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# CRUSTAL MOVEMENT AS A FACTOR IN THE GEOGRAPHICAL EVOLUTION OF SOUTH AFRICA.*

ALEX. L. DU TOIT.



1. *Introduction.*—Geology teaches us that the past history of the earth is one of continual change—geographical, biological and climatic—and there are excellent reasons for believing that such variation has by no means ceased, only that the processes go on so slowly as to be scarcely recognisable during a lifetime, though their cumulative effects, when measured over a geological period of time, may become astonishingly great.

The simplest manner of demonstrating such geographical change is by considering the effects produced by rivers carrying off waste from the land. As is well known, one of the major hindrances to irrigation in this country is the rapidity with which storage dams become silted up. "The quantity of suspended matter passing Orange River Station throughout an average year has been computed at over 50,000,000 tons, which ignores, however, the very considerable proportion of dissolved substances in the waters of the Orange River. Additional data show that the annual "load" borne by the combined Orange and Vaal just below their junction is equivalent to the removal from their catchment area of 35,000 square miles of a layer 2/3000 of a foot in depth. In other words, this represents *a general lowering of the surface at the rate of one foot in about 1500 years.*"[1]

It is conceded that human activity since South Africa became settled has greatly stimulated erosion, while calculations made elsewhere point furthermore to a somewhat lesser rate during the remote geological past. Weighing up the several factors, a mean rate over South Africa of one foot during 2,500 or 3,000 years would seem not unlikely during the interval from the Tertiary to the present. This is distinctly greater than the figures obtained in other countries, but finds its explanation in the higher stand of the Continent and the contrasted nature of its seasons.

It is my intention to take you back in time about a score of millions of years ago, to about the middle of the Tertiary Era, and hence a good deal further back than our earliest records of man, so that you may realise the vast changes that have since taken place in the configuration and climate of this great country. Curiously, our knowledge thereof is derived from two main regions—from the coastal zone on the one hand and the far interior on the other—the belt transitional between them yielding but little information for reasons that will appear later.

2. *Rising of the Coastal Zone.*—Erosion of the continent will necessarily lighten it, whereas the deposition of the derived mud upon the adjacent ocean bottom will perforce weight the latter. Since the crust of the earth is not rigid, and is indeed supposed to be floating upon a denser but more yielding substratum, the landmass will tend to rise and the sea-floor to sink until equilibrium is approximately re-established. Such would generally require the lateral transfer of deep-seated matter from beneath the sinking to below the rising portion. So long as land and sea maintain their general position, so long must there be this continual readjustment, though for various reasons the process is commonly not a steady one, but intermittent and occasionally spasmodic.

A little reflection will show that the landmass will have a tendency to bulge upwards most in its centre and the bulge so produced to be worn away by denudation at a more or less corresponding rate. Furthermore, there must be some particular section along its periphery which experiences no change of level, and such is commonly situated some little distance off-shore. Under these circumstances the upheaval will tend to raise not only the land itself, but a part or even the whole of the contiguous "continental shelf," that submerged ledge bounding the continental mass. It follows that during the process of upheaval an initially horizontal surface will become progressively more and more tilted towards the ocean. Even the continental shelf could be thus affected, without necessarily being raised above the waves, as, for instance, in the case of the broad Agulhas Bank, which possesses a gentle southerly tilt.

It can be doubted whether there is any other land except South Africa that can show so simply and convincingly the results of unloading under erosion, uncomplicated by other disturbing influences. Over an enormous period of time the southern end of the African continent would seem to have behaved quite passively, responding only to vertical forces; it would appear to have experienced neither compression nor tension, save in the most limited degree, nor did volcanicity play an important part in its evolution. In Central Africa the conditions were rather different, but in South Africa *isostatic adjustment* was, in my opinion, the dominating control.

South Africa can show along its coast some fine examples of elevated, bedded, marine deposits and of presumably wave-cut rock-shelves, the older of which record through their slight shoreward dip the effect of continued updoming of the interior. Outstanding is the Alexandria Formation, composed of Tertiary shelly limestones, etc., rising at an inclination of one and a half degrees, or 75-80 feet per mile, from near sea-level at the Zwartkops River mouth, Port Elizabeth, to an altitude of over 1,100 feet at Sandflats. Its deduced continuation inland, evolved not by the sea but apparently by rivers, ascends to over 2,000 feet around Grahamstown and Komgha. A similar surface has been developed to the west over Knysna, George, Mossel Bay and Bredasdorp, with present altitude of generally between 400 and 800 feet. These faintly-tilted surfaces have, it must be pointed out, lost some of their originally plain-like character through erosion consequent upon their emergence and elevation.

It is highly probable that the waves of the late Tertiary or Pleistocene Atlantic formerly lapped the foot of the Hottentots Holland and Winterhoek Ranges stretching northwards from Gordon's Bay to Heerenlogement Berg, and that Piquetberg Mountain, Riebeek Kasteel, the Darling Hills, etc., formed islands in that shallow sea. The Olifants River intersects a similar gently-inclined surface of marine erosion extending eastwards over Van Rhynsdorp far into that dreary region known as the Kneghts or Kners Vlakte, with northwesterly extension along the coastal zone of Namaqualand and onwards through South-West Africa. The inner limit is difficult to define in this direction. At the relatively low level of 120 feet, or so, are to be found the famous marine shingles of the Alexander Bay diamond fields.

In the opposite direction Dr. L. J. Krige has shown that marine beds occur at Durban on the Berea at an altitude of 415 feet. Both here and at Alexander Bay the shells are of species still living in South African waters, such proving the comparatively recent age of the uplift. Almost the whole of Moçambique Territory, from Zululand of the Zambezi, is built of Cretaceous, Tertiary or Pleistocene marine beds, which have been raised from beneath the waves.

Of the various younger raised beaches, coastal ledges and sea-caves, it is not intended to treat, the sole object of the preceding account being to stress the considerable amount of emergence of the continent since the earlier part of the Tertiary, an upheaval which is still in progress.

