GEOLOGICAL REPORT* ON THE COUNTRY TRAVERSED BY THE SOUTH AUSTRALIAN GOVERNMENT NORTH-WEST PROSPECTING EXPEDITION, 1903.

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[Read October 4, 1904.]

[*From "Transactions of the Royal Society of South Australia," vol. xxix., 1905.*]

PLATES XIII. TO XX.

CONTENTS.

THE RANGES OF NORTH-WESTERN SOUTH AUSTRALIA.

Although maps represent these ranges as separate entities, they must, on geological and lithological grounds, be regarded as belonging to one and the same grand system, the intervening tracts of country which now separate the individual ranges being, for the most part, superficial deposits of comparatively recent sands and sandhills, or supra-cretaceous deposits, known as the "desert sandstone."

Rising abruptly † from the surrounding sandy country,

* This paper, which has been slightly abridged, was the successful Tate Memorial Medal Thesis, 1904.

† Compare J. Forrest, Explorations in Australia, III., page 248:—"The whole country is level, the ranges rising abruptly out of the plains, . . ." Also the general statement by James Geikie, in Earth Sculpture, page 202:—"Rising boldly above the general level, they exhibit no trace of talus or debris. . . ."

they extend in an easterly and westerly direction as huge, intrusive masses within crystalline schists and gneisses, mostly devoid of vegetation, though the intruded rocks bear "mulga," pine tree, and undergrowth of bush and grass. Fertile sandy loams, carrying mulga scrub of variable extent, surround them; while beyond this belt sandhills with "porcupine grass," "desert oak," "quondong," etc., prevail.

Their main bulk consists of plutonic masses, which form the cores of anticlinal folds of metamorphic rocks. Owing to the intense metamorphism induced not only in the intruded rocks, but also at the outskirts of the igneous intrusions themselves, it is often impossible to determine the actual plane of contact. * This factor has further been the cause of the contact rocks assuming a distinctive character by re-crystallisation of the original constituents *(Hornfelsstructur).* In this process the production of epidote has been greater than that of all other minerals, it being by far the most generally distributed near intrusions.

The following section is a diagrammatic representation of the mode of occurrence of the igneous and metamorphic series.

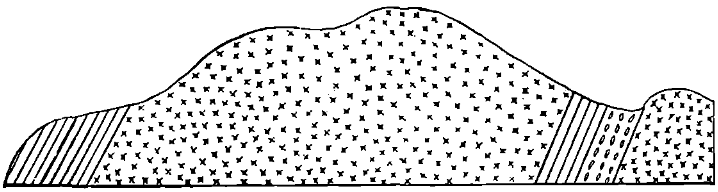

FIG. 1.—DIAGRAMMATIC SECTION THROUGH PORTION OF THE MUSGRAVE RANGES, EAST OF MITCHELL'S KNOB.

Owing to the absence of representatives of the Cambrian system in proximity to the ranges, the age of the igneous intrusions could not be definitely determined, but they certainly took place before the Ordovician period, as examples may be seen in the low-lying outskirts, as, for instance, Indulkana, of rocks of the Ordovician period overlying the intruded fundamentals, and not being themselves penetrated by the eruptives.

The Musgrave Ranges comprise an extensive series, ranging from acid to basic; the Mann principally acid and inter-

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* Mons. Michél-Levy has described similar features in the gneisses of the Central Plateau of France. He points out that whenever it is the case that the granite is massive and intrudes rocks of acid character the plane of contact is not sharp, but the intruded and intrusive rocks are connected by a contact zone.—Bull. Soc. Géol., France, Ser. 3, tome vii. pages 852 et 853.

mediate; while in the Tomkinson Ranges members of the basic and intermediate families are typical. The intermediate group is represented throughout by numerous diorite dykes, which are usually of no great thickness, but their frequent appearance within short distances of one another is in cases marked. Their plane of contact with the intruded rock is always well defined.* The diorite intrusions have occurred later than the main granitic injections of the district. This is evident from the fact that often the diorite can be found penetrating the granite.† Yet the diorite in places does not appear to have been much subsequent in time, for magmatic intergrowths may be observed between diorite and granite rock that have been produced during a state of semi-plasticity of the latter. On the other hand, magmatic inclusions of granite rock within the diorite occur. These have been torn from the walls of the fissure, into which the diorite was injected, and embedded in the mass.

The intruded rocks, where they appear in considerable and persistent thickness *(Mächtigkeit)*, may be included generally under the headings of "gneissic quartzite" ‡ or "gneiss" proper; yet other crystalline schists are not wanting, although they are not represented to the same extent. The great variations in readings of the compass needle, produced by the magnetic minerals contained in the different granitic rocks that compose these ranges, have already been noted by various explorers.

The Musgrave Ranges.

General Remarks.—The Musgrave Ranges (Gosse, 1873) lie almost wholly in the State of South Australia, only two minor offshoots passing northward to beyond the boundary, in the localities of Opparinna and Fraser Hill. They rise from the plains as a compact chain that continues in an easterly and westerly direction for a distance of over one hundred miles. They are, however, cut in several places by valleys of denudation that are now occupied by vast deposits of sand, the upper surfaces of which form elevated plains (such as Glen Ferdinand), that permit the ranges being crossed with no great difficulty transversely to their long axis. Their breadth varies, the maximum being about thirty-five miles,

* Compare Michél-Levy, *op. cit.*, pages 845 et 872.

† See also H. Y. L. Brown, Report Journey from Warrina to Musgrave Ranges, page 2 (Adelaide: by authority, 1889): and V. Streich, Scien. Res. Elder Expl. Exp., Trans. Roy. Soc., S.A., vol. xvi., pp 77 and 83.

‡ An altered (clastic) sandstone in which only a very faint indication of foliation has been brought about by the production of secondary minerals.

and the altitude is considerable. Mount Woodroffe, the highest peak, is estimated to be over 5,000 feet above sea level, and more than 3,000 feet above the level of the adjoining desert. Hence this chain of mountains is by far the most massive of the series seen during the expedition.

Igneous intrusions on a grand scale have produced the upheaval and form the inner mass of the several folds into which the intruded metamorphic beds have been thrown.

Mr. W. C. Gosse, in 1874, pointed out that the Musgrave Ranges "are composed chiefly of granite,"* and later Mr. H. Y. L. Brown † (1889) that they "are composed of eruptive granite and metamorphic granite rocks of various kinds, chiefly hornblendic, and seldom containing mica," comprising "ordinary granite, porphyritic granite, hornblendic granite, graphic granite, granulite, pegmatite, syenite, quartz syenite, and epidosite, gneiss, both hornblendic and micaceous, and siliceous and felspathic crystalline rocks of various kinds," and that they are intruded by diorite and dolerite. Mr. J. Carruthers stated:— ‡ "The Musgrave Ranges are composed principally of red granite rocks, and covered with spinifex and few scattered pines: the flats between the hills, which are principally formed by large creeks coming out of the ranges, are beautifully grassed, . . . the soils being a rich, red, sandy alluvial, and firm red loam."

Igneous Rocks.—The intrusives vary in character from highly acidic to basic, the differences, however, between the members of one and the same family being slight. The acid rocks are principally granitic, the greater bulk consisting of a rather coarse-grained porphyritic variety, with large corroded crystals of a bluish felspar (orthoclase). Ernest Giles was the first to mention§ this type of granite, and assigned to it the expressive term of "granite-conglomerate," making thereby particular reference to Mount Carnarvon, which is the eastern limit of the Musgrave Ranges. Mr. W. C. Gosse, moreover, in describing Mount Morris, wrote ‖ "that this portion of the range is composed of very coarse granite. At the entrance to Jacky's Pass, on the south, this class of granite flanks the chain, but further east the southern slopes

* Parliamentary Paper, No. 48, House Assembly, page 18.

† Report on Journey from Warrina to Musgrave Ranges. By authority: 1889.

‡ Report to Surveyor General (*Adelaide Observer*, January 16, 1892).

§ Geogr. Travels in Centr. Austr., 1872-1873, Part ii., page 84.

‖ Parliamentary Paper, No. 48, House Assembly, 1874, page 16.

consist of fine-grained gneiss, the granitic outcrops being in the heart of the range. The main intrusion thus extends east of the pass towards Mount Woodroffe, thence taking a more northerly turn in direction of Mount Carnarvon; it has its greatest development east of Harries' Spring, while on the eastern borders of the range gneisses predominate. In this respect the Musgrave resemble the Mann Ranges

A subsidiary arm of the main injection of the igneous rock produces a prominence in the neighbourhood of Mitchell's Knob, the major and minor veins of the same enclosing clastic (?) gneisses. (See fig. 1.)

The ranges on the northern flanks, north of Mount Ferdinand, present a picturesque appearance, produced by grotesquely shaped, isolated, bare, granitic masses *(Sekundäre Kuppen)*.

The granite, particularly that of the porphyritic variety, is characterised in the field by its strong tendency towards concentric weathering, large shells of rock exfoliating concentrically to the present contour of the rock surface. This feature is deserving of particular notice.

In the valley of the Ferdinand, west of the mount bearing a similar name, the character of the granite changes to a more even-grained, white variety, with irregular aggregates of hornblende and biotite distributed through its mass. Where this granite has been cut by diorite the contact is marked by a development of large idiomorphic crystals of hornblende. In the same locality minor veins of epidote granite, with a red orthoclase felspar, and graphic granite traverse the main granitic mass in a westerly course.

East of Lungley's Gully an intrusion of red aplite is delicately veined with crystalline epidote, and the planes of slickensiding, that cut the rock, are lined with a "*harnish*" of secondary mica and rhombohedral calcite. The rock is conspicuously jointed in two planes, the first of which strikes W., 20° N., and dips northerly 73°, the second striking N., 45° E., and dipping 23° S.E.; a third plane is less regular. Rocks belonging to the peridotite family were found in the form of pebbles among the wash of a small watercourse south of Mount Morris, but the rock was not observed *in situ*. Diorite dykes are very plentiful. The diorite rock is normal, quartzless, and moderately fine-grained. It is usually micaceous. Dolerite dykes are less numerous. They consist of a finely crystalline groundmass with porphyritic crystals of felspar and pseudomorphous (?) epidote. Dykes of a peculiar volcanic rock are rare. Fluidal structure is typical when viewed under the microscope, it being marked by ores of iron in a glassy groundmass. Corroded phenocrysts of olivine are plentiful.

Metamorphic Rocks.—The gneisses of the Musgrave Ranges, derived both from the alteration of sedimentary and igneous rocks, with few exceptions, skirt the chain on either side; they also form the intermediate flanks of folds produced by the intrusion of the eruptives. They do not extend to the same altitude as the igneous rocks, and, as is the case in the Mann Ranges, they appear more extensive on the eastern than on the western limits of the range.

A natural section along the course of Whittell's Creek presented a variety of schists within small range of country. The section showed a gradation from a compact gneiss through a series of beds, as follows:—Quartzite, quartz schist (laminated), schists of various kinds (mica, chlorite, epidote, and garnetiferous, with numerous perfect dodecahedral crystals of garnet in a dark quartzitic, schistose matrix); thence quartzite, jointed regularly in two directions at right angles. The strike varies from almost due north and south to east and west; the latter is, however, the general strike of the beds of this section. East of Mount Woodward the gneisses are in parts compact, in parts fissile. They are jointed vertically in direction north, few degrees east, and at right angles to this plane. The planes of foliation dip south. North of here it is distinctly granitic in character, and separated into more or less horizontal (lenticular) layers by planes of division; these layers thickening appreciably as the depth increases *(Bankförmige Absonderung)*. At the contact with a diorite dyke it has assumed a remarkable, closely foliated character; the folia, produced by a very dark coloured biotite and stringlets of quartz running parallel with the direction of intrusion.

The gorge cut by the Opparinna Creek affords another section within the gneisses that skirt the watercourse in the form of scarped, shattered walls. They show signs of earth - movement and folding, and are replaced in parts by smaller bands of chloritic and sericite schists. often traversed by small seams of epidote at the zone of contact with diorite dykes. At Opparinna Spring the country consists of a compact, dark bluish-black gneiss, vertically jointed in directions W., 20° N., and N., 10° E. (less perfectly), and in planes dipping S. 5°. Along the last-mentioned plane the rock parts readily into layers about twelve inches thick. North of the spring the metamorphic series changes to a compact brown gneiss, weathering massive granitic, and showing a regular cubic jointing. The texture, in parts, approaches the "graphic" intergrowth of some granites, the quartz occurring as rounded and elongated inclusions (*quartz de corrosion*) in the felspar.* The optically-continuous character of the quartz and felspar can readily be detected in hand specimens by suitably reflecting the light from a freshly fractured surface. The planes of foliation of the true gneiss strike W., 20° S., and dip northerly 11°.

South of Opparinna Spring the gneissic quartzites † composing the ranges are thrown into a great overthrust fold which can be observed on the eastern face of the gorge cut by Moffat Creek, by following up the exposure of two prominent parallel layers of the rock. These, on the south, dip at a low angle of about 30°, and on the north the same bands are seen dipping in the same direction at a high angle, with an inward curve at the top. The crest of the fold has been removed by denudation; yet the outline of the original contortion of the beds, upon reconstruction, was evidently as represented in the figure. Within the fold exists a zone of extensive dioritic intrusion, while the country is severely fractured.

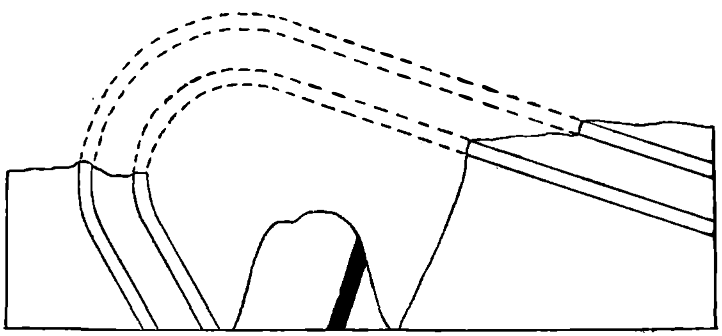

FIG. 2.—AN OVERTHRUST FOLD IN BEDS OF GNEISSIC QUARTZITE. MOFFAT CREEK, SOUTH OF OPPARINNA SPRING, MUSGRAVE RANGES.

A similar feature, though on a smaller scale, was encountered in Jacky's Pass. Beds of gneiss are in this case bent to a considerable degree; a diorite intrusion within the fold accompanied the earth-movement.

