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# Helictite

## JOURNAL OF AUSTRALASIAN CAVE RESEARCH

Keith Dekkers (WASG) negotiates a pitch in Khazad—Dûm, Junee, Tasmania. This cave forms one of the main inlets for water surfacing at the Junee Rising.

Photo: Andrew Pavey

# "HELICTITE"

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## ABSTRACTS AND REVIEWS

LIMESTONE IN THE JENOLAN CAVES AREA. By Leonie Chalker. Rec. Geol. Surv. N.S.W., 13 (2), 1971 : 53 - 60.

The rocks in the Jenolan Caves area, New South Wales, comprise early Palaeozoic sediments and volcanics intruded by a few small igneous bodies. In the west the sediments are thought to be Silurian in age because of lithological similarity to sediments of Silurian age elsewhere on the Capertee Geanticline. Towards the east this sequence is overlain by the Upper Silurian Jenolan Caves Limestone, an almost pure (96% - 99% $CaCO_3$), fossiliferous limestone containing the reworked remains of stromatoporoids, corals, brachiopods, gastropods, nautiloids and algae. The limestone is overlain by a sequence of sediments and volcanics which probably ranges up into the Lower Devonian. Muddy limestone lenses interbedded with shale are found about 1.5 km to the east of Jenolan Caves and occupy a similar stratigraphic position to that of the Janolan Caves Limestone.

Lists of fossil identifications by J. Byrnes and J.W. Pickett are included. Maps show localities, illustrate the generalised geology of the Jenolan Caves area, and plot the limestone on a contoured base map of the area. The belt runs almost north-south from just north of the Kanangra Walls road to Jenolan Caves. Outcrop is continuous for 5 km north from the southern end, but 2.5 km north of Jenolan Caves along McKeowns Valley the massive limestone becomes lenticular. The northernmost lens is 4 km north of Jenolan Caves.

The so-called Eastern Limestone Belt, 1.2 to 2 km east of Caves House, is shown to consist of isolated limestone lenses interbedded with shale. These lenses are thought to lie in a similar stratigraphic position to the Jenolan Caves Limestone, but probably represent a deeper water environment than that of the Jenolan Caves Limestone. The mapping of the Jenolan limestones was part of a survey of the limestone resources of N.S.W. - E.A.L.

NOTES ON AUSTRALIAN CAVE HARVESTMEN. By G.S. Hunt. Proc. 8th bienn. Conf. Aust. speleol. Fed., Sandy Bay, Tasmania, 1970 (published 1972) : 76 - 80.

Most species of Australian cave harvestmen belong to the Family Triaenonychidae. Cave-dwelling species in this family occur in southern continents and North America and these are listed along with the cavernicolous adaptations they possess. Adaptations include depigmentation and attenuation of appendages. Eye regression is noted in only one species, from Colong Caves, New South Wales. In the past, misidentification of some Australian species has led to false zoogeographical conclusions. - Author's Abstract.

# HYDROLOGICAL OBSERVATIONS AT THE JUNEE RESURGENCE AND A BRIEF REGIONAL DESCRIPTION OF THE JUNEE AREA, TASMANIA

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## Introduction

The results are presented for one year of field measurement and analysis of water samples at the Junee resurgence, one of the largest karst risings in Tasmania. The water emerges from Junee Cave at an altitude of approximately 300 m and forms the source of the Junee River at a point about 5 km northwest of the township of Maydena. The resurgence drains a large area along the southern boundary of the Mt Field National Park and appears to be fed by a number of streamsinks, the nearest of which are at least 2 km distant.

The only underground drainage connection proved so far is with one of the largest of these streamsinks, Khazad-dûm. This cave has been explored to a depth of 321 m and is recorded as Australia's deepest cave system. The Junee area is located in central southern Tasmania and is centred on 146°40' East and 42°45' South.

The Junee resurgence is the only significant rising known in the area and is commonly thought to drain most of the Junee area. This opinion is based largely on the interpretation of the geological structure as shown in the geological sketch map of Hughes and Everard (Hughes 1957). However, a more detailed examination of the area on which Figure 1 is based, suggests that the western limit of underground drainage towards the Junee resurgence may be more or less coincident with the axis of the NNW plunging Nichols Spur anticline. Further mapping of the geological structure, and water tracing, will be required to confirm this.

## Natural Environment

Relief and geology. The area is part of a belt of Ordovician limestone referred to by speleologists as the Junee-Florentine. The belt extends northwest from Maydena to Wherretts Lookout for a distance of 15 km and from there continues northwards along the valley of the Florentine River for another 25 km. The section between Maydena and Wherretts Lookout is referred to as the Junee area and is shown in Figure 1. It is an area of strong relief ranging from an altitude of more than 1300 m at Florentine and Tyenna Peaks to less than 300 m along the floodplains of the Tyenna and Junee Rivers. The North Branch of the Tyenna River crosses the southwest corner of Figure 1; flow is to the southeast. The Junee River emerges from Junee Cave and also flows to the southeast.

The southern boundary of the area is taken to be the Tyenna River, while the northwestern boundary is the surface divide between the Tyenna and Florentine Rivers. The northeastern boundary is formed by the surface divide between the Tyenna and Humboldt Rivers.

The oldest rocks in the area are lower Ordovician sandstones and mudstones, shown in Figure 1 as non-carbonate rocks underlying limestone. They outcrop in anticlinal cores southwest of Wherretts Lookout, at Nichols Spur in the centre near the lower margin of Figure 1, and further east along the Junee Ridge. These beds are overlain conformably by Gordon Limestone, with its five members in the Florentine Valley (Corbett 1964) having a total thickness of about 1500 m. The Gordon Limestone and the underlying sandstones and mudstones comprise the Junee Group. The rocks of this group have been strongly folded into a series of NNW-SSE trending anticlines and synclines which locally tend to plunge to the NNW.

The Ordovician rocks are overlain with angular unconformity by flat-lying to gently dipping Permian sediments which are predominantly of marine origin. They consist of basal tillites and conglomerates followed in the main by siltstones, mudstones and fine-grained sandstone with some thin beds of pebbly limestone. The stratigraphy of the Permian system in the area has been described in detail by Jago (1972) who carried out regional geological mapping in the Maydena Range south of Maydena. At higher elevations on the southern slopes of Florentine and Tyenna Peaks, the Permian rocks give way to a thick sill of Jurassic dolerite which also caps the higher peaks and summits.

The geology of the Junee area has not been mapped in detail. The only map available, a sketch map produced by Hughes and Everard in 1953 (Hughes 1957), gives a misleading impression of both the extent and the structure of the limestone - the information it contains has not been included in Figure 1. This figure is based on fieldwork and photo-interpretation carried out by the author and information supplied by other speleologists.

Climate. The climate is cool temperate and humid with precipitation distributed fairly evenly throughout the year with a slight tendency towards a rainfall maximum in late winter and spring. The area lies in a transition zone with a steep rainfall gradient from the sub-humid Derwent Valley to the east (mean annual precipitation of approximately 500 mm) to the superhumid southwest of the state (mean annual precipitation in excess of 1500 mm). Strong local differences are due to altitude and topography.

