20. *The GEOLOGY of the DISTRICTS of WORCESTER, ROBERTSON, and ASHTON (CAPE COLONY).* By R. H. RASTALL, M.A., F.G.S., Fellow and Lecturer of Christ's College, Cambridge. (Read February 22nd, 1911.)

[PLATE LI—GEOLOGICAL MAP.]

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I. INTRODUCTION AND BIBLIOGRAPHY.

DURING the Long Vacation of 1910 I was enabled to pay a visit to South Africa, partly for the purpose of making collections for the Sedgwick Museum at Cambridge, and partly for original research in South African geology. Acting chiefly on the advice of Dr. A. W. Rogers, the head of the Geological Survey of Cape Colony, I undertook the investigation of the neighbourhood of the towns of Worcester, Robertson, and Ashton, in the Western Province of Cape Colony. Owing to special conditions, the geology of this district comprises some features of exceptional interest, and the elucidation of the problems there presented would cast valuable light on several obscure features of the geological history of the country as a whole. The most important of these problems refers to the origin and age of the Worcester-Swellendam Fault, one of the greatest dislocations of its kind with which we are acquainted. This forms the principal subject of the following paper; but several other questions are dealt with in considerable detail, especially the lithological character and structure of the Malmesbury Series, the oldest rocks of this part of the Colony—a subject on which hitherto little work has been done. Incidental reference is made to other points bearing on the principal objects of the investigation.

The district is comprised in Sheets 1, 2, and 4 of the geological map, on the scale of about $3\frac{3}{4}$ miles to the inch, issued by the Geological Commission of the Cape of Good Hope, and many

references to the geology are scattered through the Annual Reports of the same Commission. The most important publications on the geology of this region are enumerated below.

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II. GENERAL GEOLOGICAL STRUCTURE.

Within the area here dealt with a considerable variety of geological formations is found, ranging from the pre-Cambrian to the Cretaceous, but with notable and important gaps in the succession. There is, in addition, a considerable development of gravels, loams, and alluvium of recent origin. The most important formation, and the one which covers the greatest area in the district, is the Cape System; while in certain parts the strata of the Karroo System also occur to a considerable extent.

The formations now actually seen in the district may conveniently be tabulated as follows:—

Recent gravels and loams.	

Enon Conglomerate, etc.	Lower Cretaceous.

Ecca Shale.	{ Permo-Carboniferous.
Dwyka Series.	
Witteberg Series.	Devonian and Carboniferous.
Bokkeveld Series.	Lower Devonian.
Table Mountain Series.	Lower Devonian or Silurian.

Malmesbury Series.	Pre-Cambrian.

In the southern part of Cape Colony, the Witteberg Series seems to pass conformably into the Karroo System, though towards the north a marked overlap occurs, so that the Karroo rocks rest unconformably on all the older systems. There is thus evidence of a differential movement, which does not seem to have noticeably affected the rocks of the south-west.

The Dwyka and Ecca rocks of the Worcester district resemble in all essential details those of the Karroo area in the north, and were undoubtedly formed in direct continuity with them; and their present isolated position is a result of post-Karroo disturbance.

Since the composition and characters of the Enon Conglomerate constitute one of the most important subjects treated of in the present paper, the consideration thereof must be deferred.

All the rocks up to and including the Karroo System have in this area undergone important disturbances and dislocations, and even the Enon Conglomerate shows unmistakable evidence of earth-movement of considerable intensity; so it is evident that in recent times the region has been subjected to great disturbance, and the prevalence of hot springs, as at Montagu and Brand Vley, suggests that activity is even now by no means extinct.

III. PHYSIOGRAPHY OF THE AREA.

The region under investigation is one of very varied topography, presenting many features of interest from the standpoint of the physical geographer, and it illustrates with especial clearness the relation between scenery and geological structure. There is perhaps no part of the world where the scenery is so closely dependent upon the character and arrangement of the underlying rocks as in the western portion of Cape Colony; and here there has been a complete absence of complicating factors, such as glaciation or recent submergence and re-elevation, which have played so important a part in modifying the topography of many northern regions. Hence the effects of a powerful and long-continued process of denudation can be effectively studied.

The area as before defined lies wholly or almost wholly within the drainage-basin of the Breede River, one of the largest streams of Cape Colony. It is bounded on the north by the Hex-River Mountains and the Langebergen, which form one continuous range trending roughly from west-north-west to east-south-east, and only broken through at intervals by some of the larger tributaries of the Breede, such as the Hex River and the Kogmans River, both of which rise to the north of the principal range. These mountains attain an average height of some 5000 feet, the culminating peak, Matroosberg, having an altitude of about 7400 feet. The southern slope of the range is exceedingly steep, and this has a most important bearing on some geological features of comparatively recent origin. In front of this great escarpment comes a narrow strip of foot-hills, varying in width from 1 to 5 miles

and usually ranging from 1000 to 2000 feet in altitude, reaching 3000 feet only in the neighbourhood of Robertson, where a large intrusion of granite forms a conspicuous peak of 3100 feet. Below and in front of these foot-hills stretches the broad valley of the Breede River, which is in parts diversified by hills of considerable height, but sometimes forms a plain as much as 10 miles wide: this is bounded on the south and west by the Zonder Einde Mountains and other ranges. In the north-western part of the district, north of the Hex River, the trend of the principal northern chain undergoes a change, curving round to the north and becoming parallel to the other mountain-chains of the coastal region of Western Cape Colony; whereas the Langebergen beyond Swellendam assume an east-and-west trend, parallel to the other ranges of the south coast. As will be shown later, this change of direction is intimately connected with geological structure, and is of the utmost importance in the study of the tectonics of the district.

The scenery is characteristic and in parts very beautiful, especially in the mountain-ranges, where some of the passes, such as the Hex-River Poort and Kogmans Kloof, show scenes of great magnificence. The contrast is very striking between the rugged and exceedingly steep mountains of Table Mountain Sandstone and the wide alluvial plain of the Breede River at Worcester, which has been carved out of the softer beds of the Bokkeveld, Karroo, and Enon formations. The scenery of the district can be well seen from the railway, since the main line from Cape Town to Kimberley and Johannesburg runs through the Hex-River Pass after leaving Worcester, and the line of the New Cape Central Railway runs along the foot of the Langebergen from Worcester through Robertson and Ashton, towards Swellendam and the south coast. The region is, therefore, easily accessible.

IV. THE WORCESTER DISTRICT.

The town of Worcester lies on the northern edge of the great alluvial flat of the Breede Valley, some 5 miles south-west of the mouth of the Hex-River Pass, which is now the principal line of railway-communication between Cape Town and the Orange Free State and the Transvaal. It forms, therefore, a convenient centre and starting-point for the investigation of the district. The outcrop of the Malmesbury Series is here unusually wide, extending over a total distance of some 6 miles; consequently this is a specially favourable locality for studying the general character of the Series. The Malmesbury rocks here vary considerably in lithological character, but the general conformation of the ground is very uniform throughout. They form an expanse of comparatively low, rounded, rolling hills, varying in height from about 1000 to 1500 feet, diversified occasionally by small crags—or kranzes, in the local idiom. Along the river-courses there is usually a good deal of recent alluvium, and in some parts exposures are rather deficient. The junction between the Malmesbury Series and the

overlying Table Mountain Sandstone is well seen in the deep kloof at the head of the Hartebeest River, sometimes called the Fairy Glen, in which the new waterworks for the town of Worcester are now being constructed.

The general strike of the Malmesbury Series is fairly uniform, being on the average about west 10° north and east 10° south. In a few localities, and especially just to the north of Worcester, there are small areas of local disturbance, due to special causes, such as igneous intrusions and dislocations; but these are not of much importance. Only one extensive rock-mass, in Brewels Kloof, appears to be of igneous origin: this will be separately dealt with hereafter. Immediately north of Worcester are some small patches which appear to be highly metamorphosed granitic dykes: all the rest of the area is occupied by rocks of undoubtedly sedimentary origin, which have undergone a considerable amount of dynamic metamorphism.

The field-relations and general characters of the Malmesbury Series can be best illustrated by a somewhat detailed account of a section running north and south, from the town of Worcester to the base of the Cape System in the Fairy Glen, a distance of about 7 miles. The relations here disclosed are illustrated in fig. 1.

As before stated, the town itself stands on the alluvium of the Breede River, which here forms a flat plain some 4 miles wide. However, immediately north of the town the ground begins to rise, and in the goods-yard at the railway-station there is a very fine exposure showing Enon Conglomerate resting upon Ecce Sandstone that yields plant-remains. The conglomerate is again well exposed at the dam of the small reservoir about a mile north-west of the church; and, owing to recent

excavations, very good unweathered specimens can here be obtained. This conglomerate forms a low rounded hill, to the north of which is a level expanse of loam and brick-earth, about half a mile wide. In this loam are a good many gullies (sluits) formed by streams during heavy rains, and, at the bottom of some of these, exposures of Ecca Sandstone can be seen. At the foot of the next slope is an outcrop of a peculiar shattered quartzose rock, which is believed to indicate the position of the great fault.