The study of the existing drainage lines that cross the coastal zone yields some useful information about the *rate of uplift*. The meandering character of these rivers indicates that they were developed upon a plain having a very low gradient initially; the observed tilt of the surface must therefore have been subsequent. During the slow uplift the looping became incised in the plain to depths dependent upon the amount of the upheaval experienced. The majority of the rivers of the Union, from the Great Berg round to the Umfolozi, show these incised meanders, the Great Fish River, in its mid-section, best of all, possibly because in that part of its course it ran eastwards along the southern edge of the Karroo-Basutoland Basin (Sect. 4, a). Nevertheless, in most cases their channels straighten out again before reaching the sea, as, for instance, in the Breede, Sundays, Great Fish, Great Kei and Umtamvuna rivers. This phenomenon would seem to have been due to abnormally quick uplift and to the rapid prolongation of the stream-channel across the newly-exposed sea-floor in a direction at right angles to the coast-line, as the latter migrated outwards. This peculiarity enables us to fix one at least of the temporary edges of the continent with considerable precision. We thus find that the width of ground added since such rapid uplift began amounts to between four and eight miles through the Transkei and Natal. In the south-west and west, however, the breadth was seemingly much greater, though more variable.

3. *Denudation of the Hinterland.*—The bulging up of the interior, deduced from the coastal zone, can be convincingly demonstrated by a study of the profiles of the larger rivers. The bed of a normal mature river flattens progressively when traced towards the sea, the longitudinal section being concave upwards. In South Africa the middle and lower reaches are usually either evenly and rather steeply graded throughout, or else are slightly convex upwards, a very good example being the Great Fish River (Cape). This proves that erosion was unable to keep pace with elevation, and that the crust has actually been flexed. In the majority of the rivers discharging into the Indian Ocean their steep gradients are maintained right down to those points where they become tidal—usually a mile or two back from the mouth —e.g., the Umzimvubu and Tugela. The lack of bordering alluvial plains, even in those parts of the country blessed with an adequate rainfall, thus finds its explanation.

Large-scale profiles disclose as a rule numerous places where a sudden change in gradient occurs—" knickpoints " they are termed in America. Many are due to the presence of a hard bar, which holds up downward erosion, but others certainly mark the upstream limit to which valley-cutting has extended following rejuvenation due to uplift, with lowering of base-level, and are frequently connected with flanking terraces. Such " erosion-cycle knickpoints " are of great significance, and their systematic study ought to shed much light upon the number and relative magnitude of the successive upheavals that affected various portions of South Africa.

Downward erosion has been most active in the belt just back of the terraced coastal zone and transitional to the relatively-level, plateau-like interior. Now, it is precisely within this region that, owing to elevation, bending of the crust could be expected to attain its maximum. Such helps to account for the extraordinary depth and narrowness of so many of the gorges traversing that intermediate region. One can cite the multitude of " poorts " cutting through the Southern Cape fold-ranges, the ravines of the central section of the Transkei, Natal and Zululand, the gashes intersecting the Lebombo, and the defiles of the Lower Orange River. This is, however, a subject upon which many pages could be written.

From a consideration of the inclination at which the coastal terraces ascend, which is between one and two degrees, it can be estimated that the Interior must have experienced an effective uplift of at least 2,000 feet, probably much more, the term " effective " implying the absolute amount of upward movement *minus* the loss in altitude due to the erosion from the surface within the corresponding period. It seems just possible that prior to its great uplift the centre of the continent at no time exceeded some 2,000 feet above sea-level except for certain isolated ranges and hills. The time involved is known to have been enormous, and was, indeed, sufficient to enable this central region, at least 700 miles wide, to become worn down, under normal erosion, into the condition of a plain of nearly ideal perfection. Hardly altered, we see it to-day composing vast stretches in Bechuanaland, Ovampoland and Barotseland, and, somewhat modified by denudation, in Southern Rhodesia, South-

Such hills as occur commonly spring with greater or less abruptness from extensive flats, resembling islands in the ocean, whence their German name of "*Inselberge*," with the term "*Inselberglandschaft*" for this peculiar landscape. As Obst[2] has pointed out, the development of the inselberge has primarily been determined by a tropical steppe climate, under which rock-weathering goes on actively during the dry season and the waste so produced is removed during the succeeding rainy period. There do not seem to be any convincing grounds for supposing, with certain authorities, that these curious relic-forms have been evolved through wind erosion, although their sculpturing may quite well have been, and doubtless was, aided thereby. Comparison with any of the regions of higher rainfall—for example, Swaziland or Natal—shows great differences in the topographical outlines, the hills tending to be rounded-off and to merge gradually with the lower ground, which is intersected by narrow or broad valleys having distinctive characters. The significance of the Inselberg landscape in South Africa will be dealt with later.

The ranges that overlook the huge central flat are few, and are strikingly situated towards its margin; no important chains are represented in its interior. They consist essentially of mountains of "circumdenudation," such as the Basutoland, Waterberg or Komas highlands, or older relics that have become resurrected by the stripping away of a blanket of younger strata—for example, the Vredefort and Asbestos Hills, Langebergen (Griqualand West), Richtersveld and Kharas Mountains.

During the latter part of the Tertiary a marked reduction in the rainfall converted the interior into a sandy waste, the surface of red sand being moulded by the wind into gentle waves over a wide region and thrown into dunes in the more arid south-western section; silicification occurred towards the base of the sand. The run-off became insignificant and the region converted into a desert; this was the primeval Kalahari. Towards the beginning of the Pleistocene, round about a million years ago, there came about a general upheaval, coupled with crustal warping and, save apparently in the Atlantic section, a return to normal and even to pluvial conditions. Erosion proceeded apace, the central desert was attacked along its margins, and the inhospitable environment transformed into one more favourable to man. Minor fluctuations, both of uplift and climate, extending down to the present day are betrayed by the sheets of gravel left behind at various heights by the rivers as they proceeded to deepen and enlarge their valleys. Certain of these gravels have yielded the bones of extinct animals, and even worn implements of human manufacture.

4. *Warping of the Interior Region.*—Thus far it has been assumed that elevation was by means of progressive and gentle up-doming of the crust. When, however, the enormous extent of the continental block is considered, the asymmetrical arrangement of its major drainage basins, the varying rates of erosion over different portions thereof, and other disturbing factors, such a postulated regularity becomes unlikely. We have accordingly to suppose that the amount of uplift must have varied appreciably over different sections, and hence conclude that a certain amount of warping must have ensued. For the time being we shall ignore sub-crustal igneous activity as a possible additional factor.

Evidence is available, as it happens, to show that differential uplift must have occurred, some portions of the crust having lagged behind in the general elevation, others having been upheaved by more than the average. Although not quite exact, the former can be referred to as "*areas of depression*" or "*basins*," being more or less circular or oval in plan; the latter are more or less linear and can accordingly be termed "*axes of uplift*," "*arches*," or "*ridges*." Usually one basin is separated from another by a ridge, the three structures being manifestly co-related. Where the surface was flat originally, its subsequent deformation is commonly simple to detect and the resulting basin easy to delimit. Where erosion has been considerable or the ground more broken originally, detection becomes more difficult, although even under such circumstances the positions of the ridge-lines are generally determinable to within small limits, since they constitute the divides from which the primitive drainages were thrown off in opposite directions, and these are usually not far removed from the present watersheds. In the majority of instances these basins stand revealed through the presence within them of Karroo strata of Permo-Triassic age that have been tilted slightly from the horizontal.

