certain theories in vogue, a complete geology of the Pyrenees has been developed, to which no Pyrenean geologist can contribute without abandoning those habits of cautious statement which are essential to the integrity of his work.

NOTE.—Since the above was posted, in January last, the points described have been largely discussed in Parisian publications. It is admitted that the granite, ophite, and supposed Trias are above and not beneath the Cretaceous. It is hence assumed that they *must be* abnormally carted caps of those ancient formations. The entire evidence of their age being admittedly false, that age is maintained by a paradox that contradicts every detail of the district. There could be no shadow of doubt that they are beneath the Cenomanien, were it not that they are frankly eruptive, and at Salies, as at a hundred other points, flanked by lentiles of eruptive breccia intercalated in the Cretaceous Flysch. In the Alps, the abnormal carting of the Brèche du Chablais is similarly assumed, to save the assumption that its volcanic vents are Triassic by micrographic theory. M. Marcel Bertrand regarding the Alps, and M. Haug regarding the Pyrenees, have propounded theories before visiting either chain. Since first exploring the rocks of Salies with the assistance of Leymerie in 1866, I have endeavoured to sacrifice all theory to observation. Unless practical geologists cease to despise controversy, they will find, like myself, that any mention of their work is an outrage, and that any field survey is intolerable polemics. The entire geology of Asia having been yesterday reformed from Vienna, similar treatment of Alps and Pyrenees is inevitable. It is easier to silence all local observation than to repeat its task.

V.—CONTRIBUTIONS TO SOUTH AFRICAN PETROGRAPHY.

By F. P. MENNELL, F.G.S., Curator of the Rhodesia Museum, Bulawayo.

IT is remarkable, considering the enormous development of igneous rocks in South Africa, that so little has been written concerning the features they present in the field or under the microscope. Right away from Cape Town into the tropics, plutonic masses, dykes, and lava-flows interrupt the continuity of the sedimentary deposits with astonishing frequency. Some of these rocks, like the Cape Town granite and dolerite, are probably of pre-Silurian age;[1] others, like the Kimberley lavas, were erupted during the Secondary period: while others, again, like the dykes and lavas of the Zambesi Valley, are probably of late Tertiary or even geologically recent date, as evidenced by the numerous geysers and hot springs[2] which represent the final phase of not long antecedent volcanic activity. They appear to bear the same relation to the volcanoes of Central Africa as the British Tertiary lavas do to those of Iceland.

[1] They are overlain unconformably by a thick formation which is itself older than the earliest fossiliferous beds (Devonian) of South Africa.

[2] See Ferguson on the geysers of the Zambesi and Kafui Valleys, Proc. Rhodesia Sci. Assoc., 1902.

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In the present chaotic state of petrological nomenclature it is necessary to explain the significance of the terms employed in describing the rocks. No system of classification can be regarded as wholly satisfactory, but it certainly seems hopeless to rely on such features as the presence or absence of particular minerals. Such a course brings together types which differ widely in chemical composition, and separates others which are chemically and genetically closely related. In the brief notes which follow, the grouping depends solely on mode of occurrence and chemical composition, a method of classification which appears to be steadily gaining ground owing to its simplicity. The significance of the nomenclature, which accords strictly with the classification adopted, will be readily perceived from the following table, names in general use being employed as far as possible and simply endowed with greater precision. In individual cases the name of the most characteristic mineral is prefixed for purposes of distinction.

	Eruptive (= Lava-flows).	Intrusive (= Dyke rocks).	Plutonic (= Rock consolidated at great depths).
Acid	Rhyolite ...	Granophyre ...	Granite
Sub-acid ...	Trachyte ...	Felsophyre ...	Syenite
Sub-basic ...	Andesite ...	Porphyrite ...	Diorite
Basic	Basalt ...	Dolerite ...	Gabbro

With these preliminaries we may pass on to the rocks themselves. In South Africa as elsewhere, acid lavas and basic plutonic rocks are rare, while basic lavas and acid plutonic masses are developed on an enormous scale. The only rhyolite which has come under my notice occurs near the Express Mine in the Umniati district of Mashonaland. It shows sparingly distributed phenocrysts of hornblende and orthoclase felspar with rarer quartz, set in a glassy groundmass crowded with globulites, margarites, and longulites. Partial devitrification is evidenced by a cloudiness between crossed nicols, but there are no signs of spherulitic structures. Ilmenite and brilliantly polarizing sphene occur as accessories, but neither is abundant.