Immediately to the north of this are several small quarries in which a variety of rock-types are to be seen, including a band of white crystalline marble associated with highly-crushed granitic dykes. This marble probably represents a band of limestone, which has been metamorphosed by the granitic intrusions, as well as crushed by earth-movements, and it is associated with some greasy-looking schistose rocks of remarkable character. For some distance north of this there are numerous bands of a hard rock, which is called by Dr. Rogers 'phyllite-gneiss.' As we shall see presently, these are undoubtedly igneous intrusions that have undergone foliation by earth-movement.

For some 3 miles northwards the ground is occupied by a monotonous series of silvery, greenish or grey, fine-grained, schistose rocks, which may be called slate, phyllite, or schist; here and there only are to be seen thin bands of grit or quartzite, which seem to be usually quite impersistent, and of little importance. A somewhat thicker band of grey quartzite occurs near a sheepfold, on a kopje about 3 miles north of the railway-station. The phyllite or slate weathers into soft, brownish-grey, sandy flags, which cover a great stretch of country: exposures are frequent, but of little interest.

Following the cart-track from this point over the low watershed to the first tributary of the Hartebeest River, we note that exposures become scarce, and a great spread of gravel and sand is encountered, which continues for some distance. The deficiencies of this part of the section must be filled in from parallel traverses, made both to the east and to the west of this line.

When next exposed, higher up the Hartebeest River, the Malmesbury rocks are represented by massive green and purple grits of a kind not before seen: the unusual colours are probably due to the fact that the specimens here obtained are unweathered, coming from the excavations for the pipe-line of the waterworks. They appear to be similar in all essential characters to the grey and brownish grits of the Hex-River Pass, on the east. These grits can be seen to disappear under the Table Mountain Sandstone; the latter has a fairly steep dip to the north, and here forms an escarpment some 4000 feet high, cut up into prominent peaks and ridges. Where last seen, the Malmesbury Grits also exhibit a strong dip to the north, at a much steeper angle than the Table Mountain Sandstone.

Throughout the whole of the distance from the Worcester Fault

almost to the foot of the mountains, a distance of about 6 miles, the dip of the Malmesbury Beds is uniformly to the south, and nearly always at a steep angle, often exceeding 50° . It is only at the extreme north of the exposure, as just mentioned, that the dip is northerly. It follows that, if there be no repetition by faulting or isoclinal folding, the total thickness must be enormous. Unfortunately, the data at our command are insufficient to decide this question. It must be stated however, that, so far as my own observations went, I could see no evidence of repetition; and the distinct difference of lithological character at the northern as compared with the southern extremity of the section is, on the whole, evidence bearing against this supposition.

Another specially favourable opportunity of examining a large part of the Malmesbury Series is afforded by the road, which passes along the right bank of the Hex River from De Wet Station in a northerly direction. Some 3 miles above the station the base of the Table Mountain Sandstone is reached, and in this distance exposures of the older rocks are frequent. The road from Worcester winds round the southern side of a low but steep hill, known as Meirings Berg; and the numerous cuttings here are excavated in a soft silvery slate, with highly developed cleavage and a generally sericitic appearance. This may perhaps be described, for convenience, as silvery phyllite. Passing northwards, a more gritty facies soon sets in; and, from a point a short distance south of De Wet Station to the base of the Table Mountain Sandstone, the whole may be classified as grit, with occasional quartzite-bands. The coarser types approximate very closely to the grits at the head of the Hartebeest River; and the direction of strike is quite in agreement with the view that these are continuous. On these grounds I have divided the Malmesbury Beds into two series, as shown in the accompanying map (Pl. LI)—a series mostly composed of grits, lying to the north, and presumably the older; and a broad belt of slates and phyllites on the south, which appear to be newer in stratigraphical sequence, and are cut off abruptly by the Worcester Fault, their actual thickness being hence quite unknown.

An interesting and important observation was made on the main road, on the other side of the Hex River. Near to the house marked on the Survey map as Maze Kraal, there was found a small exposure of a highly decomposed rock, full of small crystals of ottrelite. It seems highly probable, in fact almost certain, that this is the westerly continuation of the narrow band of ottrelite-schist at Waai Kloof, near Nuy, which lies some miles to the east, but exactly in the required direction, assuming the strike to remain uniform, as it actually appears to do. This rock was only seen at one point in the Hex-River Pass, but its assumed position is indicated on the map (Pl. LI).

V. THE PETROGRAPHY OF THE MALMESBURY ROCKS OF THE
WORCESTER DISTRICT.

As we have already seen, the Malmesbury rocks of the Worcester district can be divided on general grounds into two series, which differ somewhat markedly in lithological character. The lower division is best seen in the fine road-section along the right bank of the Hex River, north of De Wet Station, while the upper series is well displayed in the numerous kopjes which form the rolling ground extending for some miles due north of Worcester. The massive grits at the base of the whole are also now well exposed, in the excavations for the new waterworks at the head of the Hartebeest River. A short distance north of Worcester bands of limestone and masses of intrusive igneous rock occur in the upper series; while the igneous rocks of Brewels Kloof form an exceptional type, and need separate treatment.

(1) The Sedimentary Rocks.

(a) Lower division: the gritty series.—The rocks forming this series are on the whole very uniform in character, the chief variations being in the matter of colour, which is obviously of subsidiary importance. They may be collectively described as grey, green, or purple grits, usually massive and rather fine in texture [9463].¹ When weathered, they often take on a brownish colour; and here and there comparatively thin bands of white or very pale grey quartzite are met with, as for example near the farmhouse Zeekoe Gat. Passing southwards, these grits and quartzites gradually give place to a great thickness of flags and gritty slates, usually dark grey. These are very different from the silvery slates and phyllites of the upper division, which begin about half a mile south of De Wet Station.

A typical specimen of one of the grits from a short distance north of De Wet [9459], when examined microscopically, is seen to consist for the most part of angular and subangular grains of quartz, with abundant small flakes of a yellowish mica and occasional grains of tourmaline, zircon, epidote, etc., which are clearly of detrital origin. In some specimens, but not universally, grains of felspar occur in small quantity. The grains are somewhat sparsely distributed in the cementing material, which is relatively abundant. The cement is very fine in texture, so that its constituents are somewhat difficult to determine. It appears to be chiefly composed of quartz and mica in minute grains and flakes, but a good deal of some irresolvable argillaceous material also seems to be present.

It is noticeable that all the larger quartz-grains show a certain amount of corrosion at the edges, as if some kind of reaction had taken place between the quartz-grains and the constituents of the cement. This undoubtedly indicates incipient metamorphism, but whether this is thermal or dynamic in character, it is impossible to say with certainty.

¹ The numerals in brackets refer to slides in the Sedgwick Museum collection, Cambridge.

(b) Upper division: the slaty series.—The rocks of this series are notably finer in texture than those just described, and appear to have been deposited in deeper water; but they are on the whole of very similar character, and the transition from the gritty to the shaly type is gradual. The lower part of this series is well seen along the Hex-River road, on the farm Meirings Berg, and also in the neighbourhood of Brewels Kloof; while the upper part is excellently exposed on the low hills immediately north of the town of Worcester.

In this division, the dominant lithological type is a fine-textured silvery-grey or olive-green rock, which has been variously described as slate, schist, and phyllite. Cleavage and schistosity are conspicuous, while strain-slip cleavage, both microscopic and on a large scale, is very common. When weathered, these rocks take on a greenish-yellow or brownish tinge, and shatter very readily under the influence of weathering agents.

A microscopic examination of specimens of these rocks reveals a structure and mineralogical composition very like that previously described in the more gritty division, but of course on a smaller scale. In most of the specimens from this division felspar is fairly abundant in small rounded grains, and it is sometimes discernible also in the fine cement. The principal coloured mineral is olive-brown biotite, which is sometimes converted into chlorite. In these specimens also the quartz-grains show incipient metamorphism, indicated by reaction with the ground-mass. Certain beds have some resemblance to volcanic ashes, owing to the presence of broken crystals of felspar and much micaceous material.

In a deep sluit to the west of the flag-quarry, and north-west of the marble-quarry, there is a small exposure of conglomerate in the Malmesbury Series. This rock is highly schistose in character, with augen-*struktur*, and consists of scattered pebbles embedded in a well-foliated silvery phyllite, which is a good deal weathered and stained by iron-oxide. The pebbles, which are not relatively abundant, vary from half an inch to 5 inches in diameter, but the larger ones are rare; they are for the most part oval in form, and evidently waterworn. They consist of vein-quartz and quartzite, and do not exhibit any special characteristics. They are chiefly of interest as showing the former existence of sedimentary rocks older than the Malmesbury Series.