It is intended to describe the principal ridges and hollows into which the crust of South Africa was bent during the period ranging from about the middle of the Tertiary down to the present, that is to say during a score of million years or so. When it is realised that man has inhabited parts of this continent for perhaps so much as half a million years, possibly more, the figure set will no longer seem an excessively big jump backwards in time.

The only writer to treat comprehensively of this interesting subject is Krenkel,[3] whose analysis thereof is an able and suggestive one. Of the names conferred by him upon the chief ridges and basins, several have been taken over in this address. It must, however, be recognised that, owing to our limited knowledge concerning particular sections of the immense territory involved, there are still many uncertainties in the interpretation, which can only be dispelled by further work.

As will be seen from the accompanying map, the dominant structures display a certain pattern, the significance of which will be discussed in Sect. 5. These will be dealt with so far as convenient in order from south to north.

(*a*) *The Karroo-Basutoland Basin.*—This, the largest feature, fully 700 miles by 300, does not exhibit any palpable signs of its true nature, since its margins stand everywhere lower than its centre. Actually, it coincides with the well-known "Karroo Basin" of geologists, with strata everywhere dipping inwards at angles of between one and two degrees, or 100 to 200 feet per mile. Its heart is formed by the Basutoland highlands, to-day the loftiest ground in Southern Africa, composing a block which towers between 4,000 and 5,000 feet on an average above the surrounding country. There are nevertheless reasons for believing that formerly that central mass stood much higher relatively to the adjoining territory, only the latter became elevated by a greater amount. This is understandable when we remember the enormous quantity of sedimentary and volcanic material that has so far managed to withstand the attacks of the various rivers

[3] E. Krenkel: *Geologie Afrikas*, Part II, 1928, Berlin.

taking their rise in that massif. The progressive unloading of the outer region by such erosional activity would inevitably have led to some uplift along the periphery, whereas the centre of the basin remained on the contrary heavily weighted.

The consequent warping has amounted to several thousands of feet. A detailed study of the south-central portion has proved the existence therein of several minor waves or ripples with axes tending north-east or east-north-east, crossed by others trending north-south, which have been superposed upon the main basin-like structure.[4] The relatively late date at which such warpings occurred is evinced by the fact that in Barkly East and Aliwal North the Kraai River has cut across the deformed strata in an even erosion surface or peneplain, which to-day stands at about 6,000 feet above sea-level. Deeply incised meanders testify to the rejuvenation of that river.

As pointed out by Davis & Rogers, the various rivers flowing into the Indian Ocean have eaten back far into the plateau region all along the main watershed of the Union, and so caused its retreat towards the north, reducing, incidentally, by an equivalent amount the catchment of the Orange River.

(*b*) *The Griqualand-Transvaal Axis.*—A good account of this has already been given by Prof. Wellington[5] under the title of the "Vaal-Limpopo Watershed," though I would feel inclined to put its eastern end somewhat more to the north, at about the Mauchberg, from which it would run in a general westerly direction through the Witwatersrand to Lichtenburg and thence south-westwards past Vryburg and Kuruman to Buchuberg, where the Orange River has cut deeply into it, and thence west-south-westwards past Kenhardt to the Kamiesberg in Namaqualand. The altitude is generally well over 5,000 feet in the Transvaal, exceeding 6,000 feet in places; it also rises to over 5,000 feet in the heart of Griqualand West. From it the rivers flow off in opposite directions to the Vaal and to the Limpopo and Molopo over much of its length.

It is definitely *asymmetrical*, having a steep short fall on the north-west into the Bushveld and a remarkably even gentle slope of between five and ten feet per mile to the south-east, but beyond Ventersdorp the rim of the Bushveld basin turns to the north-west and the divide becomes almost symmetrical. This lengthy line should, however, be regarded *not so much* as an axis of upheaval, but as due primarily to the *sinking* of the ground on its northern side, the faint slope on the southern side being an original feature and having remained almost untilted.

Of significance is the behaviour of the Orange and Hartebeest rivers, where they cross this axis. From the junction with the Vaal the gradient of the former is both even and low, 1·7 feet a mile; at Buchuberg the value changes abruptly to 2·75 feet, which is maintained to near Upington, after which the slope increases rapidly. A slight ridging up about Buchuberg has clearly been responsible for the flattening of the channel before the axis is reached. This is even better marked on the Hartebeest River, the gradient of which from a little above Kenhardt suddenly increases from one to ten and then to twenty feet per mile, whereas to the south the Zak and Olifants Vlei rivers spread out in vast clay-flats such as Groot Vloer, Verneuk

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[4] A. L. du Toit: *Ann. Rept. Geological Commission, C.G.H.* for 1904, p. 76, Fig. 1.

[5] J. H. Wellington: *S.A. Geogr. Journ.*, XII, p. 36, 1929.

Pan, etc. Had the uplift near Kenhardt been greater or more rapid, it could be deduced that the waters from the Western Karroo would have been ponded back altogether in a series of finger-like lakes, there to be evaporated. An explanation is thus forthcoming for a feature that had puzzled Rogers.[6] The axis is traceable onwards to the Kamiesberg, where it is revealed by the warped surface of Bushmanland, and seems to have been responsible for some remarkable river capturing within the area situated between the eroded edge of that peneplain and the sea.

There are several remarkable peculiarities about this broad strip of "highveld." First, the regularity of its surface with extremely even skyline save over a few restricted areas; secondly, the widespread development of deep soils upon it often of red colour and sandy texture, that are well fitted for agriculture; and thirdly, the abundance of "pans." From Lake Chrissie in the east they dot its surface within a belt nowhere less than 100 miles wide and extending for 750 miles into Bushmanland, with an arm stretching north-west far into South-West Africa. Outside that tract pans certainly do occur, though few and irregularly scattered; it could with justification be styled the "*Pan Belt.*"

The reason for such an arrangement is admittedly obscure. It cannot be wholly geological, for although such hollows favour the practically horizontal Karroo beds, they have been equally developed upon the several lithological divisions of the latter; nor can the existing climate be alone responsible, since the rainfall ranges from 35 inches in the east down to only five inches in the west. The predisposing, if not determining, factor was, so far as can be judged, the existence of an extensive peneplain devoid of prominent drainage lines, which in turn implies very lengthy erosion without any crustal deformation. Both to north and south, where the surface experienced tilting, the streams were able to develop valleys, and the conditions soon became unfavourable either for pan development or preservation. Doubtless they were more abundant in the past, many of them having been wiped out in the process of valley erosion. Attention might be drawn to the peculiar line of pans in the South-Western Transvaal, extending southwards from the Mafeking border past Delarey to Bloemhof, of which the largest is Barbers Pan. It conceivably marks one of the primitive north-south drainage lines of the peneplain, since tapped by the Harts River near Schweizer Renecke.

