THE EVOLUTION OF THE RIVER SYSTEM OF GRIQUALAND WEST.*

By Alex L. du Toit, B.A., F.G.S.

(Read March 17, 1909.)

(With Map. Plate XXV.)

The present river system of Griqualand West and the adjoining Transvaal and Orange River Colony has proved to possess a history probably more complex than any other yet described from South Africa, and one that can be traced back clearly to a geological period considerably more remote. The factors concerned in the development of the drainage lines have been so varied and uncommon that, although much still remains to be learnt concerning this and the adjoining area, the author has thought that it might be well to put on record a general account of the evolution of the drainage system of this portion of Cape Colony.

The Dry Harts River, flowing nearly due south from Vryburg in a narrow but widening valley, joins at Taungs the Harts River, which drains the south-western corner of the Transvaal, there acquiring a more south-westerly trend. The Vaal River possesses a course nearly parallel to it from Warrenton to Riverton, but makes a bend at Barkly West, and at Delports Hope enters the Harts River at right angles.

The Vaal River Valley from this point onwards is a continuation of that of the Harts, and receives the Riet and Orange Rivers from the east, also at right angles. The latter changes its course to south-west—a direction which it maintains as far as Prieska, and is joined by the Brak River from the south a little above the point where it resumes its north-westerly direction of flow.

There is thus one continuous valley extending with a gradual curve from Vryburg to Prieska, a distance of 235 miles, and receiving from the left the Harts, Vaal, Riet, Orange, and Brak Rivers.

This valley, which, strangely enough, possesses no single name applicable throughout its entire length, although geographically so entitled, will in what follows be styled the *Kaap Valley*, from the fact

* Published with the permission of the Geological Commission.

that for three-fourths of its length it is bounded on its right-hand side by the escarpment of the Kaap Plateau.

Considering now the geological character of the area, we find rocks belonging to the extremely ancient pre-Cape formations which are, through denudation, appearing from beneath the mantle of Karroo deposits by which they had been covered in Permian and Triassic times. This erosion has revealed a land surface with a drainage system belonging to late Palæozoic times, of which the Kaap Valley formed an important branch. The evolution of the modern drainage system has to a very considerable degree been influenced and modified by its superposition upon that of the palæozoic continental mass.

The matter acquires a still higher interest in view of the fact that this land surface was intensely glaciated and its minor features considerably modified by a vast ice-sheet towards the close of the Carboniferous epoch.

The area under consideration is well situated for the elucidation of the various problems involved, for further to the east and south the old land surface becomes buried beneath younger sediments, while to the north and west the denudation has been somewhat prolonged and superficial deposits frequently conceal the formations, principally in the valleys.

Physical and Geological Features.

A notion of the physiography of the area under consideration will be gathered from the following account and from the map attached. The most striking feature is the vast Kaap Plateau, built up of the nearly flat-lying limestones, dolomites, and cherts of the Campbell Rand series. The edge of the plateau maintains an altitude of about 4,000 feet above sea-level from Vryburg down to near Read's Drift—a distance of 160 miles—the vertical fall into the valley below increasing within that distance from 150 to 800 feet. From its edge the plateau rises gradually and uniformly towards a chain of hills with curiously rounded outlines, known as the Asbestos Mountain or Griqua Town Hills, which extend from Prieska to beyond Kuruman in a curve convex to the east. The highest point is attained on the boundary between Kuruman and Barkly West, namely, 6,070 feet, and the contours of the Kaap Plateau form even curves round this central point. North of this the surface falls towards the Kuruman River.

West of the Asbestos Mountains there is rather rugged country with numerous valleys, frequently sandy bottomed, culminating in the quartzite ridges of the Langsbergen with a nearly northerly trend. The drainage from this quarter is conducted into the Orange River. South of the Orange River the same bended jaspers that compose the Asbestos Mountains form the Doornberg, a chain of steep-sided hills with similar

smooth outlines stretching south-eastwards parallel to the river to a point a little north of Omdraai's Vlei. The altitude of the Doornberg exceeds 4,200 feet at several points.

