The Geology of the Metamorphic Complex of Houghton and the Hamlyn Sand.

A.H. Spry.
Abstract.

An area of metamorphic rocks, located in [insert location], 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 microscopical slides are appended. The structure of the Amnic rocks, together with the associated underlying sedimentary series, is treated while the topography and economic aspects 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 Castlereagh on the Down River eastward to Chair of Pant on the northward through Naughton, Newbooth and the Hunting Bank with its apex beyond the South Paw River west of the Buckingham Reservoir. It is covered mainly by a series of banded and augen gneiss with associated schists (some gneiss being rich in millimetric or granular joints), together with the major area (Naughton and Newbooth) of a crystalline banded rock of igneous appearance referred to previously as the "Naughton Granite." It is considered that these rocks originated by a complex process of metamorphism and retrogression on a series of politic, calccrete, and overoomic sediments without actual igneous intrusion and are of Devonian age. They are overlain unconformably by the folded and faulted Acol Edge System - a sedimentary series of late Proterozoic age.

A complex process of metamorphism on the older sediments with addition of alkalic material and later retrograde metamorphism has brought the rocks to their present form.
The area considered consists mainly of augen gneiss with associated schist and chloritic schists while in the South-West and South-Eastern parts we represent the so-called "Ugadale Granite." For general descriptive the rocks are divided into:

(a) gneiss
(b) schist
(c) granulite
(d) leucocratic types
(e) pegmatoid rocks
(f) unclassified types
(g) sediment

As mentioned previously the "Kwihung Schist gneisses" are a predominant feature and one of the type referred to generally as "g. injected." They are dark colored rocks with light colored quartz-feldspar-biotite bands, or augen set in a somewhat sericite-biotite 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 has shown them to be chemically identical.

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

From a detailed examination, the paragenesis of these rocks appear both indefinite and complex, for nowhere in the area does there occur a rock which may be regarded as an unaltered parent type. In every case...
The rocks have suffered regional metamorphism to at least moderate, high grade, together with an addition of alkaline material and has later undergone considerable retrograde effect, with virtual superimposed shearing on a wide scale, with the consequence that the original form and nature are quite obscure. The process envisaged as having occurred takes 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 slate or perhaps gneissic. They underwent regional metamorphism which reached its maximum in the south-west where the sillimanite grade rocks occur, with progressing lower grade, garnet and biotite, then towards the north the condition of high temperature and pressure, an introduction of alkaline, chiefly potash, with soda and silica, took place. This resulted in the widespread formation of microcline, the rocks usually being present in the more high temperature paragonite. This introduction is presumed to be a working process with gentle introduction and migration of material along a previously existing S plane, bedding or schistose, lack of convincing foliatory bands and the general uniformity point to a gradual addition, not a bit by bit 'pumping' or injection. Such a rapid and powerful process as the latter, extending over such an area, presses too much for the force of igneous injection. It seems most likely that the microcline was not introduced as such, but that there was an addition of potas (i
the ions state) along preferred directions where
flowing and recrystallization took place.

At this stage, conditions became less extreme
and the rocks were in a state where temperature
was low and shearing forces predominated, i.e.
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 is now
that the general regional schistosity (w.r.
strike 170° with steep dip, steep - chiefly east -)
was produced by the wide spread alteration, to
under low grade conditions, of microcline to
sericite. Potash liberated coming sillimanite
becomes unstable and continues until the liberated
potash to form sericite while quartz is more
stable and usually only becomes partially
identifiable. "The biotite becomes, a deep iron rich
variety and deposits tiny grains of biotite."

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

The diapathons, under conditions of shear-
caused, crushing and alteration, and the effect
may be seen, are noted in all stages towards
completion.

3. Early results are the crushing and bending
of feldspar crystals, accompanied by
some peripheral sericitisation of
microlite and sillimanite. Gneiss shows indistinct extinction, mica bands are bent, and all crystals show ragged, irregular outlines.  

(2) The great grain size, smaller, as granulation and recrystallization become advanced - feldspar, 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 indistinct 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 - microlite, sillimanite and garnet have practically gone and all that remains are irregular, recrystallized pseudomorphs of quartz set in a fine-grained matrix of sericite, chlorite and biotite with chlorite grains of quartz and re-crystallized albite.  

(4) The last fine-grained, sheared stage is that of the phyllonite - this of mylonitized schist referred to in the next section.
geology of the area is the recognition of the true nature of these slabs — they are not phyllite, but phyllonite. There are no simple low grade rocks in this area.

These slabs must be classified or, more nearly by their association in the field, bands (from one foot to hundreds of feet in width) of apparent low grade phyllite are seen to be traversing or in direct contact with obviously high grade metamorphic rocks, e.g. sillimanite-garnet gneiss or granulite. Examples of slabs located in less obvious high grade areas are absolutely identical with these.

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

Alteman in his work on these gneisses did not recognize this fact and his deduction of the origin of the Houghton Gneiss is basically unsound. This will be discussed later.

Granulite.

In the southwestern and south-eastern portions of the area, around the towns of Houghton and Felsenhod, there occur a group of distinctive strongly banded foliated rocks, which has been called the “Houghton Gneiss” and which were thought to be the result of metamorphism of igneous rocks crystallized from the “Houghton Magmas.”

In normally weathered face of the flaggy slabs, the appearance is that of a normal
sedimentary rocks of granitic nature and only on inspection of a freshly broken face does the crystalline nature become apparent.

The bedding is due in part to the segregation of ferromagnesian minerals (diopside, actinolite, hornblende in the darker bands, and felDSPAR and quartz in the lighter portion), and also in part to the shearing taking place preferentially in the former bands. The perfect uniformity and parallelism of these folia in the field is remarkable. These bands may be followed a long as long as a continuous dark face may be followed. They may in width—being from to—although usually about

I general, the rocks consist of plagioclase (from albite to adobe), with or without microcline or quartz, diopside with its accompanying mafic actinolite, epidote, and the two present, often abundant, hornblende. Biotite is usually not abundant. A some varieties, biotite was abundant, prominent, while sylvin calcite, muscovite, tourmaline, agatite, chlorite, sericite, pyrite, are accessory. The composition—from an igneous aspect—varie considerably, (often within a matter of feet in the field) from granite to granodiorite, syenite and diorite, the latter being most common. In all cases, the bedding of some kind is prominent.

They weather with a typical, creosolous appearance and in distinction with the schists and gneisses, suggest little underground—these rocks underly the orchard and pastural land of the district.

The granodiorite are distinguished from the
larded green into which they merge by the abundance of plagioclase, a general lack of quartz, absence 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, foliation and schistification or an early stage in the process of quantitation of rocks originally sedimentary in nature. The abundance of fine-grained minerals is suggestive of calcareous-siliceous rock, probably a greywacke. The reason for suggesting a sedimentary origin rather than igneous origin are now considered.

0. The complete heterogeneity and variation of composition - both mineralogical and chemical points strongly to an addition of material to an originally variable sedimentary process. The pneumatolysis of an igneous hybrid might be plausible if it were not for additional evidence.

1. The presence of strongly developed bedding, regular in width, travelling for as much as 30' without significant variation. This is considered to be kinematic 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 bedding is not in the nature of uniformity, but dips at relatively shallow angles (ca. 30°-60°). At Doughton there occur folds both on a small and large scale.
examples are phyllitic, while the larger folds are mylonitic and antiformal in the region of \( \frac{4}{3} - \frac{1}{2} \) miles across. A pitching anticline is seen in the bed of the Little Pano River just north-east of Houghton.

