Karst Studies in Australia 1916

J. V. Daneš

Translated by John Pickett

picketj@bigpond.net.au

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Translator's Notes

In translating "Karststudien in Australien" I have retained the sentences constructed by Daneš himself, although these are long and frequently complex by modern standards. In other words, my sentences include the sense of all clauses and phrases used by Daneš, and the content bounded by full stops remains the same. Nonetheless, I have endeavoured to include the meaning of each phrase within his sentence, though my final ordering of individual phrases favours ease of reading rather than direct translation.

To provide accentuation German uses spaced ("*gesperrt*") characters, a convention unfamiliar to English readers. I have used italics to render this feature.

Footnotes: Because of the differences in pagination between the original and the translation, footnotes have been relocated and their numbering has been adjusted to suit the new layout.

I am grateful to colleagues Armstrong Osborne (Sydney) for assistance in ensuring precise terminology for karst features, and to Prof. Stephan Kempe (Darmstadt) for a read-through of the translation.

VI.

Karst Studies in Australia

By J. V. Daneš

Presented on 28th January 1916

Introduction

As in all other continents, limestone is a very widespread rock type and in numerous smaller or larger areas and in varying degrees of development, shows those characteristic features which are termed karst phenomena.

Unfortunately, the geographical and geological exploration of the Australian continent has so far not advanced far enough to be able to be informed of all significant limestone areas and all their surface expressions, but it is already possible to separate them into three fundamentally different major groups, according to their nature, age and extent.

The first group is comprised of those spatially insignificant but very numerous limestone areas in the old folded mountains of Australia, which have undergone generally strong tectonic disturbance and often also significant metamorphism. These, because they are small and not hydrographically independent, offer little unusual for the study of karstic phenomena. In the second group belong the great limestone plateaux of Mesozoic or Tertiary age, which make up most singular karst regions which are little disturbed tectonically and are of great extent, whose study, however, is difficult because of their remoteness from habitation and their desert character. The third group includes several cave areas of restricted area, which were developed in Tertiary lime-sand dunes, and apparently are restricted to the coastal areas of south-western Australia.

It would lead too far, were I to mention here all those limestone occurrences of the first group, which are mentioned more or less comprehensively in the geological and touristic literature, it is enough to mention those in which at least the most popular form of karst, namely caves, has been detected and at least partly examined. Most of the Silurian and Devonian limestones of the eastern montane belt of Australia, of the eastern cordillera, are known for their caves; in eastern Queensland there are two generally known and often described cave areas; one by Chillagoe far in the northeast and in the vicinity of Rockhampton (Olsen’s and Johannsen’s Caves), in New South Wales the caves at Jenolan, Yarrangobilly, Wombeyan Creek and the Wellington Caves.

For my journey to Australia the study of karst was more of a secondary matter, since my first interest was the present position and the development of the continental divide, as well as other problems concerning hydrographic relationships in Australia, nonetheless I still had the opportunity of visiting three of the cave areas in the fold mountains mentioned above: those at Chillagoe (beginning of February 1910), Olsen’s Caves (in April 1910) and the Jenolan Caves (in August 1910).

I originally intended to use the latter part of my stay in Australia for the study of the karst of the great Tertiary karst area, which is spread over the north of the Great Australian Bight in the broad surroundings of Eucla (so-called Nullabor Plain), but I then found, with better knowledge of transport possibilities in Australia, a longer excursion in the eastern margin of the great limestone plateau of tropical inner Australia, to the so-called Barkly Tableland in north Queensland, to be more profitable. I am convinced, that here, within the short time of 14 days, achieved more generally interesting observations, than I could have managed in the Eucla area at greater expense of time and money. It was a long and fairly monotonous trip from the terminus of the Great Northern Railway of Queensland in Cloncurry through the dry and wild montane country of the northern “Australian anticordillera” to the tableland at Camooweal, from there, after several excursions to the local cave and doline groups, north to the Gregory River and then through the Carpentaria lowlands via Burketown and Normanton, and through the broad southern part of Cape York to Cairns! The excellent coach connections, which even these far-flung regions of Queensland enjoy, made it possible, to cover this great stretch of semi-desert of varying kind, within six weeks, including detours, and relatively comfortably and quickly.

Since my sojourn in Queensland lasted too long, I was obliged to abandon the original plan of visiting the Eucla area, and could no longer visit even the smallest of the great limestone plateaux, the so-called Mosquito Plains, which are spread over much more closely settled areas on the boundary of South Australia and Victoria. Of the caves of the third group, I only visited those in the neighbourhood of Yallingup, south of Cape Naturaliste, at the beginning of September.

Karst in the surroundings of Chillagoe.[1]

From the basal part of the York Peninsula in north-eastern Australia north of 17° 30' S to the west of the continental divide there extends an ancient range in a SE – NW direction, which is made up of strongly folded, sometime metamorphosed Palaeozoic strata, intruded by mighty stocks of granitic rock. Now the range is deeply eroded, and only the resistant rock types form the short ridges and hills that are seldom higher than 100 m above the level of the surrounding broad valleys, and collectively can probably be considered as the remains of an ancient peneplain, only recently affected by a renewed, though quite shallow erosion cycle. The valley shapes suggest a very advanced, almost mature stage of the new cycle, although I am of the opinion that the broad valley forms develop more rapidly in an arid climate, with stronger mechanical weathering and greater effect of periodic floods, than in a normal humid climate.

In the area to the west of Almaden (intersection of the Mareeba – Chillagoe and Etheridge railway lines) toward Muldiva the first of the limestone hills begin to appear, and continue towards the NW as far as the neighbourhood of the Walsh River NW of Mungana and Redcap. The most distant appear to be those of the immediate surroundings of Chillagoe; this little town is attached to the smelters, in which the manifold ores of the area are processed. The absolute height of this region lies between 400 – 600 m.

The hard, crystalline to marble-like limestones are interbedded with quartzites, hard sandstones, soft and quartz-rich shales, which have been metamorphosed to mica-schist and gneiss towards the granite area. After a relatively superficial topographic study, the relative age relationships of the individual rock types remain uncertain, because of their strong metamorphism and complicated tectonics, the age of the limestones however, on the basis of the fossils found there, seems to have been fairly certainly determined as Late Silurian by Etheridge and Dunstan; originally R.L. Jack had assigned them to the Gympie Division of the Permo-Carboniferous system, and S. Skertchly considered them Devonian. According to Jack, it is possible that this chain of limestone continues further to the north and is connected to the thick limestone complex that was discovered by that author in the headwaters of the Mitchell and Palmer Rivers further to the north.

I could only spend a short time with my friend Dr K. Domin in the area around Chillagoe. Through the gracious co-operation of Mr MacDermott, the commercial director of the Chillagoe Company, we were provided with a man with great practical knowledge of the region, the electrician Mr T. Campbell, who, on several excursions, showed us the "limestone bluffs", the limestone hills in the greater area around Chillagoe, the sharp quartzite ridges and the lower limestone hills south of Calcifer and the limestone hills near Mungana. The best-known caves are located in the "bluffs" to the west and southwest of Chillagoe.

Drainage of the area is now mostly above ground, the main water-course is Chillagoe Creek, which only receives insignificant amounts of water from the caves, and makes only a small part of its course underground. However, it appears that vertical drainage played a greater role earlier on, but that the watercourses that

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[1] R.L. Jack & R. Etheridge, *The geology and palaeontology of Queensland and New Guinea,* pp 119 – 121, 609 – 610, 737.

R.L. Jack, The Chillagoe and Koorboora Mining Districts. *Queensland Geological Survey Report* no. 69, Brisbane, 1891.

D.S. Thistlethwaite, The Chillagoe Caves. *Proc. R. Geogr. Soc. Australasia. Queensland Branch*, vol. IX, 1894.

Sydney R.J. Sketchley, Tin Mines of Watsonville, and various tin, silver, copper and gold mines at Herberton, Montalbion, Irvinebank, Muldiva, Calcifer, Chillagoe, California Creek, The Tate River etc. *Queensland Geological Survey Report*. Brisbane, 1897.

B. Dunstan, Some Chillagoe geological notes. *Annual Report of the Secretary of Mines for the year 1910.* Queensland. Brisbane. 1901. Pp. 196–199.

R. Etheridge, Junr. On the occurrence of the genus Halysites in the Palaeozoic rocks of Queensland etc. *Geological Survey Rept.* No. 190, p. 30–32.

R. Etheridge, Junr., The lower Palaeozoic Corals of Chillagoe and Clermont, Part I. *Queensland Geol. Survey Rept.* No 231.

A. Meston, *Geographic history of Queensland.* Brisbane, 1895, pp. 159 – 160.

J.V. Daneš, Physiography of some limestone areas in Queensland. *Proc. Roy. Soc. Q'sland,* Vol. XXIII, 78 – 79.

In addition to the maps which accompany the particular works of R.L. Jack and S.B.J. Skertchly, which originate from the first period of mining activity in the region, and are obsolete as far as the topography is concerned, the following map gives a relatively good picture of this area: Sketch map of the Herberton and Chillagoe gold and mineral fields. Compiled from official and other sources under the supervision of W.H. Greenfield at the Geological Survey Office, Department of Mines 1902 (6 miles = 1 inch). In Stieler's *Handatlas* (9th edition) the position of Chillagoe, Mungana, Zillmanton and Atherton is wrongly shown.

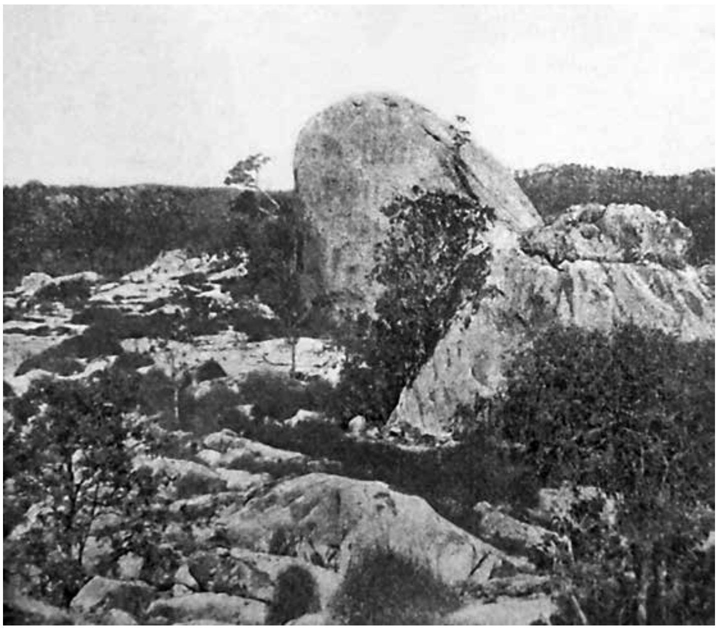
flow in the open valleys gradually took over, since they found on the granite and schists a better substrate than that in the weather-resistant limestone. However, one cannot speak here of a unified karst, either now or in the past, since in the first place the divide for the most part lies outside the limestone area, and thus the watercourses are already loaded with sand and gravel when they enter the area, and secondly, granite, schist and quartzite project above the surface between the limestone hills.

To obtain an overview of the whole area, on the first day we climbed the highest mountain in the environs of Chillagoe, the granitic Metal Mountain. This mountain rises beyond the area of limestone hills toward the northeast and is actually the ruin of a steep neck, whose slopes and peak are formed of great angular blocks, forced apart mechanically. From this peak one sees a chaos of hills and short ridges, which are mostly whitish-grey and jagged, in a broad SW – NE zone, with Chillagoe in the middle with the high smokestacks of its smelters. A picture which is reminiscent of the hills and short ridges of the Cockpit Country or the "Goenoeng Sewoe" type, but which differs strongly in the arrangement of the hilly ridges in a particular direction.

On examining the various limestone "bluffs" more closely one soon sees two types, which are strongly differentiated from one another. Mostly there are sharp, jagged hills, whose steep slopes are furrowed by deep rills, and which terminate above in sharp edges, deeply furrowed by karren; at two localities however, on the so-called Lion's Head Bluff near Chillagoe and at a place between Mungana and Redcap I encountered quite different hill-shapes; quite smooth surfaces on the rocks, only small, rudimentary karren, true evorsion forms [= potholes] and also boulders of quartz and granite; in brief, undeniable traces of strong mechanical aqueous erosion. The poorly developed karren demonstrate that the time at which two mighty streams flowed right across the zone of limestone hills, smoothing the outcrop surfaces with their boulders and sending their waters into the cave passages of the limestone zone, is not long ago. Naturally, since at that time the direction and position of the watercourses were quite different, they have also cleaned out the broad valleys, whose bottoms lie several tens of metres lower than the smooth hill of the Lion's Head, and only after a painstaking topographic and geological survey of the area will it perhaps be possible to characterise these undeniable traces of old watercourses preserved on the limestone, and better give the course, direction and geological age of these old rivers.

Judging by the secondary carbonate deposits the work of carbonate in solution has been great, for not only are the caves full of formations and their walls covered with a thick secondary layer, many chimneys completely filled by calcareous sinter mixed with clay, but also in the valleys there are often deposits of decaying soft calcareous sinter, which surely were deposited from the rapidly evaporating waters; these secondary deposits are several metres thick in Chillagoe Creek before its penetration of a harder granitic stock, where its course was stopped, forming a broad inundated surface during the annual local rains, and where evaporation was particularly rapid, causing the carbonate in the water to precipitate.

The basal area and the lower slopes of the limestone hills differ quite markedly by more abundant vegetation compared to the much sparser plant development on the surrounding terrain of different rock types, which are less advantageous for plant growth.[2] The upper parts of the hills are however mostly bare, and even in the karren furrows there remains only a small amount of karstic clay, because most of it is sluiced away in the rainy season.



Lion's Head Bluff near Chillagoe

Among karst phenomena in the karst area of Chillagoe only the karren and the caves are outstanding and characteristically developed. There are also occasional true dolines and karst depressions, particularly in the Mungana region

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[2] Domin. Queensland's Plant Associations. *Proc. Royal Soc. Queensland,* Vol. XXIII, p. 71.

I saw several shallow basin-dolines, which however do not offer much of interest. One kind of doline, namely collapse dolines, have developed in rather large numbers on the hills, themselves strongly disturbed by dolines, these however are connected all too closely with the cave phenomena that they are, so to speak, only a developmental stage of the cave cavities.

The karren in both their forms are mostly extremely deeply and sharply developed, in the purely erosional ridge-and-furrow form, as well as in the tectonically caused joint form. The steep slopes of greatly furrowed and the less steep slopes are divided into numerous sword-like, extremely sharp shapes, from the tips of which several knife-sharp edges descend several decimetres almost vertically. Only rarely are there the miniature combs and ridges so common in the Alpine and Dinaric karren fields, whose slopes are covered with shallow furrows looking as though they were artificially chiselled.

