
KO	1	Arachnida	Pseudoscorpionida	Olpiidae	
KO	1	Crustacea	Ostracoda		
KO	1	Copepoda			
KO	1	Crustacea	Copepoda		
KO	1	Insecta	Hymenoptera	Formicidae	
KO	1	Malacostraca	Isopoda: Flabellifera new family		*Tainisopus fontinalis*?
KO	1	Arachnida	Schizomida	Hubbardiidae	*Apozomus* sp. nov. 2
KO	1	Arachnida	Araneae	Lycosidae	
KO	1	Malacostraca	Isopoda: Oniscoidea		
KO	1	Arachnida	Araneae	Pholcidae	
KO	1	Malacostraca	Isopoda: Oniscoidea		
KO	1	Insecta	Blattodea	Nocticolidae	*Nocticola* sp. nov.
KO	1	Arachnida	Araneae	Lycosidae	
KO	1	Insecta	Coleoptera	Histeridae	
KO	1	Insecta	Coleoptera	Limnichidae	*Byrrhinus*
KO	Brians Pool		Crustacea	Ostracoda	
KO	Brians Pool		Crustacea	Copepoda	
KO	Brians Pool		Malacostraca Decapoda	Sundathelphusidae	*Holthuisana transversa*

Ningbing Range				*Livistona* sp. B	
Ningbing Range				*Strychnos lucida*	
Doline KNI-29		Arachnida	Araneae	Gnaphosidae	
outside KNI-19		Insecta	Blattodea		
outside KNI-19		Insecta	Hymenoptera	Formicidae	
outside KNI-19		Insecta	Insecta		
outside KNI-19		Insecta	Diptera		
outside KNI-19		Insecta	Collembola		
outside KNI-19		Arachnida	Acarina		
outside KNI-19		Arachnida	Acarina: Oribatida		
outside KNI-19		Arachnida	Pseudoscorpionida		
outside KNI-19		Arachnida	Araneae	Salticidae: Unidentati	
outside KNI-19		Arachnida	Araneae	Zodariidae	
outside KNI-19		Diplopoda	Polydesmida		
Cave Spring		Insecta	Hemiptera		
Cave Spring		Insecta	Coleoptera	Dytiscidae: Colymbetinae	*Platynectes* sp.
Cave Spring		Insecta	Coleoptera	Dytiscidae: Hydroporinae	*Tiporus collaris* (Hope)
Cave Spring		Insecta	Ephemeroptera		
Ningbing Rockhole		Vertebrata	Pisces		
Siggins Spring		Crustacea	Ostracoda		
Camp	Insecta	Hymenoptera	Apidae	*Trigona* sp.	
Camp	Insecta	Hemiptera			
Camp	Insecta	Hymenoptera	Apidae	*Trigona* sp.	

Ningbing Rockhole	Decapoda			
Siggins Spring	Vertebrata	Pisces		
Siggins Spring	Vertebrata	Pisces		
southern Ningbing Range	Arachnida	Araneae	Desidae?	
Cave Spring	Insecta	Hemiptera		
Cave Spring	Annelida			
Doline KNI-29	Arachnida	Araneae	Zodariidae	
Doline KNI-29	Insecta	Hemiptera		
Doline KNI-29	Insecta	Diptera		
Doline KNI-29	Insecta	Hymenoptera	Formicidae	
Doline KNI-29	Insecta	Hemiptera		
Doline KNI-29	Insecta	Coleoptera	Carabidae: Pterostichini	*Prosopogomus* sp.
Doline KNI-29	Insecta	Coleoptera	Elateridae: Agrypninae	*Conoderus* sp.
Doline KNI-29	Insecta	Coleoptera		
Doline KNI-29	Insecta	Embioptera		
Doline KNI-29	Insecta	Orthoptera		
Doline KNI-29	Mollusca			
Doline KNI-29	Diplopoda			
Doline KNI-29	Insecta	Lepidoptera		
Doline KNI-29	Diplopoda			
Ningbing Range	Mineral: Rillen karren			
Ningbing Range	Mineral: Rillen karren			
N Ningbing camp	Arachnida	Araneae	Oxyopidae	
unnumbered feature	Mineral			
unnear KNI-13	Mineral			
Camp ouitside KNI-9	Insecta	Coleoptera	Carabidae	*Catadromus* sp., cf *C.elseyi*
Cattle Creek Well	Insecta	Diplura		
Cattle Creek Well	Crustacea	Copepoda		
Cattle Creek Well	Crustacea	Ostracoda		
Cattle Creek Well	Crustacea	Ostracoda		
Cattle Creek Well	Mollusca			
White waterfall	Mollusca			
Cave near white waterfall	Vertebrata	Mammalia		
White waterfall	Mollusca			
White waterfall	Mineral			
White waterfall	Mineral			
White waterfall	Mineral			
Osmond Valley Station	Insecta	Blattodea	Blattellidae	
Osmond Valley Station	Insecta	Hymenoptera	Formicidae	
Osmond Valley Station	Insecta	Coleoptera	Staphylinidae: Staphylininae	*Philonthus* sp.
Osmond Valley Station	Insecta	Coleoptera	Staphylinidae: paederinae	
Osmond Valley Station	Insecta	Coleoptera		
Osmond Valley Station	Insecta	Coleoptera	Silvanidae: Silvaninae	
Osmond Valley Station	Arachnida	Acarina		
Osmond Valley Station	Arachnida	Acarina		
Osmond Valley Station	Insecta	Diptera		
Osmond Valley Station	Insecta	Coleoptera		
Osmond Valley Station	Insecta	Coleoptera		
Osmond Valley Station	Arachnida	Araneae	Lycosidae	
Osmond Valley Station	Insecta	Collembola		
Piezometer PN6D [#67]	Insecta	Hymenoptera	Formicidae	
Piezometer PN6D [#67]	Crustacea	Syncarida	Parabathynellidae	
Frank Wise Institute	Insecta	Hymenoptera	Formicidae	
Piezometer #104	Crustacea	Syncarida	Parabathynellidae	

Piezometer #104	Diplopoda			
Piezometer VEPL deep	Myriapoda			
PB2 medium (#81)	Arachnida	Araneae	Filistatidae	
PB1 medium (#91)	Crustacea	Syncarida	Bathynellidae	sp.A
KJ-8 campsite	Insecta	Orthoptera		
Camp on Station Creek	Insecta	Orthoptera		
Camp on Station Creek	Arachnida	Araneae	Salticidae	
Frank Wise Institute	Arachnida	Araneae	Salticidae	
Piezometer HI 3/78	Nematoda			
Piezometer PN5D	Crustacea	Copepoda		
Piezometer PB2	Crustacea	Syncarida	Bathynellidae	sp.A
Piezometer PB2	Nematoda			
Piezometer PB2	Nematoda			
Piezometer PB1	Insecta	Plecoptera		
Piezometer PB1	Crustacea	Syncarida	Bathynellidae	sp.A
Piezometer PB1	Crustacea	Syncarida	Parabathynellidae	*Atopobathynella* sp.
Piezometer PB1	Crustacea	Syncarida	Bathynellidae	sp.A
Piezometer PB1	Crustacea	Syncarida		
Piezometer PB1	Vermes			
Piezometer PB1	Vermes			
Piezometer PB1	Annelida			
Piezometer PB2	Nematoda			
Piezometer PB2	Protozoa			
Zebedee Springs	Isopoda	Phreatoicidea	Amphisopidae Mesamphisopinae	
Zebedee Springs	Isopoda	Phreatoicidea	Amphisopidae Mesamphisopinae	
Zebedee Springs	Insecta	Diptera		
Zebedee Springs	Isopoda	Phreatoicidea	Amphisopidae Mesamphisopinae	
Zebedee Springs	Vertebrata	Anura		
Killarney Bore:	Crustacea	Ostracoda		
Cave in Bream gorge	Arachnida	Araneae	Linyphiidae	
Cave in Bream gorge	Arachnida	Acarina		
Middle Spring	Crustacea	Ostracoda		
Middle Spring	Insecta	Coleoptera	Scarabaeidae: Aphodiinae	
Middle Spring	Vermes			
Middle Spring	Insecta	Trichoptera		
Black Rock Falls	Insecta	Insecta		
Black Rock Falls	Nematoda			
Black Rock Falls	Turbellaria			
Black Rock Falls	Nematoda			
Middle Spring	Insecta	?		
Cave in Bream gorge	Insecta	Diptera		
Cave in Bream gorge	Insecta	Lepidoptera		
Cave in Bream gorge	Insecta	Hemiptera		
Cave in Bream gorge	Crustacea	Copepoda		
Cave in Bream gorge	Crustacea	Ostracoda		
Mataranka Spring	Insecta	Ephemeroptera		
Mataranka Spring, N.T.	Mollusca	Gastropoda		
Sandstone cave	Insecta	Hemiptera	Reduviidae: Emesinae	
Sandstone cave	Insecta			
Sandstone cave	Mollusca	Gastropoda		
Sandstone cave	Arachnida	Araneae	Araneidae	*Argiope*? sp.
Sandstone cave	Arachnida	Araneae	Salticidae	
Sandstone cave	Arachnida	Araneae	Theridiidae	
Sandstone cave	Arachnida	Araneae	Uloboridae	*Uloborus* sp.