(3) The gradual transition from banded granite 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. Difference in original composition.

ii. Difference in metasomatic addition.

iii. Difference in the original grade of metasomatism.

iv. Difference in the amount of retrograde metasomatism.

(8) The frequent occurrence of textures which are extremely similar to compacted breccia are difficult to explain on igneous grounds. Natürliches grain of diopside or actinolite, these forms are persistent in some areas, and are considered to be minette after ilmenite or mica, bedding which is a feature of many old sedimentary rocks.

(9) The presence of these minerals which are fugitive in metasomatized rocks, is a feature of most of these species, e.g. fluorite, apatite, pyrite, etc.
The presence of these minerals, which are frequent in metamorphosed rocks, is a feature of most greenstones and quartzites. Hornblende, augite, pyrite, 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 musky "migmatitic" state. They are cut by pegmatites, phyllonitic schists, and by post-tectonic ilmenite veins, often several feet in diameter or larger.

Microscopically, one feature is prominent: the coarse replacement type of actinolite which shows a potash feldspar being progressively replaced by a plagioclase, and which indicates an introduction of soda after potash. While the general course of quantification, as postulated by Reynolds, "Missel," is indicated, potash additions after soda, there are abundant examples of the reverse process — see Staller, "Ternado,"

It thus seems that the original sediments were subjected to a high grade of regional metamorphism where they suffered recrystallization, addition of alkali (potash first, soda later) and partial devitrification. As the original sediments are not present, the actual mechanism is indubitable, but the replacement must have been gentle, involving by metasomatism partial volume, so that the original textural features frequently remain undistorted. At this stage, stones, even the musky semi-solid magma to become folded (elongation of quartz grains,
probably takes place here. Simple microcline pegmatite, once introduced and weakening later pegmatite, become zone of felspar and the latest are quartz–tourmaline or tourmaline quartz alone. These late veins are often filled fault and tension cracks in the solid rock. Tourmalite is frequently a very late introduction.

The rock produced was high grade, and consisted of plagioclase and diopside chiefly, but like the gneisses, suffered diapophysial alteration, although not to such an extreme degree. Secondary actinolite, epidote, allanite, with sericite, chlorite and biotite are the chief main retrograde products. Complete metamorphism is limited to narrow bands where shear is predominant.

The nomenclature of these hybrid rocks is difficult. The original term "boughton diorite" is misleading in that it infers both a constant of composition and an igneous origin. The term "granodiorite" is used to refer imply a metamorphosed sediment, of high grade, rich in plagioclase, with quartz (when present) typically elongated.

(2) Leucocrates.

Although of similar origin to the granulites, these are less abundant and constitute a distinct class. They are typified by their white color, and complete lack of ferromagnesian - diopside, amphibole, epidote and biotite - and consist of felspar and quartz with only minor amounts

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of micaite, tourmaline, muscovite, sericite or ilmenite. 

Lush is abundant and some is absent from 50 to 90 in different specimens. The felts & micaite are a plagioclase from allite to noltite, 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 Houghton School are:

(a) A fine-grained, light blue-gray, homogeneous, crystalline rock, indistinguishable in the best specimens from a quartzite.

(b) A fine-grained white variety with a strong lamination due to quartz feldspar in the formation of quartz grains.

(c) A white, extremely coarse-grained, quartz-micaite pegmatitic rock.

(d) A white rock, many fine-grained feldspar with regular bands of granular quartz traversing it. This has the appearance of a partially felty-phased sandstone.

(e) Across the road, across the Little Pam. Fire, these rocks become increasingly altered and retrograded to sericite schist.

These are the rocks which Benson called "quartzite splits" and which are widely distributed in small quantities through the southern part of the area. A:

North west of Houghton, at the position marked "silicon" on the map, is a large outcrop of a quartz rich limestone with many semi-translucent quartz and only a very little feltspar. It is harder than
prominently chlorite, the granulite. It is moderately
cornered, containing and appears to have been a
metamictized granulite to which there have been
only limited alkali additions. Associated
with it, in very small quantities are very
coarse red granitized rocks and white diorite
rocks.

These rocks appear to have originated under
more or less similar conditions to the granulite,
but differ primarily because of their original
denial composition. They are lower in lime,
iron, and magnesia, and are considered to be
due to fenestration of a pure aneramic
rock.

(3) Pegmatites and pegmatoids.

Apart from the simple quartz-muscovite
pegmatite, which occurs, there are important
even quired complex pegmatites containing
plagioclase, and which approach the leucoxene,
in characteristics.

The irregular pegmatoid rock which
Bence called "gatalite" is difficult to
explain. (He describes it as being "a light
alkali content with plagioclase" and
presence of diopside or hornblende) and
considerate spodite.

He describes it as "a coarse-grained
pegmatite, composed of wadlicite, anorthite (from
diopside), and a chlorite containing muscovite,
titaniferous magnetite, sphene and quartz.

It occurs in broad, narrow bands and
veins, near granite, but is notable as a very
large outcrop south-east of Hazelwood (shown on the map). Here it occurs in a mass several hundred yards long, surrounded by a normal plagioclase granulite, and consists of extremely coarse, 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 granulite would have been introduced as such, or as a basic segregation of excess ferromagnesian from the altered sediment, by a process of metamorphic differentiation.

(d) Unclassified types

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

These occur at Shamblinde quarry, of the Towns Gorge, the actinolite calcite schists, north-east of Haughton, the haematite schists of Inglewood and Castlemilk and the haematite - quartzite north of Haughton.

An Iranian quartzite, rich in magnetite, is interbedded with the greenschist, north of Castlemilk.

In the Fauntley area of Hazelwood South, a band of green, tourmaline schist is found.
Sediments

Bridging unconformably the Baroona metamorphic complex are the basal members of an Upper Proterozoic sedimentary series - the Adelaidite System. The unconformity may only be seen in the northern part of the index, the southern contact being of the fault type. The unconformity may be seen well at:

(1) A wild bed south of the road from the Three Hills to the Burra Burra Sanctuary. The actual erosion surface may be seen to be slightly overturned and dipping east at 90° and stratigraphically overlain by 2' of dark dolomitic quartzite & white altered sandstone at least 500' interbedded chertitic sandstones, with lesser shale and quartzites.

(2) A similar unconformity is seen north of this, to the Sand Pass Fire at the Devil's Nose. Here the contact is normal and dips steeply west.

(3) On the east side near the junction of the Kenilworth - Williams Town road and the track to the New Deloraine Mine. There is a small quarry on the west side of the road. Hence, we contain by chertitic sandstone, with a hematite schist (Mt. Beroona type) notable.

Along the southern boundary, there are major fault contacts where the sediment have been overturned from the south mainly over the metamorphic present. The displacement is usually small, but in the south-east corner, the lower phyllite and a sandstone have been...
rocked up against the greenschist and implies considerable movement. Similarly, just south of Parawhithe, there are small patches of quartzite and Lower Lown, Dolomite completely disconnected from the sediments 1 1/2 miles 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 pseudocountercurrent due to shearing at the junction. Along the southern parts of the western contact, notably at Castleton and near the Lorne Memorial Road mile, from Naughton, the local schistose sandstones of the Adelaide System have become involved in the same orogeny as suffered by the older rocks. Just at the edge the schistose sandstone becomes schistose and merges into the retinite-illite-quartz schists and shales into the Adelaiad complex. The amount of mixing at the edge is not determinable but is considered to be strictly limited.

The Lower Lown Dolomite north of Castleton shows the same orogeny and becomes recrystallized and green from illitic impurities.

The Lower sediments consist of some quartzite conglomerate with a fanglomerate cement. These are considered to be the uppermost part, 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 these are folded and faulted by the same and independent orogenic forces.