The vertical dimension strongly outweighs the horizontal, die sharp, narrow pyramids are separated by hollows at least as deep; these generally form miniature quite complex systems of furrows, which, with a more or less steep fall, terminate in expanded joints of the grikes. The grikes are mostly developed in two directions, intersecting at a right angle, and often where the joints intersect there are broad and deep holes, which as narrow chimneys or pipes often extend as far as the cavities beneath. These are then penetrated by water, which deposits secondary clay and lime formations in the subterranean cavities. With time the layer with which these deposits cover even the walls of the chimneys becomes so strong, that the remaining channel becomes narrower and narrower, and is finally choked. Very informative examples of such pipes, filled with calcareous sinter, clay and in places also with bone breccia have been observed in the big quarries in the vicinity of the smelters. I have given several samples of the bone breccia to Professor Spencer in Melbourne, who has determined the bone fragments as those of the extant species of rock wallaby.

The surface of the more extensive hill is highly chaotic and impassable, a `karren field of the wildest sort; there is an indescribable confusion of rock spikes and humps, holes, broad wells, more or less collapsed rock sections, and all surfaces exposed to the rain so eaten through, that the original surface of the beds is only hinted at by the points of the longest, bayonet-sharp rocks.

The attitude of the beds is often extremely disturbed, for the upper part of the bluffs, penetrated by caves, is broken into a multitude of “flakes”, some of which retain their original tectonic position, others however have sunk on one side or another and have often fallen further down. In this fashion the chaos of the karren fields is considerably increased by the disturbed balance of the undermined flakes. It would frequently be hazardous to try and indicate the original position of the blocks.

The limestone beds are mostly ½ - 1 m thick and are often completely eaten through by karren. In some places they can easily be split into thinner plates; the position of the beds is very disturbed; predominant is a strike of approximately SE – NW, the dip however changes often. The limestones are white, in places with red veins, mostly coarse-grained to crystalline, only the thin plates are dense. Apart from the bedding, the joints already mentioned are developed in two directions. One direction is almost parallel to the strike, die other forms a near-right angle with it. These joints are also determinant for the course of the cave passages, so that, for example, at the Mungana Caves the direction of the main disturbance is NE – SW with a dip of 70° SE, and in a small cave passage, uncovered in the quarries of the smelter, one runs SW – NE and dips almost vertically, the other N 35° E and dips less than 30° NW; there the beds strike W 30° N and dip less than 50° to the NE.

Our visit occurred at the middle of the rainy season and it was impossible for us to penetrate far into the water-filled caves of Mungana, but instead we could crawl through the cave labyrinth of the Chillagoe Caves in various directions. With the exception of some cave passages, which extend deeper, the cave passages were relatively dry except for a few siphon-like deep ponds, which however we could bypass in a different direction. It was evident that, even in the case of large floods, the water fills only the deeper spaces, during the dry season there are only a few pools in the deepest spots. One enters the caves over high piles of debris; the natural openings, through which the currents that produced them flowed back and forth, are now for the most part blocked. Cave passages in two directions dominate, ESE – WNW and NNE – SSW, which connect a larger number of larger spaces, which are up to 20 m high and are mostly richly decorated. In some of these spaces the ceiling has yielded to gravity and its debris lies on the floor with broken secondary deposits, and in others one reaches daylight; the roof has broken in and vertical to overhanging walls reach up to 20 – 30 m. The floor of the caves is mostly so covered with clay, that the debris only locally projects above it, the walls are thickly encrusted with secondary deposits. In in a few narrow passages and near a half-collapsed entrance could I observe erosional forms still well preserved, the original forms are already covered by new formations, to the point of unrecognizability. The pipes and chimneys, which open in numbers into the caves, have contributed substantially to this filling-up; some of them remain functional, as demonstrated by a thick layer of clay below their opening, others are apparently completely blocked and the only water that penetrates them in any quantity seeps slowly through. Although it was shortly after extended downpours, it would be too much to speak of seeping rainwater; only relatively few dripstones and shawl-like formations were so wet, that water dripped to the floor from them. During the dry season the moisture must be much less.

On some of the stalactites, broken off 20 – 25 years ago, new deposits can be recognised; and the thin ones it was impossible to measure them, some of the thick ones show an increase of 1 cubic centimetre or somewhat less.

Pothole-like features at the foot of Lion's Head Bluff

The rich development of secondary deposits and the collapse of the ceilings and entrances of the caves are proofs of a very advanced developmental stage and great age of this phenomenon at Chillagoe; at the same time it must be considered that the climatic and topographical relationships of the area are not very favourable for a strong development of calcareous sinter. The small thickness of the cave roofs means that, during the short rainy period, rainwater penetrates and seeps through during the high humidity without leaving much sinter, whereas the caves become so dry after the rain, that very little water enters the caves during the much longer dry season.

Concerning the beauty and variety of the cave deposits, the caves at Chillagoe compare well with many of those "world famous" caves so visited by tourists, but in other respects they are well behind, particularly in respect to the vertical dimensions of the domes they lose out. The most comprehensive description of the Caves, according to Meston was given by the "mineralogical lecturer" William Thompson in the year 1891, more or less independent of which are the descriptions given by R.L. Jack and D.S. Thistlethwaite.[3]

Mr Campbell has made me aware of a peculiar occurrence in a few places. Particularly at the entrances of narrow pipes and cave passages the surface of the rocks is often smoothed in a curious fashion; the cause of this smoothness was given to be the rock-wallabies (*Petrogale* sp.), a kind of small kangaroo, which inhabit the caves in large numbers. For this reason there are relatively few bats in the Chillagoe Caves.

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[3] In the annotations at least I would like to refer to a slightly confusing interpretation of the coralline limestones of Chillagoe. J.P. Thomson in his essay "The geographical evolution of the Australian Continent" (*Queensland Geogr. Journal* XVI, p. 11, *La Géographie* V. 1902, p. 259) writes: *"The whole of Cape York Peninsula was very likely cut off entirely from the continental area during one of the periods of prolonged subsidence. Evidence in support of this view indeed exists in the Herberton district. Here in the somewhat extensive cave features of the Chillagoe area there occurs a typical example of an ancient submarine reef structure, where the old coral formation has been developed. The locality, although not an extensive one, has evidently been at some remote period invaded by the sea, and probably represents a portion of the channel or strait by which the Peninsula was insulated."* One could easily interpret this passage to mean that it deals with limestones developed in a marine strait after the mountain-building episode; that they are thus significantly younger than the surrounding areas to the north and south. Such an interpretation would be a mistake; since the limestones are Silurian and thus older than the folding of the mountains, we have no proof that, after the great orogeny, a separation of the Peninsula from the rump of the continent occurred in just these latitudes.

Olsen's Caves.[4]

North of Rockhampton the rolling country about 100 m above sea level in the proximity of the mighty Fitzroy River is dominated by a mountain rising high above it, Mount Etna, which is named after the famous volcano because of its conical shape, although it has no genetic similarity with it. Mount Etna is made up of tough quartz schist, and rises above the softer Palaeozoic shales of its surroundings as a monadnock; to the east and west of it there is a series of low, short ridges and hills, "ridges" and "bluffs", which consist of limestone and must also be regarded as monadnocks.

Some of these are penetrated by caves, which have been known for as long as 30 years, and were described by James Smith. The best scientific description is given by William H. Rands, to whom the reader of these lines is referred for further information. Rands considered these limestones as Devonian, on the basis of the fossils found. These were affected at the same time as those of the surrounding terrain by the great mountain building of the late Palaeozoic; earlier perhaps their extent was greater, as now-exposed remains of cave deposits can be found in original position on the planated terrain, some distance from the hills which remain. More than at Chillagoe these limestone hills are differentiated by their vegetation, which covers their bases and slopes, from their flat, shale-underlain surroundings; a quite vigorous "vine-scrub", tropical thicket, is spread over the limestone, whereas only the open, dry eucalyptus forest "open forest" grows on the poor shale terrain.

I was only able to undertake a fleeting visit to Olsen's Cave, and my remarks are restricted to the karren and the caves.

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[4] R.L. Jack & R. Etheridge, *The geology and palaeontology of Queensland*. p. 610 – 612.
Contains quotations from James Smith's description of Olsen's and Johannsen's Caves, which R.L. Jack had in manuscript.

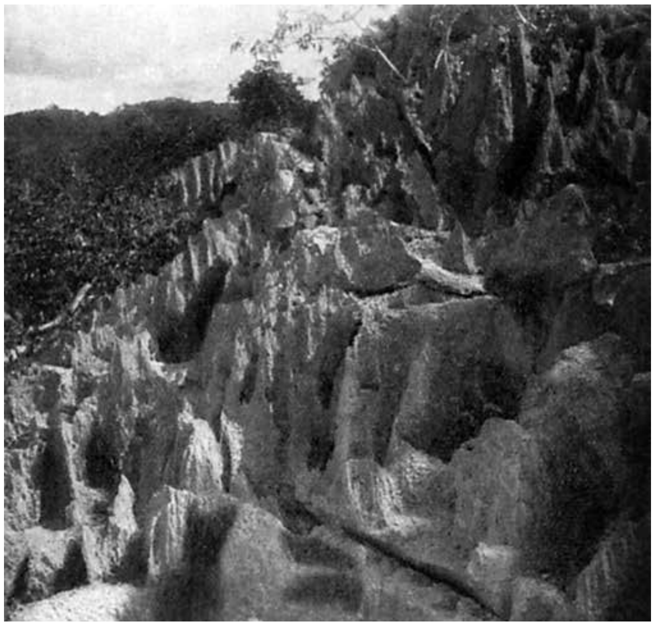
William H. Rands, Olsen's and Johannsen's Caves, near Rockhampton. *Geological Survey of Queensland; Publication* No. 86.

J. Christensen, *Olsen's Caves near Rockhampton.*

B. Dunstan, Phosphate-bearing rocks in the Rockhampton district. Records No. 1, III. *Geological Survey of Queensland Publication* No. 190, p. 11.

Lionel C. Ball, Certain iron ore, manganese ore and limestone deposits in the central and sourthern districts of Queensland. *Geological Survey of Queensland, Publication* No. 194, p. 13 – 14.A. Meston, *Geographic history of Queensland,* p. 160 – 1. Also quotes James Smith.

Daneš, *Physiography of some limestone areas in Queensland,* p. 80.



Karren on the Olsen's Caves ridge

The karren are developed in a form highly reminiscent of those at Chillagoe; the upper parts of the limestone ridges, bare of vegetation, appear as genuine, naturally very small karren fields, which have been affected relatively little by tectonic and gravitational disturbances. Their surface is thus to a certain extent gentler as that of the Chillagoe "bluffs", the karren themselves, the genuine corrosion- and erosion-karren however are deeper and wider than those at Chillagoe. The same shape dominates here as well, narrow, high pyramids with some knife-sharp edges on their flanks, and a very dangerous point, between them such deep, narrow furrows, that often one cannot reach their base with a foot, without exposing oneself to dangerous grazing high on the thigh. The surface of the "karren field" is free of vegetation and clay, as at Chillagoe, as it is completely exposed to the drenching rain of the short rainy season. Neither humic acids nor shadowing by vegetation hinder the complete development of pure karren forms, as they are washed out by rainwater. There is a difference from those encountered in other climates, particularly those where snow plays a role. The forms are much freer, more independent, simpler and more regular. I have seen very similar karren in Java, on the coast of Goenoeng Sewoe[5] on the rock platforms, above which the continuous foggy veil of the heavy beating waves pours. I am convinced, that the development of this type of karren, on the sea-coast as in the semi-arid climate of Australia, the mechanical effect of the free, even vigorous

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[5] Das Karstgebiet Goenoeng Sewoe in Java, p. 49.

collision of falling water plays a large role, as well as the chemical activity of the water.

The stage of development that I saw here on the karren of the Olsen's Caves ridge I would define as about mature, one can with difficulty imagine a greater completeness of karren forms; at Chillagoe this stage appears to have been passed; the tectonic moment, namely the much more important role of the grikes, as well as the circumstance, that the balance of the banks is disturbed in so many ways, is certainly also involved.

Olsen's Caves are a network of mostly narrow and low cave passages, which penetrate a hill about 100 m wide in different storeys. Their hydrological purpose appears to be long since over, no vein of water enlivens even the deepest of the known spaces, the ceilings, walls and floor of the grottos are mostly dry and the floors is often covered with a several metres thick layer of bat guano, which together with karstic clay and secondary lime formations surely closes many pipes, chimneys and passages. There have been attempts to use this Guano as an artificial fertiliser. Attempts up till now have been unsuccessful, though I am of the opinion that although its quantity is insufficient for the export market, this occurrence in the possibly near future could be used on a small scale for local purposes and to good effect, should agriculture develop better in the nearer vicinity. At present economic exploitation of the caves has ceased, and even tourism gives them little attention, and that with justification, since in comparison with the Chillagoe and New South Wales caves offer little by way of attractions to the eye seeking rich cave formations. Also, the penetrating, unpleasant smell of the thousands and thousands of bats which still dwell in the caves, may well put tourists off.

The paucity of secondary lime deposits is very characteristic of these caves. The walls are often bare of secondary cover, and even the cave formations are smaller and less common than in other caves of the eastern mountain belt of Australia. I cannot explain such a small participation of groundwater well, as there appear to be no external causes for the dryness of the caves. The climate is sufficiently wet, the surface of the limestone ridge is not covered with soil and vegetation which might otherwise take up the water falling on it, at least partly, and also the thickness of the cave roofs is rather insignificant.

There can be no doubt, that the caves along the cracks have arisen by the erosional activity of a watercourse, which in deepening its bed right across the limestone ridge was not able to retain its position on the surface, but was obliged to take the cave path. Even the shapes of the cave passages give eloquent testimony for such an origin, numerous potholes and similar evorsion features which originate through the spiral motion of gravel- and sand-bearing water, now partly filled by bat guano, betray the vigorous erosional activity of the stream, separated into several water-runs. The erosion probably proceeded quite rapidly and the subterranean river bed shifted deeper and deeper. With some certainty three levels can be differentiated, which represent so to say rest stages in the deepening of the cave passages and are defined by wider caves. It cannot however be excluded that the irregular deepening of the river bed is at least partly due to petrographic differences in the limestone beds.

At present the caves have been abandoned by the watercourses that created them. Thus it is more conspicuous that the caves have retained such a fresh appearance, in other words, that the secondary formations have not achieved great progress in their covering and filling. Truly, as already mentioned, there appears to remain no external cause for this, other than the assumption that the deepening of the erosional base proceeded very quickly and that the whole reversal of the landscape in the region of the caves was achieved in a relatively short time. When the river began to erode its underground course through the limestone ridge the whole surrounding terrain must have lain at the same height or even higher than the present surface of the limestone ridges, which now however, as already mentioned, form monadnocks which project 30 - 50 m above their surroundings. The geological and morphological history of eastern Australia in the latest Tertiary and the Quaternary appears consistent with such a relaively rapid planation process.[6]

According to the explanations of the settlers who accompanied me the neighbouring Johannsen's Caves must be at a similar stage of development; from the descriptions of James Smith and W.H. Rands however they appear to show more cave decoration.

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[6] G. Taylor, *Physiography of Eastern Australia*. Comm. B. Meterology. Melbourne. Bul. 8.
Daneš, On the physiography of Northeastern Australia. *Věstnik k. č. Spol. Nauk* 1911.

Other small karst regions of Australia.

