GEOLOGY OF PORTION OF THE GRAND UNCONFORMITY NORTH OF BROKEN HILL, N.S.W.

BY

R.B. LESLIE. & A.J.R. WHITE.

HONS THESIS 1952.

CONTENTS.

INTRODUCTION.

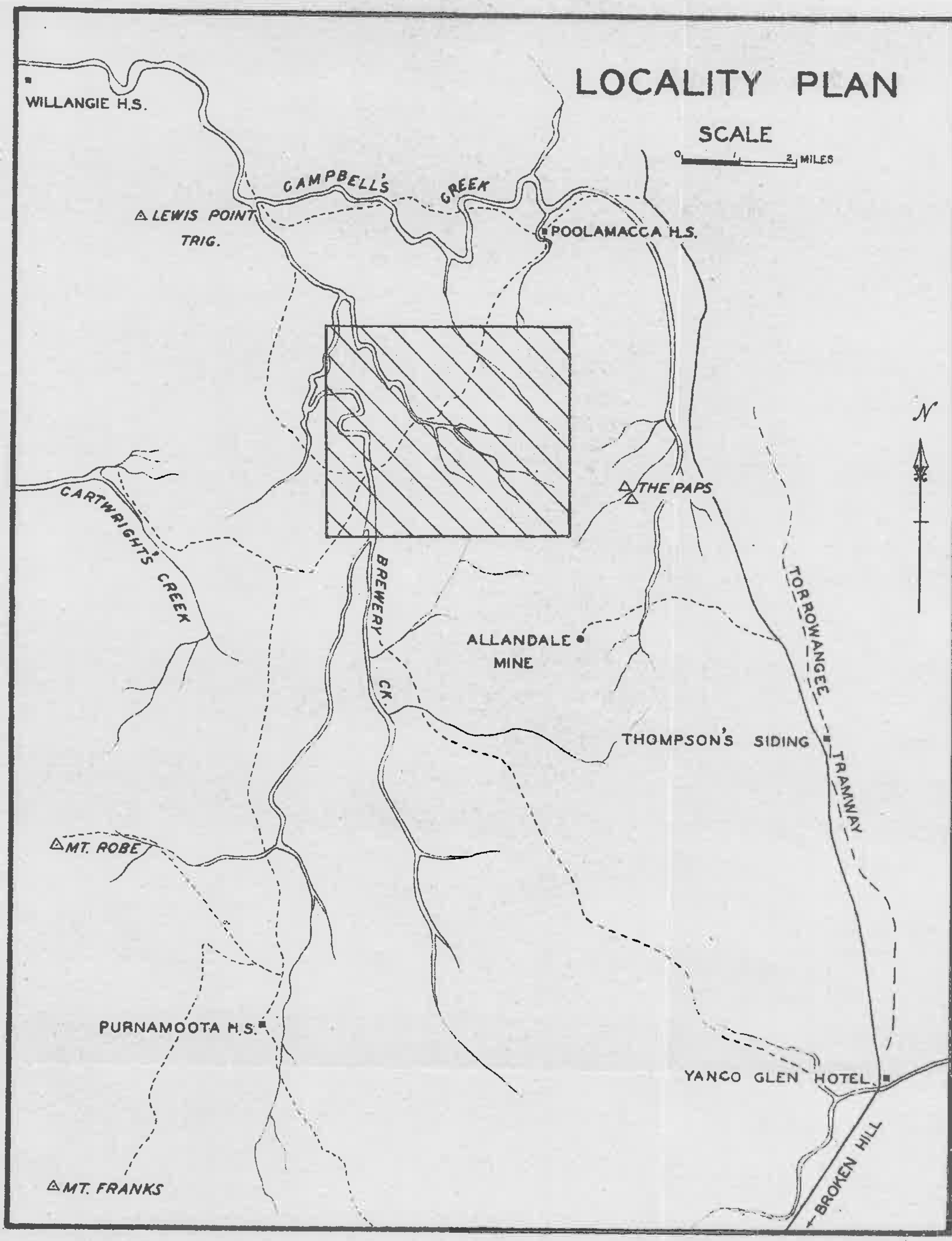
Location. The area is situated 26 miles due north of Broken Hill in the Northern Barrier Ranges. It comprises some fifteen square miles adjacent to the unconformity of the Younger Torrowangee Series and the older rocks of the Willyama Complex. From the Brewery Creek Pluton it extends eastwards to a point just west of the Paps, while the northern boundary is about 2 miles south of Poolamacca homestead.

Physiography. The topography is one of low hills which are usually covered by a typically semi-arid vegetation consisting predominantly of mulga (Acacia Aneura), Dead Finish (Acacia Tetragonaphylla) and Beefwood (Grevillea Striata) together with the everpresent saltbush.

The hills of the area fall naturally into three well defined groups. Jagged, craggy ridges in the schist area stand up in marked contrast to the rounded, boulder strewn hills of the tillites, and the pale, tor covered hills of granite.

Because of the paucity of vegetation and general lack of soil cover the rock outcrops are usually particularly good.

The country is well dissected by numerous streams, the largest of these being the Brewery and the Wookookaroo Creeks which are typical of the Barrier Ranges. These normally flow only after heavy rains, but deposits of water bearing sands along their seemingly dry beds support large red gums which give welcome relief from the scant vegetation of the hills.


LOCALITY PLAN
SCALE
0 1 2 MILES
WILLANGIE H.S.
CAMPBELL'S CREEK
LEWIS POINT TRIG.
POOLAMACCA H.S.
N
THE PAPS
CARTWRIGHTS CREEK
BREWERY CK.
ALLANDALE MINE
TORROWANGEE TRAMWAY
THOMPSON'S SIDING
MT. ROBE
PURNAMOOTA H.S.
YANCO GLEN HOTEL
BROKEN HILL
MT. FRANKS

The larger streams appear to be independent of the geological structure while the smaller tributaries tend to follow some structural feature. This is particularly evident in the trellis type drainage pattern in the more gently folded Torrowangee beds.

It is interesting to note that the whole drainage scheme is essentially to the West - even those streams which flow to the East on the Eastern margin of the area eventually link up with west flowing streams which cut through the ranges to the Lake Frome plains beyond. This, together with the meandering nature of the larger creeks, is suggestive of antecedent origin.

Previous Investigation and scope of present work.

The unconformity between the Torrowangee series and the Willyama complex was first recognised by Mawson and described by him in his memoir of 1912. This was followed by Andrews comprehensive report on the geology of the Barrier Ranges which was published ten years later. No further attempt was made to remap or reinterpret the regional geology of the area until 1950 when Zinc Corporation geologists made a broad study on a regional basis.

An important outcome of this recent work was that a post Torrowangee age was proposed for the Paps granite "dyke" which outcrops parallel to the unconformity from Yanco Glen to the Paps and then swings westward, still parallel to the unconformity towards Brewery Creek. A post Torrowangee age was likewise proposed for the Brewery Creek Pluton and other similar granite masses in the area.

These granites are a phase of the newer or Protogine granites of Mawson (1912) and the Mundi Mundi granites of Andrews and Brown (1922) and have previously been regarded as pre-Torrowangee in age.

Zinc Corporation geologists have also reported that the pegmatites which are so abundant in the older Willyama rocks have been intruded into the base of the Torrowangee series in certain localities.

The post Torrowangee age of the granites raised an important problem, in that the tillites, which occur near the base of the Torrowangee series, contain abundant large granite boulders, seemingly identical with the supposedly younger granite.

The exact nature of the unconformity itself has also been much debated in recent years. Some have gone so far as to suggest that this structure has been entirely obliterated by Post Torrowangee thrusting and metamorphism.

Another problem was the occurrence, in the Brewery Creek area, of quite a considerable thickness of highly folded glacigene sediments stratigraphically below the basal quartzite horizon which occurs along the Yanco Glen-Paps line.

These problems together with the possibility of some post Torrowangee pegmatization prompted the present investigation.

The area was mapped in considerable detail with the aid of aerial photographs kindly supplied by the Zinc Corporation — some five weeks being spent in the field.

The accompanying map was produced by the slotted-template method from the aerial photographs.

A representative cross section of the rock types occurring within the area was collected and some 60 of these were sectioned and examined microscopically.

Stratigraphy

The area contains rocks of Archean age, which are part of the Willyama Complex. These older rocks are overlain unconformably by a series of late Proterozoic sediments, the Torrowangee Series. There is no evidence of sedimentary deposition since Pre-Cambrian time.

The Willyama rocks were folded, metamorphosed, intruded and eroded before the Torrawangee sediments were deposited with marked unconformity upon them.

The contact is masked in places due to shearing but elsewhere the unconformity is well shown. Exposures in the vicinity of Brewery Well show a marked angular unconformity with the respective strikes of the older and newer beds being almost at right angles. About ¼ mile south-east of the point where the Brewery Well road crosses the Wookookaroo Creek, this angular unconformity is again clearly exposed in the bed of a small creek. (See Fig. 2). Where the unconformity swings southward on the eastern side of the area, metamorphic

(A)

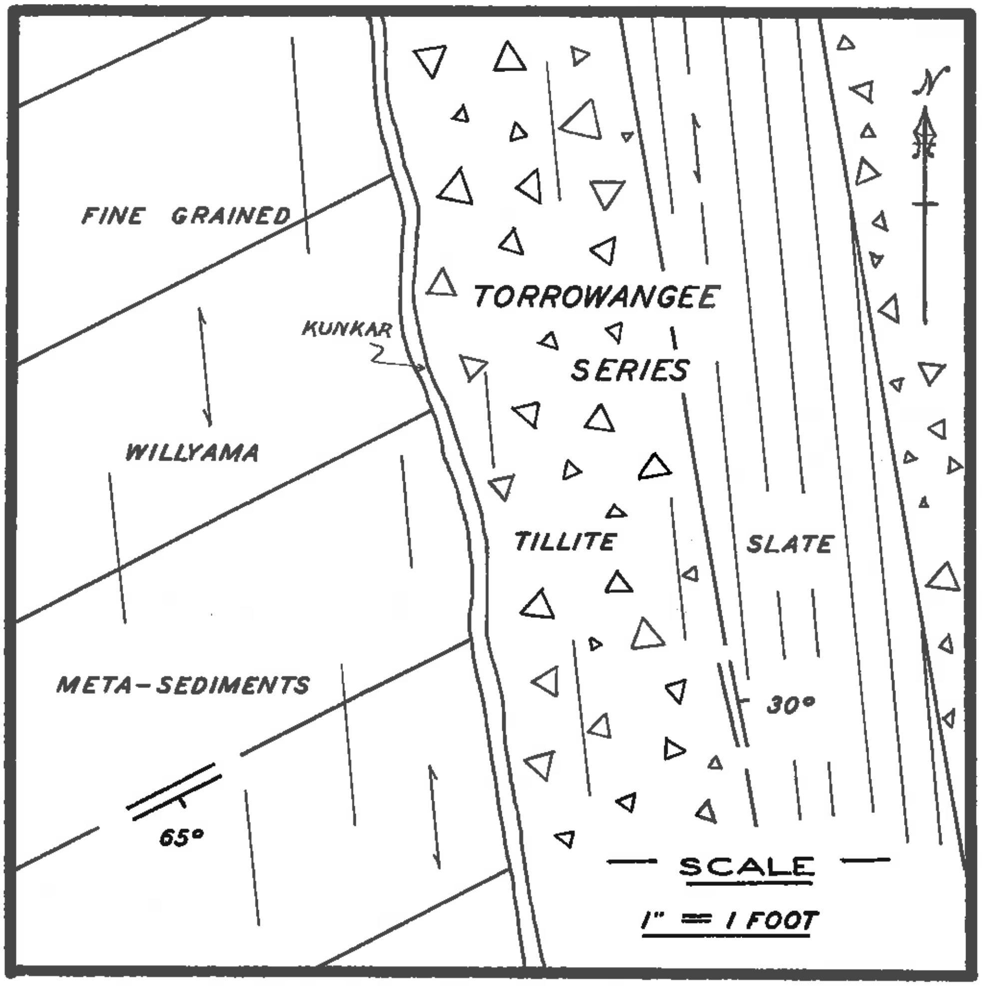


FIG 2.

Sketch of part of unconformity exposed in the bed of a small creek, one mile East of Brewery Well.

convergence due to shearing has in places caused the exact location of the unconformity to become somewhat indefinite.

Structure

The older rocks which outcrop in the south-western portion of the area have suffered a much lesser degree of metamorphism than has been the case of the Willyama Complex in general. Here, the original sedimentary nature of the rocks is still clearly seen and a broad open type of fold structure is indicated.

These beds appear to occupy a position on the eastern limb of a south pitching syncline, with dips generally very steep and in places vertical or overturned. Since accurate evidence of facings is lacking it is not impossible that these structures may be east limb anticlinal in nature which have been inverted.

The dips are usually from 60° to 70° and the pitch as indicated by drag folds is about 50° to the south. Some minor puckering of the less competent beds occurs in the noses of folds with simultaneous shattering of interbedded siliceous rocks.