A discussion of the structure is considered under the division:

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 muscovite and biotite striking at 120°, and although some variation, up to 90° from this are found, deviation of more than 10° east or west are uncommon. It deepens steeply, east usually at about 90°, but varying at times, from 65° E to vertical and 90° W.

The relationship of cleavage to bedding is not known, or compositional variation due to addition of feldspar, 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 alternations:

1. The orogenic force, which operated
in detritus has coincided in direction to that operating
since that time in the orogenies of the various
geotectonic regions have been regular from
earliest times.

(3) The schistosity may have been produced
in the greenschists by forces acting much later, and
that schistosity and the Adelaide Tertiary cleavage
have been produced in palaeozoic times,

Prehnite cleavage is only sporadically developed in
the older granites.

The granulites lack cleavage, but the notable
characteristic is a regular compositional banding,
interpreted as being formed by minute
crystallization and as indicating the position of
original bedding. From the steeply dipping
bedding in the greenschists there is a gradual
dip to the shallower dipping foliation in
the granulites. While the cleavage is regular,
this bedding varies considerably both in dip and
strike. At the foot of the cliffs it is fairly
constant at 140° strike dipping 60° W, while the
phyllonitic schists cutting it trend at 170°
with almost vertical schistosity. North of
Houghton it dips at low or 40° back east and
west, while the strike varies from 40° to 150°,
although usually north-south. Folding from
small phyllonitic contortion to larger scale
forms are found. North of the strike, about 1 mile
north of Houghton, from west to east, there is
a fold succession - mylonite, antiform, syncline
in the granulites.
Faulting, like the folding and cleavage, has been produced over an immense period by a number of successive uplifts. Within the Adirondacks there appear to have been at least possibly three successive faulting periods characterized by the type of mineralization.

1. Small faults, through the centres of phylite and chlorite mylonites, are obviously the first formed after the migmatite had reached a semi-consolidated stage.
2. Faults of larger size showing small displacements filled with chert.
3. Larger faults, similar to (a) but filled with quartz - tourmaline or other quartz.

There is later faulting potash and ulcer.

Paleozoic and Tertiary which has affected both the complex and the Adirondack System.

These have been powerful forces (of north from the east) which have caused the local sediments, against the present causes of folding, erosion, and metamorphism of the granite foundations. This, he, produced on area of bosses just north-west of Bingham - shale in a sub-triangular area.

Approximately a mile long this is a mylonite containing granulite, schist, phyllite, sandstone, 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 age of faults is not always possible, these are usually most abundant, fresh and unmineralized.

The whole of the contact around the
sutley portion of the complex consists of a system of
interlocking thrust faults.

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

These are repeated, both small and large, strike
faults in the sediment above, and these are seen to
be approximately parallel to the schistosity of the
quartzite and the axial planes of the folds in the
granulite.
Topography.

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

The smaller water courses controlled by the direction of faults or cleavage, while the larger, more important rivers (Kizer, South Para etc.) are quite independent of such major structural features and are apparently dependent on old controls now no longer visible.

The Archean Complex forms a high rugged ridge up through the Humbling Sand where it is covered by a mantle of undergrowth and trees. The granulite weathered to rounded hill, with less undergrowth and the country to the south is well cultivated.

Economic Aspects.

The association of mineral of economic importance with the old crystalline rocks is a normal feature and here deposits of gold copper, iron and lead have been worked. The most important is the gold of Humbling Sand to which reference may be made to Rowlands' paper. Copper, chalcopyrite and barite are interstratified but rarely occur in economic concentration.

Generally, many significant minerals occur: molybdenum, chalcopyrite, pyrite, barite, pyrrhotite, galena, but never are found in economic concentration.

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

Noyes has found occasional "flakes" but not in any amount in situ.

The mineralization may be considered as
(1) hypothermal disconnected with the metamorphism
and meta-sediment of the veins, etc., at an early stage;
(2) epithermal - not associated with late
faulting and brecciation;
(3) still later alluvial concentration. Small
specks of gold may be worked 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.

Be of the earliest references made to the
granulite is by Howchin, 1906, who in
reference to alkaline rocks of the Warner Valley
he says: "The external appearance of the rocks,
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: the considered by homeom to be
of igneous nature and discussed a process of
injection of silicate rocks and pegmatitic
liquids to explain the formation of the gneisses.

Beam's first performed detailed study on
the Houghton district, and referred to, "an
intrusive plutonic series" together with sedimentary
rocks. A more referred to as a porphyrite-
ampeloidite which he described but did not find
in situ in 1870, not again found,
and is considered to have been transported from
the abundant deposits to the east beyond
Eyre Peninsula. The consideration that the
"Houghton diorite," is magmatic has been disproved
and reasonable evidence advanced to suggest that
it is not. Benn also includes in his
"petrographic province" the rocks of Palmer, Hallett, Yorke Peninsula, Mawson, Bluff, while England adds those of Myponga,
Mt. Compass, Mt. Crawford, Tanderra
where later work has now been published
indicate conclusively the existence of two
episodes of metamorphism separate and distinct
in time and petrological characteristics.
It is considered that the rocks of
part of the "Houghton, Hallett, Mt. Compass,
Yorke Peninsula belong to the Archean and
are termed the Western Province, while those
quantitative types of Mt. Wiluna, Mt. Crawford,
Palmer, etc., are part of the Adelaide System in
"age and constitute an Eastern Province.
Hornfels (1935) states that "the sedimentary
origin of most of these rocks is evident. The
only important exception to this are certain areas
of granite in the Hunting Scenes."
He quotes a contact between the massive granite and the
injected schists and "believes that the angle-granite
may represent a altered igneous intrusion, changed
during while still in the plastic condition."
Alderman did note agree confirm this, and later investigation shows that having basically there is no difference between the rock types.

The most important contribution to the investigation of the argillaceous rocks by Alderman was the realization that the activities of the common oreiferous properties noted about the injected rocks, which argillaceous rocks resulted from the addition of alkali additions, by the formation of veins and to claim that the argillaceous rocks is an introduction of metasomatic

"If a examination of these rocks was based on field evidence alone, the injection metamorphism would appear to be a comparatively simple process consisting of the leaching injection into the minerals of a quartz-feldspar pegmatite. The textural properties of the argillaceous rocks and their associates would have been developed in a subsequent period of dynamic metamorphism. A comparison of the chemical composition of the minerals with that of the hardened and argillaceous rocks shows however that the injected material cannot have been quartz-feldspar pegmatite" and concludes that it was a feldspar-silicate.

As has been stated previously, the sericite schists are considered not to be simple low-grade peleites, phyllites, but to be the result of retrograde metamorphism or metasomatic solutions. It the injection of phyllites to form injection schists are present 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.
Oliver also postulates that the dynamic metamorphism suffered by these rocks is due to a more or less highly increase in volume of the rocks and the whole mass would therefore, nearly double its volume. The possibility of this statement is discounted on the following reasons.

1. That a process of exuding of liquid magmatic fluid into solid rocks would take place if it involved such an increase in volume.

2. That the addition of alkaline material did not take place without concomitant loss of material.

3. That the addition took place at constant weight and not constant volume. It is evident that all the metamorphism through the whole area took place gradually and constant without change of volume.

4. That if such a volume change did occur, it would produce a regionally constant direction of schistosity.
Oldeman also suggests 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, each of which is doubted:

1. That a process of "equilibrating" of liquid magma to liquid 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 stability which is regionally constant.

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

1. the transformation of quartz
2. the dehulling of crystals (quartz, feldspar, chlorite)
3. the bending (or warping) of twin lamellae in plagioclase or of cleavage in mica
4. the rendering of normally uniaxial minerals biaxial
5. the peripheral granulation or sericitization of crystals.