Among the doubtless quite numerous caves which occur in the common limestone layers in the mountains of New South Wales, the Jenolan Caves are particularly well known, a visit to which can be combined with a tour through the Blue Mountains, thanks to an excellent automobile connection. The state geological institute (Geological Survey of New South Wales) has collaborated with the excellent Tourist Bureau of that state to publish a very fine, popularly written and well-illustrated guide to the exceptional cave areas, among which the Caves at Jenolan can be considered the best.[7] I have only visited the Jenolan Caves myself, though the guides mentioned make it possible for me to recognise, at least in broad strokes, the stage of development of the other cave areas.

The Yarrangobilly Caves lie in the catchment area of the river of the same name, in the northern part of the highest mountain group of Australia, Mount Kosciuszko. They can be reached from Tumut or from Cooma by post-coach, lie at a height of about 1100 m and are only the best-known of many caves along a limestone area 10 km long and 1½ km wide. The geological age of this limestone has not yet been determined with certainty, but will be Upper Silurian or Devonian. The caves for the most part appear to have been abandoned by the watercourses which created them. The amount of cave deposit is impressive, the sinter cover of the walls almost complete, with the exception of the cave “The River Cave”, which is designated as “dirty and uninteresting passages” and is traversed by a water body. Many cave spaces have already been breached, as Mr Trickett imparted to me personally, in some spaces there are hills of collapsed debris.

The Wombeyan Caves, which lie on the creek of the same name near its junction with the Wollondilly River, between Goulburn and Bowral, at an altitude of about 600 m, may be of the same style as the Yarrangobilly Caves. Some of the caves described by Trickett seem to be seepage caves, only Creek Cave, eroded by Wombeyan Creek, and a few deeper passages traversed by the same creek are true river caves. In the cavity called Victoria Arch the roof has collapsed sideways and thus a huge natural shaft has arisen.

Wellington Caves lie near Wellington at more than 300 m a.s.l. near the junction of the Bell and Macquarie Rivers, in a low, flat ridge of limestone of Late Silurian or Devonian age. These caves are in their vertical and horizontal dimensions much smaller than the other officially described ones, the fill of secondary deposits is not strong enough to completely cover the primary structure. They have become known through the numerous discoveries of bone of fossil marsupials.

Jenolan Caves lie at an altitude of about 800 m on the eastern flank of the 12 – 1400 m high spine, which forms the continental divide between the catchment areas of the Macquarie and Hawkesbury Rivers, on the upper Jenolan River, a tributary of the Cox River, which empties into the Nepean and with it into the Hawkesbury.

Although situated in a very narrow band – about 200 m – of Silurian or Devonian limestones, the Jenolan Caves belong to the greatest of explored caves areas which, for the beauty of the landscape of their immediate surroundings and the superb development of the cave-decorating elements certainly belong to the touristically most rewarding in the world. The narrow limestone ridge is penetrated by two superb tunnel-caves, through which the rivers still flow at high water. These caves show, in their lower parts, fresh erosional forms, the rivers however had to force a way between mighty debris from the cave roof, and above there hang mighty stalactites. Probably there was here an intermediate ceiling which has collapsed, thus connecting an upper level of the caves with the originally lower river cave. In the upper part of the ridge above the present tunnel-caves a rocky gateway opens beneath a natural bridge. That is the remains of the original tunnel-cave. Those caves open to visitors and which are altogether richly filled with secondary deposits lie in several storeys and are mostly originally river-caves; with the exception of the Easter Cave their roofs remain so firm, that daylight does not penetrate. With the exception of several siphon-like ponds and short stretches of

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[7] O. Trickett, *Guide to the Jenolan Caves, New South Wales,* Geological Survey of New South Wales. P. 76 with good map and vertical section. By the same author are the rather less comprehensive booklets: *Guide to Yarrangobilly Caves. Guide to Wombeyan Caves* and *Guide to the Wellington Caves.*

O. Trickett himself measured the plans and vertical sections, and with the help of several keen cave supervisors has greatly extended the knowledge of caves in New South Wales. The caves mentioned have been carefully prepared for visits by tourists, and fitted with protective devices for the beautiful cave formations. Indeed, the surroundings of Jenolan Caves form a protected area which even the black-brown rock wallabies (Wallabies, *Petrogale* sp.) inhabit in large numbers.

water in the lowest storey the cave passages are without flowing water; the present subterranean watercourses are rather lower, and only at high water are the lower storeys flooded. Seeping water is busily at work; many cavities and passages of the Jenolan Caves contain numerous helictites, which are here called "mysteries". These are at least partly gypsum dripstones. Those rock surfaces flattened and polished by wallabies occure here in quantity, outside the caves and also in the hollow spaces that are not far from daylight.

The discovery of a human skeleton in one of the caves of the lower storey led to an examination of the chimneys that open into the cave roofs, mostly these are now closed by secondary deposits and collapsed material. The skeleton however could have reached the cave, far from any daylight entrance, by no other way, and it is to be assumed that it fell through one of the chimneys present above the place of discovery.[8]

I was unable to visit the caves in Victoria, South Australia and Tasmania, and have access to no literature, from which I could derive anything related to the morphological development of the cave areas.

Finally, may I be permitted to mention the caves at Yallingup in south-western Australia. These have been very well described in the Western Australian Yearbook and their evolution also excellently drawn by Edward S. Simpson.[9] Here we are not concerned with anextensive connected karst area, nor with a complex of limestone beds, rather only with lime-rich sands, which randomly dominate between the old quartz-sand dunes. They are aeolian and deposited on granitic basement, and are in places up to 100 m thick. The waters which hasten to the ocean along the granite basement have created cave passages in the strongly cemented calcareous sands, into which the roofs have collapsed locally. The caves have been rendered accessible by such collapse chimneys. The secondary deposits, namely the cave deposits, are relatively well developed and their evolution, thanks to a modest activity of seepage water, seems to have been relatively rapid, since respectable stalactites have grown even on parts of the ceiling laid bare by recent falls. The grottoes of southwestern Australia are placed collectively under the protection of a special commission (Caves Board), which issues an annual report on work done towards conservation and better access.

Barkly Tableland and the great karst area of Northern Australia

a) The extent and geological age of the tableland limestones.

From the northern part of Northern Territory into the western part of Queensland extends a low plateau, on which the Georgina and Gregory Rivers rise. This eastern part of the plateau is called the Barkly Tableland and is rimmed on the east by a more or less broad belt of an old, quite low range, which according to Suess' interpretation forms the northern member of the Australian anticordillera. The main water divide between the continental basin of central Australia and the Gulf of Carpentaria runs almost without expression over the tableland, and it would be a great mistake to presuppose a water-dividing ridge.

The Barkly Tableland[10] was explored for the first time by Landsborough in the year 1861

and named by him, so afterwards the first pastoralists arrived, tempted by the promising speeches of the discoverer, but a crisis in the year 1866 delayed the definitive settlement of this area; even in the year 1876 Hodgkinson speaks of no new station and only at the end of the seventies was the area taken up for a second time and Camooweal founded in 1880. In the eighties most of the pastoral "stations" were also taken up in the western part of the tableland belonging to the Northern Territory.

The extent of the tableland can only be given broadly. Its north-eastern and eastern limit is best determined. To the northeast it drops rather steeply and suddenly to the flat coast of the shallow Gulf of Carpentaria, its 2 – 300 m high, steep margins are dissected by a large number of narrow, almost impassable gorges, and some of the coastal rivers have succeeded in drawing part of the plateau into their catchment. Somewhat to the east of the artificial border of Northern Territory and Queensland (128° E) the edge of the table land turns sharply

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[8] The Discovery of a Human Skeleton at Jenolan Caves. By R. Etheridge Jun., & O. Trickett L.S. *Records Geological Survey N. S. Wales,* 1904. Vol. VII Pt 4, p. 325 – 328.

[9] Edward S. Simpson, Geological features of the South-Western Caves District, and C. Erskine May, Description of the limestone caves of Western Australia. *W.A. Year Book.*

[10] The tableland was originally named Barkly Plains by W. Landsborough, in honor of the Minister Sir Henry Barkly. The spelling "Barclay Tableland" or "Barclay Plains" is thus incorrect.

to the south. The Gulf depression penetrates further and between the broad valleys the remains of an ancient range emerge as a low, desert but ore-rich mountainous area, above which in the west the steep, rather upturned margin of the tableland rises like a sharp but low wall; a few mountains, among which Constance Range west of Lawn Hill is the most important, bear witness that one is dealing with a denudational margin and that the tableland earlier stretched further east. The process of denudation was probably accelerated because this area underwent a greater specific uplift (probably in the Late Tertiary and the Quaternary) than the remaining tableland experienced. At about 19° S on the upper course of the Gregory River the tableland extends further east in several spurs as far as beyond the Thornton River; only the divide between the tributaries of the Gregory and Leichhardt belong with certainty to the old metamorphosed mountains, and it runs to the south with a small bend to the east. South of the track linking Camooweal with Cloncurry recognition of these broad features of the surface becomes uncertain, one only knows that the old mountain range bends to the southwest at this point, but is however much more planed off, so that it loses its mountainous character over long distances. Here and in the southeast as further west it is impossible to give the southern border of the tableland exactly, it is possible, that it penetrates as re-entrants the spurs of the old range, such as Cairns Range, Davenport Range, Murchison Range etc.; further to the north it is apparently connected via Stuart's Plain and the area around Daly Waters with the tableland on the Victoria River, and in the northerly direction it extends, though not without disruption, far into the northern peninsula.

Very little has become known of the geological relationships of this area so far from traffic, and even today is our knowledge of the geographical extent and the geological age of various sedimentary complexes very uncertain. The fact that one part of the area lies in Queensland and the other in the Northern Territory has hindered a unified exploration, as there appears to be absolutely no scientific contact between the State surveys in Brisbane and Adelaide. Every State institute has proceeded according to its own tradition, and a higher regard for the continuity of a geological examination of the whole continent has not been considered.

The itinerary of the first explorer of the Barkly Tableland, W. Landsborough, is almost unusable from the geological standpoint. Hodgkinson, who as Warden certainly possessed much better knowledge of the most important rock types, failed to describe in his report just that part of his line of travel which followed in Landsborough's tracks. This is the more to be regretted as the later official geological expeditions, motivated mostly by practical interests, only touched the outermost spurs of the area. The question of the extent of the Great Artesian Basin and then the research of areas of mining interest were the main lines of activity for the small but active staff of the Queensland Government Geologist, overloaded with such projects, found little time for issues of a more theoretical nature.

The first serious report on the limestone plateau of the Barkly Tableland was brought by R. Daintree,[11] who on the basis of a single discovery (*Tellina*), brought to him second-hand, declared the horizontal limestones in the source area of the Gregory River to belong to the Desert Sandstone Series and of marine origin. (The Desert Sandstone Series was earlier considered Cretaceous or Tertiary, but restricted to the Upper Cretaceous by later research.) The metamorphosed mountains on the lower Gregory were declared Silurian by the same researcher.

Dr R.L. Jack, State geologist for many years, saw only the northern spurs of the tableland at Carl Creek near Riversleigh, in the year 1881. At that time he was uncertain whether he should consider these limestones as Silurian, like the area to the north, or, with Daintree, as Cretaceous, though later he opted for Cretaceous, but older than the Desert Sandstone, namely as belonging to the Rolling Downs Formation.[12] The grounds and proof on which this positive determination was built remained unknown even to R.L. Jack's younger colleagues, W.E. Cameron and L.C. Ball. The scenic botanical character of the tableland, which must have been known to R.L. Jack through dependable descriptions by others, must have contributed much to this decision, for someone who knew the landscapes so well the great similarity of this area, described by others, with the Rolling Downs Country in central Queensland, must have been very obvious, if not decisive. On his great geological map R.L. Jack designates the tableland as Rolling Downs Formation (Lower Cretaceous), supposedly as a great bight, con-

[11] Notes on the Geology of Queensland; *Quarterly Journal of the Geological Society,* 1872, p. 278.

[12] *The Geology and Palaeontology of Queensland*, p. 394.

necting with the main area to the south of the Anticordillera. In another place in his main work[13] in a list of boreholes through the Rolling Downs Formation R.L. Jack mentions two that are located on the Tableland, one in Rocklands (19° 40" S, 138° 15" E) near Camooweal, the other at Avon Downs (20° S, 137° 30" E), already in the Northern Territory west of Camooweal. Concerning the borehole near Avon Downs he remarks briefly, that it lies in Rankin's Creek at an altitude of 554 feet, and that the water was reached at a depth of 200 feet, however it did not rise to the surface; concerning the borehole near Rocklands he publishes the drilling report sent to him, stating that at a depth of 412 feet the hole was not yet complete. It would be superfluous to examine the drilling report more closely here, R.L. Jack accepted it and maintains that, from top to bottom, basalt, Tertiary, Desert Sandstone and Lower Cretaceous beds were penetrated, I however am in a position to consider this false. It can perhaps not be considered a deliberate falsification of the real facts by the recorder, but rather a careless determination by a less competent person of the rock-types penetrated. So it is quite possible that hard, red secondary filling of some earlier space were named "some sort of basalt" by an ordinary person, and were recorded as "basalt seams´and "basalt and lime rock" in the drilling report. I have examined the area around Rocklands in detail, examined the remaining debris piles with care, and, of more weight, have obtained from Mr H.A. Glissah, manager at Rocklands, the assurance that, to his knowledge, no rock apart from limestone, hard siliceous limestone and secondary cave deposits was encountered in any of the 18 boreholes.

On the widely available geological maps, published by J.B. Henderson of the Water Supply Department in Brisbane, the Tableland is depicted in the same colour as a large part of the neighbouring old range, namely as Palaeozoic "impervious rock-types, which lie below the water-bearing Lower Cretaceous and Triassic-Jurassic beds".[14] After personal inquiry no other reason for this assumption was imparted, only that in the area north of the confluence of the Georgina and Burke Rivers (NW and N of Boulia) no drilling has discovered artesian water, and thus the occurrence of the same aquiferous beds as in central Queensland can be excluded. The assumption of W.E. Cameron, that the limestones of the Tableland are post-Tertiary formations was emphatically denied by Mr Henderson.

The most recent geological map of Queensland by the Geological Survey shows these limestones as "post-Tertiary limestones" [15] and gives them a rather narrowly restricted area in the catchment areas of Lawn Hill Creek and the Gregory and Georgina Rivers, east to beyond Yelvertoft on Inca Creek. This results from studies carried out by W.E. Cameron, but again only at the extreme northern margin of the Tableland.

W.E. Cameron, on a trip in the year 1900, considerably enriched the knowledge of the geology of the old mountains in western Queensland. The metamorphic rocks of these mountains were earlier grouped as formations of uncertain age, until however R.L. Jack succeeded in obtaining fossil fragments from the area of the Cairns Range on the border of Queensland and Northern Territory, which were determined as Silurian, they were shown on the maps as Silurian, although one was well aware, that such a summary reached well beyond the permitted boundaries of generalisation. W.E. Cameron found that the rocks of the mountainous area in the region of the Cloncurry and Leichhardt Rivers are very strongly metamorphosed, but towards the northwest in the areas of the Gregory and Nicholson Rivers show much weaker metamorphism and are also less disturbed tectonically.