If the hypothesis be correct, that these remarkable hollows are due primarily to æolian agencies, one is driven to the conclusion that a lower rainfall, coupled with stronger winds, must formerly have prevailed in the central and eastern sections; the western is to-day sufficiently arid and windy. Upon the temporary drying up of a pan the dust from its clay-floor is readily blown out and the basin correspondingly deepened. This view has indeed been advocated by Penck and supported by Rogers for the rock-basins of the Eastern Transvaal, of which the largest and most striking is Lake Chrissie. The saline nature of so many of them forms a very strong point in the argument.

Evidence for a state of steppe or semi-arid conditions during one stage in the evolution of the Bushveld basin will shortly be led, and some extension thereof into the adjacent Highveld would seem not at all unreasonable. Under any circumstances, the development of higher temperatures within that basin through the lowering of its floor, would have led to increased updraft and therefore to stronger winds within it and around its margins, a condition that must certainly have aided pan-formation. The red Kalahari sand unquestionably penetrated far into the Pan Belt from the north-west and west, though the extreme limits of such invasion remain unknown, since the present streams have removed so much of that sandy covering. Within a lengthy stretch of the Pan Belt, however—from near Parys to Kimberley—over a width of from 30 to 35 miles, the sand is nearly continuous and fairly thick, depths of over 50 feet having been proved by certain wells in the Hoopstad district, while the red sandy nature of the deep soils of the Standerton-Lichtenburg region hints at an admixture of wind-borne material in them. Between Hopetown and Bushmanland there are many patches of brilliant red sand, certain of which retain the dune-form, since that is still a region of low precipitation. The red sand of the Pan Belt in the Union is older than the Palæolithic gravels of the Vaal River system, a similar relationship holding good in Southern Rhodesia also.

(c) *The Bushveld Basin.*—This structure in the heart of the Transvaal is exceptionally well defined by a nearly continuous palisade of quartzites that dip almost everywhere towards the centre of the hollow. There is clear geological evidence to show that the sagging process under which it was produced must have operated through an enormous period of time, although intermittently, and that it started so far back at least as the early Palæozoic. In its latest movements, with which we are particularly concerned, the floor appears to have sunk by as much as perhaps 1,000 feet, to which must be added the loss of elevation due to the mechanical excavation of its interior through river erosion, giving a total drop of from 1,500 to 2,500 feet, possibly more. Some inequality in the sinking is evinced by the presence beneath the Springbok Flats of at least two subsidiary warpings, whose axes are, like that of the main basin, directed east-north-east.

The evidence for the above warping is to be derived largely from the behaviour of the diamondiferous gravels of the Lichtenburg and Ventersdorp districts when they are traced up to the margin of the down-sunken area, though it is impossible in these pages to set down the full data from which such conclusions have been drawn. These gravels are indicated on the map accompanying Prof. Wellington's able geographical review of this interesting region,[7] while they have been discussed very thoroughly by Mr. A. F. Williams,[8] to which two papers special attention must be drawn.

In brief, an important gravel "run" with tributary branches is traceable in an "upstream" direction from the head of the present Molopo through the diggings to the headwaters of the Groot Marico River rising gradually in that direction, that is to say eastwards. Various far-travelled pebbles in these alluvials indicate that they were laid down by a large river, which could only have been the former prolongation of the Molopo, a river which took its rise much farther to the north-east. Among such pebbles the most abundant and distinctive consist of agates derived from the Bushveld Amygdaloid, a formation exposed to-day round about Pienaars River and Settlers, but at an altitude of always less than 4,000 feet throughout the Springbok Flats, whereas the derived gravels attain heights of 5,150 feet

[illegible] Watershed, S. A. Geogr. Journ., XII, 1929.

in places. The gravels only just cross the present main watershed, but traces of them are discoverable inside the rim of the Bushveld basin, as relics on top of certain flat-crested ridges that must be regarded as remains of an eroded peneplain, which is found actually to be continuous with the Pan Belt to the south, for example, north and west of Koster; only its slope is now gently *northwards*. These and other facts indicate that the present watershed marks very closely the hinge-line of the sunken area to the north, and that there has been a complete reversal along the " hinge " of the original drainage, which now flows into the Crocodile instead of reaching the Molopo.

Through the loss of its catchment (over which the rainfall doubtless exceeded 25 inches per annum) the Molopo has been deprived of the bulk of its flow, seeing that beyond Mafeking its channel passes into flatter and more sandy country of lesser rainfall and run-off. This would indeed serve to explain why the Molopo is to-day an insignificant river, why it normally does not flow much beyond the Setlagoli River, and why it is incompetent to fill its channel below Kuis. A similar history seems to have befallen the Schoon Spruit, near Ventersdorp, and the Mooi River near Potchefstroom, which must both have formerly possessed more northerly sources. Prof. Wellington has drawn attention to various " windgaps " between Pretoria and Zeerust, which doubtless represent abandoned " poorts " cut by north-south rivers that formerly crossed this divide and discharged southwards.

The rim of this great sink is traceable from Zeerust, through Koster, Hekpoort, Pretoria, Premier Mine, Dullstroom and round the inner curve of the Drakensbergen to the Chuniesberg and Nylstroom, following thereafter the high ground to Derdepoort and Ramoutsa. In the easterly half the axis of the hollow trends almost north-east; in the westerly one almost east-west. The area involved is some 17,000 square miles in extent.