Sub-acid lavas appear, like the rhyolites, to be poorly represented, and I am not able to refer any rocks to this division with anything like certainty. There are also a number of lavas probably belonging to the andesites, but in the absence of analyses discrimination from the basalts is a matter of considerable difficulty. A 'melaphyre'[1] from the Kimberley Mine at Kimberley belongs, however, to this class. It is a fine-grained aggregate of lath-shaped felspars with some interstitial chlorite, etc., which may partly represent originally vitreous material. Some of the felspar is untwinned, and is probably orthoclase, while the twinned crystals seem to be andesine. There is no porphyritic constituent, and the amygdaloidal cavities, which are lined with chlorite and filled with chalcedony or with calcite, are the most interesting feature of the rock. Another and rather more basic andesite occurs interstratified with sandstone

[1] This is obviously a different rock to that described by Stelzner.

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at Taba s'Induna, a conspicuous hill about 12 miles north of Bulawayo. The under part of the flow is highly amygdaloidal, but the scoriaceous upper portion was evidently denuded off before the deposition of the overlying rock. Sections from the compact parts of the mass show it to be made up of lath-shaped felspar with much less abundant granular augite. Glomero-porphyritic aggregates of larger felspars are distributed through the mass, and magnetite occurs as an accessory.

We now come to the basalts, and here our only difficulty is one of selection. Undoubted lava-flows are not particularly common in Cape Colony, but further north, and especially in the Zambesi Valley, they are developed on an extensive scale. A rock from Livingstone Island at the Victoria Falls may be taken as typical. It shows a flow structure which is by no means so clear under the microscope as on a polished surface, but is indicated by the distribution of coarse-grained glomero-porphyritic aggregates of augite and labradorite. The bulk of the rock is a granular mixture of augite, plagioclase, and magnetite, with some interstitial matter, the ophitic structure not being developed in any of the specimens I have examined from this extensive area. Another example from

Fig. 1.

the north bank of the river at the Falls is not so fresh, but otherwise quite similar. Some varieties are highly amygdaloidal, the cavities being filled with pectolite and other zeolites as well as calcite, agates, etc. The individual flows can frequently be distinguished by the occurrence of bands of these amygdules at intervals in the great masses of lava. A specimen from the Dekka River on the Falls Road presents some interesting features (Fig. 1). Resinous-looking crystals of felspar are obvious to the naked eye; indeed, they occasionally attain a length of $\frac{1}{2}$ inch, and under the microscope these are seen to form part of glomero-porphyritic aggregates which also comprise good-sized crystals of colourless augite and a few

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rounded grains of olivine, this being the only case in which I am able to record olivine from the rocks of the Zambesi Valley. The groundmass is largely of the usual type, a granular aggregate of lath-shaped felspar, augite, and magnetite, but there is also a considerable amount of glassy material, which is either brown in colour and isotropic, or bright orange, with an imperfect spherulitic structure between crossed nicols.

Though by no means the most abundant type, South Africa affords some good examples of olivine basalt. A beautiful one[1] occurs amongst the rocks which surround the volcanic pipes of the Kimberley diamond-mines, from which they were no doubt originally extended. It is holocrystalline, with a well-marked ophitic structure, and I know of no rock in which the distinction between olivine and the pyroxenes is so well indicated. Both augite and enstatite are present, and their cleavages are well developed, pinacoidal ones being shown by both rhombic and monoclinic variety in addition to that parallel to the prism. Twinning is very common, and the felspars penetrate the crystals in all directions. The olivine, on the other hand, shows distinctly higher refraction and stronger double refraction than the pyroxenes, and the absence of cleavage is in striking contrast to its conspicuous development in their case. It occurs in rounded grains and granular aggregates, which are not as a rule penetrated by the felspars, and are traversed by irregular cracks, sometimes rendered more apparent by incipient serpentinization, though in no case has this proceeded far. The felspars give lath-shaped sections showing repeated twinning, and evidently belong to a variety near anorthite, the maximum extinction angle being about 40°. There are also larger allotriomorphic crystals, which are untwinned but are strongly zoned in layers of different composition. Rather large irregular granules of ilmenite are somewhat sparingly distributed, and perofskite also appears to be present as an occasional accessory.

We now come to the consideration of the dyke rocks, which are more evenly distributed among the various types. I have adopted the term granophyre for the acid division, as it is etymologically a highly appropriate term, but not without some misgivings owing to its having unfortunately been restricted by many authors to those rocks in which the groundmass assumes a micrographic structure. Quartz felsite would perhaps be less open to objection in some respects, but any such double-barrelled expression is very cumbrous when a prefix becomes necessary. With this explanation I do not think that my usage of the term need give rise to any misconception.