Sandstone cave	Insecta	Hemiptera	
Sandstone cave	Insecta	Hemiptera	
Sandstone cave	Insecta	Diptera	Culicidae
Sandstone cave	Insecta	Psocoptera	
Bream Gorge cave	Arachnida	Araneae	Lycosidae
Bream Gorge cave	Arachnida	Araneae	
Bream Gorge cave	Arachnida	Acarina: Oribatida	
Cave Spring	Crustacea	Copepoda	
Piezo No. 30	Insecta	Diptera	
Piezo PB1	Vermes		
Piezo PB1	Crustacea	Copepoda	
Piezometer PB1	Crustacea	Syncarida	
Piezometer PB1	Crustacea	Syncarida	
Piezometer PB1	Vermes		
Palm Well Creek, Well	Crustacea	Ostracoda	
Palm Well Creek, Well	Vermes		
Tickalara Well	Crustacea	Copepoda	
Tickalara Well	Crustacea	Ostracoda	
Steel Bore, Pillara B.H.P.	Crustacea	Copepoda	
Pinbilly Well	Insecta	Diptera	Culicidae

Appendix D

Karst index

Additions to the karst index
Summary of the Kimberley karst index
    East Kimberley
    West Kimberley

Karst index

Additions to the karst index

Of the newly found caves only those few that were formally described are given here in detail— the remainder are summarised in the subsequent list. Very few of the caves that were examined have been recorded as most were cursorily examined for damp soil floors worthy of greater examination for fauna and if none was found they were not further investigated. Previous records for the area are maintained by the Western Australian Speleological Group and the Speleological Research Group, Perth.

The locations of the caves are known accurately from GPS information—the coordinates here are degraded to the nearest minute of arc.

The information for KNI-31 to KNI-41 was compiled by R.D. Brooks.

KNI-31 Recorded by D. Brooks on 8/6/94.
15° 11' S; 128° 37' E
Entrance is sheer walled sink hole. Climb in down southern edge. Tag is located under an overhang on the north wall. Climb into doline to spot tag, cannot be seen from above! Slope leads down to large tunnel, soil floored approx. 100 m long.
Fauna—cockroaches, isopods, spiders, midges, springtails.
Soil damp on date of investigation.
Connects to KNI-32.
Cursorily explored and there may be further extensions.

KNI-32 Recorded by B. Vine on 8/6/94
15° 11' S; 128° 37' E
Entrance is sinkhole. Several large passages. Soil floored for most of passage extent. Tag is located on southeast side of entrance under an overhanging area. Walk into entrance to spot the tag!
Cursorily explored. Passage on left of entrance slope when entering the cave connects to KNI-31.
Explored passage extent 250-300 m?

KNI-33 Recorded by D. Brooks on 24/6/94
15° 11' S; 128° 38' E
Entrance is in side of hill approx. 50 m from KNI-31. KNI-31 bears approx. 30° from KNI-33. Walk in entrance. Cave is tunnel with small entrance at other end. Very cursorily explored. Probability of other leads very high.
Fauna—frogs.
Tag is NNW side of entrance under overhang.

KNI-34 Recorded by Barbara Jones on 20/6/94
15° 10' S; 128° 37' E
Entrance is opening in side of cliff. Approx. 15 m high and 8 m wide. Large fallen slabs. Stream outflow. Some soil. Tag is on NW wall approx. 12 m into the cave. Small leads at end of cave, very tight.
Fauna—spiders, bats.

KNI-35 Recorded by B. Vine on 21/6/94
15° 10' S; 128° 21' E
Entrance is a rockshelter type. Cave extends back a couple of dozen metres into dark zone. There is a depression approx. 50 m to the east of this entrance. Entrance can be seen whilst standing next to the depression. Some decoration.
Fauna—bats, reduviids.
Dry, dusty.

KNI-36 Recorded by Wendy Binks on 21/6/94
15° 11' S; 128° 38' E
Entrance is hole in side of north wall of The Gorge. Extensive system with climbs. Stalactites, stalagmites, shawls, flowstone, lots of cave coral. Strong outward air flow caused by chimney effect from high daylight hole. Mainly soil floor. Dry throughout at date of investigation except for one slightly humid chamber at far end. Decoration muddied from previous exploration by persons unknown. KNI-40 can be seen across the gorge on a bearing of 247°. Tag is on east wall just inside entrance.

KNI-37 Recorded by D. Brooks on 21/6/94
15° 11' S; 128° 38' E
Cave is rockshelter type. Short, low, dusty crawl under shelf.
Fully explored. Tag on north wall.

KNI-38 Recorded by W. Binks on 21/6/94
15° 11' S; 128° 38' E
Entrance is crawl in type at base of bluff. Large chamber with decoration. Contains bats. Soil floor. Tag is on roof just inside entrance. Cursorily explored. Good chance of extensions.

KNI-40 Recorded by D. Brooks on 7/6/94
15° 11' S; 128° 38' E
Entrance is hole in side of cliff. Can easily be seen from bottom of gorge. Steep slope up into cave. Hole at back of first chamber leads to 2nd chamber which is open to sky. Hole in floor almost blocked with large boulders leads to climbable pitch which goes down to strongly draughting hole in base of rift. Cursorily explored.
Fauna—bats, spiders, reduviids.
Tag is on west wall of 1st chamber just inside entrance. Dry, dusty. Contains flowstone.

KNI-41 Nefertitis Palace Recorded by B. Vine on 7/6/94
15° 11' S; 128° 38' E
Entrance is a hole in side of bluff. Dry, dusty crawl leads to 2 other entrances. Climbable pitch down to lower level which extends into a large chamber. Surveyed.
Fauna—cockroaches, pseudoscorpions, midges, schizomids, isopods, spiders, bats, springtails, beetles, mites. Further leads unlikely.
Tag is located inside entrance on the south wall, just above edge of the false floor. Contains some decoration.

Summary of the Kimberley karst index

In the following section an abbreviated complete karst index is given, excluding the above, compiled from the sources cited (usually not the primary source).

The karst regions in the Kimberley have the following prefixes-

East Kimberley

KNI	Ningbing Range
KJ	Jeremiah Hills

West Kimberley

KN	Napier Range
KO	Oscar Range
KL	Lawford and Laidlaw Ranges
KH	Horse Spring and Hull Ranges
KG	Geike area
KP	Pillara Range

Note that the karst index for the entire west Kimberley includes only 20 caves!

East Kimberley

KNI-- 1	Cave connects to KNI--2, 4, 5 and 6	Speleological Research Group
KNI- 2	Pothole connects to KNI--1, 4, 5 and 6	Speleological Research Group
KNI- 3	Pothole	Speleological Research Group
KNI- 4	Pothole connects to KNI--1, 2, 5 and 6	Speleological Research Group
KNI- 5	Cave connects to KNI--1, 2, 4 and 6	Speleological Research Group
KNI- 6	Cave connects to KNI--1, 2, 4 and 5	Speleological Research Group
KNI- 7•	Pothole	Speleological Research Group
KNI- 8	Cave	Speleological Research Group
KNI- 9•	Cave connects to KNI--15	Speleological Research Group
KNI- 10	Pothole	Speleological Research Group
KNI- 11	Cave	Speleological Research Group
KNI- 12	Pothole	Speleological Research Group
KNI- 13	Cave	Speleological Research Group
KNI- 14	Cave	Speleological Research Group
KNI- 15	Aperture, impassable connects to KNI--9	Speleological Research Group
KNI- 16	Cave	Speleological Research Group
KNI- 17	Cave	Speleological Research Group
KNI- 18	Siggins Spring	Speleological Research Group
KNI- 19	Unnamed outflow cave	Speleological Research Group
KNI- 20	N of Tanmurra Ck	Speleological Research Group
KNI- 21	N of Tanmurra Ck	Speleological Research Group
KNI- 22	NW of Tanmurra Bore	Speleological Research Group
KNI- 23	N of 4-mile Creek	Speleological Research Group
KNI- 24	Cave	Speleological Research Group
KNI- 25	N of 4-mile Creek	Speleological Research Group
KNI- 26	N of 4-mile Creek	Speleological Research Group
KNI- 27	N of 4-mile Creek	Speleological Research Group
KNI- 28	Cave	Speleological Research Group
KNI- 29	?	
KNI- 30	?	

East Kimberley (continued)

KJ-	1	Cave connects to KJ--2, 3 and 4	Speleological Research Group
KJ-	2	Pothole	Speleological Research Group
KJ-	3	Joint	Speleological Research Group
KJ-	4	Pothole	Speleological Research Group
KJ-	5	Pothole connects to KJ--7	Speleological Research Group
KJ-	6	Cave connects to KJ--9, 10 and 11	Speleological Research Group
KJ-	7	Pothole connects to KJ--5	Speleological Research Group
KJ-	8	Cave	Speleological Research Group
KJ-	9	Vertical connects to KJ--6, 10 and 11	Speleological Research Group
KJ-	10	Vertical	Speleological Research Group
KJ-	11	Vertical	Speleological Research Group
KJ-	12	Cave near KJ--8	Speleological Research Group
KJ-	13	?	Speleological Research Group
KJ-	14	?	Speleological Research Group
KJ-	15	?	Speleological Research Group
KJ-	16	Cave	Speleological Research Group
KJ-	17	?	Speleological Research Group
8K	1	Cutta Cutta Cave (Northern Territory)	Matthews 1985

West Kimberley

KG-	1	Geikie Gorge	Matthews 1985
KG-	2	Geikie Bat Cave	Matthews 1985
KG-	3	Homestead South Cave	Matthews 1985
KG-	4	Homestead South Cave	Matthews 1985
KG-	5	Homestead South Cave	Matthews 1985
KG-	6	Homestead North Cave	Matthews 1985
KG-	7	Homestead North Cave	Matthews 1985
KG-	8	Blind valley	Matthews 1985
KH-	1	Siphon Spring	Matthews 1985
KH-	2	Horse Spring	Matthews 1985
KL-	1	Cave Springs	Matthews 1985
KL-	2	Cave Springs	Matthews 1985
KL-	3	Cave Springs	Matthews 1985
KL-	4	Network Cave, Middle Cave Springs	Matthews 1985
KL-	5	Mimbi Cave	Matthews 1985
KL-	6	Nardji Cave	Matthews 1985
KL-	7	Nardji Cave	Matthews 1985
KL-	8	Nardji Cave	Matthews 1985
KL-	9	Galeru Gorge, Mt Pierre Gorge	Matthews 1985
KL-	10	Kudata Gap	Matthews 1985
KL-	11	Pluto's Way	Matthews 1985
KL-	12	Pluto's Way	Matthews 1985
KL-	13	Pluto's Way	Matthews 1985
KL-	14	Pluto's Way	Matthews 1985
KL-	15	Pluto's Way	Matthews 1985
KL-	16	Illawarra Cave	Matthews 1985
KN-	1	Old Napier Downs Cave	Matthews 1985
KN-	2	Wangahinnya Caves	Matthews 1985
KN-	3	Barnet Spring Cave	Matthews 1985