Several island-like masses of gneiss rise above the sands to the west and south-west of the group of hills termed the Kelly Hills. One of such occurs close to a native soakage

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* Lacroix has described a somewhat similar type of gneiss from Southern India.—Record Geol. Survey, India, xxiv., page 157 (1891).

† No doubt equivalent to the "granitoid quartzites" of this locality mentioned by R. W. Murray. Extracts Journals of Explorations, by R. T. Maurice (by authority: 1904, page 29).

well, known to the natives as Tarrawaitarratarra, and it has been conditioned by the intrusion, within a series of schists, of pegmatite and greisen. The muscovite of the pegmatite is remarkable for its peculiar reddish-violet tint, closely resembling that of lepidolite, but failing to give the characteristic flame test of the latter. The mica, moreover, of one of the schists is similar to that of the true igneous rock, though it occurs as smaller individuals. The schist is usually a closely laminated, quartz-mica rock, often "knotted" by secondary mineral development; while at the contact with a diorite dyke on the summit of the hill a finely foliated gneiss has been produced. The planes of schistosity strike N., 12° E., and dip 40° E. The height above sea level of the exposure is 2,100 feet, and it stands 140 feet above the sand plains. The beds have suffered local displacements; planes of shear are thickly lined with a glossy layer of secondary minerals.

Outcrops some miles to the north of this exposure were presumably observed to be overlaid by conspicuous beds of quartzite. Opportunity was not afforded to determine whether these beds form part of the fundamental series or whether they are unconformable to the schists.

The hills further south are composed of rock of the compact granitic character already discussed. In parts they are of the "fluxion" type of gneiss, and they are characterised by weathering concentrically.

OUTLIERS OF THE MUSGRAVE RANGES.

The Musgrave Ranges are bordered on the south by numerous outliers of granitic rock, many of which are of considerable magnitude, and have consequently received separate names. A few of these outliers will be briefly discussed: —

Mount Caroline.—South of that portion of the Musgrave Ranges known as Lungley's Gully, about eight miles, stands a bold, isolated mount, over 1,000 feet above the level of the sands. It is known as Mount Caroline. Its mass is composed of biotite granite, with a slight tendency to foliation on the part of the mica. Large porphyritic, corroded crystals of orthoclase predominate, the quartz being subordinate to the felspar. The rock at the surface is decomposed. It is cut by a diorite dyke that can be distinguished on the western front from a distance as a black wall running up the entire height of the mount. Smaller portions of graphic and epidote granite are included within the mass.

The hill bears porcupine grass, pine and fig tree, and a light-coloured lichen covers the massive exposures of the granite.

Low outcrops of gneiss trending in a north-easterly direction lie not far to the north of Mount Caroline.

Mount Crombie.—Still further south, and about twenty miles from the above, another conspicuous outcrop of granitic rock, bearing the name of Mount Crombie, is situated. The northern outskirts only of this exposure were visited. They consist of gneiss, whose dark planes of biotite strike roughly east and west. The rock exfoliates concentrically at the surface into large shells, which subsequently break up regularly into cubical blocks in well-defined rows, corresponding to a latent system of planes of weakness brought into prominence by weathering. A diorite dyke intrudes the gneiss in direction W., 42° N.

Mount Kintore.—Mount Kintore rises from beneath the desert south of the gap that separates the Mann from the Musgrave Ranges. It is built up principally of metamorphic beds intruded by diorite dykes. The beds, comprising gneisses and quartzite, have been thrown into a series of simple folds, which is well recognisable on the northern face of the mount. Gross shattering and crumbling of the rock have accompanied the folding. The strike of the beds varies slightly, about south-east, and it is made prominent by the weathering of the rock into ridges conforming in direction with that of anticlinal axes.

At the western end of the outcrop the gneiss is replaced by a development of graphic granite; and diorite intrusions traverse the hill in several localities.

Echo Hill.—Echo Hill lies south of the eastern extremities of the Musgrave Ranges. It is one of many minor outcrops of granitic rock occurring in this neighbourhood, and is composed of gneiss neatly "lined" with biotite. Is is cut by veins of coarse pegmatite, with large felspathic constituents, while local developments of epidote are frequent. The rock is jointed in planes striking S. 40° W., and dipping 40° N.W. The height of the hill is 2,270 feet above sea level (by aneroid determination).

The Mann Ranges.

General Remarks.—The Mann Ranges, discovered and named by Gosse in 1873, lie to the west of the Musgrave, and are separated from them by a desert tract of sandhills bearing *Triodia* and *Casuarina*. They extend as a more or less compact chain in a westerly direction, with a slight trend to the north, across the border of South Australia and the Northern Territory, a distance of some eighty miles. Isolated hillocks can be traced to beyond the border line of Western Australia, culminating to the westward in a more pronounced development, known as the Mount Gosse group of hills. The trend of the Mann Ranges, if produced in an easterly direction across the intervening tract of sandhills, is in the same straight line as the axis of the Musgrave Ranges.

Both ranges consist of igneous intrusions* and altered sedimentary and igneous rocks. The western portion of the Mann Ranges, of no great width at this end, consists almost wholly of igneous exposures. In the centre the core of igneous intrusion is flanked on either side, namely, its northern and southern boundaries, by complexes of gneiss, schist, and gneissic quartzite; whereas on the eastern limits of the range, by far the widest portion, the main intrusion lies hidden beneath the metamorphic series, into which it was injected, to appear once more at the surface to the eastward, in the Musgrave Ranges.

A ground plan of the metamorphic exposures of the Mann Ranges gives roughly a U-shaped form, the flanks that skirt the middle of the ranges forming the straight arms of the U, the curved base of the letter being represented by the thicker mass of crystalline schists at the eastern end.

As a rule, the trend of the ranges coincides with the strike of the rock, except in a few instances, where irregularity of stress produced by igneous intrusion has interfered, and where a local bulging out of the mass, no doubt the result of an igneous offshoot, has produced a spur, the axis of which does not conform with the general direction of the range.

Though mineralogically not as rich as the Musgrave Ranges, the Mann Ranges are geologically of particular interest, as they exhibit many examples of rock movements and fracture that accompanied igneous intrusion. †

Igneous Rocks.—An intrusion of granite has been by far the greatest, it continuing uninterruptedly as the backbone of the whole range, to disappear under superincumbent gneisses on the east, and occurring as isolated outliers for a considerable distance to the west. The character of the rock varies, passing from a true granite (in portions porphyritic), to various metapyrigen gneisses. ‡

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* Compare J. Forrest, Explorations in Australia, III., page 243:—"The Mann Ranges are composed of reddish granite." Also J. Carruthers:—"The Mann Ranges are covered with pines, bloodwood, a few scattered gums, dense spinifex, and scattered patches of coarse grass, the formation being red and grey granite."—(*Adelaide Observer*, January 16, 1892, page 9.)

† Compare the statement:—". . . hills and mountains of the Mann Ranges, some few of the Musgrave chain, and all west of the Mann Ranges have been shivered into fragments by volcanic force, . . ."—E. Giles, Geogr. Travels in Centr. Austr., 1872-1873, Part ii., page 103.

‡ The term as employed by Dr. J. W. Gregory.

The plane of contact with the primary gneisses is mostly imperceptible. A contact zone is not infrequently found gradually merging into granite on the one side, and granitic gneiss on the other. In other cases the contact has been so fractured and dislocated for a considerable distance that the junction cannot be traced.

Large "floating" masses of bedrock were noted at several localities, as, for instance, north-west of Mount Whinham and south of Mount Edwin.

The granite in general occurs as bare, rounded, dome-shaped masses,* several chains' length of rock often appearing without the least fracture in the mass, though subsequent weathering produces large exfoliating shells, which detach themselves from the body of rock (concentric weathering). This feature is more usually presented by the porphyritic varieties, while a more typical granitic aspect is brought about by the natural systematic jointing of the fine-grained, uniformly crystalline rock. Frequently the mass shows neither of these physical features, but is grossly shattered throughout by the intense stress produced during the process of solidification of the crystallizing rock magma. Such instances were found south of Mount Cockburn, and on a splendid scale south-east of Hector's Pass, where the planes of fracture have assumed regular, contorted, and curved outlines, as though produced during the last stages of solidification of the magma, the more rapidly contracting envelope of the rock having caused the enclosed mass to part along certain curves of stress by virtue of the extreme pressure from without.

Diorite dykes are very numerous, forming a fairly regular system, usually, though not invariably, trending east and west. The best noted example of excessive intrusion by this rock was observed in the hills east of Mount Whinham, on the eastern extremity of the ranges. At this locality no less than fourteen diorite dykes can be counted traversing the gneissic hills in a distance of less than a quarter-mile, and can be clearly seen continued through a similar gneissic exposure a mile or two further west.

Metamorphic Rocks.—As stated above, crystalline schists and gneisses appear more extensively developed at the eastern end of the chain. Near the north-western limit of the main

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* Giles *(op. cit.)* continues his statement:—". . . most of the higher points of all these heights are composed of frowning masses of black-looking or intensely red ironstone or granite, coated with iron. *Triodia* grows as far up the sides as it is possible to obtain any soil, but even this plant cannot exist upon solid rock, therefore all the summits of these hills are bare."

range, the metamorphosed rock, close to the intrusive, occurs as a fine-grained, compact quartzite, passing further from the contact into a garnetiferous gneiss, with large lenticular crystals of felspar (a variety of adularia, or moonstone), having a satin-like lustre, and which, even to the naked eye, can be seen to be locally surrounded by a layer of finely crushed material derived from the grinding down of the felspar itself *(Morter structure)*.

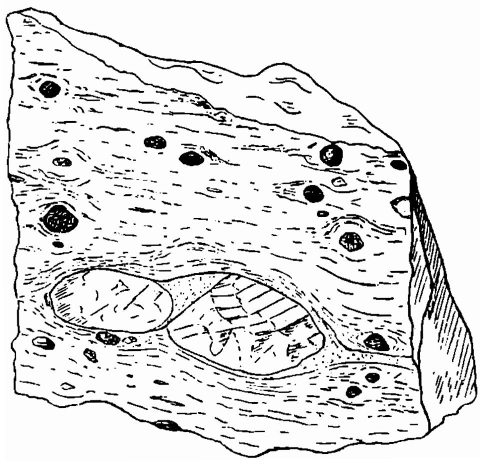

FIG. 3.—AUGEN GNEISS, MOUNT COCKBURN, MANN RANGES.

In the former instance the altered rock was no doubt originally a somewhat massive, siliceous sandstone; in the latter a finely laminated rock has probably been altered by minor injection of igneous matter between the planes of lamination (injection gneiss).

South of Mount Cockburn, however, garnet-schist* and fissile gneiss occur at the zone of contact, while gneissic quartzites overlie the gneiss. It is in this locality that a natural section affords opportunity of studying the relative positions of these altered rocks. (Section on Plate xix.) A granitic intrusion appears in the form of a central axial-core,

* W. C. Gosse writes that Mount Charles is "composed of grey granite and slate." Report and Diary of Cent al and Western Exploring Expedition, 1873. Parliamentary Paper No. 48, House Assembly, 1874, page 12. No slate was observed in this neighbourhood, and it may be that Gosse mistook the schist or fissile gneiss for the same.

trending west, which has thrown the overlying beds into a series of simple folds: an anticlinal directly conforms with the surface of the eruptive, and consists of blue garnetiferous schist and gneiss, with "eyes" of felspar, large crystals of hornblende and fractured garnets. South of this spot the overlying beds of gneissic quartzite can be traced, occurring as two perfect sigmoidal folds, the second synclinal, with a very sharp angle, thence passing to a shallow monocline that is finally lost in the zone of crushing at the contact with a second intrusive mass. The extreme southern exposures of the range occur as outlying masses of gneissic rock, the strike of which agrees with that of the country, and the dip is southerly.

At the foot of Mount Cockburn, a low outlier of the same exposures consists of quartzitic gneiss, the foliation being imperfectly developed, and large, lenticular "augen" of felspar not infrequent. The hill shows perfect parallel planes of jointing in direction N., 15° W., dipping 75° westerly. These planes are made the more conspicuous by the resulting fissures having become filled with detritus, in which a thick growth of grass and other vegetation, standing out as dark, prominent lines from the light-coloured gneiss behind, has flourished.

To the north the augen gneiss merges on the one hand into a gneiss with *linear foliation*, and on the other into a crushed rock, with large, false "pebbles" of quartz, produced from the original rock, surrounded by well-marked, concentric "lines of flow" of crushed material. Shearing and compressive stresses have certainly contributed largely to the formation of the latter, and like forces have produced the augen gneiss, while the ultimate result of rock-crushing and shearing is the finely "lined" variety of gneiss.

Striking evidence of the extreme conditions of stress that existed during the mountain-building processes is afforded at the north-eastern end of the Mann Ranges in the form of a series of *step-faults* on a fairly large scale. The country here consists of compact gneiss, with large, bluish orthoclase and folia of biotite, intruded by diorite dykes. Ten distinct, almost vertical, scarp-faces of gneiss, rising one above the other, can be seen, each surmounted by the severed portions of one and the same diorite dyke. The igneous rock, four feet in thickness, forms the floor of each step, the vertical distances between the successive steps averaging twelve feet, and each fractured mass of the diorite dyke dipping about 10° S. The several fault planes hade 10° in a direction N. 10° E.

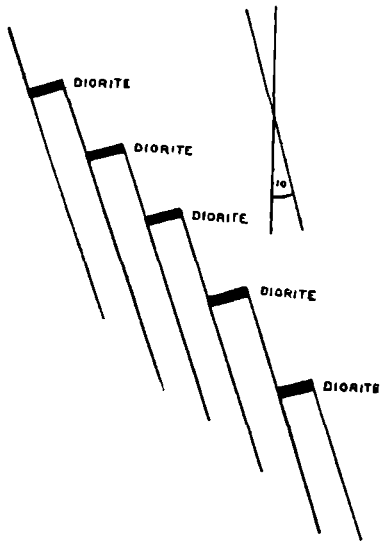

FIG. 4.—STEP-FAULTED GNEISS AND DIORITE DYKE, NORTH-EAST MANN RANGES.

