THE NATURE AND ORIGIN OF GILGAI COUNTRY (WITH NOTES ON QUATERNARY CLIMATE).

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I. Nature of Gilgais.

Gilgai country is remarkably uneven country, consisting of alternate hummocks and hollows. It occurs in its characteristic form only on the western side of the Dividing Range. Gilgai country has a similar appearance to the 'melonhole' country of the coastal swamps and the 'crab-holey' country of the tablelands, but the irregularity of the surface is much greater than these types. Sometimes in the western country we get the terms 'melonhole' and 'crabhole' applied to the gilgai areas in which the irregularity of the surface amounts only to a difference of two or three feet between the tops of the hummocks to the bottoms of the depressions. The genuine 'gilgai' country is much rougher. The differences in elevation between the knolls and the hollows amount to ten, fifteen and even twenty feet.

The hummocks are sometimes of rounded outline, but more often they are irregular in shape, usually serpentine, vermiform or variously ramified. The depressions have also correspondingly irregular shapes. The depths of the hollows may be very variable within a comparatively small area. For some time after rain they contain stagnant water. The angle of slope from the summit of a knoll to the bottom of the adjacent depression may be anything from 10° to 60°. In typical brigalow gilgai country a section of the surface would consist of a very wavy line, the crests from 25 to 50 feet apart, and the hollows 10 to 20 feet deep, quite deep enough to obscure a horse and its rider from the view of an observer on a hummock 10 yards away. The hollows vary in length from 25 to 50 or even 100 feet. The country is far too rough to ride over even when cleared.

Gilgai country may occur in small areas of only a few acres, but where typically developed a gilgai area has frequently an extent of several square miles, and along the northern edge of the Pilliga Scrub these gilgai areas occur close together, separated from one another by narrow belts of red soil, and of light sands lining the creek courses, over an area about 25 miles long and 5 to 10 miles wide. This portion of the Pilliga Scrub we can call the 'Gilgai Belt.' It has an area of about 200,000 acres, adjacent to the towns of Narrabri and Wee Waa.

The gilgai lands are, I believe, on the average more low-lying than the belts of red soil and the diluvial sands of the aggraded creek banks. I am informed that a heavy flood inundates all the gilgai country before the red soil belts and sandy belts are flooded.

II. Distribution of Gilgai Country.

As far as I am aware no description of 'gilgai' country has ever been published, but it has often been observed by surveyors and scientists in different parts of the State.

Mr. R. H. Cambage, L.S., F.L.S., informs me that he has traversed gilgai country in many districts, and that, according to his experience, it is found in various places along the western slopes, north, central and south. It occurs usually near the white box belt, the zone of *Eucalyptus albens*.

Mr. E. C. Andrews, B.A., has had a similar experience of the distribution of typical gilgai country. He has informed me that he has only met with this type of surface on the aggraded portion of the western slopes and on the plains adjoining the slopes.

Mr. G. H. Halligan tells me that he has seen gilgai country well developed between the Kalga Range and Coonamble (Urawilkie).

The universal experience of scientific workers seems therefore to show that gilgai country occurs at the base of our western slopes in areas where aggradation has been great and often in places where indications of late tertiary subsidences are in evidence. It lies in the zone between the areas of denudation and the great Black Soil Plains and Red Soil Plains of the west.

III. Characteristic Vegetation.

The typical gilgai country of the Pilliga Scrub is covered with dense brigalow and belar scrubs. The brigalow collected was identified for me by Mr. J. H. Maiden as *Acacia harpophylla*, and the belar as *Casuarina lepidophloia.* These two timbers seldom grow intermixed, but in some gilgai areas brigalow is wholly in possession, in others belar. Occasionally on the edges of gilgai country, as near Narrabri West, grey ironbark *(Eucalyptus crebra)* may be sparingly associated with the brigalow. Where such is the case the inequalities of the surface are only slight, amounting to two or three feet at the most. In other places the poplar box *(E. populifolia)* is seen to extend some chains into the gilgai, especially where belar holds sway. Wilga *(Geijera parviflora)* occurs sparingly in both belar and brigalow gilgais even in their centres, but especially where there is a tendency to the formation of red soil on the surface of the hummocks. On 'crabholey' country near the edges of gilgai areas, and also on larger blocks of 'crabholey' and 'melonholey' country, that is, less strongly developed gilgai than the deep gilgai, an oak (*Casuarina* *glauca?)* and two phylloclade bushes *(Leptomeria aphylla* and *Apophyllum anomalum)* occur together with belar, wilga and brigalow.