(c) The calcareous rocks.—The limestone-bands found in the quarry north of Worcester show a great deal of variation, apparently due to different degrees of metamorphism, depending on their proximity or otherwise to the invading tongues of granite. The rocks are here much disturbed, and the relations of the different types of limestone are difficult to make out. In one part of the quarry there is a considerable mass of white crystalline marble, and on the other side are some remarkably contorted bands of a black limestone which does not seem to be much altered: this is only a few inches thick.

The marble is a white or greenish-white rock of fine texture, and very uniform in character. In a slice [9460] it is seen to consist entirely of carbonates, with no other recognizable minerals. A sample was subjected to qualitative chemical tests, and showed no trace of either magnesia or iron, and no matter insoluble in hydrochloric acid; it must, therefore, consist wholly of calcium carbonate, and is consequently a rock of remarkable purity.

A specimen of the black limestone from the other side of the quarry was also examined in the same way: it was found to be wholly soluble in hydrochloric acid. When the solution was neutralized with ammonia, a very small precipitate came down, which probably contains both iron and alumina. A trace only of magnesia was also found. The iron, alumina, and magnesia were all too small in amount for quantitative determination, and the rock is practically pure calcium carbonate: therefore the chemical composition is not inconsistent with the view that this limestone-band is the same bed as the white marble, but less metamorphosed.

(2) The Granitic Intrusions.

About a mile north of Worcester are to be seen over a considerable area frequent outcrops of a rock which has been commonly referred to as 'phyllite-gneiss.' This is a massive strongly-foliated rock of a grey colour, nearly always distinctly lenticular, and often showing sericitic mica on broken surfaces. It is quite apparent, both from a petrographical examination and from field-relations, that this 'phyllite-gneiss' represents masses of granite or granite-porphry which have been intruded into the sediments at some period prior to the final foliation. The intrusive character is not easy to determine with certainty, but I was lucky enough to find on the ground conclusive evidence on this point. Immediately west of the small hill at the foot of which the marble-quarry is situated are several deep sluits, which have removed the sand and loam down to the surface of the solid rock. In one of these sluits, which is about 6 feet wide and 4 feet deep, there can be seen a contact of the phyllite-gneiss and the slate. From this it is clear that the granite was intruded after the major joints of the sedimentary deposit had come into existence, since the transgression is controlled by these; but both sediment and intrusion alike were affected by the latest and most powerful pressure, which produced parallel foliation in both.

When examined with the microscope [9461-62], specimens of this rock show much less alteration than might be expected from its macroscopic appearance. It is distinctly porphyritic, with phenocrysts of quartz, orthoclase, and oligoclase in a fairly fine-textured ground-mass of granulitic type, consisting of quartz and feldspar. Some patches of a dark-green chloritic mineral probably represent original biotite. This rock is a granite-porphry or quartz-porphry, of fairly acid composition and alkaline affinities.

A series of specimens of this rock collected from different points

shows a regular gradation of characters, from an almost uncrushed quartz-porphry as above described to a highly schistose rock, consisting for the most part of finely granular quartz and felspar and sericitic mica, in which the original phenocrysts are represented by much-flattened augen of recrystallized quartz and felspar. The sericitic mica, which is pale brown or colourless, forms very conspicuous streaks curving round the augen.

There is hardly sufficient evidence available to decide with certainty what the form of these intrusions may be, but it seems safe to conclude that they are for the most part of dyke-like habit. At the marble-quarry there is evidence of a considerable degree of disturbance of the strata and also of strong thermal metamorphism; in all probability these granite dykes are offshoots of a larger and more deep-seated mass which is not exposed at the surface: the form of the intrusion, as indicated in fig. 1 (p. 705), is not to be taken too literally, as it is merely diagrammatic and to a certain extent hypothetical.

(3) The Igneous Rocks of Brewels Kloof.

The exact size and boundaries of this mass are somewhat difficult to determine, owing to the roughness of the ground and the poorness of the exposures in some parts, but it appears to be somewhat elliptical in form, and about three-quarters of a mile long by half a mile broad. Where the contact of the igneous and sedimentary rocks can be seen, the former appears to be always inclined at a high angle, sometimes nearly vertical, and the outer portions of the mass show a good deal of shearing. For this reason, it is difficult to determine whether there is any difference of texture between the outer and the inner portions of the mass.

A typical specimen of this rock, when unweathered, is dark blue or grey in colour, heavy and compact, with a spotted appearance, which, as can be seen from microscope-sections, is partly due to porphyritic felspars, and partly to vesicles filled with secondary minerals. When weathered, these secondary minerals offer less resistance than the rest, so that the exposed surfaces frequently show a very conspicuous vesicular pitting.

Thin slices of this rock [9464-65] reveal abundant phenocrysts of plagioclase-felspar and pseudomorphs after some ferromagnesian mineral, together with rounded or oval vesicles, in a ground-mass which varies considerably in character owing to different degrees of decomposition.

In some specimens the felspar-phenocrysts are quite fresh, and show extinction-angles corresponding to andesine and labradorite. In other cases the felspar has become more or less turbid, owing to conversion into an aggregate of minute crystals of mica and zoisite. This gives a false appearance of strong refringency, and causes the crystals to present a curious similarity to andalusite.

The ferromagnesian mineral is now represented by chloritic

pseudomorphs, and it was not found possible to determine its original character with certainty. In some specimens it seems to have been biotite, while in others the form of the pseudomorphs is rather more suggestive of augite or hornblende.

The ground-mass varies a good deal in different specimens: in the freshest of all it consists of minute lath-shaped crystals of felspar, with grains of magnetite and flakes of chlorite and biotite. One variety shows a considerable amount of quartz with the felspar. In some specimens the structure of the ground-mass is distinctly andesitic, with well-marked flow-structure indicated by the arrangement of the felspars; while in the quartz-bearing variety the ground-mass is very like that of the porphyrites, for instance, of Canisp or the Cheviot Hills. In the more altered varieties, on the other hand, the minerals of the ground-mass have been converted into an aggregate of carbonates and micaceous substances, with iron ores.

The vesicles contain a considerable variety of minerals, of which the most important are pale-brown mica, chlorite, and epidote, generally with some quartz, and occasionally tourmaline.

With regard to the petrographical character and classification of this rock, it is difficult to make any definite statement. Owing to the high degree of alteration, as shown by the abundance of carbonates, epidote, and chlorite, it is quite evident that chemical analysis would be not only useless, but misleading. Judging from the characters of such minerals as are still determinable, the rock appears to have been originally either a lava or an intrusion of intermediate composition. Some specimens might be described as typically andesitic in character, and the vesicular structure which is so notable and conspicuous affords strong presumptive evidence in favour of extrusion, or at any rate of intrusion under a somewhat thin covering of rock. On the other hand the form of the mass is difficult to reconcile with the supposition of a lava-flow, and is much more strongly suggestive of an intrusion. Owing to the high grade of the subsequent dynamic metamorphism, it is impossible to determine whether or not the surrounding sediments have undergone any contact-metamorphism. The question must therefore be left an open one, and the rock may be provisionally described as porphyrite or andesite.

VI. THE OTIRELITE-ROCKS OF WAAI KLOOF.

When they are followed towards the east, the general character of the Malmesbury rocks is seen to remain very uniform: although, owing to the narrowing of the outcrop, the lower grits become less conspicuous.

About 12 miles east of Worcester, the Coos River cuts through the mountains in a narrow gorge called Waai Kloof, and near the mouth of this gorge is an exposure of a very interesting rock. The prevailing rock of this district is a highly crushed and slicken-sided grit of uniform character, and presenting few points of interest; but in a small cultivated field, forming an expansion of

the gorge near its mouth, and close to the base of the Table Mountain Sandstone, there is a narrow band of different character. This is considerably harder than the rest, and forms a conspicuous ridge in the middle of the field. This ridge is about 30 yards long and perhaps 15 feet high, and is composed of thick slabs of rock with their bedding (or schistosity) dipping steeply southwards. This rock weathers in a peculiar manner, forming smooth rounded surfaces with a high polish, and is locally known as the Olifants Klip, or Elephant Rock. The same rock can also be traced on the other side of the Coos River, just below the Table Mountain Sandstone, and at this point it is highly disturbed. As before mentioned (p. 707), what appears to be a much decomposed representative of this band is to be seen in the Hex-River Pass; and this observation is of much importance, since, if this really is the same band, an important clue is afforded as to the relationship of the rocks of the Malmesbury Series at these two widely separated points. According to this, the ottrelite-rock probably forms a member of the lower division of the Malmesbury Series, and it appears to lie to the north of the axis of the principal anticlinal fold, as indicated in the section (fig. 1, p. 705).