West Kimberley (continued)

KN- 4	Barnet Spring Cave	Matthews 1985
KN- 5	Window Cave	Matthews 1985
KN- 6	Window Cave	Matthews 1985
KN- 7	Pigeons Cave	Matthews 1985

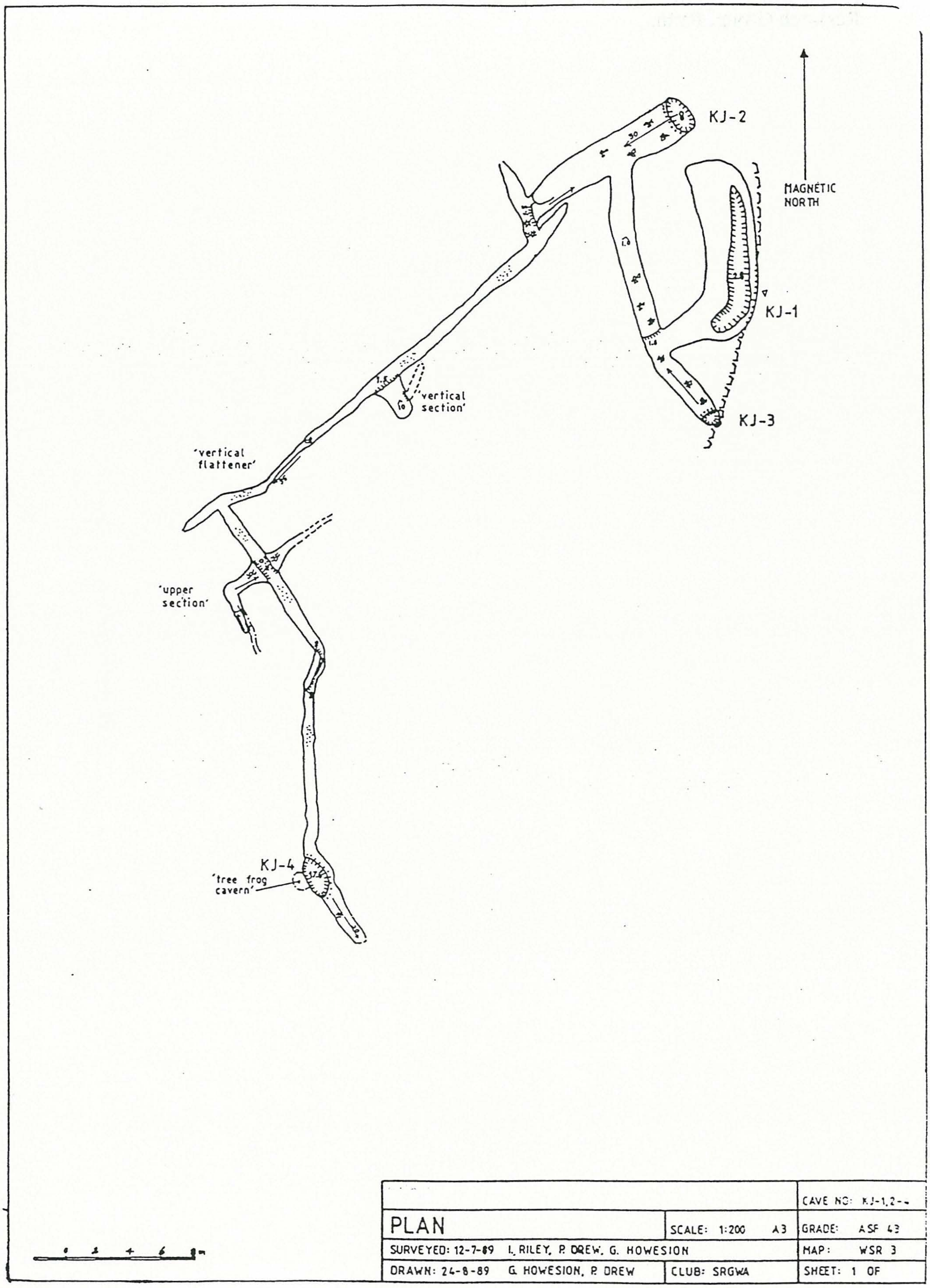
KN- 8	Bull Cave	Matthews 1985
KN- 9	Barnet Spring Gorge	Matthews 1985
KN- 10	Old Napier Downs Polje	Matthews 1985
KN- 11	Windjana Gorge, Devils Pass	Matthews 1985
KN- 12	Unnamed rising	Matthews 1985
KN- 13	Westernmost Cave	Matthews 1985
KN- 14	Westernmost Cave	Jolly and Lance 1980
KO- 1	The Tunnel	Matthews 1985
KO- 2	The Tunnel	Matthews 1985
KO- 3	The Tunnel	Matthews 1985
KO- 4	Unnamed gorge	Matthews 1985
KO- 5	Dingo Gap	Matthews 1985
KO- 6	Dingo Gap Cave	Matthews 1985
KO- 7	Brooking Yard	Matthews 1985
KO- 8	Brooking Gorge	Matthews 1985
KO- 9	Wine Spring, Bulluloo Spring	Matthews 1985
KO- 10	Pink Trigger Spring	Matthews 1985
KO- 11	Supine Spring	Matthews 1985
KO- 12	Elimerrie Spring	Matthews 1985
KO- 13	Unnamed rising	Matthews 1985
KO- 14	Fig Spring	Matthews 1985
KO- 15	Unnamed rising	Matthews 1985
KO- 16	Palm Spring	Matthews 1985
KP- 1	Menyous Gap	Matthews 1985
KP- 2	Menyous Gap Cave	Matthews 1985
KP- 3	KN-ock-on-wood Cave	Matthews 1985
KP- 4	KN-ock-on-wood Cave	Matthews 1985
KP- 5	KN-ock-on-wood Cave	Matthews 1985

Appendix E

Cave surveys

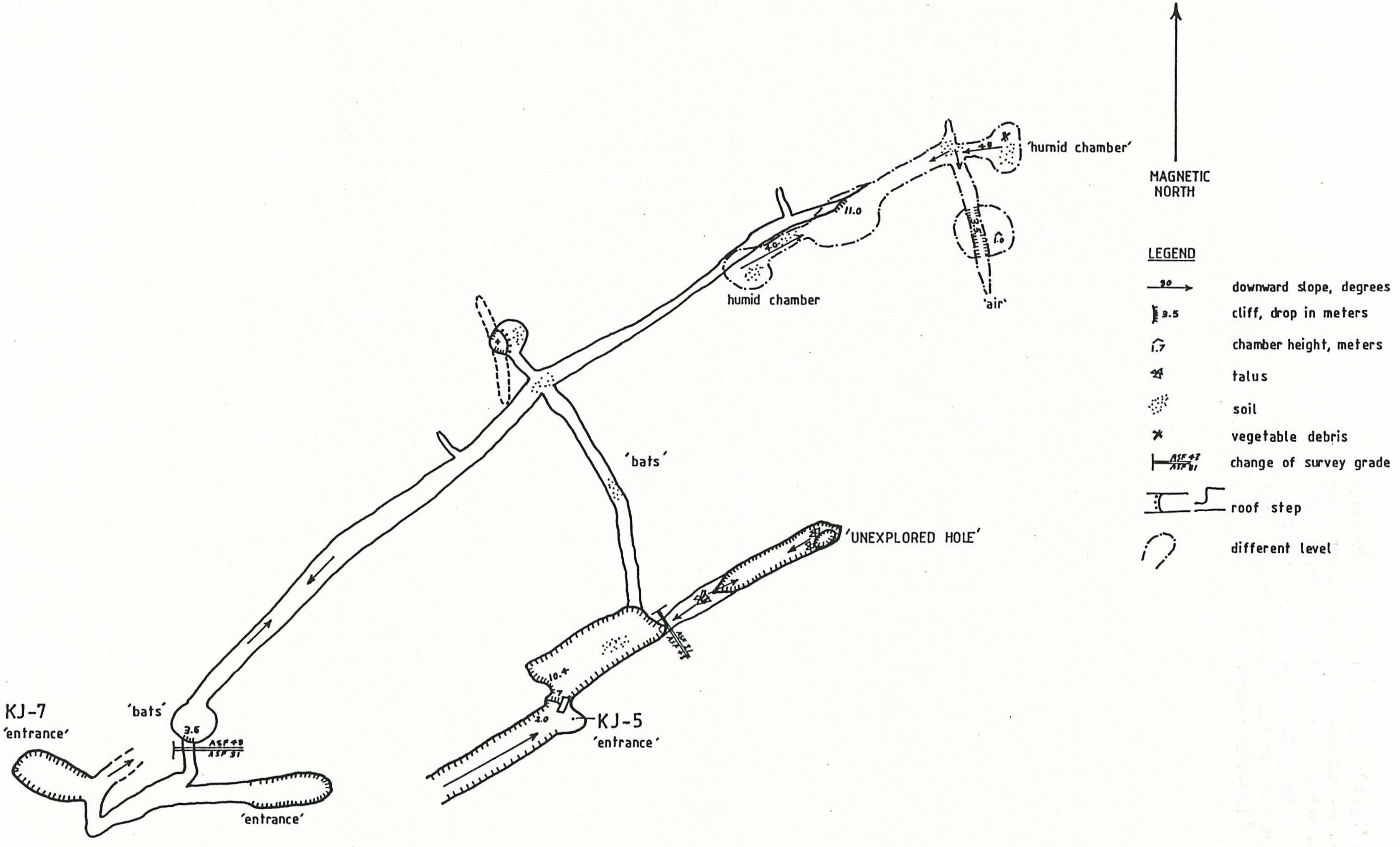
- KJ-1, 2 and 4
- KJ-5 and KJ-7
- KJ-8 and KJ-12
- KJ-8
- South Ningbing Rockhole
- KNI-1, 2, 4, and 5
- KNI-9 and KNI-15
- KNI-19
- KNI-31-37
- Central Ningbing Range
- Whale Mouth Cave—plan
- Whale Mouth Cave—section
- KNI-41

KJ-1, 2 and 4: Courtesy of Paul Drew and reproduced by permission of the Speleological Research Group, Perth.