To the east of these low grade metasediments the dynamic factor of metamorphism gradually increases and the older rocks in the central portion of the area appear to have been the locus of intense shearing movements. The schitosity of the coarser grained schists occurring here is usually vertical with a north-south direction but in places it dips steeply to the east. A strong lineation in the plane of schistosity dips south at 50° which corresponds to the pitch of the structures in the low grade metasediments further west. In this highly sheared area the original bedding structures have been almost entirely obliterated. Occasionally bands of more competant siliceous rock can be seen cross cutting the schistosity ([redacted]), but these structures cannot be followed for any great distance in the field. An attempt has been made to plot these structures from aerial photographs and the trend lines thus obtained indicate much tighter folding than is shown elsewhere. From the scanty field evidence it appears thqt these structures also pitch fairly steeply to the south. Thin siliceous bands are often sheared out giving boudinage structures which at times have appearance of quartzite boulders in a schistose matrix which could be mistaken for ancient boulder beds.

Pegmatite dykes of all sizes occur abundantly throughout the entire area of Willyama rocks studied. Where the dynamic factor of metamorphism has been greatest they normally follow the schistosity thereby suggesting a post shearing date for their intrusion. At times however these pegmatite dykes and masses are themselves sheared at the peripheries and occur as pod-like bodies with the direction of schistosity following their boundaries.

Occasionally the pegmatite has been completely sheared out giving a coarse quartz-sericite schist (Rock No. 67).

These facts suggest either 2 phases of shearing or more than one period of pegmatite intrusion. Further to the west where the dynamic factor decreases the pegmatites are less abundant and tend to follow the bedding.

The granite in general shows cross cutting tendencies toward both schist and pegmatite. At the edge of Brewery Creek pluton, in the N.W. of the area it can be seen that intrusion has occurred along the bedding of the Willyama rocks to some extent and it is probable that some structural control was involved in the intrusion of this granite mass.

Some thin dykes of granite within the schist area follow the schistosity for a considerable distance. One such dyke, at times less than 1 ft. wide was followed for $\frac{3}{4}$ mile.

Within the area which has been studied the Torrowangee rocks show a greater complexity of folding than is seen in the older rocks which they overlie.

They occupy a position on the western limb of the Yancowinna syncline which in general is a broad, open fold structure pitching to the north at a relatively shallow angle. The axis of this major syncline occurs some 2 or 3 miles to the east of the Paps. The Willyama Core of the corresponding anticline to the west is seen as a triangular shaped area of older rocks, with its apex directed to the north. This anticlinal axis lies to the west of the Brewery Creek Pluton.

The axial direction of the minor folds is dominantly north-south. Locally the north pitch varies considerably, in places being almost 60° (photo.)

Axial plane cleavage, usually vertical but sometimes dipping steeply to the east, is well developed in the less competent members of the series, and in places, particularly in the lower beds, there appears to have been some shearing

Minor drag fold in glacigene sediments showing steep pitch to North.

Bedding structures in glacigene sediments Willyama Schist in background.

movements following this weakness.

Of the other lines of weakness to be expected from a consideration of the strain ellipsoid, the north west-south east is most prominent. At least one major fault occurs in this direction. This is a normal fault at the northern end of the Brewery Creek Pluton where the granite and a small tongue of basal tillite which rests unconformably upon it has been raised into contact with beds higher up in the tillite series.

The basal quartzite horizon, noted by other workers (Mawson 1912, Andrews 1922) is not developed in the area studied but is represented by the more siliceous glacigene beds occurring just above the unconformity on the eastern side. These siliceous beds continue on in a north-westerly direction so that a considerable thickness of glacigene sediments lie stratigraphically below them. These underlying beds are explained by overlap, caused by the deposition of lenticular beds in a glacial valley, during the early stages of glaciation.

In general the basal beds appear to be infolded into the older rocks and several small inliers of Willyama Schist and outliers of tillite occur.

The sinuous curves displayed by the unconformity indicates a high degree of folding of this line if we are to assume a moderate pitch in the overlying beds. These facts together with the steep dip of the tillite off the Brewery Creek granite seem incompatible with the relatively simple fold structures which exist in the basement rocks of most of the area.

However, in considering this unconformity the following facts must be taken into account:-

1. Large depositional dips are likely to have occurred in the glacigene sediments, particularly in the case of the coarser boulder beds, although none of the slump structures which usually accompany large depositional dips were observed.

2. The topography of the pre-existing land surface, especially in the vicinity of the dynamically metamorphosed schists, is likely to have been highly irregular and this fact may explain the presence of both inliers and outliers.

3. A small amount of folding of the basement rocks may produce considerable crumpling of the overlying sediments if these are confined between the relatively steep sides of a glacial valley.

4. Upthrusting of the basement from the south along the pre-existing south pitching lineation in the Willyama schist may have caused abnormal pitches in the basal beds of the Torrowangee series.

5. The overlying sediments may have folded independently of the more stable Willyama basement rocks by decollement.

6. Some overthrusting from the east has occurred. A thrust fault of this type has been mapped in the central portion of the area.

7. Metamorphic convergence due to shearing along the unconformity has also occurred.

It is probable that all of these factors have contributed to the complexity of the unconformity as now observed. Also the steep dip of the Torrowangee series off the granite mass may have been complicated by a strike fault parallel to the eastern margin of the pluton. This fault would be difficult to detect as it would be parallel to both the cleavage and the bedding of the glacigine sediments. Evidence to suggest a fault is the straight north-south trend of the unconformity and also the occurrence of a small amount of brecciated rock (No. 2) at the unconformity just north of Brewery Well. This brecciated rock may possibly represent cemented scree material. The southern extension of this linement is seen in the north-south trend of the Brewery Creek, however in this region there is no evidence of displacement of the Willyama beds along this line.

The Willyama Rocks

The term Willyama Complex was first applied by Mawson (1912) to the extensive tract of ancient rocks outcropping in the Barrier Ranges of New South Wales, and the adjacent areas of South Australia. These rocks which were originally a series of argillaceous and arenaceous sediments, now appear as a complex of schists and gneisses due to intense Pre-Torrowangee metamorphism.

The highest grade of metamorhpism occurs in the vicinity of Broken Hill itself as is evidenced by the abundant development of sillimanite in this region. The intensity however, falls off in the northern part of the ranges so that in the area under investigation the rocks are of relatively low grade, normally not exceeding the biotite-chlorite sub-facies.

The Metamorphosed Sedimentary Rocks.

Fine grained meta sediments.

These rocks, which probably represent the lowest grade of metamorphism in the Willyama Complex, consist dominantly of very fine grained arenaceous and argillaceous schists, sometimes finely laminated, together with graphitic 'chiastolite' phyllites and thin bedded chert-like rocks.

The chert-like rocks are compact, thin bedded and extremely fine grained. Although they have a superficial resemblance to chert it is probable that they had a clastic origin and are therefore better described as meta-siltstones. Their colour varies from pure white to buff and almost black while many are flecked and banded.

Rock No. 74 is typical of the darker varieties which have flint like characteristics. The fracture is conchoidal and the weathered surface is considerably paler in colour than the unaltered fresh interior. Under the microscope the rock is seen to be a completely recrystallised aggregate of quartz (80%) with subordinate felspar and some small flakes of green biotite and muscovite. The texture is granoblastic. It is extremely fine grained with average grain size .04 m.m. A feature of the rock is the abundance of small black graphite inclusions in all of the minerals. These occur mainly towards the edges of the crystals and sometimes give the outlines of the original detrital grains. In places the quartz has cleared itself of these graphitic inclusions and the graphite occurs in somewhat larger flakes.

Plagioclase is the only feldspar present and this occurs as completely unaltered xenoblastic crystals with composition Ab_{90}.

Zircon and iron ores occur as accessories.

In the hand specimen rock 92 is similar in appearance to Rock No. 74. It occurs in approximately the same stratigraphic horizon as the above rock but was collected near the contact of the Brewery Creek granite. The grain size of quartz is larger (.08 m.m.). Micaceous minerals are more abundant and some brown biotite has developed. Graphite, although less abundant, occurs as larger segregations up to 1 m.m. across. Felspar is not present.

These differences suggest that the rock has been modified by contact effects from the granite.

Of the paler varieties rocks Nos. 69 and 73 are typical. The latter is pale buff in colour with dark elongated spots which are due to the segregation of tiny flakes of graphite. This was confirmed by chemical tests.

Rock No. 88 is a flecked and banded type collected from a bed which averages 2ft. in width and can be traced in the field for over 1 mile. The banding is due to laminae of different composition while the flecks are due to segregations of green biotite flakes. These segregations are elongated parallel to the bedding structures.

The other fine grained metasediments of this area differ from these chert-like rocks by the increased amount of argillaceous impurity originally present in the sediments. This is now represented by sericitic micas and the relative amounts of sericite and quartz varies up to the stage where sericite becomes the main constituent of the rock.

Rock No. 4 is a flecked, fine grained quartz sericite schist. It consists of dark grey flecks or spots about 2 m.m. in length in a pale grey base. These flecks are oriented parallel to the schistosity which is at right angles to the bedding. Under the microscope the rock is seen to be exceedingly fine grained with a pronounced schistose structure. Quartz and sericite are the main constituents but brown-green biotite and greenish chlorite material are also present. These coloured minerals are more abundant in the spots and here show less preferred orientation than is present in the sericite base.

Zircon, tourmaline, graphite and magnetite occur as accessories.

Rocks similar in mineral composition to the above but lacking the development of spots are not uncommon.

Tourmaline has a wide distribution throughout all the metasediments of this region. Usually it occurs as an accessory but at times becomes an important constituent.

Rock No. 171 is a tourmaline-quartz-sericite schist. It is a fine grained silver-grey rock which is finely laminated and shows a distinct preferred orientation. The only mineral recognisable in the hand specimen is sericite but under the microscope the rock is seen to consist dominantly of tourmaline, quartz and sericite with subordinate felspar and accessory magnetite.

The tourmaline although too small to be recognised in the hand specimen is the outstanding feature of the thin section. It occurs as small idioblastic crystals .04 m.m. across, which are more or less oriented parallel to the schistosity. It is the normal brown variety being pleochroic from almost colourless to dark brown.

Two rock types having limited stratigraphic distribution, but being rather distinctive in appearance are represented by rock Nos. 22 and 23.

Rock No. 22 is a pale grey spotted metasediment consisting of large dark ellipsoidal spots about 3 m.m. in diameter set in a fine grained grey matrix. The spots which consist of aggregates of dark mica are surrounded by a white rim, usually about 1 m.m. wide, thus increasing the contrast between the dark spots and the paler base.

Under the microscope the rock is seen to consist of a granoblastic aggregate of quartz and felspar, together with green biotite and some muscovite. The felspar is easily distinguished from the quartz by its lower refractive index. Pericline and albite twinning is common but no microcline twinning could be found although potash felspar may be present. Average grain size is .08 m.m. The spots consist of segregations of the darker porphyoblastic micaceous minerals green biotite and chlorite. These larger crystals of biotite and chlorite poeciloblastically include both quartz and felspar. The whitish coloured spots so prominent in hand specimen are seen to consist of granoblastic aggregates of felspar with some quartz and muscovite.

Tourmaline occurs rather abundantly scattered throughout the whole rock as small rod shaped idioblastic crystals.

One section of this rock contains a rounded mass (about 4.5 m.m. in diameter) of tiny sericite flakes. This may be a completely sericitized metacryst.

Rock No. 23 is a pale grey rock consisting of quartz, biotite and muscovite. Pale spots averaging about ½" across are abundant. They are rounded but some are less elongated parallel to the poorly developed schistosity. The spots consist of a diablastic aggregate of very fine grained sericite and quartz, together with abundant large flakes of poeciloblastic muscovite and some biotite, tourmaline, apatite and plagioclase.

The edges of the spots are not clearly defined or regular in shape and it is impossible to say whether the sericite represents altered metacrysts.

From the unconformity, at a point about 1 mile E.S.E. of the Brewery stockyards, thence continuing to the south beyond the lower boundary of the area, there occurs a highly distinctive formation of dark, bluish grey phyllites and fine grained sandy schists which contain abundant but completely altered metacrysts of chiastolite.

These chiastolite rocks which occur as two main beds have a total thichness in places of over 1000 ft.

Rock No. 14 is typical of the darker variety. It consists of large metacrysts set in a dark phyllitic base. The metacrysts are square shaped in cross section and often display the zoning so typical of chiastolite. They are normally ½ inch across but some, especially those in the more sandy beds are up to one inch across and 5" to 6" in length.

Under the microscope the chiastolites are seen to be entirely replaced by an aggregate of fine sericite and the zoning is due to graphitic inclusions. The dark colour of the matrix is the result of abundant finely disseminated graphite. Some large flakes of muscovite occur but these like the fine grained quartz of the ground mass have abundant fine graphitic inclusions.

This rock is very similar to the chiastolite phyllite described by Browne (1922) from Mt. Franks, some 15 miles further south. In the case of the rock from Mt. Franks, however, some andalusite was recognised in the thin section.