A small number of specimens of the prevalent rock of this district were collected, and they were found to be for the most part somewhat crushed and slickensided grits of moderate to fine texture, consisting of angular and subangular fragments of quartz, in a rather schistose ground-mass of white mica and minute grains of quartz. The edges of the larger quartz-grains are usually more or less corroded, and in some specimens the characteristic sutural structure of a quartzite can be discerned. There is here evidence of a high grade of dynamic metamorphism. These rocks do not differ in any essential character from the grits in the Hex-River section.

A considerable number of slices was cut from the rocks of Olifants Klip, but all of them showed very similar characters, and they may all be included in one general description [9466-67].

The principal minerals of this rock are quartz, white mica, and ottrelite. In most specimens the rock may be described as composed of more or less rounded grains of quartz of obviously clastic origin, sometimes compound grains or minute fragments of quartzite; along the planes of schistosity lie in great abundance flakes of white mica, somewhat fibrous in character and often curved and contorted. In some cases there is a development of strain-slip cleavage. Scattered through this ground-mass, with a distinct tendency to aggregate in certain bands, are a large number of crystals of ottrelite, measuring up to 1 millimetre in diameter. They usually are roughly hexagonal or rounded plates, thin in proportion to their diameter, so that sections normal to the basal plane show a prismatic form. The edges of the crystals are very irregular, and consequently prismatic sections never show any termination, but are rather fringed at the ends.

The colour of the crystals is to the naked eye very dark blue or

black, and in thin sections a greenish-blue or bluish-grey. The pleochroism is fairly strong, considering the paleness of the colour: the usual tints being greenish-blue for rays vibrating nearly parallel to $c001$, and very pale grey or colourless for rays vibrating normal to this. The crystals are optically positive, and the absorption scheme may be expressed as follows: $a=b>c$. The extinction is oblique, $c\wedge z = \text{about } 9^\circ$. A peculiar form of twinning is conspicuous, so that the usual prismatic sections appear to be divided into four portions, of which opposite diagonal pairs extinguish simultaneously. The refractive index is fairly high and the birefringence rather weak. All these characters agree with those of *ottrelite*.

This rock may be defined in general terms as an *ottrelite-schist*; and it is highly probable that, in this case at any rate, *ottrelite* is a product of dynamic metamorphism, since there is no evidence of any contact-action in this neighbourhood. The rock shows a strong resemblance to the typical rocks of *Ottrelé* in the Ardennes.

VII. THE ROBERTSON DISTRICT.

In general structure this district closely resembles the neighbourhood of Worcester, but here a slight element of variety is introduced by the occurrence of a large mass of granite in the Malmesbury Series. This mass of granite forms a group of hills, of which the highest rises to an elevation of just over 3000 feet, a height considerably greater than that attained by the sedimentary rocks of that series. As we shall see later, the presence of this mass of hard rock has produced a considerable deviation in the general direction of the Worcester-Swellendam Fault, and this gives rise to a question of great interest: namely, what is the exact nature of the relations between the dislocation and the granite mass?

In this district, just as near Worcester, we can divide the country topographically into three regions: (1) the great escarpment of the Table Mountain Sandstone, here rising to nearly 6000 feet, and forming the range of the Langebergen; (2) the narrow strip of Malmesbury rocks forming foot-hills to the mountain-range; (3) the region south of the great fault, which here forms a district of somewhat more varied topography than farther west. It comprises a hilly region about Roode Berg and Gorees Hoogte, composed of highly folded beds of the Cape System; another hilly region to the west of this, extending from Lang Vley to Nuy, mostly composed of Dwyka Conglomerate and Ecce Shales; and a level or gently undulating district east and south-east of Robertson, which seems to consist for the most part of Enon Conglomerate.

The highly-folded Cape rocks on this side of the fault present some remarkable features: they are bent into a series of rather steep anticlines and synclines, but the most striking feature is that the axes of these folds are almost exactly at right angles to the direction of the great fault, which is parallel to the strike of the Cape rocks in the Langebergen. From the point of view of the physio-

grapher, another interesting feature is that, broadly speaking, the anticlines form hills and the synclines valleys, contrary to what is usual in folded regions. The Breede River cuts through an anticlinal hill about 4 miles west of Robertson, and in the gorge thus produced some magnificent examples of folding on a large scale may be observed both from the road and from the railway. In general terms, it may be said that throughout this district the most elevated ground consists of Table Mountain Sandstone and Witteberg Quartzites, whereas the Bokkeveld Beds, being softer, form low ground, and are often completely hidden by alluvium.

(1) The Malmesbury Rocks.

The rocks composing the Malmesbury Series in the district near Robertson are very similar in general character to those of Worcester; hence it is hardly necessary to describe their lithological character in detail. They consist of a fairly uniform series of rather fine grits and slates of a grey, greenish, or silvery colour when fresh; but, when much weathered, as is commonly the case, the prevailing tint is a pale olive-brown. A bed of dolomite is seen at Keur Kloof, about a mile north of Robertson, and another outcrop of what is (in all probability) the same bed occurs in the road which runs up the valley of the Hoops River, about 3 miles to the east.

The outcrop of the Malmesbury rocks is here rather narrow, averaging not more than a mile in width, except in the neighbourhood of the granite mass, where it expands greatly, as seen on the map. There are not sufficient data available to show to which division of the series, as defined at Worcester, they should be assigned.

In the neighbourhood of the granitic intrusion of Wolve Kloof the Malmesbury rocks are highly disturbed, but there is little or no evidence of thermal metamorphism, although the actual contact of the granite and sediments is exposed in several places. Along the footpath which runs from Robertson to Wolve Kloof, near the ruined water-mill at the entrance to the Kloof, there is a rapid alternation of granite and apparently unaltered sediment, each of which occurs along the path in patches a few yards wide. The junction is evidently very irregular, with tongues of granite projecting into the slates. The latter are much sheared, but no development of contact-minerals can be seen. A short distance north-east of this point, at the top of the first cultivated field on the side of the hill, is an exposure of rock of the phyllite-gneiss type, evidently a crushed granite-dyke.

The succession of the Malmesbury rocks is seen most completely along the road which leads up the valley of the Hoops River. From Robertson as far as the river this road runs over Witteberg Slates and Enon Conglomerate, both of which are well exposed in several cuttings. Near the drift over the river, about 2 miles east of Robertson, there are not many exposures; but a few yards beyond the drift there is by the roadside a patch of typical Malmesbury

Slate, with a dip totally different from that of the Witteberg Beds. Hence it is certain that the main fault must cross the river very near the drift. At this point the road turns northwards and runs parallel with the river for some miles, over a monotonous series of grey sandy flags and mudstones, with occasional bands of silvery slate and soft olive-green shale. The strike of these rocks is about west 10° south, and east 10° north, and the dip is always southwards at an angle varying from 20° to 50° . About half a mile north of the drift is the band of dolomite previously mentioned (p. 715), and close to it is a rather coarse grit, as also a very peculiar schistose rock containing large blocks of black vein-quartz, which impart to it a sort of augen structure. This appears to be a crushed conglomerate, since the blocks of quartz are certainly of detrital origin. This may be compared with the conglomeratic band seen close to the marble-quarry at Worcester, and it is just possible that they are the same, since in each case the conglomerates occur in conjunction with a calcareous band.

Throughout this series cleavage and jointing are very conspicuous in the finer beds, while the gritty beds show these structures less perfectly. Vein-quartz is abundant almost everywhere, and always shows a peculiar blue-black colour. The quartz-veins were evidently injected before the final foliation of the Malmesbury rocks.

Calcareous beds occur in several localities in the neighbourhood of Robertson. The most important of these are on the farm Dassies Hoek, where they are associated with black graphitic shales.¹ Beds of dolomitic limestone are also seen on the Hoops-River Road, and in Keur Kloof, north of the town; the latter occurrence was at one time worked for lime-burning. It is a dark bluish-grey rock, which weathers in a peculiar manner, becoming covered with a thick, pulverulent, white crust. A rough quantitative analysis of this rock showed the presence of 10 per cent. of matter insoluble in hydrochloric acid, 6 per cent. of ferrous carbonate, and 37 per cent. of magnesium carbonate, so that it is correctly described as an impure gritty dolomite.

(2) The Granitic Intrusion of Wolve Kloof.

This large mass of granite has a roughly oval form, and measures, as at present exposed, about $4\frac{1}{2}$ miles from north to south and $2\frac{1}{2}$ miles from east to west. It forms conspicuously high ground, and its central portion rises to a height of over 3100 feet above the sea. The exact outline is difficult to determine, owing to the rugged nature of the ground and a thick covering of vegetation on the lower slopes. By far the best section is seen in Wolve Kloof, a deep and narrow gorge formed by the Nels River, which cuts through the granite for a distance of about $1\frac{1}{2}$ miles. The precipitous sides of this gorge are formed of smooth rounded surfaces of granite,

¹ A. W. Rogers & A. L. Du Toit, 'Geology of Cape Colony' 2nd ed. (1909) p. 24.

presumably curved joints, but presenting a strong deceptive resemblance to the curved 'boiler-plate slabs' so characteristic of igneous rocks in glaciated regions. The rock is much weathered, and it is somewhat difficult to obtain really fresh material.