An interesting phenomenon was encountered in this series of gneisses some dozen miles north-west of the western extremity of the main range, where low outcrops skirt the eastern limit of a large depression or "salt pan," the saline deposits of which rest directly upon a bed of similar gneissic rock. These outcrops have weathered by a process of *æolian erosion* into mushroom-shaped masses *(Pilzfelsen)*, with smooth central columns, narrow at the base, and gradually widening upwards to support a flat, tabular mass at the top. The stalk is abraded by deflation, the wind hurling the coarse grains of sand, which do not rise to beyond a few feet above the level of the ground, incessantly against the base of the column. (Plate xiii., fig. 2.)

Streich has reported* mushroom-like forms of sand to occur in the wind-drifted sands of the Great Victoria Desert. He states that the sand is generally loose, though somewhat consolidated by means of a clay cement, but only on the surface. When the uppermost crust has been broken through, the wind gradually blows away the underlying loose sand, leaving the upper layer unsupported around the

* Scient. Res. Elder Expl. Exped., 1891-2, Geology. Trans. Roy Soc. S.A., vol. xvi., page 88.

border. The phenomenon is really resistance to transportation of the consolidated crust by wind rather than abrasion or erosion of the underlying loose sand by æolian agency.

A further factor that plays an important part in the weathering of rocks in the desert was noted in the outcrops of garnetiferous gneiss immediately west of the shores of Lake Wilson. This form of weathering, the *Seele der Verwitterung* of Schweinfurth, consists of the flaking off of the rock as a result of crystallisation of salt within minute fissures in the mass. Portions of the outcrops, that have been previously locally hardened by cementation (concretionary), have resisted this weathering to some extent, and consequently those portions project from the surface of the decomposing gneiss as irregular, partly serrated, ridges, the direction of which is usually consistent with that of an original constant geological feature of the rock.

Veins, etc.—Comparatively few true fissure veins or lodes were noticed in the Mann Ranges. At the salt pan just mentioned an exposure of a "quartz reef" occurs in combination with a coarse pegmatite (*i.e.*, secondary quartz, in the intrusive). The quartz of the "reef" is very coarsely crystalline, the faces of the prisms exhibiting oscillatory combination to a marked degree. The felspar of the pegmatite occurs as large pink idiomorphic crystals of orthoclase. The lode is non-metalliferous.

A common method of formation of so-called "quartz blows" in the ranges is nothing more than metamorphism by igneous intrusion into the bedrock, the ultimate product consisting of a highly altered quartz schist. The best example of this phenomenon was met with south-east of Mount Edwin. The quartzose outcrop there consists of three parallel ridges of metamorphic quartz schist and granular quartz, the planes of schistosity of the former being visible either as thin layers of secondary mica or the direct products of decomposition of the same. The outcrop trends W. 40° S., and is jointed in directions: (a) N.E., dipping 70° S.E., the rock being finely laminated in this direction, and the planes of lamination a fraction of an inch in thickness; (b) N.W., in well-defined, parallel planes, few inches apart; (c) W. 10° N., and N. 20° W., in less perfect partings. This quartzitic exposure is, beyond doubt, a true product of contact metamorphism, and the difference between its strike and that of the country is explained by parallel outcrops of garnetiferous diorite dykes between the separate ridges of the formation; for these have been the cause of the metamorphism of the original schistose beds lying directly in contact with them.

Owl and Bat Guano.—In the Mann, Musgrave, and Ayers Ranges caves were found containing a considerable floor deposit of so-called guano, the droppings of owls and bats. These caverns have been produced in the granitic rock masses by the denudation and subsequent removal of included softer portions or by the more rapid weathering of the material along planes of parting in the rock. In the former case they were usually observed opening out on to the bare, more or less vertical, joint faces. Owls (principally *Strix delicatula*) appear to be frequent inhabitants of such caves at the present time. Similar deposits were discovered in the Fraser Range by the Elder Expedition.*

The "guano" consists of a faintly yellowish to dirty white, compact to flaky, or lamellar mass, with a peculiar, penetrating odour resembling that characteristic of the excrement of flesh-eating birds. The bottom and oldest layers of the deposit have assumed, not invariably, a more or less elastic character when in mass, making it somewhat difficult to detach in small pieces with a hammer. It breaks away as distinct layers or slabs.

In April, 1902, Mr. H. Y. L. Brown reported† on cave deposits occurring in quartzite near Yunta. The "guano" from this locality is almost identical with that from the ranges of Central Australia. I have had opportunity of comparing hand specimens collected by Mr. Brown with those I gathered in the Mann and Ayers Ranges. An analysis of guano from the Yunta caves made by Mr. Goyder proved the presence of phosphoric acid and nitrogen in different samples in the following proportions:—Phosphoric acid (P_2O_5): (a) ·55; (b) 6·00; (c) 2·57 per cent.; and nitrogen: (a) 1·68; (b) 23·44; (c) ·6 per cent.‡ It is evident from the above estimations that some of our cave deposits are equal to high-class manures, though it may hardly be expected that they will ever become of commercial value. On account of their limited extent, to say nothing of the troublesome journey to the above ranges.

Analyses of cave deposits have also been published from Victoria and New South Wales.§

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* V. Streich: Trans. Roy. Soc. S.A., vol. xvi., page 99.

† Report of Government Geologist to Minister of Mines, April, 1902.

‡ See Macivor, On Australian Bat Guano, etc., *Chem. News*, May 13, 1887, page 3.

§ Notes and Analyses of Some N S.W. Phosph. Minerals and Phosph. Deposits, by J. C. H. Mingaye. Aus. Asso. Adv. Sc., vol. vii., 1893, page 332.

Mount Gosse, W.A.

Mount Gosse is situated in Western Australia, about two miles from the boundary of that State and South Australia, and ten miles north of the projected border line between the Northern Territory and South Australia. It is composed of an intrusion of granite within schistose to granitic gneiss, the foliation of which strikes west, slightly north. The rock shows cubical jointing, and the gneissic rocks are overlaid by a compact blue quartzite* possessing a perfect conchoidal fracture, the whole formation being traversed by the never-failing diorite.

A prominent hill, situated seven miles east of north of Mount Gosse, and almost on the border line, stands 2,250 feet above sea level, and 325 feet above the desert, which bears *Xanthorrhœa* and *Triodia.* It has been determined by an intrusion of granite, with porphyritic blue felspars, the trend of the intrusion being slightly north of west.

The injection lies within a linearly foliated gneiss, showing closely set veinlets of quartz. In portions the gneiss is schistose, or slightly fissile, and passes to a fine-grained, felsitoid quartzite. Minor veins of graphic granite, with a white (decomposed) felspar matrix, and epidote, are also met with.

Tomkinson Ranges.

General Remarks.—These ranges occupy the north-western corner of the State of South Australia proper, and extend westward to beyond the border into Western Australia (Mount Hinckley). They were named by Gosse in 1873. Generally speaking, their dominant features are similar to those of the Musgrave and Mann Ranges, namely, igneous intrusions within crystalline gneisses. In the case of the Tomkinson Ranges, however, the intrusive rock consists largely of gabbro, accompanied by diorite dykes. Moreover, the ranges are not as persistent and compact as those already described.

The higher intrusive bosses bear scanty vegetation, as porcupine grass,† mallee, and pine, while the lower spurs of gneiss are covered with mulga and kangaroo grass. The intervening gullies and flats were thickly clothed with grass and herbs.

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* "The formation at Mount Gosse is a quartzite, with frequent diorite veins and dykes, . . ." W. R. Murray, Extracts from Journals of Explorations, by R. T. Maurice (by Authority: 1904), page 17.

† See also E. Giles, Geogr. Travels in Centr. Austr., 1872-1874, II., page 103; and J. Carruthers:—"These hills are covered with spinifex, . . ."—Report to Surveyor-General (*Adelaide Observer*, January 16, 1892).

The Mount Davis chain includes, among others, a large intrusion of granular olivine-gabbro, * varying in colour from dirty green, through various shades of green, to faint blue. In the last case the predominance of plagioclase felspar and the presence of only a small amount of olivine have produced the bluish tint. The intrusion trends east and west as a massive, rugged chain, flanked by less conspicuous diorite dykes.

The latter, though individually smaller, are very numerous. Their direction of intrusion possesses no regularity, often cutting one another at various angles. Upon one hill, about three miles south-east of Mount Davis, two conspicuous diorite dykes can be traced up the hill slope. These dykes gradually converge towards the summit of the hill, where they ultimately cross one another at an angle of about 30°, each continuing its own course after the point of crossing. The direction of intrusion of the diorite appears more constant (east and west) on the northern side of the ranges than is the case of the more numerous examples on the south.

Very often smaller dykes can be traced in a direction nearly at right angles to the larger, from which latter they have been injected into minor fissures of the rock. The trend of these smaller dykes, in several cases, was noticed to correspond with that of the planes of foliation of the intruded gneiss, and their outcrops can be traced down to the adjacent sandy flats, from which they stand out, by their superior weathering, as marked, low, parallel walls. † As a general rule the diorite rock of the Tomkinson Ranges is of one type only: a finely crystalline, black-looking (hornblendic) variety.

A few miles south of Mount Davis a slight exposure of graphic granite occurs. The quartz that produces the hieroglyphic markings on the surface of the rock is colourless and embedded in a red orthoclase felspar matrix. The whole rock is traversed by veinlets of crystalline epidote.

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* J. Carruthers, *op. cit.*: "The Tomkinson Ranges . . . are composed of grey and red granite, with large outcrops or dykes of basalt." No basalt was found in the neighbourhood of the Tomkinson Ranges, and it is possible that the gabbro was mistaken for basalt by Carruthers. W. C. Gosse, Report and Diary of Central and Western Exploring Expedition, 1873, Parliamenta Paper No. 48, House Assembly (1874), page 13, writes:—"Mount Davis must be at least 1,500 ft. high. This portion of the range is composed chiefly of grey granite." W. R. Murray, Extracts Journals of Explorations by R. T. Maurice (by authority: 1904, page 17).

† Which Mr. Streich compares with the "ruined w lls of houses." Scient. Res. Elder Expl. Exp., Trans. Roy. Soc., S.A., vol. xvi., page 93.

Metamorphic Rocks.—The gneisses occur as broken spurs and ridges, extending far outward into the sandy plains. On the north their character is granitoid and foliated, the planes of foliation striking north-easterly. The rock is characterised by bands of quartz and the presence of secondary minerals in more or less distinct layers.

North of Mount Davis outcrops of hypersthene-bearing granulite, which trend slightly east of north, present splendid examples of spherulitic weathering *(Kugelige Absonderung)*. This rock is compact and granular, with little or no evidence of foliation on freshly fractured surfaces, though it is apparent on weathered faces. The rock has a peculiar olive-green waxy appearance.*

The most westerly exposure of the Gosse's Pile Spur† consists of gneiss, which is normal, though quartzitic, the quartz occurring in the form of elongated lenticles, and the mica as small flakes in regular layers of no great thickness. The rock is thickly studded with red garnets *(Almandine)*. This class of gneiss predominates in the Tomkinson Ranges, it being also met with south of the main range.

Veins, etc.—Non-metalliferous quartz veins of a bluish tint and a shattered glassy character are fairly plentiful. They are usually seen in direct association with diorite dykes.

The Murru Yilyah Outcrop.—This outcrop, which was stated to be auriferous, skirts the northern foot of the Mount Davis chain for some miles in a westerly direction (W. 20° N.), with a prominent escarpment facing the north. The deposit consists of a fresh-looking, highly-siliceous rock, varying from an impure siliceous ironstone through chalcedonic and semi-opaline varieties of quartz, the chalcedony often occurring, encrusting, drusy or slightly stalactitic, or pervading the rock as irregular planes of infiltration. The silica has been tinted by mineral salts in solution, the colour ranging from a rich brick-red through pale yellow to a bright green (chromium). Small, irregular cavities exist in the rock, which are either coated with a drusy form of quartz or filled with haematite, compact to cellular. The rock breaks with a conchoidal to sub-conchoidal fracture, and small fragments, the result of weathering, cover the adjacent slopes and

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* Mr. G. W. Card, of the Geological Survey of New South Wales, who examined a section of this rock for me, writes that the hypersthene is not very abundant, and is of a deep colour. Apatite is present in noticeable amount. The bulk of the rock consists of granular quartz and felspar. Granulitisation and recrystallisation are not complete in the case of the felspar, residual portions of which may still be seen.

† Compare "Gosse's Pile Hill is of grey granite, with diorite, ." W. R. Murray, *op. cit.*, page 17.

flats. A pseudo-brecciated appearance within the rock is produced by simultaneous precipitations of compounds of iron and chromium and chalcedony. Surface cappings of travertine and small deposits of magnesite rest upon the outcrop in places, and more frequently upon the diorite dykes in proximity to it. The deposit is of no great thickness, and can be seen on the west directly overlying diorite. Its origin is doubtful, as it can hardly be referred to the "desert sandstone," though in some respects it is not dissimilar to it. The formation has been proved to be non-auriferous.

Everard Ranges.

General Remarks.—The Everard Ranges lie to the south of the Tomkinson, and south-west of the Musgrave Ranges. They are the most southerly of the series of elevations in Central Australia, the other members of which have already been described. They were discovered in 1873 by Ernest Giles, and subsequently (1891) visited by the Elder Expedition. Mr. V. Streich, the geologist to that expedition, points out* that the Everard and Birksgate Ranges consist almost entirely of eruptive granite, although representatives of a schistose series overlying the granite were observed, usually as outliers of the main range. Mr. Carruthers also pointed out that they "are chiefly composed of red granite."† Only the eastern limits of the range were visited by the North-West Expedition, although the main granitic chain, with Mount Illbillie as a prominent feature, was sighted in the distance, and therefore the following notes relate to that portion of the range only.

Igneous Rocks.—True granitic intrusions, often with large porphyritic felspars, have penetrated granitic gneiss. The granite at the borders of the intrusions has assumed a gneissic character, the apparent planes of foliation having a waved and plicated outline. These planes have, beyond doubt, been produced by movement of the rock magma after partial crystallisation of the constituent minerals. Veins of epidote and epidote granite, in which epidote replaces mica, are general, while interrupted veins of coarse acid secretions are not infrequent.

The intrusion of the granite has taken place in a direction a few degrees south of west, and the weathering of the softer portions of the rock has left huge, bare massifs, upon

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* Scient. Res. Elder Expl. Exped., Trans. Roy. Soc., S.A., vol. xvi., page 83.

† Rep. to Surveyor-General (*Adelaide Observer*, January 16, 1892).

the surface of which lie boulder-shaped tors that often rest in perilous positions.