It should be however observed that only portion of the strain effects may be considered as being due solely...
Throughout the metamorphic belt there occur a range of porphyroclasts ranging from schists and gneisses to granulites, all being sedimentary, which have suffered the combined effects of metamorphism to a high grade, recrystallization with the addition of potash to the schists and gneisses and potash and soda to the granulites, with late retrograde metamorphism well advanced. The sediments, originally pelitic, calcareous and argillaceous reached the sillimanite grade in the south, garnet grade in northern and central parts, and the biotite grade to the north. Alkali addition caused the formation of rocks of ijosans and injected appearance and retrograde metamorphism caused the widespread presence of sericitisation, micasitisation, kaolinitisation and delaminatisation with the extra production of abundant phylloclase.

Metamorphism produced a range of migmatites (granulites and "injected" rocks), which at this stage caused folding in the granulites, and continuation of orogenic forces caused late folding and varied mineralization. Since this time, retrograde metamorphism has been widespread and has caused the processes...
of sedimentation, metamorphism, pseudometamorphism and alteration, with the production of a range of peliticlastic types.

Since the Adelaide System has been laid down unconformably on the crystalline rocks, erosive forces have caused continued folding and faulting. These are attributed to Early Palaeozoic and Mid-Devonian times. After the sedimentary deposition of Permian times, the area has apparently been too terrestrial, and subjected to continued erosion until the middle and late Devonian when some granites were deposited laid down.

Discussion of the Map

Due to limitations of scale a solid block plan is presented, without minor features such as alluvial and fluvial gravel, bed of which we have never 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, due to being transitions between the two. For the same reason, some marine facies, particularly north of Barabool, are shown as gneisses, although their affinity with the granulites is marked.
AII  Acknowledgments

It is pleasant to the author now wished to express thanks to Sir Douglas Mawson, G. W. Kleeman and R.F. Wilson for their assistance and encouragement.
 Petrology

The rocks are differentiated due to certain definite characteristics and into the division shown and brief petrological description are appended for indicating the common types and varieties within each group.

I. Conglomerates

(a) "Dioritic" type

(b) Dioritic varieties.

II. Schists

(c) Metamorphic rocks

III. Sediments (Pelecanide System)

IV. Other

A typical example of the "diorite" from Petrolona is orthomylonite, free grained with a slight directed texture due to strings of plagioclase grains. Chiefly felspar (Albite and Or) showing twinning on the Albite or Border. Albite-Periderite lenses with reflective index alone below and nati on in the symmetrical face II. Peridotite for the most part allied to actinolite (or strongly chloritic) light colored needles, or fibrous crystals. Epidote in yellow or large yellow pleochroic crystals or in tiny eulitine grains. There is no quartz or potash felspar present, becoming an abundant eulitine grain and plagioclase. Epidote and may be called eulitine tremolite grains occur at the plagioclase.

This rock is in oligoclase-granulite.
A fine grained folypar rock from Venbrook. Being
the general appearance of a quartzite in the
land species. It differs from loam only by
having a little granitic gneiss griggs. a more
basic plug, hornblende (Pb 68) and a somewhat
finer feldspar composition. Some of the plagioclase
show bent twin lamellae. Accessory are
muscite, epidote, melilitite, and fahler.

Typical of the cross-bedded gneissites from
Venbrook this rock has alternate coarse
crystalline light colored bands, and fine
gneiss grayish bands. The latter showing
the actinolitic cross bedding.

The slide was cut so as to show portion
of both bands, and reveal that the only
differences apart from grain size between
these are (1) quartz is abundant in the fine
grained portion (the band
shows the cross bedding and
is apparently newer than the original
state of the rock) while
banding in the coarse portion.

(2) hornblende veins are less abundant
in the fine part.

The abundant plagioclase in hornblende (Pb 68)
while actinolite is well developed, frequently
as closely packed fibrous bands, across the
slide.

Accessories are epidote, ilmenite, and fahler.
A similar cross-bedded granulite (p. 103). The
plagioclase is Al-plagioclase (Ab 32) in
irregularly shaped crystals. There is a porphyry
microcline present also actinolite and a
little quartz. There is more practically no
residual pyroxene remaining. Garnet is
abundant.

Acceary diopsite, epidote and apatite.

This is an example of the schistose granulite.
I shall write with a distinct banding and a
fissility imparted parallel to this. The schistose
by micas.

The micas on a slide, the change from a
homogenous, granoblastic texture to that of a
gneiss is well illustrated. There are alternate
bands (a) quartz microcline porphyroblasts and
quartz and
(b) fine grained sericite + diopside.

The quartz shows radicular extinction and
granulation while the micas show
fissure and perpendicular sericitization.

In the schistose parts, skeletal crystals of
plagioclase showing twinning remain as
rauchite residues after practically complete
replacement by sericite. There is a
considerable amount of white mica in coats
and cracks within the grains and edges
as though potash had entered along cracks
and partially replaced the micas.

Biotite is moderately well crystallized.
Strongly band ed greenish granulite, feldite are alternately dark and light being rich in ferromanganous or felspar, respectively. A broken face parallel to the banding shows a strong degree of preferred orientation in green illinit. The thin section was cut so as to show back a light and dark band and the No. 125 shows a baric detail in the petrology of the granulite. The light part of the rock is rich in unannealed felspar, albite (No. 123), while the darker part is shows recrystallization of the plagioclase, particularly along cleavage. Here is present also biotite, unannealed albite grains, illinit and quartz; the latter being almost frequently zonarphytic with the felspar. Accessory are convoluted ilmenite and fission...
Near west of Langton, up the little Porchier. A light colored, rather more coarse-grained rock than the average showing plagioclase with macroscopically visible multiple twinning and a little blue opaline quartz.

Despite the untextured appearance of the hand specimen, the thin section shows considerable recrystallization with the resultant texture of many ragged polygonal crystals set in a fine-grained micaceous groundmass. The plagioclase is Albicline (85%) and MICROcline showing an unwonted stage in the replacement by plagioclase shows the common antiperthitic form. It is notable that the microcline is always farther than the plagioclase, whereas the recrystallization takes place from the outside and preferentially along cracks and twin planes.

Accessories are micaite and leucoxene surrounding it, also muscovite, fairly large mica-like flakes.

In this variation the texture is far more regular with quartz (58%), feldspar (chiefly microcline - 22% and albicline (22%) in a fine, even-grained, groundmass aggregate.

Among them, slight elongation while the microcline is faint, but a little Albicline is present. Biotite occurs in common
directed, well spaced, laths with dark brown pleochroism.

Apatite, microcline, ilmenite and garnet constitute 2.7%.

**225**

**Venner Gorge quarry**

A light colored rock with very little feldspar or mica minerals.

Microscopically it is fine grained and consists chiefly of a mafic core: mica, plagioclase, quartz, and clinopyroxene. Sensitization has taken place in the veins and patches.

**60**

**Venner Gorge quarry**

This has the appearance of a gneissic granite being a light colored granite foliated rock with abundant black, commonly oriented black mica.

In thin section it is a moderately coarse-grained rock with little directional feature apparent. It consists chiefly of porphyritic microcline with slight base change. Foliage frequently drawn out into elongated forms. Biotite is not well crystallized and a little oligoclase is present. The gneissic or foliated mica, with much sericite and feldspar.