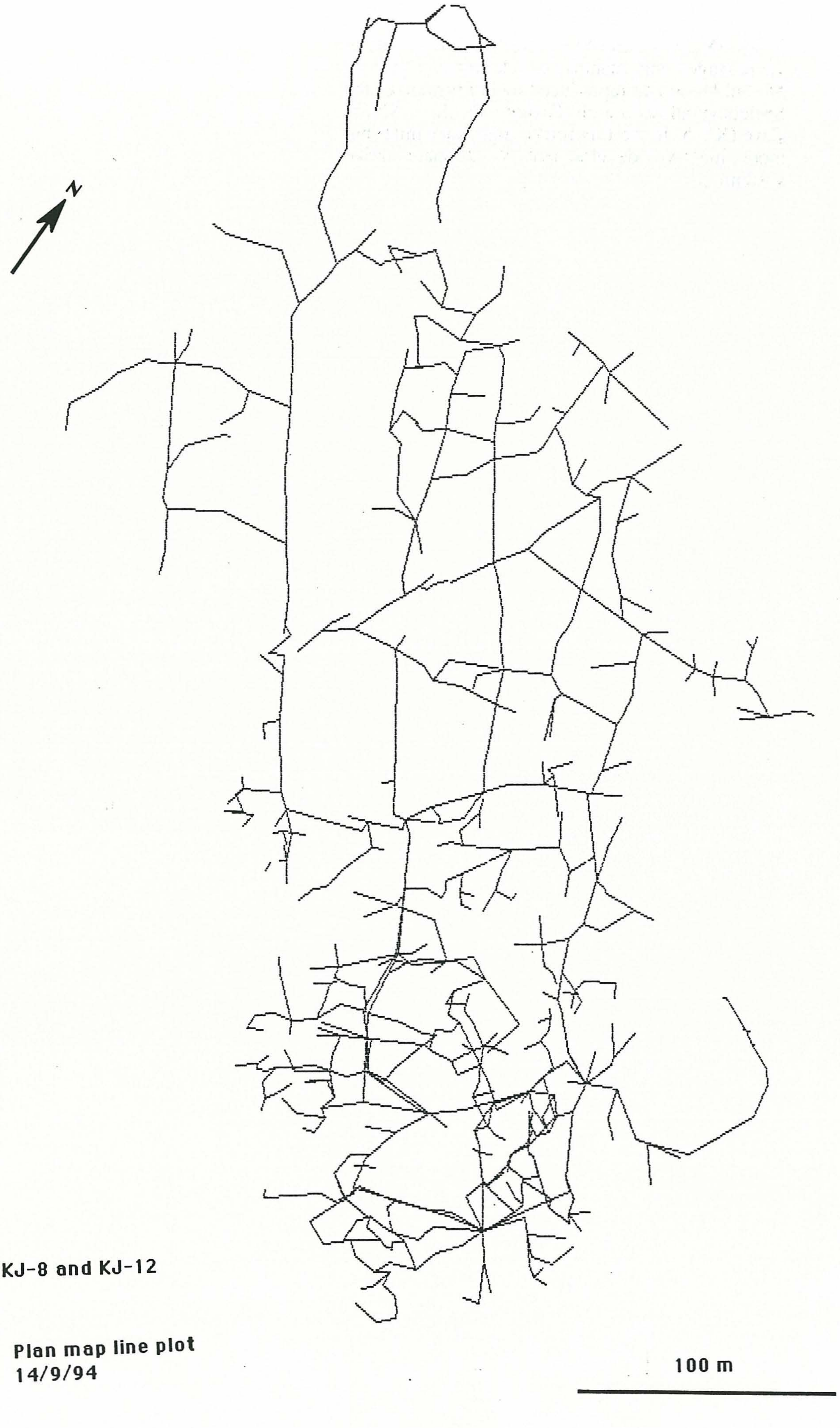
CAVE NO: KJ-1,2--
PLAN
SCALE: 1:200 A3
GRADE: ASF 43
SURVEYED: 12-7-89 I. RILEY, P. DREW, G. HOWESION
MAP: WSR 3
DRAWN: 24-8-89 G. HOWESION, P. DREW
CLUB: SRGWA
SHEET: 1 OF

KJ-5 and KJ-7: Courtesy of Paul Drew and reproduced by permission of the Speleological Research Group, Perth.

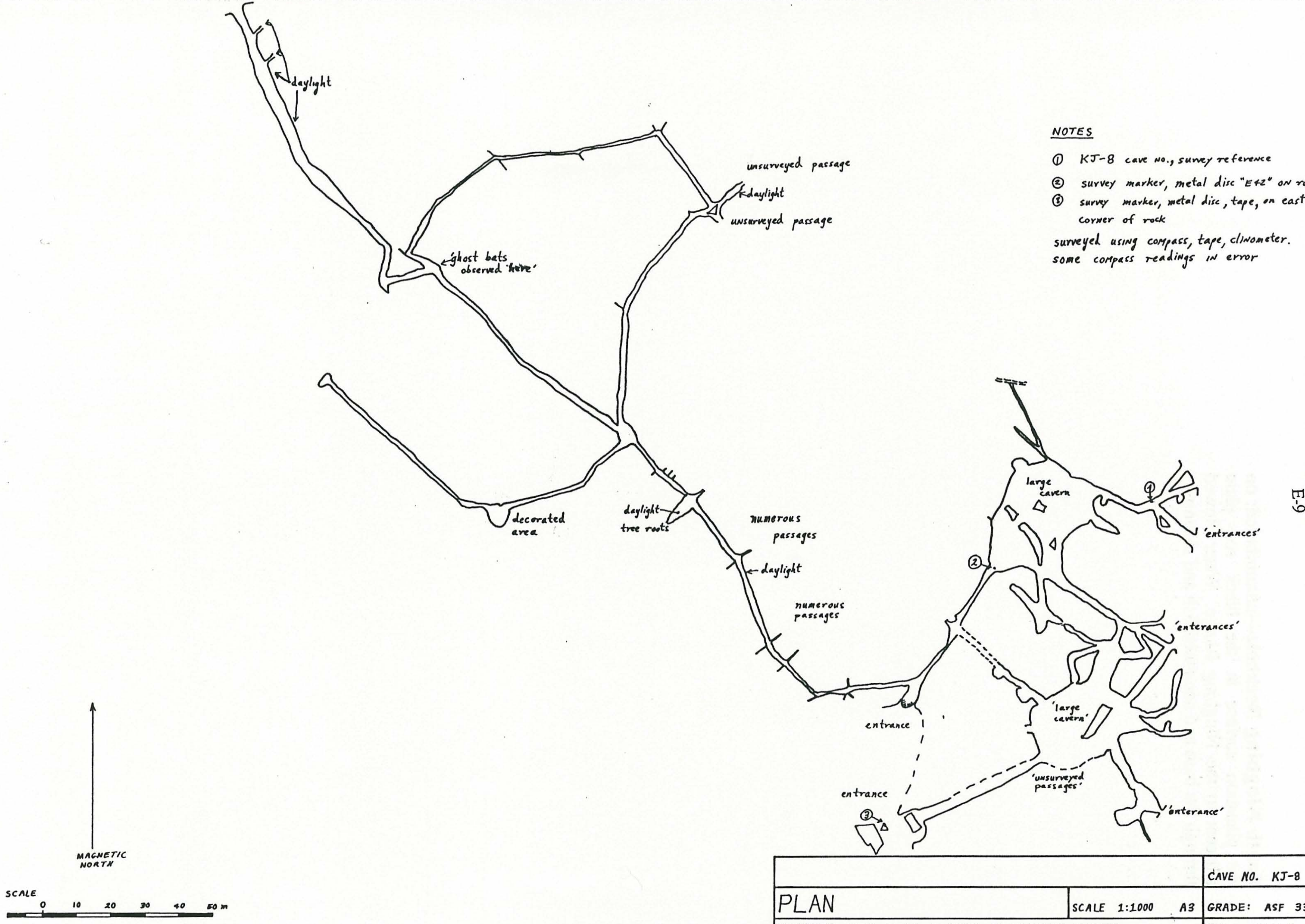


		CAVE NO. KJ-5,7
PLAN	SCALE 1:200 A3	GRADE: ASF 43/31
SURVEYED 12,13-7-89 N.& R. POULTER, R. MASTERS, I. RILEY, P. DREW		MAP: WSR 6
DRAWN 24-9-89 P. DREW, N. POULTER	CLUB: SRGWA	SHEET 1 OF

KJ-8 and KJ-12: This is a line plot of the main passages within the cave and shows clearly the manner in which the cave development follows the grid pattern of the grike development. Courtesy of Paul Drew and reproduced by permission of the Speleological Research Group, Perth.


N
KJ-8 and KJ-12
Plan map line plot
14/9/94
100 m

KJ-8: Detail of part of the cave showing details of the passages and chamber development. Courtesy of Paul Drew and reproduced by permission of the Speleological Research Group, Perth. Mimbi Cave (KL-5) in the Lawford Range is a similar but more massive development in a giant grike system.