This circumstance is probably due to there being no great projecting granite masses in the north-western region (on the Gregory River), such as often occur near Cloncurry and on the Leichhardt River.

The steeply dipping old schists are unconformably overlain with little disturbance by quartzitic sandstones, particularly in the Constance Range and by almost horizontal limestones on Lawn Hill. Cameron was unable to determine the mutual position of these two stratigraphic complexes with certainty, but considered them as apparently of Devonian age, that is, a little younger than the more disturbed and metamorphosed "Silurian" beds. Cameron also conqu-

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[13] *l.c.,* p. 418 – 419.

[14] *Map of Queensland showing positions of Artesian Bores and Perennial Springs also the approximate area of the artesian water bearing strata.* Brisbane 1908.

[15] Geological sketch map of Queensland showing mineral localities prepared under the supervision of R. Dunstan F.G.S., acting Government Geologist and compiled by H.W. Fox at the Geological Survey Office, Brisbane. 1905.

ered the Constance Range and at a distance of about 1 English mile from the Range determined horizontal limestones lying on the sandstone, these extending far and wide to the west and southwest and forming a sparsely vegetated tableland, at the margins of which the sandstones, dipping to the west beneath the limestones, are demarcated by much livelier landscape forms and darker vegetation. Towards the south, where the track to Herbert Vale Station climbs on to the Tableland, the sandstone surround disappears gradually and then the edge of the Tableland turns to the southeast, where limestone knolls about 50 – 60 feet high lie immediately on a basement of metamorphic rocks. Cameron noted that this border of the limestone plateau, from Lawn Hill Creek in the north to the Seymour River in the south, has been known for quite a while, as it is already shown on the geological map of Queensland from the year 1895, although as "Lower Cretaceous". It appears that R.L. Jack himself saw only a part of this boundary on the Gregory River (Carl Creek), but he certainly found contacts who could give him reliable information. I have myself met a former prospector in this region, who has been living in the region south of Burketown since the year 1868.

Cameron considers these plateau limestones to be much younger than R.L. Jack. The reason is palaeontological proof. In April 1900 two species of gastropods were found in these limestones by E.R. Brackenberg, which R. Etheridge jun. determined as *Helix* and *Isidora*; the fossils were found in a salient of the limestone plateau, which includes the island between Carl Creek Gregory and O'Shanassy.

Not far from this place (near Verdon Rock) the author has found, in the same limestone, bone fragments of marsupials, and his travelling companion Edwin Lowe later found remains of a crocodile skull embedded in hard limestone. On the basis of these discoveries W.E. Cameron made the following diagnosis *"The universal horizontality of the Barklay Tableland junction lying in a basin surrounded by land standing a higher level than its uppermost beds, together with the occurrence of the recent Helix and Isidora, and the marsupial and crocodilean remains point to a much more recent age [than Cretaceous], and the beds no doubt represent a deposit of Post Tertiary Age. The occurrence of the land and freshwater fauna point to the inference that in these recent times the Barklay Tableland was the site of a great inland sea into which carbonate of lime was brought by the streams draining into it, and where it was collected in the shells of molluscs or slowly deposited by gradual evaporation from the surface of the lake during times of drought to form the present exiting bed of limestone.*[16]

To be named as the most recent explorer from the Queensland side is Lionel C. Ball, who undertook two trips to north-western Queensland, the particular purpose of which was a geological examination of the ore occurrences of the so-called mineral field at Burketown. This explorer however interpreted his assignment in a broad manner, and in his monograph[17] he gave a most industriously worked-out picture of the geological situation of the north-western corner of Queensland, the accent being on the immediate neighbourhood of the mines at Lawn Hill and Mended Hill. L.C. Ball consider the Silurian age of the local metamorphic rocks to be proved, and indicates that a similar formation has been found on the MacArthur River in the Northern Territory, which was considered Permo-Carboniferous by H.Y.L. Brown. The quartzitic sandstones of the Constance Range he considers to be of the same age as other similar occurrences further east, which for tectonic reasons cannot be differentiated from the other disturbed beds, and are decidedly older than the horizontal limestone beds of Lawn Hill, which Ball surely with reason considered evidence, and connected them to the tableland limestones. With Cameron however he considers the tableland limestones to be post-Tertiary; new evidence for this he sees in several discoveries of Dentalium to the north of Mended Hill and in the specimens collected by me below the Tarpeian Rock and at about the same place as by W.E. Cameron at Riversleigh. I will return to this evidence later.

Officially then there is general acceptance that the tableland limestones are late Tertiary, or more likely post-Tertiary.

I can only offer a few observations and age determinations for the Northern Territory. Augustus C. Gregory mentioned in his diary several places along his great journey of 1857 between the Victoria and Roper Rivers where horizontal limestones underlie a sandstone which is almost the same as the Desert Sandstone of Queensland[18], and also mentions the

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[16] *l.c.*, p. 190 – 1.

[17] The Burketown Mineral Field. *Geolog. Surv. of Q-sld.* No. 232.

[18] Journal of the North Australian Exploring Expedition. *Journal R. Geograph. Soc.* Vol. XXVIII, p. 84.

"Downs" character of the landscape. The conscientious and highly meritorious H.Y.L. Brown, for many years Government Geologist of South Australia, travelled back and forth through the Northern Territory on many journeys, and from him comes the great geological map of the Northern Territory, on which the occurrences of the tableland limestone appear to have been entered conscientiously. From the extremely modest and laconic reports of this geologist one unfortunately learns little about the detailed form of the surface of these limestones; it is mostly "Downs Country" with abundant grass on dark, rich soil; the limestones only project above the surface occasionally; "gibber plains", gravel surfaces and low gravel hills alternate with the grassy downs, which are surely the last remains of the desert sandstone hills, which have been sacrificed to the denudation. On his map of the Northern Territory[19] Brown designates these limestones as "crystalline limestones, and dolomites with flint and chert, limestone conglomerate etc." of indeterminate age, but apparently Palaeozoic. The blue colour of these limestones covers great areas of the map, which however are separated from one another by large areas of other coloration and white areas. At the eastern border with Queensland they begin in high latitudes (from about 19° 20" to 21° 20" S), take up the entire upper catchment of the Georgina, then covers quite large areas near Brunette Downs (19° S 136° E), differentiated from areas designated as "Upper Cretaceous", further to the west a broad area along the continental telegraph line between 15° and 16° S, large areas along the Victoria River north and south of the 16° parallel and a particularly big area which extends from the catchment area of the Daly River in a north-westerly direction as far as the plains of its lower course. Had one also taken into consideration A.C. Gregory's diaries, one would have been well able to connect this latter area with that along the telegraph line, since the researcher confirmed limestone at several places on the Dry River. A few small blue patches connect the large areas and confirm the great extent of these tableland limestones even further, particularly in the south-east. As I heard by word of mouth from Mr Brown, he was originally of the opinion that this limestone plateau was only to be considered as a continuation of the Rolling Downs, and that his own limestones belong to the same geological age, but later a not entirely trustworthy fossil discovery at Alexandra Downs, along with more of his and H. Basedow's further discoveries of Cambrian fossils at the Daly River, moved him to ascribe a much greater age to the entire limestone complex. At two places in the Daly River area traces of Cambrian fossils (Salterella) have indeed been found, which, placed in connection with trilobite finds (Olenellus at Alexandra Downs Station, Agnostus and Macrodiscus at Tennant's Creek) represent sufficient grounds to ascribe the great tableland limestone area of the Northern Territory to the Cambrian, in the opinion of H.Y.L. Brown and H. Basedow.[20] These limestones lie horizontal and discordant on the folded Precambrian at the Daly River.

Compared with what we observe in Queensland, that is a fine result, *the tableland limestones are post-Tertiary in Queensland and Cambrian in the Northern Territory!* Can one ask for more!

In my opinion however one can bring these extremely divergent age determinations into agreement quite easily. In the catchment of the Gregory River and its tributaries this plateau limestone lies thoroughly discordantly on the older formations, which have been referred to the Palaeozoic (Silurian – Permo-Carboniferous), it must thus be younger than these, but is still older than the so-called Desert Sandstone Formation, which, though it has mostly disappeared from its surface but for the gravel and dreikanter areas of the gibber plains, in my experience still remains preserved in the source area of Wooroona Creek at an altitude of 20 – 30 m, and further to the east may form the divide between the waters flowing to the Georgina and Gregory Rivers. This experience and

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[19] Geological map of the Northern Territory of South Australia, by H.Y.L. Brown, F.G.S., Government Geologist. Physical geography compiled by C. Winnecke, F.R.G.S. from private and official Records. Adelaide 1898. Scale 20 miles = 1 inch.

[20] *Northern Territory of South Australia. North-western district. Reports (geological and general) resulting from the explorations made by the government geologist and staff during 1905.* Adelaide, 1906. pp. 5 – 20. General Geology H.Y.L. Brown and H. Basedow. p. 14. *"In lithological characters this formation is similar to the [sic] covering large areas between the Katherine Station and Flora Falls, also to that at Jasper and Timber Creeks, off the Victoria River, between the Elsey and Daly Waters Stations on the Transcontinental Telegraph Line, at Anthony's Lagoon, Brunette Downs, Alexandria Station, and other places. It is most probably continuous beneath the basalt, sandstone and other later formations. The occurrence of Cambrian fossils near the Daly River and Alexandria Station (Alexandra Downs) prove that these widely separated expanses of limestone are identical in age."*

the nature of the landscape, the penetration of the old mountains by embayments brings me to the firm assumption that these tableland limestones are of the same age as the Rolling Downs Formation and that they are only differentiated in so far as here the porous, pure limestones dominate, whereas in the Artesian Basin the Rolling Downs [Formation] is principally represented by impervious limy shales and marls.

The "Olenellus" from Alexandra Downs Station was found on the dump heap of a borehole, and probably in shaly marls, whose relationship to the limestones is still not explained. That Cambrian fossils have been found on the Daly River is no certain proof that the enormous limestone area must be of the same age. On the contrary, on the MacArthur River probably Permo-Carboniferous coaly shale has been found below the limestones, and by all accounts usually lies directly on the limestone of the Desert Sandstone Formation!

It is easily possible that by chance the Cambrian limestones are connected to the much larger area of the younger Lower Cretaceous limestones, and demonstrate no obvious discordance nor any other obvious differences. Altogether it is almost certain, that in Western and Central Australia much older mountain areas are present, that in the so-called Australian Anticordillera and Cordillera; it is thus easily explainable that the Daly River Cambrian still rests horizontally on the disturbed Precambrian, while further east even the formations of the later Palaeozoic have undergone tectonic disturbance.

It is much easier to explain the error, that the same limestones in Queensland are considered post-Tertiary and freshwater. Is there anywhere at all where freshwater limestones occur over an area of many thousands of km^2, with a thickness of hundreds of metres or more? This observation fits only for the superficial beds and cavity fills, i.e. for purely secondary formations, which fill the older cavities and joints in varying thickness, and were also deposited in greater or lesser thickness in pooled freshwater, which formed on the surface of the Tableland, particularly on its northern edge, for morphological or climatic reasons. These deposits and those fossils found in them are most certainly secondary, and the great mass of the tableland limestone is older, *older than the Desert Sandstone Formation and younger that the disturbed Palaeozoic!*

Unfortunately, I have no palaeontological evidence for this conviction; I have not succeeded in finding clear evidence of fossils in the complex of limy strata, although at Camooweal at a depth of over 60 m in one cave the individual beds could be perused: I hope however, that with a more thorough examination primary fossils will be found, that will substantiate the opinion expressed here.

My Journey on the Tableland

The track from Cloncurry to Camooweal leads in its eastern half through the old mountainous area, in its western half over the Barkly Tableland. Cloncurry lies at about 200 m A.S.L., the track climbs to the watershed between the catchments of the Cloncurry and Leichhardt Rivers, which lies at about 400 m,[21] drops to the valley of the West Leichhardt below 300 m, rises again in the Wagga Boonya Range to over 400 m then with a few undulations drops to the valley of the Georgina at Camooweal, at an altitude of about 230 m. The eastern part of the mountainous country, particularly in the area of the Cameron River and Argylla Creek, is a wild, desert and geologically very complicated area, whose highest peaks do not rise above 700 m a.s.l.; crystalline schists, marble, quartzites alternate in colourful confusion with stocks of plutonic rocks.[22] The mountainous area was reduced to a peneplain and is at least partly covered with Desert Sandstone, but was however apparently uplifted again in the Late Tertiary and ripely dissected by valleys; the valleys of not only the main streams, but also of their tributaries, are exceptionally wide, although the actual river- and creek-beds are for the most part dry: but the rare mighty downpours, which often make the post-road quite impassable for weeks in the rainy season, cause mighty powerfully rivers to arise, and which clear weathered debris almost completely and transport it into the broad valleys with little gradient. The population is extremely sparse because of inhospitability and lack of water. Miners seeking gold and mainly copper scratch, and in recent years hunters as well, who are after the very numerous large mountain kangaroos (Wallaroo).

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[21] Interesting cross-sections of the relief on the Cloncurry – Camooweal – Burketown run are contained in Report by Mr. George Phillips, C.E. upon the advisability of constructing Railways, and ports connected therewith, in the Gulf of Carpentaria. Brisbane 1909.

[22] Lionel C. Ball, Cloncurry Copper Mining District. Part 1 & 2. *Queensland Geological Survey Publ.* No. 215. Brisbane 1908. is the best geological monograph on the greater area of Cloncurry.

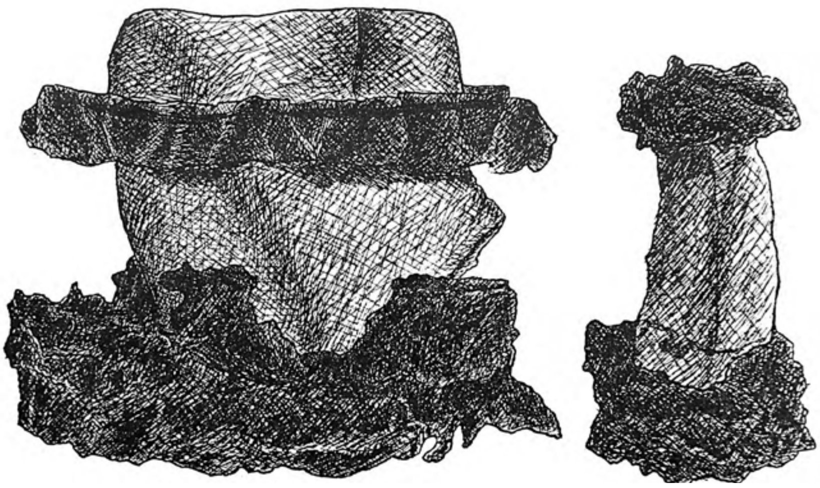
The natives, apart from a few who serve the whites, have died out; mostly they have fallen victims of formal hunts, which were carried out on them in the eighties. Beyond the West Leichhardt River the track leads almost north-northwest, winding through broad waterless valleys and between low and jagged quartzite ridges. The divide between the tributaries of the Leichhardt River and the Georgina is crossed either in Kennedy's Gap or in a pass on the Wagga-Boonya Ridge. The dividing ridge only rises insignificantly above its surroundings, particularly to the west the drop is very slow. The ground is mostly covered with loose, angular quartz debris and coarse sand, which bears an impoverished gidya [*sic* – presumably gidgee] scrub and Triodia grass [spinifex]. Only at some distance from the divide do small strips of open downs country begin to appear, which have a rich, dark soil that is covered with very luxuriant and juicy grass. These strips of good pasture have attracted a settler, a selector, who has established himself in the Gundaria Quadrangle on Johnsons Creek; an almost complete paucity of water threatens his enterprise greatly, as the waterholes in the bed of the creek are mostly not permanent and a well, dug almost 100 feet deep, passed through sand and gravel into the quartzite, without reaching a continuous supply of groundwater. Near the earlier Post and Telegraph station Yelvertoft, now burnt down, the grassy areas become broader, but the limestone cannot be seen cropping out anywhere; then the track climbs again, covering mostly real gibber plains of angular debris of jasper, chalcedony, agate and other varieties of quartz, miserable wattle scrub and tussocks of Triodia grass, and are especially remarkable for the numerous termite mounds, up to 3 m high. On the black soil there are no obvious termite mounds.

