The Geology of the Metamorphic Complex of Houghton and the Humbug Scrub.

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Index.

I Abstract.

An area of metamorphic rocks ~~situated~~ is discussed with reference to their mineralogical, petrological and petrographic properties and certain deductions as to their paragenesis are forwarded.

The constituent minerals of the rocks are tabulated and their properties described. A series of descriptions of microscope slides are appended. The structure of the Archean rocks together with the associated overlying sedimentary series is mentioned while the ~~top~~ topography and economic aspect of the area are briefly touched upon.

The discussion of the origin of the metamorphic complex is made with reference to views expressed by previous workers ~~and~~ A geological map is included, together with a new chemical analysis of one of the rocks.

II Introduction

The area under consideration is sub-triangular in shape, extending from Castambul on the Torrens River eastwards to Chain of Ponds & northwards through Houghton, Kersbrook and the Humbug Scrub with its apex beyond the South Para River west of the Barossa Reservoir.

It is covered mainly by a ~~se~~ a series of banded and augen gneisses ~~with associated schists~~; (some ~~gneisses~~ being rich in sillimanite or garnet) with associated schists ~~and~~ together with two major areas (Houghton and Kersbrook) of a crystalline banded rock of igneous appearance referred to previously as the "Houghton Diorite". It is considered that these rocks originated by a complex process of metamorphism and metasomatism on a series of pelitic, calcareous and arenaceous sediments without actual igneous ~~or~~ intrusion and are of Archean age.

They are overlain unconformably by the folded and faulted Adelaide System - a sedimentary series of Late Proterozoic ~~age~~ age.

A complex process of metamorphism on the older sediments with addition of alkaline material and later retrograde metamorphism has brought the rocks to their present form.

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Petrography

The area considered consists mainly of augen gneisses with associated sericitic and chloritic schists while in the South-Western and South-Eastern parts are representatives of the so-called "Houghton Diorites". For general description the rocks are divided into :-

(a) gneisses
(b) schists
(c) (1) granulites
  (2) leucocratic types
  (3) pegmatoid rocks.
(d) unclassified types
(e) sediments

(a) As mentioned previously the "Humbug Scrub Gneisses" are a predominant feature and are of the type referred to generally as of "injected".

They are ~~dark~~ ~~coloured~~ gneissic rocks with light coloured quartzo-felspathic bands or augens set in a ~~somewhat~~ schistose dark matrix of sericite and chlorite, being classified in the field as banded gneisses or augen gneisses. These two varieties merge into each other in the field, and Alderman[6] has shown them to be chemically identical.

Mineralogically they consist of potash felspar with quartz in varying amounts, much sericite (with chlorite and biotite) with only minor amounts of plagioclase. In addition there occur in ~~other~~ rocks of the required grade, sillimanite or garnet.

From a detailed examination, the paragenesis of these rocks appears both indefinite and complex, for nowhere in the area does there occur a rock which may be ~~regards~~ regarded as an unaltered parent type. In every case the rocks have suffered regional metamorphism to at least moderately high grades, together with an addition of alkaline material and have later undergone considerable retrograde effects with marked superimposed shearing on a wide scale, with the consequence that the original form and nature are quite obscure. The process is envisaged as having ~~occurred~~ taken place in several stages, where a wave of regional metamorphism has swept over the area in successively lower grades.

As far as can be guessed, the originally rocks were pelitic – slates or perhaps greywackes. They underwent regional metamorphism which reached its maximum in the south-west where the sillimanite grade rocks occur, with progressively lower grades – garnet and biotite zones towards the north. At conditions of high temperature and pressure, an introduction of alkalies – chiefly potash &, with soda and silica, took place. This resulted in the widespread formation of microcline, the soda usually being present in the coarse high temperature perthite. This introduction is presumed to be a "soaking" process with gentle introduction and migration of material along ~~g~~ previously existing S-planes:- bedding or schisto lack of crosscutting felspathic bands and the general uniformity point to a gradual addition not a lit-par-lit "squirting" or injection. Such a rapid and ~~forceful~~ powerful process as the latter, extending over such an area, presumes too much for the forces of igneous injection. It seems most likely that the microcline was not introduced as such, but that there was an addition of potash (in the ionic state) along preferred directions where fluxing and recrystallization took place.

After this stage, conditions became less extreme and the rocks were in a state where temperatures were low and shearing forces predominate, ie a low grade of regional metamorphism. Whether or not there was a further addition of potash at this stage is not certain - probably there was sufficient alkali freed by the breakdown of microcline to sericite, to allow the addition of potash to associated minerals. ~~It~~ It is now that the general regional schistosity (viz. strike 170° with ~~dip~~ dips steep - chiefly east -) was produced by the wide spread alteration, ~~of~~ under low grade conditions, of microcline to sericite. ~~Potash is liberated causing~~ Sillimanite becomes unstable and combines with the liberated potash to form sericite while garnet is more stable and usually only becomes partially chloritized. The biotite becomes a less iron rich variety and deposits tiny granules of iron ore ~~limonite~~.

The shearing is by no means uniform and effects certain areas to a greater degree than others :- in some schists, no traces of original high grade minerals remain, while in others, only a slight retrograde effect is noticeable.

The diapthoresis under conditions of shear causes crushing or ~~and~~ alteration, and the effects may be seen to be ~~to~~ arrested in all stages towards completion.

(1) Early results are the cracking and bending of felspar crystals, accompanied by some peripheral sericitisation of

microcline and sillimanite. Quartz shows undulose extinction, mica laths are bent, and all crystals show ragged, irregular outlines.

(2) The general grain size is smaller, as granulation and sericitisation becomes advanced – felspar, sillimanite and quartz appear to be corroded, with cracks and cavities filled with white mica. Garnet, ilmenite and quartz crystals are frequently fractured. Quartz shows undulose extinction, an axial angle of 5°, and often elongation due to flow. Apatite is fractured and shows an axial angle of 30°.

(3) In the later stage, all high grade minerals – microcline, sillimanite and garnet have practically gone and all that remains are irregular, recrystallised porphyroblasts of quartz set in a fine grained matrix of sericite, chlorite and biotite with clear granules of quartz and regenerated albite.

(4) The last fine grained, sheared stage is that of the phyllonite – the ~~f~~ mylonitised schists referred to in the next section

(b) Schists.

The schists are typified by ~~[illegible]~~ possessing the fine grained, sericitic, highly directed texture of the gneisses but lacking the porphyroblasts. They are very schistose and are considered to be merely the more highly sheared or altered rocks of the retrograde series and ~~not~~ are not simple low grade rocks. Possibly the most fundamental requirement for a correct interpretation of the geology of the area is the recognition of the true nature of these schists :— they are not phyllites but phyllonites. There are no simple low grade rocks in this area.

These schists ~~are~~ must be classified as above mainly by their association. In the field, bands (from one foot to hundreds of feet in width) ~~are~~ of apparent low grade phyllites are seen to be traversing or in direct contact with ~~obviously~~ high grade metamorphic rocks eg sillimanite - garnet gneisses or granulites. Examples of schists located in less obvious high grade areas are absolutely identical with these.

Microscopically the schists are seen to be the same as the schistose portion of the gneisses and grade into them, thus they are the ultimate stage in retrogression.

Alderman[6] in his work on these gneisses did not recognise this fact and his deduction of the origin of the Humbug Scrub gneisses is basically unsound. This will be discussed later.

(c) Granulites.

In the south-western and south-eastern portions of the area, around the towns of Houghton and Kersbrook, there occur a group of distinctive strongly banded felspathic rocks, which has been called the "Houghton diorite" and which was thought[5.7] to be the result of metamorphism on igneous rocks crystallised from the "Houghton Magma".

On normally weathered faces of the flaggy slabs, the appearance is that of a normal sedimentary rock of quartzitic nature and only on inspection of a freshly broken face does the crystalline nature become apparent.

The banding is due in part to the segregation of ferromagnesian minerals (diopside, actinolite, ilmenite in the darker bands and felspar and quartz in the lighter portions, and also in part to the shearing taking place preferentially in ~~the former~~ some less resisting bands. The perfect uniformity and parallelism of these foliae in the field is remarkable - ~~[illegible]~~ bands may be followed as long as long as a continuous ~~outcrop~~ rock face may be followed. They vary in width - being from ¼" to 2" - although usually about 1".

In general, the rocks consist of plagioclase (from albite to andesine), with or without microcline or quartz, diopside with its accompanying uralitic actinolite, epidote, and the ever-present, often abundant, ilmenite. Quartz is usually not abundant. In some varieties biotite was ~~abundant~~ ~~abundant~~, prominent, while sphene, calcite, rutile, tourmaline, apatite, chlorite, sericite, pyrites are accessories. The composition - from an igneous aspect - varies considerably, (often within a matter of feet in the field) from granite, to granodiorite, syenite and diorite, the latter being most common. In practically all cases ~~the~~ a banding of some kind is prominent.

They weather with a typical, ~~[illegible]~~ blocky appearance and in distinction with the schists and gneisses support little undergrowth - these rocks underly the orchards and pastoral land of the district.

The granulites are distinguished from the banded gneisses into which they merge by the abundance of plagioclase, a general lack of quartz, the presence of diopside, actinolite and epidote together with a homogeneous texture relatively unaffected by shearing.

These rocks are considered to be the result of high grade metamorphism together with considerable transfer of material by metasomatism, ~~felspathic~~ felspathization or an early stage in the process of granitization on rocks originally sedimentary in nature. The abundance of lime-bearing minerals is suggestive of calcareous-siliceous rock, probably a greywacke. The reasons for suggesting a sedimentary ~~origin~~ rather than igneous origin are now considered.

(1) The complete heterogeneity and variation of composition - both mineralogical and chemical points strongly to addition of material to an originally variable sediment by metasomatic processes. Late pneumatolysis on an igneous hybrid might be plausible if it were not for additional evidence.

(2) The presence of strongly developed banding, regular in width, travelling for as much as 30' without significant variation. This is considered to be mimetic after an original bedding and could only be explained on an originally igneous basis by an exceedingly complex and improbable course of differentiation, intrusion or metamorphism. The banding is not in the nature of schistosity and dips at relatively shallow angles (c.a. 40-60°). At Houghton there occur folds both on a small and large scale. Smaller

examples are ptygmatic, while the larger folds are synclines and anticlines in the region of $\frac{1}{4} - \frac{1}{2}$ mile across. A pitching anticline is seen in the bed of the Little Para River just north-east of Houghton.