The only herbs which seem to grow on typical gilgai country in the natural state are members of the saltbush tribe *(Rhagodia* species, *R linifolia* and others).

The vegetation grows mainly on the hummocks sending long surface roots into the depressions. The gilgai vegetation is characterised by abundant surface roots and an absence of tap root.

IV. The Soils of the Gilgai Areas.

The soils of the gilgai country are mostly dark grey or almost black clays which in appearance suggest a considerable degree of salinity. They resemble soils which have been irrigated with saline artesian water for a period of years. A small gilgai belt lying 10 – 12 miles south of Cuttabri, on the track to Cubbo, has red clay soil, and small patches of crabholey country also occur in the red soil belt along Baradine and Dubbo Creeks.

In mechanical composition (See Table A) the gilgai soils are chiefly heavy stiff clays with a small percentage of rather coarse sand. In dry weather they crack with the formation of deep fissures just like the most heavy clay soils of the Namoi Black Soil Plain. In wet weather they are very boggy, and on drying they become as hard as cement. A crowbar or pick has to be used to get a soil sample.

In the hummocks we find a layer of soil from six inches to two feet from the surface in which white specks and nodules, ranging up to the size of a pea, occur. These white lumps consist of carbonate of lime, chemically precipitated. This precipitation of carbonate of lime in the subsoil of the hummocks indicates a rise of salts by capillarity from the hollows, and their precipitation by the evaporation of the water in a zone where the effects of dew and rainfall by downward percolation are negligible.

The chemical nature of these soils is remarkable. They are alkaline in reaction on the hummocks, but the hollows may be acid. The gilgai soils proved on analysis (Table B.) to be far from well balanced, the amounts of phosphoric acid and sometimes potash being low in proportion to the lime (Table B). They are very high in soda and magnesia, and also in manganese oxide. The amount of soil insoluble in acid is lower than in the case of normal black soils.

The water extract (Table C) contains in addition to colloidal clay a considerable amount of salts, chiefly sodium carbonate and common salt. Water-soluble magnesia and lime are practically absent in the hummock soils, being insoluble in alkaline solution. The sulphuric acid radicle is quite absent, no reaction for that ingredient being obtainable.

The volatile matter in the gilgai soils ranges from 4·50 to 9·86 per cent., averaging 6·42 per cent., but very little of this, probably not more than 3 per cent. is organic. The balance is combined water contained in the colloidal clay. Nitrogen is in most cases low, averaging ·070 per cent.

Occurrence of Manganese.—The manganese oxide (Mn_3O_4) not carried down with iron, was estimated in the gilgai soils and is generally speaking high. Manganese being one of the most soluble constituents of acid soils tends to accumulate in undrained depressions. In the numerous complete analyses of soils given by Hilgaard in his book on the 'Soil,' the percentage of manganese seldom exceeds ·020 in leached soils like the Hawaiian volcanic soils or those of the Californian orchard slopes; in other soils manganese ranges from ·010 to ·300 per cent. averaging ·100, the humid soils giving a slightly higher average than the arid ones. The reason for this is not clear, and the accumulation of further data may reverse the result.

Our own experience in the Department of Agriculture of New South Wales is that leached laterite soils like those of The Dorrigo, the Robertson Range and the Macpherson Range, even when derived from highly manganiferous formations, are low in manganese and high in humus. Coastal marsh soils, highly acid peat soils, are quite free from manganese. Manganese is, on the other hand, high in soil from undrained depressions having a local catchment and no outlet except in flood time.

In alkaline soils an accumulation of manganese might be expected when the alkalinity is due to carbonate of soda. This has been found to be the case, and is due to the fact that manganese enters largely into the composition of colloidal clay (see Hilgaard).