Diorite and pegmatite dykes occur in fair number, the former more frequently than the latter.

Metamorphic Rocks.—The gneiss occurring in this locality is, without exception, granitic and largely "metapyrigen." The best exposures that came under notice are those occurring south-east of Artootinna soakage well. At this spot the planes of foliation, greatly contorted and folded, strike easterly, and the rock is vertically jointed in direction north and south. The foliation is made conspicuous by planes of dark-coloured biotite, the mica in the original intrusive mass being in parts poorly developed or absent.

Veins, etc.—Veins of barren quartz within the bedrock are not wanting. To the east of the ranges, further, small pegmatitic veins exist within the gneiss, containing irregular secretions of magnetite.

Ayers Ranges.

General Remarks.—The group of hills, situated for the most part in the southern limits of the Northern Territory and partly in South Australia proper, and generally known as Ayers Ranges, is hardly deserving of such a geographical term. In appearance the hills are similar, though smaller and more disconnected than the previously mentioned groups of elevation. Mr. Ernest Giles, describing these "ranges," which he discovered in 1872, from the summit of Mount Sir Henry, stated* that "the mount and all others connected with it rose simply like islands out of a vast ocean of scrub," and that the mount "consisted of enormous blocks and boulders of red stone, so riven and fissured that no water could lodge for an instant upon it."

The hills are of fair altitude; yet they appear comparatively low. This is because the red sands from which they rise cover their flanks to a considerable height. The highest point, Mount Cavenagh,† stands 2,200 feet above sea level, but only 300 feet above the adjoining sands. They may be divided into three groups: firstly, that comprising Mounts Cavenagh, Barrow, and Reynolds, all of which are portions of the same outcrop and in proximity to one another; secondly, Mount Sir Henry, situated about three miles south of the former; and lastly, a prominent southern ridge that extends into South Australia proper. All these prominences have been determined by igneous intrusions, the first two sets consisting of granite, the last of an extensive belt of diorite dykes.

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* Geogr. Travels in Centr. Austr., 1872-1874, I., page 78.

† Mount Cavenagh of Giles was re-named Mount Burton by Carruthers' party.

Lying between these masses, disconnected, rounded hills of metamorphic rock appear, rising, as in previous instances, from a vast expanse of sand.

Igneous Rocks.--The granite is somewhat coarsely crystalline, normal to slightly porphyritic, the felspar often occurring as porphyritic individuals. Magnetic ores of iron are plentifully developed. The rock is superficially rotten. The mass shows typical granitic features, with a regular, vertical system of jointing, which sometimes, by weathering, have formed large caves, notably north-west of Mount Cavenagh. The intrusion appears to have occurred in a direction north of west, and the Mount Cavenagh outcrop is divided by a series of parallel gullies running in a northerly direction. Outcrops of identical rock were found intermediate in position between Mount Sir Henry and Mount Carnarvon, thus geologically connecting the Musgrave and Ayers Ranges. About fifteen miles south of Mount Cavanagh a different type of granite is found adjacent to a belt of dioritic intrusion. It is a highly felspathic graphic granite, the felspar being a light red orthoclase, and in parts is pegmatitic. Further east it has suffered considerable metamorphism, and is veined by saussuritic rock and a coarsely crystalline, felspathic, acid modification.

Diorite intrusions are exceedingly plentiful. The southern extremity of the ranges is a pronounced ridge, rising about 200 feet above the plain, about a mile wide, and extending for several miles east and west. It is composed almost entirely of diorite intrusions, with the exception of a few "floating" masses of highly altered rock in the same. The dykes trend within a degree or two of due west, and are either regularly jointed into quadrangular blocks or weather into rounded masses resembling granitic tors. Between this prominent ridge and Mount Sir Henry a marked series of parallel diorite dykes, usually of no great thickness, continues for nearly the whole distance, a dyke being met with at every few chains. Their direction is east and west, with very few exceptions. A few low exposures of the bedrock were met with, consisting of various modifications of altered granite.

Metamorphic Rocks.—The gneiss has its greatest development in the east of the ranges, occurring as more or less isolated bare hillocks. It is linearly foliated, the planes of foliation striking N. 10° E., and dipping W. at Kurrekapinnya soakage. This fact seems extraordinary, as in all other cases noted the foliation of the gneiss coincided in direction with the trend of the intrusion, and this evidence, in conjunction with other physical features, has suggested a change in the direction of intrusion of the granite. The rock is jointed in well-defined planes, striking W. 25° N., with a northerly dip, and, less conspicuously, in planes striking N. 3° E., with a dip of 75° W. Secondary minerals line the walls of these joints, along which, moreover, slight faults and hitches have occurred.

The Indulkana Outcrop.

About twelve miles east of Indulkana Spring, adjacent to Chambers's old wagon track, a small exposure of bedrock exists, and, whilst not many square miles in extent, indications are not wanting that the rock may be found at no great depth over a much wider area. The exposure is 1,300 feet above sea level, and is surrounded on all sides by a capping of "desert sandstone" barely exceeding 30 feet in thickness.

Igneous Rocks.—The intrusive rocks are of the acid and intermediate families. Diorite dykes predominate, though it is often difficult to determine the exact planes of contact with the intruded schists on account of the severe shattering of the rock. At least four major diorite intrusions have occurred in direction east and west, with slight variations, due possibly to subsequent earth movement. The largest measures one hundred yards in breadth. In places where the contact with the schist is visible the latter rock appears baked and highly schistose, with upturned planes of schistosity. The diorite is for the most part fine-textured, quartzless, and micaceous; on the surface the rock is usually "honeycombed" by unequal weathering of the constituent minerals, the liberated iron oxides coating the surface with a "rust."

Intrusions of graphic granite, pegmatite, and greisen have occurred previous to that of the diorite. This is evident from the fact that the diorite dykes are often found cutting the pegmatite, the latter having thereby frequently suffered lateral displacement. The mineralogical character of these acid rocks varies considerably. Their common feature is coarse crystallisation of the constituents. In some dykes quartz predominates, in others it is subordinate to felspar, while mica occurs as irregular aggregates in the greisen and occasionally as an accessory in the pegmatite—in the latter case usually in a state of partial decomposition. On the western limits of the exposure igneous intrusion is marked by dykes of graphic granite and schorlaceous greisen, the latter including large, perfect crystals of black tourmaline and a light-coloured microline. The general direction of intrusion is east and west, although dykes may be found running at right angles to this. True granite is feebly represented by a coarsely crystalline rock, with pink crystals of orthoclase, rather subordinate quartz of a bluish sub-opaline character and a greenish biotite.

Metamorphic Rocks.—In traversing the outcrop from south to north a gradual alteration in the structure of the bedrock will be noticed, the rock grading from a quartz mica schist on the south, through a highly micaceous black biotite schist, to a finely foliated quartzitic gneiss, to a typical augen gneiss on the north. The strike of the beds varies (in zones of extreme pressure considerably), though the general direction appears slightly south of west. The dip is doubtful, possibly northerly. The augen gneiss, compact and granitic, contains lenticular veinlets of quartz, which are often considerably distended as a result of lateral pressure during a state of semi-plasticity, and in addition are frequently found turned upon themselves or complex-folded. The schist can be distinguished from the gneiss in the field even at a distance by contrasting its serrated lines of outcrop with the rounded, massive, boulder-like outcrops of the gneiss. On the north-east the rock consists of a rotten biotite schist, in which planes of mica have become so aggregated that the rock appears to be almost entirely built up of the pure mineral biotite. Even in hand specimens the curved and crinkled lamellæ of the mica indicate how great a stress the beds have been subjected to. The planes of schistosity of the rock strike from 10° to 20° south of east, and dip N. 32°. The beds are further jointed in directions E. 10° S., with a dip of 60° S., N. and S., with a dip of 85° W., and irregularly by a poor vertical plane. To the south this rock becomes less persistent, and has yielded more to weathering. A small development of chlorite schist occurs in contact with the augen gneiss, and a local production of hornblende epidote schist has taken place at the contact with certain diorite dykes. Skirting the north-western limits of the outcrop a finely crystalline gneiss seems to point to a zone of crushing of an igneous rock. (See Appendix. Pages 94-5.) Outcrops of quartz schist, mica schist, and gneiss extend more or less continuously westwards to Indulkana soakage well, at which spot the gneiss contains coarse vein-segregations of felspar with a development of tourmaline and titaniferous iron ore. Repeated searching for tin ore proved fruitless.

Some miles south of the main outcrop low surface exposures of ferruginous clay slates and mud stones appear, the sharp, serrated edges of the same standing out conspicuously. In some parts the rock comes near to a phyllite, and is traversed by very many small quartz veins.

Veins, etc.—The so-called "quartz reefs" of the locality are of two kinds, namely, those forming portions of a true igneous (pegmatitic) dyke, and those formed subsequently by deposition from solution in fissures of the rock. The latter have a remarkably fresh, compact, crystalline appearance, and in no case do they extend downward to any depth, but pinch out in less than a dozen feet; they are the fillings of wedge-shaped fissures within the diorite dykes. A typical instance of a "reef" occurs one mile east of Krupp Hill. It measures four feet in width at the surface, but its walls rapidly converge to a point in depth. The fissure walls strike E. 8° S., the northern wall dipping 60° S., the southern 80° S. The quartz is either milky or glassy. The formation may be termed a "dead lode,"* although pyrites is disseminated through the vein, and in one instance a trace of grey copper ore was discovered. The pyrites crystals that impregnate the mass are decomposed near the surface, leaving small cavities containing sulphur and a little limonite, the remaining products of decomposition having stained the numerous cracks and crevices in the quartz. Slight quantities of secondary minerals (chlorite) occur locally, and the walls of small cavities are coated with drusy quartz.

Few miles west of Indulkana soakage a lode of siliceous ironstone† stands out conspicuously from a fissure in the crystalline schist. It is possible that this lode overlies a diorite dyke.

Cambrian.

No representatives of the Cambrian system were discovered in the vicinity of the north-western ranges, none of the contact rocks having disclosed any trace of organic remains in any shape or form. However, limestones that must without hesitation be correlated with the Cambrian strata of the Flinders Range occur at the head of Lake Torrens. The outcrop occupies but a small area at the surface, being about three miles in length, in direction east and west, by two miles north and south. The beds are massive, though they extend to no great vertical height above the general level of the country; they stand as large, separated blocks resting upon a more compact body of rock below. The beds seem to strike westerly, although considerable variation (up to N. 25° W., and more) were observed. On the southern limits of the exposure they have the form of a slight syncline, the dips of the strata on either side of the axis of folding being low (12° and 25° respectively). They are jointed vertically in two directions at right angles to one another. The rock mass, as a

* One sample of this rock, that was subsequently assayed, returned a mere trace of gold (accidental?).

† Mr. H. Y. L. Brown has noted a "lode outcrop of ferruginous quartzite and iron oxide" to occur in this locality, and is probably the same as that referred to.

whole, shows no signs of bedding, but the impurer portions (siliceous) exhibit faintly planes of deposition and current bedding that are rendered more apparent on partial denudation of the rock. The character of the rock varies from a bluish, sub-crystalline limestone to a granular marble, to be in parts replaced (in the upper layers) by coloured siliceous and dolomitic limestones. The crystalline limestone contains accessory minerals, as small, perfect crystals of fluorite and aggregates of ankerite, while carbonates of copper occur as locally concentrated fissure fillings and pockets of inconsiderable magnitude or quality. Chert nodules that have possibly been derived from solution of contained radiolarian tests, or enclose the spicules of Cambrian sponges,* weather from the surface of the limestone, by virtue of their superior hardness. They are flattish-ovoid in shape, and are bounded by regularly curved, smooth surfaces.

ORDOVICIAN.

Exposures of beds of the Ordovician period were met with in districts widely separated from one another, namely, at Indulkana, Mount Conner, and the Mount Kingston outcrop.

INDULKANA.—Mr. H. Y. L. Brown visited this outcrop in 1889, and reported† similar rocks to extend in a direction southward to Arcoollina Well, and for a long distance westwards. Mr. V. Streich passed the same outcrops two years later,‡ and traced the western boundary of the same formation to Townsend Ridge, over one hundred miles beyond the border line of Western Australia.

On approaching the Mount Chandler range from the north, it has the appearance of a tableland, with its surface sloping slightly westward. This is not, strictly speaking, the case, for, on entering the range, it is found to consist of a series of parallel ridges trending from east to west. The whole formation at this locality appears in the form of a shallow, synclinal trough, the axis of which pitches east and west. The strike of the beds is E. 5° S. The rock is composed principally of a

* Since writing this paper Mr. R. Etheridge, jun., of Sydney, has kindly examined a section of one of these nodules for me. He writes that "the micro-section of the nodule appears to consist of calcite and chalcedony, with perhaps a third undetermined mineral. I cannot distinguish any trace of organic structure."

† H. Y. L. Brown: Report on Journey from Warrina to Musgrave Ranges (by authority: Adelaide. 1889).

‡ V. Streich: Scien. Res. Elder Expl. Exped., 1891-2, Geology. Trans. Roy. Soc., S.A., vol. xvi., page 80.

hard, compact, fine-grained quartzite, merging in parts to a more friable sandstone and grit, portions being ferruginous. A prominent parting of the rock coincides with the original planes of bedding, while further two joints, not very persistent, occur: one in direction N. 20° E., dipping 65° easterly, and another at right angles to this. Planes of shear are highly polished by slickensiding, and in parts the rock has been severely fractured. Drift bedding is much in evidence, and makes the determination of strike somewhat difficult at the eastern limit of the outcrop. The rock has a tendency to cavernous weathering, one of the largest caves having been occupied as a store by the Government surveyors.

The quartzite overlies unconformably schists and clay slates, the planes of schistosity and cleavage of which stand at a high angle. The direct junction is for the most part hidden by the "waste" of rock that has accumulated at the foot of the escarpment, but in a small watercourse on the east the direct contact can be observed for a limited distance, the quartzite resting upon decomposed clay slate.

Although the underlying pre-Cambrian beds are extensively intruded by diorite, pegmatite, and other dykes, no such intrusion was observed to penetrate the overlying quartzite.* The same is true with regard to large quartz reefs occurring in the immediate neighbourhood. From Mount Chandler the quartzite extends eastward as low, disconnected ridges, and was subsequently found at Camp 7 (Krupp Hill) overlying pre-Cambrian schists, but not overlain by desert sandstone, which, however, directly overlies low outcrops of pre-Cambrian rocks in the vicinity. This fact would indicate a fair altitude of the quartzite during late Cretaceous times.