The nearest stations for which climatic records are available are Maydena (altitude approx. 275 m) and Lake Fenton (altitude 1000 m). Maydena is located just south of the southeastern corner of the area shown in Figure 1 and Lake Fenton is 6.5 kilometres northeast of Tyenna Peak. Nicolls and Aves (1961) give calculated average yearly rainfalls (for the standard period 1911-1940) of 1300 mm at Maydena and 1650 mm at Lake Fenton. The precipitation at Lake Fenton is probably lower than is characteristic for that

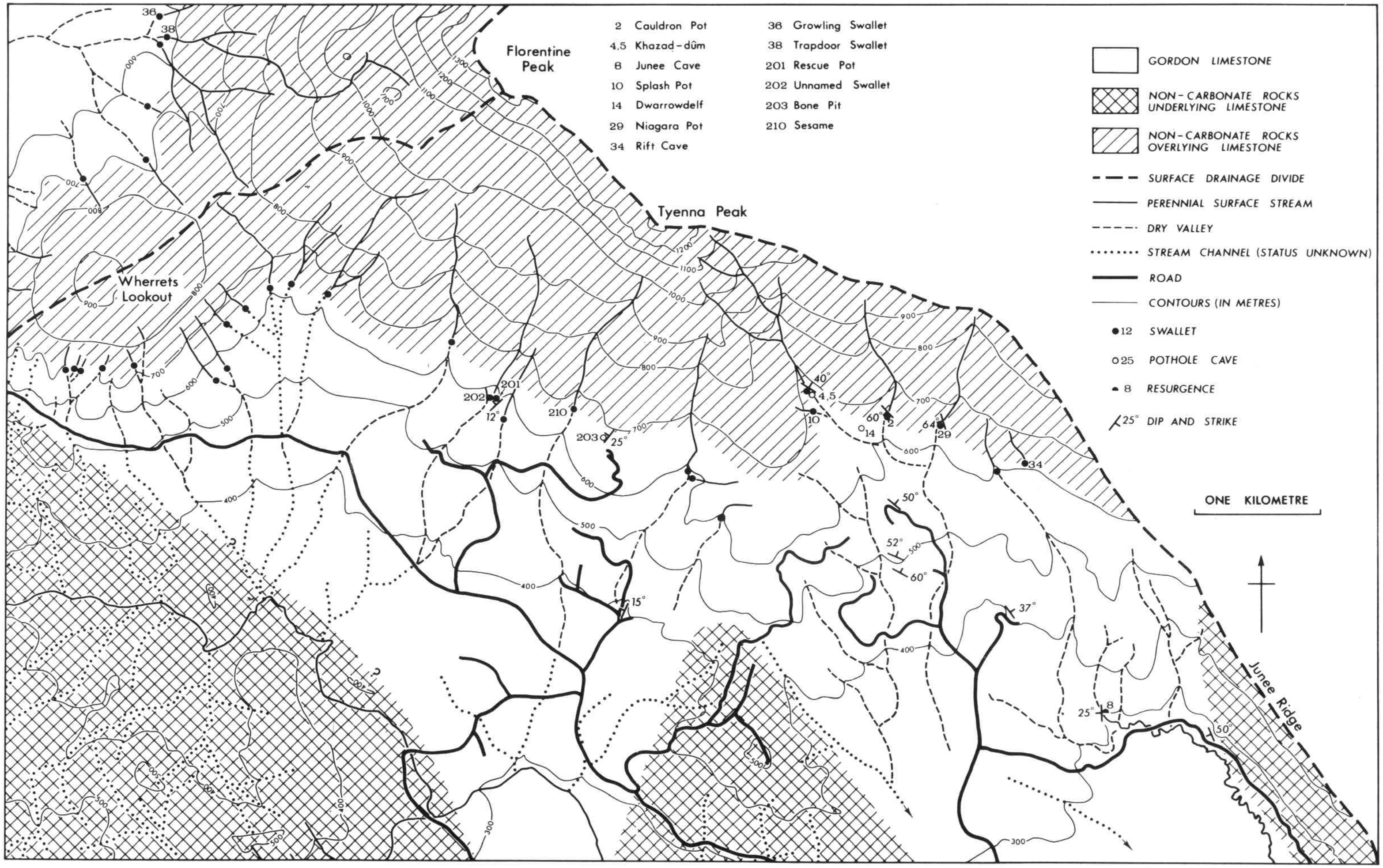

Figure 1. Selected geological and topographic features of the Junee area, Tasmania.

elevation as the site is located in a basin bordered by mountains to both the west and east. Frosts at night are common in winter down to the lowest elevations and, above 900 m, snow may remain on the ground for considerable periods between May and November. Freak snowfalls sometimes occur in midsummer. Frost shattering on limestone is evident above 600 m, but appears to be a fossil phenomenon related to colder climatic conditions than at present.

*Vegetation*. The natural vegetation up to an altitude of 900 m is wet aclerophyll forest with an upper storey of *Eucalyptus regnans* and a second storey of mature rainforest species characterized by *Nothofagus cunninghamii* (evergreen beech) and *Atherosperma moschatum* (sassafras). Rainforest is dominant in damp, steep-sided valleys. Sub-alpine dwarf forest is found at greater elevations and gives way to alpine moorland and micro-shrubbery. Most of the area above 600 m is included in the Mt Field National Park and the natural vegetation is little disturbed, except by occasional fires. At lower elevations, extensive forestry activities are carried out by Australian Newsprint Mills. Controlled burning is practised following logging and felling of the natural vegetation to encourage regrowth of eucalypts.

*Soils*. In the Junee area, the limestone at higher elevations has developed steep slopes with thin soil and humus covers. Forestry activities have caused soil stripping, exposing areas of bare limestone frequently characterized by well-developed rounded solution runnels (*Rundkarren*). At lower elevations, slopes are generally much more gentle and the limestone is covered extensively by deeper soils and alluvial deposits.

*Dry valleys*. The contact between the Gordon Limestone and the Permian sediments is sub-horizontal and rises from about 600 m near Junee Ridge to 750 m on Wherretts Lookout. The boundary is an important one as all the streams draining the steep upper slopes of Florentine and Tyenna Peaks disappear into streamsinks at, or close to, the contact. There is no surface drainage on the limestone at present, except over short distances during heavy rain. Extending across the limestone, however, is a well-integrated system of deeply incised and sometimes gorge-like dry valleys which are graded to extensive alluvial fans in the lower lying area to the south. A few good exposures of these fans are found in road cuttings. The fans contain large well-rounded dolerite boulders and pebbles which have been only superficially weathered. The fresh appearance of dry valleys and the relatively weak weathering of the dolerite materials in the fans suggest that surface drainage on the limestone last occurred not earlier than, and probably during, the Last Glaciation.

Whatever the origin of these dry valleys, it seems probable that they were subject to active modification in the Last Cold Period. It is unlikely, however, that this was the result of permafrost restoring surface flow as there is no evidence of past permafrost conditions anywhere in Tasmania. It rather appears that, at the onset of a glacial period, streamsinks were prone to blockage by a heavy sediment load of coarse gravels derived from the action of periglacial processes of weathering and mass movement.

These processes are known to have operated in Tasmania during the cold periods of the Pleistocene at least as low as 300 m. The streams would be forced to adopt surface courses across the limestone. With climatic amelioration, the sediment load would decline and the operation of solution processes would enable the streams to re-establish contact with the pre-existing underground drainage net. This is supported by evidence from Khazad-dûm where the dry valley just downstream from the present streamsink shows evidence of at least three former sinking points and exploration has shown that at least one of these is related to a partially gravel-filled former underground channel.

A similar hypothesis was put forward to explain the underground drainage in the Ida Bay area, southern Tasmania (Goede 1969). It was suggested that an anabranch of the D'Entrecasteaux River had reverted from an underground to a surface course following a period of aggradation under glacial conditions.

If substantiated, the hypothesis implies that only limited cave development occurred during glacial periods in Tasmania, as only seepage water would contribute to underground drainage. This contrasts with the view of Jennings and Sweeting (1959) who favour the association of cave elaboration with cold climate in the Mole Creek area, northern Tasmania. However, Jennings (in press) has determined a similar history to that proposed here, in his study of a dry valley on Cooleman Plain, southern New South Wales, where periglacial action also took place.

## Measurements

During the period April 1971 - March 1972 a series of measurements was made at the Junee Rising at approximately fortnightly intervals. As a few additional readings were taken during intermediate visits, a series of 29 sets of measurements is available for the period.

A fairly wide range of parameters has been measured in order to gain a better understanding of temporal variations in the physical and chemical nature of the rising water, to evaluate the most suitable parameters for continuous recording, and to collect data for the estimation of the karst denudation rate of the limestone catchment drained by the rising. Definitions of parameters measured and the sampling procedure followed are outlined in the Appendix.