The manganese estimated during the course of my work was only a portion of the total present, for the portion which was carried down with the iron was not separated and added on. The figures given therefore only represent from one-half to at most two-thirds of the manganese present. Clearly these soils are high in manganese, a fact suggesting that they have been accumulated in an undrained basin. The salt and carbonate of soda present are evidences in the same direction. The remarkable thing is that the faintly acid gilgai soils Nos. 5 and 15 are most highly manganiferous, while the strongly alkaline soils Nos. 4 and 11 are least so. This paradox is rendered less startling when it is stated that the chemical work proved the alkalinity due mainly to carbonate of lime, the soda present being never a very excessive amount, though quite sufficient to be injurious.

It appears then that while the lime which creeps into the hummocks by capillarity is precipitated there and accumulates in them, the manganese may creep up too, but is washed back to the depressions every time a spell of wet weather brings about a decay of leaves and a restoration of surface acidity. The manganese therefore tends to accumulate in the less alkaline depressions. The accumulation of manganese in these is evidence of absence of subdrainage, for if any escape existed the manganese would be carried away in the faintly acid soil water which may accumulate here.

The capillary power of most of the gilgai soils is very poor, though the small patches of faintly acid red gilgai country may have very good capillary power. Small as the amount of sodium carbonate is in the alkaline soils it is yet sufficient to destroy their mechanical condition. The water capacity is highest in the case of the alkaline, colloidal clay soils.

V. Origin of Gilgai Country.

A number of theories have been advanced to explain the uneven nature of gilgai country. The most accredited are:

1. Collapse of substrata causing a breaking up and partial subsidence of the top soil.
2. Expansion and contraction due to alternate wetting and drying.
3. Removal of soluble soil ingredients, as for instance lime, by percolation into the underlying sandy, subartesian strata.
4. Wind action.
5. Effect of vegetation.
6. Effect of sodium carbonate in destroying soil crumbs, and causing partial collapse of the soil.
7. Mud springs.

1. The theory that the irregularites in surface are due to faulty substrata, or subsiding substrata, is widely

accepted by surveyors. Support is lent to this theory by the fact that gilgai country occurs only along the belt of heavy Tertiary and Post-Tertiary alluviation, at the western base of our western slopes. The deep detrital accumulaions of this belt are no doubt settling down and being rendered more compact by their own weight. But a subsidence due to this cause can hardly be expected to give rise to the vermiform depressions and tortuous hummocks observed in the gilgais. The whole surface would be expected to subside at a uniform rate, and if ridges were formed at all, one would expect them to have a definite alignment and to be of a gentle nature.

It has been suggested that the depressions are due to an underlying limestone formation, which is being removed by subterranean waters and causing overlying soils to sink into the hollows so formed. This suggestion can be dismissed with the statement that borings in the district show no limestone in the substrata but only sands and clays. Nor is there a scrap of geological evidence to favour the suggestion. It has also been suggested that subterranean streams in the underlying subartesian strata might be undermining the surface soil, bringing about its collapse. No such streams have been met with, nor could such a cause produce the tortuosity of the gilgais over such a wide area.

2. Alternate expansion and contraction of clay lands from wetting and drying is known to produce an uneven surface. The inequalities produced in this way seldom exceed six or twelve inches. On p. 114, 'The Soil,' by Hilgaard, such country is described under its American name 'hogwallows.' This cause by itself could not produce the gilgais, though it might give a start to the formation of a hummocky surface which might develop into gilgai from other causes.

The coefficient of expansion of gilgai soil on wetting is certainly great as illustrated by the experiment described in Appendix I.

The crabholey and melonholey country of our tablelands and coastal regions is often formed in the same way as 'hogwallows.'

3. The removal of soluble ingredients by downward filtration cannot have produced the gilgais, for the soil is almost impervious, being exceedingly clayey, and if removal by downward percolation were the cause of gilgai formation the hollows should contain less manganese. Drained soils are usually low in manganese; gilgai soils are high in that constituent. There can be little or no downward drainage into subjacent water-bearing strata.

The gilgai holes hold water for many months after rain and appear to lose it only by evaporation.

4. Great inequalities of surface are often caused in arid regions by wind action on loose detrital deposits. One might suppose the gilgai surface to have originated in a quaternary, very arid, cycle prior to any kind of vegetation getting a hold on it, by the wind scooping out the hollows. At the present time the country is too well wooded for the wind to have any such effect.

But hummocks raised by the wind should have definite shape and alignment. The irregularity of the gilgai surface cannot be explained on this hypothesis.