What appears to be the same bed stratigraphically occurs at the contact with the Brewery Pluton on its southern and western sides. Here the rock (No.90) is dark grey in colour and the 'chiastolites' are only about ½ to 1 m.m. across and 1 c.m. in length. Ill defined spots several mm across consisting of aggregates of biotite and muscovite

'Chiastolite' phyllite X8

Enlargement of cross section in top Left corner of above showing replacement of Chiastolite by quartz and mica — Crossed Nicols

X 55.

are also present. Microscopically the rock consists of square shaped pseudomorphs after chiastolite, irregular segregations of biotite and large poeciloblastic muscovite crystals in a fine grained matrix of quartz, sericite, biotite and abundant graphite. Iron ore (haematite) and tourmaline are also present. The chiastolite pseudomorphs appear as square shaped aggregates either of quartz poeciloblastically including fine sericite or dominantly small muscovite flakes. Usually the boundaries of the pseudomorphs are surprisingly sharp, particularly when quartz is the secondary mineral. At times the cross sections are seen to be divided into 4 segments by the diagonals of the square and each of these segments seem to be separately replaced, giving the appearance of a twinned crystal. Quartz, apart from the large crystals replacing the chiastolites occurs abundantly in the matrix as tiny xenoblastic crystals averaging .02 m.m. in size. This recrystallized quartz is crowded with graphitic inclusions. Muscovite is also present as fine grained aggregates and as larger poeciloblastic flakes averaging .25 m.m. in length. Biotite is not as abundant as muscovite. It occurs mainly in segregations about 2 mm across showing decussate structure. It is also present together with muscovite and quartz in the chiastolite pseudomorphs, but when it is present the pseudomorphs are irregular and not clearly defined. The biotite is a greenish brown variety, x = pale brown, y=z = dark brownish green. Haematite and graphite are abundant as small black opaque grains while tourmaline is accessory.

Jagged outcrops of Willyama Schist

The Dynamically Metamorphosed Willyama Rocks

To the east of the 'chiastolite' phyllite formation the dynamic factor of metamorphism increases.

The coarse grained quartz-mica schists and micaceous quartzite occurring in this area contrast sharply with the finer grained schists to the west, both petrographically and in their manner of outcrop. They often appear as jagged razor-back crags which have a characteristic manner of weathering that produces large open holes commonly a foot or more across within the rock (photo).

Rock No. 75 is typical of these schists. It is silvery-grey in colour with pronounced schistosity due to orientation of micas. Microscopically the rock is seen to consist essentially of quartz, muscovite and chlorite with crystalloblastic texture. Quartz occurs as irregular grains always less than 1 mm across while muscovite is present as ragged flakes up to 2 m.m. The latter is often seen to be developing from fine grained sericite.. Chlorite occurs both as small, clear, pale green flakes, which are arranged in clusters, and as larger flakes up to 2 m.m. or more across which are cloudy with abundant fine inclusions of iron ore. Tourmaline is a common accessory as idiomorphic grains. Zircon is also present. This rock is a member of the Muscovite-chlorite subfacies of metamorphism while a similar rock (No. 76) which was collected near one of the numerous pegmatite dykes in the area is seen under the microscope to

Typical weathering of Schist

Relic bedding structures in Willyama Schist contain both biotite and garnet in addition. Quartz is smaller in grain size and less abundant, while the biotite present has formed at the expense of some of the chlorite. Garnet which is not particularly abundant may have been introduced from the nearby pegmatite which also carried garnet.

Although the majority of the schists in this area are of medium grain size, Rock 31 is an example of a fine grained type.

This is a pale silvery-grey schist with a phyllitic sheen on the fracture surface. Cataclastic structure is evidenced by the small lenticular shaped aggregates which appear sheared out in the direction of the schistosity. In thin section the cataclastic structure is again evident and in places the structure is almost mylonitic, there being streaks and bands of sericitic material alternating with bands consisting dominantly of quartz. The bands of sericite consist of small crystals oriented parallel to the schistosity so that all appear optically continuous. This is a feature of many of the schists in this area. Although not particularly pronounced in the hand specimen, quartz is the most abundant mineral, it has an average grain size of .02 m.m. and in places shows evidence of recrystallization. Muscovite, chlorite and green biotite are also present while tourmaline and apatite are accessories.

Metamorphosed impure quartzites, normally a foot or so wide, commonly occur as hard resistant bands which represent original bedding. Specimen 78 is an example. It is a fine grained, dark greenish-grey rock, with a sheen on the fracture surface. Of the two visible lineations the weaker appears to be a poorly developed false cleavage which gives the surface a wavy appearance. Quartz, muscovite and chlorite are discernable in the hand specimen.

Under the microscope it is seen that quartz is by far the most abundant constituent. The largest grains are about 1 m.m. across but the average grain size is much less. Undulose extinction is common and the edges of the grains show signs of granulation although this has now been recrystallised.

Chlorite as small green flakes, giving anomalous blue interference colours, occurs in association with fine grained quartz and muscovite as shear lines, which cross the slide and contribute to the foliated nature of the rock. Somewhat ragged flakes of muscovite up to 4 m.m. in length are aligned along the schistosity. Tiny grains of iron ore are scattered throughout the slide and in places show alteration to limonite. Zircon in small rounded grains occurs as an accessory.

Rock No. 97 is another fine grained quartzose rock but this contains both felspar and biotite. Under the microscope quartz and felspar are seen to form a mosaic with interlocking sutured grains. Quartz with undulose extinction is twice as abundant as felspar. The felspar appears to be all plagioclase but the exact composition can not be determined due to the high degree of alteration. Biotite, chlorite, muscovite and magnetite are present and zircon is a common accessory occurring as small rounded and ellipsoidal grains.

In the vicinity of the intrusive granites and pegmatites the schist is often seen to be knotted and in at least one locality appears to have been felspathised. Rock 20 is a greenish grey, knotted, quartz-mica schist. Microscopically the texture is seen to be porphyroblastic with muscovite in flakes up to 4 m.m. across developing from fine grained sericite and poecilitically enclosing small grains of quartz. Green chlorite with low double refraction occurs in irregular masses with abundant inclusions of small grains and rods of magnetite and small laths of muscovite. The chlorite appears to be formed as an alteration product of biotite. In places chlorite and muscovite are interleaved. Quartz is recrystallised with sutured interlocking borders. Apatite is a common accessory, occurring as idiomorphic grains up to .25 m.m. in length. Zircon is also present as small rounded grains.

Rock No. 83 is a dark grey schistose rock with muscovite, biotite, quartz and tourmaline visible in the hand specimen. Microscopically the texture is porphyroblastic with large ragged flakes of muscovite, often set at an angle to the schistosity, developing at the expense of the fine grained sericitic mica which crosses the slide in wavy bands. Biotite is fairly abundant as irregular masses and clots and is strongly pleochroic with x = pale brown, y = z = dark brownish black. Both magnetite and chlorite are associated with the biotite. The quartz which has all recrystallised occurs as irregular grains in the sericitic base. Transverse tension cracks at right angles to the schistosity are common.

Rock 82 is similar in appearance to rock 83, however, in this rock the development of porphyroblasts of muscovite has not advanced to the same stage, although much of the fine sericitic mica appears optically continuous. Biotite and chlorite are present in aggregates of small laths showing decussate structure. Apatite occurs as an accessory.

To the east of the large pegmatite mass in the south-eastern corner of the area the rocks appear to belong to a slightly higher grade of metamorphism. Examples of these are:-

Rock No. 101. A dark grey quartzose rock with a definite foliation which is produced by narrowly spaced shear planes rich in sericite. Tiny shiny black flakes of biotite are abundant and larger flakes of muscovite up to 2 m.m. across glisten on the fracture surface. Microscopically the rock is seen to consist essentially of quartz and micas the latter showing a preferred orientation. Quartz is most abundant constituent and this has recrystallised, displaying sutured interlocking margins and showing strong undulose extinction. Inclusions are rather abundant. Muscovite occurs in flakes up to 2 m.m. in length and is seen to be developing from the fine grained sericitic mica which crosses the slide in subparallel schlieren. Biotite is abundant as smaller flakes up to 1 m.m. in length which are distributed throughout the slide showing a preferred orientation. The biotite is the greenish brown variety and is strongly pleochroic. Alteration to green chlorite which shows anomalous brown interference colours and is biaxial negative with low 2V. Sometimes biotite and chlorite are intergrown. Magnetite occurs in small grains associated with both chlorite and biotite. A few grains of plagioclase occur, showing both albite and pericline twinning. Extinction angle is + 17° giving composition of Ab_{65} (acid andesine). The plagioclase is optically negative with large 2V and is considerably altered to sericitic mica. Zircon is a common accessory and occurs as small rounded and ellipsoidal inclusions in quartz showing high relief and giving bright 3rd order interference colours. Rock No. 100 is a dark grey, compact silliceous rock consisting of fine grained greyish quartz which is studded with small shining black flakes of biotite. These mica flakes show a preferred orientation and the rock tends to break more readily in this direction. Microscopically the rock is seen to be essentially a granoblastic mosaic of quartz through which is studded some parallel laths of biotite. The average grain size of the quartz is about 0.2 m.m. with largest grains 0.5 m.m. Extinction is undulose and inclusions are common. The biotite is strongly pleochroic from pale straw to dark green-brown and laths are up to 0.5 m.m. in length. Muscovite is much less abundant and occurs as somewhat larger ragged flakes, which are derived from the fine grained interstitial sericite. A few polygonal and rounded crystals of pale pink isotropic garnet are present but are not abundant. Occasional grains of felspar with composition acid Andesine occur in the quartz mosaic. Zircon occurs as an accessory.

The mineral assemblage in this rock and rock No. 101 which was obtained from the same locality indicates a somewhat higher grade of metamorphism than exists in the rocks further northwards in the schist area.

The Pegmatites

Other authors refer to the great development of these rocks in the Willyama Complex of the Barrier Ranges.

Mawson (1912) says "In no other part of the world can pegmatite formations occur on a more extensive scale".

To the south of Pollard's Well occurs a mass of pegmatite more than half a mile wide. This mass is intimately mixed with country rock, particularly at the margins and is traversed by cross cutting dykes of the later granite from which it is easily distinguished in the field. Not only is there a textural difference, even when the pegmatite itself is fine grained, but the granite invariably weathers into distinctive rounded tors.

From these cross cutting relationships a pre-granite age for the pegmatite is inferred, and although some pegmatite may have been associated with the later granite there is no evidence to support this.

Apart from this large mass, several smaller masses occur while dykes are very abundant. In the central area, where the dynamic factor has been greater, the dykes are usually parallel to the schistosity while further to the west where metamorphism has been of a lower grade the dykes tend to follow the bedding.

Although dykes of pegmatite quite commonly extend to the unconformity, they are never seen to intrude the adjacent Torrowangee rocks suggesting that in this area, at least, all pegmatites are pre-Torrowangee in age.

As mentioned previously, the pegmatites at times show evidence of shearing at their peripheries, and in at least one case a pegmatite had been completely sheared out (Rock No. 67).

The pegmatite is usually very coarse grained and barren, consisting dominantly of felspar and quartz, which are sometimes beautifully intergrown giving graphic granite.

The felspars are sometimes up to 3 inches across but normally they are about half this size.

The average composition of the pegmatites is about 60% felspar (both albite and microcline), 38% quartz and 2% accessories. (Rock No. 112). Accessory minerals include muscovite, garnet and tourmaline. Magnetite occurs rarely. Garnet which is widely distributed occasionally becomes an important constituent, making up about 10% of the rock in specimen No. 77. Usually it occurs as euhedral Rhombic Dodecahedrons, occasionally as Icositetrahedrons. Commonly, reddish brown in colour and up to half an inch across, the garnet gives a positive chemical test for manganese..

Muscovite is not particularly abundant in the pegmatites, but occasionally muscovite rich segregations occur. In one such segregation are relic crystals of some previous mineral, now pseudomorphed in fine grained sericite. These crystals are up to one and a half inches long and have diamond shaped cross section (specimen No.79). Their general appearance and mode of occurrence is suggestive of pinitised topaz.

In the field all stages from feldspar rich pegmatites to quartz reefs can be seen. Tourmaline, although occurring sporadically in most of the pegmatite, seems to be concentrated in some of these quartz reefs. Sometimes crystals in the latter have large dimensions; one crystal collected, although of imperfect crystal shape, was three inches across and seven inches long.

Introduction of boron into the country rock adjacent to pegmatites has sometimes produced tourmaline schists (Rock No. 80).

The fact that the pegmatite does not appear to be associated with any granitic intrusion, its great size abundance and barren nature all suggest a replacement origin by the process of pegmatisation.