(3) The gradual transition from banded granulite to banded gneiss to augen gneiss points to a common origin for the two; The difference between the two may be explained as due to

(i) a difference in original composition.
(ii) a difference in metasomatic additions,
(iii) a difference in the original grade of metamorphism
(iiii) a difference in the amount of retrograde metamorphism.

(4) The frequent occurrence of textures which are extremely similar to current bedding are difficult to explain on igneous grounds. Outlined in grains of diopside or actinolite, these forms are persistent in some areas and are considered to be mimetic after ilmenitic cross bedding which is a feature of many old sedimentary rocks.

~~(5) The presence of those minerals which are frequent in metasomatized rocks is a feature of most of these specimens eg. tourmaline, apatite, pyrites etc.~~

(5) The presence of those minerals which are frequent in metasomatized rocks is a feature of most gneisses and granulites. Tourmaline, apatite, pyrites etc. are common.

In the field the strike of the foliation is much less regular than the regional schistosity and these rocks appear to have been contorted and folded while still in a mushy "migmatic" state. They are cut by pegmatites, phyllonitic schists, and by post-tectonic ilmenite veins, often ~~[illegible]~~ 6" in diameter or larger.

Microscopically one ~~feature~~ feature is prominent :- the coarse replacement type of antiperthite which shows a potash felspar being progressively replaced by a plagioclase, and which indicates an introduction of soda after potash. While the general ~~was~~ course of granitization as postulated by Reynolds[8], Misch[9] etc. ~~is~~ indicates potash additions after soda, there are abundant examples of the reverse process - see Shaller[10], Fernando[11], [12]

It thus seems that the original sediments were ~~[illegible]~~ subjected to a high grade of regional metamorphism where they suffered recrystallization, addition of alkalies (potash first, soda later) and a partial desilication. As the original sediments are not present, the actual mechanism is in doubt, but the replacement must have been gentle, molecule by molecule with constant volume, so that the original textural features frequently remain undistorted. At this stage, stress causes the mushy semi-solid migma to become folded (elongation of quartz grains probably takes place here. Simple microcline pegmatites were introduced and successively later pegmatites become barren of felspar and the latest are quartz-tourmaline or ~~simple~~ quartz alone. These late veins ~~are~~ apparently fill faults and tension cracks in the solid rocks. Ilmenite is frequently a very late ~~are~~ introduction.

The rocks produced were high grade, and consisted of plagioclase and diopside chiefly, but like the gneisses suffered diapthoresis ~~s~~ although not to such an extreme degree. Secondary actinolite, epidote, albite ~~and~~ with sericite, chlorite and biotite are the ~~chief~~ main retrograde products. Complete sericitization is limited to narrow bands where shear is predominant.

The nomenclature of these hybrid rocks is difficult. The original term "Houghton diorite" is misleading in that it infers both a ~~ap to~~ constancy of composition and an igneous origin. The name "granulite" is used to ~~infer~~ imply a metamorphosed sediment, of high grade, rich in plagioclase, with quartz (when present) typically elongated.

(2) Leucocrats.

Although of similar origin to the granulites, these are less abundant and constitute a distinct class. They are typified by their white colour, and complete lack of ferromagnesians - diopside, actinolite, epidote and biotite and consist of felspar and quartz with only minor amounts of rutile, tourmaline, muscovite, sericite or ilmenite. Quartz is abundant and varies in amount from 50% to zero in different specimens. The felspar is microcline or a plagioclase from albite to andesine, ~~and~~ with the former showing replacement textures well.

Within the limits stated, members of the group vary considerably as regards texture, grain size and composition. Examples from the vicinity of the Haughton School are

(a) A fine grained, light blue-grey, homogeneous crystalline rock, indistinguishable in the hand specimen from a quartzite.
(b) A fine grained white variety with a strong lineation due to ~~quartz grains and~~ the elongation of quartz grains.
(c) A white, extremely coarse grained, quartz-microcline pegmatitic rock.
(d) A whitish rock, mainly fine grained felspar with regular bands of granular quartz traversing it. This has the appearance of a partially felspathized sandstone.
(e) Towards the north, across the Little Para River, these rocks become increasingly stressed and retrograded to sericite schists.

These are the rocks which Benson[5] called "greisenic aplites" and which are widely distributed in small quantities through the southern part of the area. A.

North-west of Inglewood, at the position marked "siliceous" on the map, is a large outcrop of a quartz rich leucocrat with glassy or blue opalescent quartz and only a very little felspar. It is banded, but less prominently than the granulite. It is moderately coarsely crystalline and appears to have been a recrystallized quartzite to which there have been only limited alkaline additions. Associated with it, in very small quantities are very coarse red granitoid rocks and white dioritoid types.

These rocks appear to have originated under somewhat similar conditions to the granulite ~~but~~ and differ primarily because of their original chemical composition. They are lower in lime, iron and magnesia, and are considered to be due to felspathization of a pure arenaceous rock.

(3) Pegmatites and pegmatoids.

Apart from the simple quartz-microcline pegmatites which occur, there are important even grained complex pegmatites carrying plagioclase, and which approach the leucocrats in characteristics.

The irregular pegmatoid rock which Benson[5] called "yatalite" is difficult to explain. ~~(He describes it "as having" a high titanium content, acid plagioclase, original presence of diopside (now actinolite) and considerable apatite)~~

He describes it as "a coarse grained pegmatite, composed of uralitic actinolite (after diopside), albite containing microcline, titaniferous magnetite, sphene and quartz"

It occurs in ~~narrow~~ narrow bands and veins near Houghton but is notable as a very large outcrop south-east of Kersbrook (shown on the map). Here it occurs in a mass several hundred yards long, surrounded by a normal plagioclase granulite, and consists of extremely coarsely crystalline actinolite and ilmenite. The amphibole occurs in dark green crystalline masses, several feet across.

This may be regarded as a pegmatitic intrusion into the sediments, in which case the diopside, actinolite and ilmenite of the granulites would have been introduced as such, or as a basic segregation of excess ferromagnesians from the altered sediments by a process of metamorphic differentiation.

(d) Unclassified types.

In addition to the major schists, gneisses granulites and pegmatites, there occur minor amounts of rocks which are not strictly classified as above.

These ~~occur~~ are the hornblende gneisses of the Torrens Gorge, the actinolite-calcite schists north-east of Houghton, the haematite schists of Inglewood and Castambul and the haematite-quartzite north of Houghton.

An Archean quartzite, rich in magnetite is interbedded with the gneisses north of Castambul.

In the Forestry Reserve of Hurling Scrub, a band of quartz-tourmaline schist is found.

Sediments

Overlying unconformably the Archean metamorphic complex are the basal members of an Upper Proterozoic sedimentary series — the Adelaide System. The unconformity may only be seen in the northern parts of the inlier, the southern contacts being of the fault type. The unconformity may be seen well at.

(1) In a creek bed south of the road from One Tree Hill to the Humbug Scrub Sanctuary. The actual erosion surface may be seen to be slightly overturned and dipping east at 85° and is stratigraphically overlain by 2' ~~ark~~ dark arkosic quartzite
6' white arkosic sandstone
at least 500' interbedded ilmenitic sandstones, with lesser shales and greywackes.

(2) A similar unconformity is seen north of this, ~~at~~ on the South Para River at the Devil's Nose. Here the contact is normal and dips steeply west.

(3) On the east side near the junction of the Kersbrook - Williamstown road and the track to the New Deloraine Mine. There is a small quarry on the west of the road. Gneisses are overlain by ilmenitic sandstones with a haematite schist (Mt. Bessemer type) notable.

Along the southern boundaries, there are major fault contacts where the sediments have been overthrust from the south mainly over the metamorphic basement. The displacement is usually small, but in the south-east corner, the Lower Phyllite and a sandstone have been moved up against the gneisses and implies considerable ~~a~~ movement. Similarly just south of Paracombe there are small patches of grit and Lower Torrens Dolomite completely disconnected from the sediments ¼ ~~[illegible]~~ mile to the south. These are small residual outliers remaining after erosion of the overthrust block.

An interesting feature in common between the two series of rocks is a pseudoconformity due to shearing at the junction. Along the southern parts of the western contact, namely at Castambul and near the Lower Hermitage Road   miles from Houghton, the basal ilmenitic sandstones of the Adelaide System have become involved in the same orogeny as suffered by the older rocks. Just at the edge the arkosic sandstones become schistose and merge into sericite-chlorite-quartz schists and thence into the Archaean complex. The amount of mixing at the edge is not determinable but is considered to be strictly limited.

The Lower Torrens Dolomite north of Castambul shares the same orogeny and becomes ~~green and~~ recrystallized and green from chloritic impurities.

The Tertiary sediments consist of coarse ~~ferruginous~~ quartzite conglomerates with a ferruginous cement. These are considered to be ~~Miocene~~ river gravels. They are abundant, at least 20' thick in parts and horizontally bedded.

Structure

The general structure of the area is that of a crystalline massif overlain unconformably by a younger sedimentary system. Both of series are folded and faulted by the same and independant orogenic forces.

A discussion of the structure is considered under the divisions.

(1) cleavage (schistosity and foliation)
(2) faulting
(3) folding.
(4) unconformity

The most prominent structural feature of the Archean rocks is the almost constant regional schistosity. The schists and gneisses show a regular flow cleavage produced by the micaceous sericite and chlorite striking at 170°, and although some variations up to 90° from this are found, deviations of more than 10° east or west are uncommon. It deeps steeply east - usually at about 80° but varying at times from 65°E to vertical and 80° W.

The relationship of cleavage to bedding is not known, as compositional variations due to addition of felspar, together with metamorphic effects have completely obliterated any feature in the gneisses which may be interpreted as bedding. In some schists there is a distinct compositional banding perpendicular to the schistosity, but these are uncommon.

It is a notable feature that the regional schistosity of the Archean coincides frequently with the cleavage of the overlying Adelaide System. This suggests two alternatives —

(1) The orogenic forces which operated

in the Archaean have coincided in direction to those operating since that time ie the orogenies of the sinking geosynclinal basin have been regular from earliest times

(2) The schistosity may have been produced in the gneisses by forces acting much later, and that schistosity and the Adelaide System cleavage have been produced in Palaeozoic times concurrently.

Fracture cleavage is only sporadically developed in small shear zones.