5. In swampy country of our coastal districts and tablelands and in lowlying country frequently flooded, we frequently find a tussocky grass or grasstree (*Xanthorrea*) grass growing in tufts. The roots of each tuft keep on raising the spot on which the tuft grows by their decay and intervening spaces between the tussocks are lowered by nutriment being drawn away from them. The tussocks

also tend to raise the spots on which they stand by catching atmospheric dust and débris. In this way 'melonhole' country often forms in coastal districts. Its formation may be aided by the alternate expansion and contraction of the soil on wetting. Indeed coastal 'melonhole' country is usually on peaty clay soils and the knobs being more peaty than the hollows would probably expand at a more rapid rate and to a greater extent on 'wetting.'

While such causes might have helped to produce the beginnings of gilgai country in the Pilliga Scrub, they are no longer operative, for the soils are not peaty in nature, nor do the roots of the plants existing there at present act as do the tussock grasses of swamps.

The roots of belar and brigalow being mainly surface roots certainly help to maintain the hummocks intact, but I cannot believe that they have produced these irregularities. Indeed belar grows abundantly on country which is not 'gilgai,' and I believe this is the case with brigalow also.

6. Mr. J. F. Campbell, L.S., in a paper on Soil Physics read at a meeting of the Institute of Surveyors on May 18th 1909, suggested that 'melonholes' ('crabholes' or 'small gilgais') are due to the effect of sodium carbonate in destroying soil crumbs and causing the soil to subside by counteracting the cementing crumb-producing properties of carbonate of lime.

Possibly this cause may at times produce 'melonhole' country, but I cannot believe that our gilgai country could have been produced in this way. Chemical evidence is also against this theory, for in my soils the hummock soils had the highest alkalinity, whereas their alkalinity should be least under Mr. Campbell's hypothesis.

7. Mudsprings exist according to the statements of many old pioneers of the Pilliga Scrub in the country lying about

15 to 20 miles south of Brigalow Creek on the back runs of old 'Cubbo' station. These mudsprings are described as mound springs. One is described as being situated in the centre of a round clay pan. The bushmen believe that these clay pans are often formed by the subsidence of country round the vent of a mudspring. Clay pans with a saline soil, studded with extinct mounds built up by mud-springs are reported as numerous in the comparatively unknown parts southward from Brigalow Creek. It has been suggested to me by local men that the gilgais are the result of mudspring action, but while I can readily understand that round mounds and circular depressions can be formed in this way, I fail to see how the labyrinthine courses of the gilgai contours can be formed in this way.

Having now disposed of the various theories advanced by others, I desire, before advancing my own to discuss a question which bears considerably on the result. It is that of Late Tertiary Climate.

VI. Late Tertiary Climate.

In several papers[1] I have given facts in evidence of remarkable changes of climate in our western districts in Late Tertiary and Quaternary times. It is generally agreed by geologists that in the late Tertiary periods large areas of Central Australia consisted of lakes receiving sediments from the high ranges that separated these parts from the coast. Central New South Wales and Queensland constituted a depression in which extensive alluviation took place. Mammalian drift occurs in places and gives evidence in favour of a moist, if not very wet, climate. The remarkable fauna of giant marsupials which existed up to the end

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[1] Prelim. Note on the Geol. History of the Warrumbungle Mountains, Proc. Linn. Soc. of N.S.W., May, 1906. Geology of the Warrumbungle Mountains, *loc. cit.*, August, 1907. Geology of the Nandwar Mountains, *loc. cit.*, 1907.

of the Tertiary period was decimated owing to the establishment of desert conditions. Drainage became disintegrated. Arid erosion succeeded normal erosion.

To the west of the Warrumbungle Mountains near Tooraweanah, at Coonamble, at Nyngan, and throughout the Pilliga Scrub I have obtained abundant evidence of a period not far removed from the present, in which drainage was completely disintegrated, and erosion was wholly of the arid type.

The late Tertiary wet period leaves its insignia in the form of old water channels bestrewn with boulders so large that the floods of present streams are unable to account for anything like them in the same districts, and in the form of huge accumulations of sand and coarse gravel underneath the varied soils of the western plains.

The dry cycle which followed levelled up the country, filling former creek beds with windblown drift, and arid erosion added to the accumulation of detritus at the base of the slopes.