Towards Kenhardt is another tract of elevated country trending, like the Doornberg, north-west and south-east, but not quite so high, and composed chiefly of Kheis quartzite and mica-schists. South-east of the areas of high ground referred to is a wide undulating tract formed principally by the Dwyka series, the basal portion of which, resting unconformably upon the underlying formations, is the celebrated Dwyka conglomerate or "tillite" of glacial origin. In this area, composed of material of late Palæozoic age, are numerous inliers of older rocks, principally the volcanics of the Ventersdorp system. These inliers form, with rare exceptions, ground higher than the surrounding tillite, and obviously represent the ridges of the pre-Karroo land surface, the troughs and valleys in most cases remaining buried beneath the glacial deposits.

Such inliers are found west and south of the Doornberg, and form a regular chain extending from Omdraai's Vlei to the Orange River near Hopetown. The older rocks form high ground in the angle between the Orange and Vaal Rivers, and again in the neighbourhood of Schmidt's Drift. Between the Harts and Vaal Rivers they constitute a belt broadening to the north-east and covering a wide area in Vryburg and south-western Transvaal.

Towards the south and south-east of the area the general level of the country rises, the covering of Karroo sediments and intrusive dolerite becomes thicker in that direction, and the scenery is that typical of the Karroo.

A critical examination of the available data shows that the extremely slight southerly inclination of the Karroo beds over the greater portion of the area in question is most probably an original feature due to conditions of deposition. In the extreme south and south-east the dip of the strata becomes appreciable, the fall of the Karroo floor is rapid, and it is likely that there has been a slight sinking of the crust in this direction. Omitting this tract, however, it is clear that over almost the whole of the area in question the elevation subsequent to the deposition of the Karroo sediments was of uniform amount, and consequently that there was no warping either of the Karroo beds or, obviously, of the pre-Karroo surface underlying them.

Where denudation has been insufficient to lay bare this surface entirely, remnants of the Karroo formation still occupy the bottoms of the depressions in it, and thus the ridges and valleys of the palæozoic land mass can be determined. Where the tillite has but recently been removed the surface of older rock possesses in a remarkable degree the characteristics of a glaciated region, while in many places the rocks still retain glacial

striæ. Even where the older rocks are hidden by the entire Dwyka series there are certain cases in which the directions of the major valleys in them can still be made out.

Obviously the undulating surface thus determined is that of the continent at the close of the Dwyka glaciation. In making a restoration of the surface as it appeared prior to glacial times the effects of glacial action in modifying the topographical features have necessarily to be taken into account. That a considerable thickness of rock was removed from the continent is evident both from the vast area occupied by the southern Dwyka, from its great thickness, and, in the case of the northern Dwyka, from the high proportion of material in it, obviously of local origin. Differential erosion is indicated by the occurrence of rock basins, and the lower portion of the Kaap Valley has probably been much deepened, firstly owing to the direction of glaciation almost coinciding with that of the valley, and secondly to the fact that the strata forming its floor were softer and easier removed than the beds composing the high ground to the north-west and south-east. Apart from this there is evidence to show that, except for the rounding off of ridges and the widening of valley bottoms, the intensity of the relief of the ground could not have been altered to any appreciable extent. It seems, therefore, not too much to presume that the main pre-Glacial drainage lines are represented with but slight modification in the major valleys of the glaciated Karroo floor.

The Palæozoic Drainage.—There is no portion of the area, indeed, where the palæozoic drainage lines can be more clearly seen than that immediately south of Vryburg, for the present river system is practically a replica of that of the past. At Brussel's siding the valley is about a mile wide and at least 300 feet deep, but at Taungs it broadens and the depth must have been over 800 feet. The main artery extended down the Kaap Valley, receiving a small tributary from the north-west at Boetsap and a larger one near Read's Drift. The channel probably continued to near Prieska, and then turned southwards in opposition to the course of the Brak River, passing between the T'Kuip hills and the ridges north of Beer Vlei; further into the Karroo its exact direction cannot be traced. The evidence regarding the area north-west of Prieska is not quite conclusive, but so far as it goes does not support the assumption that the valley of the Orange River from Prieska to Kheis is cut along a pre-Karroo valley. The drainage from the southern part of Hay and from the Doornberg Range in all likelihood entered the main valley at Prieska.

Another important branch came down from the Transvaal; it crosses the present Vaal River, first above Warrenton, again at Windsorton, receiving two tributaries from the east, and leaves it at Pniel, striking in a south-westerly direction to Douglas, where it joins the main stream in the Kaap Valley.