Some beautiful granophyres, in the ordinary acceptation of the word, occur near Fort Gwelo in Matabeleland. Large phenocrysts of felspars (chiefly plagioclase), and more rarely of corroded quartz, are set in a groundmass which is partly spherulitic and partly 'microgranitic.' The former type largely predominates, and the spherulites are frequently seen to be composed of radially disposed

[1] This is no doubt the rock referred to by Professor Bonney, GEOL. MAG., 1897, p. 449.

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micrographic intergrowths of quartz and felspar; indeed, under a high power most of them are resolvable into micropegmatite. Large flakes of biotite occasionally occur, and smaller, sometimes idiomorphic, crystals of hornblende are also present. Both ferro-magnesian minerals are somewhat decomposed, chlorite and calcite occurring as alteration products. The felspars are beautifully zoned and for the most part very fresh. They frequently form a nucleus for the spherulites, or the latter may diverge from their angles.

Another type of granophyre occurs in Northern Rhodesia (British Central Africa), near the junction of the Chibwe and Zambesi Rivers. It shows good-sized phenocrysts of felspar, and smaller ones of quartz, set in a purplish groundmass. It bears a considerable resemblance to the well-known 'quartz porphyry' which occurs so abundantly as boulders in the New Red Breccia near Teignmouth in South Devon. The groundmass is, however, of a finely granular type, and is by no means so red. Both quartz and felspar occur in idiomorphic but corroded crystals, and the latter seems almost entirely referable to microcline, though decomposition has obscured the cross-hatching in many cases. Magnetite and sphene are abundant accessories, while there are also occasional prisms of zircon.

At Francistown, in Bechuanaland, occurs a granophyre in which hornblende is the principal porphyritic constituent. A second generation belongs to the groundmass, which is, however, composed principally of quartz and felspar with abundant apatite and sphene. The quartz, though not thoroughly idiomorphic, occurs in grains and granular aggregates, and almost invariably presents convex boundaries to the felspar. Orthoclase predominates, but twinned plagioclase is also present.

A rock which has quite a granitic appearance in hand-specimens occurs at the Dopodge River near Waukie, in Northern Matabeleland. It shows large porphyritic felspars, which are seen under the microscope to be orthoclase. They are frequently twinned on the Carlsbad plan, and often show rounded inclusions of quartz. Plagioclase is also present. Both muscovite and biotite occur, sometimes as aggregates, and the latter is largely chloritized. The groundmass, which does not make up a very large bulk of the rock, is partly micrograniti and partly micropegmatitic. In the latter case the quartz is of what has been called the 'vermicular' type, being rounded and showing a wavy outline in longitudinal sections.

The designation felsophyre has been adopted instead of the very ambiguous term felsite for the dyke rocks corresponding to the syenites. A number of the 'amygdaloidal diabases' and 'felsites' of Cape Colony no doubt belong to this division, but without chemical analyses it is difficult to assign them to their proper position. A large intrusion near Belingwe, in Matabeleland, may, however, be referred here with some certainty (Fig. 2). It consists of idiomorphic felspars (orthoclase and oligoclase) imbedded in a 'felsitic' groundmass, stained with chlorite, representing the original ferro-magnesian mineral. The orthoclase is identified by the simultaneous straight extinction of the two halves of a Carlsbad

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twin, while the oligoclase gives a maximum extinction angle of about 10°, and is nearly always twinned on the pericline as well as the albite type. The prism faces are well developed, especially in the orthoclase, and the crystals are usually elongated in the direction of the vertical axis. A few grains of ilmenite occur in the groundmass. Another rock from Belingwe may be referred to the porphyrites. It is very similar to the last in appearance and structure, but is obviously more basic. Andesine is the predominant porphyritic felspar, and patches of chlorite appear to represent a ferro-magnesian constituent which was also possibly porphyritic. Numerous granules of leucoxene indicate the presence of original ilmenite, and apatite also occurs in shortish prisms. Epidote and calcite are decomposition products.