The gibber plains are the last denudational remains of the Desert Sandstone Beds, which covered the Tableland. About 50 km east of Camooweal in the catchment of Wooroona Creek the track approaches within ½ km of the low remains of the Desert Sandstone plateau, which rises, with steep slopes, 30 – 40 m above its base, and apparently becomes higher and broader to the east.

Wooroona or Warona Creek is cut into limestone south of the track, on the left side of its bed there is even a doline, about 4 m deep and 10 m in diameter, its base covered with alluvium. The bed of the creek is cut into horizontal, thin plates of a white, ringing, hard, quartz-like limestone, set through with vertical cracks crossing each other at right angles, which border the deeper parts of the creek bed so sharply that it resembles a water-container chiselled into the limestone. From here on there is an initially steep gradient, then from Nowranie Creek on it is almost flat to Camooweal. Here to the gibber plains with scrub predominate over the open downs country. The bed of Nowranie Creek, where it is crossed by the track, contains an enduring, large, deep pond (waterhole), the water of which apparently cannot seep into the complex of limy beds below. On a broad plain, deforested far and wide, lies Camooweal, a town of about 20 houses, and important shopping and recreation centre for a gigantic district, whose area is almost as large as Germany and has at the most 500 white inhabitants. Towards Camooweal converge not only the cattle stations on the Barkly Tableland in Queensland, but also a much larger area in the Northern Territory. The transports to and from the stations go via Camooweal to Burketown or to Cloncurry, in the local inns the solitary, well-paid drivers, drovers and shepherds are now and then relieved of large sums.

Camooweal lies only about ½ km from the broad, shallow bed of the Georgina River, which to the west of the town flows from NNW to SSE, and forms a shallow lake, Lake Frances, where it is nearest to the town. This is only a perennial pond, through the bottom of which water does not sink to the depths. About 4 km NNW of Camooweal, close to Rocklands Station, there is a much larger perennial waterbody in the bed of the Georgina, this is Landsborough's Lake Mary, he who also named Lake Frances. Usually the river bed is dry outside and between these waterholes, only in the rainy season (December – April) does the river bed become a mighty stream, which in places broadens to a lake. Part of the water flows away at the surface, but much more just evaporates and a large proportion disappears in stream sinks which lead to branching cave passages and finally to the base level of the groundwater in the karst area. In the dry bed of the Georgina River at Camooweal and Rocklands the horizontal limestone beds are exposed as steps, which in places show rudimentary fine karren, the joints and gaps are mostly secondarily filled with cherty deposits, which were apparently at least in part originally clayey and limy, but have been infiltrated by silicic acid carried by the water which seeped through the Desert Sandstone beds. It is known that such cherty infiltration is common in Australia, very often on an unusually large scale. The origin of this free silicic acid is not yet clear. Just at the base of the tableland limestones there are sandstones turned to quartzite, which are widespread, and the Desert Sandstone beds contain enormously much secondarily silicified material as well, which as its last remains forms the "gibber plains".

These cherty deposits are naturally more resistant than the limestone beds, particularly as here, on the quietly flowing Georgina, chemical erosion is more effective than mechanical; because of this miniature ledges and lumps of various kinds are produced, when the primary limestone has already lost a great deal of volume. In some places strange forms are created by this unequal corrosion, of which I have brought two fine samples from Rocklands Station to Prague. These have been examined by Dr Radim Kettner, who has kindly put the results of his examination at my disposal. These are given word for word in the footnote.[23] See illustration also.



Corrosion relics from Rocklands Station. The primary mass of limestone is pale, the cherty deposits are dark. ⅓ natural size.

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[23] The cherts, examined on the basis of two specimens, form lensoidal or irregularly-bounded intercalations, apparently completely concordant; they are of a light bluish or yellowish colour with conchoidal fracture. Under the microscope they appear quite dense, structureless, in places clear and translucent, elsewhere rendered yellowish and opaque by accumulated submicroscopic particles of a chloritic and limonitic substance. Under crossed nicols the chert is a dense mix of tiny quartz grainlets, which are either angularly intergrown and mostly show undulose extinction, or are interwoven with an amorphous, isotropic opaline substance. Often small sphaerocrystals of fibrous chalcedony can be seen. In this dense cherty groundmass dolomite grainlets may be embedded, in places rarely, in others in masses, which stand out strongly from the groundmass because of their strong polarisation colours. Even in normal light and with strong magnification and lowered condenser they can be observed easily. As a rule they are bounded by completely developed rhombohedral faces and almost never twinned. – Traces of organic remains could not be recognised in any of the thin sections. A thin section prepared from a siliceous dreikanter shows quite similar relationships compared to the sample of cherty intercalation described above, only the dolomite spar is more rarely developed in the cherty groundmass. Thus it can be easily maintained that the angular pebbles spread over the surface are derived from similar cherty layers in the limestone beds. As far as the *origin* of the cherts which interest us is concerned, I am of the opinion, that they have originated from *dolomitic limestones* by a gradual metasomatic replacement of the $CaCO_3$ by silica. This is evidenced by the presence of dolomite crystallites in the siliceous groundmass of the cherts. Seeping vadose waters bringing colloidal silica dissolved from above, dissolved and removed the more soluble $CaCO_3$ of the originally dolomitic limestones and replaced it with silica; the less soluble $MgCO_3$ did not enter solution and thus remained in the rock. The limestones were shown to be dolomite-bearing by microscopic examination as well as testing one of the thin sections prepared from the cherty limestone with dilute hydrochloric acid. The aspect of the thin section appears to be the same as described by e.g. J.H.L. Vogt from Norwegian dolomitic limestones* or Fran Tučan from those of the Croatian karst area.** Whereas the dolomite grains, when closely crowded, show the characteristicsaccharoidal structure and appear as polygonal, straight- or curved-sided individuals, the calcite can be recognised by its zigzag outlines and frequent twinning. Another explanation of the origin of the cherts under consideration does not appear plausible to me. Contrary to the assumption of an organic origin for the chert intercalations, which their concordant relation to the limestone beds might support, there is the absolute absence of any organic remains in the cherty material. One can hardly accept the opinion that the chert filled pre-existing voids in the limestone, because of the complete absence of structure in the chert. If this last opinion were correct, the chert deposits should show the concentric structure of agate formation. The chert nodules (a hand-specimen from Glissan Caves) from the lower Cretaceous limestones are composed of a mix of grains of quartz, chalcedony and opal, and also contain numerous remains of foraminifera, the shells of which consist of lime. The following genera of foraminifera could be determined: *Operculina, Globigerina, Nodosaria, Haplophragmium, Cristellaria* and *Textularia*. I do not venture to decide the source of the siliceous material forming the nodules, am however of the opinion that is probably not of organic origin, since foraminifera, as is well known, deposit limy shells.

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*) *Norsk marmor, Norges Geologiske Undersögelse,* Kristiania 1897.

**) Die Kalksteine und Dolomite des kroatischen Karstgebietes, *Annales géologiques de la Péninsule balkanique*, vol. VI, Part 2, Belgrade 1911.

Keys In the neighbourhood of Camooweal as well, the plains covered by siliceous gravel take up a much greater area than those on which the limestone is only covered by its own eluvial clay.

The surface is only very rarely exposed, and where one really sees the bare banks in a total thickness of several metres, as already said, the joints and furrows are mostly infilled. The surface of the limestones can thus not function as a sieve, the gaps which might lead the seepage water to depth, are surely mostly blocked. Were this not so, Lake Frances and Lake Mary could not be maintained as perennial waterbodies. It is also quite possible that their lakebed is made up of the siliceous, thinly bedded limestones which are almost impervious to water.

With the exception of the rudimentary karren which can be seen on the exposed limestone banks, there are no other karst phenomena far and wide, and one could travel extensively back and forth without any impression of the karstic nature of the tableland limetones. The cause is naturally only that the tableland was previously covered by Desert Sandstone, that the limestone surface is only occasionally truly exposed, and that the free action of seeping water is hindered by secondary deposits.

Groups of dolines, chimneys and collapse shafts occur only widely separated from one another, mostly they lie near the river bed, and great masses of water disappear through them during high water. With the co-operation of the Camooweal citizens and especially of the Manager of Rocklands, Mr H.A. Glissan, it was made possible for me to get to know all cave groups in the nearer vicinity.

In so far as the Tableland can still be regarded as virtually a terra incognita, so also is knowledge of caves in the vicinity of Camooweal not widespread. In his diary Landsborough mentions only a single locality about 5 km north of Lake Mary, near to Hervey's Creek, "a strange deep rocky pit". Apparently from Landsborough's indications this shaft was taken into the official "Queensland Four-Mile Map" (Sheet 16 D) as "cavern". In his Geographic History of Queensland (issued in the year 1895) A. Meston has the following note (p. 161) on the caves on the Tableland: "Far north-west, in the Camooweal district, on the Georgina River, are peculiar underground limestone caves representing irregular chasms over 100 feet in depth, the walls formed by large limestone boulders, and the floor covered by limestone slabs resembling tombstones. There are side passages, and small caves, some adorned by beautiful stalactites covering the roof." A further remark probably relates to the caves in general "Bones of animals and aboriginals, and heaps of drift, are found on the floors of these remarkable subterranean caverns", for the inhabitants of Camooweal could tell me of such sensational discoveries. The only comprehensive description, of the so-called Nowranie Caves, was given by T.P. Keys,[24] and which was printed only in brief excerpts. Mr Keys was occupied as a teacher in Camooweal for several years, and is still famous as having the best knowledge of the caves and as an exceptionally good climber.

From Rocklands Station I first saw the group of caves on Little Harvey's Creek, which lie near its confluence with the Georgina. It consists of a large shallow asymmetrical doline which is deepest on the north-eastern side and opens beneath a steep wall in a stream sink about 8 m below the upper margin. In the wet season part of the water of the Georgina and Harvey Creek flow to depth through this doline, in the dry season it was quite dry, and it was possible to enter the cave passage which is illuminated from above by an open chimney about 25 m from the entrance. According to Mr Glissan's description the passage was almost horizontal, almost completely lacking in cave deposits, a partly blocked secondary passage led to the collapsed cave entrance somewhat further south. This year the water remained in the doline, although the river beds has been dry for a long while; the stream sink was quite firmly blocked by material washed in and perhaps also through collapse of part of the roof, so that the water could not flow away. In this way Rocklands Station was enriched by a fine "waterhole", most welcome to the management, as on the upper Georgina there are only three waterholes (Grassmere waterhole, Keribobla waterhole and Redford waterhole,[25] which however exceptionally, during long-lasting quite rainless dry seasons, also dry up.

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[24] Description of some caves near Camooweal. (Read before the Royal Society of Queensland, August 19, 1899. *Proceedings of the Royal Society of Queensland.* Vol. XV. 1900. Pp. 87 – 88.

[25] On the map in Stieler's *Handatlas* Redford and Grassmere are denoted as small settlements. Presumably the abbreviation W.H. caused an error. On German maps W.H. indicates an inn [Wirtshaus], but in Australia merely a pond, sometimes with bad and stinking water.

The eastern rocky margin of this doline runs almost N – S, and about 25 m further east the chimney and the collapsed cave lie in the same direction. The debris does not permit access to the cave passage. The freshly broken off beds of the former cave roof are mostly quite thin and siliceous, only deeper in the cave are there thicker beds. The siliceous beds here and there also contain chert nodules and the joints are partly filled by cherty, hard intermediate layers. I gave the name H.A. Glissan's Group to these caves, to acknowledge the great merit that gentleman earned for the exploration of the hydrographic relationships of the area during the quarter-century of his sojourn on the Tableland, and for their economic opening.

Approximately 2 km further north-west lies another doline, arisen by collapse. On the north side it is enclosed by a steep wall about 13 m high, on the other sides the ground rises step-like, below the wall lies the rather blocked stream sink opening, to judge by quite fresh traces the water stood at about 2.5 m below the upper edge. On the return journey we saw about a further 1½ km NW of Lake Mary a doline with oval outline, originating by collapse, whose longer axis runs WNW – ESE and is about 14 m long, 10 m wide and 10 m deep.

The next day we saw the caves on Emu Creek, about 15 km north of Redlands. Here, in flat-lying exposed limestone beds are a few rudimentary dolines, then further east a large basin-doline about 5 m deep, with a small stream sink at its deepest point, and close by a large half-uncovered cave, which occupies a space about 50 m long N – S, and 30 m wide; only less than half of it remains as a cave, while the roof has collapsed over the remainder. Two small chimney openings lead vertically through the about 5 m thick roof into the cave. The debris of the collapsed roof lies in chaos on the floor of the free space, it is still only slightly affected by corrosion, so the collapse can be considered relatively recent, the step-like slopes and the bared surfaces of beds in the vicinity are weakly karstified. The roof of the cave is completely without cave deposits, its floor is covered with dry dusty loam, the stream sink is covered by debris. On the western side of the covered section, part of the roof remaining, 3 beds thick, is broken off at a thickness of over 1 m and forms a continuous terrace rising above the cave floor. About 50 paces east of the basin-doline is another of oval outline, with steep, rocky edges, and still partly filled by water. The depth of the uncovered slopes is 3 m, the depth of the water still more than 1 m. This is the collapse doline, much filled by material which has been washed in.

About 8 km north-west of this group is another so-called Hassel's caves on Elizabeth Creek, which are very deep and accommodate a large number of bats.

In a southerly direction from Lake Frances the Georgina forms another "lake", Lake Canellan, which dries up in very dry years. About 1 km west of this pond lies a collapse doline in the process of formation. A slightly elliptical almost round space about 30 m in diameter is filled by a confusion of broken, thick beds, broken into large and small plates, which sink concentrically towards the centre; here however there remains a stable bridge, beneath which there is a narrow, partly collapsed but still 5 m long cave entrance leads, from which several very low horizontal passages branch, and are almost completely filled with loam. A few 3 – 5 cm long stalactites hang from the roof of this passage. Some rocks at depth show the effect of sand carried in eddies well. Fifty metres in an easterly direction from this big collapse doline lies a small, shallow basin-like round doline, whose floor lies only about 30 cm below its margin. Small, shallow karren are eaten into the surfaces of the beds, even the corners of the disturbed, lying debris have been attacked. During high water an arm of the Georgina River disappears through this cave.