The granulites lack a cleavage, but the notable characteristic is a regular compositional banding, interpreted as being formed by mimetic crystallization and as indicating the position of original bedding. From the steeply dipping banding in the gneisses there is a ~~regular~~ gradual change to the shallower dipping foliation in the granulites. While the cleavage is regular, this banding varies considerably both in dip and strike. ~~At Houst~~ East of Kersbrook it is fairly constant at 140° strike dipping 60°E, while the phyllonitic schists cutting it trend at 170° with almost vertical schistosity. North of Houghton it dips as low as 40° both east and west, while the strike varies from 90° to 180°, although usually North-south. ~~Folding~~, from small ptygmatic contortion to larger scale folds are found. Across the strike, about 1 mile north of Houghton, from west to east, there is a fold succession - syncline, anticline, syncline in the granulites.

(4) Faulting, like the folding and cleavage, has been produced over an immense period through by a number of orogenic upheavals. Within the Archean there appear to have been ~~two~~ possibly three successive faulting periods characterized by the type of mineralization.

(1) small faults through the centres of ptygmatic drag folds are obviously the first formed after the migmatite had reached a semi-competent stage.

(2) faults of larger size showing small displacements filled with ilmenite.

(3) large faults, similar to (2) but filled with quartz-tourmaline or barren quartz veins.

There is later faulting probably both Palaeozoic and Tertiary which has affected both the Complex and the Adelaide System. There have been powerful forces (? mostly from the east) which have thrust the basal sediments against the pavement causing induration, brecciation and metamorphism of the ~~basal~~ ilmenitic sandstones. This has produced an area of brecciation just north-west of Gumeracha - where in a sub-triangular area with sides of approximately ½ mile long ~~sides~~ there is a crush zone containing granulites, schists, phyllites, sandstones and dolomite. A little mineralization (calcite, pyrites, gold) has occurred in this area.

The final faulting is of Tertiary age, and although differentiation between the 4 ages of faults is not always possible, these are usually most abundant, fresh and unmineralized.

The whole of the contact around the

southerly portion of the Complex consists of a system of interlocking thrust faults.

The contact is unconformable to the north, and warping of the junction is seen.

There are repeated, both small and large strike faults in the sediments above, and these are seen to be approximately parallel to the schistosity of the gneisses and the axial planes of the folds in the granulites.

Topography.

The geomorphology of the district is complex, being controlled by structural forms, durability of various rocks and fluctuations of the continental level, and a discussion will not be attempted.

The smaller creeks are controlled by the direction of faults or cleavage, while the older, larger rivers (Torrens, South Para etc) are quite independant of even major structural features and are apparently dependant on old controls now no longer ~~a~~ visible.

The Archean Complex gneiss forms a ~~high~~ high rugged ridge up through the Humbug Scrub where it is covered by a mass of undergrowth and trees. The granulites weather to rounded hills with less undergrowth and the country to the south is well cultivated.

Economic Aspect

The association of minerals of economic importance with the old crystallic rocks is a normal feature and here deposits of gold copper, silver and lead have been worked. The most important ~~is~~ is the gold of Humbug Scrub ~~to which~~ and reference may be made to Hossfeld's[13] paper. ~~Copper ores minerals - chalcopyrite and bornite are widespread, but like galena etc rarely occur in economic concentrations~~

Generally, many significant minerals occur widely eg. chalcopyrite, ~~pyrite~~ bornite, pyrites galena, rutile etc. but rarely are found in economic concentrations.

The iron ores ilmenite and haematite are common but still in insufficient quantities to warrant extraction.

Barytes is found as occasional "floaters" but not in any amount in situ.

The mineralization may be considered as
(1) hypothermal and connected with the metasomatism and metamorphism of the gneisses etc & at an early stage or
(2) Epithermal – and associated with later faulting and brecciation.
(3) Still later alluvial concentration. Small specks of gold may be washed from most of the creeks of the area.

Discussion.

As the views presented here are in direct contrast with those of previous workers, it is desirable to summarize earlier theories and to determine whether they satisfactorily explain field and laboratory evidence

One of the earliest references made to the granulites is by Howchin[14] 1906, where, in reference to Archean rocks of the Inman Valley he says: "The external appearance of these beds is very deceptive, for the molecular reconstruction has been so complete in many instances that what looks in general form like a sedimentary rock, shows, on fracture, complete crystalline structure." He considered them however to be of igneous nature and discusses a process of injection of schistose rocks by pegmatitic liquids to explain the formation of the gneisses.

Benson[5] first performed detailed study on the Houghton district and referred to "an intrusive plutonic series" together with sedimentary schists. A rock referred to as a scapolite-amphibolite which he described but did not find in situ ~~is considered~~ ~~has~~ could not ~~been~~ be again found, and is considered to have been transported from the abundant deposits to the east beyond Gumeracha. The ~~consideration~~ theory that the "Houghton diorite" is magmatic has been discussed and reasonable evidence advanced to suggest that it is not. Benson also includes in his "petrographic province" the rocks of Palmer, Adgate, Yankalilla, Moonta, Olary, Jamestown ~~etc~~ while England[14] adds those of Myponga, Mt Compass, Mt. Crawford, & Tanunda whereas later work (much as yet unpublished) indicates conclusively the existence of two epochs of metamorphism separated and distinct in time and petrological characteristics.

Lost It is considered that the metamorphic rocks ~~of igneous~~ ~~and rocks~~ of Houghton, Adgate, Mt. Compass, Yankalilla etc belong to the Archaean and are termed the Western Province while those ~~granitic types~~ of Mt. Kitchener, Mt Crawford, Palmer etc. are post-Adelaide System in age and constitute an Eastern Province.

With reference to ~~the~~ gneiss, Hossfeld (1935) states that "the sedimentary origin of most of these rocks is evident. The only important exceptions to this are certain areas of gneiss in the Humbug Scrub —". He quotes a contact between the massive gneisses and the injected schists and "believes that the augen-gneisses may represent an altered igneous intrusion, changed partly while still in the plastic condition."

Alderman[6] did not ~~agree~~ confirm this, and later investigation ~~[illegible]~~ shows that ~~basicly~~ basically there is no difference between the rock types.

The most important contribution to the investigation of the augen gneisses was by Alderman who ~~contended~~ stated ~~that the schists of the area were phyllites and that the injected schists and augen gneisses were the result of alkaline addition~~ - ~~by the evidence of chemical analysis~~ ~~by chemical analyses evidence he claimed that there was an introduction of sodium silicate~~. "If an examination of these rocks was based on field evidence alone the injection-metamorphism would appear to be a comparatively simple process consisting of the lit-par-lit injection into the schists of ~~f~~ quartz-felspar pegmatite. The textural properties of the augen gneisses and their associates would have been developed in a subsequent period of dynamic metamorphism. A comparison of the chemical composition of the schists with that of the banded and augen gneisses shows however that the injecting material cannot have been quartz-felspar pegmatite" and concludes that it was an ~~alkali~~ soda-lime silicate.

As has been stated previously, the 7. sericite schists are considered not to be simple low grade ~~phyllonites~~ phyllites but to be the result of retrograde metamorphism on metasomatised sediments i.e. the 'injection' of phyllites to form injection schists and gneisses could not have taken place. As the schists which are found are not primary and un-injected then Alderman's deduction of the addition of soda is unsupported by evidence.

(2i)

Alderman also postulates ~~that the dynamic~~ metamorphism suffered by these rocks is due to ~~a~~ ~~occur~~ a bodily increase in volume of the rocks ~~&~~ – "the whole ~~rock~~ would, therefore, nearly double its volume." The validity of this statement is questioned for the following reasons ~~on two points~~.

(1) That A process of 'squirting' of liquid magmatic fluid into solid ~~rocks~~ ~~would~~ take place if it involved such an increase in volume.

(2) ~~That~~ the addition of alkalies ~~material~~ may not take ~~took~~ place without concommitant loss of material

(3) That the addition took place at constant weight and not constant volume. It is considered that ~~all~~ the metasomatism through the whole area took place gradually ~~at constant volume~~ without change of volume.

(4) That if such a volume change did occur, it would produce a regionally constant direction of schistosity.

Alderman also suggests ~~postulates~~ that the dynamic metamorphism suffered by these rocks is due to a bodily increase in volume — "the whole rock would, therefore, nearly double its volume". This is questioned, as such a mechanism would assume the following statements — each of which is doubted :-

(1) That a process of "squirting" of liquid magmatic fluid into solid rocks could take place if it involved such an increase in volume.

(2) That the addition of alkalies took place without simultaneous loss of material.

(3) That the addition took place at constant weight and not (as is generally accepted) at constant volume.

(4) That if such a volume change did occur, it would produce a schistosity which is regionally constant.

In this paper the effects of retrograde metamorphism under low grade conditions is discussed and certain properties ~~to~~ of the rocks are ascribed to be effects of stress. These are

(1) the undulose extinction of quartz
(2) the shattering of crystals (quartz, felspar, ilmenite)
(3) the bending (or warping) of twin lamellae in plagioclase or of cleavages in mica
(4) the rendering of normally uniaxial minerals biaxial.
(5) the peripheral granulation or ~~and~~ sericitisation of crystals.

It should be however observed that only portion of the strain effects ~~these~~ may be considered as being due solely to large scale orogenic stresses as ~~many~~ Reynolds ~~attributes them frequently to replacement effects.~~ states that they may frequently be merely replacement effects.

X Summary.

Throughout the metamorphic inlier there occurs a ranges of para-gneisses ranging from schists and gneisses to granulites, all being sediments which have suffered the combined effects of metamorphism to a high grade, metasomatism with the addition of potash to the schists and gneisses and potash and soda to the granulites, with later retrograde metamorphism well advanced. The sediments, originally pelitic, calcareous and arenaceous reached the sillimanite grade in the south, garnet grade in southern and central parts and the biotite grade ~~to~~ the north. Alkali ~~addition caused the formation of rocks of igneous and injected appearance and retrograde metamorphism caused the widespread processes of sericitization, uralitization, saussuritization and chloritization with the also production of abundant phyllonites.~~ metasomatism produced a range of migmatites (granulites and "injected" rocks.) Stress at this stage caused folding in the granulites, and continuation of orogenic forces ~~to~~ caused later faulting and varied mineralization.