Another line of drainage starts a little to the east of Kimberley, extending in a south-westerly direction; in its lower reaches it almost coincides with the Orange River just above the junction of the latter with the Vaal. South-westwards from Belmont past Hopetown and down to

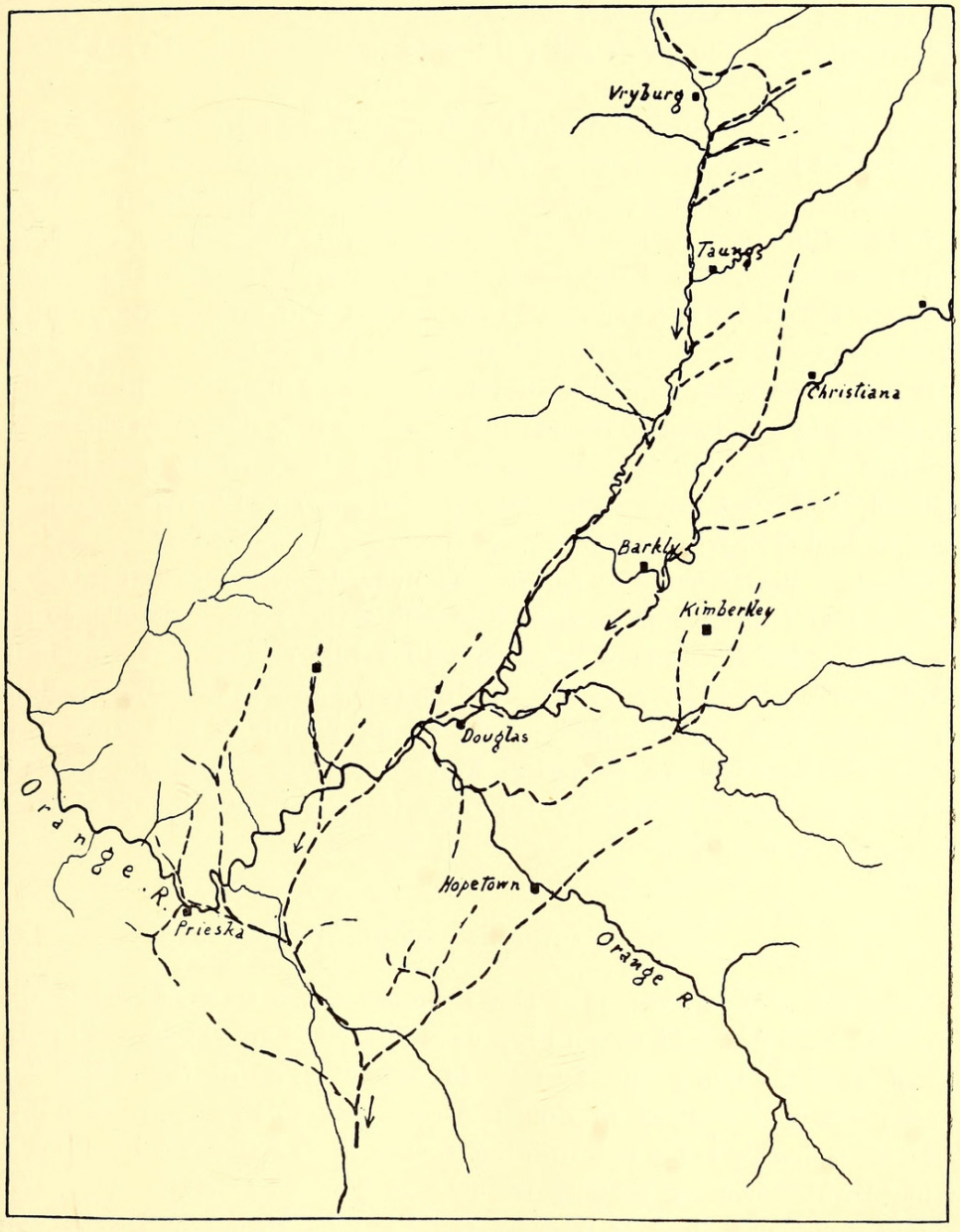

FIG. 1.

Beer Vlei an important feeder can be traced, traversing an area of little relief, but nevertheless possessing a rather intricate drainage system.

West of the Doornberg some of the rainfall certainly flowed in a southerly direction.

The palæozoic valleys are intimately connected with the strike of the underlying formations, hence the majority of the river-courses strike south-westwards; wherever the direction of the folding changes that of rivers is correspondingly altered, as, for example, around and to the west of the Doornberg where the strike of the rocks is now south-eastwards. Transverse valleys also occur, but are not so conspicuous or so important. The direction of the principal palæozoic drainage lines is indicated in Fig. 1.