The present period can only be described as subarid. There is a sufficient rainfall to permit erosion to take place and the drainage systems have become re-integrated. Additional evidence of increased rainfall is afforded by the present creeks cutting V shaped valleys along their present courses through the heavy thicknesses of Tertiary and Quaternary drift, especially along their upper courses. Along their lower courses over the plain the tendency is largely to aggrade in flood time.

In the Pilliga Scrub gilgai belt the two or three hundred feet of sand, gravel and clay under the surface soil, consist largely of detritus borne down from the Warrumbungle and and Nandewar Mountains in the wet period of the Tertiary.

During the succeeding dry climate the detrital deposits were added to and drainage became disintegrated by the silting up of the outlets of numerous swamps and marshes along the courses of stream channels. Subsequently wind-action filled in these channels. In the Pilliga Scrub the gilgai area, originally a depression, which was during the wet cycle receiving Warrumbungle detritus carried down by large rushing streams, became a sea without outlet, and later, as the streams became extinct, a series of salty marshes into which little trickles of water, highly charged with solids, came from a great abundance of mudsprings in the back country.

The dark (black and dark grey) gilgai soils were laid down at this time. Their peculiar chemical and mechanical nature shows that they are not true alluvial soils like those of the Black Soil plain. Their high lime and magnesia, without correspondingly high potash and phosphoric acid, suggest that they were derived from the evaporation of spring waters. Their salt and soda contents show accumulation in an undrained basin, and this conclusion is strengthened by the high manganese.

Mudsprings might have existed locally over the gilgai area, but probably the muds were chiefly supplied by springs some little distance away on the flanks of the Coghill hills in the centre of the Pilliga Scrub.

In these saline marshes various coarse grasses would grow in tufts and give rise to inequalities of surface, which would be increased by, (1) the greater shrinkage and cracking on drying of the intervals between the tufts than of the knolls which the roots would tend to hold together, and by (2) the chemical deposition of carbonate of lime round the grass roots and stems on every occasion that a particularly droughty spell caused the evaporation of a marsh. This kind of precipitation of lime we often see where sea-water has been carried by spring tides into the small swampy depressions behind the hurricane bank of the shore and undergoes quiet evaporation. In this way the knolls would grow in size especially as the fine matter carried down by the small streams would tend to deposit both its dissolved and suspended material chiefly on the tussocks.

One can state with absolute certainty that the gilgai soils were not deposited by normal streams from the Warrumbungles either in the late Tertiary wet period or in the present semiarid period. Both the floods of the former and of the latter are chiefly responsible for sandy material such as we see along present creek beds or in the alluvial strata underlying the gilgai at a depth of 30 to 40 feet.

While I cannot agree that the hummocky surface of gilgai country is due to subsidence of underlying strata, I am strongly inclined to think that the formation of large basins which developed into gilgai areas was partly due to subsidence of late Tertiary sands and gravels of a loose nature which have a great thickness under these areas. It is true that these depressions always occupy sites along a belt of our western slopes which is largely downfaulted, but the faulting was probably in progress in the wet cycle of our late Tertiary period and responsible for the thick accumulation of detritus deposited along this belt at that time. The amount of subsidence in the arid period was probably very slight, so slight that it can easily be accounted for by the settling down of loose sediments.

Other Evidences.

(a) *West of the Warrumbungles.*—On the plain country westward from Tooraweanah and Tundebrine, on the western side of the Warrumbungle Mountains, it is a common thing to find the present creeks separated by slight ridges, each of which is capped by an old creek bed consisting of boulders and heavy gravel. Almost invariably the highest ground is a gravel ridge marking the course of a former stream. These ridges are usually only from 10 to 15 feet higher at the most than the intermediate gullies. The present streams in this vicinity are denuding the country, otherwise they would not occupy depressions, but the water would come down in a sheet from the mountains, and the old creek gravels as well as the intervening country would be covered with a uniform level sheet of recent silt. In very recent geological times (Quaternary) there was an arid period in which the ancient creeks ceased to run, when débris accumulated in the mountain valleys of the Warrumbungles mainly through arid erosion, when the small spring fed creeks flowed only to the edge of the mountains and became absorbed in the thirsty soil while they deposited their fine silt in the form of small black soil plains. In this period the country immediately north and west of the mountains became a plain, levelled by arid agencies. When again a moister climate came, the streams, though large enough to cut down, were not large enough to remove the boulder beds of the old stream channels, hence we find present streams carving down in the old alluvial plain formed by the floods of the wet cycle leaving the old channels as intervening ridges. This I take as clear evidence of a more arid climate than the present in recent geological time.