Sensitization is well advanced.
Penbrook. A light brownish rock with elongated bluish opalescent grains, together with much feldspar and biotite and a little epidote. Microscopically, it is holocrystalline, hypidiomorphic with granoblastic texture consisting of quartz, feldspar, micas, cloudy plagioclase and biotite with accessory epidote, chlorite, leucocore, magnetite, and garnet.

The quartz is frequently elongated, the mica shows cross birefringence, and the feldspar shows a Alogaline (6B2). Biotite is abundant as irregular laths, pleochroic from light yellow to green. Epidote is present as the two common varieties, yellow and colorless.

**Analysis:**

| SiO₂ | 69.25 |
| Al₂O₃ | 13.90 |
| Fe₂O₃ | 2.64 |
| FeO | 1.47 |
| MgO | 1.53 |
| CaO | 2.47 |
| Na₂O | 3.03 |
| K₂O | 4.68 |
| H₂O | 4.49 |
| H₂O⁺ | 1.12 |
| P₂O₅ | 1.13 |
| MnO | 0.01 |
| TiO₂ | 0.91 |
| C₂O | 0.02 |

| Ba²⁺ | trace |
| Sr | trace |
The rock is non-phyric in composition.

1253.

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

In thin section the rock is typified by the abundance of plagioclase mica observed by alteration, and in many cases, showing partial replacement of microcline, the latter being first in appearance. Banded actinolite with accompanying actinolite is abundant. Epidote, ilmenite, and mica, present while apatite forms large crystals, some showing square isotropic sections.
Strongly banded, crystalline rock with the usual fine and coarse alternating white and dark bands, the latter carrying frequent large white plagioclase crystals and irregular patches of ilmenite, epidote and actinolite.

Microscopically similar to 103 with a little more ferromagnesian. 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 cm) bands traversing it.

Microscopically, the rock consists of quite large cloudy plagioclase crystals of irregular shape, interlocked with subordinated microlite, epidote, actinolite, and ilmenite.

The plagioclase is frequently antiperthite with relics of similarly orientated microlite distributed through it. The bimineral frequently bent and warped in plan give irregular non-symmetrical extinction angles. There is a little periplanar grainfracture.

Epidote is abundant in quite large, brownish crystals, pleochroic with absorption 4 V, and biaxially positive with a 2V = 42°. Epidote is frequently intimately associated with it. Ilmenite often has actinolite growing around it.
A light colored rock of fresh appearance with a slightly greasy 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 calcite with leucocene, a pale diopside, and tiny cubical tourmaline crystals.

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

An even grained crystalline rock, consisting chiefly of white felspar, but with irregular bands with a fine, micaceous biotite.

Microscopically a medium grained crystalline rock, the texture being chiefly granoblastic but tending towards gneissose in the part with a biotite.

The felspars are most abundant, being fresher than usual and consisting of an almost pure albite (Plagioclase) and microcline as the coarse a-epitetic. The albite is most abundant and is frequently mantled by large crystals while fine granules of segregated felspar are abundant in the otherwise ground mass.
A compact, fine-grained grey, banded, rock with the general appearance of the banded grains of a quartzite. In the thin section, the rock is rather leuocratic, being deficient in ferromagnesian silicate. Quartz, feldspar, and mica are the main minerals, with a little chlorite, and a little epidote. A little plagioclase, andalusite, and garnet (Dre03) is present, while muscovite is present in the form of small, scattered grains. The rock is generally unfoliated, although the chloritic and epidotic minerals suggest that it is abundant. Accessory minerals are garnet and quartz.
(b) Democratic granulite

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

1724.9+8.

Among north of the Stoughton School:

This is the type described by Bennett as a granitic gneiss. It is a white, pure white color, fine-grained, with the general appearance of a gneiss, but which on closer inspection is seen to consist chiefly of crystalline foliation with extremely well-marked lineation due to tightly elongated quartz grains to 1.5 cm in length but about 1 mm. diameter. In the field the lineation is a regional feature and is a constant in the schistosity in other rocks.

The rock slides B and 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 feldspar. The majority of the latter is a plagioclase—hornblende 76.08—frequently enclosing relics of cross-hatched muscovite or antiperthitic relics. Accessory are a little muscovite and biotite.
2. This shows the drawn out nature of the growth— which does not show marked undulose extinction. Muscovite is more abundant than mica.

2a. Near North of Houghton School. A sample somewhat related rock to 1 1/2, this is white and fine grained, with a slight banding and a few flakes of muscovite. Microscopically, a granoblastic aggregate of small, black muscovite and quartz. A little amphibolite plagioclase— Albite. Horn is present. Muscovite occurs as quite large colourless flakes, while there are some inclusions and patches of a fine sericite mica. Albite and muscovite are abundant accessory.


In thin section, the rock is seen to have a few quartz than feldspar and consists of large, reddish crystals of plagioclase. Albite, horn—muscovite, muscovite, and tourmaline. The plagioclase is mixed with the Albite or combined Albite-Periclase cores and shows some twin lamellae like Albite, tourmaline, and shows some twin lamellae like Albite, tourmaline. Albite has produced a mass of tiny white mica flakes, or inclusions. The banding being frequently more dense towards the center.
parts of the crystals; or along cleavages and twin lamellae.

Penbrook.

A white, coloured, fine-grained, crystalline felspar rock with the appearance of a quartzite. A little monzoar, hornblende, is inserted in joints.

Microscopically, the rock is practically all irregularly shaped plagioclase crystals, olivine, andulite, and only a little biotite, sericite, chlorite, diorite, and some tiny cubic crystals tourmaline. Here is a little antiperthitic, microcline and quartz left entirely lacking.

This is a black, well-tourmalinated rock which is considered here for convenience. It is not a leucocratic granulite, but being of metasedimentary origin it is somewhat less, due to the general types of rocks it is described here.

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

Microscopically, a medium to fine-grained rock with diablastic texture, it
consists solely of equal amounts of tormaline and quartz. While the former appears to be more abundant in the hand specimen, the latter predominates in thin section. Orientations are well developed and the texture is granoblastic.

The quartz is frequently elongated and shows marked undulose extinction. The tormaline is usually quite large and euhedral while the smaller crystals approach idiomorphic outlines. Pleochroism is strong:

- Light greenish yellow.
- Deep green-brown.

There is accessory feldspar.

I. Next to Woughton School.

A white irregulalry grained granofelsic crystalline rock, the quartz being concentrated as grains in bands. Tormaline, muscovite and mica are visible in tiny grains.

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

Plagioclase and muscovite are both present in the same Allite. Mica is outlined in both allite and perlitie forms and the latter often compose antiperthitic.

Muscovite is well crystallized and is accessory with muscovite (and perlitie), and tiny euhedral tormalines. There is some twinning and recrystallization.
Schists

Microscopically, these rocks are fine grained, micaceous and markedly schistose, ranging in color from gray (serinite) to various shades of yellowish green to dark green (chlorite). Field observations, combined with laboratory work, normally indicate them to be phyllitic and not simply low grade phyllite. The uniformity of the schists over the area indicates that here are no purely low grade rocks present.

Microscopically, they are shown to be identical with the schistose gneisses of the argon 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 true cataclastic effects. They show a finely micaceous schistose texture and consist of serinite with chlorite and biotite; the micas frequently forming sound scaly plates small quartz polypodlitic relics of fragmented and stretched quartz.

A banded form within the granulite at Inglewood.

A highly serinite rock, pale green in color consisting of serinite and chlorite.

In the thin section, the texture is fine grained with a foliation due to strings of quartz, polysilicate parallel to a schistosity formed by the common orientation of small laths of serinite and chlorite.
Quartz is plentiful, also clear and colourless, in broken and irregularly shaped crystals. The microlits are a colourless sericite in small laths, and a bluish pleochroic from yellow to green as subhedral and sheaths.