The sediments derived from the denudation of this palæozoic land surface must have been carried southwards and deposited in that direction. Since this process of denudation was terminated by the Dwyka glaciation, and since in the south of the Karroo there is a perfectly conformable succession from the Cape into the Karroo system, the inference is obvious that this land surface was a source, and an important one too, of the sediments that formed the Cape system of rocks.

It is not necessary to go into details regarding the physiography of the area during late Palæozoic times; this has been fully discussed elsewhere.* Sufficient is it for our purpose to state that the surface was intensely glaciated, and then buried beneath the Karroo sediments during the Permian and Triassic epochs.

Whether the Stormberg series was ever deposited over central and northern Cape Colony is a matter of conjecture; the evidence so far is very slender, but if the view is correct that this series is represented in central and northern Transvaal, in Rhodesia, and in the Bechuanaland Protectorate, then the formation was in all likelihood laid down in this portion of Cape Colony as well. At the close of Stormberg times the Karroo strata were injected by innumerable sheets and dykes of dolerite over an enormous area.

The post-Karroo Denudation.

From the commencement of the Permian down to the Jurassic epoch at least the old drainage system lay dormant, so to speak, beneath a great pile of strata. Upon the surface of this "plain of deposition" the present drainage system of South Africa was initiated. According to Professor Schwarz † the determining factor in the stream directions was a "main watershed" extending from Cape Town to Delagoa Bay. This view has, however, been adversely criticised by Professor Davis,‡ while the author § has shown that in the Drakensberg area the drainage is

* Rogers and Du Toit, "Geology of Cape Colony," chap. xiii., 1909.

† E. H. L. Schwarz, *Geographical Journal*, xxvii., 1906, p. 265.

‡ W. B. Davis, *Bull. Geol. Soc. of America*, vol. 17, p. 387, 1906.

§ A. L. Du Toit, *Trans. S.A. Phil. Soc.*, xvi., pt. 1, p. 53, 1905.

intimately connected with the gentle warping of the strata in that region. It is most suggestive to find that the two principal directions of the rivers are north-west and south-west, and that to the latter belong the head of the Orange River, the Kraai River, and Caledon River, all flowing in gentle synclines, though the explanation of the course of the Vaal is not quite clear.

Whatever may have been the character of the Karroo drainage when initiated, it is not unlikely that it had been considerably modified even at the early period at which it can be recognised in the area under discussion. It has been pointed out that as a result of denudation an extensive peneplain was produced at the 6,000-foot level in the Stormberg area at a period when the continent stood at a much lower level than now; from this peneplain there rose to a height of from 2,000 to 5,000 feet—possibly higher—such portions of the volcanic masses of the Drakensberg and Basutoland as had escaped erosion by the head-waters of the Orange River. A peculiarity of the present main watershed right through the Karroo is that the northerly flowing streams take their rise at the edge of an escarpment which faces the south; owing to the cutting back of the latter there can be no doubt that the crest has gradually been shifted northwards and that the divide formerly lay very much further to the south of its present position.

Following this period of planation which was caused either by the cessation of the upward movement of the Continent, or possibly by a slight subsidence, there came a renewal of the uplift of such an amount that the river meanders were incised to a depth of over 1,000 feet between the Drakensberg and Aliwal North, and ultimately the present surface was formed at an altitude of between 4,000 and 4,500 feet over the area north and north-west of the Stormberg.

It is of great significance to find that in the area under consideration the oldest recognisable peneplain is that whose lowest altitude stands now somewhere about 4,000 feet above sea-level and into which the Orange River near Prieska has cut its channel to a depth of about 1,000 feet.

This remarkable physiographic parallelism in two areas, 250 miles apart, namely, a period of extensive planation followed by incision of the valleys to a similar amount in each case, subsequent to which there has been comparatively little variation in the character of the erosion, is very suggestive. The probability is therefore considerable that the same forces operated over the whole of the area in question and that the planation in Griqualand West was synchronous with that in the Stormberg.

A large portion of the Griqualand West peneplain remains hardly modified in the Kaap Plateau, with its gradual and uniform rise of from 15 to about 25 feet per mile from its edge (4,000 feet) towards the north-west. It is cut in crystalline limestones and dolomites, and the few

gentle features which vary its monotonous aspect are caused by beds of resistant chert. The post-Karroo origin of the plateau is proved by the fact that both at Boetsap and near Mark's Drift the Dwyka shales have been cut to a flat equally with the Campbell Rand limestones.