## Analysis of the Data

The data are presented in numerical form in Table I and in graphical form in Figure 2. Many of the variables have a seasonal trend with a maximum in autumn and a minimum in spring. This trend is clear in the data for calcium and total hardness, conductivity, temperature and pH. A tendency towards higher values in winter is shown by discharge but no trend is indicated for 'pH difference'. From Figures 2 and 5 it appears that conductivity is a good indicator for the amounts of calcium and total hardness present. Figure 2 also indicates that variations in hardness bear a positive relationship to temperature and a negative one to discharge. The range of values obtained for each of the variables in Figure 2 is as follows :-

| | |
|---|---|
| Temperature | 6.0 - 8.8$^{\circ}$C |
| Conductivity | 100 - 210 microhm/cm |
| Field pH | 7.40 - 8.65 units |
| pH difference | 0 - 0.4 units |
| $CaCO_3$ | 44.0 - 94.5 ppm |
| $CaCO_3 + MgCO_3$ | 51.0 - 108.0 ppm |
| Discharge | 202 - 3616 litres/sec. |

Scatter diagrams of all possible combinations of pairs of variables reveal that in most cases a linear regression line would adequately present the relationships between the variables. The exception is discharge which shows non-linear trends with temperature, conductivity and both calcium and total hardness. These relationships become linear, however, when plotted on log - log paper.

Linear correlation regression analysis has been carried out and the resulting correlation matrix is shown on Table II. The figures in the lower left hand half indicate correlation coefficients for log - log relationships and, as expected, correlations are significantly higher than the linear ones between discharge on the one hand and temperature, conductivity and hardness on the other.

From the correlation matrix it can be seen that temperature, conductivity, calcium hardness, total hardness and discharge are all very closely related. Several of these relationships have been graphed. Figure 4 shows the extremely close positive linear relationship ($r = .997$) between calcium and total hardness and gives an indication of the degree of reproducibility of the titration procedure. Figure 5 shows the positive linear relationships between conductivity and both calcium hardness and total hardness. Variation in conductivity 'explains' 90.44% of the variation in calcium hardness and 90.82% of the variation in total hardness.

The portable conductivity tester used is dependable, but not particularly accurate. Conductivity values in excess of 100 units, as at Junee, can only be read to the nearest five units. When repeated measurements are made on water taken from the same sample, variations of up to 10 units may occur, indicating that most of the unexplained variation is probably due to instrument error. However, since conductivity is a measure of the total amount of ionizable substances in solution, it may in part reflect independent variations of substances other than carbonates.

Figure 6 shows the negative non-linear relationship of discharge to calcium and total hardness. Variation in discharge 'accounts for' 84.82% of the variation in calcium hardness and 81.18% of the variation in total hardness. Hardness has been determined with considerable accuracy. Some of the unex-

## TABLE I - Water Analyses, Junee Resurgence, Tasmania

| Sample Number | Date Collected | Time | Temp °C | Cond. microhm/ cm | Field pH | Saturation pH | $CaCO_3$ p.p.m. | $CaCO_3$ + $MgCO_3$ p.p.m. | Calc. discharge (1/s) |
|---|---|---|---|---|---|---|---|---|---|
| S13 | 5-iv-71 | 1530 | 8.4 | 210 | - | - | 91.5 | 107 | 233 |
| S14 | 18-iv-71 | 1610 | 8.2 | 195 | 7.95 | 7.95 | 94.5 | 108 | 202 |
| S16 | 3-v-71 | 1315 | 7.8 | 160 | 8.15 | 8.15 | 62 | 71.5 | 1214 |
| S17 | 11-v-71 | 1415 | 7.2 | 115 | 8.10 | 8.35 | 52 | 60 | 3282 |
| S18 | 18-v-71 | 1120 | 7.0 | 133 | 8.50 | 8.60 | 62 | 71 | 1214 |
| S19 | 26-v-71 | 1020 | 7.0 | 140 | 8.35 | 8.65 | 66 | 78.5 | 617 |
| S20 | 1-vi-71 | 1215 | 7.0 | 115 | 8.45 | 8.60 | 57.5 | 65 | 1158 |
| S24 | 14-vi-71 | 1210 | 7.0 | 125 | 7.80 | 8.10 | 61 | 71 | 1196 |
| S25 | 28-vi-71 | 1230 | 6.5 | 104 | 8.20 | 8.60 | 54 | 63.5 | 3475 |
| S26 | 8-vii-71 | 1200 | 6.2 | 110 | 8.20 | 8.30 | 54 | 65.5 | 1662 |
| S27 | 11-vii-71 | 1230 | 6.6 | 125 | 8.20 | 8.50 | 54 | 65 | 2372 |
| S28 | 26-vii-71 | 1200 | 6.2 | 155 | 7.60 | 7.80 | 67 | 78 | 709 |
| S29 | 9-viii-71 | 1250 | 6.4 | 145 | - | - | 63 | 73 | 855 |
| S31 | 22-viii-71 | 930 | 6.0 | 112 | 7.95 | 7.95 | 52 | 60 | 1452 |
| S32 | 5-ix-71 | 1340 | 6.2 | 130 | 7.70 | 7.80 | 55 | 65 | 1196 |
| S33 | 20-ix-71 | 1140 | 6.0 | 118 | 7.60 | 7.80 | 49 | 56 | 1312 |
| S34 | 4-x-71 | 1200 | 6.8 | 120 | 7.40 | 7.75 | 51.5 | 60 | 1971 |
| S35 | 18-x-71 | 1120 | 6.5 | 110 | 7.80 | 8.00 | 49 | 56 | 2372 |
| S36 | 1-xi-71 | 1200 | 6.8 | 100 | 7.60 | 8.00 | 44 | 51 | 3616 |
| S37 | 15-xi-71 | 1225 | 7.4 | 140 | 7.70 | 7.80 | 63.5 | 74 | 923 |
| S38 | 29-xi-71 | 1220 | 7.0 | 130 | 7.70 | 8.00 | 54 | 62.5 | 1577 |
| S39 | 13-xii-71 | 1245 | 7.2 | 125 | 7.75 | 7.80 | 59.5 | 69 | 941 |
| S42 | 26-xii-71 | 1330 | 8.0 | 165 | 7.60 | 7.60 | 77 | 88.5 | 474 |
| S43 | 10-i-72 | 1200 | 8.0 | 130 | 7.70 | 7.70 | 57.5 | 66 | 1618 |
| S44 | 24-i-72 | 1325 | 8.0 | 170 | 7.50 | 7.70 | 76.5 | 88 | 408 |
| S45 | 7-ii-72 | 1250 | 8.0 | 140 | 7.80 | 8.00 | 62 | 70.5 | 838 |
| S46 | 21-ii-72 | 1230 | 8.2 | 180 | 8.40 | 8.55 | 77 | 89.5 | 461 |
| S47 | 6-iii-72 | 1220 | 8.8 | 180 | 7.95 | 8.10 | 81 | 93 | 287 |
| S48 | 19-iii-72 | 1225 | 8.0 | 145 | 8.50 | 8.55 | 65 | 74.5 | 434 |