Sections were cut from specimens collected from different parts of the mass, but all are very similar, the chief difference consisting in the presence or absence of phenocrysts of felspar, which are never very abundant and sometimes wanting. Another difference lies in the amount of foliation: the central portion, especially in Wolve Kloof, is free from foliation, whereas near the margin a gneissose structure is often conspicuous. In certain parts aplitic veins are fairly abundant, but otherwise the rock shows little variation.

The granite is a rock of moderately coarse grain, of a prevailing bluish-grey colour when fresh, with scattered phenocrysts of white felspar measuring up to 1 inch in length. The principal minerals are quartz, felspar, and mica, with accessory iron-ores and sphene. The quartz, which was the last mineral to crystallize, forms large irregular crystals, much cracked and shattered, and exhibiting conspicuous strain-shadows. Several varieties of alkali-felspar can be recognized, including orthoclase, microcline, microcline-perthite, and micropertthite. These are usually quite clear and fresh, whereas the plagioclase, which occurs in subordinate amount, is distinctly turbid, and for the most part converted into an aggregate of white mica and zoisite. The plagioclase shows very small extinction-angles, corresponding to oligoclase. The soda-molecule of the plagioclase has evidently given rise to soda-mica, while the lime-molecule has formed zoisite. The principal coloured mineral is an olive-brown biotite, which is usually much chloritized and then green in colour. It is full of inclusions, some of which are epidote, while others consist of black opaque iron-ore surrounded by a ring of sphene. This latter fact suggests that the iron-ore may be ilmenite, which has given rise to sphene as a reaction-product. A few large original sphenes are also present. Some of the bigger flakes of muscovite which occur in places may possibly be of primary origin, but the greater part of this mineral is undoubtedly derived from plagioclase-felspar. Some specimens of the granite, especially the more porphyritic examples, show a strong tendency to micrographic intergrowths of the quartz and felspars of the ground-mass [9470-71].

The aplite forms narrow veins and strings penetrating the granite in all directions, but its distribution is somewhat restricted. It consists of quartz and a great variety of felspars, all of alkaline composition, with only the merest trace of biotite. Sphene and small garnets are occasionally present. In this rock the quartz has commonly crystallized before the felspar. No notable difference of composition can be detected between the normal granite and the aplite; the variation is chiefly a matter of texture, though the aplite appears to be of somewhat more acid character [9468-69].

Since the inner parts of the granite mass, where cut through by the Nels River in Wolve Kloof, show no foliation, while the outer portions are much crushed and shattered, it is clear that the

intrusion took place before the final foliation, and that the great size of the main mass protected the interior from crushing, while the margin and the peripheral dykes were strongly foliated. Thus, even at this early stage, before the deposition of the Cape rocks, this intrusion acted as a horst, and that fact has some bearing on the problem of the later faulting.

VIII. THE CAPE AND KARROO ROCKS OF WORCESTER AND ROBERTSON.

For the purposes of the present paper, it is unnecessary to enter into a lithological description of the rocks of these two series. They are quite normal in character, and call for no special remark. Perhaps the most noteworthy feature is the entire absence of any exposure of the Bokkeveld Series in the neighbourhood of Worcester, on the north side of the Breede River. Since typical Witteberg shales and quartzites are seen in the banks of the river south of Goudini Road Station, and also for some distance in the neighbourhood of Brand Vley, and these beds dip north, it is possible that the whole of this great alluvial flat is really underlain by Witteberg and Karroo beds, although it is frequently assumed that such large valleys are excavated out of Bokkeveld beds, which, as a matter of fact, is generally the case.

Somewhat farther south, over a great area stretching from Brand Vley and the Hoeks River on the west to some miles east of Lang-Vley Station, the ground is occupied by a great development of Karroo rocks, with a strip of Enon Conglomerate on the north. The rocks of the Karroo Series are here quite normal, and just like those of the main area of the Karroo itself. The Dwyka Conglomerate is very thick, but the boulders are mostly small. Good specimens of the whole series can be obtained near Lang-Vley Station; and close to the station in the Ecce Shale is a bed of anthracite, which is now being worked under the name of graphite.

The sandstones of the Ecce Series are exposed at several points near Worcester. In the goods-yard at the station is a very fine exposure showing Enon Conglomerate resting on Ecce Sandstone; and the same sandstone can be seen in many places, in the floors of the sluits formed by heavy rains in the brick-earth flat north of the station. About 3 miles west of Worcester Station is a curious small conical hill, by the side of the railway, which has been quarried, and this also consists wholly of Ecce Sandstone. Here the rock strikes north-north-west and south-south-east, and the dip is about 20° to the east. In all these exposures the dip of the sandstone is either more or less parallel to the fault or towards it, which is of course unusual on the downthrow side. The rock is everywhere very uniform, and consists of a fine-grained greenish or yellowish sandstone with obscure plant-remains, among which sufficient forms have been recognized to establish the age of the formation, at any rate in a general way, as Ecce Sandstone. This sandstone probably underlies a good deal of the alluvial flat of the Breede Valley south of Worcester.

Small isolated patches of Dwyka and Ecça rocks are also seen close to the town of Robertson, and especially along the railway and in the low hills immediately north of it. There is a good exposure of typical Dwyka Conglomerate near the water-mill to the north-west of the town, at the mouth of Wolve Kloof. These rocks are normal, and require no further description.

IX. THE ENON CONGLOMERATE.

One of the most important formations for the purpose of the present investigation is the Enon Conglomerate. It is unnecessary here to recapitulate the evidence on which this deposit has been correlated with the marine Cretaceous strata of the Uitenhage Series: this correlation may be taken as fully established. Within the area here dealt with, almost all the deposits of this age are of a terrestrial and torrential character, and were apparently formed under conditions very similar to those now prevailing in the district. At any rate, it is sometimes difficult to distinguish the more weathered portions of the Enon Conglomerate from the coarse gravels of recent and subrecent origin which cover such great areas in the valleys and lower parts of the district. A careful examination, however, shows that the character of the pebbles is different: that is to say, they have been derived for the most part from different formations, as will later be explained in detail.

In the district under consideration there are three disconnected patches of Enon Conglomerate: a small one north-west of Worcester, a larger one running more or less along the course of the Nuy River, and a very large spread stretching from Robertson to Ashton. This outcrop is roughly oval in shape, and measures about 15 miles in length by 6 miles in width.

The Enon Conglomerate is well seen at Worcester Station, resting unconformably upon Ecça Sandstone. The pebbles here average about 3 inches in diameter, and are embedded in a reddish sandy matrix, which appears to be much weathered. The pebbles are almost wholly composed of hard, dark grits. Much fresher material can be obtained from an excavation recently made close to the new reservoir-dam, north-west of the town, and many blocks have been used in the construction of the dam. The conglomerate is here extraordinarily hard, and the pebbles are on the average somewhat smaller, so that it can be dressed into hand-specimens. The cement is partly ferruginous and partly calcareous. The conglomerate is also exposed in many places in the sluits before mentioned, but is here much weathered. The pebbles are everywhere almost exclusively hard, dark-green, grey, and red grits and rocks of a somewhat jaspery appearance. It is noticeable that the pebbles are very frequently bent, fractured, faulted, and indented, indicating pressure, as in the Polygenetic Conglomerate of Cumberland, to which this rock shows a striking resemblance. It is highly probable that most, if not all, of the rounded gravely

hills north-west of Worcester really consist of Enon Conglomerate, with perhaps a thin coating of recent gravels; but, in the absence of exposures, it is impossible to decide this point with certainty, owing to the before-mentioned difficulty of distinguishing between the weathered Enon and the newer gravels.

Prof. E. H. L. Schwarz¹ has mapped and described as Enon Conglomerate a patch of gravel on the farm Lange Kloof (Geol. Surv. Map, Sheet 4), east of the Hex River; he refers to it as 'an exposure of gravel, evidently very old, but of which the pebbles are made of slate.' Unfortunately, owing to bad weather and floods in the Hex River, I was unable to visit this interesting and important exposure; but, judging from a comparison of the published description with what is seen elsewhere in the neighbourhood, I feel the gravest doubts whether this gravel is of Cretaceous age, as claimed by Prof. Schwarz. The absence of slate in the conglomerate at Worcester is noteworthy, and it is improbable that there would be so complete a difference of composition in so short a distance (less than 5 miles), especially as the Enon Conglomerates of Robertson and Ashton (30 and 40 miles away respectively) are exactly like those at Worcester, and contain no slate.