Gravels are still found *in situ* on this surface, namely, between Kuruman and Vryburg, at an altitude of 4,750 feet, the pebbles having obviously been transported some distance, and along the edge of the Kaap at 4,000 feet, near its south-eastern extremity, where water-worn pebbles of the jaspers of the Griqua Town Hills predominate.

The occurrence of these durable brown jasper pebbles is of immense value in determining the existence of former deposits of gravels, for the rocks from which they were derived are only known in the Griqua Town and Doornberg Hills, and inclusions of this material are not found in the Dwyka tillite in the area under consideration.

These jasper gravels are found *south* of the Orange River as far away even as Hopetown—a distance of 70 miles from their nearest possible source, and at an altitude of 3,600 feet. Small fragments are not uncommon over Hopetown and Britstown up to altitudes of nearly 4,000 feet, and, though some can be accounted for as having been carried by the aborigines for the purpose of making implements, they are so numerous that there can hardly be any doubt that they are the relics of gravels deposited by streams arising in the north and north-west, for it is noteworthy that the pebbles become gradually smaller in size to the south-east.

Further south in Carnarvon, Victoria West, Richmond, and Philipstown lies a belt of rugged country, composed of terraced dolerite-capped hills, in which isolated peaks attain an altitude of over 5,000 feet, and in some instances of over 6,000, and which is situated some distance to the north of the main watershed of the Colony. In this important mountainous region, owing to subsequent erosion, no traces of the peneplain remain.

The course of the rivers over the original surface of this peneplain, which can be named the Kaap Peneplain, is naturally impossible to determine with any pretensions to accuracy. In the north the emergence through the cover of Karroo rocks of the crests of the once-buried ridges must have determined the water partings in that quarter. In the north, therefore, the old drainage was re-established, but in the south, where the ancient rocks were still deeply buried, new drainage lines were set up and attained some measure of permanency. The evidence obtainable seems to show that the position of the Orange River lay many miles to the south of its present course in Hopetown. Below Prieska its direction may have followed more or less that of its present course, and it is noteworthy that the evidence for the existence of the peneplain in this quarter is found in the remarkably flat-topped ridges of the Doornbergen, the Kheis Hills, Ezel Rand, and Langebergen in contrast to their jagged

foothills and despite the facts that the hard strata forming them are highly tilted and disturbed.

From the positions of its gravel terraces the Vaal River seems to have occupied a course probably not very far removed from its present one, but from the occurrence of fragments of crocidolite and jasper in the gravels near Klipdam—it is most likely that the Harts River was not then in existence. If we therefore reconstruct in imagination this surface we find it extending away from the foot of the basalt terraces of Basutoland, north-westwards to beyond Prieska, and northwards over the Orange River Colony and the south-western corner of the Transvaal.

Between Aliwal North and Prieska the fall of the surface will have been from the 6,000 to the 4,000-foot contour, or at the rate of 9 or 10 feet per mile—just about twice the gradient of the Orange River in this section. Should this value be thought too much, it may be stated that in post-Karroo times the southern and south-eastern portions of the Colony appear to have been in a more unstable condition than the interior, and that there may have been a tilting of the surface of planation due to a greater uplift in the Drakensberg region. A comparison with the Kaap Plateau, however, brings out the fact, that in the latter the gradient possesses a somewhat greater value.

In attempting to determine the geological date of this uplift, it seems most likely that the movement was closely connected with that by which the outliers of Uitenhage (Lower Cretaceous) beds were faulted down in the folded belt of the south of the Colony, for in every case the upthrow is on the north or inland side. Again in late Cretaceous times there was a gental crustal flexuring which affected the belt of high ground (Drakensbergen) running almost parallel to the Indian Ocean—a feature which has been ably discussed by Professer Penck.*

On this assumption the cutting of the Kaap-Stormberg peneplain can be ascribed to the close of the Cretaceous epoch while the entrenchment of the river valleys and the development of the present surface features may have been produced entirely within Tertiary and post-Tertiary times. In this connection, therefore, it may be noted that in comparing the amount of the denudation in the Karroo with that in Arizona Professor Davis † has pointed out that in the former the amount of erosion appears to be less than would be expected if it had taken place during much of Cretaceous as well as the whole of Tertiary times.