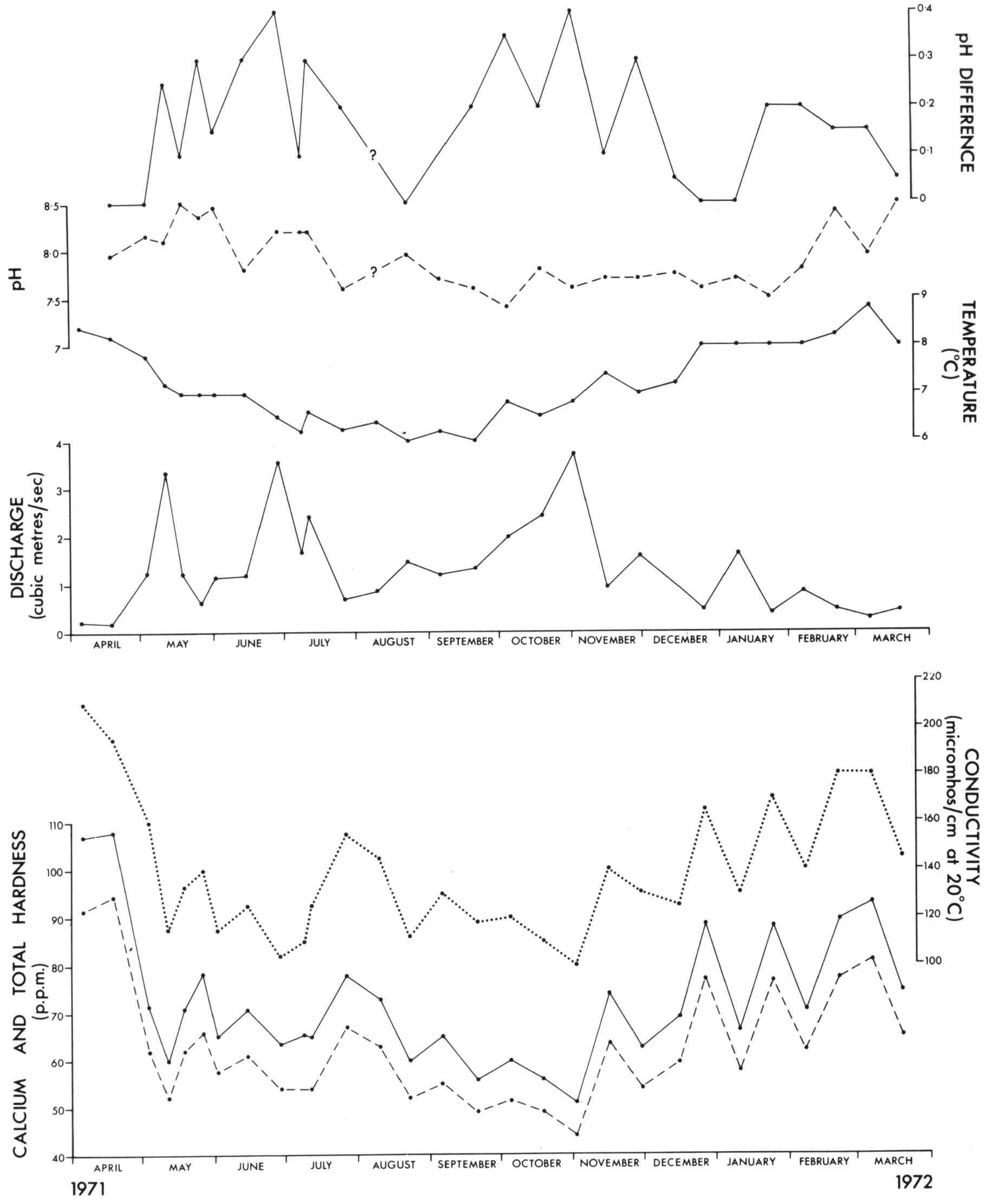

Figure 2. Variations of physical and chemical parameters of water flow at the Junee Rising for the period April 1971 to March 1972.

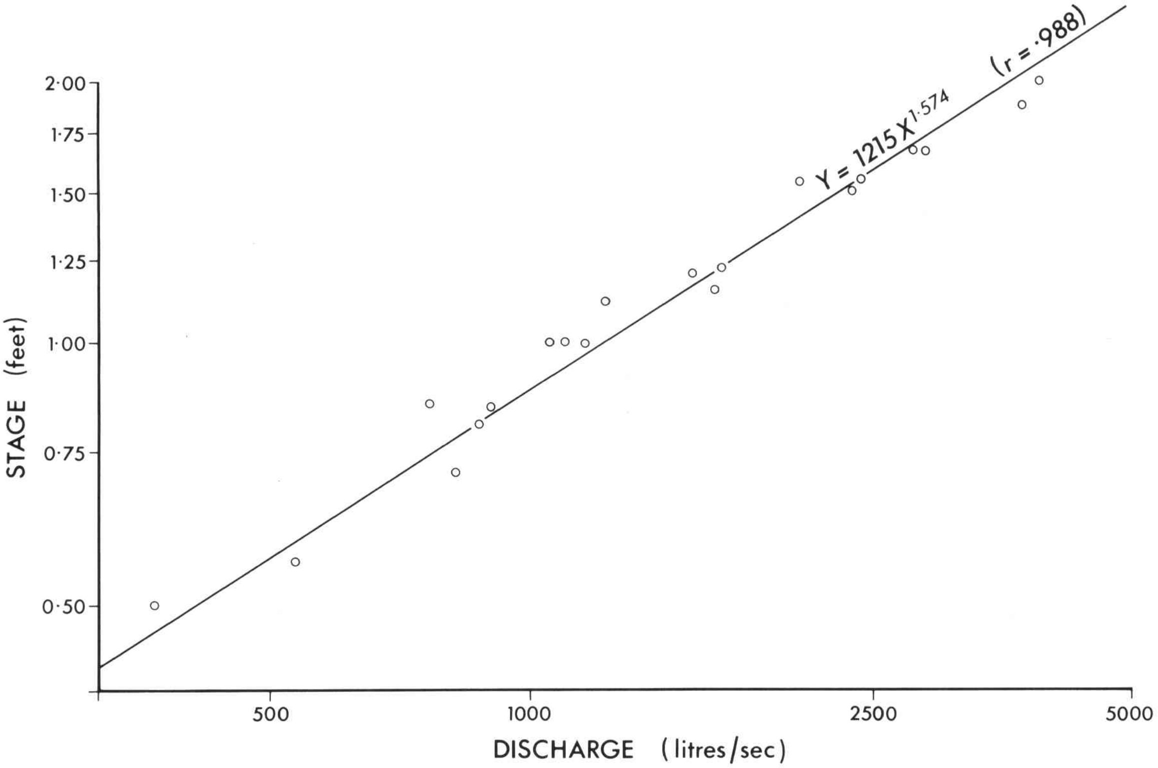

Figure 3. Relationship of stage to discharge.

plained variation may be due to errors in the determination of discharge, although individual errors are largely eliminated by the use of calculated rather than measured discharge (see Appendix). Most of the unexplained variation is probably due to other factors such as :-

1. Sampling when discharge is changing rapidly. For a given discharge hardness tends to be higher during the rising stage of a flood pulse and lower during the falling stage than under stable flow conditions.

2. Under flood conditions the relative contributions to the flow of streamsink and seepage water may change quite rapidly and, since seepage water derived from soil covered limestone is likely to contain higher concentrations of carbonate than streamsink water, this may be another source of variation.

3. Temporal variations in the concentration of carbon dioxide in the soil may cause variations in the amount of carbonate dissolved by seepage water contributing to the flow.

Table II also indicates that field pH and saturation pH are closely related to each other, but bear no significant relationship to any of the other variables. pH difference, which can be regarded as a measure of aggressiveness of the water, shows a significant positive linear correlation with discharge (Figure 7) and a probably significant negative relationship with calcium and total hardness (Figure 8) as well as with conductivity. The values for 'pH difference' must be regarded as rather crude, since they range from 0 - 0.4 pH units, while each of the measurements needed in their determination can be read only to the nearest 0.05 of a unit when the limits of accuracy of the pH meter are taken into account. The relationships found are at least suggestive and would probably improve if pH difference could be determined with the same degree of accuracy as the variables with which it is correlated.

Total hardness shows a highly significant positive correlation with temperature and a similar negative correlation with discharge. Although temperature and discharge show a highly significant inverse relationship to each other, they vary in part independently. Therefore, the possibility should be examined and total hardness can be predicted more accurately when discharge and temperature are both taken into account as 'independent' variables. Multiple correlation regression analysis can be used to test this possibility.

The technique may be used where a single independent variable X cannot adequately predict the value of a dependent variable Y. In such a situation Y may be related to a set of independent variables $X_1$, $X_2$ , ... $X_k$ which, between them, enables one to make a much more accurate prediction of the value of Y.