The drainage pattern displays quite a number of peculiar features. Conspicuous is the north-easterly course of the Elands-Oliphants River down to Malips Drift, and also of its tributary, the Lower Steelpoort River, which for miles cuts obliquely across the " grain " of the country. A complex history is intimated by the various " poorts " by which the encircling ranges are pierced on the north-east, and even on the south in the case of the Magaliesberg and Daspoort chains. These are occupied by " *antecedent* " rivers, which have successfully managed to maintain such channels despite the hardness of these barrier rocks. Concurrent sinking of the less durable interior of the basin must have aided materially in the sawing-down process. On the south the Olifants and Crocodile, and to a less extent the Marico, have eaten back into the hinge-line defining the highveld, and thereby tapped out part of the subterranean supply from the Dolomite and directed it into the Bushveld basin—" underground piracy " it can be called—e.g., at the Pretoria and Steenkopjes Fountains, and in minor springs farther to the west. The detailed description given by Wellington[9] of the phenomena of the secondary divides within the longitudinal valleys along the southern margin would appear to support the hypothesis proposed.

On the east the Olifants River has sawn a spectacular chasm through the quartzites of the Drakensbergen. On the north-east four

[9] J. H. Wellington: *S.A. Geogr. Journ.*, XII, pp. 39-40, 1929.

rivers within a short distance pierce from north to south the palisade made by the Strydpoort Range, namely, the Malips, M'Phatleles, Chunies and Zebediela rivers, tributaries of the Olifants with an unusual history. The north-easterly trending reaches of the Upper Nyl are formed by miles of wide swamps having a slight gradient, while the watershed to the south is extremely indefinite, which suggests that the downwarping along the northern hinge-line dismembered that river east of Warmbaths and enabled the Elands or else the Pienaars River to capture its headwaters.

A very recent subsidence is suggested finally by the extensive chain of alluvial or soil-covered flats linking the Elands with the Pienaars and Crocodile rivers, following what is considered to be the axis of the basin. Such can be ascribed to aggradation within the gentle axial depression so developed.

Excluding a moderate number of elevations the floor of the basin generally lies at well under 4,000 feet, much of it at between 3,500 and 3,750 feet, dropping to about 2,000 feet in the extreme east. On the south the highveld plateau rises to over 5,000 feet, and in places well exceeds that in altitude. On the east the encircling mountain-ring ascends much higher, but on the north the Nyl Valley presents a wide gap separating the former from the much-reduced chains that stretch from Nylstroom to Derdepoort. Just how much of this great difference in level—from 1,000 up to 3,000 feet—is due to actual sinking of the crust and how much to scouring out of the basin by the rejuvenated Olifants and Crocodile systems, is as yet uncertain. In the Zwartruggens area the amount of such scour as performed by the Upper Elands River does not exceed 700 feet, which supports the view arrived at from other evidence that the proportion due to sinking must have constituted a goodly fraction of the whole.

This joint lowering of the floor must have raised the mean temperature by From 5° to perhaps 10°F., and correspondingly reduced the rainfall. To-day the mean precipitation is round about 25 inches per annum, falling off to 20 inches at both eastern and western ends, the low values being in part due to the fact that the depression is hemmed in by blocks of mountain land. Earlier in this paper reference was made to the evolution of "inselberg" topography under tropical steppe conditions. Significantly many such erosion relics are to be found in the Bushveld. The largest is the Pilandsberg, rising abruptly a thousand feet and more from a peneplain that has been cut evenly across several distinct rock formations. Lesser, though still prominent knobs are numerous between it and Pretoria, while larger masses are conspicuous in the east in Secocoeniland.

Striking, too, is the presence in a number of cases of a fringe of red wind-borne sand about the bases of such elevations, a feature that in general becomes more marked as one proceeds westwards. Secondary limestone crusts characterise certain of the flat country—for example, to the south-east of Zebediela. Putting these and other observations together, it is hard to escape from the conclusion that (1) the Bushveld basin participated in the same cycle of steppe or semi-arid conditions during the past as the Kalahari, (2) its topography became appreciably modified thereunder, and (3) the subsequent return to a more humid climate removed most of the sandy covering, smoothed down the outlines of its elevations, and so obscured, though it did not entirely obliterate, its previous rigorous history.

(*d*) *The Kalahari-Rhodesia Axis.* — For some distance above Messina the Limpopo flows down a gentle depression trending somewhat north of east towards the Sabi River, but details of this subsided zone are as yet unknown. To the north the ground rises steadily up to the main watershed of Southern Rhodesia, which Maufe[10] has so well described as running in most regular fashion from Marandellas in the north-east to Plumtree in the south-west. Within that distance its crest-line falls by over 500 feet—from over 5,000 to 4,500 feet above sea-level, after which there is a further rapid drop of more than 1,000 feet around Francistown. Beyond that gap I have found what appears to be its continuation through the higher ground behind Serowe in the Bechuanaland Protectorate striking south-southwest to Molepolole and thence to Kooi with an altitude of usually over 4,000 feet.

From this lengthy and slightly asymmetrical arch the rivers have been thrown off at right angles in opposite directions, and are hence "consequent streams." The south-eastern slope is the steeper, but having a gradient of apparently not more than about 30 feet per mile as a rule, though this surface has suffered much from erosion by the tributaries of the Limpopo. The north-western surface is on the contrary remarkably even throughout, and falls steadily away at the rate of between seven and nine feet per mile to the Zambesi and the Kalahari. All of it that falls within Bechuanaland, and much of its continuation in Rhodesia, still possesses the thick mantle of Kalahari sand spread by the wind during a period of semi-aridity over the enormous plain a little prior to the warping of the latter. With the return to humid conditions the newly-established rivers were able, thanks to the tilt given them, to cut deeply into or even right through the sandy covering, as, for example, in the case of the grid-iron drainage of the Gwaai River to the north of Bulawayo. The degree of such dissection becomes progressively greater towards the north-east, where altitude and rainfall are appreciably higher.

There can be little doubt that formerly the Okavango River flowed with very flat gradient right across the Kalahari *via* the present Botletle River to join with the Limpopo. The arching up of the crust athwart this important waterway was ultimately sufficient to break the flow of the river and pond it back over the great flats of the Makarikari, wherein to-day the waters of its lineal descendant, the Botletle, and of its tributary, the Nata, are evaporated.

From the presence of large stone implements of very primitive type in certain of the gravel terraces of the Gwaai system, it follows that the upheaval took place just before the advent of man, and hence somewhere about the close of the Pliocene epoch.

(*e*) *The Ngami-Okavango-Linyanti Depression.* — Elsewhere[11] I have referred to the sinking of a tract about 350 miles from north-east to south-west with a maximum width of 100 miles across the parallel-flowing Okavango, Linyanti (Chobe) and Zambezi rivers, which event radically changed the hydrography of that region. The subject has also been discussed very fully by the late Prof. E. H. L. Schwarz.[12] The huge lake thereby created—the so-called "Greater

[10] H. B. Maufe: *Some Problems in Rhodesian Physical Geology, S.A. Journ. Sci.,* XXIV, pp. 30-6, 1927.