* A. Penck, "Sitz. Kgl. Preuss. Akad. d. Wissen.," p. 230, 1908.

† W. M. Davis, *Bull. Amer. Geol. Soc.*, vol. 17, p. 444, 1906.

Dissection of the Kaap Peneplain.

Through a renewal of river activity brought about by this elevation of the continent, aided by such tilting as may have occurred, the peneplain was gradually dissected into its present condition. That the erosion was everywhere uniform in degree is shown by the relics of gravel terraces preserved here and there at different altitudes. The causes for these are, without doubt, complex, but the most important factors certainly are—intermittent elevation, climatic variation, and the existence of rock barriers athwart the stream-courses.

The evidence derived from the coastal area, as shown by shelves or ledges at different altitudes,* points to spasmodic elevation, but in the interior, which was presumably an area of lesser instability, this process was very possibly more uniform. The succession of gravel terraces is not necessarily a proof of intermittent elevation, for in a number of cases these shelves can in the clearest manner be seen to have been caused by the action of rock barriers, as these were one after the other exposed by the rivers in sawing down through the cover of Karroo deposits. The possibility of climatic variation will be considered later on.

The elevation of the continent was no doubt due to isostatic adjustment following the denudation of its surface.

The Orange River from the Basutoland border down to Hopetown, flows at a depth of from 100 to 200 feet below the surface of the adjoining country. Wherever a dolerite dyke or sill crosses the river its channel becomes narrow and the gradient steeper; above such a point there is usually a smooth reach for several miles. A good example of such a barrier is just above the railway bridge at Hopetown. Below this point there begins a peneplain at an average altitude of 3,600 feet above sea-level, and traceable over a considerable area in the Hopetown Division. Its origin may possibly be connected with the cutting of the channel of the Orange through the hard rocks below Prieska. At Hopetown itself this terrace is from 140 to 200 feet above the level of the present river, and the gravels contain abundant pebbles of amygdaloidal basalt from the Drakensberg, such pebbles being absent from the high-level deposits of the Harts and Vaal Rivers. Below Hopetown the Orange River leaves the Karroo formation and plunges into a deep gorge cut in diabase and quartzite, and its rapid fall only terminates when it enters once more an area of Dwyka tillite and shale. From this point down to its confluence with the Vaal it courses along the base of a ridge of diabase rising in places to a height of 800 feet above it. At Read's Drift it has sawn a narrow channel, with precipitous sides in a peneplain cut in the Campbell

* E. H. L. Schwarz, *Q. J. G. S.*, p. 70, 1906; *Amer. Journ. Science*, Sept., 1907, xxiv., p. 185.

Rand limestones ; below the point down to Prieska its winding channel is hemmed in by banks of Dwyka tillite. All along the course of the river, and sometimes nearly 15 miles away to the south are terraces capped with gravels cemented with carbonate of lime, and usually prominent features in the landscape. For this reason the gravels, which appear to be diamondiferous, are unworkable. At Prieska the altitude of the river-bed is only 3,020 feet, so that the Kaap peneplain has been dissected to a depth of about 1,000 feet. The Riet River is in many respects a duplicate of the Orange. Along with its tributary, the Modder, it drains a wide area of but little relief in the Orange River Colony, enters a deep and narrow gorge cut in diabase below Modder River Station, and for some distance before joining the Vaal River has its channel incised in a terrace cut equally and uniformly in both shale and dolerite.

A most interesting feature about the Vaal River is that in a distance of 100 miles above Christiana the fall is only 30 feet, or less than 4 inches per mile, whereas from Warrenton to Barkly West the fall in 60 miles is just over 300 feet.

In sawing downwards the Vaal River has come across several of the buried ridges of the pre-Karroo diabase, and in them it has in time cut deep and steep-sided gorges. The two most important barriers are the one between Warrenton and Windsorton and that between Barkly West and Longlands. Above such a barrier downward erosion has been checked, while below it the Dwyka tillite has been rapidly removed ; hence at the lower end of each gorge are several gravel terraces occasionally with slopes connecting those at different levels, whereas above the barrier there is usually a single terrace the period of the formation of which is equal to the sum of those below the gorge. For this reason it is very difficult to correlate according to age terraces along different sections of the river.