One of the first applications of the technique in the earth sciences was used by Krumbein (1959) to predict the foreshore slope of a beach in terms of four independent variables consisting of sedimentary parameters related to beach 'firmness'. Full details of the general linear model to be used here are given in Krumbein and Graybill (1965).

## TABLE II - LINEAR AND LOG LINEAR CORRELATION MATRICES FOR VARIABLES SHOWN IN FIGURE 3

| | Temperature | Conductivity | $CaCO_3$ | $CaCO_3$ $+MgCO_3$ | Discharge | Field pH | Saturated pH | pH difference |
|---|---|---|---|---|---|---|---|---|
| Temperature | - | .743<br>*** | .739<br>*** | .716<br>*** | -.501<br>** | .103 | -.026 | -.339 |
| Conductivity | .728<br>*** | - | .953<br>*** | .951<br>*** | -.763<br>*** | .022 | -.140 | -.433<br>* |
| $CaCO_3$ | .721<br>*** | .934<br>*** | - | .997<br>*** | -.756<br>*** | .103 | -.057 | -.423<br>* |
| $CaCO_3 + MgCO_3$ | .692<br>*** | .926<br>*** | .996<br>*** | - | -.747<br>*** | .116 | -.037 | -.403<br>* |
| Discharge | -.633<br>*** | -.894<br>*** | -.921<br>*** | -.901<br>*** | - | -.043 | .178 | .588<br>** |
| Field pH | .108 | .020 | .131 | .145 | -.064 | - | .929<br>*** | -.126 |
| Saturated pH | -.016 | -.149 | -.039 | -.018 | .126 | .927<br>*** | - | .250 |
| pH difference | -.324 | -.437<br>* | -.431<br>* | -.410<br>* | .490<br>** | -.124 | .256 | - |

* significant at $P < 0.05$; ** significant at $P < 0.01$; *** significant at $P < 0.001$

n = 29 for correlations not involving pH parameters; n = 27 for correlations involving one or two pH parameters

Linear coefficients are shown in upper right half of table; log linear coefficients in lower left half of table

The assumption is made that the following model fits the situation, at least as a first approximation:

$$Y = \mu_Y + e$$

where $\mu_Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots \beta_n X_n$

with $\beta_0, \beta_1, \beta_2$, etc. as the unknown parameters and e as an error term.

One of the objectives of multiple regression analysis is to find a prediction equation for Y where the expected value of Y is denoted by E(Y) and

$$E(Y) = \hat{\beta}_0 + \hat{\beta}_1 X_1 + \hat{\beta}_2 X_2 \ldots \hat{\beta}_n X_n$$

where $\hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2$, etc. are the estimators of $\beta_0, \beta_1, \beta_2$, etc. respectively.

Predictor equations for Y can be calculated for any one (simple linear model) or any combination of more than one independent variable (general linear model). In the case of the simple linear model, the adequacy of the independent variable in predicting a value for Y is measured by the correlation coefficient (r) while in the general linear model the measure of adequacy is the multiple correlation coefficient (R), which is basically the simple correlation coefficient between the actual and the predicted values of Y.

Use is made of a computer programme (MULTREG-F, U1666, F) adapted for use with the University of Tasmania's Elliott 503/PDP - 8L computer by Chick (1972) from the original programme (DUMRA) developed for the Elliott 803 by Dr. B.A. Davies, University College of Wales, Aberystwyth, U.K. In the analysis, the logarithm of total hardness is taken as the dependent variable and the logarithms of discharge and temperature as the 'independent' variables. The following regression equation is obtained :-

$$\log H = 2.169 + .303 \log T - .191 \log D$$

where H - total hardness, T - temperature and D - discharge. The multiple correlation coefficient R = .931; thus the percentage of variance 'explained' is 86.74%. In the investigation of logarithmic relationships, it has previously been found that discharge alone 'explains' 81.18% of the variance of total hardness and that temperature alone explains 47.89%. Therefore temperature variations which are independent from discharge account for only 5.56% of the variance of total hardness. But since temperature and discharge are closely related to each other (Table II) their effects cannot be isolated and all one can say is that discharge is a more important factor than temperature in explaining variations in total hardness.

Figure 9 shows the instantaneous rates of calcium and magnesium 'carbonate equivalent' removal and are obtained by multiplying discharge by total hardness. The rate of removal of carbonates can be expected to bear a very close statistical relationship to discharge, since it is one of the two variables used in the calculation and the other variable, total hardness, is closely related to discharge. However, since the latter relationship is not linear, a non-linear relationship must be expected between rates of removal and discharge.

When correlation regression analysis is applied to this relationship using the logarithm of discharge as the independent variable and the logarithm of carbonate removal rate as the dependent variable, the following regression equation is obtained :

$$C = .3241\, D^{.7809} \qquad (r = .993)$$

where C - instantaneous rate of calcium and magnesium 'carbonate equivalent' removal and D - discharge. The correlation coefficient is significant at the 0.1% level and the percentage of variance 'explained' is extremely high at 98.68%. It shows that discharge alone can be used to predict the rate of carbonate removal to a high degree of accuracy.

The mean instantaneous rate of calcium and magnesium 'carbonate equivalent' removal is calculated from the data as 85.41 g/sec. The amount of carbonate material removed in solution over the one year period of record is calculated as $2.693 \times 10^6$ kg or 2693 tonnes.

## Discussion of Results

The observations made at the Junee resurgence show that concentrations of carbonate are surprisingly low when compared with values obtained in Western Europe and particularly the British Isles. In Australia, only one other study is available, where Jennings (1972 a,b) for a number of years has carried out regular sampling at the Blue Waterhole, Cooleman Plain, N.S.W. The hardness values he obtained are comparable with those observed at Junee Cave.

There may be two reasons for the low hardness values :

1. The mature wet sclerophyll forest which covers most of the area appears to have a low growth rate which, combined with shallow soils on many of the steeper slopes, may limit $CO_2$ enrichment of the soil atmosphere.

2. A substantial amount of the water emerging at Junee Cave is supplied by streamsinks and apparently moves rapidly through the limestone in large conduits. This is supported by the only water tracing carried out so far in the area, when 4.5 kg of fluorescein was used to trace the connection between Khazad-dum and Junee Cave. Although the linear distance between the two is approximately 3.4 km, the first of the dye appeared at the resurgence only 11 hours after being injected at the streamsink. Conditions of flow at the time were above average, but well below flood level.

The analysis of measurements suggests that conductivity is a good indicator of the amount of carbonate present and, with a more sophisticated instrument, could be used for continuous monitoring of the degree of hardness. Measurements of variation in field and saturated pH seem to bear no close relationships to any of the other variables and remain largely unexplained. However, 'pH difference' appears to be a potentially useful measure of the degree of aggressiveness of the water, provided it can be determined more accurately than was possible in this study.

It has been shown that discharge is the most important variable controlling the rate of removal of carbonate, and its long-term recording is therefore most important in calculating meaningful rates of limestone removal.

## Further Research

The ultimate aim of this continuing study is to calculate denudation rates for the area of limestone drained by the Junee Rising and further investigations on the drainage of the area are planned:

1. Accurate determination of the watershed of the Junee catchment. As indicated earlier this will involve further geological mapping and water tracing.

2. Examination of the nature of the water entering the streamsinks along the limestone margin. Sampling of the three largest (Khazad-dum, Cauldron Pot and Niagara Pot) is being undertaken on a fortnightly basis, while concurrent observations are continuing at Junee Cave. Indications are that sinking waters already contain appreciable concentrations of carbonate when they first enter the limestone and that these concentrations differ significantly between the three streamsinks.

3. Since there is such a close correlation between the rate of removal of carbonates and the discharge at the Junee Rising, the possibility of reconstructing a longer discharge record will be investigated by examining the relationship between discharge and climatic parameters recorded at the Maydena climatic station and/or with the discharge record of the Hydro-Electric Commission's Westerway stream gauging station on the Tyenna River downstream from Maydena.