~~In Post Archean times – after deposition of the Adelaide System there has been~~

Since this time, retrograde metamorphism has been widespread and has caused the processes of sericitization, uralitization, saussuritization and chloritization, with the production of a range of phyllonitic types.

Since the Adelaide System had been laid down unconformably on the crystalline rocks, orogenic forces have caused continued folding and faulting. These are attributed to Early Palaeozoic and Mid Tertiary times.

After the sedimentary deposition of Pre Cambrian times the area has apparently been ~~one~~ terrestrial, and subjected to continued erosion until the middle and late Tertiary when some gravels were ~~deposited~~ laid down.

XI Discussion of the Map

Due to limitations of scale a solid block plan is presented, without minor features such as alluvial and Tertiary gravels both of which are however developed extensively.

The contacts between granulites and gneisses are frequently only approximate because of soil cover and poor outcrops and also because of the similarity in the two rock types, there being transitions between the two. For the ~~The fault contacts to the south are frequently difficult to fix~~ same reason, some massive felspathic rocks, ~~gneisses~~ particularly north of Kersbrook, are shown as gneisses although their affinity with the granulites is marked.

XII Acknowledgements

~~It is desired to~~ The author ~~des~~ wishes to express his thanks to Sir Douglas Mawson, and Messrs. A.W. Kleeman and A.F. Wilson for their assistance and encouragement.

Petrology.

The rocks are differentiated due to certain defined characteristics and into the divisions shown and brief petrological descriptions are appended for indicating the common features and varieties within each group.

I ~~III~~ Granulites
(a) "Dioritic" type
(b) Jervoisitic varieties.
II ~~III~~ Schists
III ~~III~~ ~~Gneisses~~ metamorphic rocks.
V. IV) Sediments (Adelaide System).
other

108.

A typical example of the "diorite" from Reybrook. Holocrystalline, fine grained with a slight directed texture due to strings of ilmenite grains. Chiefly felspar (Oligoclase Ab_{70}) showing twinning on the Albite or & combined Albite-Pericline laws with Refractive index above balsam and extinction in the symmetrical zone 11°. Diopside, for the most part altered to actinolite (as strongly idioblastic light coloured needles or fibrous crystals). Epidote ~~in yellow~~ in large yellow pleochroic crystals or in tiny colourless grains. There is no quartz or potash felspar present. Accessories are abundant colourless apatite, ilmenite and many tiny euhedral tourmaline prisms occur in the plagioclase.

This rock is an oligoclase-granulite

141.

A fine grained felspar rock from Kersbrook having the general appearance of a quartzite in the hand specimen. It differs from 108 only by having a little granophyric quartz; a more basic plag. Andesine (Ab 68) and a somewhat fresher diopside. Some of the plagioclase show bent twin lamellae. Accessories are rutile, apatite, epidote and zircon.

102

Typical of the cross-bedded granulites from Kersbrook this rock has alternate coarsely crystalline light coloured bands and fine grained greyish bands, the latter showing the actinolitic cross-bedding. ~~The~~ .

The slide was cut so as to show portions of both bands and reveals that the only differences apart from grain size between them are
(1) quartz is abundant in the fine grained portion (this band shows the cross bedding and is apparently nearer the original state of the rock) while lacking in the coarse portions.
(2) ferromagnesians are less abundant in the fine part.

The abundant plagioclase is Andesine (Ab 68) while actinolite is well developed frequently as closely packed fibrous bands across the slide.

Accessories are epidote, ilmenite, apatite.

113.

A Similar cross bedded granulite to 107. ~~The grain~~ The plagioclase is Oligoclase Ab_{72} in irregularly shaped crystals. There is a perthitic microcline present – also actinolite and a little quartz. There is ~~none~~ practically no residual pyroxene remaining. Ilmenite is abundant.

Accessory biotite, epidote and apatite

129.

This is an example of the schistose granulite. A dark rock with a distinct banding and a fissility imparted parallel to this ~~the~~ direction by micas.

In the microscope slide, the change from a homogeneous granoblastic texture to that of a gneiss is well illustrated. There are alternate bands (a) granulose microcline perthite and quartz and

(b) fine grained sericite - chlorite schistose bands.

The quartz shows undulose extinction and granulation while the microcline shows fracture and peripheral sericitization.

In the schistose parts, skeletal crystals of plagioclase showing twinning remain as vague residuals after practically complete replacement by sericite. There is a considerable amount of white mica in cracks and ~~cavities~~ enclosures within the quartz and felspar as though potash had entered along cracks and partially replaced the minerals.

Biotite is moderately well crystallized

and there is accessory leucoxene, apatite, zircon & ilmenite

89

Strongly banded gneissic granulite, foliae are alternately dark and light being richer in ferromagnesians or felspar respectively. A broken face parallel to the banding shows a strong degree of preferred orientation in green chlorite.

The thin section was cut so as to show both a light and dark band and like No. 129 shows a basic detail in the petrology of the granulites. The light part of the rock is rich in unaltered felspar Albite (Ab 92) while the darker portion shows sericitification of the plagioclase particularly along cleavage. There is present also biotite, untwinned albite granules, chlorite and quartz - the latter being abundant - frequently granophyric with the felspar. Accessories are corroded ilmenite and zircon

161.

B. The specimen is representative of a biotite rich schistose band (eastern one shown on the map in the South-Eastern corner) in the Renbrack granulite.

Microscopically it is a fine grained rock consisting of microcline perthite and a fresh, brown, irregularly ~~shaped~~ coloured biotite.

Accessories are apatite and zircon while ilmenite is abundant.

85.

North West of Haughton, up the Little Pine River.
A light coloured, rather more coarsely grained rock than the average showing plagioclase with macroscopically visible multiple twinning and a little blue opalescent quartz.

Despite the unaltered appearance in the hand specimen, the thin section shows considerable sericitization with the resultant texture of many ragged porphyroblasts set in a fine grained micaceous groundmass. The plagioclase is Oligoclase (Ab75). Microcline showing an arrested stage in the replacement by plagioclase shows the same anti-perthitic form. It is notable that the microcline is always fresher than the plagioclase, where the sericitization takes place from the outside - and preferentially along cracks and twin planes.

Accessories are rutile with leucoxene surrounding it, also muscovite as fairly large ~~crystal~~ flakes.

295.

In this orientation - the texture is far more regular with quartz (58%) felspar (chiefly microcline) - 22% and biotite (7%) in a fine even grained granoblastic aggregate.

Quartz shows slight elongation while the microcline is fresh and a little Oligoclase is present. Biotite occurs as commonly

6.

directed, well spaced laths with dark brown pleochroism.

Accessories are apatite, muscovite, ilmenite and zircon totalling 2.7%.

225.

Quarry in Gar the Torrens Gorge.

A light coloured rock with very little ferromagnesian minerals.

Microscopically it is fine grained and consists chiefly of a rather coarse microcline-albite perthite with less quartz, subordinate micas, epidote and calcite. Sericitization has taken place in whisps and patches.

60.

Torrens Gorge quarry.

This has the appearance of a gneissic granite being a light coloured quartz-felspar rock with abundant black, commonly orientated black mica.

In thin section it is a moderately coarse grained rock with little directional features apparent. It consists chiefly of perthitic microcline with slightly less quartz frequently drawn out into elongated forms. Biotite is not well crystallized and a little oligoclase is present. Ac

Accessories are rutile with much leucoxene, & zircon.

Sericitization is well advanced.

70

Renbrook. A light brownish rock with elongated bluish opalescent quartz, together with much felspar and biotite and a little epidote. Microscopically it is holocrystalline, hypidiomorphic with granoblastic texture consisting of quartz, fresh microcline, cloudy plagioclase and biotite with accessory apatite, ilmenite, leucoxene, magnetite and zircon.

The quartz is frequently elongated, the microcline shows cross hatching, and the ~~p~~ plagioclase is an Oligoclase (Ab_{12}). Biotite is abundant as irregular laths, pleochroic from light yellow to green. Epidote is present as the two common varieties – yellow and colourless.

Analysis.

SiO_2	69·25
Al_2O_3	13·40
Fe_2O_3	2·64
FeO	1·47
MgO	1·53
CaO	2·47
Na_2O	3·03
K_2O	4·66
H_2O+	·49
H_2O-	·17
P_2O_5	·13
MnO	·01
TiO_2	·91
CO_2	
BaO	trace
S.	trace

Norm.

Mode:

quartz	26·1
microcline	31·4
plagioclase	32·3
biotite	9·3
access	·9%

The rock is monzonitic in composition.

125B.

A light grey, medium grained, banded rock chiefly pink felspar with prominent ilmenite and actinolite.

In thin section the rock is typified by the abundance of plagioclase much obscured by alteration and in many cases showing partial replacement of microcline, the latter being fresh in appearance. Uralitized diopside with accompanying actinolite is abundant. Epidote, ilmenite with rutile, are present while apatite ~~shows~~ appears as large crystals, some showing square isotropic sections.

103.

Strongly banded, crystalline rock with the usual fine and coarse alternating ~~white~~ grey and ~~grey~~ white bands, the latter carrying frequent large white plagioclase crystals and irregular patches of ilmenite, epidote and actinolite.

Microscopically similar to 107 with a little more ferromagnesians. The alteration of epidote to actinolite is well shown and the plagioclase is an oligoclase.

11

A light grey rock with a fine even grained texture with regular wide (1-2 mm.) bands traversing it.

Microscopically the rock consists of quite large cloudy plagioclase, interlocking crystals of irregular shape, ~~interlock~~ with subordinate microcline, diopside, actinolite, and epidote.

The plagioclase is frequently antiperthitic with relicts of similarly orientated microcline distributed through it. The twins are frequently bent, and warped twin planes give irregular non symmetrical extinction angles. There is a little peripheral granulitisation.

Apatite is abundant as quite large, brownish crystals, pleochroic with absorption $Y > X$ and biaxially positive with a $2V = 42°$. Epidote is frequently intimately associated with it.

Ilmenite often has actinolite growing round it.

14.

A light coloured rock of fresh appearance with a slightly gneissic and irregular texture, consisting chiefly of felspar with a little dark green actinolite and yellow-green epidote in veins and patches.

In thin section it is a medium grained crystalline rock with no particular directed texture, consisting chiefly of plagioclase with diopside, actinolite and epidote. There is abundant accessory ilmenite with leucoxene, a pale biotite, and tiny euhedral tourmaline crystals.