[11] A. L. du Toit: *Report of the Kalahari Reconnaissance of 1925*, p. 32; *The Kalahari and Some of its Problems, S.A. Journ. Sci.,* XXIV, p. 88, 1927.

Ngami "—proceeded to act as a trap for the fine sand brought down by these three perennial rivers, and has, with the lapse of time, become filled up to an altitude of approximately 3,100 feet above the sea, or between 100 and 200 feet below the level of the adjoining undepressed Kalahari plain.

Dropping from the north into the hollow by the Katima Molilo rapids, the Zambezi has developed a winding channel across the wide flood plain to escape through the higher ground on the south at Katombora. Due to its smaller volume the Linyanti has become entangled in vast marshes wherein it loses the bulk of its flow and finally joins the Zambezi. The Okavango has built out to the farther side of the depression a gigantic delta full of channels and swamps and thickly wooded; the relatively small fraction that struggles through is discharged in part north-eastwards into the Mababe depression and in part south-westwards into the Botletle with a smaller quantity into Lake Ngami. Of the huge volume entering from Angola only an insignificant proportion ever reaches the Makarikari, and that only in certain years, during mid-winter. Before this warping occurred the Okavango must have been a stately river flowing south-eastwards through the arid Kalahari, and not improbably constituted the main stream of the Limpopo of that period. The peculiar swamp-bearing trough linking the Okavango to the Zambezi is in a sense " exotic," in that it could in imagination be removed geographically without in the slightest way altering the essentially semi-arid nature of its Kalahari setting.

(*f*) *The Mid-Zambezi Trough.*—Between the Kariba Gorge, north-east from Wankie, and the Quebra Baço Rapids above Tete, this river flows in a gigantic trough with its floor—composed mainly of Karroo Beds—sunk a couple of thousands of feet beneath the plateau block on either side, but details regarding this lengthy depression are rather scanty. It embraces some extensive alluvial and gravel-coated stretches.

(*g*) *The Urema Sunklands.*—In Moçambique Territory back from Beira we find this remarkable trough, so called by Teale,[13] which differs from the rest in being situated so close to the ocean and in having its floor standing at under 200 feet above sea-level. It is from 30 to 40 miles wide, connecting the Zambezi flats with those of the Pungwe, and continuing thereafter in a south-westerly direction for some distance up the Buzi River. On the inland side it is bounded by rapidly-rising crystalline rocks; on the eastward side by scarps that define the Sheringoma and Sofala plateaux, which are composed chiefly of Tertiary marine limestones, the sudden drop to the plain being due primarily to a sharp fold. The floor is a continuous plain of black clay, of which wide areas are flooded annually.

This arrangement is most instructive, first because it would appear to be a typical tectonic trough of relatively late age—certainly post-Eocene—and secondly because it becomes connected in the northerly direction with the " Rift Valleys " of Nyasaland and Tanganyika.

(*h*) *The Komas Axis.*—Trending north-east south-west, this constitutes the backbone of South-West Africa and forms the highest ground on the western side of the continent, rising to over 7,000 feet in altitude in a number of points; alternatively, it is known as the

"Windhoek Highlands." At the base of this mountainous mass on north-east, east and south-east commences the Kalahari sand-plain, with a total fall of over 1,000 feet or at the rate of nearly four feet per mile to the Botletle, and of between eight and nine feet per mile to the Molopo. The Nossob and its feeders, the Auob and Elephant, and also the Fish, are obviously "consequent rivers"; incidentally, they only function for a short period during the year.

(*i*) *The Ovampoland or Etosha Depression.*—To the north lies the Otavi "Swell," as Krenkel calls it, beyond which the country falls steadily for over 1,000 feet to the sandy and bush-clad plain in which is set the great Etosha Pan, an immense saline flat 80 miles in length from east to west.

The latter is connected with the perennial Cunene River by some remarkable shallow channels or "spillways" which to-day function only rarely, though up to recently they seem to have brought down seasonally much water to the pan, there to be evaporated. The Etosha forms an extremely close duplicate of the Makarikari, and seems furthermore to have experienced a somewhat similar history.

Dr. W. Beetz has pointed out to me in conversation that the lower section of the Cunene is of geologically recent age, and that in the past that river must have fed the Etosha Pan, which in turn suggests that at some prior date the river continued still farther to the south or east.

(*j*) *The Great Kalahari.*—We are now in a better position to discuss this enormous region, which extends from the Orange River at Upington right up to the Zambezi-Congo divide and from the Upper Kafue River in Northern Rhodesia westwards to the Cunene in Angola. By quite a number of geographers it is usually referred to as a "basin," but in the light of the aforegoing description such a designation is not quite correct. It has been moulded, it is true, by warping out of a marvellously extended plain, but the deformation has not led to a common central dip. Comparison can more properly be made with a warped gramophone record unaffected at its centre but crinkled along its margins. These crinkles are, however, not radially disposed, but oriented roughly in a north-east south-west direction. The margin of the Kalahari attains its maximum elevation, of round about 4,000 feet or over on the north, to west of Wankie, to north of Plumtree, near Serowe, near Molepolole, and in the Gobabis and Grootfontein districts. Its minimum of 3,000 feet, and under is reached at the Victoria Falls, Makarikari, Upington, Etosha Pan and Rua Cana Falls on the Cunene.

On nearly all sides subsequent and intense erosion has eaten back irregularly and deeply into this warped, sand-covered region, causing the larger part of its ragged periphery to terminate to-day in a prominent escarpment that stands 100, 200, 300 or more feet in height above the outside territory. Devoid of permanent water supplies, save those derived from the Congo divide, the Kalahari constitutes the "dead heart" of South Africa and sets a barrier to communication between east and west. So much has already been written or said about the Kalahari, its landscape, vegetation, climate and animal life, that further remarks regarding those aspects would be indeed superfluous. It is merely desired to make clear the rôle played by this huge interior "desert" in respect to the surrounding regions during the physiographical evolution of South Africa.

5. *Interpretation of the Warpings.*—From the preceding account it will be apparent that within an area of one and a half million square miles there is found widespread evidence of warpings of quite considerable magnitude, since they have involved vertical movements in the crust of from one to several thousands of feet. Clearly revealed in both the coastal zone and hinterland, they can in places be made out in the Transition Belt in the Southern Cape, as is inferable from the varying altitudes of the so-called "high-level gravels" within that region, for instance in the districts of Oudtshoorn, Willowmore and Prince Albert.