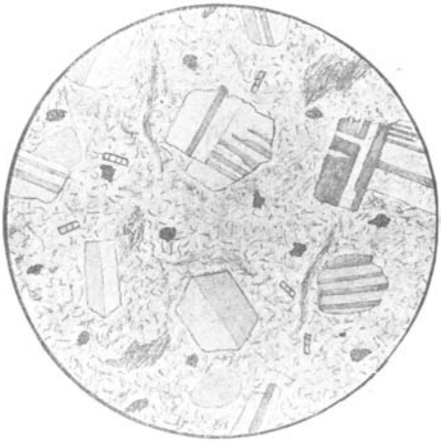

FIG. 2.

Quite another type of porphyrite is represented by a specimen from the Modder River. It consists of an aggregate of fair-sized lath-shaped felspars, with elongated crystals of augite, largely chloritized, granules of ilmenite, small but numerous, and a good deal of glass. The last is of quite a bright green colour and perfectly isotropic, but it encloses numbers of minute colourless spherulites, which never give a black cross in polarized light, but show an extinction curve exactly similar to the 'brushes' of a biaxial interference figure. The felspar seems to be mostly andesine. Like many of the South African dyke rocks this example is amygdaloidal. The amygdules are almost spherical as a rule, and are made up of calcite and quartz, sometimes intermixed, with a border of feebly pleochroic chlorite. Crystals of pyrites occur as inclusions in the calcite.

We now come to the dolerites, which present great diversity of structure. Glassy examples occur at the Criterion Mine not far from Bulawayo and at the Bonsor Mine in the Selukwe district of Matabeleland. At the former locality the intrusion appears to be

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completely glassy. It is considerably altered, being practically a 'palagonite,' but the mass of the rock is quite isotropic, though it is crowded with crystallites (longulites) and minute specks of magnetite. It shows occasional rather irregular spherulites. At the Bonsor Mine the glass forms the margin of an intrusion into quartz schist, and becomes rapidly more crystalline and apparently also more basic as it is traced from the contact. About an inch from the edge it is dark brown in colour, and crowded with crystallites and tiny microlites. It shows also idiomorphic phenocrysts of augite and more or less corroded felspar, the latter evidently a basic variety and largely converted into epidote.

The more crystalline varieties are usually of the granular type and do not as a rule contain olivine. The dykes which pierce the Cape Town granite afford good examples. They consist of lath-shaped felspar, augite, rarely idiomorphic, but of prior consolidation to the felspar, magnetite, ilmenite, and a little interstitial matter. Chlorite occurs as a decomposition product of the augite. The felspar appears to be labradorite, and one specimen of the rock gave a silica percentage of 52·41.[1]

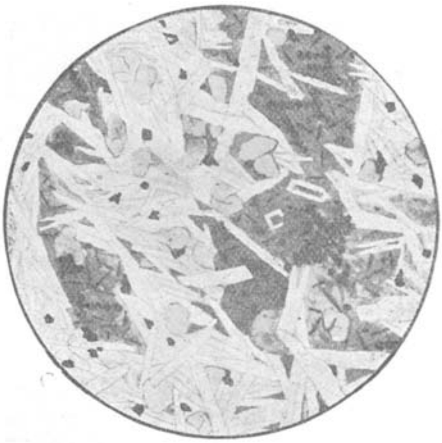

Fig. 3.

A very similar rock, but with a good deal of glassy matter, penetrates the Matopo granite mass near Forest Vale (Fig. 3). The glass is brown in colour and quite isotropic. It is crowded with little rods of magnetite, very long and thin, while skeleton crystals of felspar are also of frequent occurrence. Magnetite is very abundant all through the rock and is almost invariably idiomorphic, little octahedra being common which are frequently grouped in rows, sometimes apparently along the edges of a cube. The lath-shaped felspars often show bifurcated terminations and inclusions of the groundmass. This rock is near the margin of one of the outliers of Tertiary (?)

[1] Cohen: N.J. für Min., 1874. See also Shaw: Proc. S.A. Phil. Soc., vol. i, pt. 2 (1879), p. 59.

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sandstone which rest unconformably on the Bulawayo schists and the marginal portions of the Matopo granite mass. These are evidently of the same age as the coal series and associated beds of the Zambesi Valley, from which several lavas have been described. A dyke penetrating the sandstone itself at Mafungaburi Peak, Matabeleland, is of the same type, but contains a smaller proportion of glass, while the crystalline constituents are of larger size. The augite is frequently idiomorphic, and is of prior consolidation to the felspar. Good-sized rods of magnetite are abundant, but do not show the definite outlines of the Forest Vale variety. Another rock from the Zimba River, Northern Rhodesia, is holocrystalline and rather coarser-grained. The felspars frequently show pericline as well as albite lamellation, and must be nearly related to anorthite. The augite occasionally shows crystal outline, and microlites occur as inclusions in the felspar, but the latter sometimes penetrates the larger crystals. Rods of magnetite are freely scattered through the mass, and apatite is also present.