The plagioclase is much fresher than usual and is an albite:- it contains the antiperthitic microcline.

6.

An even grained crystalline rock, consisting chiefly of white felspar, but with irregular bands rich in finely micaceous biotite.

Microscopically a medium grained crystalline rock, the texture being chiefly granoblastic but tending towards gneissose in those parts rich in biotite.

The felspars are most abundant, being fresher than usual and consisting of an almost pure Albite (Ab_{98}) and microcline as the coarse antiperthite. The albite is most abundant and is frequently untwinned even in large crystals while fresh granules of regenerated felspar are abundant in the schistose ground mass.

In one part a gneissic texture is produced by a fresh pale green to brown biotite with some chlorite - the micas occurring as abundant shreds and poorly formed laths, both large and small. These have the appearance of being secondary - being produced in a band of shear.

Apatite is an abundant and well formed ~~in~~ (frequently hexagonal or lath sections) accessory, together with ilmenite and a little leucoxene, and zircon.

89.

A compact ~~grey~~ fine grained grey, banded rock with the general appearance in the hand specimen of a quartzite.

In the thin section the rock is rather leucocratic - being deficient in ferromagnesians with ~~of~~ granoblastic texture and consisting mainly of ~~anhedral~~ ~~more~~ xenoblastic microcline and quartz. A little plagioclase - Andesine (Ab_{63}) is present, while muscovite as narrow laths, ~~and~~ fresh green biotite and a little chlorite are the ~~only~~ notable. A carbonate mineral, presumably calcite - although the idioblastic outlines suggest dolomite is abundant. Accessories are zircon and rutile.

(b) Leucocratic granulites

These are in general, light coloured rocks, of varying textures and grain-size notable because of the complete lack of the ~~type~~ minerals typical of the normal granulites — diopside, actinolite, hornblende, epidote and biotite and also because of the frequent abundance of quartz.

172. A+B.

Quarry south of the Houghton School:

This is the type described by Bernard[6] as a gneissic aplite. It is a ~~white~~ pure white colour, fine grained, ~~of~~ with the general appearance of a quartzite but which on closer inspection is seen to consist chiefly of crystalline felspar with a ~~extremely~~ well marked lineation due to ~~highly~~ extremely elongated quartz grains — to 1.5 mms in length but about 1 m.m. diameter. In the field this lineation is a regional feature and is as constant as the schistosity in other rocks.

The rock slides A + B are sections cut across and along the lineation respectively.

(A) Crystalline with a regular, fine grained texture with approximately equal amounts of rounded crystals of quartz and felspar. The majority of the latter is a plagioclase - Andesine Ab68 — frequently enclosing relicts of cross-hatched microcline as antiperthitic relicts. Accessories are a little muscovite and sphene.

B. This shows the drawn out nature of the quartz - which does not show marked undulose extinction. Microcline is more abundant than in A.

2.

Quarry North of Houghton school

A similar ~~somewhat~~ related rock to 177, this is white and fine grained, with a slight banding and a few flakes of muscovite.

Microscopically a granoblastic aggregate of xenoblastic microcline and quartz. A little antiperthitic plagioclase - Albite Ab92 is present. Muscovite occurs as quite large colourless flakes while there are some wisps and patches of a fine sericitic mica.

Ilmenite and rutile are abundant accessories.

171.

Quarry south of Houghton School

A leucocratic quartz-felspar rock of coarse grain with only a little dark mineral.

In thin section the rock is seen to have a coarser grain than usual and consists of large subhedral crystals of plagioclase - Andesine Ab69 - with subordinate quartz. There are accessory rutile and tourmaline. The plagioclase is twinned on the Albite or combined Albite-Pericline laws and shows some twin lamellae bent. Alteration has produced a mass of tiny white mica flakes as inclusions - the clouding being frequently more dense towards the outer parts of the crystals; or along cleavages and twin lamellae.

157

Kershoek.

A white coloured, fine grained, crystallic felspar-rock with the appearance of a quartzite. A little micaceous haematite is encrusted in joints.

Microscopically the rock is practically all irregularly shaped plagioclase crystals - Oligoclase - Andesine Ab_{70} - with only a little biotite, sericite, chlorite, ilmenite and some tiny euhedral tourmalines. There is a little antiperthitic microcline and quartz is entirely lacking.

✳ to page 24

200. Forest ~~reserve~~ Hurling Scrub.

~~This is a black, ~~schist~~ tourmaline schist which is considered here for convenience. It is not a leucocratic granulite but being of metasomatic origin ~~it is~~ and even less akin to the general types of schists it is described here.~~

A dark coloured, fine grained somewhat schistose rock consisting of an aggregate of black crystallic tourmaline with less quartz. It is quite distinct from the quartz tourmaline ~~occurring~~ veins or graphic intergrowths.

Microscopically a medium to fine grained rock with diablastic texture, its consists solely of approximately equal amounts of tourmaline and quartz. While the former appears to be more abundant in the hand specimen, the latter predominates in thin section. Lineation is not developed and the texture is granulose.

The quartz is frequently elongated and shows marked undulose extinction. The tourmaline is usually quite large and xenoblastic while the smaller crystals approach idioblastic outlines. Pleochroism is strong

ε - light greenish yellow
ω - deep green-brown

There is accessory zircon.

1

Next to Houghton School.

A white irregularly grained quartz-felspar crystalline rock, the quartz being concentrated as grains in bands. Tourmaline, muscovite and rutile are visible in tiny grains.

Microscopically a granoblastic rock with felspar and quartz, the latter being mainly concentrated in a band across the slide although also interstitial between the felspars.

Plagioclase and microcline are both present the former Albite Ab_{93} frequently twinned on both albite and pericline laws and the latter often coarsely antiperthitic.

Rutile is well crystallized and is accessory with muscovite (and sericite), and tiny euhedral tourmalines. There is some crushing and sericitization.

II Schists

Macroscopically these rocks are fine grained, micaceous and markedly schistose, varying in colour from grey (sericitic) to various shades of yellowish green to dark green (chloritic). Field observations ~~macroscopic~~ together with ~~labo~~ laboratory work invariably indicate them to be phyllonitic and not simple low grade phyllites. The uniformity of the schists over the area indicate that there are no purely low grade rocks present.

Microscopically they are shown to be identical with the schistose groundmass of the augen gneisses and are the result of the retrograde mineralogical degradation of high grade minerals to low minerals stable under low grade regional metamorphism with shearing forces high. There has been some pure cataclastic effects. They show a finely micaceous schistose texture and consist of sericite with chlorite and biotite; the micas frequently flowing around scattered small ~~porp~~ porphyroblastic relicts of fragmented and strained quartz.

47.

A band ~~from within enclosed~~ traversing the granulite at Inglewood.

A highly fissile rock, pale green in colour consisting of sericite and chlorite.

In the thin section, the texture is fine grained with a foliation due to strings of quartz porphyroblasts parallel to a schistosity formed by the common orientation of small laths of sericite and chlorite

Quartz is plentiful, ~~in bro~~ clear and colourless, in broken and irregularly shaped crystals. The micas are a colourless sericite in small laths, and a chlorite pleochroic from yellow to green as whisps and sheafs.

Calcite is also present as idioblastic crystals slightly brownish and pleochroic – each crystal being intimately associated and surrounded by a dark semi-opaque skeleton which resolves itself into rutile with some haematite. The breakdown of sphene to calcite plus rutile is not recorded and seems doubtful.

Tourmaline is an abundant accessory as pleochroic brown prisms and hexagonal sections – the latter frequently showing colour zoning with a lighter centre. Pyrites is also abundant.

50.

A pale green schist of phyllitic appearance with a distinct banding and a well developed schistosity.

Microscopically very schistose, consisting of a finely divided aggregate of flakes of sericite and chlorite with ~~granules of~~ quartz. The latter shows granulation and recrystallization in lenticular groups – elongated in the direction of the schistosity.

Colourless sericite and pale chlorite constitute the schistose part, flakes being frequently set athwart the fissile direction.

A string of rutile grains also cuts

across the schistosity. There is accessory apatite.

204.

A dark green coloured schistose rock, consisting ~~apparently~~ of a green mica. It occurs as a band cutting the granulites of the Dorens Gorge.

Microscopically it shows a well directed, highly schistose texture with small porphyroblasts of quartz, untwinned plagioclase, rutile ilmenite and apatite.

The mica is mainly a green ragged biotite with an abundance of paler green chlorite, both frequently set at an angle to the schistosity. Augens of apatite are frequent. Accessories include leucoxene and micaceous haematite.

13.

A soft green schist composed chiefly of micaceous ~~material~~ ~~with~~ and actinolite ~~and~~ ~~bro~~ with bands of white calcite.

In thin section this schist differs completely from the usual phyllonite. The schistosity is at a high angle to the compositional banding due to calcite. Minerals are fresh ~~and~~, well crystallized and are mostly orientated similarly, consisting of amphiboles, micas, calcite and quartz. The amphibole is present in the ~~two~~ varieties with a pale a colourless tremolite growing around the pleochroic brown hornblende. The two appear to be in perfect optical continuity - the tremolite often so having the same extinction angle (from a cleavage traversing both minerals) and interference figure. The junction between the coloured and uncoloured varieties is sharp.

Also present are a green biotite and a pale green pennite. Ilmenite is seen in an arrested stage in the breakdown to leucoxene ~~rutile~~ and micaceous haematite.

Accessories are apatite & epidote, while a band rich in quartz cuts the slide.

III Gneisses.

These ~~gneisses~~ rocks are of the so-called "injected" or "migmatitic" types and may be classed as augen gneisses or banded gneisses – ~~the~~ In the field these two varieties merge insensibly into ~~banded~~ gneiss each other and into banded granulites or schists.

66

Castanbul

A light grey gneiss, irregular and coarse in grain with large (3 cm.) felspars and some quartz enclosed in a micaceous mass of sericite and chlorite.

Microscopically very coarse grained with large crushed and altered augens of felspar and quartz surrounded by a fine mesh of mica flakes.

Felspars are chiefly a fresh microcline with lesser much altered plagioclase – a pure Albite (Ab 98). The alteration has taken place along cracks and cleavages and large areas of the plagioclase are frequently made over to an aggregate of white mica. Twin lamellae are often bent. The microcline is perthitic and also contains granophyric quartz. The latter usually occurring in large irregular crystals – clear and colourless with undulose extinction.