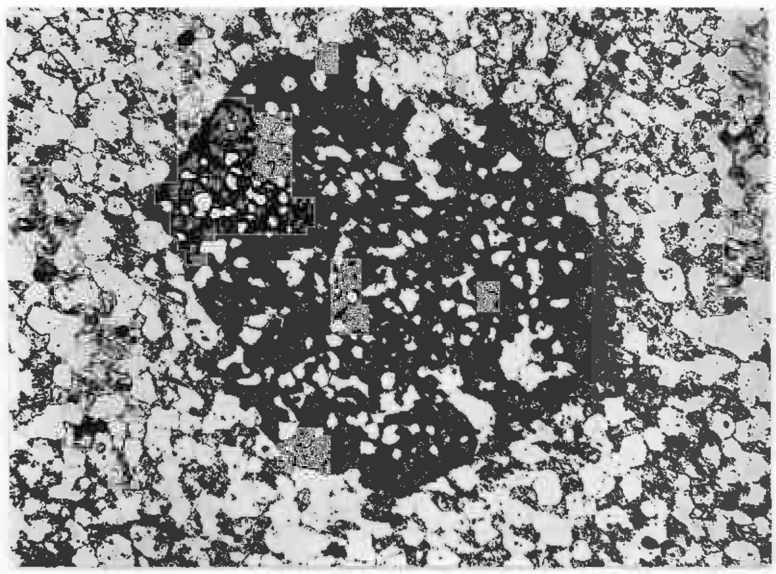
Such processes are akin to granitisation and may necessitate the removal of certain basic material from the original rock (Reynolds 1947, Bowes 1952). It is interesting to note that within the large pegmatite mass certain rocks occur which are decidely more basic than any other rocks within the area. It appears obvious that these rocks are not connected with any basic intrustions, but rather, field evidence suggests that these rocks represent an original sedimentary bed. Three variations in rock type occur (Rock Nos. 103, 102A, 102B) and these may represent progressive stages in basification of the rock.

Rock 103 is a biotite garnet granulite. It is pale grey banded metamorphic rock similar in appearance to the "flecked" metasiltstones which outcrop a mile or so to the west. Unlike the latter, however, this rock is studded with many porphyroblastic garnets which display the typical rhombic dodecahedral shape. The banding is obviously sedimentary bedding.

Under the microscope the rock is seen to consist of a granoblastic aggregate of quartz and plagioclase through which is scattered subordinate biotite and chlorite flakes and an occasional porphyroblastic garnet crystal. There is no lineation of the tabular minerals. The average grain size is .2 mm.

Quartz makes up about 50% of the rock.

Plagioclase (45%) appears to be the only feldspar present. It occurs as colourless xenoblastic crystals which are usually cloudy due to incipient alteration. Multiple twinning is poorly developed on some grains and absent on others. This, coupled with the marked undulose extinction of both plagioclase and quartz, renders the exact determin-



Poecilo blastic garnet in Biotite - garnet Granulite Slide 103 X20 ation of the plagioclase impossible.

The following properties however, suggest a composition near basic andesine.

(a) It is biaxial + ve with 2V $\simeq$ 80 .

(b) The refractive index is just greater than quartz.

Garnets occur as porphyroblastic pink coloured crystals averaging about 1 mm. in diameter. Most of the garnet crystals enclose numerous small quartz crystals giving them a pronounced poeciloblastic or "sieve"-structure (see photo.) The biotite is a brown variety, X = pale yellow brown, Y = Z = Dark brown. Apatite, magnetite and zircon are accessories.

Rock 102 (a) is a Quartz-Clinozoisite-Hornblende Rock.

This is a dark coloured medium grained rock with amphibole and quartz easily recognisable in hand specimen. Microscopic features:- The texture is dominantly granoblastic although in patches where there is a large development of hornblende, the rock has a gneissic appearance. Apart from these more or less elongated segregations of hornblende, the rock has no directive features. It consists of quartz, hornblende and clinozoisite with accessory apatite, magnetite and sphene.

Quartz is by far the most abundant constituent while feldspar is absent. The extinction in the quartz is undulose. Hornblende is very abundant. It occurs as green, pleochroic, subidioblastic crystals scattered throughout the rock, and as aggregates with clinozoisite.

X = pale greenish brown, Y = dark greenish brown, Z = dark bluish green. $Z \wedge C = 14^{\circ}$.

Clinozoisite is present as aggregates of small xenoblastic crystals with high relief and moderate birefringence. Some sections give anomolous blue interference colours. Apatite, as moderately large idiomorphic crystals, is an abundant accessory. Magnetite and sphene are also present. The latter occurs as aggregates of small rounded grains, almost colourless, but with a high relief and birefringence. It is biaxial +ve, but 2V appears to be very low. The rock would be classified in the Chloritoid Almandine subfacies of metamorphism.

Rock 102B - Hornblende plagioclase quartz gneiss.

This rock is similar to rock 102A in general appearance, except that it has a more pronounced gneissic structure, especially noticeable on the weathered surface. The ataxitic texture of rock 102A is not present.

In section the rock is seen to consist of a granoblastic aggregate of quartz and plagioclase with segregations of dark green hornblende. The latter possesses some directional features and gives the rock a rude gneissic structure.

The rock differs from No. 102A in the absence of clinozoisiste and the abundant development of plagioclase. The plagioclase constitutes about 35% of the rock. It is colourless, but slightly cloudy due to alteration. Twinning on the Albite law is not well developed but pericline twinning is more common. The plagioclase is biaxial +ve with a large axial angle. The maximum extinction angle measured in the zone ⊥ to the 010 is +28 . These properties indicate a composition of Ab50. (Acid Labradorite). The hornblende is perhaps a little darker green than in rock 102A and many of the crystals are idio-morhpic.

X = pale green, Z = dark bluish green, Y = dark greenish brown. Apatite, sphene and magnetite are again abundant accessories.

The Granite

Post dating the schists and pegmatites of the Willyama Complex is an intrusive leucocratic granite. This is a phase of the Newer or Protogine Granite of Mawson (1912) and the Mundi Mundi Granites of Andrews and Browne (1922).

Apart from the main mass of granite which has been termed the Brewery Creek Pluton, other smaller masses out-crop along the upper reaches of the Wookookaroo Creek. These masses are more or less continuous and have been considered by Zinc Corp. Geologists to be an extension of the dyke which extends from Yanco Glen to north of the Paps along the general trend of the unconformity.

The northern extremity of this 'dyke' has been mapped and studied in great detail and no evidence can be found in this locality at least to suggest a dyke-like origin.

Rather, it seems to be part of the irregular roof of a larger granite mass below. This is supported by the following facts,

(1) The intrusive contact between the granite and the steep dipping schist is in places seen to be almost a horizontal plane.

(2) The common occurrence of the granite in the bed of the creek appears to be due to the deeper erosion which has occurred here, and the trace of the granite contact often follows the contours around the valleys running into the main creek, thereby suggesting that the granite-schist contact is flat lying.

(3) Exfoliation sheets, which are considered by some to be parallel to the margins of the granite mass, are in this case horizontal.

Numerous smaller masses and dykes of the same granite are widely distributed throughout the Eastern part of the area. These dykes, which are usually very thin, commonly follow the schistosity. The abundance of these smaller occurrences is also suggestive of the nearness of a larger granite mass below.

For many years the granite was considered to be Middle Precambrian; however, in 1951 a post Torrowangee age was postulated, mainly on structural evidence (Zinc Corp.). From a detailed study of the Brewery Creek pluton and the adjacent Torrowangee sediments a pre-Torrowangee age is now certain.

Intrusive contact between Granite
and Willyama metasediments.

Flat lying contact between Granite and Schist
in bed of Wookookaroo Creek.

Exposure of Granite on Southern margin
of Brewery Creek Ploton.

Mural jointing in Granite
Brewery Creek Ploton.

On the eastern side of this pluton, contact metamorphic effects on the Torrowangee sediments are entirely lacking while Willyama rocks occurring as roof pendants, and along the contact of the southern margin of the granite have been altered. This coupled with the abundance of granite erratics in the basal beds of the tillite; which overlies the granite, would seem to indicate that the granite was pre-tillite. This is confirmed by outcrops in the Brewery Creek Gorge in the vicinity of the Paragon mine, which is situated about a half mile beyond the North Western limit of the area mapped.

Here the basal beds of the Torrowangee series can be seen resting unconformably upon the eroded basement of granite. Near the unconformity, the bedded tillite consists almost entirely of granite boulders in an arkosic matrix, but this grades into normal tillite higher up in the series. At the contact between the Willyama sediments and the granite in this locality, the granite has been intruded along bedding planes, giving a distinctive type of veined rock. Boulders identical to this composite rock can be found in the adjacent tillite.

Although evidence points to a pre-Torrowangee age for the granite certain exposures along the unconformity both north and south of Brewery Well and particularly in the vicinity of the stockyards seem to contradict this. These are discontinuous outcrops of granite which in general keep rigidly to the unconformity itself although

Granite intruded along bedding in Willyama Sediments
Brewery Creek.

Boulder of above in overlying tillite.

in two isolated cases a small amount of tillite is seen between the granite and the unconformity.

First impressions suggest that these are dyke like bodies which have been intruded at a date later than the tillite deposition. However, all the dykes and smaller masses of granite occurring in the area and the marginal facies of the Brewery Creek mass are relatively fine in grain size (Rock No. 94) yet these occurrences now being considered are coarse grained (Rock No. 114) and very similar to the coarser granite occurring in the central portion of the Brewery Creek Pluton (Rock No. 95).

After a thorough investigation of these outcrops we are of the opinion that they represent large boulders and blocks of granite which rested upon the original erosion surface at the time deposition commenced.

The typical granites are leucocratic rocks in which the percentage of dark mineral rarely exceeds 4%. They are characterised by a high percentage of muscovite and by a slight excess of plagioclase over microcline. The former always has a composition approaching pure albite. According to the Shand classification, these are per-aluminous Sodi-Potassic granites while they compare closely to the Alaskites of Johannsen (1932) (see Table 1 Column V1)

Towards the centre of the Brewery Creek Pluton the granite is medium to coarse in grain size, but elsewhere it is comparatively fine-grained. The granite is stressed to the extent of producing undulose extinction in the quartz, with some granulation at the edges of grains but nowhere is any gneissic structure developed.

The coarse grained granite from the Brewery Creek mass is pale pinkish grey in color (Rock No. 95). Under the microscope the rock is holo-crystalline with hypidiomorphic granular texture. Plagioclase is the most abundant constituent as colorless subhedral crystals, usually cloudy due to alteration. It is commonly twinned on Albite law with symmetrical extinction of twin lamellae ~~in zone~~ ⊥ to 'a' of $-13\frac{1}{2}^{\circ}$ giving composition Ab_{95} (Albite). An interesting feature of the plagioclase is the growth of numerous small laths of colorless mica within the crystals. This is a feature of the plagioclase of these granites in general and a similar occurrence of white mica replacing plagicclase has been reported from America by Chayes whoconsiders it to be a late magmatic effect.

Microcline as colorless subhedral crystals is less cloudy than plagioclase and inclusions of colorless mica are much less abundant. Typical microcline cross-hatching is well developed but in some cases the twinning is more prominent in one direction.

Quartz occurs as anhedral crystals up to 1 cm. across, often containing strings of fine inclusions and numerous hair-like rods. The extinction is commonly undulose and some grains are slightly biaxial due to strain.

Muscovite makes up about 10% of rock while biotite is much less abundant. The latter occurs as clusters of smaller individuals often showing alteration to chlorite and magnetite.

The biotite is the normal brown variety, X = pale brown, Y=Z= dark brown.

Tourmaline, which is often recognisable in the hand specimen, occurs as subhedral grains pleochroic from pale pinkish-brown to dark greenish-grey.

Apatite and zircon occur as accessories, the latter often as tiny inclusions in biotite.

The Chemical analysis of this rock is given in Table 1, column 11 and the following is the composition of the Norm.

Norm of Brewery Creek Granite.

Quartz	32.88
Orthoclase	26.22
Albite	33.38
Anorthite	1.67
Corundum	2.86
Hypersthene	.73
Magnetite	.69
Ilmenite	.30
Apatite	.23
Pyrite	.09
Zircon	.04
Water (-)	.15
Water (+)	.70

TABLE 1.

	1	11	111	1V	V	V1
SiO_2	73.08	74.07	74.50	72.60	70.40	75.05
Al_2O_3	14.78	14.77	13.72	15.99	18.84	13.48
Fe_2O_3	0.67	0.51	0.60	0.34	1.34	0.84
FeO	0.79	0.46	0.90	0.78	0.67	0.63
MgO	0.28	0.16	0.44	0.20	0.14	0.21
CaO	0.55	0.51	0.52	0.38	0.38	0.24
Na_2O	4.35	3.89	3.47	4.30	5.21	4.20
K_2O	4.17	4.43	5.13	4.36	2.82	5.03
H_2O-	0.24	0.15	0.18	0.05	0.03	0.34
H_2O+	0.77	0.70	0.26	1.15	0.57	
TiO_2	0.24	0.19	0.17	0.13	0.20	0.03
P_2O_3	0.11	0.10	0.27	0.14	0.16	0.08
MnO	0.01	0.01	0.03	0.03	0.01	0.04
BaO	0.02	--	0.05	--	--	--
ZrO_2	0.01	0.03	--	--	--	--
S	--	0.03	--	--	0.03	--
Others	--	--	.11	--	--	.03
	100.07	100.01	100.35	100.45	100.80	100.20

(1) "Paps granite", S. of Poolamacca, Barrier Ranges, N.S.W.