Along this portion of its course the Vaal River forms a most interesting study, and shows in a clear manner the mutual dependence of different sections, the results of interference caused by minor obstructions, and the delicate readjustments of the rate and extent of the erosion in both a vertical and lateral direction. The peculiar hummocky surface of the diabase, with its Dwyka-filled, steep-sided, and ramifying depressions has obviously exercised an important influence in shifting the course of the river and its lateral streams from time to time.

Gravels, usually diamondiferous, are found along the Vaal River at altitudes up to 400 feet above its present bed preserved on slopes or shelves cut in amygdaloidal diabase, sometimes miles away from the river.

Whereas the Vaal River was hampered by hard diabase, in which it

ultimately has succeeded in cutting its channel to a depth in places of 400 feet, a small tributary which may possibly have joined it near Klipdam was only faced with shales and dolerite. It was therefore able to cut its way backwards, at the same time shifting its course laterally towards the north-west and finally forming the Harts Valley.

This river, although possessing only a fraction of the flow of the Vaal River, has been able to re-excavate a section of the pre-Karroo Kaap Valley, capturing during its progress the drainage which the Vaal would have received from the north and north-west. The removal of material, principally shale, has been so extensive that the Harts River in the lower part of its course now meanders in a broad valley, whereas the Vaal is devoid of loops with the exception of the curve known as the "Bend," which is due to the excavation of a basin filled with Dwyka tillite and shales. The most interesting feature concerning the Harts River, and one that is so dependent on the nature and history of the palæozoic land surface is the fact that over a great distance its channel possesses a far lower gradient than that of the Vaal River.

That a tributary should flow at a lower level than the main stream for such a distance is almost unique, and upon this peculiarity a great irrigation scheme has been based.* It has been proposed, in fact, to divert a portion of the flow of the Vaal River just above Warrenton and lead it up the Harts Valley as far at least as Taungs. As a matter of fact, the altitude of the Vaal River is 3,880 feet above sea-level, while that of Taungs Station is 3,590, and Brussel's siding only 3,700—that is, the water could be taken to within a few miles of Vryburg, 70 miles away to the north.

The Kaap retains its peneplainic features to a marvellous degree; this is apparently due to two causes. Firstly, the Dwyka tillite and shale which was banked up against the limestone escarpment has protected the face from active erosion up to a very late stage. Secondly, owing to the jointed nature of the limestone the rainfall is conducted underground, as is proved by the numerous springs along the base of the escarpment. The surface has also been protected to a certain extent by a deposit of calcareous tufa. South of Griqua Town, however, the Sand River has been very active in removing the Dwyka where the peneplain is continued over this formation.

Lastly, we come to the consideration of the Brak River and its various tributaries which drain the area north of the main watershed in De Aar, Richmond, Victoria West, and Britstown. Over the greater part of this tract of typical "Karroo" country the rivers flow along channels but slightly incised in the broad flat plains, but here and there they have cut narrow gorges through dolerite ridges and occasionally through miniature

* Report of the Director of Irrigation, &c., Parliamentary paper G 41, 1906, p. 57.

sandstone plateaux. Below T'Kuip the Brak River flows in a moderately broad depression excavated in tillite to a depth of 200 feet below the general surface; along this section it receives no important lateral streams, the area both to east and west being characterised by the depressions known as "pans." In the Brak River catchment area gravel terraces occur at various altitudes and sometimes at a distance from the present channels; the boulders consist principally of dolerite, and lydianite and quartzite produced by the contact action of the intrusions upon the Karroo shales and sandstones.

Origin of the Veld.

Under this title Professor Davis * has discussed a number of possible theories as to the development of the present surface features of central South Africa. Passarge † has pointed out how a peneplain might gradually be formed in an arid region and how it might subsequently be dissected either by warping or else by a change to a more humid climate; he has suggested that this might be the case with the Kalahari, and that the latter, and consequently the Karroo as well, might have been dissected at their present level.

Against this view we have the improbability that the Karroo was elevated continuously several thousands of feet, for the nature and position of the cretaceous rocks and the recent marine terraces in the coastal region show that this elevation proceeded by steps and that the upward movement has continued down to within recent times. Peneplains are, moreover, normally developed at low levels with respect to the surface of the ocean. With regard to the question of climatic variation, Passarge ‡ has elaborated a cycle of changes from humid to arid and back to humid conditions in Tertiary and Pleistocene times. It is not yet known, however, to what extent the phenomenon of the silicification of sands and limestones can be relied upon as indication of a former arid climate.