At Ewintinna soakage outcrops of the same formation take a northerly curve, the beds locally striking N. 25° E. The rock at this spot is, similarly, a quartzite, slightly banded and sub-fissile, and in parts traversed by numerous wavy veinlets of secondary quartz. The rock is parted by a prominent strike-joint, dipping about 75° westerly, and another plane dipping 85° in the direction N. 25° W. A few miles south of this soakage the quartzite was found to have its strike identical with that of the Mount Chandler outcrop.

MOUNT CONNER.—This monolith, rising to a height of 2,600 feet above sea level, and about 800 feet above the level

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* Compare the statement:—". . . the granite and other dykes and quartz reefs do not extend into these rocks." H. Y. L. Brown, Report of Geological Examination of Country in Neighbourhood of Alice Springs (by Authority: Adelaide, 1890).

of the desert in which it stands, forms one of a remarkable series of three conspicuous landmarks situated north of the Musgrave Ranges; the other two being known as Ayers Rock and Mount Olga. Mount Conner, rising abruptly from the surrounding desert, is a huge, table-topped outlier of a once continuous extensive geological formation. The base of the mount has a circumference of about six miles, while the plateau itself is roughly two miles long by three-quarters broad. It is surrounded on all sides by a talus, having an angle of repose of from 30 to 35 degrees; above the talus an abrupt escarpment rises to the edge of the plateau, a vertical distance of about 250 to 300 feet. With the exception of one or two pine trees the escarpment is practically destitute of vegetation.

The rock is a close-grained, compact, siliceous quartzite. The beds show a pronounced horizontal parting, corresponding with the original planes of bedding, and the rock is in portions sub-fissile and fractured, the cracks and crevices affording shelter for numerous hawks and owls.

The topmost layers of the rock are composed of a glossy, white, hard quartzite, while the lower portions assume a softer, arenaceous character, and are stained red by precipitated products of decomposition. In places the quartzite contains irregular bands of well-rounded pebbles of altered sedimentary rock (banded and black quartzite), producing locally a conglomerate. Peculiar false-bedding-like markings are found, not infrequently surrounding these conglomeritic portions, and the quartzite contains segmented ferruginous segregations, which are not altogether unlike organic remains. The strike of the rock varies from west up to 30° north of west, the beds forming a shallow synclinal fold. Portions of the quartzite are shattered into small blocks, fairly regularly bounded by conchoidal surfaces, huge masses being in cases thus reduced to fragments, lying loosely together in a state of unstable equilibrium. This phenomenon is a direct result of insolation. (Plate xiv., fig. 2.) Mount Conner is surrounded by low, rugged outcrops and ridges of fissile quartzite, "covered with dense mulga" and "marked by a low cliff."* The quartzite is banded, and weathers into large flat slabs. The strike varies.

THE MOUNT KINGSTON OUTCROP.—Mount Kingston is situated west of Mount Watt, the portion of a southern Ordovician outcrop that was examined by Messrs. Tate and

* W. H. Tietkens: Journ. Cent. Austr. Expl. Exped., 1889, page 59.

Watt on the Horn Expedition. These authors report* that Mount Watt is composed of a hard, dense quartzite, much fissured, and with few ferruginous bands. Fossils were obtained in the form of casts in large numbers in the quartzite.

The exposure† examined by us is situated about six miles south-west of Mount Kingston, and appears in the form of three or four well-defined parallel ridges trending north-easterly. The rock is a compact, fine-grained quartzite, in parts highly ferruginous. In certain zones the rock is fissile, breaking into fairly large slabs from a fraction of an inch to several inches in thickness. The strike is E. 36° N., and dip 60° north-westerly. The beds are jointed in directions N.W., dipping 60° N.E., and N. 10° W., dipping easterly at a low angle. A ferruginous coating is found covering slickensided surfaces, and bands of highly ferruginous rock occur within the rock. A concretionary structure and dendritic precipitations of iron oxide are common.

The outcrop appears in the midst of the desert sandstone tablelands, the broken outliers of which surround the quartzite on almost every side. Its physical features are, however, quite distinct from those of the table-top formation, although hand specimens of the two formations may be not altogether dissimilar.

The height of the exposure above sea level, by aneroid determination, is about 1,950 feet, and about 260 feet above the level of the sand.

Mount Olga and Ayers Rock.—No doubt exists in my mind that Mount Olga and Ayers Rock are isolated remnants of the Ordovician system, the former consisting of a conglomerate,‡ the latter of a coarse metamorphic grit. These features suggest that Mount Olga was probably situated close to the old Ordovician land surface, Mount Conner being distant, and Ayers Rock in a position intermediate between the two.

The geologists of the Horn Expedition § have already hinted at the possible Ordovician age of Mount Olga and Ayers Rock, while Mr. Brown, judging from specimens col-

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* Tate and Watt: Rep. Horn Exped. Centr. Austr., General Geology, page 59.

† Mr. Wells has erected a small pile of stones on the highest point of this exposure.

‡ Compare W. C. Gosse, Parliamentary Paper No. 48, House Assembly, 1874, page 11:—"This range is formed of a number of round-topped masses of solid conglomerate rock (known as pudding stone), but with stony, spinifex slopes, from 100 to 300 feet rising to their foot. Each hill is a separate rock."

§ Tate and Watt: *op. cit.*, page 59.

lected by Mr. Tietkens, was inclined to consider Mount Conner younger than the other two members.*

Desert Sandstone.

The term Desert Sandstone, which was originally used by Daintree for a highly siliceous deposit that is often found overlying the fossiliferous Cretaceous of Australia, is, to a certain extent, misleading, as the formation is only to a limited extent a true sandstone. Mr. H. Y. L. Brown employed the term Super-Cretaceous, and later Professor Tate and Mr. Watt Supra-Cretaceous, for the same formation. Messrs. Jack and Etheridge regard the desert sandstone as Upper Cretaceous.

No conclusive evidence concerning the exact relationship was found, but I observed that the desert sandstone in many places, particularly at Indulkana, unconformably overlies intruded primary schists. This fact, if the formation is to be correlated with the cretaceous, would demand, as Professor Tate suggested, that the desert sandstone overlaps the latter

Beds of this formation occur along the track from Oodnadatta westward to Indulkana. Such trigonometrically-surveyed heights as Mount Mystery, Mount Alberga, and De Rose Hill are prominent members of the series. From Indulkana, the north-western limit of the formation in South Australia runs east of north in a direction west of Crown Point; beyond this line the primary and intrusive rocks of the Musgrave, Mann, Tomkinson, and Everard Ranges, no doubt, were high land surfaces during the deposition of the desert sandstone formation. Slight surface exposures only of the so-called sandstone were observed, immediately south of the Mann Ranges at Hector's Pass, in the form of a low bank of rather decomposed, friable, silicified quartzite and white, semi-opaline quartz a mile or two east of the pass. A similar semi-opaline rock was found a few miles south-east of Giles West Camp (Musgrave Ranges), and south of Ayers Ranges, in the Northern Territory. Indications of the formation exist, as rock fragments, strewn on the surface, north of the Mann Ranges.

To the south, the whole of the elevated country lying between Oodnadatta and Lake Torrens that was traversed by the Expedition, consists of desert sandstone, with the exception of comparatively few exposures of palæozoic rocks, as in the neighbourhood of Mount Woods and at the head of Lake Torrens.

The formation, as a whole, occurs either as isolated table-topped hills or as groups and ranges of the same. The

* W. H. Tietkens: Journ. Centr. Austr. Expl. Exped.: Section by H. Y. L. Brown.

hills are almost invariably capped by an exceedingly hard, silicified layer of rock, the base being of a more friable and softer character.*

At Indulkana the top layer is composed of a compact, chalcedonic grit, with irregular, sub-angular fragments of colourless and blackish quartz scattered through the mass, with a secondary interstitial cement of a form of quartz. Though the rock may be a coarse grit, the surfaces of fracture, which are in parts sub-conchoidal, are remarkably smooth; the compactness of the rock causing the planes of fracture to pass through the included particles. Professor Tate described the desert sandstone as being composed of "sharp grains of glassy quartz, varying much in size, cemented by opaque, white siliceous matter, and more or less stained red by oxide of iron." This description would apply equally well to the Indulkana outcrops. In places the formation becomes very fine-grained, showing a laminated character or a distinct fissility, and a fairly regular system of vertical jointing, in a north-easterly direction.

A second variety of desert sandstone has been produced by an opalisation of the mass. Examples of this character were seen at Hector's Pass (Mann Ranges), south-east of Giles West Camp (Musgrave Ranges), and south of Ayers Ranges (Northern Territory). The rock is an impure form of common opal; in colour white to bluish-white; containing cellular cavities and small black inclusions of carbonaceous matter. It breaks with a true conchoidal fracture. Surface outcrops only were found of this variety.

At North Creek the formation consists of a very fine-grained, splintery, chalcedonic quartzite, the individual grains being hardly distinguishable with the naked eye. The rock is traversed by small veinlets of oxide of iron, subsequently precipitated. The colour varies considerably: white, yellow, reddish, blue, and purple. The rock is brittle and rings when subjected to the blows of the hammer.

At Yarrabollinna Waterhole the character of the rock again changes entirely. Large, bluff-shaped masses are composed of an excessively fine-grained form of silica, so fine that it shows no sign of a gritty feel when rubbed between the fingers, resembling somewhat the touch produced with kaolin, which mineral is present in small measure only. The pure forms are snow-white, others are variously tinted. Within this deposit nodular masses of a cherty form of silica occur, which are bounded by an outer concentric growth of white chert. (See Plate xv., fig. 1.)

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* See Tate and Watt: Rep. Horn Exped. Cent. Aus. Phys. Geog., page 8; General Geology, page 68.

In the same bed are found nodules of barytes, with a radiating, concretionary structure. They are more or less spheroidal in shape, being flat or concavely indented in the plane of the longer axis. Others are flatter, broadly discoidal. Their dimensions vary considerably, the largest being about four inches in diameter. The smaller forms have a tendency to slit horizontally in two.*

A more argillaceous variety of desert sandstone, spangled with tiny flakes of mica, was observed south of Stuart's Creek Cattle Station. This outcrop weathers more like a shale than the sandstone generally.

Fossilised wood was found in the desert sandstone at a few localities, notably west of William Creek, in the neighbourhood of Beltabeltana Waterhole, where it is plentiful. Other fossils were not observed in this formation.

The most picturesque and rugged range of disconnected masses of the desert sandstone formation came under notice in the locality known as the Serrated Range. This range is composed of peaks, bluffs, pillars, and tables, often of a very quaint appearance, and tinted in various shades of colour. The formation may with justice be called the Mauvaises Terres of Australia, as have been termed the Cretaceous desert formations of North America.

Owing to the porcelainised, brittle character of the rock, particularly of the overlying hard band, it gives way readily and suddenly when subjected to irregular strain. It is on this account that the sandstone, wherever met with, has been more or less broken up into fragments, often terminated by conchoidal faces; the phenomenon being the result of subjection to extremes of temperature within a short period of time (insolation). These fragments are subsequently scattered over the plains between the table-hills by the floods which occur at rare intervals, and are known as gibbers (less frequently shingle or gravel). The gibbers form

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* I have recently had opportunity of seeing identical concretions in the Sydney University Museum, which were collected by Mr. E. F. Pittman from the opal-bearing strata at White Cliffs. Through the courtesy of the Mines Department of New South Wales I have been permitted to annex the following analysis by Mr. J. C. H. Mingaye:—

ANALYSIS OF A NODULE OF BARYTES OBTAINED FROM OPAL-BEARING STRATA AT WHITE CLIFFS.

04·1666

Barium sulphate ...	95·35
Ferric oxide and alumina	·50
Silica	2·60
Water	·72
Lime, magnesia, and undetermined	·83
	100·00

stony plains, and have already been referred to by Sturt as the stony desert. Owing to the extensive denudation of the desert sandstone the gibbers cover a considerable area of Central Australia. The lateral transportation of the stones by water action cannot be considerable, owing to the level contour of the intervening plains; in fact, they are deposited, on the removal of the softer, underlying portions more or less vertically below their original position *in situ*. On the slopes of many of the hills in process of disappearance the stony "wash" has accumulated in rounded terraces or steps, transported by torrential floods.

The reflection of light from the smooth surfaces of these stones, when travelling towards the sun, is irritating to the eye. The glaze has been described by Mr. Brown as being "probably due to the action of siliceous water," and the effect is in small measure increased by a slight, glossy surface coating of precipitated iron oxide. The superficial polish has also been assisted, as has been suggested, by the action of wind-driven sand.

The gibbers consist mainly of different varieties of quartz —forms of agate, jasper, chalcedony, and semi-opal—while in association with them occur concretionary forms of limonite, often assuming grotesque shapes. Gypsiferous clays were met with throughout the area covered by this formation, and, in them, large slabs of transparent gypsum that have been produced by crystalline intergrowth. In addition to these, various nodules, that occur in the softer portions of the rock and resist the denudation to a greater extent, are found.

Obsidian Bombs (Volcanic).—These are widely distributed over the desert sandstone area, and have been the cause of much discussion, without any satisfactory deductions as to their origin. The phenomenon, which points to a former surface deposition, somewhere, of volcanic *ejectamenta* has given rise to various theories, such as meteoric, glacial, and of volcanic action *in situ*. Comparatively few examples were found during the Expedition, though single specimens were collected near to the Mann, Musgrave, and Ayers Ranges. I have, however, received a number of specimens from Mr. McNamara, from the neighbourhood of the Peake. Their universal distribution has, no doubt, been assisted by the agency of the native and the emu (in the form of "gizzard stones"). The natives call obsidian bombs *Pandölla* and *Kaleya korru*, the latter meaning "emu eye." They are collected by the medicine men of the tribes, and applied in the healing of sickness.

Recent Deposits.

Sand.—With the exception of the various outcrops of rock previously discussed, sandy deposits cover all the diacent country to the north-western ranges of South Australia, and extend for many hundreds of miles north, south, and west, the tablelands on the east checking the accumulation to a slight degree in that direction.