## Acknowledgments

I am much indebted to fellow members of the Tasmanian Caverneering Club and to members of the Southern Caving Society for their company in the field and for information they have supplied on the Junee area. The Australian Newsprint Mills kindly made available their large-scale contoured maps which form the basis of Figure 1. Thanks are due also to Miss K. Draper who drew the figures.

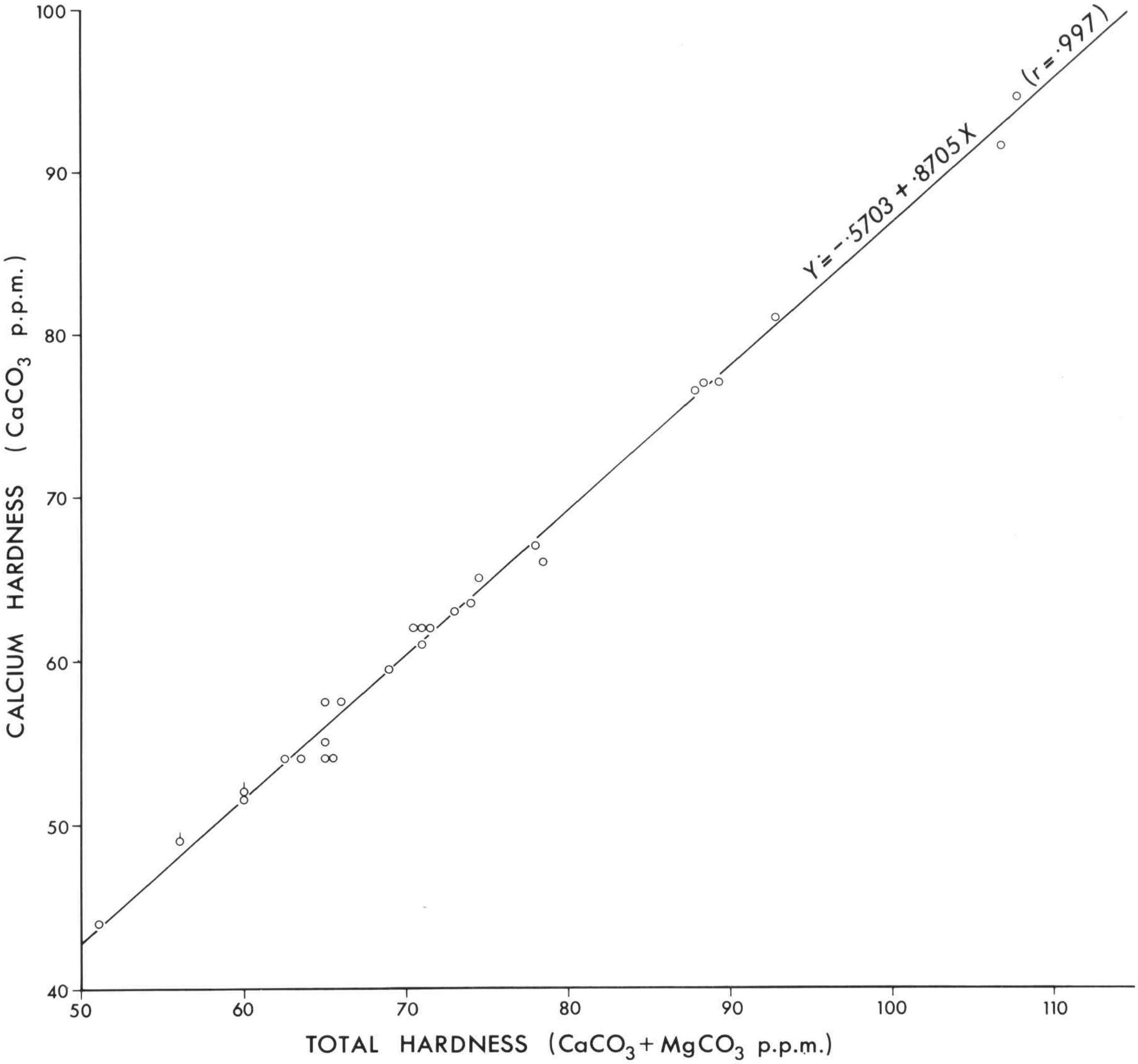

Figure 4. Relationship of total hardness to calcium hardness.

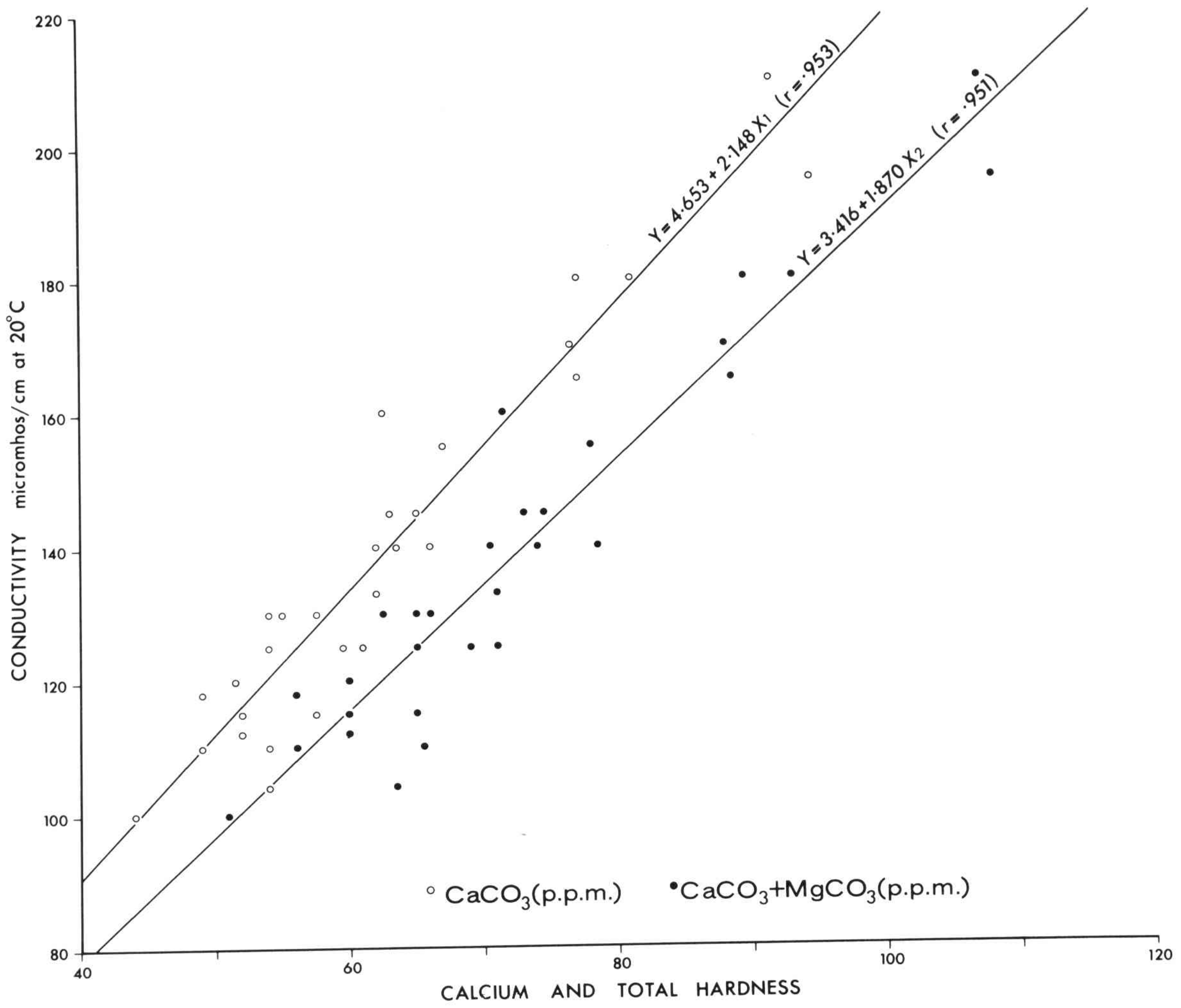

Figure 5. Relationships of calcium and total hardness to conductivity.