Biotite as very ragged laths, often in intimate growths with sericite and chlorite from which it is forming or to which it is altering. Ilmenite is fragmented and in places iron appears to have been released to form a dark mica as a zone about the iron ore in the general matrix of sericite.

The schistose portion contains much sericite, biotite, chlorite, ilmenite and frequently skeletal relicts of albite may be seen covered by a replacing mesh of sericite.

Accessories are apatite, calcite, zircon and rutile.

78 Jones Gorge.

This is the type rock for a variety of massive, dark coloured augen gneisses which constitute the major rocks of the southern part of the area. They may contain sillimanite or garnet or both.

No. 78 a dark grey massive to gneissic rock with white fibres of sillimanite and also occasional small patches of chlorite after garnet.

Microscopically this rock possesses the common gneissic texture with large stressed and broken porphyroblasts of quartz and often microcline in a well directed schistose matrix.

Sericite is present as fresh tabular crystals or in all stages to complete ~~sect~~ sericitisation. Garnet is less abundant and shows chloritisation, often ~~remaining~~ fine as relicts fragments surrounded by pennite.

The biotite is typical of these sillimanite gneisses and is similar to that found in similar rocks at Broken Hill, Yankalilla etc - being very dark brown, strongly pleochroic and riddled with tiny opaque inclusions of iron ore. It is seen as intergrowths with quartz, sericite, sillimanite and chlorite.

Pyrites is quite a common and prominent accessory.

78B Similar but containing sillimanite but not garnet.

78C. Similar with sillimanite and only a little garnet remaining although chlorite pseudomorphs are common.

75 This gneiss contains only a little sillimanite, with no garnet although Zircon occurs as quite large crystals.

201

Kersbrook.

In the hand specimen garnet is visible as abundant tiny brown grains, concentrated in bands. Sillimanite is not present.

21.

Gorge Road Quarry.

Sillimanite and garnet are not present, while biotite is abundant.

224.

[illegible] Jones Gorge.

A dark green gneiss with a fine schistose groundmass of hornblende and biotite with small augen of felspar. This is not a typical

The augen gneiss, being one of the extremely varied types in the zone between the banded granulites and the true augen gneisses.

Microscopically the rock is seen to consist of bands rich in hornblende or felspar - these being the only constituents of any importance. The plagioclase is extremely altered and is Andesine (Ab 68) while the hornblende is the fresh brown variety with associated tremolite.

Accessories are epidote, apatite, sericite, ilmenite and zircon.

IV Other Metamorphic Rocks.

Here are considered several odd specimens which do not fit in with the groups mentioned previously.

200 From page 14.

84.

Little Para River.

This is a rock of which only one specimen was found – a black haematite quartzite. It was found within the Archean ~~rock~~ area and is one of the older rocks.

A hard, massive quartzite of darkly flinty grey being essentially homogeneous and possessing no directed characteristics.

As microscopically a very fine grained quartzite with a notable amount of micaceous haematite present. The iron ore lies in compositional banding in one direction and is elongated giving a schistosity at widely varying – frequently high – angles to this.

37

A light coloured fine grained quartzite from just within the Archean boundary, interbedded with gneisses. Sericitic material gives it a somewhat schistose aspect, ~~an~~ while it is notable because of the abundance of glittering grains of magnetite.

In thin section it is a fine grained quartz rock of ~~uneven~~ texture with ~~an~~ abundant euhedral magnetite, with some

(3) continued) whisps and patches of micaceous material.

Some of the quartz show recrystallization about the larger magnetite crystals, while fine, opaque iron ore is abundant along the slide. Also present is sericite with lesser pale green biotite and a little cloudy felspar

Accessories are zircon and tourmaline.

V Sediments of the Adelaide System.

Close to the Archean massif various younger sediments, acted on by later metamorphic processes assume interesting appearances.

218. A

A light coloured highly schistose rock consisting chiefly of sericite with bands or patches of green mica, frequently at 30° to the schistosity. There is a slightly speckled appearance due to small grains of ilmenite. This is a sheared ilmenitic-arkosic-basal sandstone, in the field it is almost indistinguishable from the older sericite schist.

Microscopically it differs from the retrograde phyllonites - the sheared nature is apparent and plagioclase relicts are lacking

Cracks in ~~the~~ abundant quartz are ~~filled~~ often filled with sericitic mica ~~orientated grains~~ in parallel orientations, frequently associated with leucoxene, which is abundant.
Green chloritic mica is present as whisps and patches

2

Lower Tower Dolomite.

A pale green crystalline dolomite with smears of glossy green chlorite imparting a schistose tendency. There has been recrystallization of the carbonate in veins and patches.

Microscopically a partially recrystallized rock consisting almost entirely of dolomite which varies considerably in grain size. Some of the carbonate shows multiple twinning. The only other minerals present ~~are quartz~~ ~~and~~ are a pale fibrous chlorite, ~~limonite~~ with a little quartz, limonite and magnetite.

first

Mineralogy.

~~As a preliminary to a discussion of the~~

As a preliminary to a petrological discussion, the characteristics and more important optical properties of each individual mineral found in the area will be presented; approximately in order of importance or abundance.

I. Felspars.

Abundant felspar is a characteristic of all but the highly sheared phyllonitic schists and either microcline or a moderately acid plag occurs in widely varying amounts depending on the rock type. Generally -

(a) the schists carry ~~little~~ no recognisable felspar - apart from tiny granules of untwinned albite

(b) the gneisses carry microcline with amounts of plagioclase (albite to andesine) usually low. The common sillimanite-garnet gneisses usually lack plagioclase

(c) the granulites are notably felspathic - with perthitic microcline and antiperthitic plagioclase (albite to andesine) in widely varying proportions.

Plagioclases vary from an almost pure albite Ab98 with extinction angle from 010 19° to an andesine Ab angle °. Twinning is usually present, on the albite law and frequently the Pericline law is added, but may be absent. Strain effects ~~have been~~ are noticeable giving (1) bent twin lamellae

(2) undulose extinction

(3) warped twin lamellae

(4) irregular secondary twinning
(5) peripheral granulation.

The felspar is almost invariably clouded due to extensive alteration and compositions could not be estimated by complete orientation ~~methods~~ procedure, and ~~others than~~. ~~The method and~~ the class of plagioclase was reckoned by the zonal method which gave certain anomalies. Symmetrical extinction angles to 010 were by no means satisfactory ; rotation of the crystal on the universal stage so that the twin plane is vertical do not always give symmetrical angles, and the possible reasons for this are several.

(1) difference in composition across the twin plane.
(2) warping of the twin plane

In reference to (1) it is noticeable that those crystals which show angles 18°-16°, 18°-14° etc have a differing degree of alteration in each set of twins. Emmons ~~states~~ notes " a very disturbing occurrence of such variations is in adjacent twin lamellae which may differ optically in composition by more than 10%.

Actual recognition of warping of the twin plane is possible and the effect of this while appreciable is unmeasurable.

It is sometimes noticeable that maximum symmetrical extinction angles sometimes vary as much as 5° between various members of the same rock and this is believed to be due to actual compositional differences which would amount to five percent — in the

2 specimens Nos. 177, 125 B, 2 etc

description of the rocks, in each case the ~~maximum~~ angles only are given.

The optical properties are ~~as usually~~ normal, ~~biaxial~~ interference figures are biaxial and from albite to andesine the optical sign is positive to negative to positive, with axial angles from 80-90°.

~~The~~ One of the most significant textures present is that of a coarse antiperthitic intergrowth which only occurs in the granulites. Here, quite large crystals of microcline are enclosed by a matrix of plagioclase -(usually albite) with each individual inclusion in a group in complete optical continuity with the host and the other inclusions. Where both felspars show twinning, this uniformity of orientation is obvious. The 010 direction of the albite twinning in each felspar coincides exactly, while the twin planes of the microcline and pericline twinning in the potash and soda felspars respectively are at 54° to each other - thus the 001 coincides also. This ~~grave~~ feature is due to a replacement of the potash felspar by soda and implies an introduction of soda into these rocks.

The alteration of the plagioclase which is invariably well advanced gives rise to small colourless granules of epidote or to a multitude of small colourless mica laths, frequently orientated parallel to the twin planes. This may be the soda mica paragonite but as albite is usually stable ~~and~~ under such metamorphic conditions and appears to form mostly small clear untwinned grains even under the most severe conditions of shear, such does not seem likely. At times the alteration is more advanced around edges ~~and~~ of crystals, cleavages and twin planes as though the source of potash was outside the crystal. However ~~but~~ for the majority the explanation appears to be that the plagioclase, formed by the replacement of microcline, ~~he~~ contained an appreciable amount of potash held in unstable solid-solution and under stress conditions this was rejected as a sericitic white mica. In the more gneissic sheared rocks the plagioclase is replaced progressively by increasing amounts of sericite until there is a mere faint skeleton showing multiple twinning in a highly orientated mesh of fine sericite laths. This implies an addition of potash, which is supplied by the simultaneous breakdown of microcline to sericite.

The application of the calcic content of plagioclases as an indication of metamorphic grade or facies would not be ~~[illegible]~~ ~~in this [illegible]~~ strictly accurate in these rocks, as the lack of equilibrium is indicated frequently.

Oligoclase is the most abundant variety, and is the almost unvarying member in the granulites, while albite is more common in rocks in the South Western corner of the area. It seems a valid generalisation that the Rosebrook granulites carry a more basic plagioclase and the acidity increases to the east.

It is a striking fact that the granulites which are chiefly felspar and which consequently appear free from any schistosity (as differentiated from a foliation) show a high degree of preferred orientation and anisotropy when ever a brief petrofabric analysis is conducted.

The potash felspar is invariably microcline and orthoclase was not found. Cross hatching is frequent and even those not showing twinning were found on complete orientation to be triclinic. It is commonly micro-perthitic, containing albite as moderately coarse, ~~elongated~~ spindles, ~~ribbon-like lenticles~~ and appears to be a normal high temperature exsolution perthite. This variety occurs in both gneisses and granulites.

Extinction angles from 010 cleavage is 12°. It is noticeable in the hand specimen that the microcline is white while the plagioclase is flesh coloured in contradistinction to the usual habit. In this section the microcline is colourless and fresh, and sericitization only takes place from the edges of crystals. All stages of fragmentation and alteration are seen.