(b) *North of the Warrumbungles.*—To the north of the Warrumbungles on the drainage areas of Cubbo Creek, Dubbo Creek, and Baradine Creek, similar facts are in evidence. Great alluviation took place in the wet cycle, the streams depositing most of their sand and gravel as soon as they reached the level country. A dry period followed in which all inequalities were levelled by wind action, the courses of old streams becoming infilled with drift sand. Many of these former courses are easily picked out by their more sandy soil and by gum and apple trees mingling with pine along them instead of the usual association of pine and box. That this arid period has come to a close is evidenced by the deep U-shaped depressions or gullies cut by the present creeks from the Warrumbungles in the deep late Tertiary alluvial. Thus at Baradine, the creek is a deep gully 40 feet below the surrounding level country. The banks of the creek rise steeply, indicating that this gully has been carved and is being enlarged by each successive flood. The same is the case with Bohena or Borah Creek and other creeks until they get 20 or 30 miles away from the mountains. Along their lower courses in the plain country these creeks still occupy depressions, more shallow courses carved by the rare and occasional big floods, and filled up again with sand by smaller floods. The smaller creeks in this plain country do not actually occupy depressions. Their beds are lower than their banks but about the same level as the country passed over. The banks are built up of sand washed down from the hills; is the product of the period of arid erosion redistributed by water in the present cycle.

This is the case in the *gilgai belt* where small creeks like Oakey Hole Creek and Brigalow Creek are entrenched between banks of their own flood products. The fact that streams carrying down sheets of sand have been able to sweep over the gilgai plain indicates a restoration of integrated drainage by the advent of moister conditions.

(c) *The Castlereagh and Coonamble Plains.*—At Coonamble and on the surrounding plains we also get abundant evidence of an arid period having existed prior to the present period. The deep alluvial soils are underlain by great thicknesses of sandy drift and clays deposited over the Coonamble district area in the wet periods of Tertiary time. The lake or swamp in which this alluviation took place dried up on the inauguration of arid conditiens, but when occasional heavy downpours occurred in the Warrumbungles water would come down in a sheet, carrying with it the fine silt now forming the Black Soil Plain. After a period of great aridity, in which wind blown detritus only accumulated, moister conditions again allowed flood waters to come down from the mountains. The larger floods carved shallow beds in the level country. These were promptly infilled with sand by smaller floods, while the finer silts settled on the flooded plains adding to the black soil deposits. The old stream beds formed in this way are known as 'monkeys.' The country being very level, the rivers would continually change their courses as it was easier for fresh floods to sweep across the black soil than to sweep over the old sand beds which were often higher than the intervening country, owing to the greater subsidence on drying of mud than of sand. The continual change of course by the Castlereagh River in the early part of the present cycle was probably aided by the fact that the drainage system had not yet become reintegrated. Occasionally the flood waters would sweep westwards from Coonamble and empty into the Macquarie marshes. At other times they would sweep north-west into marshy country near the present junction of the Castlereagh with the Barwon.

That conditions are moister now is shown by the fact that the present bed of the Castlereagh is a definite U-shaped hollow containing little or no sand.

The Gwydir and Moree Plains.—Similar observations were made on the Gwydir River near Moree.

The Bogan and Bogan Plains.—At Nyngan on a visit about two years ago, I noticed similar evidence of a recent arid period. The red soil plains on the western side of the Bogan are fine grained windblown soils derived from the Cobar massive of metamorphic rocks. The black or rather brown soils on the eastern side of the Bogan consist of a mixture of windblown detritus and silt deposited in a kind of marsh by floods from the Central Tableland in the period of increasing rainfall before integrated drainage was re-established. Evidence of a greater rainfall at the present time is afforded here by two facts, (1) a slight amount of undulation has been produced in the windblown detritus by rainwaters in the present cycle, (2) the Bogan River flows in a slight depression and reaches the Darling in flood time so that the drainage has become integrated.