The small patch of Enon Conglomerate west of Robertson calls for no special remark, but in connexion with the large expanse of conglomerate east of the town a most important question arises. On the map of the Geological Commission, on the farms De Hoop and Aasvogels Nest, the conglomerate is shown, doubtfully, overlapping the fault, and resting directly upon Malmesbury Beds. If correct, this observation fixes the age of the fault as between Ecca and Enon, a result diametrically opposed to my observations elsewhere. I therefore examined this region most critically and carefully, and came to the conclusion that this mapping is unjustified by the evidence. The ground is very obscure, and there are no exposures in the form of excavations.

The Malmesbury rocks here form fairly high ground, with a steep slope, in fact a kind of escarpment, and on the next farm, Klaas Voogds Rivier, a curious wedge of Witteberg Beds comes in along the fault, and makes a conspicuous feature in the form of a rocky ridge. On De Hoop and Aasvogels Nest low rounded hills of gravel lie at the foot of the escarpment, and the northernmost of these certainly lie to the north of the fault. But these hills do not all consist of the same kind of material: the southern hills are undoubtedly Enon Conglomerate, but the hills north of the fault-line consist of quite different material, without the characteristic red pebbles of the Enon Conglomerate. The last hill of all, at the foot of the escarpment, is different again, being composed of large blocks

¹ 'Geological Survey of the Divisions of Tulbagh, Ceres, & Worcester' 10th Ann. Rep. Geol. Comm. Cape Colony, 1905, p. 289.

of Table Mountain Sandstone, which is not seen in the southern hills. It is quite clear that the material of which these hills are composed has been derived from at least three sources; and, from a careful examination, it appears certain that the gravels are successively newer towards the north. Fig. 2 shows the interpretation of the section which I adopted, after a critical examination in company with Dr. Melle, of Robertson, who is well acquainted with the geology of the neighbourhood. Of course, in this section the exact position of the fault is hypothetical, but compass-bearings of points where it is known give the general position with fair accuracy. It must come somewhere under the gravel-ridge marked G, which obviously overlies the Enon Conglomerate, and is overlain in turn by the coarse breccia B.

Fig. 2.—*Diagrammatic section through the southern part of the farm De Hoop, 3 miles east-north-east of Robertson.*

[M.M.=Malmesbury Slates. W=Witteberg Slates. E.C.=Enon Conglomerate. G=Recent gravel. B=Scree-breccia, with large blocks of sandstone.]

I conclude, therefore, that the Enon Conglomerate does not extend over the line of the fault on to the Malmesbury Beds, but is cut off by the fault on the northern side.

It is of interest to note that the Enon Beds of this area are not wholly conglomeratic; but near Klaas Voogds Station there is a development of fine grey or white sandstone, which shows some approximation to the more normal marine Cretaceous deposits of the Uitenhage district. This is probably the westernmost point to which the marine Uitenhage facies has been traced. Unfortunately, no fossils were found here.

X. THE ASHTON DISTRICT.¹

Ashton Station, on the New Cape Central Railway, lies about 12 miles east of Robertson, and from it an important road leads through Kogmans Kloof to the town of Montagu, which lies on the other side of the Langebergen. The general character of the country is very similar to what is seen farther west, but on the whole the topography is simpler.

The belt of Malmesbury rocks is here much narrower, being not

¹ See Cape Colony Geol. Surv. Map, Sheet 2.

much more than half a mile wide where cut through by the Kogmans River, which affords a very good and nearly continuous section. In the right bank of this river, near Ashton Station, is

Fig. 3.—Geological map of the district round Montagu and Ashton.

[The geological boundaries in this map, with the exception of those in the immediate neighbourhood of Montagu and Ashton, are copied from the published map of the Geological Commission of the Cape Colony, Sheet 2.—M. = Malmesbury Series.]

a section of Enon Conglomerate, which is by far the largest and clearest in the whole district. Some valuable information was also obtained from a well sunk by Mr. J. O'Connor, of Ashton, on the west of the Kogmans River, by the side of the main road to

Robertson. This well passed through about 60 feet of Enon Conglomerate, and a fine typical collection of pebbles could here be examined in detail.

The general structure of this district is simple, but of considerable interest; and its principal features can be made out from an inspection of the small map (fig. 3, p. 722). At Kogmans Kloof there is a noticeable kink in the general trend of the Langebergen Range, and this kink is accompanied by what appears to be a thrusting forward of the Cape rocks towards the south-west. On the right bank of the river, just below the mouth of the pass, the Enon Conglomerate appears to be in contact with Table Mountain Sandstone; but, unfortunately, it is impossible to determine what underlies the conglomerate at this point. There can, however, be no reasonable doubt that here, as elsewhere, it rests on Witteberg Beds: this question will again be referred to later. The position of this mass of Table Mountain Sandstone is doubtless due to two nearly parallel faults, the more important running nearly along the line of Kogmans Kloof towards Montagu, while the second follows closely the line of the upper part of Wild Paarde Kloof and crosses the Keisies River to the north-west of the farm Uitvlugt. These are tear-faults, and between them a block of Table Mountain Sandstone about 2 miles wide has been pushed nearly a mile to the south-west. This faulting is of earlier date than the Enon Conglomerate.

The banks and bed of the Kogmans River, from near Ashton Station to the mouth of Kogmans Kloof, afford a very clear section in which the relations of the different rock-groups can be made out with certainty. This is illustrated by fig. 4. The Enon Conglomerate, when best exposed for a thickness of about 40 feet, consists of large rounded and subangular boulders embedded in a red sandy matrix: it shows distinct bedding, with a gentle dip to the south. On the left bank of the river it is clearly seen lying on Witteberg Beds.

which are here reddish shales with occasional bluish grit-bands, intensely folded and contorted. This folding is of a very peculiar character, since many of the folds are in the horizontal position, with their axial planes vertical. It is evidently impossible to represent this in a diagram. Sometimes, for considerable distances the strike of the beds is nearly north-east and south-west, that is, at right angles to the normal strike of the district; but the general trend appears to be north-west and south-east. In the arches of the anticlines are occasional patches of crush-breccia. The total width of the outcrop of the Witteberg Beds in the river is about 1000 yards.

The exact position of the great fault between the Witteberg and the Malmesbury Beds is very clearly indicated, and the strikes of the two series are quite different. The structure of the Malmesbury Series is much simpler, and the dips more uniform; the folds which can occasionally be seen are not of much importance. The rocks of this series are for the most part silvery or blue slates, weathering yellow, with occasional grit-bands. The width of the outcrop of Malmesbury Beds is here about 800 yards, and at one point a fault is very clearly seen in the middle of the series.

The junction with the Table Mountain Sandstone is almost vertical, and the lowest bed of the latter, about 4 feet thick, appears to be a basal conglomerate of quartz-pebbles, which has been afterwards infilled with vein-quartz. It presents a strong superficial resemblance to the bankets of the Rand, and has been unsuccessfully prospected for gold. The Table Mountain Sandstone itself is here of the usual character, and calls for no comment.

This section is of especial interest, since it displays very clearly and in a compact form a typical series of the rocks of this district. Incidentally it may be mentioned that the published map of the Geological Commission of the Cape of Good Hope, on the scale of $3\frac{3}{4}$ miles to the inch, is incorrect at this point, since it shows the river flowing over Malmesbury Slates and Enon Conglomerate only, whereas the Witteberg Slates are seen in the banks of the stream for nearly 1000 yards. It appears, therefore, that there is actually a narrow tongue of Witteberg Beds running between the outcrop of the conglomerate and the fault, across the stream; and the Enon Conglomerate is here not cut off by the fault, although it comes against it a little farther north.

The fine exposure of Enon Conglomerate on the right bank of the river forms a prominent cliff about 40 feet high, of which the uppermost 10 feet or so is recent alluvium, consisting of yellow gravel with very big boulders of Table Mountain Sandstone up to a cubic yard in bulk. About 30 feet of the conglomerate is exposed, consisting of boulders measuring as much as 1 cubic foot, embedded in a reddish sandy matrix. Bedding is distinctly shown, and the dip is about 10° southwards. The boulders in this conglomerate consist exclusively of sandstones and grit, mostly resembling those of the Witteberg and Ecce Series; and, despite the most diligent search, no fragments of Malmesbury rocks could be found.