Quartz is one of the most abundant minerals of the schists and gneisses while occurring to a far less degree in the granulites. Macroscopically it may be colourless and glassy or ~~frequently~~ slightly blue and opalescent. In thin section it is clear and colourless, varying in shape from rounded granoblastic shapes to irregular, lobe and lenticular outlines.

In the schists, quartz is the only mineral of any appreciable size and is seen as irregular porphyroblasts set in a mortar texture.

In the leucocratic rocks and less frequently in the granulites, it occurs as extremely elongated (index of elongation as high as ten) rounded crystals, formed by flow and recrystallization under conditions of high temperature and pressure.

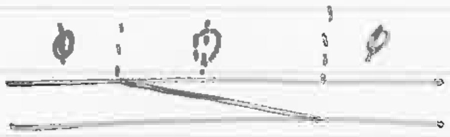
Felspar crystals frequently enclose small rounded and elongated blebs of granoblastic quartz. This has the appearance in different specimens of being both introduced and replaced quartz.

Optically the quartz is ~~[illegible]~~ positive and uniaxial with frequently a low axial angle.

Investigation of the undulose and shadowy extinction ~~of the quartz~~ shows it to be the result of flow and partial recrystallization of the quartz rather than the result of strain distorting the crystal lattice.

It seemed most likely that the undulose extinction would be caused by differing optical orientations in various parts of the crystal and as one gave a difference in extinction of 60° between the ends it was desired to plot the optic axes to show distortion of individual crystals. Orientation on the universal stage showed that crystals either extinguished completely in one ~~com~~ direction so that all optical axes were parallel to the axis of the microscope or that ~~as~~ in a certain position the crystal was revealed to be made up of several portions with slightly different orientations with sharp divisions between them. It thus appears that the undulose effect is here produced by the process of recrystallising with ~~a tendency~~ ~~towards~~ growth towards a common orientation between two originally distinct fragments. The junction between the two is sharp when viewed in the correct direction, but at angles oblique to this there appears to be an area of intermediate orientation between the two – this being caused by the light passing through two successive crystals. See Fig :

(a)



(b)

Amphiboles. are members of the tremolite-actinolite and the hornblende series and are the most abundant ferromagnesian mineral found. They occur only in the granulites ~~and the transitions to schists~~ and their immediately derived schists and gneisses and not at all in the leucocrats or augen gneisses.

(ii) All members of the tremolite-actinolite series are represented, being secondary or uralitic alteration products from diopside and vary in colour from completely colourless (white in hand specimen) to shades of pale green. There is a close relation between these and the fresh brown hornblende and the two are frequently intimately associated.

The tremolite-actinolite is pleochroic from

X - colourless
Y - very faint green
Z - pale green

and the hornblende

X yellow green
Y green
Z brownish green.

The two have identical optical properties and are biaxially positive with 2V of 70° and an extinction angle measured Z∧c of 22° The double refraction is moderate, colours up to 2nd order being visible. The lighter variety is sometimes found growing around the brown type with a sharp colour change between them but with cleavages continuing across both, and with the same extinction position and optical properties

The amphibole occurs as tabular,

felted or idioblastic needle-like crystals as growths about the pyroxene and also about epidote, and is uralitic in origin.

A light green fibrous actinolite is frequently visible as individual grains or as veins through the granulites. Large masses occur in the pegmatite Yatalite (See Benson) and in an outcrop near Penbrook crystals over a foot across are visible. In certain of the granulites a structure simulating cross-bedding is seen, traced out by green actinolite. This is a persistent feature and is believed to be mimetic after original cross bedding in ilmenite, indicating the sedimentary origin of the crystalline rocks.

The pyroxene which occurs is a pale green diopside and remains only as relicts surrounded by uralite. It occurs only in the granulites and is rarely found unaltered. This decomposition makes determination of exact optical data impossible but it is found to be biaxially positive with a moderately low axial angle. Extinction angles from tabular cleavages are ca. 40°

The diopside indicates the original high grade of metamorphism of these rocks and also shows the original sediments to be rich in lime and magnesia while its arrested uralitification reveals the progress of the retrograde metamorphism.

V Micas

Various members of the mica groups are important constituents of most of the rock types - the abundance and variety depending on the rock. They are :-

(a) white mica - there appear to be two generations which are referred to here as muscovite (primary) and sericite (secondary)
(b) biotite - also primary and secondary
(c) chlorite - diapthoretic product.

(a) White mica found almost invariably as minute laths of sericite is of major importance while large, well crystallised (frequently bent) crystals of muscovite - quite uncommon are considered primary metamorphic products ie those formed in the original regional processes, not by later low grade phases.

The sericite which is the chief part of the schistose groundmass of schists and gneisses is secondary and appears to form from a variety of minerals - indicating a general addition of potash in low grade conditions with shear acting. By Turner's[2] classification this would be the muscovite - chlorite sub-facies of the greenschist facies. It is frequently seen in arrested stages of formation and the origins are considered —

From microcline:

In stressed rocks, microcline is frequently seen to become granulated at the periphery and further to be cracked or crushed.

with the accompanying breakdown to a potash mica. This transformation is common[3] and as it involves a liberation of potash may be the source of at least part of the migrating potash in these rocks. That there was sufficient microcline originally present to allow the formation of such quantities of mica is debatable.

From sillimanite.

Sillimanite, especially in the gneisses of the Torrens Gorge is seen to be altering to a mesh of sericite laths as a retrograde effect. Billings[4].

This process is apparently almost identical to the one occurring at the Gorge and Billings concludes (from not very convincing evidence) that the potash was introduced from an outside source.

Harker[3] gives the reaction

With plagioclase:

A notable feature of the plagioclases in many of these rocks is the clouding due to abundant, minute laths of a white mica as inclusions frequently orientated parallel to the albite twin-plane.
~~This mica appears to be sericite rather than the soda-mica paragonite~~
This process is mentioned previously (p3) under a consideration of plagioclase.

(b) Biotite

The dark mica which predates the retrograde processes is in ragged laths, frequently bent, with pleochroism from light to a very dark brown. There are usually abundant inclusions of
(a) iron ore in the southern parts of the area
(b) rutile grains in the northern part
(c) interleaved quartz (elongated)
(d) sericite (interleaved)
(e) chlorite (interleaved)

There is a fresh lighter green mica in irregular flakes which appears to be usually secondary.

Biotite is of frequent occurrence in the schists and gneisses but is sporadic in the granulites - although the rocks ~~seen~~ in the most northerly part of the granulite area near Haughton may be particularly rich in dark mica.

In some gneisses it is seen to be the product of a reaction between ilmenite and sericite. Diagram 1. shows the area immediately surrounding a fractured ilmenite crystal is rich in a green biotite while the mica further away is sericitic almost solely.

(C) Chlorite.

This mica imparts a notable green colour to many of the schists but in quantity is relatively unimportant. A pale green to colourless mica with very low birefringence - interference colours being in low grays or anomalous blues - it appears to be a pennite. It is the index mineral showing the low grade conditions under which the diaphthoresis took place.

It forms by the breakdown of higher grade minerals particularly biotite while it appears as pseudomorphs after garnet.

VI Epidote Group.

There are three representatives of this group here - (a) epidote

(b) zoisite

(c) orthite

(a) ~~The~~ common iron epidote is abundant, being visible as typical green grains in the hand specimen or as strongly pleochroic yellow to colourless crystals in thin section. The birefringence is high and this variety is frequently intimately associated with actinolite which grows around it. Harker[3] records the alteration of actinolite to epidote but the reverse retrograde step is apparently not common.

(b) A colourless zoisite with high relief and low polarization colours is frequent as tiny rounded grains and inclusions as a saussuritization product of plagioclase.

(c) Orthite a is quite common in some augen gneisses to the north and occurs as deep brown pleochroic crystals, rounded in shape with high refractive index and double refraction. The interference figure is biaxially positive with a high axial angle.

VII Sillimanite

Geographically the sillimanite zone covers a reasonably large area but the actual abundance of the mineral is not high due to its frequently replacement by sericite.

In the hand specimen it may be recognized by the pseudomorphic fibrous sericitic material, or in ~~the~~ its original state as clear, white, silky fibres.

The presence of sillimanite immediately next to the granulites indicates the highest grades of metamorphism.

In the thin ~~the~~ section it is colourless in quite large often euhedral or tabular crystals with a prominent cleavage giving straight extinction. Its relief and birefringence are both high. It is frequently present in various stages of alteration or as mere "ghost" pseudomorphs of sericite.

Optically it is biaxially positive and like many of the South Australian sillimanites has a low axial angle. Specimens from Yankalilla may be 2V for 10 - 15 while from Houghton the 2V is less than 5° - in some interference figures the isogyres barely separate.

VIII Garnet.

A red-brown garnet - near almandine in composition occurs in gneisses in the Torrens Gorge and about Kersbrook. It may be quite abundant in certain specimens and indicates a high grade of metamorphism.

It is a frequent detrital mineral in river sands throughout the area.

It is notable that sillimanite and garnet occur together ~~total~~ in the vicinity of the western (Houghton) granulite, while garnet alone is found near the eastern (Kersbrook) outcrops - even though the usually more basic ~~plag~~ to plagioclase to the east suggests a higher grade of metamorphism. This factor ~~[illegible]~~ is another point in the evidence that equilibrium was probably ~~not~~ achieved at very few points in the ~~area~~

Tourmaline

A persistent and common mineral occurring in every variety of rock throughout the whole area. It may be found as (1) large crystals in all quartz veins through the greisens, (2) as graphic intergrowths with quartz

(3) tiny euhedral crystals in greisens and granulites e.g. in specimens 108, 14, 159, 47.

(4) major constituent of the quartz tourmaline schist of the Hunley Sound.

It is usually strongly coloured and pleochroic from deep brown to light green occurring as anhedral crystals to euhedral prisms. In an actinolite schist from Haughton (No. 13) there are lighter coloured zoned crystals (~~lighter~~ paler coloured in the core) while embedded in ~~the~~ some plagioclases are ~~perfectly~~ euhedral prisms showing perfectly developed crystal faces - coloured in various shades of pink and purple.

Tourmaline indicates the overall pneumatolytic action and appears to have been introduced

(a) as the mineral in veins etc

(b) as boron to produce the mineral by reaction with various alumino silicates.

Ilmenite

The chief iron ore of the district is titaniferous and very feebly magnetic – magnetite is ~~not~~ rarely found. It occurs as tiny grains or as large masses – veins 6" across are found in the granulites east of Keslook, and is heavy, black and lustrous.