NOTES

① KJ-8 cave no., survey reference

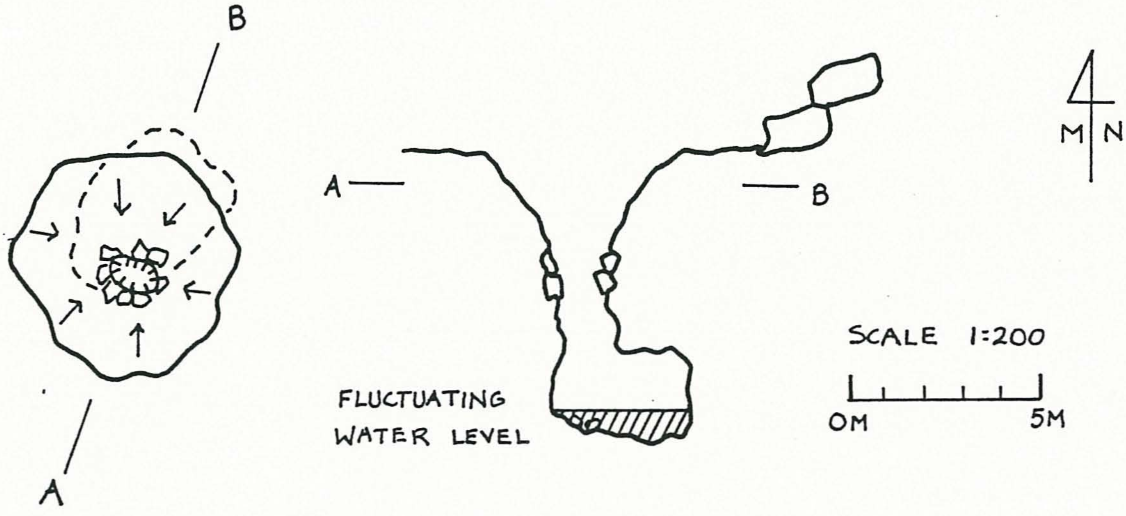
② survey marker, metal disc "E+2" on rock

③ survey marker, metal disc, tape, on east corner of rock

surveyed using compass, tape, clinometer.
some compass readings in error

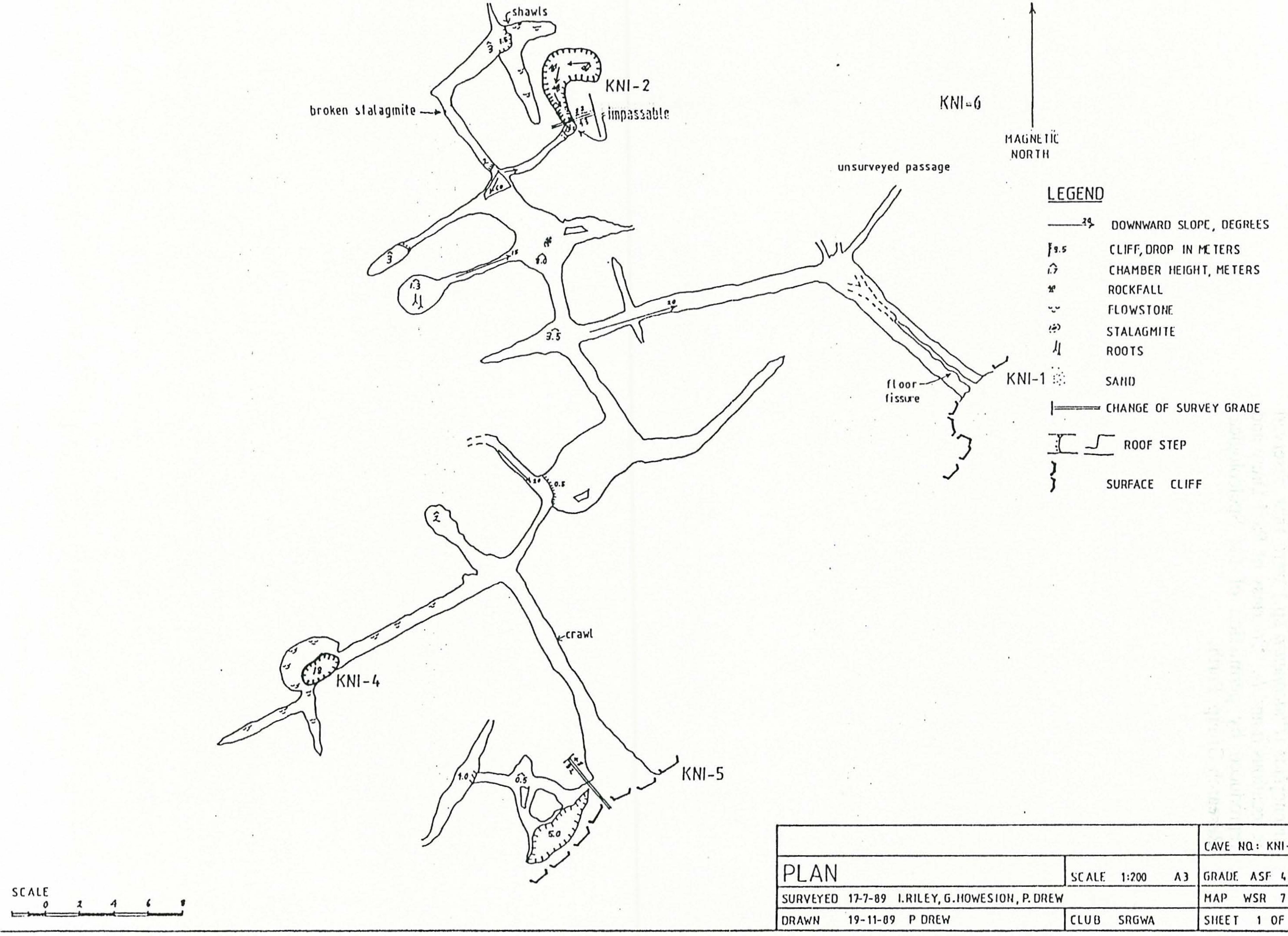
		CAVE NO. KJ-8
PLAN	SCALE 1:1000 A3	GRADE: ASF 33
SURVEYED 14,19-7-89 I. RILEY, G. NOWESION, P. DREW		MAP WSR 4
DRAWN: 3-9-89 P. DREW	CLUB: SRGWA	SHEET 1 OF

South Ningbing Rockhole—unnumbered: on the planation surface in the black soil plain adjacent to the Ningbing Range. Water flowed through the base and contained fish and shrimps.



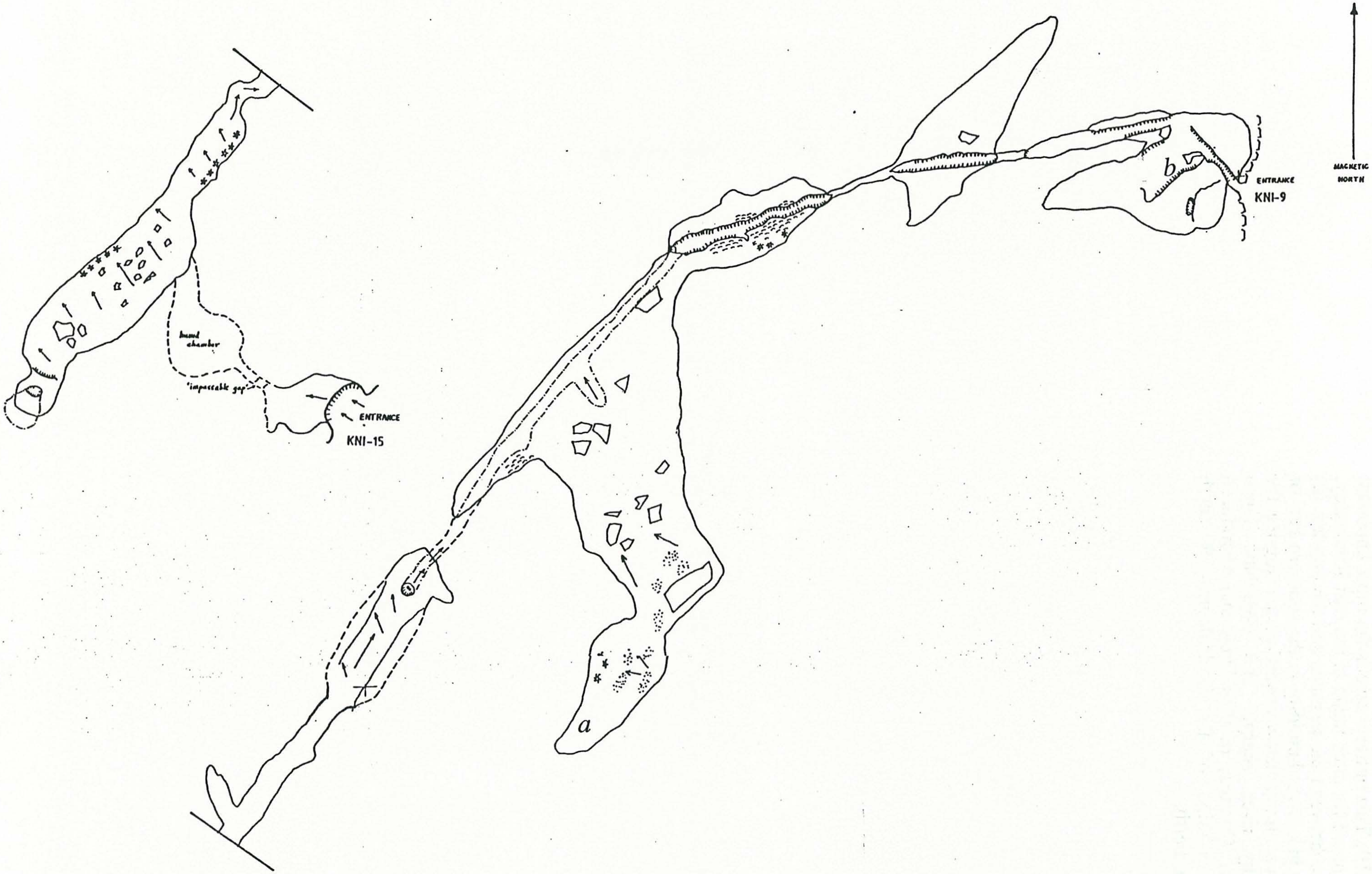
SKETCHED USING COMPASS & ESTIMATED DISTANCES ON 7-5-94 BY DARREN BROOKS

KNI-1, 2, 4, and 5: Cave development follows the grid pattern of the grike development. Courtesy of Paul Drew and reproduced by permission of the Speleological Research Group, Perth.