The height above sea level of these deposits is considerable, the sand ascending to an altitude of 1,900 feet in the Ayers Ranges, and to 2,200 feet in the locality north of Opparinna Spring. It is on this account that all the larger valleys cutting the ranges have become filled up with elevated deposits, from which large, gum-lined creek beds emerge, to be subsequently "lost" in the sands adjoining the ranges. This drifting cover is embarrassing to the prospector, as the higher portions of the ranges alone can be examined, the more favourable contact-rocks being for the greater part hidden underneath the great depth of sand.

The material of the deposits consists of a moderately fine-grained, incoherent sand, the grains being usually superficially coated red by oxide of iron. In proximity to the ranges these sands are more loamy, and have been bound together by vegetation. There, also, they contain other constituents derived from the decomposition of the primary rocks, such as cleaved fragments of felspar and hornblende, flakes of mica, small nodules of limonite (iron-shot), and occasional patches of garnets. Beyond the belt influenced by the ranges, the sand is loose, incoherent, and subject to a continual drift. In these regions the sand accumulates in the form of more or less parallel undulations or sandhills, mostly incoherent throughout, but occasionally very slightly cemented superficially. The direction in which these sandhills trend, being at right angles to prevalent winds, is east and west, south of the Musgrave Ranges, although the more usual direction observed further south, in the basin of Lake Torrens, is south-west. Frequently two such parallel undulations unite to form one,* thence continuing as one in the same direction. Nuclei which had in the first place started the formation of sandhills were observed north of Mount Crombie, in the shape of low outcrops of granite, while a few miles south of Stuart's Creek a prominent "sandhill" consists of a former tablehill of desert sandstone, almost completely covered with drift sand, few exposures only of the rock being visible, and limited to one side of the hill. The source of this vast amount of sand must be attributed to the æolian waste of the desert sandstone formation.†

* Streich states that the "sand dunes" of the Great Victoria Desert are "very seldom found confluent."—Trans. Roy. Soc., S.A., vol. xvi., page 89.

† Compare E. F. Pittman: On the Cretaceous Formation in the North-Western Portion of New South Wales. Rec. Geol. Surv. N.S.W., vol. iv., Part iv., page 146.

The wonderful capacity for binding the sand displayed by the porcupine grass (*Triodia spp.*) can be favourably compared with that of *Spinifex hirsutus* on the dunes of our sea shores.

Travertine.—Travertine was only found as small, local, surface coverings, most frequently along the banks of creek beds, where it is regarded as a valuable guide to subterranean water. Examples occur along the course of Opparinna Creek and certain creek beds in the Tomkinson Ranges.

Travertine was further noted in many instances to overlie diorite dykes, a breccia having often resulted from the cementation of originally loose rubble derived from the dykes (Opparinna). The travertine occurring at the foot of Mount Davis, in the Tomkinson Ranges, deserves notice on account of its extreme compactness and hardness, it being almost resistant to the blade of a knife. At Stuart's Creek a small deposit of banded travertine has been produced by the precipitation of successive layers differently coloured by varying magnesian and carbonaceous contents.

A thick incrustation of calc-tufa was discovered in the Musgrave Ranges. To the west of Opparinna Spring a series of rock waterholes is to be found along the bed of a rugged gorge enclosed by steep walls of gneiss. One of such holes is situated at the base of a waterfall that has been produced by the intermittent flow of a creek over a locally hardened band of blue garnetiferous gneiss, the softer rock below having become undermined. This deposit of earthy, calcareous sinter, with a fair percentage of included organic matter, occurs as regular stalactitic and mammillated masses, hanging from the under side of the indurated ledge or bank of gneiss. The formation produces an imposing aspect.

APPENDIX.

Petrological Notes on Rocks Collected on the Expedition.

GRANITE.

Locality.—Mann Ranges, outcrop fourteen miles west of Mount Samuel.

Macroscopically.—Granitic, porphyritic; the felspar occurring as large (up to 2·7 cm.), more or less lenticular, porphyritic crystals, rounded by the chemical (?) corrosion of the rock magma. Felspar dark grey, fresh, in places not unlike the greasy-looking elaeolites of syenites.

Quartz in smaller, blackish, segregations throughout the mass. Mica black, not infrequently as lenticular aggregates having their long axes indistinctly parallel, and surrounded by a border of pink secondary mineral. The rock has suffered from the effects of mountain building forces.

Microscopically.—Rock with a holocrystalline groundmass, in which the larger crystals of felspar are embedded.

In parts the quartz (appearing normal in plain light) when viewed in plane polarised light, proves to be microscopically separated into numerous contiguous particles; micrographic intergrowths with the felspar common; generally speaking it is allotriomorphic, crowded with inclusions, and its fissures stained by oxide of iron, subsequently precipitated.

The potash felspar is clouded and crowded with minute inclusions, which are frequently arranged in parallel bands, and some, on decomposition, locally stain the enclosing mineral. The felspar crystals are corroded and surrounded by a border of secondary mineral fibres, radially arranged; the cleavage cracks are filled with secondary mineral, polarising with high colours. "Strain shadows" traverse the quartz and felspar crystals on rotating the stage with crossed nicols.

The mica, a rather decomposed dark green biotite in irregular aggregates of crystals, is almost invariably surrounded by a broad band of closely set, pink garnets, which are minute (averaging ·005 millimetres in diameter). The individual grains appear rather to have been separately developed than to be crushed parts of larger garnets. Optical anomalies are general among them.

Magnetite is scarce; the rock also contains patches of an earthy form of iron oxide. Epidote as a scantily developed accessory (secondary), in small though conspicuous (on account of the high refractive index) aggregates with no definite geometrical boundaries.

Granite.

Locality.—Mount Sir Henry, Ayers Ranges.

Macroscopically.—A moderately coarse-textured, holocrystalline rock, considerably decomposed; the quartz and felspar appear brown from iron pigment; the black-looking mica in fairly large, irregular aggregates.

Microscopically.—Texture typically hypidiomorphic granular, the rock being composed essentially of quartz, felspar species, and biotite. The normal order of crystallisation from the rock magma has generally prevailed, although the mica occurs in parts interstitial to the felspar. A micrographic intergrowth between quartz and felspar on a very minute scale is apparent, and the former contains numerous unindividualised inclusions in parallel bands.

Felspar is of two species: orthoclase and a delicately twinned plagioclase. Decomposition has acted to a considerable extent upon many of the constituents; the felspar, being clouded when viewed by plain transmitted light, becomes brilliantly tinted in the dull portions under crossed nicols on account of the strong double refraction of the products of decomposition (kaolin). Orthoclase is somewhat subordinate to plagioclase; the cleavage cracks and borders of both are lined with oxide of iron.

The mica, a green biotite, occurs principally as aggregates of flakes, partially decayed; the whole rock section, moreover, is speckled with minute particles of biotite.

Magnetite is fairly plentiful, usually surrounded by a layer of secondary mineral.

Apatite is present as stout, prismatic individuals, with prominent cross fracture.

Hornblendic Granite.

Plate xviii., fig. 2.

Locality.—Glen Ferdinand, Musgrave Ranges.

Macroscopically.—Rock granitic, normal; composed of white felspar, colourless quartz, dark mica, and hornblende, as largish, cystalline secretions.

Microscopically.—Texture hypidiomorphic granular; the quartz and felspar uniformly distributed over the sections; the mica and hornblende not so. A fine mosaic of microcline and quartz is characteristic.

The felspar is represented both by orthoclase and microcline, the former being occasionally crowded with numerous very slender, crystalline needles of zircon.

Mica (strongly pleochroic, brownish biotite), as irregular, curved, and twisted lamellæ, partially or wholly altered to a dark-green chlorite, more or less fibrous, and with a weak double refraction. Pink, fractured garnets of fair size are rather plentiful, usually, though not necessarily, in proximity to the mica and the altered chlorite.

Magnetite is present as irregular particles.

Granite.

Locality.—Everard Ranges.

Macroscopically.—A coarsely crystalline, normal granite with prominent pink felspar (orthoclase) and dark-coloured mica. The rock is deeply "honeycombed" on its surface, this being a result of the ready decomposition and removal of the felspar.

Microscopically.—Rock typically hypidiomorphic granular, consisting of clear quartz, a clouded orthoclase, and a strongly pleochroic biotite. Micrographic intergrowths between quartz and felspar are common. Magnetite scarce.

Epidote Rock (Altered Granite).

Plate xvii., fig. 4.

Locality.—Musgrave Ranges, Titania Spring.

Macroscopically.—A granular rock, composed of clear quartz and white, clouded felspar, traversed by veinlets of epidote, the small columns that build up the bulk of the epidote standing with their long axes at right angles to the bounding lines of the veins in the section.

Microscopically.—The texture of this rock, though no doubt originally holocrystalline, has been obscured by the secondary secretion of epidote; the rock has, moreover, suffered considerably from crushing.

The felspar is orthoclase, though little of its primary characteristics remains, it having yielded to metamorphism by transformation into epidote. Intermediate stages of this conversion are general.

The epidote, which is light greenish-yellow in colour, covers fully three quarter parts of the section, as aggregates of irregular, elongated, and columnar individuals. The strong relief produced by the total reflection at the border of the epidote is characteristic, and the cleavage is conspicuous in the larger individuals only.

An imperfect "cross-hatched" appearance is here and there visible on the faces of the felspar under crossed nicols. This is an extreme case of "strain shadowing" as a result of pressure.

Hematite (micaceous) is present as dark reddish-brown (by transmitted light), hexagonal plates, presenting a slight metallic lustre by reflected light. The perfect forms range up to ·27 mm. in diameter, and the adjoining minerals are invariably stained red by iron pigment for some distance around.

Gneiss.

Plate xviii, fig. 1.

Locality.—Indulkana, Krupp Hill West.

Macroscopically.—A fine-textured gneiss, consisting essentially of quartz (colourless), felspar, and biotite, the last-named being arranged in a more or less parallel manner without the production of distinct, continuous planes of foliation *(Quincuncial structure).* It is traversed by shattered veinlets of quartz. A green accessory mineral (epidote) is developed as irregular particles and patches throughout the rock, imparting a faint yellowish-green tint to the rock mass.

Microscopically.—Texture finely crystalline, granulitic, with faint parallelism in the arrangement of the constituent minerals. In parts a feeble *centric structure* is discernible.

The sections appear fresh, though a fine groundmass is here and there noticeable, connecting the individual minerals; this is the result of crushing.

The quartz occurs as small grains, with irregular or rounded boundaries, with numerous fluid pores arranged in parallel bands or scattered.

Felspar predominates; microcline crowded with inclusions (unindividualised) more or less grouped; a very small amount of plagioclase is present. "Strain shadows" are much in evidence.

Mica occurs as a dark, brownish-green biotite, with prism axes roughly parallel; some flakes have undergone partial decomposition peripherally, with the production of a green, fibrous mineral.

Magnetite, as opaque particles, with no definite boundary, rarely idiomorphic, elongate, frequently enclosed by biotite.

Zircon is fairly well represented as inclusions in the microline appearing with the rather rare elongated prismatic habit. The prisms polarise with red and green interference colours under crossed nicols; they are not surrounded by a pleochroic halo.

Epidote produced at the expense of the felspar, as colourless or faintly yellowish individuals, without definite form. Some of the felspar individuals can be observed to be partially converted into epidote, the latter appearing (with crossed nicols) as very numerous brilliantly coloured specks, almost entirely obliterating the characteristics of the felspar.

The gneiss in many respects resembles a granulite, though garnets, usually characteristic of granulites, are entirely absent.

The rock seems beyond doubt a "metapyrigen gneiss."

Gneiss.

Plate xvi., fig. 2.

Locality.—Mann Ranges, south-west of Mount Samuel.

Macroscopically.—A compact granitic rock, with a tendency to foliation, the mica in elongated patches, whose major axes point in one direction; advanced in decomposition superficially.

Microscopically.—Texture granular with a quartz-orthoclase mosaic, and larger felspars embedded in a crushed groundmass.

Quartz clear, with gaseous and liquid inclusions, arranged more or less distinctly in streaks; also few individualised inclusions of elongate-rounded form, the largest measuring ·03 mm., with a high refractive index and double refraction (zircon).

Felspars essentially orthoclase and microcline; plagioclase very subordinate, irregular, and finely twinned; crystal outlines generally corroded, and the mineral clouded by partial decomposition; the cleavage cracks tinted by subsequently deposited iron ores. Twinning after the Karlsbad law is observed in the orthoclase. Microline subordinate. A micrographic (granophyric) intergrowth between quartz and felspar on a small scale is visible in parts of the section.

Biotite strongly pleochroic, from light greenish-brown to almost black.

Magnetite as small, angular individuals.

Garnet Gneiss.

Plate xvii., fig. 2.

Locality.—Mount Davis (two miles north), Tomkinson Ranges.

Macroscopically.—A fine-grained quarzitic gneiss, with a rich, red-garnet development; foliated, the biotite in regular planes, the quartz and felspar foliations often wedging out. Portions of the rock appear very quartzose, compact, with largish fragments of smoky quartz.

Microscopically.—A quartz orthoclase mosaic. The foliated character, though clearly visible in hand specimens, is not apparent under the microscope.

The quartz contains minute liquid inclusions, and aggregates of black particles disseminated through its mass, which appear to be carbonaceous, the former not infrequently grouped centrally. A fair amount of isotropic mineral is also present

Felspar: large clouded crystals of orthoclase and smaller subordinate plagioclase.

Biotite strongly pleochroic, in shades of brown to almost black, when the rays vibrate parallel to the cleavage; elongated or irregular, and is in parts decomposed, the resulting iron oxides staining the adjoining minerals reddish-brown; often enclosing magnetite and felspar.

Magentite as fine dust and larger individuals, sometimes filling fissures between the felspar.

Shattered crystals of red garnet, the largest of which are a millimetre in diameter, are plentiful. They behave completely isotropically under crossed nicols, though the quartz and felspar exhibit undulose extinction rather markedly.

This rock appears to be a "clastic gneiss."

Contact Gneiss.

Locality.—Opparinna, Musgrave Ranges.

Macroscopically.—A closely foliated, fine-grained gneiss, with prominent dark planes of mica *(linear foliation)*, and narrow lenticles of quartz and felspar. The rock occurs in direct contact with a diorite dyke, and its planes of foliation have the same strike as the walls of the dyke.

Microscopically.—The distinct gneissic foliation remains prominent even under a high power objective; the mica in regular parallel stringlets. The fine state of crushing of the rock appears to be an ultimate stage of metamorphism.