In the thin section it is quite opaque, silvery by reflected light and is frequently intimately associated with, rutile, leucoxene or sphene to which it has supplied titanium or by ~~diopside~~ actinolite or hornblende for which it has been the source of iron.

Stress has often made crystals lens shaped or fractured them.

The apparent cross bedding shown by actinolite in the granulites is apparently due to the formation of amphibole from the original iron ore without appreciable movement.

In the field, the ilmenite may fill veins cutting across folded granulites and appears to introduced at a late stage in the original metamorphic process. It is also a primary constituent of the original sediments!

Ilmenite is a notable constituent of the Jeslook yatulite.

XI Apatite Group

Apatite occurs in some amount in all the rocks and shows a variety of properties, signifying an appreciable range of composition

(1) Colour. The mineral may be colourless to pale brown - in the latter case it is feebly pleochroic with absorption $\varepsilon > \omega$.

(2) The refraction index varies considerably

(3) Optically it is positive but has an optic angle varying from 0 – 40°

Its presence indicates a pneumatolytic addition of phosphorus – and the varieties probably have varied amounts of chlorine and fluorine which control their properties.

It may often be intimately associated and surrounded by growths of sphene.

XII Rutile & Leucoxene

Occurring not abundantly but persistently over a wide area, rutile is deep brown and pleochroic with a brilliant lustre by reflected light. Optically it is uniaxially positive. It is ~~most~~ commonly associated with ilmenite which is apparently the parent mineral. Leucoxene also occurs quite abundantly as finely granular aggregates.

XIII ~~Rutile~~ Zircon

As accessory only, rutile is common and always retains its oval - detrital shape showing its original sedimentary nature.

XIV Haematite.

Micaceous in habit and of local importance only, haematite occurs in various schists and a haematite - quartzite from the Little Para. At scattered localities, it is found as bright specular flakes, particularly in cavities and veins.

It is of considerable importance in the overlying Adelaide System in the basal beds ~~particularly~~ on the eastern side of the Archean massif - particularly at Mt. Bessemer.

XV Sphene

This mineral occurs in some granulites and to a less extent in the leucocrats & gneisses. It is brown and usually as anhedral crystals, strongly pleochroic with high double refraction

Calcite →

XVII Magnetite

This iron oxide is of no importance, occurring as euhedral crystals in the quartzite bands in the gneisses in the South - Western corner of the area.

XVIII Pyrites ~~yellow gold by reflected light~~ is fairly abundant in ~~among~~ the gneisses especially the sillimanite mica varieties, while occasionally chalcopyrite and bornite are recognized both in the hand specimen and thin section.

XVI Calcite is not abundant, it also occurs as colourless light brown, frequently euhedral crystals in schists usually, but granulites also.

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~~Explanation~~

Key to A-C-F Diagrams

(1) Granulite facies.
This indicates the highest extent of the metamorphism

(2) Amphibolite Facies - sillimanite almandine sub facies. - Some dioritoid rocks probably fall in this range.

(3) Albite - epidote - amphibolite facies.
This stage is reached in retrograde metamorphism by granulites and gneisses.

(4) Greenschist facies, muscovite - chlorite sub-facies. The schists and gneisses generally fall within this class.

Key to Microsketches

1. Portion of a gneiss from Castambul. It shows an ilmenite crystal which has been fractured and liberated iron to surrounding sericite to form a zone of chlorite.
2. Portion of a granulite from Inglewood. It shows actinolite growing on epidote.
3. Portion of a granulite from Kersbrook. It shows the fibrous sheafs of uralitic actinolite.
4. Portion of a gneiss from the Torrens Gorge. It shows the typical sillimanite in a mesh of sericite.
5. Similar to No. 4.
6. Quartz - tourmaline schist from Humbug Scrub.

	SiO2	Al2O3	Fe2O3	FeO	MgO	CaO	Na2O	K2O	P2O5	TiO2		
constit %	69·25	13·90	2·64	1·42	1·53	2·47	3·03	4·66	·13	·71		
Mol props.	1154·	136 ✓	16 ✓	21 ✓	38 ✓	45	48 ✓	50 ✓	1 ✓	11 ✓		
Quartz	446										·446	26·76
Orthoclase	300	50						50			·0400	22·24
Albite	288	48					48				·0384	19·91 20·12
Anorthite	~~228~~ 76	38				38					·0152	4·17
Diopside	12				6	6					·024	1·49
Hyp	32				32						·064	6·40
Haemat			6								·009	×1·3
Magnetite			10	10							·016	×3·7
Ilmenite				11					11		·026	×3·6
Apatite						31		1	3		·002	×0·7

D

Si	889	868	916	1010	811	833	863	1018	1009	819
Al	155	154	156	146	176	151	152	155	153	184
Fe	65	91	90	117	143	155	156	61	97	118
Mg	93	65	166	49	168	165	135	114	64	211
Ca	246	241	150	46	193	198	150	114	93	218
Na	16	16	61	65	35	27	545	76	50	27
K.	44	46	9	66	3	4	7	7	24	2.
Tyr A.	95	92	86	55	134	120	100	72	79	135
C	246	241	150	46	193	198	150	114	93	218
F	108	156	216	166	311	320	291	175	161	331
	449	489	482	237	642	638	541	361	433	6.84
A	21	18	18	10	22.	19	19	20	19	20
% C	55	48	37	19	30	31	29	32	21	32.
F	29	34	45	71	48	50	53	48	60	48.
Oss A	60	62	70	121	39	31	52	83	74	29
C	95	92	86	25	134	120	100	72	79	135
F	359	305	310	187	366.	398	341	217	105	414
	514	459	466	333	542	549	493	372	358	578
a.	11	14	15	37	7	6	11	22	22	4
c.	18	20	19	6	26	22	70	19	25	25
f	71	66	56	57	67	62	19	59	53	71
S	889	869	916	1010	811	833	863	1018	1009	809
Al	155	154	156	146	176	151	152	155	153	164
F	354	397	232	211	504	518	441	289	254	549
	1398	1420	1304	1367	1491	1502	1456	1452	1416	1532
S	64	61	71	74	54	55	51	70	71	54
α	11	10	11	10	13	11	30 19	11	11	11
f	25	29	18	16	33	34	19 30	19	18	35

X

Various Diorite etc. England.

	V/	Y	Y/	Haug Etc.	Dol Mgg.	Mgg.	K.	Narl ~~Mass~~	Moa	D. Mor
Al_2O_3	15·79	15·67	15·88	14·94	17·99	15·44	15·53	15·75	15·57	16·67
Fe_2O_3	3·69	5·38	·68	8·12	2·13	3·07	4·77	2·74	1·40	1·90
FeO	1·37	1·76	5·85	1·07	8·44	8·44	6·91	1·77	5·70	6·76
MgO	1·73	2·62	5·06	1·96	6·72	6·61	5·42	4·55	2·58	8·54
CaO	13·81	13·48	10·09	2·60	10·81	11·15	8·42	6·43	5·19	12·19
Na_2O	1·04	·99	3·76	3·40	2·23	1·74	2·82	4·69	3·06	1·74
K_2O	4·15	4·31	·76	6·16	·30	·43	·72	·73	2·31	·24
Al	155	154	156	146	176	151	152	155	153	164
Fe_2	46 23	34	4	51	13	19	30	18	9	12
Fe	19 18	22	8	12	106	106	96 86	22	72	84
MgO	43	65	126	49	168	165	135	114	64	213
CaO	246	241	180	46	193	198	150	114	93	218
Na_2O	16	16	61	55	35	27	45	76	50	27
K_2O	44	46	9	66	3	4	7	7	24	2
A	95	92	86	25	138	120	100	72	79	135
C	246	241	180	46	193	198	150	114	93	218
F	84	121	138	112	287	290	251	154	145	309
	425	454	404	183	618	608	501	340	317	662
A	22	23	21	13	22	20	20	21	25	20
C	57	53	44	26	31	33	30	24	29	33
	79	76	65	39	53				54	
F	21	24	35	61	47	47	50	55	46	47
	6	7	8	9	10	11	12	13	14	15

	S.P.1. Ag	Dacite Pumice [illegible]	B.A. 3 Ag	B.A. 17 Bandadag.	B.A. 49 B.G.	B.A. 21 Shaykh.	B.A. 23 Sgd.	B.P. 3 Sgd.	Basic [illegible]	Granite [illegible]	Acid [illegible]
SiO_2	66.89	59.93	71.19	69.69	68.31	59.26	61.53	60.02	56.85	69.25	58.20
Al_2O_3	14.96	14.07	15.26	15.51	15.12	22.94	20.70	21.94	14.76	13.40	15.05
Fe_2O_3	2.53	.35	1.66	2.22	2.52	2.41	2.96	4.67 Fe	4.48	2.64	4.3
FeO	1.73	2.87	1.05	1.29	1.46	1.49	2.35		1.21	1.47	1.35
MgO	1.57	5.02	.78	1.10	1.22	1.00	1.69	2.11	3.84	1.53	8.70
CaO	1.59	11.77	.56	.44	.91	.63	.26	.43	7.91	2.43	3.95
Na_2O	2.13	3.72	2.64	2.84	2.41	7.13	.71	1.09	5.34	3.03	4.75
K_2O.	5.54	.36	5.87	4.91	5.33.	3.42	6.24	6.25	1.91	4.66.	3.05.
SiO_2	1115	997	1189	1191	1138	958	1025	1000	948	1154	970
Al_2O_3	147	138	150	152	148	225	203	214	147	131	147
Fe_2O_3	32	10	22	28	32	30	38	~~[illegible]~~	56	32	54
FeO	24	40	19	18	21	21	33	65	17	21	19
MgO	39	126	19	27	30	22	42	49	143	38	99
CaO	29	211	11	7	16	11	5	5	97	45	155
Na_2O	34	60	42	45	39	113	11	18	87	48	77
K_2O.	59	4	^{3}63	^{4}52	^{4}56	^{2}36	^{3}26	67	421	350	^{4}33
	1479	1588	1510	1520	1480	1416	1423	1618	1516	1517	1553
SiO_2	74	✓	79								
Al_2O_3	10	10	10								
FeO	4	44	2								
MgO	3	[illegible]9	1								
CaO	2	15	1								
Na_2O	2.5	4									
K_2O.	4	–									