		CAVE NO: KNI-1,2,4,5
PLAN	SCALE 1:200 A3	GRADE ASF 43
SURVEYED 17-7-89 I.RILEY, G.HOWESION, P.DREW		MAP WSR 7
DRAWN 19-11-89 P DREW	CLUB SRGWA	SHEET 1 OF

KNI-9 and KNI-15: This important fauna cave is where the ants (*Paratrechina* sp.) attending meenoplids (*Phaconeura* sp.) were first observed at locations *a* and *b*. Courtesy of Paul Drew and reproduced by permission of the Speleological Research Group, Perth.



		CAVE NR. KNI-9,15
PLAN	SCALE: 1:200 A1	GRADE ASF 43
SURVEYED: 18-8-89 G. HOWESION, I. RILEY		MAP WSR 6
DRAWN: 5-9-89 P. DREW, G. HOWESION	CLUB: SRGWA	SHEET 1 OF

KNI-19: This outflow cave is the most important cave known for cave fauna in the east Kimberley. Airflow between the entrance and the dog-leg (*b*) results in a lower humidity in the southern half of the cave. Immediately inward of the dog-leg the humidity rises sharply and troglobitic fauna occurs. Courtesy of Paul Drew and reproduced by permission of the Speleological Research Group, Perth.

CAVE NO. KNI-19

SURVEYED: I. RILEY, G. HOWIESON, P. DREW

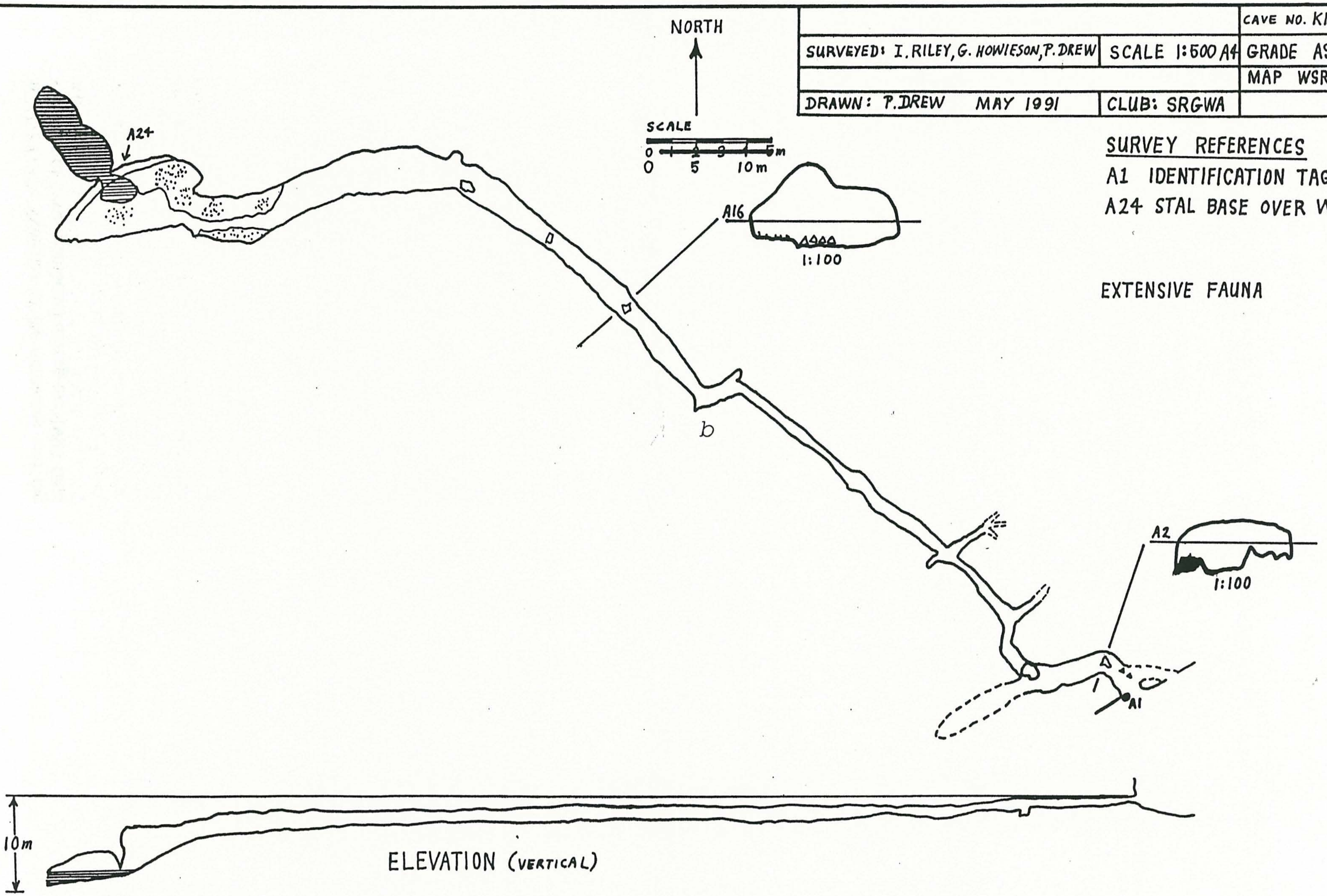
SCALE 1:500 A4

GRADE ASF 43

MAP WSR

DRAWN: P. DREW MAY 1991

CLUB: SRGWA



SURVEY REFERENCES

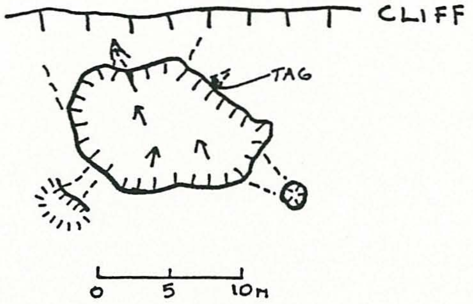
A1 IDENTIFICATION TAG

A24 STAL BASE OVER WATER

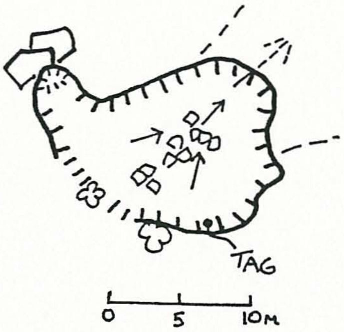
EXTENSIVE FAUNA

KNI-31-37: Sketches of the entrances and tag locations of caves numbered during the 1994 field work.