The quartz occurs as excessively crushed particles that display marked "shadowy extinction" when viewed under crossed nicols. It is comparatively fresh-looking, and free from interpositions except the minutest.

The felspar, orthoclase, as small, irregular individuals, showing shearage on a microscopic scale, with few individualised inclusions.

Microperthite is developed to a limited extent, and displays a very delicate lamination under crossed nicols.

The biotite is clear, strongly pleochroic, and appears in the form of elongated flakes.

Schistose Quartz Rock (so-called "Quartz Blow").

Locality.—Mann Ranges, south-east of Mount Edwin.

Macroscopically.—A fine-grained, white quartzose rock, schistose, with well-defined planes of brown secondary mica, in parts decomposed and brown.

Microscopically.—Essentially composed of closely aggregated, allotriomorphic grains of quartz, the boundaries of which are usually sharp, and the grains in direct contact with one another. A fair amount of amorphous silica is present. The quartz is fresh, but contains numerous unindividualised fluid inclusions, with stationary and mobile gas bubbles, usually arranged in fairly broad parallel bands, crossing in a continuous line several adjacent grains. It, therefore, appears that the inclusions are to a certain extent not original, but have subsequently been produced by the metamorphism of the rock by igneous intrusion. Individualised inclusions occur in the form of elongated prisms of colourless apatite, with indistinct, rounded prism-terminals and transverse fracturing.

The decomposed mica flakes do not exhibit any striking tendency to parallel orientation. Dark strain shadows crossing the quartz on rotation of stage between crossed nicols give ample evidence of stress to which the rock has been subjected.

Olivine Gabbro.

Plate xvii., fig. 1.

Locality.—Mount Davies, Tomkinson Ranges.

Macroscopically.—Dark green, coarse-grained, heavy rock, apparently composed essentially of a pyroxene. Fracture very rough.

Microscopically.—Texture hypidiomorphic to allotriomorphic granular, of medium-sized grain; composed principally of diallage, olivine, and plagioclase. The diallage varies in colour from very faint green to colourless, and shows the basal striation to perfection. Well-defined, irregular cross-partings are prominent. Alteration to serpentine is seen in different stages of progress.

Olivine greenish to colourless, darkened by granular iron ores by decomposition. Crystal boundary rounded, and the cleavage (010) is distinct in a few examples. The crystals of olivine are altered to serpentine, sometimes completely, with deposition of a ferruginous "dust."

The plagioclase (labradorite) is scanty, and occurs chiefly in aggregates. The albite twin lamellæ frequently "wedge out." Undulatory extinction, produced by pressure, common. The scarcity of this mineral gives a decided basic character.

Ores of chromium were not observed in the rocks examined, although the Murru Yilyah outcrop, adjoining the gabbro, contains a secondary siliceous infiltration which is stained by chromium.

Diorite.

Plate xvii., fig. 3.

Locality.—Indulkana.

Macroscopically—Heavy, compact, dark-coloured, finely crystalline rock, coated on the surface with a rusty brown product of weathering.

Microscopically.—Fine-textured, holocrystalline rock. In the sections examined quartz is absent.

A slight amount of orthoclase occurs as irregularly bounded individuals, often squeezed in between idiomorphic crystals of plagioclase. The plagioclase felspar is twinned according to the Albite and Karlsbad laws, the former being often accompanied by Pericline. From determinations on sections from the zone at right angles to (010) the felspar appears a slightly basic Andesine. Zoning comparatively scarce. The felspar is clouded (more so along the central portions) by kaolin and possibly calcite.

Hornblende light brown, enlarged in certain directions by an outgrowth of secondary, often fibrous, green mineral (hornblende); crystals not infrequently twinned, decomposing with a large deposition of red oxide of iron. Mica scarce as well-defined flakes of strongly pleochroic brown biotite.

Magnetite plentiful, arranged in groups, the individual constituents of which have a strong tendency to parallel arrangement, as though conforming with some pre-existent crystal constant. Hornblende has, no doubt, yielded to its formation.

The absence of quartz, feeble development of orthoclase, and the brown tint of the hornblende indicate a basic type of diorite.

Dolerite.

Locality.—Mount Olga.

Macroscopically.—Slate-coloured, uniformly crystalline rock of fine grain. The minute needles of felspar are dimly recognisable, and here and there larger secretions of a green mineral are apparent (olivine). The rock decomposes to a richly coloured ochreous powder.

Microscopically.—Holocrystalline; of fine texture. The lath-shaped felspars, on an average about ·2 mm. in length, are clouded; on that account they exhibit twin lamination and cleavage cracks very imperfectly, and are variously tinted in polarised light. The arrangement of the laths produces a poor *fluxion structure.*

The augite in the sections examined has been almost completely altered to a scaly, green, chloritic mineral, possessing a very faint double refraction.

Between the felspars a subsequent crystalline segregation has taken place radially to small granules of magnetite. These aggregates show the characteristic black cross under crossed nicols, having its arms parallel to the cross wires of the microscope.

Olivine as greenish, irregularly bounded individuals.

Magnetite is distributed generally through the mass as small granules and cubes; or it darkens the constituent minerals in the form of a very fine dust.

A secondary serpentinous, fibrous mineral present is probably another product of the decomposition of the augite.

Ordovician Quartzite.

Locality.—Mount Chandler.

Macroscopically.—A highly compact, fine-grained, white, siliceous quartzite, breaking with a splintery fracture.

Microscopically.—Consists of closely set, rolled grains of clear quartz, so compacted by pressure as to have left but little space for interstitial cement, which is also of silica. The interstices are slightly stained by iron salts. The average dimensions of the quartz grains of this particular specimen are ·5 mm., although elsewhere the rock passes into a coarse grit and conglomerate. The quartz is either perfectly clear or encloses interpositions, either central, scattered, or arranged in bands. They are mainly unindividualised. Undulose extinction is apparent under crossed nicols.

Felspar is very subordinate, or practically absent.

The orginal planes of bedding are indistinctly discernible by a general tendency of the longer axes of the separate grains to arrange themselves in parallel lines.

No trace of any organism has been preserved in the sections observed, but a similar rock at Mount Watt is highly fossiliferous.

METAMORPHIC GRIT (Ordovician).

Locality.—Ayers Rock, Northern Territory.

Macroscopically.—A dark, metamorphic grit,* which on casual observation may be, and has been, mistaken for an eruptive rock, the large felspars showing up conspicuously from the mass with their surfaces of cleavage. The quartz grains are clearly recognised as derivative *("clastic")*. A black mica, ores of iron, and other foreign minerals are among the grains. The rock may be termed a *greywacke (Grauwacke)* or *arkose.* The aggregation of waterworn grains of quartz and felspar (one single grain of the rock, moreover, often consisting partly of quartz and partly of felspar, still in juxtaposition as orginally in an igneous rock) suggests the disintegration of granite.

Microscopically.—The rock† is compact and composed essentially of quartz and felspar *(allothigenous)*, with additional fragments and flakes of ores of iron and mica *(authigenous)*.

The quartz occurs as more or less irregularly rounded and rolled grains, containing numerous gaseous inclusions in bands and streaks, or scattered. Some of the grains, moreover, exhibit a microscopic intergrowth between quartz and felspar.

The felspar is of several species. A typical microcline predominates. and is often traversed by narrow parallel streaks of strongly doubly refracting altered mineral (kaolin). Micrographic intergrowths of this felspar, with quartz, appear to be prominent, although the effect is masked. "Strain shadows" under crossed nicols.

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* "The rock is a very indurated. and, to some extent, altered, arkose sandstone, decidedly gritty in parts."—Tate and Watt: Rep. Horn Exped. Centr. Austr., Phys. Geog., page 8.

† A description of a similar rock, by Messrs. Smeeth and Watt, has appeared in the report of the Horn Expedition, Petrology, "Arkose"; No. 213, page 83.

Orthoclase is clouded and strongly illuminated under crossed nicols as a result of its alteration.

Plagioclase is subordinately represented, the fragments being comparatively small. A dark mica (biotite), in aggregates of curved flakes, is plentiful. It is very probably secondary,* and occurs interstitially. Its decomposition has produced hematite. Few tiny flakes, apparently white mica, are also present.

Ores of iron are plentiful. Ilmenite occurs as asymmetrical masses, opaque, and (by incident light) shows the imperfect system of striation and characteristic brownish tinge. Moreover, this form is replaced in parts by a semi-transparent variety, "with a clove-brown colour,"† suggestive of micaceous titanic iron. Magnetite is also represented as irregular patches.

With regard to the constituents of this rock being essentially of grains of quartz, orthoclase, and microcline, it is interesting to note that Dr. C. Chewings has described‡ a granite from Mount Olga (a sister outcrop to Ayers Rock), which is composed almost essentially of quartz, orthoclase, and microcline. The constituent grains of the rock from Ayers Rock, therefore, have in all probability been derived from the same granite as the specimen from Mount Olga. Mount Olga consists for the most part of a metamorphic conglomerate.

EXPLANATIONS OF PLATES.

PLATE XIII.

FIG. 1.—Mount Conner; an outlier of Ordovician quartzite, surrounded by saltbush flats.

FIG. 2.—Æolian erosion; mushroom-shaped outcrops of gneiss in the deser north-west of the Mann Ranges.

PLATE XIV.

FIG. 1.—Intrusion of porphyritic granite within hornblendic garnetiferous schist, south of Mount Cockburn, Mann Ranges.

FIG. 2.—Ordovician quartzite, shattered by insolation, Mount Conner.

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* Compare Tate and Watt: *op. cit.*, page 8—"Although once a sedimentary rock, it has been to some extent altered by metamorphic agencies, a small amount of mica, perhaps of secondary origin, having been formed."

† Rosenbusch: Microsc. Phys. of Rockmaking Minerals (Iddings), 1900, page 167.

‡ Chas. Chewings: Beiträge zur Kenntnis der Geologie Süd- und Central Australiens, Heidelberg, 1894—"Ein Granit von Mount Olga (Central-Australien) besteht fast ganz aus Quarz, Orthoklas, und Mikroklin."

PLATE XV.

FIG. 1.—Range of desert sandstone at Yarrabollinna Waterhole. The bluff consists of excessively fine-grained arenaceous material, with nodules of chert and barytes.

FIG. 2.—Krupp Hill; a table-hill of desert sandstone unconformably overlying primary schists.

PLATE XVI.

FIG. 1.—Table-hills of the desert sandstone formation east of Indulkana.

FIG. 2.—Talus blocks of gneiss in Garnet Glen, south of Mount Edwin, Mann Ranges. This rock is described in the text on page 95.

PLATE XVII.

FIG. 1.—Olivine gabbro, Mount Davies, Tomkinson Ranges.

FIG. 2.—Garnetiferous gneiss, north of Mount Davies, Tomkinson Ranges.

FIG. 3.—Diorite, Indulkana.

FIG. 4.—Epidote rock, Titania Spring, Musgrave Ranges.

PLATE XVIII.

FIG. 1.—Gneiss, Indulkana, west of Krupp Hill.

FIG. 2.—Hornblendic granite, Glen Ferdinand, Musgrave Ranges.

FIG. 3.—Hypersthene-bearing granulite, north of Mount Davies, Tomkinson Ranges.

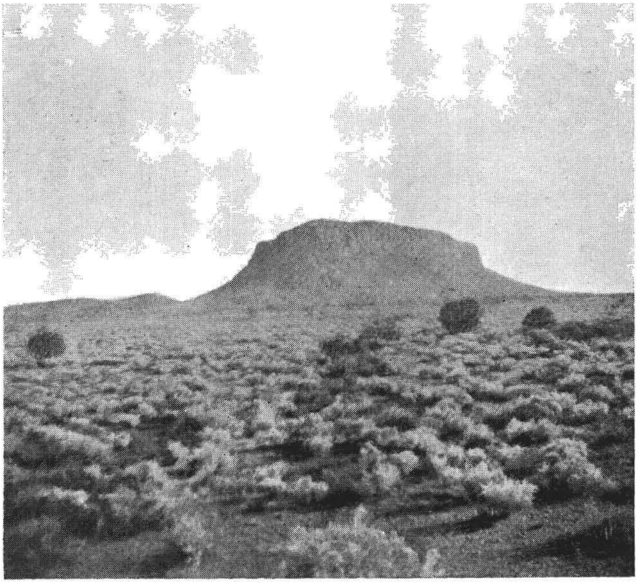
FIG. 4.—Altered augite granite, south of Giles' West Camp, Musgrave Ranges.

PLATE XIX.

Sketch section across the Mann Ranges, extending south from Mount Cockburn. Distance, about 2½ miles.

PLATE XX.

Geological sketch map of the Ayers Ranges.