Calcite is also present as idioelastic crystals slightly more pinkish red pleochroic, each crystal being intimately associated as surrounded by a dachy opaque skeleton which evolves itself into muscovite with some kaolinite. The breakdown of plagioclase to calcite plus muscovite is not recorded and seems doubtful.

Carnallite is an abundant accessory as pleochroic brown prisms not hexagonal section, the latter frequently showing colour zoning with a lighter centre. Carnallite is also abundant.

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

Micromorphically, very schistose, consisting of a closely divided aggregate of flakes of sericite and chlorite with quartz of quartz. The latter shows granulation and recrystallization in particular groups elongated in the direction of the schistosity. Colonized sericite and pale chlorite constitute the schistose part, flakes being frequently set at right angles to the final direction.

A string of muscovite grains also cuts...
across the schistosity. There is accessory opalite.

309.

A slate green coloured schistose rock, striking approximately of a green vein. It occurs as a band cutting the granulite of the Daves Gorge.

Microscopically it shows a well defined, highly schistose texture with small quantities of quartz, unswinned plagioclase, mica, ilmenite andapatite.

The vein is mainly a green ragged biotite with an abundance of pale green chlorite, both frequently set at an angle to the schistosity. Fragments of apatite are frequent. Accessories include leucocore and micaceous haematite.

13.

A soft green schist composed chiefly of micaceous material with actinolite and kyanite well band of white calcite.

In this section the schist differs completely from the usual pyroclinite. The schistosity is at a high angle to the concretionary bedding due to calcite. Minerals are fresh, well crystallized and are mostly oriented similarly, consisting of amphibole, mica, calcite and quartz. The amphibole is present in the two varieties with a pale
colorless tremolite growing around the pleochroic brown hornblende. The two appear to be in perfect optical continuity, the tremolite often growing in the normal extinction angle (from a cleavage traversing both minerals) and interference figure. The transition between the colored and uncolored varieties is abrupt.

Also present are a green tremolite and a pale green pumpelite. Pumpelite is seen in an advanced stage in the breakdown to tremolite and microcline felspar.

Accompanied are opaques epidote, while a hand piece is ground into the slide.
Grains. These grains, one of the so-called injected or "migratic" types and may be channeled in large grains or bands of grains - the two varieties merge insensibly into bands of each other and into banded granulite or schists.

Gneiss. A light gray gneiss, irregular and coarse in grain with large (2 cm.) feldspar and some quartz enclosed in a micaceous mass of sericite and chlorite.

Microscopically, very coarse grained with large rounded and altered angles of ferous ad quartz surrounded by a fine mesh of micro-foliated feldspar. Ferous are chiefly a fresh microlite with lesser much altered plagioclase - a pure Albite (Ab 98). The alteration has taken place along cracks and cleavage and large areas of the plagioclase are frequently made over to an aggregate of white mica. Twin lamellae are often bent. The microlite is prismatic and also contains granoplastic zones. The latter usually occurring in large irregular crystals - clear and colorless with a sublustrous extinction.

Biotite as very ragged blades, often in intimate growths with sericite and chlorite from which it is forming or to which it
is altering. Chalcopyrite is fragmented and in places iron appears to have been released to form a dark vein or a zone about the iron core in the general matrix of sericite. The schistose portion contains muscovite, biotite, chlorite, amphibole and frequently skeletal relics of albite may be seen merged in a replacing web of sericite. Accessories are apatite, calcite, garnet and muscovite.

28 Inner Gorge.

This is the type rock for a variety of manganiferous, dark-colored augen gneisses which constitute the major rocks of the northern part of the area. They may contain millimetric garnet, or both.

No. 78 a dark gray manganiferous gneiss rich with white fibe. Of millimetric and also occasional small patches of chlorite after garnet.

Microscopically this rock presents the common gneissic texture with large, stretched and broken porphyroblasts of garnet and often microlites in a well directed schistose matrix.

Sericite is present as fine tubular crystals or in all stages to complete sericitization. Garnet is less abundant and shows chloritization, often remaining as relics, frequent surrounded by sericite.

The biotite is typical of these manganiferous gneisses and is similar to that found in
similar rocks at Bolder Hill, Varnellita etc., being very dark brown, strongly pleochroic and
muddled with very opaque inclusions of iron ore. It is seen in intergrown, with quartz,
sericite, sillimanite and chlorite.

Gyrite is quite a common and prominent accessory.

38b Similar but containing sillimanite but not garnet.

38c Similar with sillimanite and only a little garnet remaining although chlorite pseudomorphs
are common.

75 This grain contains only a little sillimanite with no garnet although fuchsite occurs in quite
large crystals.

201

Kenbrook.

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

21

Gorge District.

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

224

Egg Tower, Gorge.

A dark green grain with a fine white
groundmass of hornblende and biotite with
small lens of feldspar. This is not a typical
The augen gneiss, being one of the extremely
named types, is the forerunner between the bound-
granulite and the true augen gneiss.
Microscopically, the rock is seen to consist
of bands which is hamulcide or feldspar, these
being the only constituent of any importance.
The plagioclase is extremely altered and is
dendritic (AM 88), while the hamulcide is
the green brown variety with associated
mesolite.

Accessaries are epidote, apatite, sericite,
immenite, and green.
The Metamorphic Rock.

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

Little Poco River.

This is a rock of which only one specimen was found — a black haematite quartzite. It was found within the Arkona mica schist, and is one of the older rocks.

It is a hard, massive quartzite of darkly flinty grey color, being essentially homogeneous and possessing no directed characteristics.

Microscopically a very fine grained quartzite with a notable amount of micaceous haematite present. The iron ore lies in compression banded in one direction and is elongated giving a schistosity at widely varying frequencies.

A light colored fine grained quartzite from just within the Arkona boundary, interbedded with gneisses. Semi-ochre material gives it a somewhat ochreous aspect, while it is notable because of the abundance of glittering grain of magnetite.

In thin section it is a fine grained quartz-feldspar rock of uneven texture with abundant cubical magnetite, with some...
(3) continued) wisps and patches of micaceous material.

Some of the quartz shows recrystallization about the larger magnetite crystals, while finer opaque iron ore is abundant through the white. Also present is sericite, with lesser pale green biotite and a little cloudy feldspar.

Accompanied are garnet and tourmaline.
Sediments of the Adelaide System:

Close to the Problem massif various goit and metasomatic processes assume interesting appearances.

A light coloured, highly schistose rock consisting chiefly of sericite with bands of patches of green mica, frequently at 50° to the schistosity. There is a slightly speckled appearance due to small grains of felsite. This is a sheared chloritic amphibole-basal sandstone; in the field it is almost indistinguishable from the older sericite schists.

Microscopically it differs from the retrograde phylloschist, the tremolite nature is apparent and peritectic relics are lacking.

Tracks in the abundant quartz are filled with sericite, often filled with quartz, some are parallel orientation, frequently associated with leucogneisses, which is abundant. Green chloritic mica is present as wisps and patches.

2

Izone. Dolerite:

A pale green, crystalline dolomite with traces 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, a pale green chlorite, limonite with a little quartz, limonite and magnetite.
Mineralogy.