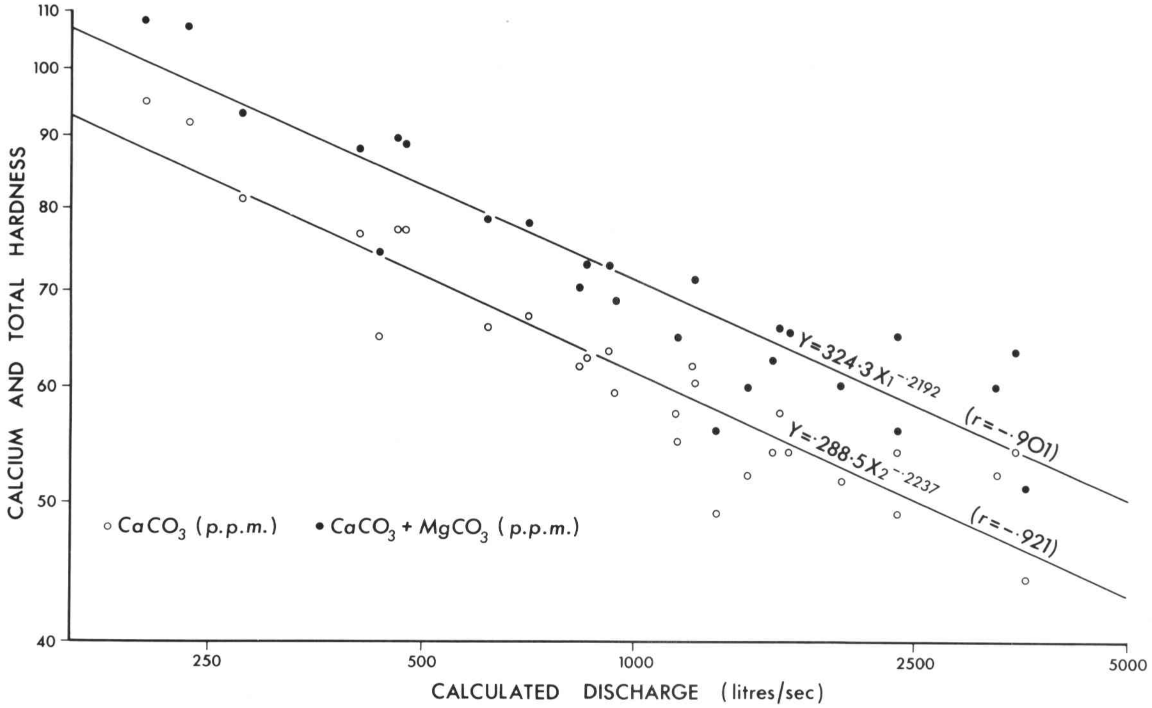

Figure 6. Relationships of calculated discharge to calcium and total hardness.

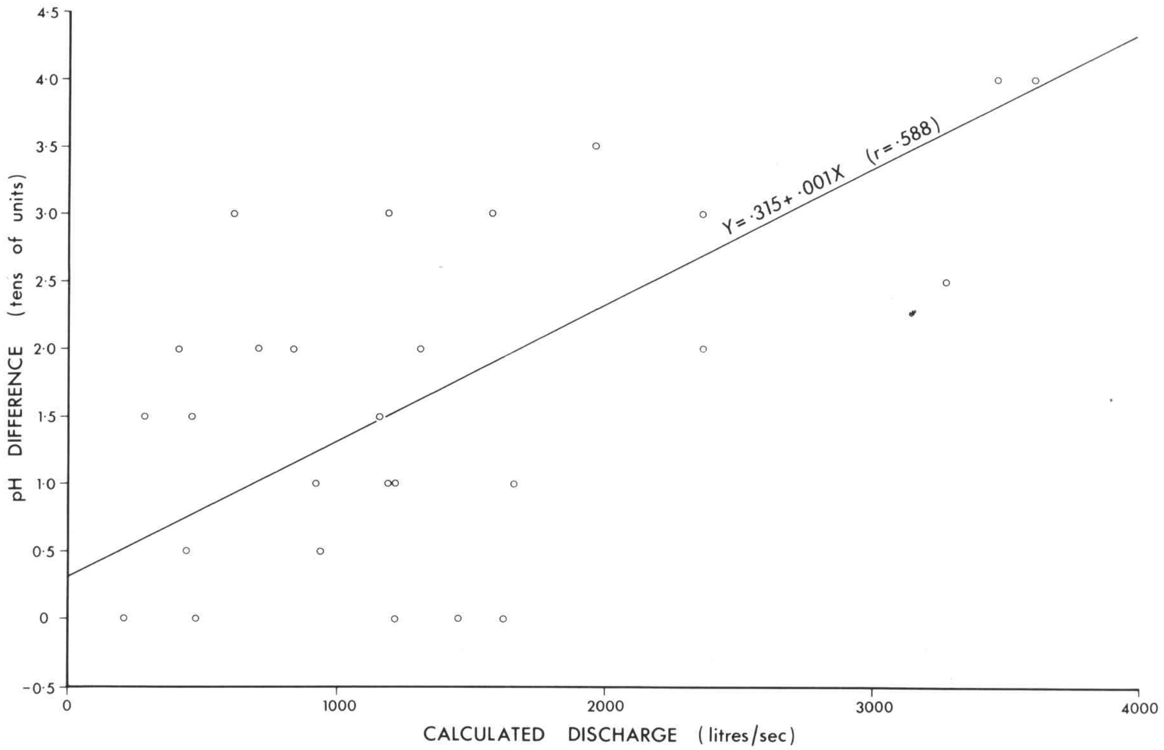

Figure 7. Relationship of calculated discharge to 'pH difference'.