A careful examination was also made of a well, sunk by Mr. J. O'Connor about half a mile west of Ashton Station, by the side of the main road to Robertson. The following section was compiled from personal inspection, and from data supplied by Mr. O'Connor:—

	<i>Thickness in feet.</i>
Soil, clay, etc.	30
Hard marly clay	25
Boulder-bed	5
Enon Conglomerate	60

The recent deposits of soil and clay are here of extraordinary depth, no less than 60 feet being passed through. The lowest 5 feet of this consists of a bed of big boulders, chiefly of Table Mountain Sandstone, well rounded by water-action. A very large pile of pebbles from the Enon Conglomerate was carefully examined. They range up to 18 inches in diameter, and the largest came from the bottom of the well. Abundant specimens of Dwyka Conglomerate were observed, while the blocks of sandstone closely resemble the grit-bands in the Witteberg Series, and are quite unlike the Table Mountain Sandstone. It is an observation of the utmost significance that the Enon Conglomerate of this neighbourhood contains no fragments of Malmesbury rocks, and this statement is fully confirmed by Mr. O'Connor, who has an intimate knowledge of all the rocks of this neighbourhood. There is also some evidence that boulders of Dwyka rocks are more abundant below, and those of Witteberg rocks above.

XI. GENERAL CONCLUSIONS.

The dominant tectonic feature of Cape Colony is the occurrence of conspicuous lines of folding, which are very clearly indicated by the outcrop of the rocks of the Cape System. Over an immense area in the centre and north of the Colony the rocks of the Karroo System are horizontal; but, towards the south and west, they begin to show increasingly steep dips, and at the margin of the outcrop they are very highly inclined along with the Cape rocks. In the south the two systems are apparently conformable, but towards the north there is a conspicuous overlap of the Karroo System. The markedly rectangular form of the south-western corner of the Karroo outcrop is intimately connected with the direction of the principal lines of folding. These are divided into two well-defined sets: near the west coast the trend-lines run north and south, while near the south coast they run east and west. These are called by Dr. Rogers the Cederbergen and Zwartebergen Series respectively.

These two sets of folds come together in the neighbourhood of Worcester and Robertson, and it is necessary to consider the nature of their junction or syntaxis. The matter is further complicated by the occurrence of the great Worcester-Swellendam Fault, which cuts obliquely across the syntaxis, and has brought down a small area of Karroo rocks on its southern, or downthrow side. It is

evidently, therefore, of the first importance to determine, if possible, the age of this fault.

Furthermore, a careful study of a geological map of the region shows that the two sets of folds may be regarded as spreading out

Fig. 5.—*The dominant trend-lines of the south-western part of Cape Colony.*

in a somewhat fan-like manner from a point or region situated somewhere in the neighbourhood of Somerset West, on the east side of False Bay: if a line is drawn from this point in a north-easterly direction, the folded mountain-chains are arranged more or less symmetrically with regard to it, and the Worcester Fault cuts it

approximately at right angles. It is also noticeable that the fault is curved, running nearly parallel at either end to each of the sets of folds, and changing its general direction from north and south at one end to east and west at the other. From these considerations, it is evident that the fault has a close genetic connexion with the folding.

Although these two phenomena are obviously connected, it must not be assumed that they are contemporaneous: in fact, such is clearly not the case. From a study of the structure of the rocks of the Cape System on either side of the Worcester Fault, there can be little doubt that the faulting is in the main later than the folding, although it is probable from other considerations that no long interval of time separated them.

The faulting is certainly later than the rocks of the Ecce Series, since the Dwyka Conglomerate and Ecce Sandstone and Shale are brought into contact with Malmesbury and Cape rocks. The question next arises, whether the fault is or is not newer than the Enon Conglomerate; and to this it is somewhat more difficult to give a conclusive reply, since some of the evidence is not very clear. The most important fact to determine for this purpose is whether or not the Enon Conglomerate is cut by the fault, and as to this some doubt has hitherto existed. There is no doubt that the fault forms, in a general way, the northern boundary of the Enon facies of the Cretaceous in this region¹; but, on the maps of the Cape Geological Commission, the conglomerate is mapped in places as just overlapping the fault, apparently for a few hundred yards. This, on the face of it, is improbable: if the present distribution of the conglomerate is independent of the fault, it is unlikely that its boundary would follow so closely the line of the fault for scores of miles, and overlap it occasionally for a few yards only. There is no real field-evidence for this interpretation, and the general form of the patches of Enon Conglomerate is very strong presumptive evidence in favour of their truncation on the northern side by the fault, exactly in the same way as the Karroo rocks are truncated. Hence, we may conclude almost with certainty that the Worcester-Swellendam Fault is, at any rate in part, newer than the Lower Cretaceous.

Another line of argument may also be pursued, namely, that derived from the character of the blocks and pebbles of which the Enon Conglomerate is composed. In the first place, so far as my own most careful observations go, the Enon Conglomerate at Worcester, Robertson, and Ashton does not contain pebbles of the Malmesbury rocks. The only possible exception to this is the somewhat doubtful case described by Prof. Schwarz at Lange Kloof near the Hex-River Pass, and as to this I am frankly sceptical,

¹ Dr. Rogers & Mr. Du Toit consider that the Enon Beds of the Oudts-
hoorn region were formed in a different basin of deposition; see their
Geology of Cape Colony 2nd ed. (1909) p. 321.

since it is obviously so different from all the other occurrences in the neighbourhood. I paid especial attention to this point in the exposures of Enon Conglomerate near Robertson and Ashton, and was unable, after several prolonged searches, to find a single piece of Malmesbury slate.

But a further point may also be put forward: the coarse grits and quartzites of the lower part of the Table Mountain Series could not be identified with certainty in the Enon Conglomerate. It appeared to me, and to the local observers who were kind enough to assist me, that all the blocks in the Enon Conglomerate could be referred to the Witteberg and Eccra Series (including, of course, in this last designation the Dwyka Conglomerate). This is an argument which must not be pushed too far, since it is obviously impossible to state dogmatically that every pebble of quartzite or of sandstone is Witteberg or Eccra Sandstone and not Table Mountain Sandstone. Still, it may be safely asserted that the general facies of the pebbles in the Enon Conglomerate led to the belief that the Table Mountain Sandstone is not represented therein.

If these facts are admitted, we are at once led to an important conclusion, namely: that at the time of the formation of the Enon Conglomerate the Malmesbury Series and the lower part of the Cape System were not exposed in the district here investigated.

In order to appreciate the full significance of this conclusion, we must now consider what were the conditions under which the Enon Conglomerate was formed. It is obviously a torrential deposit, composed of well-rounded blocks, embedded in a sandy matrix, with occasionally, and especially in the higher part of the succession, beds of a finer texture and sandy or marly character. This deposit has evidently been formed under terrestrial conditions, and it is very similar to the deposits now being formed, or which have recently been formed, at the foot of the mountain-slopes of the region, and especially where the larger streams cut through the ranges. Reference has already been made to the difficulty of distinguishing between weathered Enon Conglomerate and some of these recent deposits, and their manner of formation must have been very similar. When bedding is visible in the Enon Series, it is often evident that the material came from the north, showing that at that time also the high ground lay in that direction.

However, it appears improbable, from two independent lines of argument, that the Enon Conglomerate was formed in exactly its present position. In the first place, it has been shown that the Enon Conglomerate has taken part in some, at any rate, of the movement of the Worcester Fault, hence it must have been formed at a higher level: and secondly, the materials of the conglomerate are not of a character consistent with formation at the present level.

It may be suggested, then, that at the time of the formation of the Enon Conglomerate a range of mountains existed in approximately the same geographical position as the Langebergen, but at a higher level, so that it was composed of Witteberg and Karroo

rocks. These were undergoing rapid denudation, and the denuded material accumulated at the foot of their steep southern slope, most probably in disconnected basins, corresponding more or less to the present distribution of the conglomerate, but of larger size.

In order to gain some idea of the height above the present level at which this denudation and accumulation took place, we must take into account the thickness of the Cape System. According to the best authorities, the Table Mountain Sandstone is about 5000 feet thick, the Bokkeveld Series 2500 feet, and the Witteberg Series also 2500 feet. On the assumption that only Witteberg Beds were exposed, the ground-surface must then have been some 7000 or 8000 feet higher than at present. This height need not necessarily have been absolute height above sea-level, but may be referred to some arbitrary datum-line—for example the base of the Cape System, which may then have been absolutely either higher or lower than at present.

According to this view, then, the Enon Conglomerate resulted from the denudation of a land-surface, possibly a mountain-range, formed of Witteberg and Karroo rocks, while the underlying pre-Cambrian rocks were not exposed. There is some evidence that Dwyka Conglomerate is more abundant in the lower part of the conglomerate, and Witteberg Beds in the upper part, thus indicating a progressive uncovering of lower and lower beds; but on this point much more work is needed before it can be regarded as established. Then, after the formation of the Enon Conglomerate, the major portion at any rate of the fault-movement took place, bringing Enon Conglomerate in places into juxtaposition with Malmesbury rocks. This fixes the age of the fault as post-Cretaceous.