As a preliminary to a discussion of the

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

Plagioclase is a characteristic of all
but the highly sheared phyllonitic schists
and either microcline or a moderately acid
plagioclase in widely varying amounts,
depending on the rock type. Generall-

(a) the schists carry little or recognizable feld-

apart from tiny grains of untwinned

albite

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

(c) the gneisises are notably feldspathic
with perthite microcline and anorthoclase
plagioclase (albite to andalucite) in widely
varying proportions

Plagioclase vary from an almost pure albite
to an andicnic plagioclase in almost pure albite
and extinction angle from 0° to 19° to an
andicnic plagioclase. Twinning is
usually present on the albite law and frequently
the twinning law and is absent, but may be
abound. Staining effect lamellation are
noticeable giving

(1) bent twin lamellae

(2) undulose extinction

(3) warped twin lamellae
(4) irregular secondary trimming

(5) peripheral granulation.

The feldspar is almost invariably clouded due to extensive alteration and composition could not be estimated by complete orientation methods procedure used. The method used the class of plagioclase was reconned by the normal method which gave certain anomalies.

Symmetrical extinction angles to 0.10 were by no means satisfactory. Rotations 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.

(i) difference in composition across the twin plane.

(ii) warping of the twin plane.

Reference to (i) it is noticeable that those crystals which show angles 18°-19°, 18°-14° are have a differing degree of alteration in one set of twins. Commonly states a very disturbing occurrence of such variation 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
description of the rocks, in each case the maximum angle, only, are given.

The optical properties are normal; bisected interference figures are bisected and form albite to andeline. The optical sign is positive to negative to positive, with axial angle from 40°-90°.

The one of the most significant textural problems is that of a coarse anepidote, intergrown which only occurs in the gneissic. Intergranular, quite large crystals of microcline are enclosed by a matrix of plagiodores (usually albite) with each individual inclusion in a group in complete optical continuity. The birefringence shows this uniformity of orientation. The one direction of the albite twinning in each feldspar coincides exactly, while the twin planes of the microcline and potash twinning in the potash and soda feldspars respectively are at 56° to each other - thus the one coincides also. This group feature is due to a replacement of the potash feldspar 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 colorless granules of epizote or to a multitude of small colorless minor tubules, frequently oriented parallel to the twin planes. This may be the soda micro-pericline but the albite is usually stable and under such metamorphic conditions and appears to form.
nearly small clear untwinned grains can under the most severe conditions of heat, such do not seem likely. In time, the alteration is more advanced around edges of crystals, cleavages, and twin planes, or through the source of potash, was outside the crystal. Rock for the majority the explanation appears to be that the plagioclase, formed by the replacement of microcline, contained an appreciable amount of potash, held in unstable solid solution and under stress conditions this was rejected as a precipitate while unice. In the new quartz fresh rocks the plagioclase i replaced progressively by increasing amounts of sericite until there is a more perfect skeleton showing multiple twinning in a highly oriented 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 plagioclase as a indication of metamorphic grade or facies would not be accurate in these rocks, as the lack of equilibrium is indicated frequently.

Plagioclase is the most abundant variety, and is the almost unvarying member in the quarzilites, while albite is more common in rocks in the South Western area. It seems a valid generalization that the Donner quarzilites carry a more basic plagioclase and the metasome warmer.
It is a striking fact that the granulite, which are chiefly felspar and which consequently appear free from any solubility (as differentiated from a foliation) show a high degree of preferred orientation and anisotropy when even a brief petrofabric analysis is conducted.

The potash felspar is invariably microcline and orthoclase was not found. Even darkening is frequent and even black mica not showing limonite were found in complete association to be euhedral. It is common for epidote, containing albite as radiating cores, elongated, oblolute leucocorines and appears to be a normal high temperature exsolution perthite. This variety occurs in both granites and gneissites.

Extinction angles, from one cleavage is 120°. It is noticeable in the hand specimen that the microcline is white while the plagioclase is flesh colored in contrast to the usual habit. Micro in thin section the microcline is colorless and fresh, and conchilitic only takes place from the edges of crystals. All stages of fragmentation and alteration are seen.
Granite is one of the most abundant minerals of the sublith and gneisses, while occurring to a far less degree in the gneissites. Macroscopically it may be colorless and glassy or freckled light and opaque. In thin section it is clear and colorless, varying in shape from rounded granophyric shapes to irregular, bolder and lenticular outlines.

In the gneisses, granite is the only mineral of any appreciable size and is seen as an irregular, porphyroblastic set in a matrix texture.

In the leucocratic rocks, and less frequently in the gneissites, it occurs as an extremely elongated (index of elongation as high as ten) rounded crystals, formed by slow and recrystallization under conditions of high temperature and pressure. These crystal frequently enclose small rounded and elongated blocks of granophyric quartz. This has the appearance in different specimens of being an introduced and replaced quartz.

Optically the quartz is isometric, 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 slow 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 different
optical orientation in various parts of the crystal and on one gave a difference in extinction of 60° between the ends. It was decided to plot the optic axes to show distortion of individual crystals. Experiments on the universal stage showed that crystals either extinguished completely in one direction so that all optics axes were parallel to the axis of the microscope or that in a certain position the crystal was revealed to be made up of several portions with slightly different orientation with sharp division between them. It then appears that the unidirecct orientation is here produced by the process of crystallization and not necessarily a common orientation between two originally distinct fragments. The junction between the two is sharp when viewed in the correct direction, but at angle, 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.
Amphiboles are members of the tremolite-actinolite and the hornblende series, and are the most abundant ferromagnesian minerals found. They occur only in the graphites, and the transition to schists and their immediate derived schists and gneisses, and not at all in the leucosomes or rhyolite gneisses. All members of the tremolite-actinolite series are represented, being secondary or residual alteration products from diopsidic and naevic in colour from complete colourlessness (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 for:

Y - colourless
Z: - pale green
and the hornblende
X: yellow green
Y: green
Z: brownish green.

The two have identical optical properties and are bisinically positive with 2V of 70° and an extinction angle measured 2.7° of 23°. The lighter variety is sometimes found growing around the brown typhoe with a sharp colour change between them but with cleavage continuing across both, and will the same extinction position and optical properties. The amphibole occurs as tabular,
feldspar or idiomorphic needle-like crystals, about 1 cm across, are also abundant. Epidote and actinolite are also present, as are some quartz and feldspar.

A dark green fibrous actinolite is frequently visible as individual grains, or as a vein through the graphite. Large masses occur in the pegmatite, typically near the surface, and are often several feet across. Certain thin sections of the graphite show a structure resembling von kovitzite, with some thin, dark bands, and may be mistaken for actinolite. This is a possible feature and is believed to be minable after original von kovitzite. The bedding in porphyrite indicates the sedimentary origin of the crystalline rock.
The pyroxene, which occurs in a pale green diopside and remains as relics, is surrounded by quartzite. It occurs only in the graphitic and is rarely found unaltered. The 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 cleavage are 40°.

The diopside indicates the original high grade of metamorphism of these rocks and also shows the original sediment to be rich in lime and magnesium while its unmeted orthorhombic is the product of the retrograde metamorphism.
Various minerals 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—sheer appearance to be two generation which are referred to here as muscovite (primary) and sericite (secondary)
(b) biotite—also primary and secondary
(c) clorite—diagnostic product

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

The sericite which is the chief part of the sericite ground zone of schists and gneisses appears to form from a variety of minerals indicating a general addition of potash in low grade conditions with slow acting. By Turner's classification, this would be the muscovite--chlorite mica facies of the greenschist facies. It is frequently seen in arrested stages of formation and the origin are considered from mica.

A strained rock, mica-rich; frequently seen to become granulated at the periphery and further to be cracked and crumbled.
with the accompanying breakdown to a potash
mica. This transformation is common 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
microlite originally present to allow the
formation of such quantities of mica is
debatable.

From sillimanite.

Sillimanite, especially in the presence of
the Taconic Gorge is seen to be altering to
a mesh of sericite laths or 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 a outside source.