The western bank of the bed of the Georgina and that of the lakes in it as well is less steep and high than the eastern bank, this same phenomenon is apparent on other N – S flowing waters on the Tableland.

About 2 km north-east of Camooweal in the immediate vicinity of the track now used by the Cloncurry coach there lies a group of depressions. North of the track there is an irregular doline with branching margins, which harbours a waterhole; its diameter reaches about 30 m, the depth 5 m, it is filled with soil and other material washed in. South of the track there is an even more irregular depression, actually a group of stream sinks with a common outer margin. The depression has partly arisen by sinking of the thick plates, which are partly covered by hard, silicified, red secondary deposits. Water flows into one of these stream sink openings, now partly filled with mud, into another a sharp cutting leads from the southern side. The cuttings are mostly joints, broadened by the swirling motion of the water, one can clearly see how the water partly disappears sideways beneath the beds, but how, after heavy rain, the greater part of the water reaches the stream sinks and has great evorsive power, as it takes quartz gravel and sand from the surroundings with it. About 400 metres to the SW lies another depression, whose centre is taken up by a gorge with vertical walls, which arose by collapse of the roof over a cave which formed a regular parallelogram. The eastern and western sides are about 30 m long, the others about 10 m; one can climb in through deep water-made cuttings from the northern side, the depth from the base to the margin of the depression measures about 25 m. In the southernmost part of the space a section of the roof remains preserved; on the floor lie the remains of the roof with broken, short stalactites, partly covered by damp, dark red mud. The deepest part lies in the south-western corner, where there is a blocked stream sink. A sharp water cutting also leads into the space from the southern side.

About 6 km east of Camooweal lies another group of stream sinks, which are almost regularly four-cornered depressions with somewhat abraded margins, lying two together. The floors are covered with sandy clay. Two are larger, with about 5 m length of their sides and 2 – 3 m deep, two smaller, about 1½ m wide and 1 m deep. In a northerly direction from these sinks near the telegraph line there is a doline originating through collapse, which is connected with a still-covered cave on the western side. The diameter of the pentagonal doline measures over 20 m, the depth about 15 m, the entrance to the cave is 13 m wide. The roof is penetrated by two round chimney openings, in the south-western corner there is a stream sink, blocked with mud. The eastern part of the cave has gentle slopes to about 6 m depth, but in the lower half they are almost vertical; there was apparently a funnel-doline, which then was deepened by collapse of the roof. Karstification only weak, no speleothems.

The Nowranie Caves,[26] which the "servile" portion of the local population refers to as the "Lamington Caves" (after the Governor, Lord Lamington, who visited the caves) lie about 20 km south-east of Camooweal, near the shallow bed of Nowranie Creek, some of whose waters flow into the cave at high water. A spacious natural shaft occurs in the middle of an oval room which descends in step-like fashion, with a narrow base on the ENE side, with two walls about 40 m long, which intersect at an acute angle in the SW. The depth below the short base wall is about 40 m, here a high cave-gate opens, to the SW rises a big debris pile, so that in the sharp corner the depth of the floor is less than 20 m and divided by a great rock jammed in it. From the two corners of the base wall two sharp cuttings lead into the shaft, through which floodwaters in part reach depth. P.T. Keys describes three storeys in this cave; we were only in a position to visit two of them, in the third, deepest, there was still water remaining. Two kinds of cave entrance can be differentiated, the high and broad passages which run in sharply determined directions, and then the adjacent caves and low lateral passages, which in the upper storey only are more widespread. The upper storey communicates with the lower through a broad hole, hollowed out in the hard, siliceous, ca. 1½ m thick layer between by the swirling motion of water. At the end of the accessible passage of the upper storey beneath the debris there are other holes, now inaccessible. A narrower, chimney-like hole leads from the lower storey to the water level, which lies more than 73 m below the surface. The upper storey lies more than 40 m, the lower about 55 m below the edge of the natural shaft. Different directions become apparent in the course of the main passages, mostly WSW – ENE dominates, then come WNW – ESE, SSW – NNE and SSE – NNW. The length of the main passages of the upper storey that we walked measures about 160 m, those of the lower storey about 60 m. The floor is formed of flat bedding planes, is covered in places with fallen debris from the roof, introduced clay and gravel fill the joints between the flat, tombstone-like plates. As already indicated, the floor of the upper and also the lower storey are formed of these thin, cherty limestone beds, which have been eroded through mechanically at distant points. Secondary lime deposits are extremely sparse, stalactites are rare and short, stalagmites only rudimentary and even rarer, only below some narrow chimney pipes are there thick travertine columns and shallow terraced overflows on the floor. The air is very cool and at a few places in the upper main passage there is an eddying, strong draft of wind, which is apparently caused by openings in the roof; the poor lighting with torches did not permit a closer examination of the upper parts of the high passages.

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[26] It is the great natural shaft and the cave leading from it that T.P. Keys described in the Queensland Royal Society Proceedings.

About 100 m WSW of the natural shaft there is an oval depression, in the middle of which a chimney of about 3 m diameter is situated. The chimney is at least 50 m deep, but appears not to communicate with the other caves at present, since burning bundles of straw we threw down were suddenly extinguished at a certain depth.

I have asked about other caves in the more distant surroundings and obtained information about only three; one, which is shown as Jopp's Cave on the map, about 30 km south of Camooweal on the Georgina River, and takes up part of the high water; about 20 km west of the Georgina Happy Creek flows almost parallel with it, and is formed from its tributaries Kiama, Bustard Creek and Cattle Creek. On Bustard Creek there is also a cave and an arm of Happy Creek disappears into another about 10 km further south.

In the territory of Avon Downs Station (the only sheep-raising station in the Northern Territory) there are no known caves.

If all these cave groups enumerated here are marked on the map even approximately correctly, they are aligned quite obviously in three approximately N – S zones; the eastern one with Nowranie Caves and the stream sink group and the doline on the Telegraph line east of Camooweal, the middle one along the course of the Georgina and the third, western one, on Happy Creek. It appears that in these zones there are lines of weakness affected by faulting, perhaps the asymmetry of the river beds, already discussed also has a tectonic cause.

From Camooweal towards the north-east the track leads mostly over gibber plains with large quartzite and chert blocks, numerous gravels of jasper and agate, often with typical dreikanter or multi-sided forms; the limestone beds rarely rise above the surface in more or less karstified form. The scrub is rare, but the rich areas of grass are reduced in relation to the sparsely grassed gravel surfaces. About 13 km from Camooweal one passes Bullring Waterhole on Chester Creek, a tributary of the Georgina. The water reserves do not suffice in dry years, and so a subartesian borehole not far to the east must help out, to water the cattle. Even further to the NE the track crosses another creek, now of course dry, which purportedly ends in a waterhole, probably a doline.

On the banks of the dry bed of the O'Shanassy River the thin-bedded, cherty limestones are exposed, and only let very little water through to depth and show no inclination to karstification. About 6 km further there is a zone in which very slightly karstified limestone forms the surface, the karren are common, but mostly not deep, and a large number of rudimentary dolines is present. Towards Old Morstone these beds are covered over rather large areas by a quite thin layer of conglomerate, which includes gravel and angular fragments as well as sand, cemented by calcareous sinter. These are doubtless secondary deposits, such as are known elsewhere in tropical, subarid climates. [27] Further east the matrix of the conglomerates becomes more siliceous.

Morstone sheep station is situated on the O'Shanassy River, whose bed is marked by abundant gallery-forest. Only in recent years has the river dried out complexly, it supposedly always had water before; water is obtained mostly from the waterholes and from shallow and not very productive wells. Deep bores have not yielded good results, although water was reached at several levels, but never in sufficient quantity to justify pumping it out.

Conditions on the adjacent Beaumont Station are similar. The limestone high country continues without break along the track to the Thornton River, but on the right bank of the broad, currently dry river bed, sharp quartzite ridges alternate with limestone rocks, and on the Seymour River one is among the strongly folded metamorphosed schists of the old mountain country, through which towards the north follows the valley of Police Creek. The mountain country is very much desert and waterless, but still strongly coursed by valleys, the relative height of the highest points is small. The area has no owner, belongs to no station, and the only large waterhole – Lilly – on Police Creek serves only the post horses and the camping area for transports between Camooweal and Burketown.

The valley of Police Creek becomes ever broader, the last spurs of the old mountain are held back and a flat, unforested area with sparse grass continues as far as the green strip of the gallery-forest accompanying the bed of the Gregory River. The Gregory River is perennial and flows between banks 15 – 20 m high, has a broad high-water bed and several "anabranches" and "billabongs", but for most

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[27] Branner J.C., Aggraded limestone plains of the interior of Bahia and the climatic changes suggested by them. *Bulletin of the Geological Society of America,* vol. 22, pp 187 – 206. 1911.

of the year only forms a 10 – 15 m wide, quite deep, clear stream. The whole inundation area is wooded with semitropical scrub, the actual river bed is often accompanied by an impenetrable Pandanus thicket.

From the Gregory Downs Hotel I undertook a six-day excursion, which led me to the west into the Burketown mineral field, from where, in a south-easterly direction, I reached Riversleigh Station via the Lillydale ford on the Gregory River, and then in an easterly direction to Lilly waterhole to arrive at a familiar track back to Gregory Downs Hotel. This area has been dealt with in some detail in the oft-quoted report of W.E. Cameron and the monograph of L.C. Ball, and in travelling through briefly I could not gain more than a general impression. From Gregory Downs westward one travels first through a gently undulation landscape, dominated by the Desert Sandstone. Only about 40 – 50 km further one travels between short, low ridges, mostly formed of old metamorphosed schists, limestones and quartzites. The limestones are different from the Tableland limestones, are almost marble-like and decidedly much older. A little-disturbed, locally very hard quartzitic sandstone appears to overlie this old succession, and in places where the tableland limestone succession is preserved, forms its immediate bedrock. This can be seen in different places further south near Riversleigh and on the Thornton River, and I believe that W.E. Cameron is correct in describing this sandstone succession as younger and tectonically less disturbed than the old complex of beds immediately underlying it. Here two different quartzites and two different limestones must be differentiated; the older ones belong to the old succession and form only zones or lenses within it, the younger ones lie discordantly on the old metamorphosed succession, the quartzite-sandstones domed and the limestones almost horizontal. These however are only present in compact [!] form in the west of the area forming the edge of the tableland, in the Burketown mineral field they are only preserved as “témoins” or witness-hills, among which the hill at Lawn Hill Station is best-known.

The tectonic evolution of the area is interpreted by me, much in agreement with L.C. Ball, as follows. The sandstone series was only formed, as the old Palaeozoic mountains were already deeply eroded, but underwent its last reverberating movements as well. Later however, after the Cretaceous transgression, which left the tableland limestone and at least partly the Desert Sandstone series behind, a new, shallow arching in the nature of a large fold arose, which was connected with another, much higher arching of the mountain country of Cloncurry. In the up-arched area the Cretaceous cover was removed, apart from small, perhaps somewhat sunken plates. The present border of the tableland also approximately marks the boundary of this anticlinal structure, there the Cretaceous beds remain almost undisturbed. At the same time as the up-arching of the large anticlinal structure or later, the area of the Gulf of Carpentaria sank, and the activity of the rivers flowing through it was rejuvenated. A later stage of the falling sea-level can also be determined, since the rivers are altogether deeply cut into the alluvial plain, and some of them must adjust to the jump in levels by a waterfall in their lower courses (e.g. Leichhardt River). This renewed erosional activity has enlivened the battle between the individual rivers. A broad valley runs through the Burketown mineral field from south to north, in which there are now low divides. The northern part is drained by Louie Creek, the southern by Little Creek, to the Gregory River. This old valley, whose southern part was named Daneš Valley by L.C. Ball, lies in the continuation of a similar dry valley, which separated Verdon Rock south of Verdon Creek from the tableland, and this again is only an extension of the O’Shanassy River valley. Apparently the changes of balance benefitted the Gregory River so that it could deepen its valley backwards faster, and turned the O’Shanassy to its tributary.

I have already mentioned how I found secondary fossils in the limestone at approximately the same places as W.E. Cameron and his informants. It remains to remark that the Gregory River below the Lillydale ford has deposited much travertine and lime-cemented conglomerate, which has diverted an arm of the river as Carl Creek. The bed of this, as is that of the main river, divided by travertine barriers into several deep reservoirs, between which the water flows as rapids or cataracts. The highest of the waterfalls lies about 4 km downstream of the ford, where the river, as two mighty streams and numerous small ones, forces a way through an almost impenetrable pandanus thicket, and from about a height of 5 m drops into a long, little moving channel. Above the ford there are also “rapids”, and near the main sources of the karst river also some reported by Landsborough. Thus, much travertine is deposited by the river, and even near Gregory Downs the gravels are rapidly cemented and tree-trunks encrusted.

Hydrographic Relationships of the Tableland

A large part of the Tableland is drained towards the outflow-free area of central Australia. The Georgina River with its tributaries belongs to the catchment of Lake Eyre, north-west of it there is a myriad of small watercourses, which supply the so-called polygonum swamps, broad, morphologically expressionless shallow basins, which are sometimes dry. The Georgina has a greater gradient and spreads its area at the cost of these periodic lakes. The entire enclosed area however is mightily attacked from the north-eastern side, the rivers hurrying to the Gulf of Carpentaria forever cut more into the edge of the Tableland, and move the watershed further inland. Almost all rivers, and in their headwaters all of them, only carry water periodically, and that only in the wet season, which often begins as early as December and often continues until April. The amount of rain falling in this area is rather irregular, it is subject to such gross variations as that further south-east, where periodically very devastating, long-lasting droughts occur, caused by an almost complete failure of the wet season. The Tableland does not suffer such devastating droughts, and this advantage of the climate is greatly valued by the cattle-breeders, and praised in all printed matter seeking the attention of settlers to this area.

The average annual rainfall in Camooweal is about 300 mm, to the south and south-west it is certainly less, to the north-west however, greater. On the Roper and Daly Rivers it measures on average almost 1000 mm. In the wet season the flat area often is several times turned into wide expanses of water by continuing rain; the rivers and creeks all overflow their banks and flood their surroundings far and wide. The higher gibber plains then form islands of different size and extent, on which the cattle and all the mammalian fauna seeks refuge. If however the flood comes suddenly, it is not uncommon for the sheep stations to suffer significant losses of the unprepared sheep herds by drowning.

The water flows quite slowly away in the shallow river beds, a large proportion is lost to evaporation and part of it enters the joints and particularly the sinks, and feeds the groundwater. Those rivers which flow the entire year are generously supplied by this groundwater. No stream flowing inland taps the groundwater, only those perennial rivers flowing to the Gulf of Carpentaria and the Timor Sea, which represent an anomaly for their climatic zone.