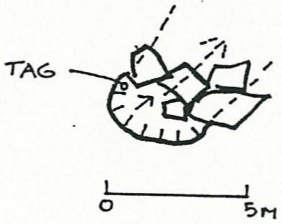
KN1 31



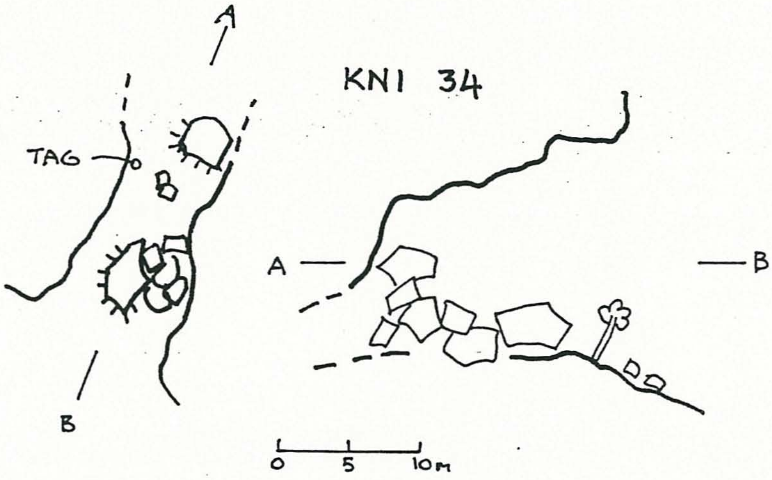
KN1 32



KN1 33

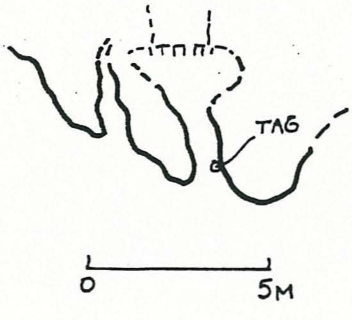


KN1 34

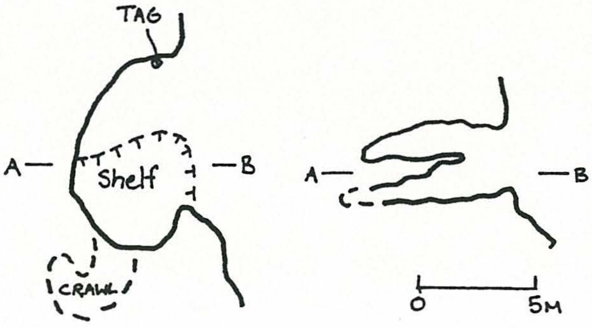


KN1 35

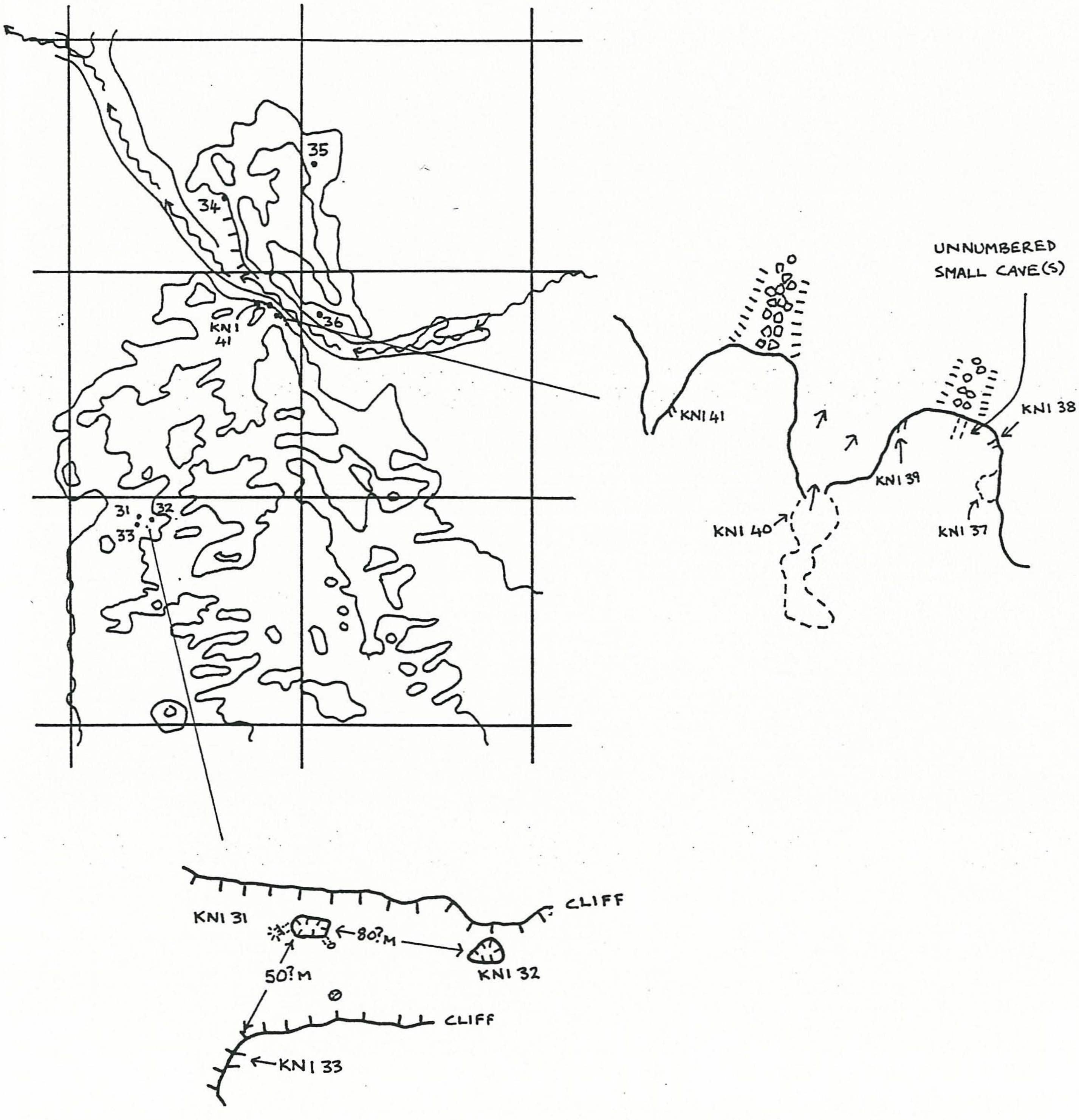
KN1 36



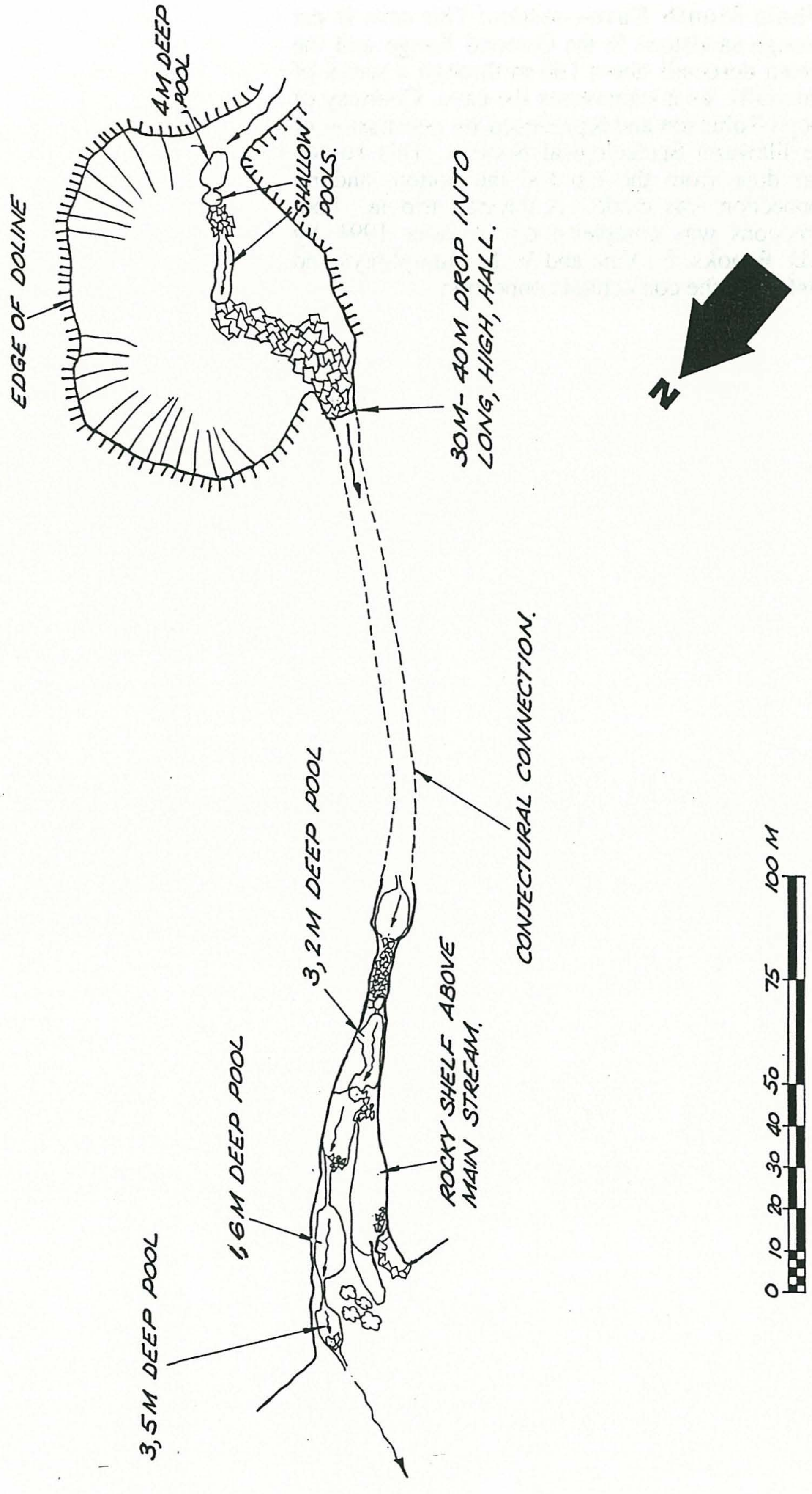
KN1 37



Central Ningbing Range: Sketches of the relative positions of some caves numbered during the 1994 field work. Some features useful for identifying the location of the caves have been deleted.


35
34
KN1 41
36
31
32
33
UNNUMBERED SMALL CAVE(S)
KN1 41
KN1 38
KN1 39
KN1 40
KN1 37
KN1 31
80?M
CLIFF
KN1 32
50?M
CLIFF
KN1 33

Whale Mouth Cave—plan: This cave is cut through sandstone in the Osmond Range and the stream descends about 160 m through a series of waterfalls as it transverses the cave. Courtesy of Lloyd Robinson and reproduced by permission of the Illawarra Speleological Society. This survey was done from the top and the bottom and no connection was made. A through trip in both directions was completed on 14 June 1994 by R.D. Brooks, B. Vine and W.F. Humphreys and confirmed the conjectural connection.