Analyst A.J.R. White

(11) Brewery Creek Granite, Poolamacca, Barrier Ranges, N.S.W.

Analyst R.B. Leslie.

(111) Granite, N.W. of Paps, Barrier Ranges, N.S.W.

Analyst J.C.H. Mingaye.

(lV) Soda-Potash Granite, E. end Binberrie Hill, S.A.
Analyst, W.S. Chapman

(V) Soda-Potash Granite 1/3 mile N. of Apatite Mine, Boolcoomatta Hills, Analyst W.S. Chapman

(Vl) Average of 3 typical alaskites - Johannsen, 1932.

A specimen typical of the fine-grained granite was collected from an outcrop in the Wookookaroo Creek (Rock No. 93) and this was chemically analysed for comparison with the coarse grained Brewery Creek granite (Table 1, column 1).

It is a pale grey, fine even grained granite which under the microscope is seen to be holocrystalline with allotriomorphic to hypidiomorphic granular texture.

Microcline is slightly more abundant than albite and many crystals show typical crosshatching while others show ragged twinning which is more pronounced in one direction.

Plagioclase shows both Carlsbad and Albite twinning and has composition of Ab_{95}. The development of colorless crystals of mica within the plagioclase is again common as with the coarse grained granite described above.

Quartz occurs as anhedral grains averaging 2 mm. across. It shows undulose extinction and is again slightly biaxial.

Muscovite is an important constituent. Biotite shows little alteration but dark pleochroic haloes are common.

X = pale brown, Y = Z = very dark brown, black.

Apatite is a common accessory while magnetite is rare.

Composition of the Mode (Weight %).

Quartz	29.9
Microcline	28.4
Albite	27.6
Muscovite	10.1
Biotite	8.6
Apatite	0.3
Magnetite	0.1

Composition of the Norm (93).

Quartz	33.3
Orthoclase	24.56
Albite	36.82
Anorthite	2.05
Corundum	2.45
Hypersthene	1.23
Magnetite	0.92
Ilmenite	0.30
Apatite	0.24
Zircon	0.02
Water	1.11

Although the granite is normally fairly uniform in composition, certain local variations occur. This is usually reflected in the color of the rock which varies from pale grey to pinkish grey and dark grey. These variations are due to the varying pdoportions of microcline and albite, the presence or absence of tourmaline, and the relative amounts of biotite and muscovite.

One such variation (Rock No. 85) is a distinctive rock which is studded with small rounded flakes of black biotite. Quartz, microcline and Albite are present in approximately equal amounts. Biotite, which is usually a minor constituent, makes up about 10% of this rock, while muscovite is present to the extent of only 1%.

Another rock (No. 86) collected adjacent to this biotite granite, is dark grey in color and contains almost twice as much albite as microcline. Muscovite is dominant over biotite which makes up about 4% of the rock.

The occurrence of tourmaline appears restricted to the larger Brewery Creek mass itself. A specimen (Rock No. 61) collected at the northern extremity of this pluton is a medium grained tourmaline bearing variety which is pale pinkish grey in color.

Microscopic features; It is medium grained, holocrystalline and hypidiomorphic granular with an average grain size of about 3 m.m.

Quartz occurring as colorless anhedral grains from 2 to 4 m.m. across makes up 34% of the rock. Irregular fractures and strings of fine inclusions traverse the grains.

Microcline (29%) is colorless but often cloudy due to incipient alteration. It has an average grain size of 3-4 m.m.

Plagioclase (23%) is colorless, but very cloudy, and occurs as lath-shaped crystals 3-5 m.m. in length.

Twinning on both albite and pericline laws is common. Symmetrical extinction ⊥ to 'a' is $-16\frac{1}{2}^{\circ}$, giving composition of pure Albite (Ab_{100}).

Muscovite (10%) occurs both as large individuals and as small flakes replacing Albite.

Biotite (2%) occurs as clusters of small brown flakes often altered to chlorite and iron ore. It is strongly pleochroic with X = light straw, Y = Z = dark brown to black.

Tourmaline (1%). Irregular grains up to 1 m.m. in length are strongly pleochroic from pale yellow to dark greenish brown.

Apatite is an accessory.

Within the country rock near the southern margin of the Brewery Pluton are several aplitic dykes normally a foot or so wide. These dykes are apparently offshoots from the main granite mass. They are pale buff to whitish in color and have a fine, even grained saccharoidal texture. Colorless to greyish quartz, white feldspar and silvery muscovite are visible in the hand specimen(Rock No. 91).

Under the microscope it is seen as a fine-grained equigranular granitic rock with an allotriomorphic texture. Average grain size is slightly less than 1 m.m. Quartz and plagioclase are present in approximately equal amounts, while microcline is much less abundant. The quartz which contains dusty inclusions shows irregular fractures and undulose extinction with some granulations at the edges of the grains. The granulated quartz has recrystallised and appears to contain a greater amount of fine inclusions. Plagioclase is cloudy due to incipient alteration. It has a composition of pure albite (Ab_{100}).

Microcline has been almost completely sericitised. Some large flakes of muscovite are present while biotite is rare. The latter shows alteration to chlorite and magnetite.

Apatite and zircon are accessories.

Associated with the granite in the extreme eastern margin of the area are two greisen dykes about 2 feet wide. These consist essentially of quartz and muscovite, the latter occurring as small books about half a centimetre across studded throughout the rock giving a typical greisen texture (Rock No. 99).

<u>Contact Metamorphic Effects of Granite.</u>

Apart from a zone of felspathisation a few inches wide, along the immediate contact, there is little evidence of thermal metamorphism. This together with the composition of the granite is suggestive of low temperature 'wet' intrusion.

The abundance of tourmaline and muscovite both in the granite and the surrounding country rock is evidence of the latter.

The maximum extent of thermal metamorphism is seen in the roof pendants and xenolithic blocks of fine grained mica hornfels which are abundant at the northern end of the Brewery Creek Pluton. All the xenoliths have a definite lithologic resemblance to the fine-grained Willyama rocks immediately to the south of the pluton.

A common type of xenolith (Rock No. 58) is a biotite muscovite hornfels showing bedding structures.

This is a brownish grey coloured compact rock, very fine in grain size with muscovite, quartz and some biotite recognisable in hand specimen. The micas have no preferred orientation but are scattered throughout the rock in a random manner.

Microscopic features:- The texture is somewhat porphyroblastic as the rock consists of porphyroblasts of muscovite and biotite up to 3 m.m. in length, together with a finer grained aggregate (average size .06 m.m.) of quartz, sericite and accessory tourmaline, magnetite and possibly graphite. The rock has no directional features except the bedding structures which are seen to consist of bands rich in biotite and muscovite flakes. These bands were probably more argillaceous laminae in the original sediment.

Quartz is the most abundant mineral making up about 40% of the rock.

Colourless mica (30%) occurs as both poeciloblastic crystals and as fine sericitic material.

Biotite (25%) is the dark brown variety X = straw coloured, Y = Z = dark brown.

Feldspar could not be detected but some of the fine aggregates of sericite may represent altered patches of feldspar.

As has been mentioned previously, the schists surrounding the smaller masses of granite, which outcrops along the Wookookaroo Creek, are more knotted in appearance than normal and carry biotite, either replacing, or in addition to chlorite.

The intrusive contact here is usually particularly sharp, but occasionally the schists have been feldspathised near the contact.

The Torrowangee Series.

The existence of a thick sequence of glacial and fluvioglacial sediments on the northern and north eastern extension of the Barrier Ranges was first reported by Mawson (1912). These rocks which overly the Willyama Complex with violent unconformity have been termed the Torrowangee Series, and from their characteristic lithology they have been correlated with the Sturtian Series of the Adelaide System.

The Torrensian Series of the Adelaide region is here absent and coarse boulder beds or sometimes massive quartzite or silicified tillite mark the beginning of the later Precambrian sedimentation.

The silicified bed which forms the base of the Torrowangee Series in much of the Barrier Range region is underlain by a considerable thickness of glacigene sediments in the vicinity of Brewery Well.

This overlap is probably of the order of 2,000 feet, although the lens-like nature of the beds and complicated folding makes an accurate determination difficult.

In the area under investigation the 'basal quartzite' horizon is represented by a sandy tillite which often contains large numbers of a siliceous blue-grey quartzite erratic and interbedded grits. With decrease of overlap this horizon becomes silicified and in places a dense quartzite tillite (Rock No. 56) is produced.

The glacial origin of these lower boulder beds has been queried by some workers but there is strong evidence to support such an origin. Although intercalated stratified lenses of greywacke (grits) and slates occur the beds are in general completely unsorted. The size range is extreme, varying from the finest rock flour up to boulders 12 feet across. Angular, subangular and sometimes facetted fragments are present but the majority of the coarser detritus is comparatively well rounded. This is in conformity with the material forming the terminal moraines of some present day glaciers. which often shows a remarkable degree of rounding.

Pressure grooving in the form of sub-parallel markings is occasionally seen on the surface of boulders

Large boulder of Soda Granite weathering out of Tillite

Blue-grey quartzite boulder weathering out of Tillite but none which could be accepted as genuine glacial striae were found. However, Mawson (personal communication) reports glacial striae on a pebble found near Yanco Glen.

The lithological similarities with the undoubted tillites and fluvioglacials of the Sturtian Series of South Australia are further evidence supporting a glacial origin.

Many of the boulders are of local origin, particularly in the beds lying stratigraphically below the basal quartzite horizon. These include most of the rock types occurring in the nearby Willyama Complex, namely chiastolite phyllite, flecked and banded cherts, fine grained quartz-mica schists, pegmatites and most abundant of all fine, medium and coarse grained granites. A number of these granite boulders were sectioned and examined microscopically. They were seen to be identical to the locally occurring granite, thus giving further evidence in support of a Pre Torrowangee age, for its intrusion. True erratics, foreign to the area, are less abundant in the lower beds, but become more important higher up in the series. Of these a dense blue grey quartzite is the most conspicuous.

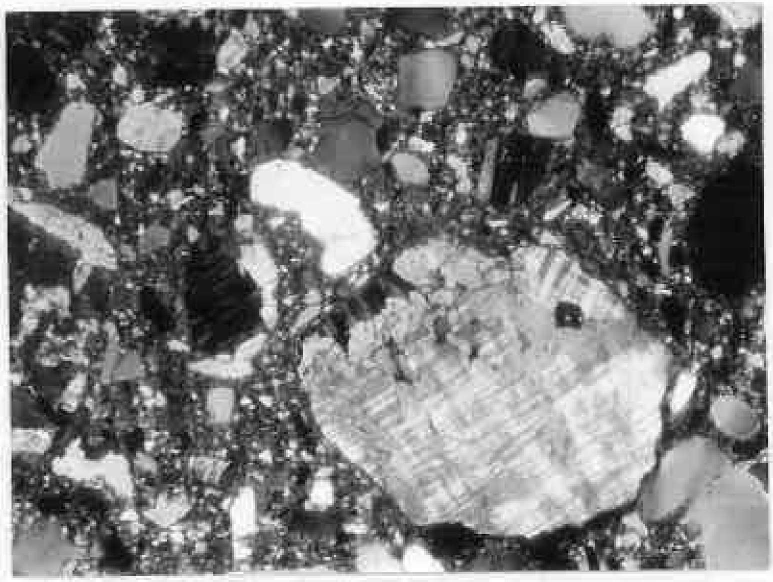
It seems certain that the lowest beds are the result of the action of local land ice, since this alone can explain the abundance of boulders of the immediately underlying rock. Higher up in the Series where the beds become more continuous, it is probable that deposition took place under water.

The base of the Torrowangee Series in the area studied, consists for the most part of coarse boulder beds locally sheared but not silicified as is general along the Yanco Glen - Paps line. Occasionally a band of arkosic grit, normally only a few feet thick, can be seen resting on the Willyama schist.

Perhaps the most interesting basal rock is that seen resting directly on the eroded surface of the Brewery Creek granite. This rock we have termed a "granite tillite" as it consists almost entirely of granite boulders in an arkosic matrix.

Microscopically the unweathered rock is pale grey in color and typically unsorted. Angular, sub-angular and rounded fragments showing great variation in size are set in a pale grey base of fine rock flour. Most of the larger fragments are of granite and many of the smaller individual and composite grains of quartz and feldspar have been derived from the grinding up of the underlying granite. Fragments of fine grained slaty and chert like rocks of the Willyama Complex are present but less abundant.

Due to the preponderance of granitic material the weathered surface of the rock, as seen outcropping in the field, shows a marked resemblance to the adjacent granite. In thin section (Rock No. 110) the unsorted nature of the rock is most apparent. Angular and sub-angular fragments vary in size down to the minute particles in the rock



'Granite - tillite' Slide 110
Crossed Nicols X 20.