Under 3 give the reaction
With plagioclase:

A notable feature of the plagioclase in many of these rocks is the cladding due to abundant, minute balls of a white mica, or inclusion, "cemented" parallel to the albite twin-plane. This mica appears to be sericite rather than the usual muscovite. This process is mentioned previously (p3) with a consideration of plagioclase.

Biotite

The dark mica which precedes the retrograde process is in ragged sheets, frequently bent, with pleochroism from light to a very dark brown. These are usually abundant inclusions of (a) iron ore in the southern part of the area, (b) mitchie grain in the northern part, (c) interlaced quartz (elongated), (d) sericite (interleaved), (e) chlorite (interleaved).

Here is a fine light, green mica in irregular flakes, which appears to be unusually secondary. Biotite is of frequent occurrence in the schists and gneisses, but is sporadic in the granulites - although the most, in the most northerly part of the granulite area, new groundwork 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, with its green biotite, while the mica further away is vermicite almost solely.

(c) Ilmenite

The mica imparts a notable green colour to many of the schists but in quantity is relatively unimportant. A pale green to colorless mica with very low birefringence - interference colours being a low grey or anomalous blue - it appears to be a perovskite. It is the index mineral showing the low grade conditions under which the diaplectic took place.

It forms by the breakdown of higher grade minerals, particularly biotite while it appears as pseudomorphs of tourmaline.
VI. Epidote Group.

There are three representatives of this group:
(a) epidote
(b) grüne
(c) ophite

(a) The common in epidote is abundant, being visible as typical green grain in the hand specimen or as strongly pleochroic yellow to yellowish crystals in thin section. The biotite is high and cleavage is frequent intermediately associated with actinolite which grows around it. It is recorded the alteration of actinolite to epidote but the reverse retrograde step is apparently not common.

(b) A colorless grüne with high relief and low polarization color is frequent as tiny rounded grain and inclusion as a saussuritization product of plagioclase

(c) Ophites are quite common in some angiosperms to the north and occurs as deep brown pleochroic crystals, rounded in shape with high refractive index and double refraction. The interference figure is binocularly positive with a high axial angle.
VII. Sillimanite

Geologically the sillimanite was once a reasonably large area, but the actual abundance of the mineral is not high due to its frequent replacement by sericite. In the hand specimen it may be recognized by the pseudomorphic fibers, sericitic material, or in the original state as clear, white, silky fibers.

The presence of sillimanite immediately next to the garnets indicates the highest grade of metamorphism. In the thin section it is colorless in a quite large often euhedral or tabular crystal, 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 more ghost pseudomorphs of sericite.

Optically it is biaxially positive and like many of the South Australian sillimanites has a low axial angle. Specimens from Yarrawalla may be 2V for 10-15 while from tough tor the 2V is less than 5° in some interference figures the inky green rarely separate.
Garnet

A red-brown garnet - near almandine in composition occurs in gneisses in the Tomauqua Range at about 6000 ft. 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 well in the vicinity of the metatonite (Houghton) granulite, while garnet alone is found near the contact (Hemlock) outcrop. Even though the usually more basic pegmatite presence is more likely, the garnet suggests a higher grade of metamorphism. This factor is another point in the evidence that equilibrium was probably 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 pale green vein through the greisen.
2. Graphic intergrowth with quartz.
3. Tiny euhedral crystals in greines and granulites e.g. in greines 138, 14, 159, 97.

4. Major constituent of the quartz + tourmaline schist of the Bunting Synclinorium.

It is usually strongly coloured or pleochroic from deep brown to light green occurring as euhedral crystals to subhedral prisms. In an actinolite schist from Boughton (No. 13) there are light coloured fanned crystals (lighter at the outer margin) while embedded in the plagioclase, are perfectly euhedral prisms showing perfectly developed crystal faces - coloured in various shades of pink and purple.

Tourmaline indicates the overall pneumatolytic action and suggests it has been introduced:

(a) as the mineral in veins etc.
(b) asansom to produce the mineral by reaction with various aluminium silicates.
The chief iron ore of the district is titaniferous and very feebly magnetic, magnetite, is rare. It occurs as tiny grains or as large masses, veins 6 inches across, are found in the granulite, east of Hemlock, and in large black and lustrous masses.

In the section it is quite opaque, reflecting little light and is frequently intimately associated with muscovite, leucocore or other to which it has supplied titanium. It is also a constituent of barite; it is the source of iron, the ore having often made crystal, lens-shaped or fractured them.

The apparent cross-bedding shown by the granulite is apparently due to the formation of amphibole from the original iron; without appreciable movement.

In the field, the ilmenite may fill veins, cutting across folded granulite, and appear to introduce at a late stage in the original metamorphic process. It is also a primary constituent of the original sediment.

Ilmenite is a notable constituent of the Hemlock gneiss.
X.1. Apatite Group

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

(1) Color: The mineral may be colorless to pale brown; in the latter case it is feebly pleochroic with absorption in w.

(2) The refractive index varies considerably.

(3) Optically it is positive but has a negative angle ranging from 0° to 40°.

It usually indicates a pneumatolytic addition of phosphate and the variolite probably has varied amounts of chlorine and fluorine which control their properties.

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

XII. Rutile & Lemcovite

Rutile, not abundantly but persistently, over a wide area, usually in deep brown and pleochroic with a brilliant luster by reflected light. Optically it is uniaxially positive. It is most commonly associated with ilmenite which is apparently the parent mineral. Lemcovite also occurs quite abundantly as fine granular aggregates.
XIII. 

Foramen ovale. 

An accessory org., vertebral is common and always retains its oval - dental shape showing its original arthritic nature.

XIV. 

Baculite. 

A marine i. Inhabit and of local importance only, baculite occurs in various sections and is baculite - quartzite from the Little Para. At several localities, it is found as bright specular flake, particularly in quartite and veins.

It is of considerable importance in the analyzing Adelaide System i. the local beds - quartzite on the eastern side of the Barossa massif - particularly at Mt. Benson.

XV. 

Serpentine. 

This mineral occurs in some quarries and to a lesser extent in the limestone. It is brown and usually mottled crystal, strongly pleochroic with high double refraction.

XVI. 

Calcite. 

XVII. 

Magnesite. 

The iron oxide is of little importance, occurring as individual crystals in the quartzite beds. The garnet in the South Western corner of the area.
XVIII Ignite yellow gold by reflected light is fairly abundant in some of the gruviers, especially in the silliconite with varicolored, white occasionally black pyrite and bornite are recognized back in the hard gruvier and this section.

XVI Calcite is not abundant, it only occurs as colorless, slight lustrous, frequently cubical crystals in white marly, but quartzite also.
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Explanation

Key to B.C.F. Diagrams

1. *Granulite facies.*
   
   This indicates the highest extent of the metamorphism.

2. *Amphibolite Facies* - sillimanite, amphibole, and quartz. Some diorite rocks probably fall in this range.

   
   This stage is reached in retrograde metamorphism by granulite and gneisses.

4. *Green-shist facies.* sillimanite - chlorite subfacies. The schists and gneisses generally fall within this class.

Key to Microsketches

1. Portion of a granit from Castlemilk. It shows a sillimanite crystal which has been fractured and liberated iron to surrounding sericite to form a zone of chlorite.

2. Portion of a granulite from Drybridge. It shows actinolite growing on epidote.

3. Portion of a granulite from Trentham. It shows the fibrous sheet of vermiculite actinolite.

4. Portion of a quern from the Rome Gorge. It shows the typical sillimanite in a mesh of sericite.

5. Similar to No. 4.

6. Quartz-feldspatic schist from Dunbarton Sand.
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