A transition to the ophitic structure is seen in a specimen from the Waterworks, about 4 miles from Bulawayo. It consists of large plates of augite, for the most part in a beautifully fresh condition, and very decomposed felspar. It seems evident that the augite originally tended to be porphyritic, but when the felspar commenced to crystallize out, crystals continued to grow instead of a second generation forming in the groundmass. This is shown by the fact that the felspars never occur as inclusions in the augite, and seldom penetrate more than a very short distance from the margin of the crystals. If there was originally any glassy matter it is now lost in the confused mixture of decomposition products due to the alteration of the felspar. Ilmenite is abundant, and sometimes shows fine examples of skeleton crystals, while a colourless mineral with very strong refraction and double refraction is probably sphene.

A beautifully fresh ophitic olivine dolerite occurs near Fort Gwelo, Matabeleland, on the Sebakwe Road. The felspar gives the usual lath-shaped sections in most cases, and frequently shows pericline lamellation. The augite is penetrated by the felspar in all directions, and often occurs in aggregates. The olivine is rarely penetrated by the felspar, and shows a rougher surface and higher interference tints than the augite. The cleavage is occasionally shown, and the mineral is traversed by the usual irregular cracks, which are now and then rendered more prominent by incipient serpentinization. A curious feature is the enclosure in the olivine of small crystals of a brownish pleochroic hornblende with well-developed cleavage. A few minute flakes of biotite also occur. Both these minerals are usually associated with grains of magnetite.

Among the plutonic rocks the granites afford examples of a number of varieties. The coarse-grained biotite granite of Cape Town has been described by Cohen [1] and others, so that it is needless to enumerate its normal features. One variety, however, seems worthy

[1] N.J. für Min., 1874.

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of mention, a graphic modification with tourmaline as an abundant accessory. The latter mineral seems to be intergrown with the felspar in a similar way to the quartz. It is a yellowish variety without marked pleochroism, and the interference tints are not masked, as is often the case, by the strong absorption. It may possibly be regarded as having replaced quartz, but it seems more likely that the intergrowth is more apparent than real, and is due to the penetration of the mineral into cleavage cracks in the already consolidated felspar. A graphic granite from Northern Rhodesia, about midway between Kalomo and Monze, may also be noticed. The felspar, which builds pink crystals several inches in length, is microcline. The quartz does not occur in well-defined skeleton crystals, but gives a somewhat irregular wavy longitudinal section and a rounded transverse one. Occasional small flakes of muscovite are present.

The great granite mass of the Matopos, which forms the backbone of Southern Matabeleland, presents some interesting features. The normal granite in hand-specimens closely resembles the Dartmoor rock (e.g. that of Hay Tor). In a rather fine-grained example from the Khami Valley the dominant felspar is, however, seen under the microscope to be microcline. It is obviously the last product of crystallization, as it even encloses the small patches of micro-pegmatite which occasionally occur. Orthoclase and oligoclase are also present, the former being apparently the felspar of the micrographic intergrowths. Biotite is the ferro-magnesian constituent. Sphene and apatite are the accessories. Near Bulawayo, which is situated on the contact zone, the rock assumes a very different aspect. The structure is decidedly gneissic, and the felspars are flesh-coloured. The appearance of foliation is probably due to movement before complete consolidation (Fig. 4). This seems to be implied by the granulation of the quartz and microcline[1] and the absence of deformation in the minerals of prior consolidation. It does not do, however, to place too much reliance on this feature, for, as I have previously[2] pointed out, it is precisely these minerals which most readily yield to the effects of pressure, and the quartz may be completely granulitized before the other minerals are appreciably affected. Hornblende is here the dominant ferro-magnesian constituent, though biotite is present in most slices. In the pegmatite veins which ramify through the mass and are obviously of late consolidation, microcline takes the place of the other felspars, but in the normal rock orthoclase seems to be rather more abundant and oligoclase frequently forms large pseudo-porphyritic crystals. Sphene, apatite, and zircon are all fairly abundant, the two former building rather large crystals.

The syenites are represented by what I may term the Hillside intrusion, three miles from Bulawayo, which is of so much interest that I hope to describe it fully in a future paper. I may mention,

[1] See MacMahon on the gneissose-granite of the Himalayas, Geol. Mag., 1897, pp. 345–355.