'Granite - tillite' exposed in bed of Brewery Creek.

flour matrix.

Fragments of granite showing allotriomorphic to sub hypidiomorphic granular texture contain quartz, microcline, plagioclase, Tourmaline and muscovite. Quartz is the most abundant of the individual grains and this often shows the thin hair-like rods which are common in the quartz of the local granites.

Feldspar fragments consist of both microcline and albite. The former shows crosshatching between crossed nicols and is more abundant and somewhat larger in grain size than the plagioclase. The cleavages are particularly well shown in both feldspars.

Small angular grains of tourmaline showing strong pleochroism from pale to dark greenish brown are scattered throughout the slide. Detrital flakes of muscovite are rare.

A few fragments of fine grained meta-siltstone are present and these are identical with the fine grained Willyama rocks which occur nearby and have no doubt been derived from this source.

The fine grained base contains smaller particles of the material forming the larger fragments together with abundant sericite which has been derived from the decomposition of feldspar.

Above these basal beds normal glacigene sediments occur. These consist of interbedded and lenslike occurrences of coarse boulder beds, greywacke type grits, washed arkosic grits, slates and shales. These latter are invariably grey in color and vary from normal argillites to calcareous and arenaceous types. Many are banded and finely laminated while some true varves occur. Occasional sporadic boulders and pebbles are not uncommon in these fine grained sediments and are indicative of the presence of floating ice. One isolated bed of buff colored, impure limestone about one foot wide was traced in the field for 150 yards before lensing out.

The tillite is typical of the massive Sturt Tillite of South Australia, however, near the base the lens-like character is very pronounced. The thin bedded glacigene sediments often lens out into masses of structureless tillite which must have been heaps of glacial moraine on the depositional surface. The occurrence of this massive tillite in the noses of many of the minor fold structures seems more than coincidental and possibly these masses of coarse detritus have exerted some structural control.

The larger boulders in the tillite are usually quite well rounded and in general range up to about one foot in diameter. However occasionally, patches of tillite are encountered in which ellipsoidal boulders up to 4 feet long are quite common and exceptionally, blocks up to 12 feet in length are found.

Tillite occurring near the unconformity in the vicinity of Brewery Well (Rock No.3) differs from the granite-tillite which occurs further north in that the majority of the rock fragments have been derived from the Willyama sediments. In addition a rude slaty cleavage has been developed. Under the microscope many of the fragments are seen to be highly angular and the rock shows directional features not present in the granite tillite described above. Angular fragments and splinters are arranged with their longer axes more or less parallel and in some a cross fracture has developed at right angles to this direction.

Fragments of fine grained meta-siltstone, slates and schists of the Willyama Complex are relatively abundant.

Granite fragments are notcommon and although quartz is well represented as individual grains, feldspar is subordinate.

A few flakes of detrital muscovite and angular grains of tourmaline are present.

The rock flour matrix contains abundant small flakes of sericitic mica which are aligned in the direction of the cleavage.

It is noticeable that the lithology of the tillites in this area varies sympathetically with the nature of the parent rock. This is particularly evident with the 'granite-tillite' and the tillite consisting dominantly of fine grained meta-siltstone described above. Another variation is what may be termed a 'slate-tillite' (Rock No. 37.) This rock consists mainly of slate fragments together with subordinate fragments of granite and quartz. The platy phenoclasts of dark grey slate have a common orientation which is probably due to their tabular nature at the time of deposition. This gives the rock a sheared appearance, unlike the adjacent tillite in which the phenoclasts are equidimensional.

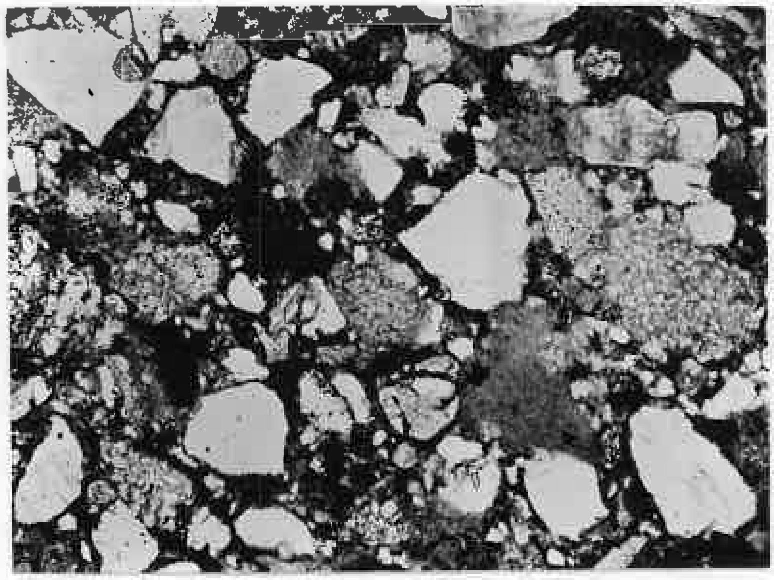
This sympathetic variation of tillite with the underlying rock has been observed elsewhere. In the Barrier Ranges such types as "Quartz-magnetite tillite" and "augen gneiss tillite" have been described, while near Poolamacca H.S. occurs what appears to be a "pegmatite-tillite" and a "biotite gneiss-tillite".

The glacigene sediments interbedded with the massive tillites have already been mentioned as being useful in unravelling the complex structures of the lower part of the Torrowangee Series. They occur as small discontinuous beds normally only a foot or so in thickness, which lens out over a distance rarely more than a few hundred yards. The most abundant of these intercalated sediments are glacigene greywackes and other arenaceous types which show all gradations from well washed quartzites to arkosic grits and greywackes. Some of these arenaceous beds display cross bedding structures while the more typical greywacke types show graded bedding or merely alternation of coarser and finer material.

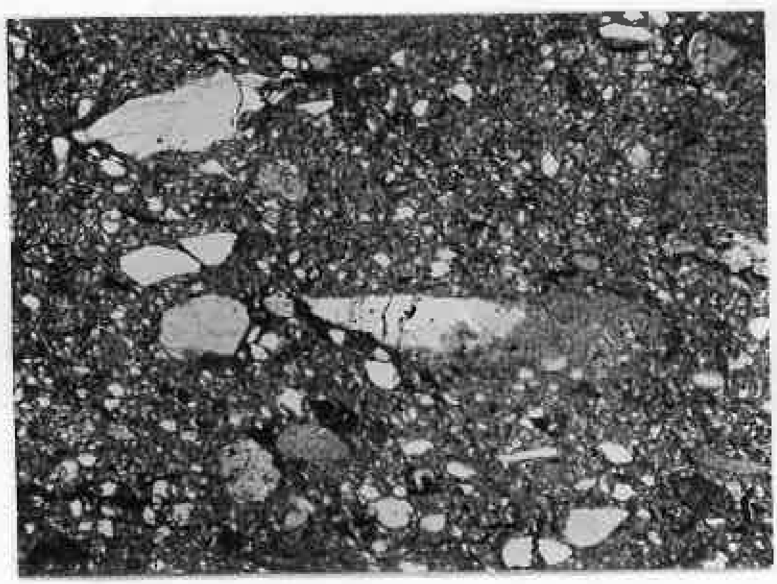
The greywacke types which are perhaps the most abundant of all the arenaceous sediments are typically dark brownish-grey in color. (Rock No. 38.) Quartz and feldspar can be recognised in the hand specimen and under the microscope (slide 34B) the coarser bands are seen to consist of angular fragments in the size range .5 to 1 m.m., very few grains being larger than this. A large proportion of the fragments are quartz but plagioclase with composition of albite is well represented. Tourmaline occurs as detrital grains, some still showing in part their original euhedral form. Microcline is not present. Other fragments consist of composite grains of feldspar and quartz, probably derived from the granite, while other rocks of the Willyama are represented by fragments of fine grained meta siltstone, quartzite and schist. The fine grained matrix of quartz and sericite is similar to the rock flour of the tillite but is much less abundant.

The finer bands (slide 34) differ mainly in the grain size and here the average size of the larger fragments is about 12 m.m. It would appear that the rock has been derived from the same source as the tillite but that some sorting has occurred resulting in the separation of the larger fragments and boulders and with simultaneous diminution in the relative amount of rock flour matrix.

Other specimens (Rock No. 39) show a lesser degree of sorting, while further winnowing of the fine grained material from the glacigene greywackes has produced all gradations to a clean arkosic grit (Rock No. 47). This is a pale buff coloured clastic sediment in which quartz, feldspar and



Glacigene grit Slide 34B X 20



Tillite matrix Slide No 3. X 20
showing cross fracture in quartz splinter

muscovite can be easily recognised.

Microscopically the rock is seen to consist dominantly of quartz and feldspar with average grain size of .5 to 1 mm. Quartz (50%) occurs as irregular angular grains, recrystallised in part. Granulation and recrystallisation has welded the grains together in a sutured interlocking mosaic. Feldspar (35%) is mainly albite, microcline being quite subordinate. Incipient sericitisation has taken place in some of the feldspar making it very cloudy while other grains of albite are quite clear and fresh. Detrital flakes of muscovite are not abundant and are bent and twisted around quartz grains. Small ragged flakes of biotite both greenish and golden brown in color are scattered throughout the slide. Fine grained sericitic mica occurs in the interstices between the larger grains together with a small amount of limonite.

Metamorphism of Torrowangee Sediments

Within the area studied the regional metamorphism of the Torrowangee rocks has not been great, and rarely exceeds the muscovite-chlorite subfacies.

Dynamic metamorphism along the unconformity has in places produced a cataclastic schist from the tillite, in which elongated boulders may be seen. This grades into the older Willyama schists through a zone of metamorphic convergence which may be up to several yards in width but is usually quite narrow.

The first stage in the conversion to schist is the production of sheared tillite (Rock No. 25). This is a greenish grey rock containing fragments of quartz, quartzite, slate, granite, etc. The rock shows evidence of considerable shearing and one large quartzite pebble gives the impression that it has been stretched out.

Microscopically the rock is seen to differ from the ordinary tillite in that the boundaries between rock fragments and matrix are less sharply defined. Quartz fragments are least affected but even they show recrystallisation. Fragments of other rocks tend to merge into the matrix and this is due in part to the fact that the sericite in the base has developed into somewhat larger flakes than is the case in the normal tillite.

No feldspar is present, even in fragments which appear to have been granite, and evidently all original feldspar has been reduced to sericite.

Detrital muscovite flakes are bent and broken. Idiomorphic brown tourmaline prisms showing a preferred orientation along the direction of shearing apparently represent recrystallised detrital grains.

In some of the sheared tillites (Rock No.17) there has been a development of porphyroblastic flakes of muscovite which are set athwart the schistosity and poecilitically enclose quartz. Some of these larger flakes are bent and it appears that recrystallisation has been both post and para tectonic.

The interbedded glacigene grits have also been involved in this shearing producing a white sericitic quartzose schist (Rock No. 64). Under the microscope the texture is crystaloblastic with sutured interlocking grains of recrystallised quartz which are elongated in a common direction. Wisps of fine sericitic mica follow the direction of the schistosity.

In places there is a complete gradation from sheared tillite, through tillite schist, to schist which cannot be differentiated from the Willyama schist. At the unconformity, near its north-eastern extremity, where this zone of metamorphic convergence is of the order of two yards wide, specimens of tillite schist (Rock No. 65) and schist (Rock No. 66) were collected along the strike of the schistosity.

The former contains many boulders of both granite and quartzite, usually elongated and sheared, but the specimen collected is of the sheared matrix. It is a greenish grey colour and contains no recognisable rock fragments. However, many phenoclasts of quartz are present. Some of these have the typical lenticular shapes common to highly sheared rocks. The cataclastic nature of the rock is accentuated by the numerous shear planes which traverse the rock 2 or 3 m.m. apart. These shear planes are covered with a film of sericitic mica.

Under the microscope the cataclastic structure is particularly evident. The rock consists dominantly of fragments of quartz of varying angularity and size, set in a matrix of fine particles of sericite, chlorite and quartz. The grain size varies from several m.m. down to minute fragments.

Tourmaline occurs sporadically. Often it shows effects of granulation and crushing, but occasionally well shaped crystals are developed probably as a result of recrystallisation.

The sericite and chlorite flakes which average .06 m.m. in length are more or less oriented around the larger quartz fragments. Occasionally large poeciloblastic crystals of muscovite occur and some irregular grains of magnetite are present.

Shattered and rounded crystals of apatite are accessory.

The quartz mica schist (Rock No. 66) contains no rock fragments suggestive of sheared erratics either in hand specimen or in thin section. In this rock a much more pronounced cataclastic structure is seen as irregular lenses of quartz and mica oriented in a common direction. Here, however, there is a much greater development of both sericitic mica and chlorite giving the rock a definite schistose appearance. Due to parallel arrangement of these minerals the planes of schistosity have a silvery grey sheen.

In thin section the cataclastic structure is again evident, but in this rock the grain size of the quartz is much smaller while that of the chlorite and muscovite is somewhat larger. The latter minerals are also more abundant.