Landsborough has already noticed the great difference between the ever-flowing Gregory River, which arises suddenly from springs, and the O'Shanassy River, which, although it shows higher water levels, is otherwise often dry. A.C. Gregory correctly held the springs rising from the limestone area as the source of the continuous supply of water to the Victoria and Roper Rivers. W.E. Cameron correctly recognised that the great permeability of the limestone complex is the cause of this phenomenon, already knew the results from the subartesian bores, and drew the right conclusion that water can be reached at a particular level by boring everywhere on the limestone plateau.

Naturally, in economic circles, people were not satisfied that only subartesian water, which had to be pumped artificially to the surface at significant cost, was reached, and there were also experiments to see if it was possible to drill to a level, from which the water would reach the surface under its own pressure. In this way subartesian water was obtained in several boreholes in the area of Rocklands Station at a depth of 60 – 80 m, but two boreholes were sunk deeper (bore no. VI, 190 m, bore no. VII, 250 m), but naturally no water under artesian pressure was reached, since boring was carried out only in limestone. On Alexandra Downs station in the Northern Territory a borehole was in fact sunk to a depth of 1700 feet (more than 520 m), still in limestone, and that happened, although the groundwater level was reached at about 100 m. As the Great Artesian Basin of Australia lies under the superficially similar downs country of Queensland, it was reckoned with certainty that under the "downs country" of the Tableland artesian water would also be found. After several unsuccessful experiments to find an artesian source below the subartesian one, the results were finally accepted. Even the representatives of science accepted this fact, but could not find an explanation of it anywhere. It would have been very appropriate however, to explain to the cattlemen who didn't spare money or effort to obtain a reliable water supply, that in the porous and much-jointed limestones the extraordinary pressure regimes that cause the water to rise to the surface, are not to be reckoned with.

It has been determined in numerous bores that over the whole Tableland, insofar as it is made up of limestone (with the exception of the eastern part, where the impervious siliceous and dolomitic limestones dominate), water can be reached, but which only rises to a certain level, or can only be reached at this level by boring. According to the assumption of the most knowledgeable persons of the conditions, the results of all bores so far suggest a common level for the groundwater, which apparently drops slowly from south to north. A direct proof cannot yet be given, as our knowledge of the absolute and relative heights of the individual boreholes is only superficial, and cannot be obtained with the necessary approximate surety using available means.

Mr H.A. Glissan of Rocklands has made available to me the complete data on bores made on this cattle station, I have only been able to obtain general information on the depth of the underground water levels orally and from literature for the remaining region. At the time of my stay on Rocklands Station in 1910 there were already seventeen functional subartesian wells: No. I. 405 feet deep, water is pumped from a depth of 312 feet; No. II. 300 feet, pumped from 250 feet; No. III. 320 – 250 feet, No. IV. 300 – 200 feet, No. V. 320 – 270 feet, No VI. 610 – 280 feet, No. VII. 800 – 185 feet, No. VIII. 406 – 320 feet, No. IX. 380 – 280 feet, No. X. 300 – 260 feet, No. XI. 380 – 260 feet, No. XII. 300 – 260 feet, No. XIII. 380 – 260 feet, No. XIV. 380 – 260 feet, No. XV. 360 – 260 feet, No. XVI. 340 – 280 feet, No. XVII. 300 – 260 feet, No XVIII. Water level not yet reached.

Even if all these data cannot be exactly compared, and one has to be satisfied that they all point to a uniform groundwater level, two at least can be considered separately, namely bore No. VII, which is situated about 15 km south of Camooweal in the bed of the Georgina River and bore No. IV, which lies about 7 km further to the SE on Don Creek. In both of these bores the water is pumped from an exceptionally small depth. This fact surely indicates that the water level drops from south to north, which is supported by data from other stations further south.

On Morstone Station in the north-western corner near the O'Shanassy River two boreholes were sunk to a depth of about 300 feet with good result; further east and south-east however all attempts at finding artesian water failed; one borehole was sunk to 500 feet, but no water was reached. My informant (the manager in Morstone) told me that only limestone was penetrated; apparently there near the old mountains the more impervious quartz-rich beds predominate, of there is even a tectonic fault, which cut off the connection of this eastern part of the Tableland with the uniform groundwater level.

There are boreholes with subartesian water on Flora Downs station, Lake Nash station, Hervert Vale, Avon Downs, etc., mostly the water is pumped from 60 – 100 m. May I be permitted to quote here just one section from the "Report" of the explorer David Lindsay,[28] which refers

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[28] Land-Grant Railway across Central Australia. The North Territory of the State of South Australia as a field for Enterprise and Capital. S. so. (D. Lindsay, Report on "The Tableland" 25th July 1898.)
Large supplies of good fresh water have been obtained at varying depths up to 200 feet, and no doubt exists that water can be obtained any where [sic] by sinking. It is just possible that artesian water may be found. A trial bore on the Alexandria station, put down to a depth of 1664 feet, failed to strike artesian water, although at 238 feet water was met with, which rose 19 feet and yielded 24,000 gallons per day, the utmost capacity of the pump, without diminishing the flow. By means of windmills the water from wells can be very cheaply raised and pumped into tanks. During the dry season – the winter – strong winds blow regularly, ensuring the satisfactory working of these mills. Owing to the absorption of the immense bodies of water which find their way on the western portion of this tract of country, and the rock formation of the ranges near the telegraph line, artesian water should be found over a considerable are, but here the grasses are not nearly so good as on the eastern portion of the Tableland. Throughout the whole of this area all the surface water is fresh. Soil. – For the most part the soil is of a rich black or red loam mixed with clay. On the bluebush flats and part liable to inundation the soil is loose and very porous, and in the dry season full of cracks, through which immense quantities of water flow to the subterranean reservoirs and channels. This is specially noticeable on the western half of the Tableland.
Equally important is the evidence of Mr John Costello from Lake Nash station, before the Royal Commission, who wrote (*The Northern Territory of South Australia. Papers read before the Royal Geographical Society of Australasia, South Australian Branch.* Adelaide 1901, p. 11.): *"There is a large area of country from Newcastle Waters and the head of the Roper to the Queensland border at Camooweal. This magnificent belt of country known as the tableland may be said to be the cream of the pastoral land of the Territory. I have the fullest and greatest faith in the future of squatting in it. I have travelled over most sheep raising country in Queensland, and I can safely say that in no part of that Colony have I seen country better adapted for wool growing than this splendid table-land. A permanent supply of water can be obtained in this country at a depth varying from 150 to 250 feet. It would not require an expensive boring plant to put down a 7-inch tubed well that depth. At each such well, 6000 to 8000 head of cattle could be watered.*

to that part of the Tableland stretching between the Queensland border and the transcontinental telegraph line.

On Milne River station an inexhaustible supply of water was reached by boring at a depth of 40 m. In the opinion of the owner (in the year 1885) it was possible to reach water at the most 45 m deep over much of the surroundings. In Carrandotta and Hedingley somewhat further to the south fresh water was reached at different depths between 15 – 20 m and each bore had a boundless supply of water. *"I take it to be a general underflow of water all through this country and no local soakage"* says the informant Mr J.S. Little.[29]

Somewhat south of Carrandotta (22° S) is the southern end of the Tableland to be sought. This accords with the information given by W.O. Hodgkinson in his report on the nature of this region.

The western and south-western boundaries are still not known, since no drilling at any scale has been undertaken further west of Brunette Downs; as however shines out from the report of the cattle inspectors, it is much in the interest of the cattle-growers and particularly for the maintenance of the cattle droving tracks (stockroutes), for the government to take the initiative and begin drilling in the area east and west of the telegraph line.[30] In the northernportions of the Tableland however, artificially obtained water is no longer so necessary, since the catchments of the Daly and Roper Rivers receive a high annual precipitation and the number of perennial "waterholes" and natural springs is large. There remain only the lasting, unceasing springs that arise on the limestone terrain, and the perennial rivers continuously nourished by, it as natural proof of the inexhaustibility of the amount of water stored in the limestone complex.[31]

[28 [cont.]] *It would be a certain reserve store in case of drought. I think I might safely say that (with sufficient wells) the stations from Lake Nash to the head of the MacArthur would be equal to supporting 10,000,000 sheep."*

[29] The land-grant Railway across Central Australia etc. p. 72. (Extracts from three reports to the Government Resident by Mr J.S. Little.)

[30] *Government Resident's Report on the Northern Territory 1909*. Adelaide, 1910, p. 7.

[31] In this context A.H. Glissan expressed himself very clearly in his excellent letter to Mr George Phillips, which I give here in extensor (Report by Mr George

[31 [cont.]] Phillips C.E. upon the Advisability of constructing Railways etc. in the Gulf of Carpentaria. pp. 38 – 9.) *Following up my promise to you when here to commit some of my experiences on the question of the Gregory River and our sub-artesian water supply to paper, I will now do so. In a conversation I had with you, you gave me to understand that some of the residents on or about the Gregory River were of opinion that the flow of water down that magnificent stream had to some extent given out. I certainly cannot confirm this, as after twenty-three years living in this part, and seeing the Gregory on many occasions (where I have spent many pleasant days fishing), I cannot think for one moment that the normal supply of water has decreased. I fancy that the idea of the flow having decreased in this way (and no doubt rightly too) has its origin in the fact that the rainfall at the heads of the river in some years is very much heavier than in others, so that the surface drainage is greater and continues longer in some years than in others. Beyond all doubt the Gregory is fed from the enormous supplies of water stored under the surface, and contained in the limestone formation of the Barkly Tableland. I feel sure that if careful measurements were made of the supply of water passing a given point in the Gregory River, in dry or very dry years, that the supply would vary very little if any. Once the surface drainage is exhausted then the subterranean flow would, I feel sure, be very regular. I would here staet that I have had put down on Rocklands eighteen sub-artesian bore wells, which have been in use for over fifteen years, and in no single instance have I had to lengthen my pump casing to reach the water; all have stood at the same levels as when first struck. One pump, the working barrel of which is only 6 feet in the water, has been running with engine-power for weeks and months (double shifts), and has never exhausted the water or necessitated the lowering of the pump. I would here mention that I had one bore tested very severely with large engine and 4¼ inch pump, and the pump run at barely a safe speed, which gave the splendid result of 120,000 gallons in twenty-four hours, and never reduced the supply as far as we could tell. This will show you enormous supply of splendid water under the surface of the Barkly Tableland. You have seen a little of our rolling downs, and I will say that God gave us splendid country, superficially dry, but with an unlimited supply of the best water beneath our feet. I was sorry that your time would not permit of my showing you round. I mentioned to you the numbers of caverns and places where water gets beneath the surface. There are several places on the property where the river and other large creeks run into for weeks, some years, and the water is going away into the interior of the ground all the time, the cavern never standing full. At the Nowranie Caves we can go down with ropes for about 240 feet till you come to the standing water, which, so far, though known for years, has never been dry, having been visited on many occasions. I will here mention that there are no doubt, subterranean air passages extending for miles. In some bores the current of air is so strong, when the wind is in a certain direction, that it would blow your hat away if held over the hole. I have seen the*

Thus the water stored in the limestone complexes becomes an inexhaustible source of life in the entire gigantic region, by creating permanent rivers and springs on the one hand, on the other, providing boreholes with the necessary water for the extensive exploitation of the higher areas, which without this reachable underground water supply would be almost unsuitable for exploitation. It can be considered quite certain that only after many years will we learn to properly appreciate the economic importance of this underground water supply, until even in the Northern Territory people have outgrown the baby-shoes of attempts at settlement.

It cannot be doubted that here we are dealing with a uniform groundwater level in a very large and deep karst area. Naturally the rock is not so jointed, that water can be expected at the specified level at every place, but if one bores somewhat deeper one does obtain water, which then rises to an almost stable level. Such local differences can also be brought about by intercalations of impermeable beds or by secondary intercalations.

In the karst area of the north Australian tableland there lies a young, tectonically very little disturbed karst area. The morphological exploration of this has only just begun. With the exception of a portion of the eastern spurs of this area, the region around Camooweal on the Barkly Tableland, the description of which is attempted in this article, we have only a few older data from other areas lying far to the north, which report the karstified nature of individual landscapes or limestone complexes. References to these from J.E. Tenison Woods[32], A.C. Gregory[33] and H.Y.L. Brown[34] may be cited here. I am however convinced that dolines and

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[31] [cont.] *Georgina River in very big flood, and 4 feet over the 8-inch bore-hole for ten days, and the hole could not be filled. I went to see how things were at the bore, in my boat; the swirl of water was over the hole all the time. This shows you the enormous intake of water there is, and that there is very little chance of the Gregory River ever failing.* It is very significant that the water level in the boreholes moves so little; because of the decided character of the wet and dry seasons one would expect something quite different. This circumstance is probably to some extent explained by the enormous areas over which the groundwater spreads. Locally the level of the water is probably raised strongly by the intensive inflow in the rainy season and the increased pressure would also raise the outflow rate of the karst rivers at their springs, but during the dry season the water level never sinks below a certain minimum.

[32] J.E. Tenison Woods, *Report on the Geology and Mineralogy of the Territory*. The Northern Territory of South Australia. Adelaide 1888. *"Next in succession to the granite and the folded and contorted slate strata comes a small outlier of ancient crystalline limestone, which occupies a small area of a few hundred acres at the Eveleen mine. The strata are contorted and even bent and folded into rude circles. Besides presenting the usual appearance of limestone, of fantastic pinnacles etc., this formation has a most peculiar aspect from the nature of the rock."* Eveleen mine lies north of the tableland near the upper reaches of the Mary River. Tenison Woods compares this limestone with similar ones in Queensland, in the Malayan Peninsula, on Borneo, in China and in the Philippines; these are Devonian or lower Carboniferous. The limestone at Eveleen may perhaps be of the same age. – That refers to the series considered by Brown – Basedow to be Precambrian.