Under both the red and black soils of the Bogan we get hundreds of feet (from 300 to 1500 feet) of Tertiary gravels and clays which were deposited under wet meteorological conditions, possibly in a lake. The coarseness of the sands and gravels interbedded in this series shows that big streams deposited here the material carried from the central parts of the Cobar massive. The great differences in depth to bed rock in the various bore holes around Nyngan show that the depression in which this heavy alluviation took place was probably formed by downfaulting in a period when the Cobar massive was a rugged mountain group widely different from the smooth and weatherworn aspect it presents at the present time. In fact mesas of Triassic rock occur under the Bogan silts, though to-day no Triassic (Trias Jura) rocks remain on the Cobar massive, proving that a block of country around Nyngan was depressed or downfaulted in early Tertiary period.

Two points of interest might here be briefly touched on.

Firstly—The difference in climatic conditions between the period of aridity and the present is not great, and it might be held that the restoration of integrated drainage is the effect of an uplift of the Central Plains rather than of increased rainfall. Whether this is the case or not I cannot say, but I think that recent conditions are less arid than those of the period of disintegrated drainage.

Secondly—There appears to be good reasons for believing that in quaternary times a number of semiarid periods and arid periods have alternated, just as did the glacial and inter-glacial periods of the last Ice Age. For some of the red clay bands in the upper clay bands interbedded with the late Tertiary alluvials and drifts underlying the plains might well be wind blown deposits of arid intervals between the wet periods which gave us the gravels. Again the numerous 'monkeys' of the Castlereagh and other rivers may each have had its course formed in a wet period, and might have been filled with drift sand in the succeeding dry period. This too is a plausible theory.

VII. Origin of Gilgais.

It is possible that a tussocky herbaceous growth has been aided by the contraction and expansion of clay soils with wetting and drying, and by the chemical precipitation of lime and magnesian salts on plant roots during periods of drying up in the formation of a hummocky surface over the gilgai area of the Pilliga Scrub.

The question arises, if such an origin be assumed, why did the inequalities not vanish when marshy conditions disappeared with the restoration of integrated drainage?

Not only have the hummocks remained, but they have become enlarged and the depressions have relatively deepened. There can be little doubt that the salinity of the Pilliga Scrub gilgais has been reduced by repeated floods in the recent period. There can be little doubt that the present flora of belar, brigalow and saltbush took root as soon as moister conditions commenced and that these plants have helped to preserve the hummocks and to resist their collapse.

But the vegetation could not have performed this work without the assistance of another factor which has done much to produce an accentuation of the hummocky surface.

This factor is the migration of salts and carbonates of lime and magnesia into the hummocks by capillarity. Chemical analysis shows the hummocks to contain a higher percentage of these substances than the depressions. So great has the precipitation of lime been in the hummocks, that at a depth of six inches it forms little pea-shaped nodules or concretions in the soil. Unquestionably the forces of capillarity have in the present cycle done much to enlarge the hummocks. Inequalities of surface must have pre-existed and might have been produced by one or all of the suggested causes, but the main features of gilgai country as distinct from 'melon-hole' country is the augmentation of existing inequalities of surface by capillary action.

Mudsprings.—Some mudsprings are supposed to be still active in remote portions of the Pilliga Scrub. Many extinct ones occur, as well as salt pans formed by mudsprings. These occupy a line along the border between the flat alluvial belt of the north-western plains and the outermost outcrops of Trias Jura formation. Not having seen these mudsprings it is not possible to say anything with confidence about them. Yet their presence along the border between the belt of heavy Tertiary alluviation and the Trias Jura suggests that they might have been produced by the expulsion of enclosed water from the loosely cemented Tertiary débris by the settling down of this material under its own weight. The Tertiary gravels of the Pilliga Scrub are very water bearing, though only pumping supplies are obtained in the bores.

The bearing of the here suggested origin of the mudsprings has an important bearing on the origin of artesian water. The matter is of economic interest and wants further investigation.

VIII. Summary.

In this paper I have given a description of gilgai country, some remarks on the distribution of such lands, and possible mode of origin. It is suggested that in the gilgai zone of the Pilliga Scrub this type of country was a lake without outlet at no distant geological period. In this period the rainfall of our north-western districts was exceeding low, and the gilgai lake was dry at intervals, receiving only small streams from mudsprings in the hilly country twenty miles away.