In all the cases described above the axes of uplift and the longer diameters of the areas of depression, including auxiliary warpings, lie directed between north-east and east-north-east, which indicates that *they owe their origin to one and the same controlling set of tectonic forces.* Save for their milder development, they agree in their nature with the similarly-oriented, relatively-recent warpings and fracture-zones that traverse Northern Rhodesia, Moçambique, Nyasaland and the region farther to the north, known collectively as the "*Central African Rift System.*" A correlation with the latter is unescapable, and such would accordingly extend that already lengthy arc of crustal movement—which commences in 37° of N. Lat.—almost to the 33rd parallel of S. Lat.—a total distance of just 5,000 miles!

Rifting in the African-Arabian mass attained its maximum intensity in the tropics, where, through a lengthy period extending from the beginning of the Tertiary at least right down to the present day, differential crustal movement has occurred on a gigantic scale. In the southerly direction the intensity is known to have fallen off rapidly, which would serve to explain the much feebler development of the displacements in South Africa, and that by means of gentle flexing of the crust rather than by actual dislocation. Although the forces concerned have incidentally deprived South Africa of widespread irrigable lands and navigable rivers—save in the case of the Lower Zambezi—they have at least, by upheaving the land, conferred the inestimable benefit of a cooler climate upon the interior, and thereby contributed largely to the subsequent human occupation and economic development of this country. For appreciation thereof one only needs to make comparison with the conditions prevailing over the interior and north of Australia, where the mean elevation is far less although the latitudes correspond closely.

That all movement has not ceased in the south is nevertheless signalled by the fact that the centres of the occasional earthquake shocks experienced by the Union are all but confined to the Bushveld and Basutoland basins, these being most significantly situated on or close to the margins of the latter, where any further bending would on *a priori* grounds tend to occur. Thus, the southern of the two basins is outlined by the three well-known centres of Koffyfontein on the west, Kokstad on the east, and Vryheid on the north-east; the northern by Rustenburg on the west, Rooiberg on the north, and Pietersburg on the north-east. These quakes and the powerful shock experienced on the last day of 1932, which seemingly originated in North-eastern Zululand, furnish tangible proof that the vast subterranean forces of the globe are not exhausted beneath our continent, and that slight adjustments of the crust are seemingly in progress over its interior.

The volcanic activity, so characteristic of the Rift System, is admittedly absent from the south, though within the heart of the Bushveld is the remarkable Pretoria Salt Pan, an extinct crater, which the late Dr. P. A. Wagner considered as being possibly of fairly late Tertiary age. Noteworthy, too, are the hot springs, of which two dozen can be cited, that are restricted to the more mobile zones of the several regions in question, a geographical relationship which can scarcely be accidental.

6. *The Movements in Relation to Man.*—It is necessary to dispel the impression that may perhaps have been conveyed that all the movements in question had terminated before the appearance of mankind. While it is true that as yet nothing has been found to show that man was contemporaneous with the prolonged general upheaval and warping of South Africa, he was certainly in existence during the later stages thereof, that is to say in the Pleistocene. The time-equivalent of the latter is placed by the best authorities at a little over one million years ago, and it is usually admitted that in the Northern Hemisphere beings of human type were in existence at the very beginning of that epoch, if not a bit earlier. Our own archæological researches are, on the other hand, still very imperfect, and the few outstanding observations not simple to fit together, though not at all inconsistent with the results of investigation elsewhere.

While a few crude implements have been found in the 15 to 20ft. raised-beach of the south, it could well be objected that their presence does not by itself prove uplift of the land, since it may have been the sea that had fallen in level. Of far more importance are the extensive talus and gravel deposits in the Western Province fringing the base of the mountains between Somerset West and Wellington, which are in certain spots literally crowded with large palæoliths of Chellean and Acheulian types. Goodwin's observations[14] go to show that there must have been subsequent valley-erosion to the depth of 100 feet and possibly as much as 250 feet in places.

It is very significant that these terrestial and fluviatile deposits should be developed essentially along the slopes of the ranges and within fairly narrow vertical limits. Now, as mentioned in Section 2, during the cutting of the Cape-Malmesbury-Piquetberg peneplain, the waves probably lapped the foot of the mountains in question. The abundance of implements along that approximate former contour would seem to suggest either that man inhabited a narrow strip lying between the mountains and the ocean of the time, or else that he proceeded to occupy the wave-cut plain as the sea retreated. For certain reasons the latter hypothesis would appear the more likely one.

From the interior there is a good deal of valuable data. Maufe considers that the major uplift of the Rhodesian axis took place somewhere about the close of the Tertiary (Pliocene), and in this view I believe that he is justified. Over a great area the rivers have since cut down through the Kalahari sand to depths that must reach fully 350 feet in places. Along the Umgusa and its tributaries to the north of Bulawayo the following sequence has been worked out[15]:—

[14] A. J. H. Goodwin: *Ann. S.A. Museum*, XXVII, pp. 20-1, 1929.

| | | |
|---|---|---|
| Present period of erosion | Semi-arid | Recent. |
| Upper rusty alluvium | Humid | ? |
| Second period of erosion | Semi-arid | |
| Lower grey alluvium | Humid | |
| First period of erosion | Semi-arid | Early Palæolithic. |
| Kalahari Sand | Desert | Tertiary. |

It can be suggested, however, that the alternation in erosion and deposition, which has been interpreted as due essentially to variation in rainfall, might in part at least have resulted from intermittent uplift of the Rhodesian axis with consequent changes in the river gradients.

The finding of primitive implements in the old agate-bearing gravels on the Zambezi at the Victoria Falls, which were laid down before the lip of the cataract had, under headward erosion, retreated to its present position, points to the immensity of time since Palæolithic man first dwelt in that neighbourhood.