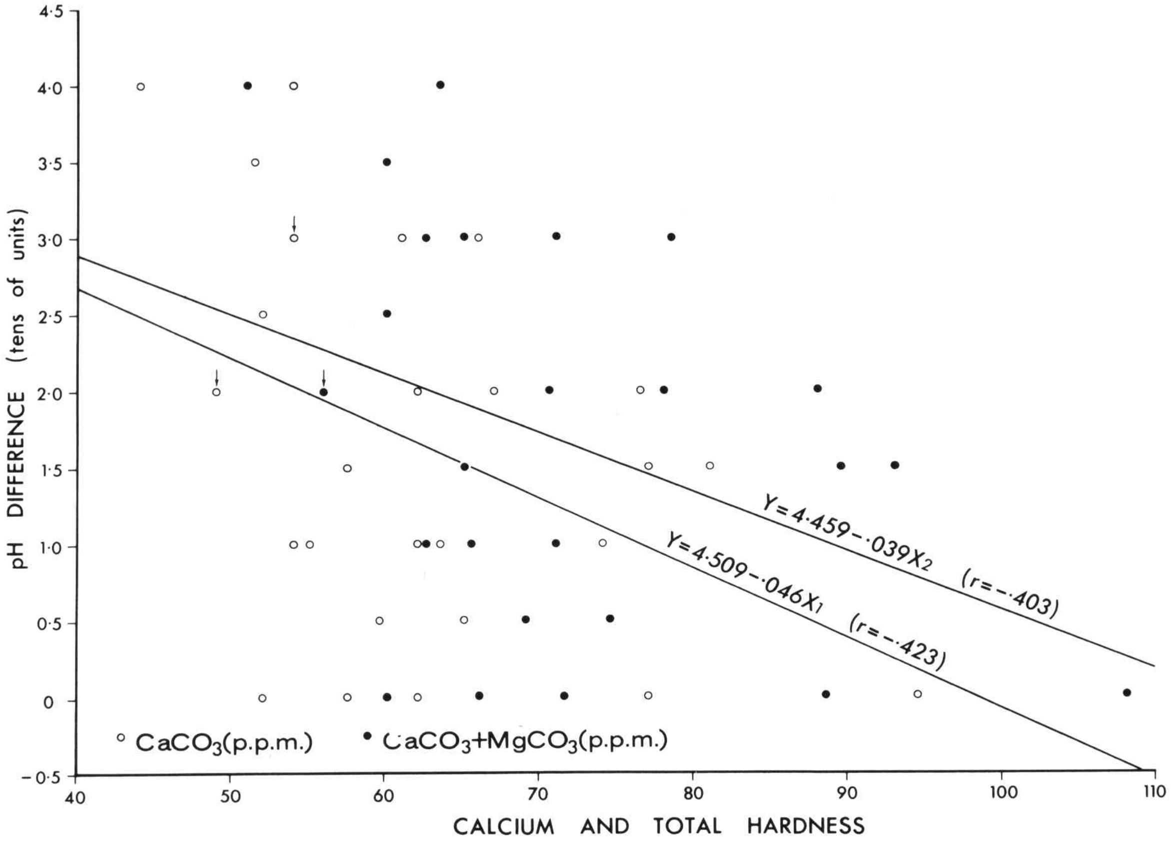

Figure 8. Relationships of calcium and total hardness to 'pH difference'.

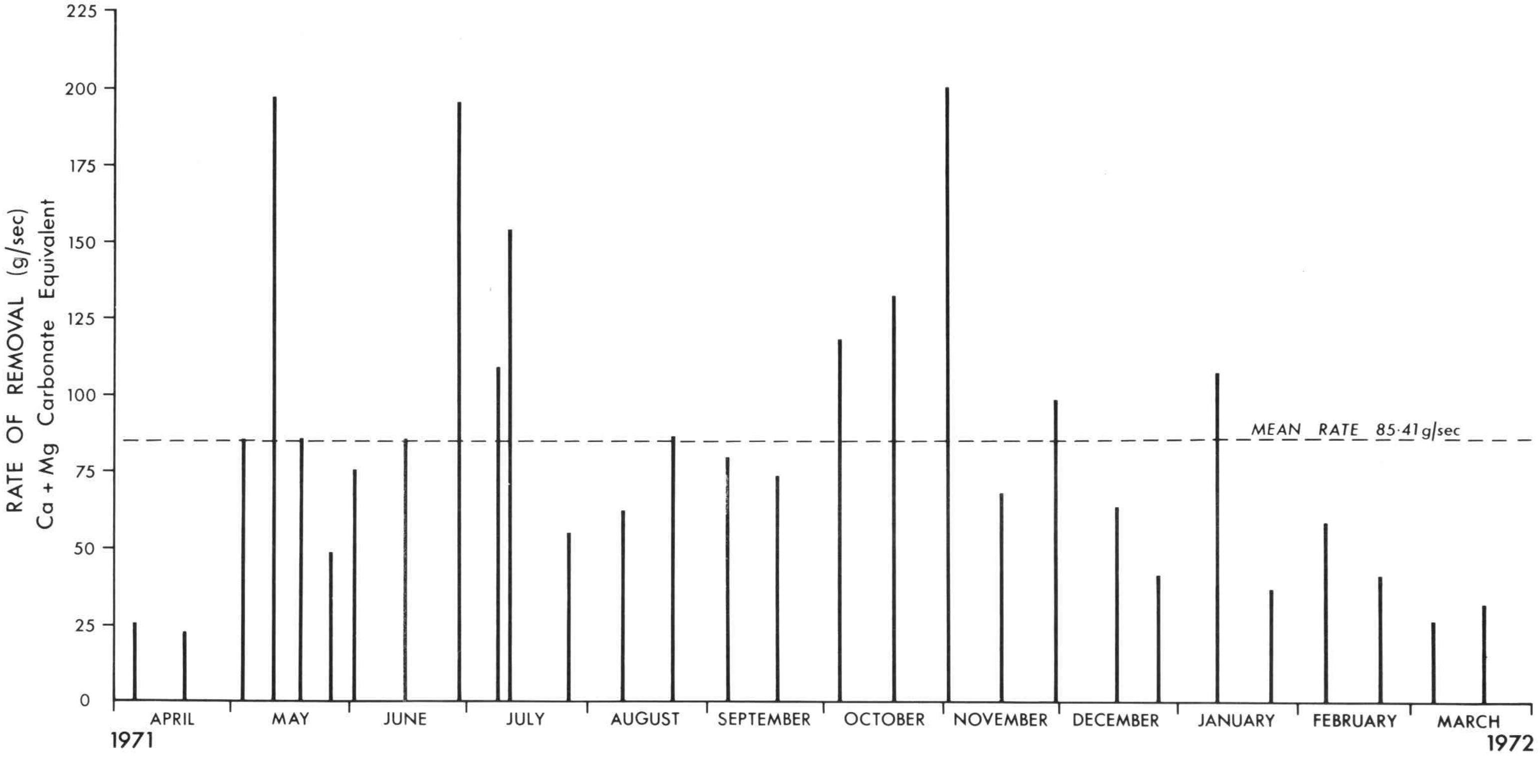

Figure 9. Instantaneous rates of Ca + Mg carbonate equivalent removal for the period April 1971 to March 1972.

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## APPENDIX

### Methods of Measurement

All measurements except discharge were made just inside the cave mouth within the threshold zone.

Temperature was measured to the nearest 0.2° Celsius using a 3 inch immersion "Townson and Mercer" thermometer immersed to the required depth.

Conductivity was measured in 'Dionic' or Conductivity Units (equivalent to one microhm/cm at 20°C) with a 5-range portable 'Dionic' conductivity tester. Where the conductivity of samples was less than 100, values were read to the nearest unit. With values greater than 100, the instrument was read to the nearest five units. The cell was always rinsed with water from which the sample was to be taken before the conductivity of the sample was measured.

Field pH was determined with a Model 101 transistorised pocket pH meter checked against pH 7 and pH 4 buffer solutions and read to the nearest 0.05 of a pH unit.

Saturation pH was obtained by adding excess pure calcium carbonate (AnalaR analytical reagent) to the sample used for the determination and shaking vigorously at intervals until a new balance was reached. The new reading was higher, the same, or lower than the field pH, depending on whether the water was under-saturated, saturated or supersaturated with calcium carbonate. In the case of the Junee resurgence, saturation pH was never lower, sometimes the same and usually higher than the field pH. The difference between the two, the pH difference, was obtained by subtracting field pH from saturation pH. It gives an indication of the degree of undersaturation of the sample.

Carbonate content. Samples for the determination of calcium carbonate ($CaCO_3$) and total carbonate ($CaCO_3$ + $MgCO_3$) were collected in polythene bottles which were capped underwater and brought back to the laboratory for chemical analysis. Analyses were usually carried out the same night and never later than the following day. The method used (Smith and Mead 1962) proved very satisfactory for the Junee Rising. Each determination of calcium and total hardness shown in Table I represents an average value based on six titrations and can be regarded as accurate to within 1 ppm.

Discharge was measured in cross-section using a Hilger-Watts current meter. However, as no suitable cross-section could be found inside the cave mouth, measurements were made from a footbridge approximately 150 m downstream where the stream was approximately 4 m.wide.. Although the stream had an alluvial channel at this point, the banks were reasonably stable and no tributaries joined the Junee River between the cave entrance and the footbridge. Observations were made at horizontal intervals of 30 cm using the two-point method. Over a period of one year, 21 discharge measurements were made. Stage was recorded from a non-metric staff installed inside the cave entrance.

When discharge is plotted against stage on a logarithmic scale, a straight line relationship is obtained with very little scatter (Figure 3). The regression equation for this line is used to calculate discharges from the stage heights recorded at the time of sampling. The use of calculated discharges eliminates possible errors involved in individual measurements and also errors due to the time lag between sampling and measurement of discharge. Wherever the term 'discharge' is used in this paper, it refers to calculated discharge unless stated otherwise.

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