The evidence in Bechuanaland,§ slight as it is, is in favour of some variation in climate, and it seems not unlikely that during a certain stage in the elevation of the continent more arid conditions prevailed over northern Cape Colony at least.

It cannot be denied that, as stated by Davis, the Karroo exhibits a decidedly mature type of erosion; this can be well seen in Hopetown and

* W. Davis, *l.c.*, p. 435.

† Passarge, "Zeitschr. d. Deutsch. Geol. Gesellsch.," lvi., 1904, protokol, p. 193; "Naturw. Wochenschr.," new series, vol. iii., 1904, p. 657.

‡ Passarge, "Die Kalahari," Berlin, 1904.

§ *Ann. Rept. Geol. Commn.* for 1907, pp. 155–7.

Britstown for example. Although this is the case over a large area, I think that the proportion of country possessing stronger relief has been much underestimated. For example, we have the Karreebergen and the block of rugged ground joining the Nieuwveld to the Sneeuwbergen and Stormbergen. The Dwyka and Ecca shales crumble away rapidly and form flats dotted with little dolerite ridges and pinnacles, while the Beaufort sandstones are far more resistant. Again, the inclined sheets or sills of dolerite form far more serious obstacles to denudation than the nearly horizontal intrusions; the latter, when they occur on the flats, are not uncommonly decomposed to a friable material. The time required for the dissection of the peneplain into such an area of low or moderate relief may therefore have been comparatively small; thus the argument that with a late uplift of the continent the stream-courses would be incised and the rivers would have been unable to cut out a peneplain is very much weakened. As a matter of fact, however, it is just the incised nature of the channels of the Orange and Vaal Rivers which has prevented the development of irrigation schemes along their courses, while it has already been pointed out that the Orange River flows in a gorge throughout this area, the same being true of its channel below Prieska and below Upington. With a late uplift, however, there may have been rejuvenation of the lower reaches of the Orange, while the upper portion of the drainage system may have been but little affected by the elevation.

The view that the "Veld" is due to erosion under arid conditions within recent times is not borne out by facts. Firstly, gravel terraces occur at various altitudes as already described; secondly, the existence of dry river-channels, such as the Molopo in Bechuanaland, indicate that the rainfall is probably less at present. At the present day the rivers are quite able to dispose of the products of disintegration, for the flats are covered with but a scanty soil. Belts of sand cover extensive tracts of country, but the material is principally wind-borne, and is due to invasion from the north-west; practically, however, the whole of the sand is fixed by grass.

The existence of numerous pans inland affords no decisive evidence of climatic changes. There is no doubt that they have been formed principally through the agency of the prevailing northerly or north-westerly winds,* but while some pans are being filled up with sand at the present day others are undoubtedly being deepened. Their positions are usually independent of any drainage system.

From the writings of the older travellers, which are confirmed by the accounts of the oldest residents in the Colony, there is no doubt that the human habitation of the Colony has been a most important factor, and one that has not been sufficiently reckoned with in modifying the face of the

* *Ann. Rept. Geol. Commn.* for 1906, p. 131.

country, unfortunately not for the better; the overstocking of the farms and their deforestation are reducing the Karroo to a barren tract.

Summary.

In Palæozoic times a continent extended over the area in question, and the drainage from it was directed southwards, the Kaap Valley forming the principal channel. At the close of the Carboniferous epoch this continent, which stood at a lower level than it does now, was intensely glaciated and finally buried beneath the Permo-Triassic Karroo deposits; upon the surface so formed the modern drainage was initiated.

The denudation of the newly formed continent has been greatly aided by the elevation which has in time brought it to its present altitude; but this uplift has been spasmodic, and appears to have acted during several distinct periods in late Jurassic and in Cretaceous and Tertiary times. With each cessation of movement the rivers have been enabled to cut a peneplain, and one of the most important of these surfaces extended from the Stormberg probably into Griqualand West, where it is represented by the Kaap Plateau. Since late Cretaceous or early Tertiary times this surface has experienced denudation; the rivers have cut down and laid bare in this area the pre-Karroo floor with its drainage lines, and the development of the modern river system has been greatly influenced by reason of its superposition upon that of Palæozoic times. The Karroo owes its peculiar type of scenery in part to its geological structure, in part to the prolonged nature of the erosion to which it has been subjected, and in part to the climatic conditions which existed during its development.