The disposition of the minor lines of folding in the region to the south of the fault is in favour of the view that a close connexion exists between the folding and the faulting. North of the fault the strike of the Cape rocks of the Langebergen is uniformly east and west, and the dip is steeply northwards. South of the fault, however, they are ridged up into a series of sharp anticlines and synclines, with axes running approximately north-north-east and south-south-west, and occasionally accompanied by parallel faults: as, for example, west of Lady Grey. The trend-lines of these structures are, therefore, nearly at right angles to the principal fault. It appears, then, that when the region to the south of the fault sank down, it also underwent a sort of lateral crumpling due to compression.

Let us now turn to a consideration of the events which succeeded the formation of the Enon Conglomerate. As we have already seen, the evidence suggests that the conglomerate was formed on an old land-surface, composed of Ecca, Witteberg, and Bokkeveld rocks. Then, as a result of earth-movement, or possibly on account of a release of pressure, subsidence took place along a fault-line (which had probably been already initiated), resulting in the formation of the great Worcester-Swellendam Fault. This fault must be

regarded as a fracture and depression occurring in the triangular area between two sets of folds at right angles one to the other. A very similar phenomenon is the well-known area of the Warm Bokkeveld, which is also a depressed region, and immediately north of it is a small patch of Karroo rocks, let down by a fault on the north-eastern side. This fault runs parallel with the Worcester Fault, and is probably due to the same set of causes.

These folds are obviously due to lateral thrust, since they are clearly asymmetric, but it is still a matter of discussion from which side the greater pressure came. Prof. Schwarz¹ has put forward the view that the folding of these ranges is due to the intrusion of the vast sheets of dolerite in the Karroo System, thus implying that the maximum pressure came from the interior. This idea is ingenious, but (so far as we know at present) inconsistent with the field evidence.² The general structure of the region and the disposition of the folded chains can be much more easily explained on the supposition of pressure acting from the exterior towards the interior, and consisting of two sets of thrusts:—one towards the north, which produced the east-and-west folds of the Langebergen and other parallel ranges, the Zwartebergen folds of Rogers; the other towards the east, giving rise to the ranges of the west-coast region, the Cederbergen folds. These two sets of thrusts interfered mutually where they came in contact, in the south-western corner of the Colony, thus producing the fan-shaped arrangement of mountain-chains which is so characteristic a feature. It appears that this fault was formed subsequently to the principal period of folding, and it probably occurred when the pressure was released to a certain extent, thus allowing of a great subsidence.

This final, post-Enon, movement was evidently accompanied by considerable earth-pressure, since the pebbles of the conglomerate are commonly fractured and indented, and this process presumably took place concurrently with the formation of the fault.

To sum up: the dominant features of the geology of this region are:—

(a) The conspicuous folding, of post-Karoo age, in part pre-Cretaceous: this led to the formation of mountain-chains in two sets, east-and-west and north-and-south respectively, with a syntaxis in the south-western corner of Cape Colony.

(b) A post-Cretaceous period of movement, which resulted chiefly in a great subsidence to the south of a fault-line cutting obliquely across the syntaxis; accompanying or preceding this were minor lines of crumpling on the downthrow side of the fault, leading to the formation of subsidiary folds striking north-east and south-west, or thereabouts. It is impossible to say with certainty whether the faulting was wholly subsequent to, or in part con-

¹ 'Causal Geology' London, 1910, pp. 141-43 & fig. 10.

² A. W. Rogers & A. L. Du Toit, 'Geology of Cape Colony' 2nd ed. (1909) pp. 123-24 & fig. 9.

temporaneous with the formation of the Enon Conglomerate, but it was certainly for the most part later than the formation of this deposit.

One more point still remains to be dealt with, that is to say, the extent of the Worcester Fault. Many estimates have been given of the maximum throw of this fault as at present existing, and it is undoubtedly very great. At its most favourable development it brings into contact Enon Conglomerate and Malmesbury Slate, but the throw is not necessarily represented by the thickness of all the strata which elsewhere occur between these limits. At different points the conglomerate rests upon Ecça, Witteberg, and Bokkeveld Beds; and, as we have seen, there is reason to believe that before the formation of the fault these rocks had undergone very considerable folding and denudation, so that it is obviously incorrect to add together the total thickness of the missing formations to obtain the throw. We can only say with absolute certainty that the throw must be at least equal to the difference of level of the upper surface of the Malmesbury rocks on either side of the fault, and there is unfortunately no means of measuring this directly. The lowest bed on which Enon Conglomerate rests directly is the Bokkeveld, so the minimum throw must be at least equal to the sum of the thicknesses of the Table Mountain Sandstone and part of the Bokkeveld, but this need not necessarily be much more than 5000 feet. This may be regarded as the lower limit. On the other hand, the higher limit is, as explained above, the total thickness of all the strata between the Malmesbury Series and some horizon in the Ecça Series.

The thicknesses may, then, be tabulated as follows:—

	<i>Feet.</i>
Ecça Sandstone	1000
Dwyka Conglomerate	2000
Witteberg Series	2500
Bokkeveld Series	2500
Table Mountain Sandstone	5000
Total	<u>13,000</u>

It is here assumed that the highest Ecça bed seen along the fault is 1000 feet above the top of the Dwyka, and this, although a very rough estimate, is probably not far from the truth.

Hence we see that the throw of the fault must be something between 5000 and 13,000 feet, and in all probability it is nearer to the larger figure than to the smaller. It is of course possible, and indeed highly probable, that the throw of the fault varies, since it has a visible length of some 70 miles and may be continued much farther. At any rate, it may safely be said that in the middle of its length, near Robertson, the throw is probably something like 10,000 feet, and perhaps more, a figure which is certainly large enough to justify its inclusion among the greatest dislocations at present known to geological science.

In conclusion, I have much pleasure in expressing my indebtedness to those gentlemen whose kind co-operation did so much to render this work possible: to Dr. Melle, of Robertson, and Mr. J. O'Connor, of Ashton, I owe a debt of gratitude for hospitality and help in the field; but above all, my thanks are due to Dr. A. W. Rogers, on whose suggestion the work was undertaken, and without whose help and encouragement it could not have been carried out. To these and other friends who have aided me by advice and criticism, I tender my most hearty thanks.

EXPLANATION OF PLATE LI.

Geological map of the neighbourhood of Worcester (Cape Colony), on the scale of 1·8 miles to the inch, or about 1 : 115,000.

DISCUSSION.

MR. G. W. LAMPLUGH said that, for him, the chief interest of the paper lay in the statements regarding the relation of the Enon Conglomerate to the Worcester Fault. He paid a flying visit to the Worcester district six years ago under the guidance of his friend Dr. A. W. Rogers, and he then gathered, without, however, himself seeing the evidence, that the Enon Conglomerate was known to rest directly upon the Malmesbury rocks north of the fault and to contain pebbles from these rocks. This implied that the fault was believed in the main to be pre-Enon, though it was recognized that there were minor movements along it at a later date. Important conclusions as to the geological history of South Africa generally had been based on this supposed relationship, which was now challenged. If the Author was able to prove that the previous investigators were wrong in their observations, he had done good work in South Africa; but, unless his evidence was perfectly clear, he must be prepared for sharp criticism, as the matter was of far-reaching consequence.

DR. J. W. EVANS thought that the Worcester-Swellendam Fault might be an 'isostatic' fault, determined by the gradual rise of the high ground on the north-east and depression of the sea-floor on the south-west, as the former was worn down by subaërial agencies and the resulting material accumulated on the latter. It often happened that a certain amount of basement-conglomerate occurred on the upthrow side of such a fault, and that might be the case near Worcester, even if the movement continued after the deposition of the Enon Conglomerate. With reference to the conflict of evidence as to the occurrence of Malmesbury rocks in the conglomerate, he suggested that, even on the supposition that the greater portion of the conglomerate was deposited before these rocks were laid bare, some of it might date from a later period when they were exposed at the surface.

THE AUTHOR, in reply to the points raised by Mr. Lamplugh, pointed out that post-Cretaceous faulting did not necessarily imply

GEOLOGICAL MAP OF THE NEIGHBOURHOOD OF WORCESTER (CAPE COLONY)

[O.S.=Ottrelite-schist; E.S.=Ecca Sandstone; E.C.=Enon Conglomerate; I.=Igneous rocks.]

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that the Cretaceous rocks were deposited at a height above their present level equal to the total throw of the fault. He had no doubt that a large part of the movement was of earlier date, and considered that a post-Cretaceous movement of 2000 or 3000 feet was sufficient to account for the phenomenon. He certainly did not believe that the Cretaceous rocks ever extended over the Karroo, and regarded the Enon Conglomerate as a torrential deposit formed at the foot of a mountain-escarpment, probably a fault-scarp. He much regretted that he had had little opportunity of discussing the matter with Dr. Rogers, and awaited with great interest the opinion of South African geologists on the paper. In reply to Dr. Evans, he stated that conglomerates do exist to the north of the fault, but these are of quite different character and undoubtedly recent. In conclusion, the Author admitted that the view put forward by the Cape geologists offered an easier interpretation, but he did not believe it to be correct.