[33] Journal of the North Australian Exploring Expedition under the commando of Augustus C. Gregory Esq. *The Journal of the Royal Geographical Society, Lond.* Vol XXVIII. 1858. p. 82. July 4, 1857. *"At 15° S near Dry Creek "limestone was frequent and rendered the surface very rough and frequent depressions of the surface appeared to result from the falling in of the roofs of caverns beneath, the existence of which was also indicated by deep clefts and holes in the rock, into which the surface water flow during the rains."* p. 83. July 10. *"limestone appeared, deep isolated hollows were frequent. In one of these hollows which was 30 yards in diameter and 19 ft. deep there was in the centre a chasm in the rock 15 ft. deep and 3 ft. wide extending to E and W."* p. 84. July 12. *"This sandstone rests on a hard cherty limestone similar to that of the Victoria. In this rock many depressions occur, apparently caused by the falling of the roofs of caverns, as there are usually deep fissures in the rock at the bottom of these hollows, into which the surface water runs during rain. In some places the sandstone resting on the limestone have sunk many feet below the general level, with areas varying from 1 – 10 acres, sometimes sloping towards a central point of depression 10 – 30 ft. below the plain, and in other cases they have abrupt rocky banks 3 to 8 feet high, and the bottom perfectly level. The level character of the country is unfavourable for investigations of this nature and the thickness of the strata not easily determined; but the collective thickness of the strata above the limestone may be assumed as less than 100 ft. The porous nature of the limestone precludes the existence of surface water by draining the whole of the upper part of the tableland, while it causes strong springs in the lower ground to the E., where the limestone is exposed on the banks of Elsey Creek and the Roper River."*

[34] *Northern Territory of South Australia. North-Western District. Reports on the explorations made by the government geologist and staff during 1905.* p. 14. Limestone beds E of Mt Litchfield to the Katherine River (2 miles north of Noltenius Billabong and c. 9 miles from Daly River) *"beds of a compact blue-grey and yellow sub-crystalline limestone are horizontal ... The exposed surfaces have been eroded in*

stream sinks in particular will be found scattered in many other places. What is the cause of this weak development of karst phenomena on the surface? Probably the main reason for the fact is to be sought in that the whole area of these complexes was covered by the Desert Sandstone, and is still largely covered by it. The secondary infiltration of silicic acid in the limestone beds beneath, along the joints and bedding planes, has also made the uppermost beds of the limestone more resistant to chemical corrosion and greatly reduced the natural porosity of the rock, so that the corrosive activity of the surface water could only be developed at favourable sites. However, where the occasionally flowing water has succeeded in widening access to depth, it has also succeeded in creating a wide stream sink and cave passages as well, both chemically and mechanically, as far as the groundwater level. The high waters always carry very much gravel and sand and have great erosive power. To this chiefly erosive power of the swirling water is due that the hard impervious quartz-rich interbeds are broken through in places and so the development of the various storeys of the caverns could arise.

There we have before us an entire youthful karst, but a covered karst, whose surface development is dependent not only from chemically corroding forces, but to a great extent also from mechanical effects. There are only rarely karren and those only on longer-exposed limestone beds, there are rarely genuine solution dolines, instead there are mostly mechanically potholed stream sinks, and caves that are broken in or collapsed. The relationships are much complicated by the impervious interbeds.

Some remarks on the development of karst phenomena, on karst hydrography and on the geographic cycle in karst.

As already outlined in the first part of my karst studies in the tropics, a certain dissatisfaction with the results of karst study in the tectonically strongly disturbed mountains of Europe drove me to seek less-disturbed karst areas beyond Europe and in other climatic regimes. Whether I have been successful in this can be judged from the three parts in which my karst studies in the tropics are contained in extenso. I saw there many new forms and needed to change my opinions on the origin of others to a certain extent. It would be superfluous to go into detail and deal with the different karst researchers and spelaeologists whose opinions I either share or must counter.

In Goenoeng Sewoe and in the karst plateau of the Barkly Tableland I was particularly surprised by the multitude of forms due to collapse. The true corrosion forms of the surface, real dolines, are here in the background. Whereas, for example in the Dinaric karst, one can reckon with such a great preponderance of true corrosion forms, that e.g. B. Cvijić and Grund considered forms derived by collapse to be exceptions and devoted little attention to them, one can consider these collapse forms to be typical of the areas visited by me. It can certainly be suggested that "cockpit country" or "Goenoeng Sewoe" might represent a very advanced style of karst, that thus perhaps the numerous collapse forms are characteristic of the old stages of the geographic cycle in karst. Contrary to this I can suggest that in a karst area as young as the northern Australian tableland, these forms dominate completely; that, however, I have not encountered a greater number of typical collapse structures in a region very similar to a typical "cockpit country" north of the lower Narenta and in other approximately similarly developed areas of the Dinaric karst. I am obliged to think of other causes of such a frequent occurrence of collapse structures. As emerges from the descriptions of other very little disturbed karst region, collapse structures are also widespread there, as e.g. in Florida, in Yucatan, in the South Australian karst area of Eucla; the corrosion dolines so common in Europe are scarcely mentioned. I am strongly inclined to suppose that the tectonic element plays a big role. It can indeed be supposed that the limestones that show relatively more collapse forms have a much lesser degree of solidity than the others that do not collapse so easily. Three elements are of importance here: 1. the origin of the limestones could be very different, 2. their geological age ditto, or 3. the influences by which the rock becomes firmer and tougher. The first element can be excluded, since we must suppose a process in the ocean which is overall similar for the great masses of limestone, but different in detail; the second cannot weigh very heavily, since Cretaceous and older Tertiary limestones are found among the less solid ones as well as among the solid ones, that show little collapse; but really,

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[34] [cont.] *a remarkable manner by the atmosphere, and appear in the form of sharp, confluent, serrated ridges, grading downwards on all sides; the whole giving the effect of a model of mountain chains on a small scale."*

the third element can be decisive for the most part. It cannot be denied that the strong mountain pressure developed particularly during the folding, mountain-building processes, must increase the toughness of the rocks exposed to it enormously. The mass of these must become denser and heavier under the pressure, many local differences in solidity become equalised, in short, that rock once exposed to folding is better able to resist the influences of gravity. It would certainly be very interesting to verify this assumption empirically in the laboratory, but the number of quoted examples alone seems to be convincing enough.

This difference between the folded and the tectonically little disturbed limestones also finds a strong expression in the detail of the morphological forms. There is however another difference, namely the arrangement of the karst phenomena is much more natural, freer in the flat-lying, unfolded limestones, as there are fewer tectonically pre-disposed lines and zones. The influence of tectonic conditions on the development of the karst phenomenon in folded mountains is great; it can of course not change the basic provisos of karst phenomena and karst hydrography, but the frequency, the arrangement, larger or smaller karst phenomena in certain tectonically pre-disposed zones or along certain lines, are quite important and interesting problems which greatly complicate questions about the nature, the distribution and the causes of the individual phenomena. The chaos brought about by erosion is, in tectonically very disturbed areas, seldom so irregular as in the flat-lying limestones, one can easily find out more and less favoured zones, areas and lines on a map; this cannot be said for a karst landscape such as typically occurs on Jamaica or in Goenoeng Sewoe.

In reference to those forces working on karst I must accentuate that the mechanical erosion of permanent watercourses and its washing away play a greater role in the formation of karst phenomena than is usually accepted. Not only the cave rivers, but also the seepage waters that penetrate the joints and widen them to pipes and chimneys bring much gravel and sand with them, thus calling forth strong eversion activity with the swirling action of the water. Young cave passages and chimneys that are scarcely changed by secondary deposits show extremely common and obvious forms that are only explicable by eversion. Mechanical action then aids the chemical, particularly where there are either primary or secondary impervious layers. Less porous or impervious layers are probably more common than so far accepted, and with the different complications of the karst cycle and the karst hydrography can be explained.

I am inclined to ascribe an important role to the impact of the strongly flowing water even in the case of karren formation; arid or subarid climatic zones and also the surf zone at the seacoast really appear to be the most advantageous for true karren forms; almost complete lack of vegetation, rapid washing away of decomposition products, unhindered impact of large masses of water are probably the most important conditions for development of true karren. Concentrated mechanical power of draining water has created the larger karren-holes, karren-springs and chimneys, chemical erosion in the case of such formations can perhaps only be regarded as the second most important factor, which competes for the position with density and the collapses.

With the true, corrosive dolines the chemical activity of the water is probably expressed most purely; it occurs most frequently where no short watercourses, not even very short ones, can form, where no gravel and little sand is present and mechanical erosion has to remain at a minimum. The share of mechanical erosion on the morphological shaping of a karst area is very important, for the rate of progress of the geographic cycle in karst depends to a great extent on the participation of mechanically functioning forces. The more water carrying gravel and sand is involved in the destruction of limestone areas, the faster the tempo of the course of the geographic cycle. Where the karst reaches as far as the watershed, where it receives no water from an area of impervious rock, is where the true corrosion forms reign; the more water laden with gravel and sand enters the karst, the more vigorous the work of destruction. Connected cave passages occur in just these areas in large numbers and great length, where rivers from impervious rock areas enter the karst. That is also where the rate of development of the caves is fastest, the level is lowered rapidly and cave systems with several storeys occur.

According to A. Grund and A. Penck the true polyas are senkungsfelder, which are only considered karst phenomena because of their peculiar hydrographic relationships. I advanced justified objections to this narrow concept of polyas ten years ago,[35] which have been recog-

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[35]*Ein Beitrag zur Kenntnis des Karstphänomens. Földrajzi Közlemenyek*. Vol XXXIV Part VIII.

nised at least in part by A. Grund[36]; since I saw Jamaica I can protest such a narrow definition of polyas with even greater justification. Particularly in Jamaica development of polyas can be observed instructively in several cases in which a purely tectonic cause is completely excluded. In the lower Narenta region I have already ascribed a large and important share of the development of polyas to mechanical erosion, and can only confirm this interpretation after my experiences in Jamaica. In the Narenta area we are dealing with, first of all, mostly a removal of impervious strata from the polya area itself, in Jamaica with the share of the rivers charged with gravel and sand, coming from the impervious terrain in forming the polyas. Where greater involvement of mechanical erosion is excluded, polyas are absent. I can however, try as I might, see no justifiable difference between the polyas of the Dinaric region and those of Jamaica, they are troughs very similar to one another, which cannot be differentiated with reference to their horizontal or vertical dimensions, nor do they show other characteristics which might justify such a separation. The exposed or open basins, drained at the surface, which earlier were karst polyas, are no longer true polyas, since they lack an important feature, namely internal hydrographic unity, but can be considered, just like the canyons in karst, as a late stage in the development of caves. And mostly it is canyons which have originated by the continued collapse of the cave roofs above the originally underground watercourses, which have broken through the formerly closed edge of such an exposed polya.

Concerning karst hydrography, I have found my opinions developed in the year 1905 to be correct, and have had opportunity to test them in many cases. At that time I considered the various forms of subterranean hydrography in karst as stages of a geographical cycle, and still do so today. In young karst areas the reigning hydrographic element is groundwater, only later do subterranean rivers develop. The larger and deeper the karst area, the smaller the effect of tectonic disturbance and mechanical erosion, and the longer the original conditions can remain, the slower do connected caves systems develop. In small karst areas which stand in the way of surface watercourses, development proceeds rapidly; a tunnel cave several hundred metres in length can be eroded out by a river in a relatively short time. This is particularly true of small ribbon- or lens-like shallow karst areas, whose hydrographic relationships develop simply and clearly. I cannot understand why F. Katzer gives a greater importance to groundwater for just these areas – in my opinion it may be merely a special incidence, namely a shallow karst area filling a synclinal depression.

In the great tableland area of northern Australia, of which I have only been able to examine a small part personally, I see a good example of a morphologically young, deep karst, in which a uniform groundwater level exists, and which has been established by numerous bores. In that area a more or less closed karst channel system is quite excluded, rather, all joints are filled with water up to a certain level and this level drops gently towards the north. Only one question can complicate this set of facts; can there be one or more cave rivers, perhaps at the edge of the karst area, that reach the daylight, independent of and higher than those springs arising from the groundwater? That appears to me the salient point of the heated discussion of Grund-Katzer and others and I think that the solution of this problem is very simple. When there are one or more less porous layers in the limestone complex forming the karst area, such a situation can arise and preserve independent karst channels, even high above the level of the groundwater or the lower storey of the karst channel. Whether or not they are actually independent or the water at least partly flows or seeps to the lower level one cannot say without a detailed examination of each individual case. So I consider conditions such as those that Katzer draws in his section and also explains, to be quite possible, but not at all general. Wherever such conditions exist they are but to be considered exceptions, complications, that have been caused by the dissimilar nature of the different layers in the complex of limestone beds. Approximately the same is valid for that secondary blurring [lack of clarity] assumed by Sawicki,[37] which can occur just below the surface as well as on the floor of a cave storey. Sawicki has certainly made correct observations, but has made the so modern generalised conclusions that are rather exaggerated. If Grund[38] expresses opposition to

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[36] *Beiträge zur Morphologie des Dinarischen Gebirges.* Leipzig – Berlin. 1910, pl. 226.

[37] Ein Beitrag zum geographischen Zyklus im Karst. *Geographische Zeitschrift.* Vol. XV, pl. 185 et seq.

[38] Der geographische Zyklus im Karst. *Zeitschrift der Gesellschaft für Erdkunde zu Berlin.* 1914, p. 627. [The number for this footnote is missing from the original text. Its author is Alfred Grund.]

Sawicki's conclusions, he is actually fighting against his own method, against unjustified generalisations, which, particularly in the development of our knowledge of karst, has caused such unnecessary difficulties. If Sawicki imagines that the surface of a karst area can be so thoroughly blurred [lacking in clarity] that there should be no communication at all between groundwater in the karst and that flowing on the surface, then he is only assuming the most extreme case, which is but theoretically possible, but in reality certainly does not occur. That blurring can be a very important factor, that it can produce the existence of a large number of small, hydrographically quite independent catchment areas on the surface of a true karst area, is indicated by the superb example of the "Goenoeng Sewoe" area with its numerous telagas.

The foregoing considerations of karst phenomena and particularly of karst hydrography have all proceeded from the assumption that one had before one a karst area of a complex of limestone beds, in which all beds were similarly "pure", similar in solubility, similarly jointed, equally porous. An ideal case has been constructed, one has made observations referring to such an ideal situation and then drawn generalised conclusions, without worrying about whether such ideal conditions actually exist in reality, or where. We must still be content with only general data on the chemical nature in particular and on the relationship of chemical composition to the solubility of limestone, and in studying karst one has still devoted very little attention to differences which individual beds or layers of limestone can show, which can occasionally however have an important role in the development of cave phenomena and for the hydrography of the particular area. The more one pays attention to such differences in chemical composition, in solubility and porosity of the individual rock layers, the more complications and deviations from the ideal case appear in the realities of karst hydrography. Every karst area certainly shows great deviations from the theoretically postulated conditions. The reality is seldom so simple as it ought to be according to a generally conceived theory, such as that of Grund's karst water theory.

In his, regrettably final, essay "the geographic cycle in karst" Alfred Grund regarded the "cockpit country" described by me as the mature and old stages of the geographical cycle of a karst landscape, and presented his interpretation very graphically. I can only agree with him that I knew from the beginning that such forms as occur in cockpit country can only be characteristic of a landscape already well advanced in its morphological development, but cannot avoid saying once again, however, that a truly irregular "cockpit country" can only be found in tectonically little-disturbed regions, and that the examples from the Dinaric karst area quoted by Grund himself therefore differ quite significantly from those examined in the first and second parts of these studies.

Contents

	page*
Introduction	2
Karst in the Chillagoe area	3
Olsen's Caves	7
Other small karst areas of Australia	9
Barkly Tableland and the great karst area of northern Australia	
a) The distribution and geological age of the Tableland limestones	10
My journey on the Tableland	15
(* A petrographic diagnosis by Dr. R. Kettner pp. 40 – 42.)	
Hydrographic relationships of the Tableland	23
Some remarks on the development of karst phenomena, on karst hydrography and on the geographic cycle in karst	27

Illustrations

Lion's Head Bluff at Chillagoe	4
Pothole-like holes at the base of Lion's Head Bluff	6
Karren on Olsen's Caves Ridge	7
Corrosion relics from Rocklands Station	17

[*page numbers adjusted to this translation]