The contraction of the clay deposits on drying, the growth of tufty grasses in the salt marshes and chemical precipitation on the tussocks gave rise to a hummocky surface. When moister conditions revived the creeks from the Warrumbungle Mountains integrated drainage was restored. The inequalities of surface on the gilgai area were accentuated by capillarity when new conditions had been established.

Various facts of physiographic interest pointing to grave climatic changes in recent and late Tertiary times are recorded in this paper.

Analysis of Gilgai Soils.

Table A.—*Mechanical Analyses.*

No.	Colour.	Reaction.	Water Capacity. Per cent.	Capillarity. Inches in three hours.	Gravel Per cent.	Sand. Per cent.	Clay. Per cent.
4	black	strongly alkaline	good 49	fair 3	10·2	18·3	71·5
5	,,	faintly acid	fair 44	fair 4	7·4	10·7	81·4
6	,,	alkaline	good 47	fair 3	10·7	19·3	70·0
9	,,	alkaline	good 47	fair 4½	10·0	22·3	66·9
11	,,	strongly alkaline	high 63	poor 2	2·4	1·0	96·6
15	red	very faintly acid	low 33	excellent 10	16·4	31·7	51·9

Table B.—*Chemical Analyses.*

No.	Moisture. Per cent.	Volatile. Per cent.	Nitrogen. N. Per cent.	Lime. CaO Per cent.	Potash. K_2O Per cent.	Phosphoric Acid. P_2O_5 Per cent.	Manganese Oxide Mn_3O_4 Per cent.
4	6·52	6·67	·042	1·080	·215	·152	·085
5	6·58	9·86	·142	·446	·225	·188	·155
6	7·55	7·27	·070	·600	·335	·128	·100
9	3·50	4·50	·042	·308	·087	·049	·120
11	6·29	5·21	·014	·712	·126	·079	·062
15	1·94	5·01	·112	·260	·175	·113	·270

Table C.—*Water Soluble.*

No.	Total Solids including colloidal clay Per cent.	Salt. NaCl Per cent.	Alkalinity as Na_2CO_3 Per cent.	Total Solids without colloidal clay Per cent.	Lime CaO Per cent.	Sulphuric Acid H_2SO_4 Per cent.
4	·154	·023	·069	...	trace	absent
5	·106	012	·005	...	,,	,,
6	·100	·041	·010	...	,,	,,
9	n.d.	·006	trace	·058	,,	,,
11	·863	·058	·040	·103	,,	,,
15	...	...	...	...	,,	,,

No. 4 = Belar gilgai hummock, Yarrie Lake. No. 5 = Belar gilgai hollow, Yarrie Lake. No. 6 = Cleared belar gilgai, Yarrie Lake. No. 9 = Belar gilgai, Alexander's, Yarrie Lake. No. 11 = Brigalow gilgai, Trindall's, Brigalow Creek. No. 15 = Red gilgai belt, brigalow and wilga, Cubbo-Cuttabri track.

Appendix I.

Two open cylinders, A and B, each $1\frac{3}{4}$ inches in diameter, were closed at one end with a piece of muslin, and were filled with coarsely powdered soil to a depth of $5\frac{1}{2}$ inches and $5\frac{1}{4}$ inches respectively. In A was placed gilgai soil (No. 11), in B black soil of alluvial origin (Namoi alluvial). Each cylinder was thoroughly drenched with water until the soil in it was saturated.

The soil in A expanded to $6\frac{7}{8}$ fnches and then became puddled, that in B expanded to $5\frac{7}{8}$ inches. The soil was then allowed to drain, thereafter it was dried at 100° C., removed from the cylinders, broken up to the same degree of fineness as before, and then replaced in the cylinders and measured. The soil in A had shrunk to 5 inches and that in B to $5\frac{1}{4}$ inches.

The difference in volume between the saturated soil and the same dried at 100° C. was then calculated. The result obtained gave an expansion on wetting of 37·3% for the gilgai soil and an expansion of 17·1% for normal Namoi alluvial. The expansion of gilgai soil on wetting is therefore more than twice as great as that of black alluvial soil.