The rock consists of lenticular patches of sericite, chlorite and shattered quartz. The quartz often contains abundant small inclusions of all other minerals and rows of bubbles. These lenticular patches are surrounded by sericite and chlorite aggregates which in places develops into large porphyroblastic crystals of muscovite and chlorite.

Magnetite and apatite are accessory.

From the evidence available it is impossible to say whether this quartz mica schist represents a sheared tillite or one of the Willyama schists which it closely resembles.

Apart from the low grade regional and dynamic metamorphism which has probably accompanied the folding, the Torrowangee sediments are but little altered. No evidence of post Torrowangee igneous activity has been found, but quartz veins up to a foot or so wide and several hundred feet long commonly follow the axial plane direction or the main shear directions of the strain ellipsoid. Occasionally quartz blows of larger dimensions are seen.

Summary of Geological History

(1) Deposition of Willyama Sediments.

Since there is a persistant pitch to the south, it is possible that the little metamorphosed Willyama sediments occurring within this area may represent the earliest sedimentation in the old Willyama geosyncline. Sedimentation was eugeosynclinal in nature with predominantly argillaceous and arenaceous types, many of which are extremely fine grained and are often characterised by an abundance of graphite. Thin bedded chert-like rocks may represent primary cherts but this cannot be determined with certainty.

(2) Metamorphism of Willyama Sediments.

The sediments were folded and metamorphosed in older Precambrian times giving quartzites, phyllites, etc. Subsequently they were metamorphosed on a regional scale but with deficient shearing stress. This latter metamorphism gave rise to chiastolite phyllites, mica schists and other rocks with characters similar to thermally metamorphosed rocks, but developed on a regional scale and far removed from igneous intrusion.

Later shearing movements formed the cataclastic schists in the Eastern part of the area, but the dynamic factor diminished rapidly towards the West. In the relatively unsheared rocks the chiastolites are merely replaced by sericitic mica whereas further to the east all stages may be traced until the chiastolites are completely sheared out.

(3) Formation of Pegmatite.

The shearing was followed by a period of pegmatization. The pegmatite being formed in situ at the expense of the pre-existing rock but in places becoming mobilised and intruded along the schistosity or bedding.

Some of the pegmatite masses are sheared at their peripheries indicating some later renewal of shearing movements.

(4) Intrusion of Granite.

The period of pegmatization was followed by the intrusion of a cross-cutting granite. The age of this granite is probably Middle Precambrian as suggested by David & Browne (1950). Contact metamorphic effects were slight but an interesting phenomena related to this granite is the replacement of chiastolites near the contact by quartz and mica. Some pegmatites may be associated with the intrusion of this granite.

(5) Eparchaen Interval.

Following the igneous activity in the Middle Precambrian time was a long period of erosion during which the granite became exposed.

(6) Deposition of Torrowangee Sediments.

Later Precambrian sedimentation did not commence in this area until Middle Proterozoic or "Sturtian" times. Early the accumulation was due to the action of local land ice, later sub-aqueous sedimentation occurred.

(7) Folding and metamorphism of Torrowangee Sediments.

These glacigene sediments were folded along north-south axes during lower palaeozoic time. Metamorphism was slight except at places in the immediate vicinity of the unconformity where cataclastic schists have been developed.

BIBLIOGRAPHY.

ANDREWS, E.C. And Associates. 1922 "The Geology of the Broken Hill District". Mem. Geol. Surv. of N.S.W. No.8.

1948. "Geology of Broken Hill, N.S.W." Proc. Int. Geol. Cong. (Lead and Zinc).

BOWES, D.R. 1952. "The transformation of quartzite by migmatization at Mount Fitton, South Australia". Sir Douglas Mawson Anniversary Volume.

CHAYES, F. "On a distinction between late-magmatic and post-magmatic replacement reactions". Amer. Jour. Sci. V. 248.

DAVID, T.W.E. & BROWNE, 1950. "Geology of the Commonwealth of Australia."

JOHANNEN, A. 1932. "A Descriptive Petrology of the Igneous Rocks". Vol. II.

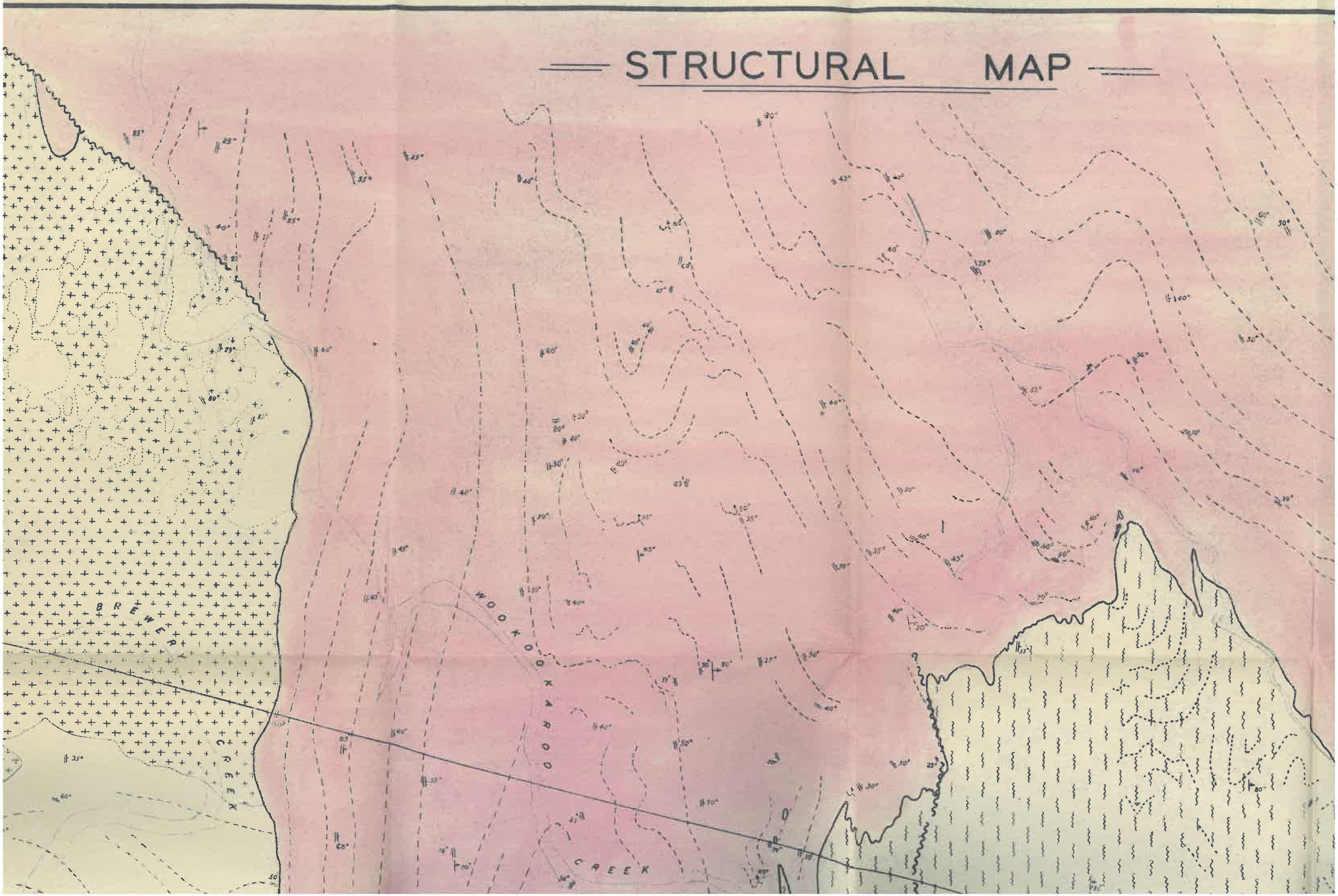
MAWSON, D. 1912. "Geological Investigations in the Broken Hill area." Mem. Roy. Soc. of S. Austr.

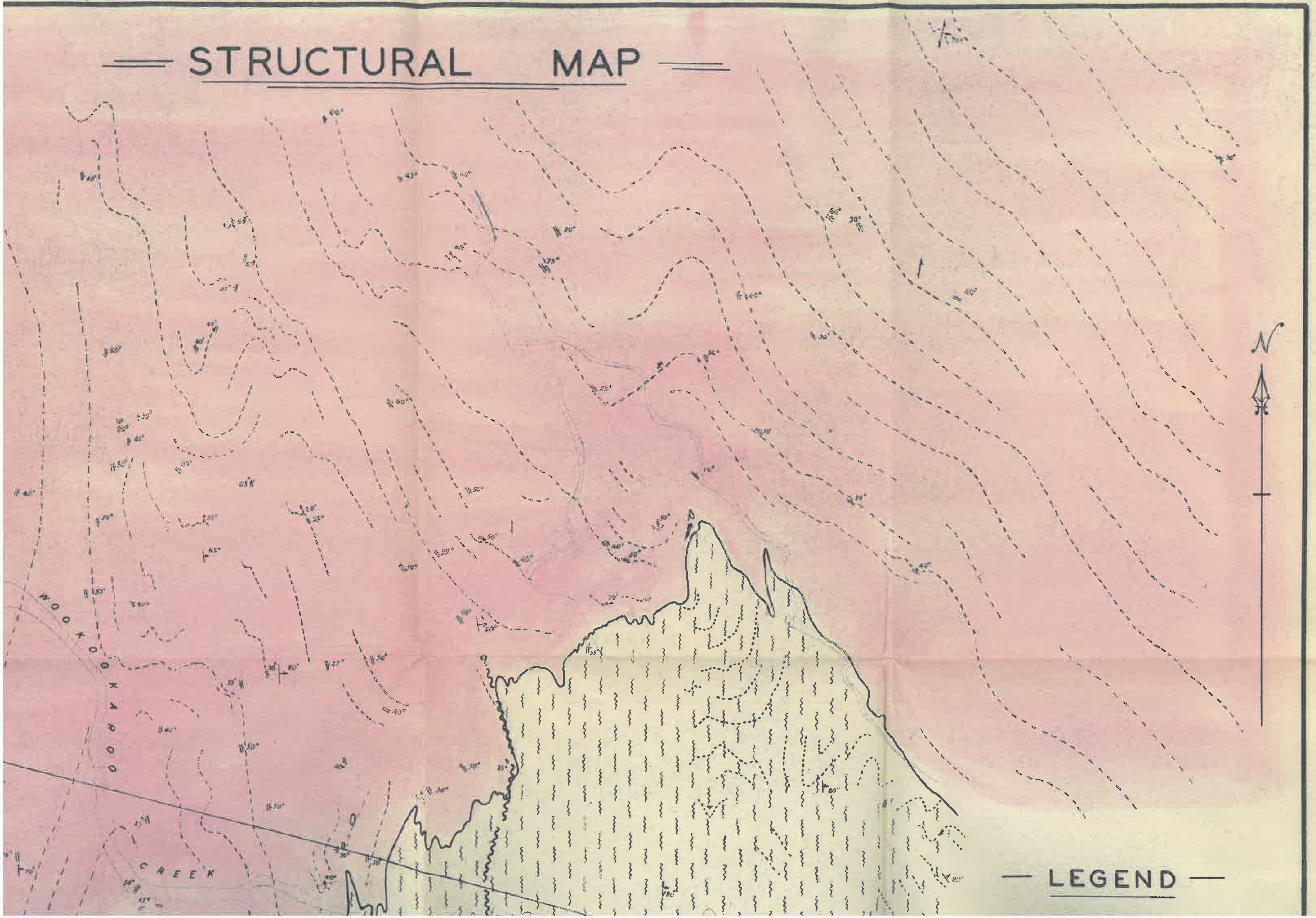
1926. "A brief resume of present knowledge relating to the igneous rocks of South Austr." Aust. Assn. Adv. Sci. Vol. XVIII.

1949. "The Late Precambrian ice age and glacial record of the Bibliando Dome". Jour. and Proc. Roy. Soc. N.S.W. 82.