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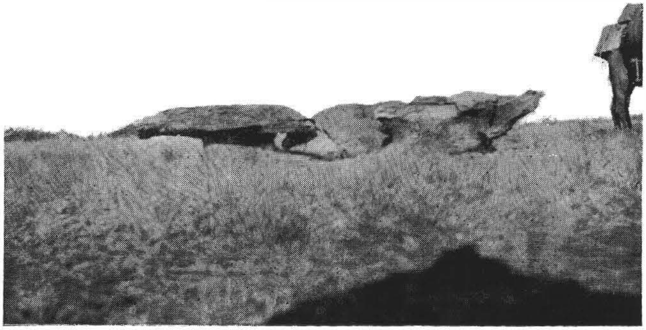

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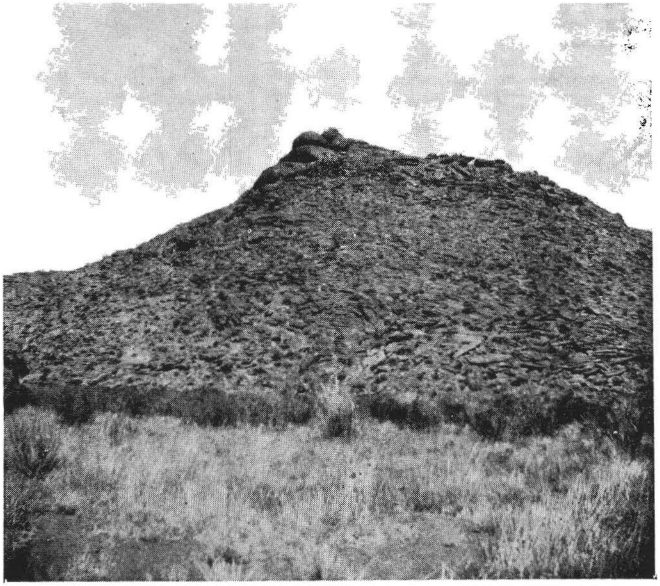

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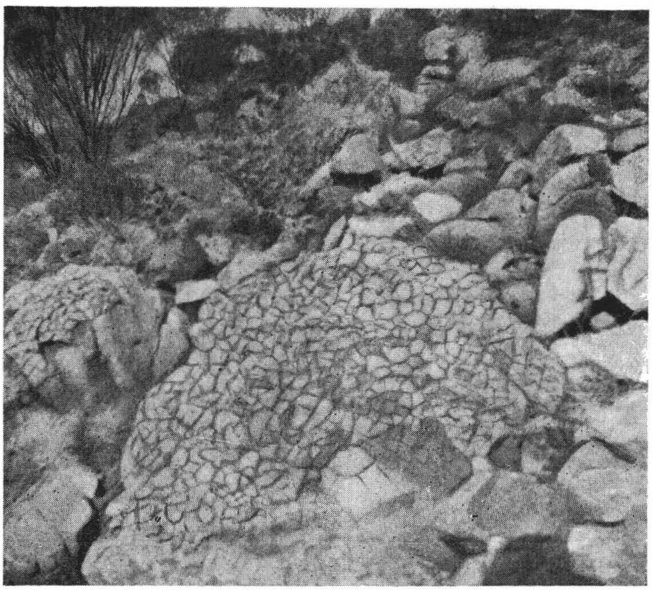

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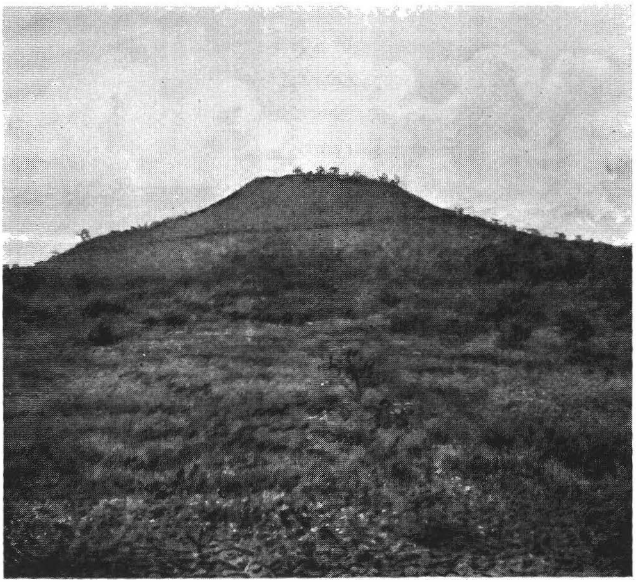

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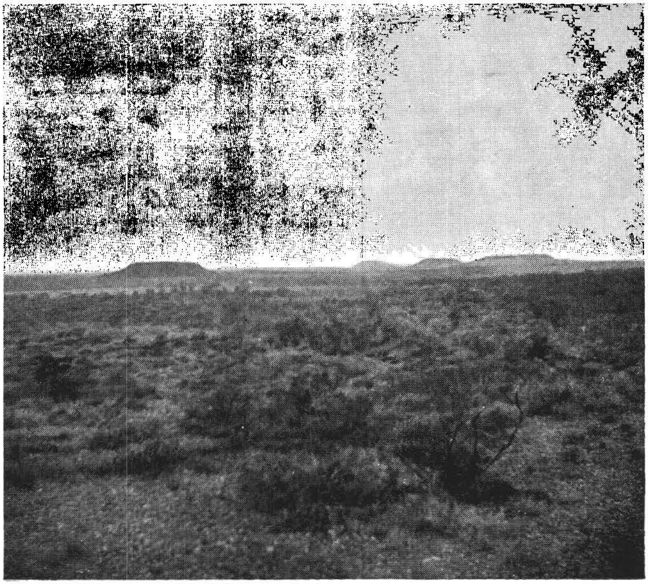

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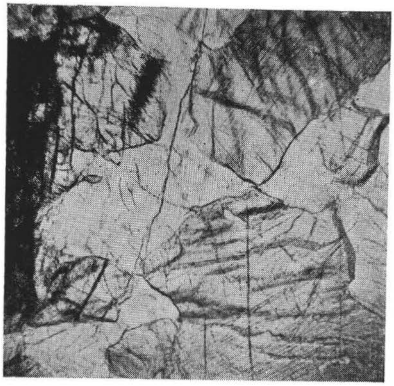

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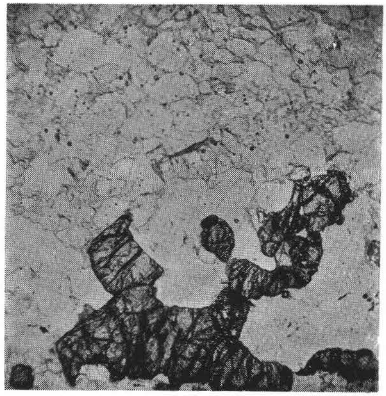

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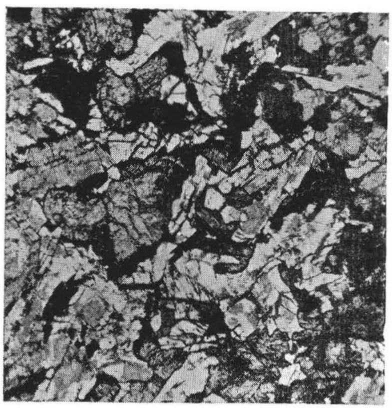

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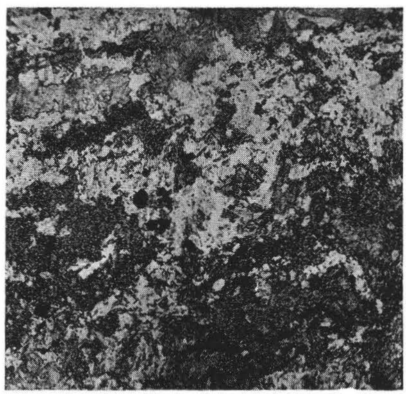

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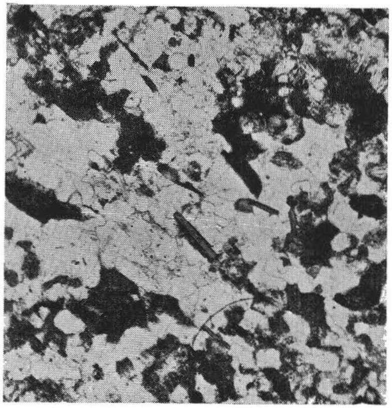

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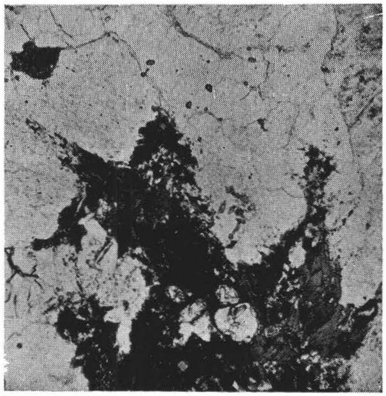

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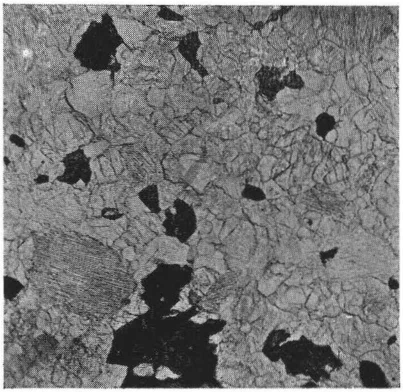

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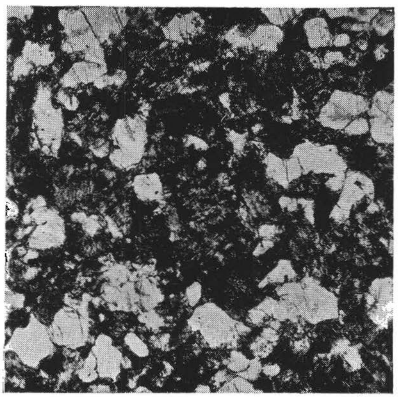

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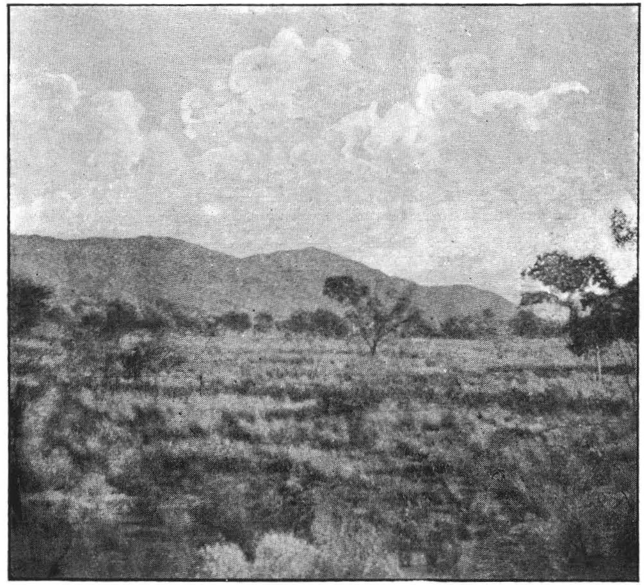
SKETCH SECTION

across the

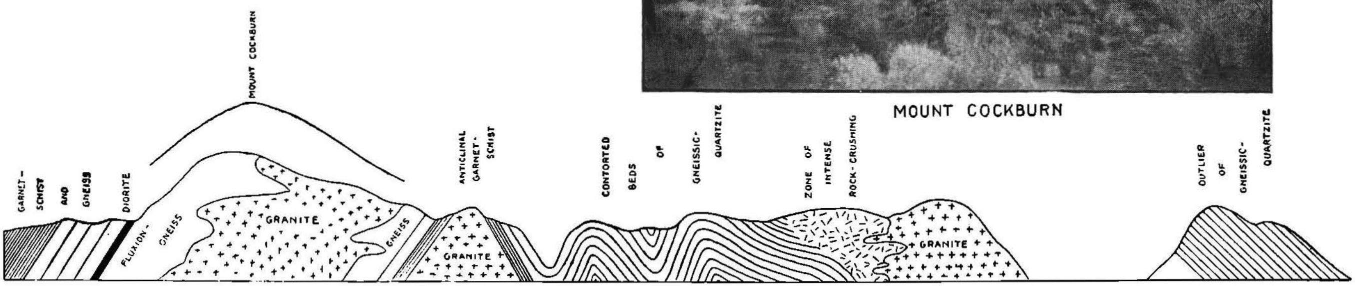
MANN RANGES,

extending South from Mount Cockburn.

Distance: About 2½ Miles.



MOUNT COCKBURN



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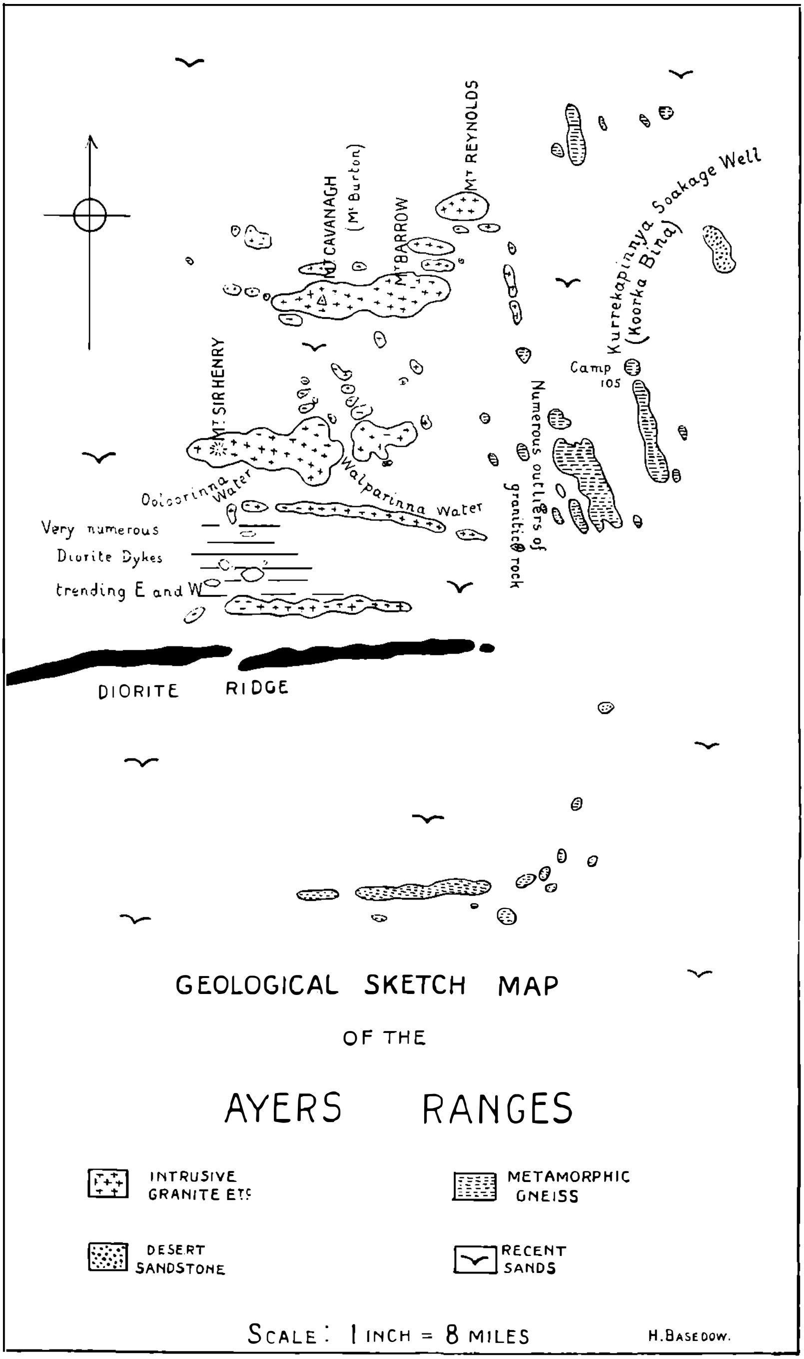

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