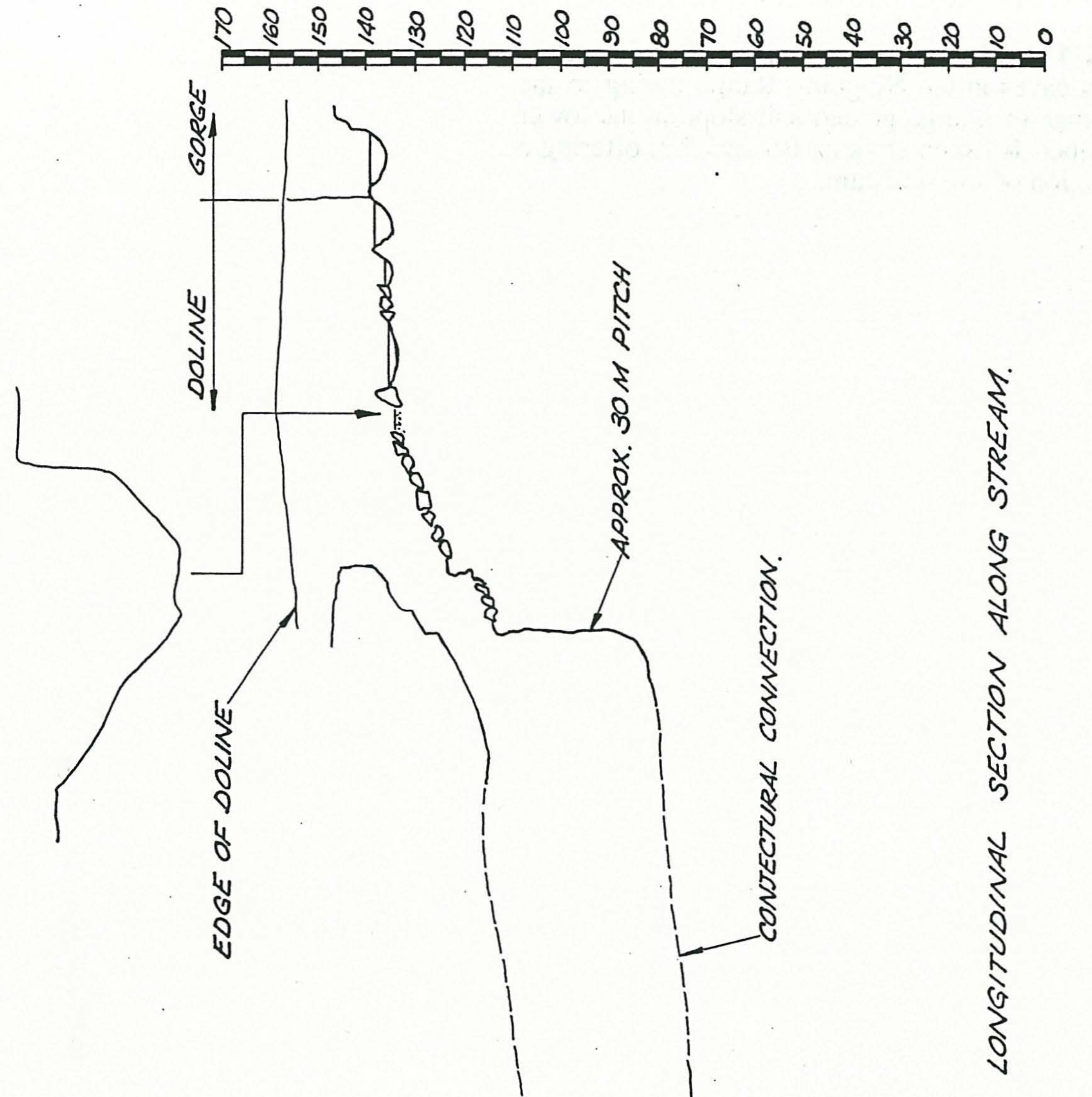
SURVEYED BY: JOE JENNINGS,
BILL, DI & HARLEY ATKINS, LLOYD &
LINDA ROBINSON & DAVE DICKER.

DRN - DAVE DICKER 6-6-82
SCALE 1:2000 ASF GRADE 5·5

WHALEMOUTH CAVE
OSMOND RA.
EAST KIMBERLEY, W.A.
SHEET 1

I.S.S.
Nº 46

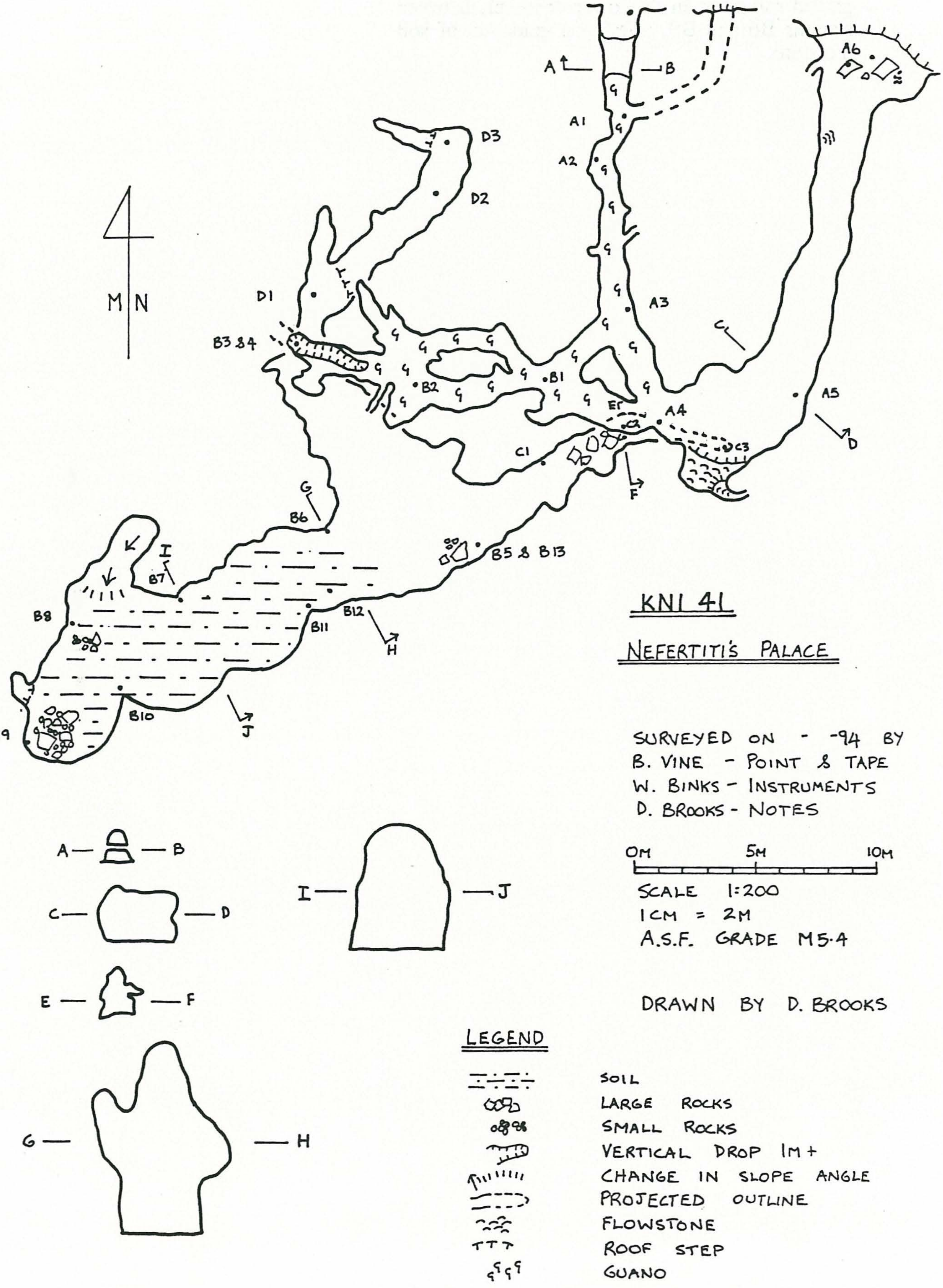
Whale Mouth Cave—section: This cave is cut through sandstone in the Osmond Range and the stream descends about 160 m through a series of waterfalls as it transverses the cave. Courtesy of Lloyd Robinson and reproduced by permission of the Illawarra Speleological Society. This survey was done from the top and the bottom and no connection was made. A through trip in both directions was completed on 14 June 1994 by R.D. Brooks, B. Vine and W.F. Humphreys and confirmed the conjectural connection.



DEVELOPED LONGITUDINAL SECTION ALONG STREAM.

DRN- DAVE DICKER 7-6-82 SCALE 1:2000	WHALEMOUTH CAVE SHEET 2	ISS MAP N° 46

KNI-41—plan. This is one of the important fauna caves in the Ningbing Range owing to the presence of a large graded soil slope in the lower chamber, between stations B6 and B9, offering a gradation of soil moisture.



KNI 41

NEFERTITI'S PALACE

SURVEYED ON - -94 BY
B. VINE - POINT & TAPE
W. BINKS - INSTRUMENTS
D. BROOKS - NOTES

0M 5M 10M

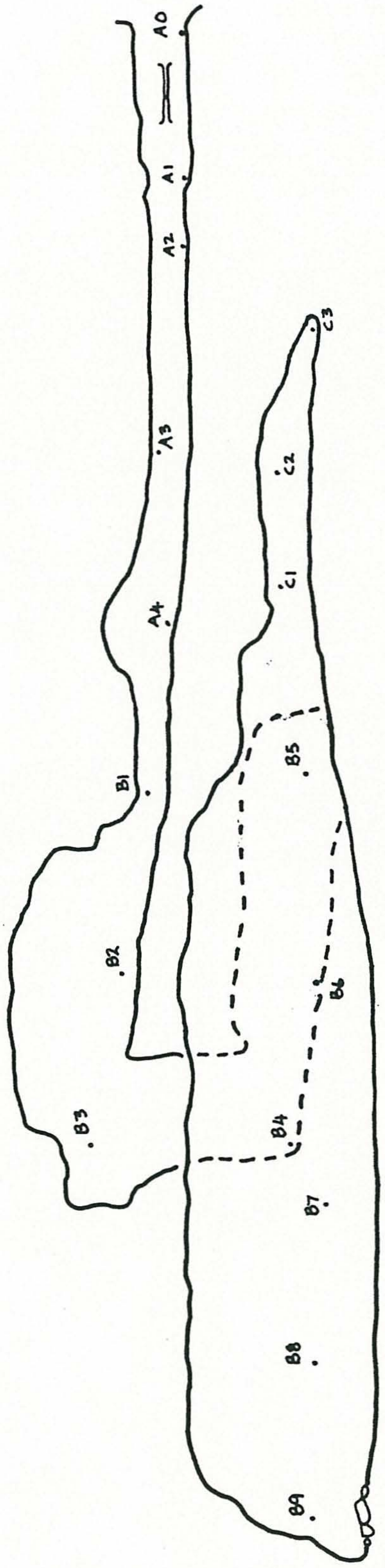
SCALE 1:200
1CM = 2M
A.S.F. GRADE M5·4

DRAWN BY D. BROOKS

LEGEND

SOIL
LARGE ROCKS
SMALL ROCKS
VERTICAL DROP 1M+
CHANGE IN SLOPE ANGLE
PROJECTED OUTLINE
FLOWSTONE
ROOF STEP
GUANO

KNI-41—section rotated 90° counter clockwise. This is one of the important fauna caves in the Ningbing Range owing to the presence of a large graded soil slope in the lower chamber, between stations B6 and B9, offering a gradation of soil moisture.


A0
A1
A2
A3
A4
B1
B2
B3
B4
B5
B6
B7
B8
B9
C1
C2
C3