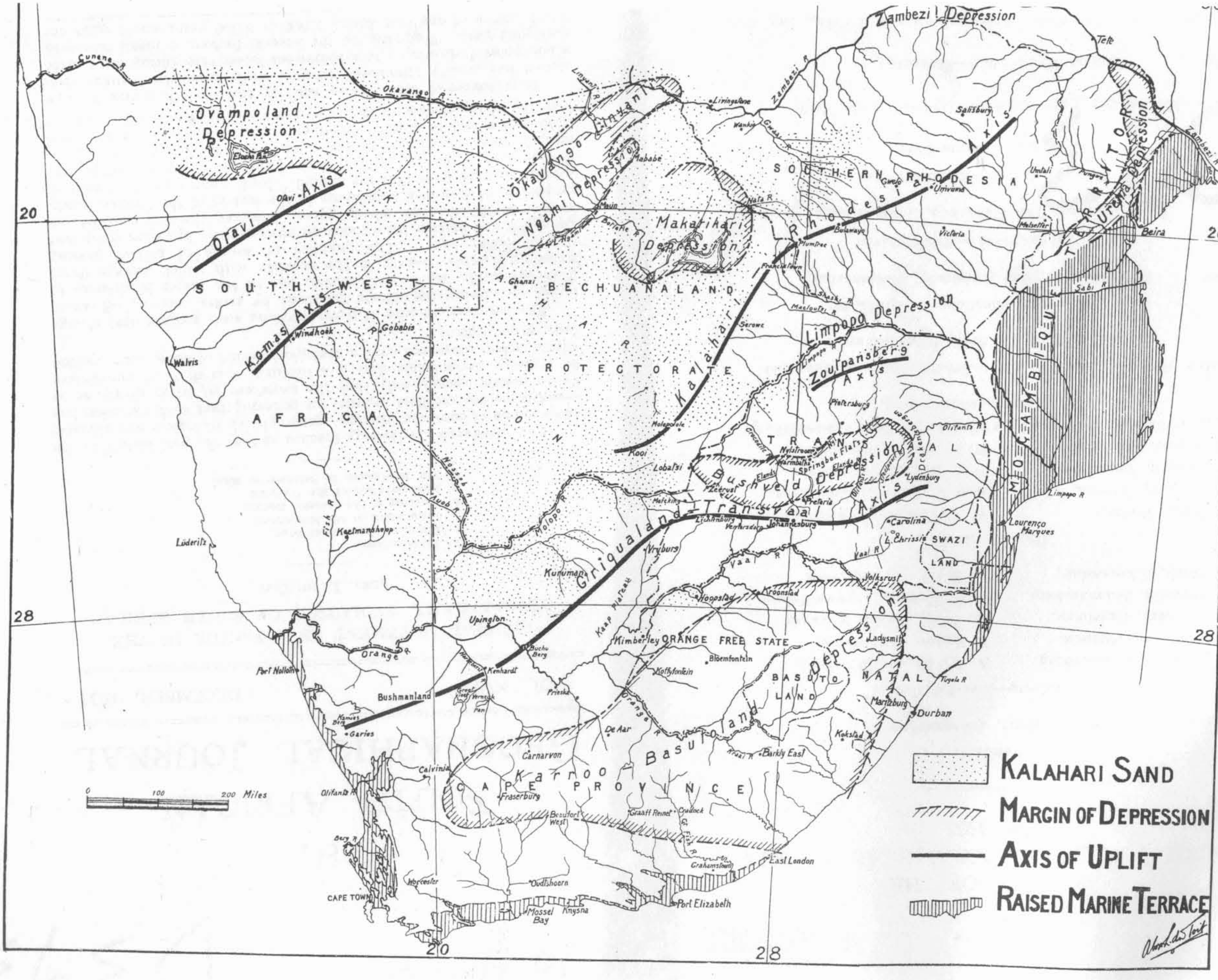
The myriads of excavations made by the diamond diggers in the deep gravels of the Lichtenburg and Ventersdorp districts have not produced any undoubted implements, at least not from strata lying beneath the immediate surface layers. Implements have, however, been found in other, though decidedly younger, gravels in those areas.

An instructive story is furnished by the alluvial terraces of the Vaal and its tributaries, the very highest of which, rising some 300 to 400 feet above the rivers, have not yet yielded artifacts, though the middle terraces, standing at from 15 to 60 feet, have proved to be richly implementiferous in certain spots, e.g., Bloemhof, Pniel and Barkly West. Since their formation the rejuvenated rivers have cut their channels by those amounts into solid diabase. These deposits also furnish evidence of climatic variations, of which at least one arid and two humid periods can be taken as established. These variations can indeed be viewed as feebler continuations of those more extreme climatic oscillations under which the great central, sand-covered plain of South Africa became evolved.

All this is in harmony with research in East Africa and in Europe, as so ably set forth at the Durban meeting of the South African Association for the Advancement of Science by General J. C. Smuts.[16] A hint can be thrown out that a study of the gravels of the Crocodile, Pienaars and Elands rivers, where they cross the central, soil-covered belt of the Bushveld (Section 4, c), might, perhaps, through the medium of contained implements, enable a more precise dating to be achieved of what would appear to be the youngest crustal movements in the interior of the Union.

The interesting problem of changes since the Palæolithic, despite its immense importance because of the alleged "drying up" of South Africa, opens up too wide a field for discussion in this paper. It is nevertheless hoped that the aforegoing brief account of a distinctly complicated subject will have served a useful purpose, if it has made out a *prima facie* case for a partial correlation of climatic as well as geographical changes with movements of the earth's crust in Southern Africa. Upon the evidence submitted it is ventured that among the principal causes of such climatic fluctuations in South Africa can be reckoned the intermittent elevation of the continent coupled with the intervening periods of relative stability, during which the land surface became de-levelled by erosion and consequently proceeded to revert.

In most other countries it is possible to obtain abundant and weighty corroboration of a botanical character from the plant remains contained in the Pleistocene and older formations. Unfortunately, in this land such sub-recent fossils are all but absent, and we are therefore compelled to rely almost exclusively upon geographical and geological criteria in our reconstruction of the climates of the immediate past.


Ovampoland Depression
Otavi Axis
Komas Axis
SOUTH WEST AFRICA
KALAHARI REGION
Okavango-Linyanti
Ngami Depression
Makarikari Depression
BECHUANALAND PROTECTORATE
Kalahari
Rhodesia Axis
SOUTHERN RHODESIA
Zambezi Depression
Limpopo Depression
Zoutpansberg Axis
TRANSVAAL
Bushveld Depression
Griqualand-Transvaal Axis
ORANGE FREE STATE
BASUTO LAND
Basutoland Depression
NATAL
SWAZI LAND
MOÇAMBIQUE TERRITORY
Urema Depression
CAPE PROVINCE
Karroo
Bushmanland
Windhoek
Walvis
Lüderitz
Upington
Kimberley
Bloemfontein
Johannesburg
Pretoria
Durban
East London
Port Elizabeth
CAPE TOWN
Mossel Bay
Beira
Lourenço Marques
Salisbury
Bulawayo
Livingstone
0 100 200 Miles
KALAHARI SAND
MARGIN OF DEPRESSION
AXIS OF UPLIFT
RAISED MARINE TERRACE