[2] "The Copper-bearing Rocks of South Australia": Brit. Assoc., 1901.

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however, that the most abundant variety is an even-grained rock of typically granitic structure, but entirely destitute of quartz. The felspar is almost exclusively microcline, while hornblende and augite are about equally abundant. Sphene occurs in very perfect yellowish crystals, while apatite, zircon, and magnetite are also present. An augite-diorite occurs as a basic modification of the mass, but more typical diorites occur as segregations from the Matopo granite near Bulawayo. In these hornblende is the ferro-magnesian constituent, while microcline, oligoclase, and orthoclase are present as in the granite itself. Apatite and sphene are very abundant, and often form large though somewhat irregular crystals. There are also a few granules of magnetite.

Fig. 4.

Numerous intrusions or segregations of gabbro occur in the very interesting plutonic complex round the Umniati River in Mashonaland. One example from the Goedyema Road, north of the Sarui River, is a beautifully fresh rock made up entirely of augite and felspar. The structure is typically granitic and the grain coarse and even. There is not a single grain of magnetite present, and the rock is consequently remarkably light-coloured for so basic a variety. Most of the augite shows diallagic striation and schillerization, due to the presence of two sets of rather large, regularly arranged inclusions. The felspar is evidently near anorthite, giving symmetrical extinctions up to 37°. Specimens from three other localities in the same district have characteristics which seem to be due to the influence of the rocks into which they were intruded. In one from the Sarui River, enstatite is the most abundant ferro-magnesian constituent. It occurs in elongated crystals of considerable size and is partially altered to serpentine. Augite is also common, and often shows good cleavage and a basal striation. This, combined with twinning on the orthopinacoid, gives rise to good examples of the 'herring-bone' structure. Repeated twinning is also well

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shown, one large crystal being divided into six equal-sized lamellæ. The felspar is allotriomorphic. It forms large grains which exhibit Carlsbad, albite, and pericline lamellation. The extinction angle rises to at least 30°. Small flakes of biotite and granules of ilmenite are present. A little quartz also occurs, chiefly as micropegmatite. A specimen from the Gwelo-Selukwe Road shows more abundant biotite in small, very pleochroic flakes. The dominant ferro-magnesian mineral is, however, augite, in which the herring-bone structure is almost always shown. A little enstatite and hornblende are present, the latter sometimes bordering the augite. The plagioclase evidently approaches anorthite in composition, and forms larger grains than the other constituents. Ilmenite sometimes builds good-sized irregular granules, while quartz, chiefly in micrographic intergrowth with felspar, is sparingly distributed. A specimen from another locality is remarkable for the abundance of strikingly pleochroic yellowish biotite, so that it may be described as a biotite gabbro. Hornblende is also present and sometimes borders the augite. In other respects the rock is similar to the two previous varieties.

Though somewhat rare, as in other parts of the world, ultrabasic rocks are widely distributed in South Africa. They have, indeed, received more attention from European geologists than any of the other divisions. The breccia and eclogite of Kimberley and of Jagersfontein in the Orange River Colony are so well known that it is needless to do more than mention them. The very interesting melilite-bearing rock from the Spiegel River in Cape Colony, described by Professor Cohen,[1] provides the only instance of the occurrence of a felspathoid, other than nepheline, in our province, though leucite basalts, etc., have been recorded from Kilimanjaro in Central Africa. Picrites have been described from the Transvaal and elsewhere by various writers, so I will confine myself to a brief mention of a rock from Porselt's Vlei on the road from Inciza to Belingwe in Southern Matabeleland. It is very coarse-grained and of a uniform dark-green colour. Olivine appears to be the sole constituent, as iron-ores are conspicuous by their absence, and there are no indications in thin section which would lead one to suspect the presence of any other ferro-magnesian mineral. The rock is beautifully fresh and quite free from even incipient serpentinization.

VI.—River Development.

By S. S. Buckman, F.G.S.

In the Quarterly Journal of the Geological Society, May, 1902, vol. lviii, p. 207, Mr. A. Strahan has a paper on the "Origin of the River-System of South Wales, and its Connection with that of the Severn and Thames." It is with the part of the paper expressed in the latter portion of the title that I am more particularly concerned; for in that connection Mr. Strahan remarks

[1] T.M.M., 1894, p. 188. See also Ann. Rep. Cape Geol. Comm., 1898.

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