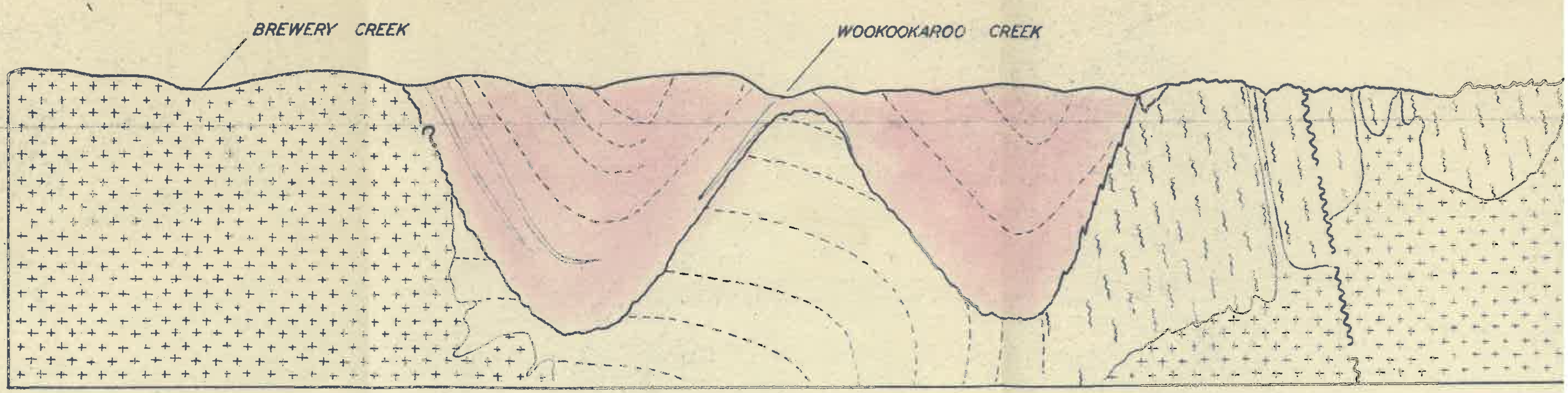
REYNOLDS, D.L. 1947. "The association of basic "fronts" with granitization". Sci. Prog. 35.

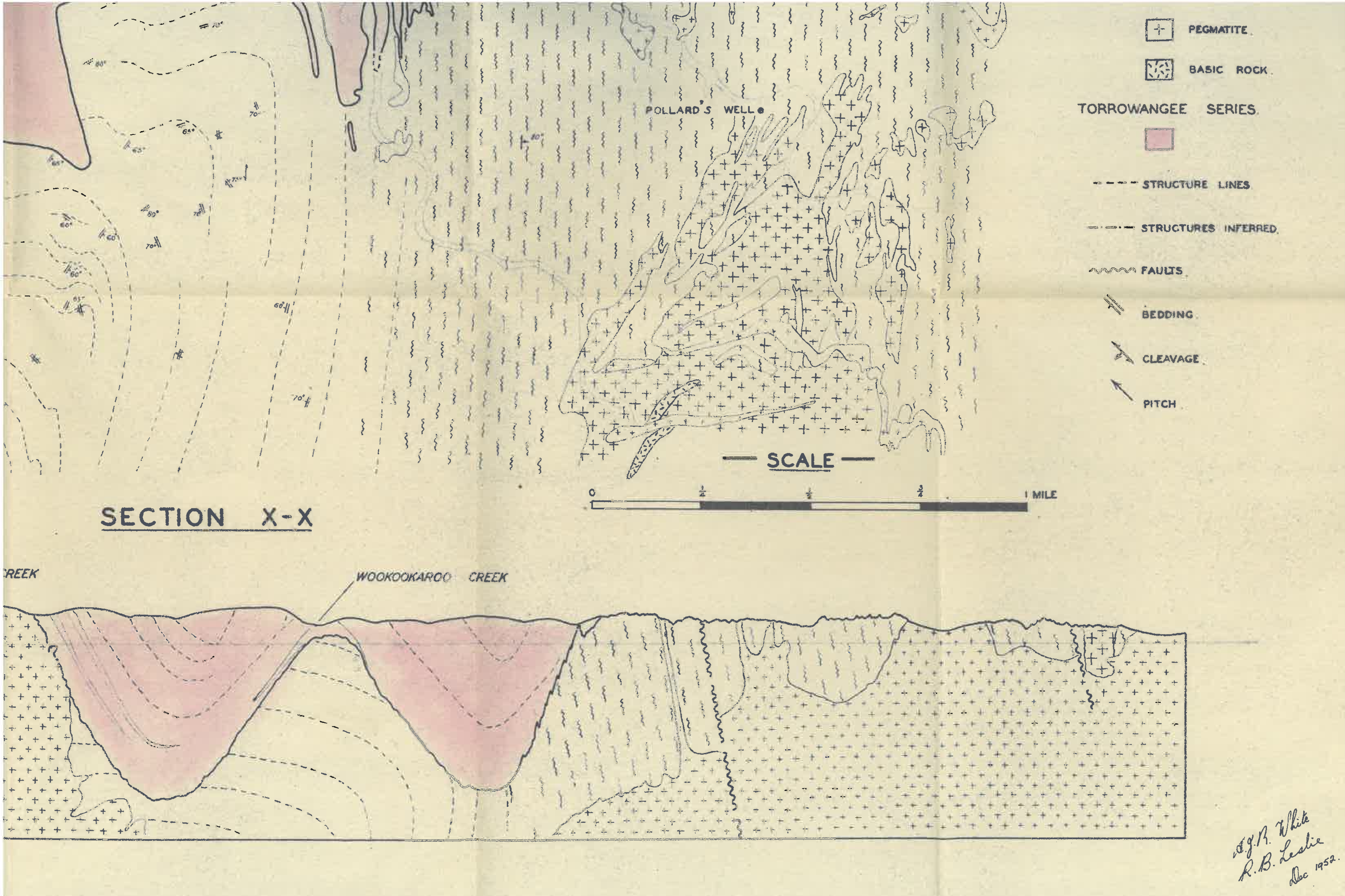
ZINC CORPORATION & Staff, 1951. "Geology of the Broken Hill District". (In Press).


STRUCTURAL MAP
BREWERY CREEK
WOOKOOKAROO
CREEK

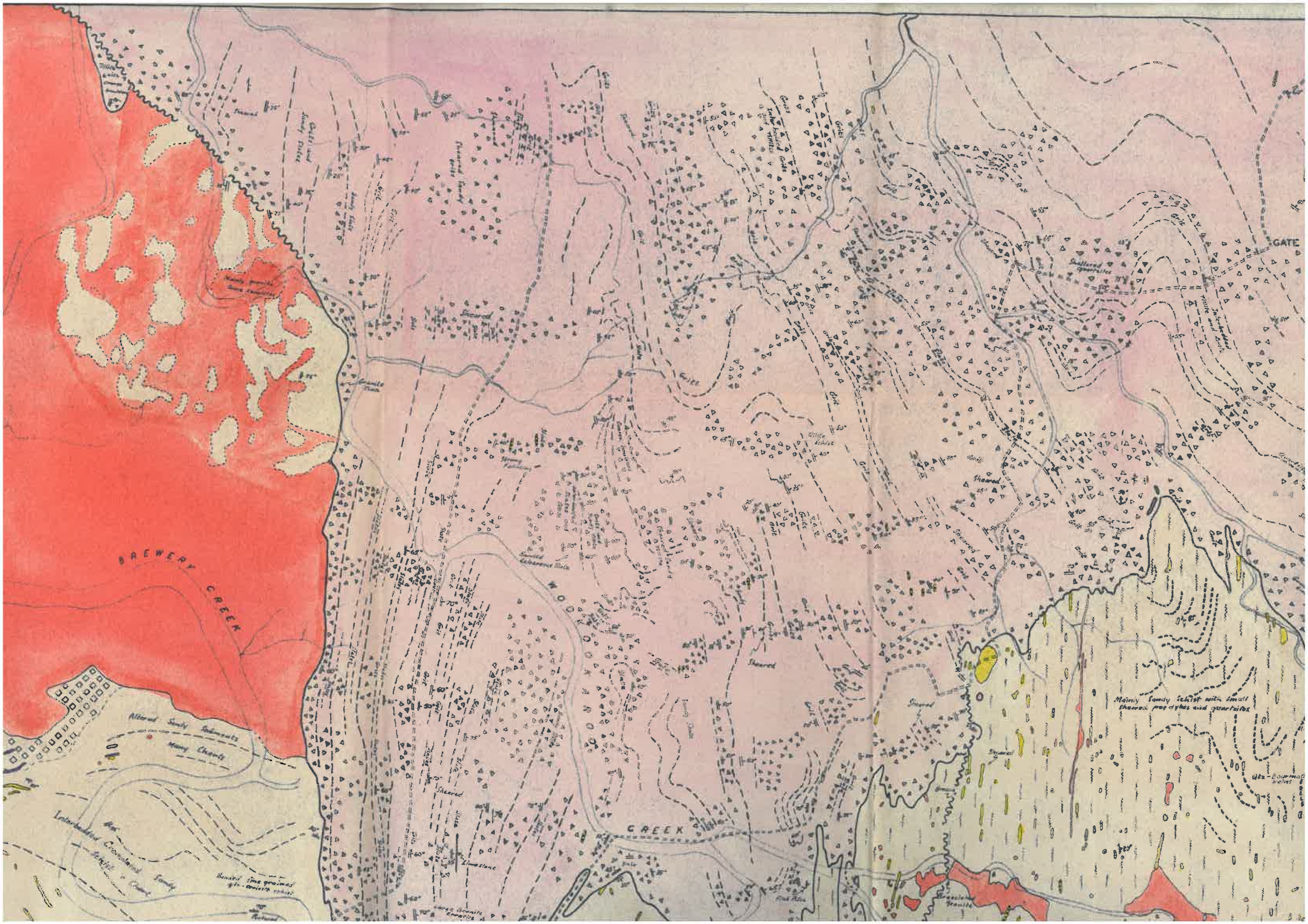

STRUCTURAL MAP
N
WOOKOOKAROO
CREEK
LEGEND

SECTION X-X

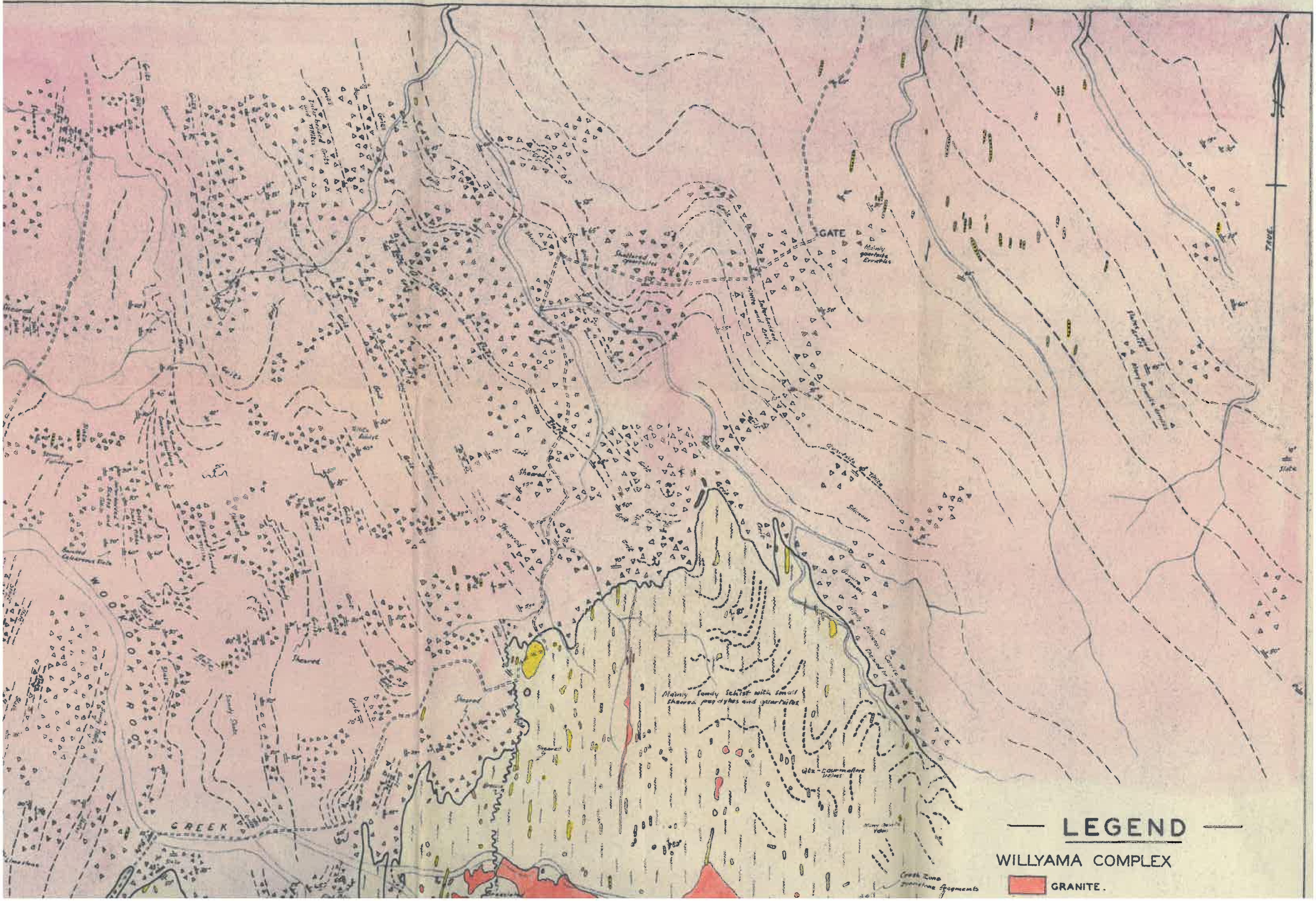




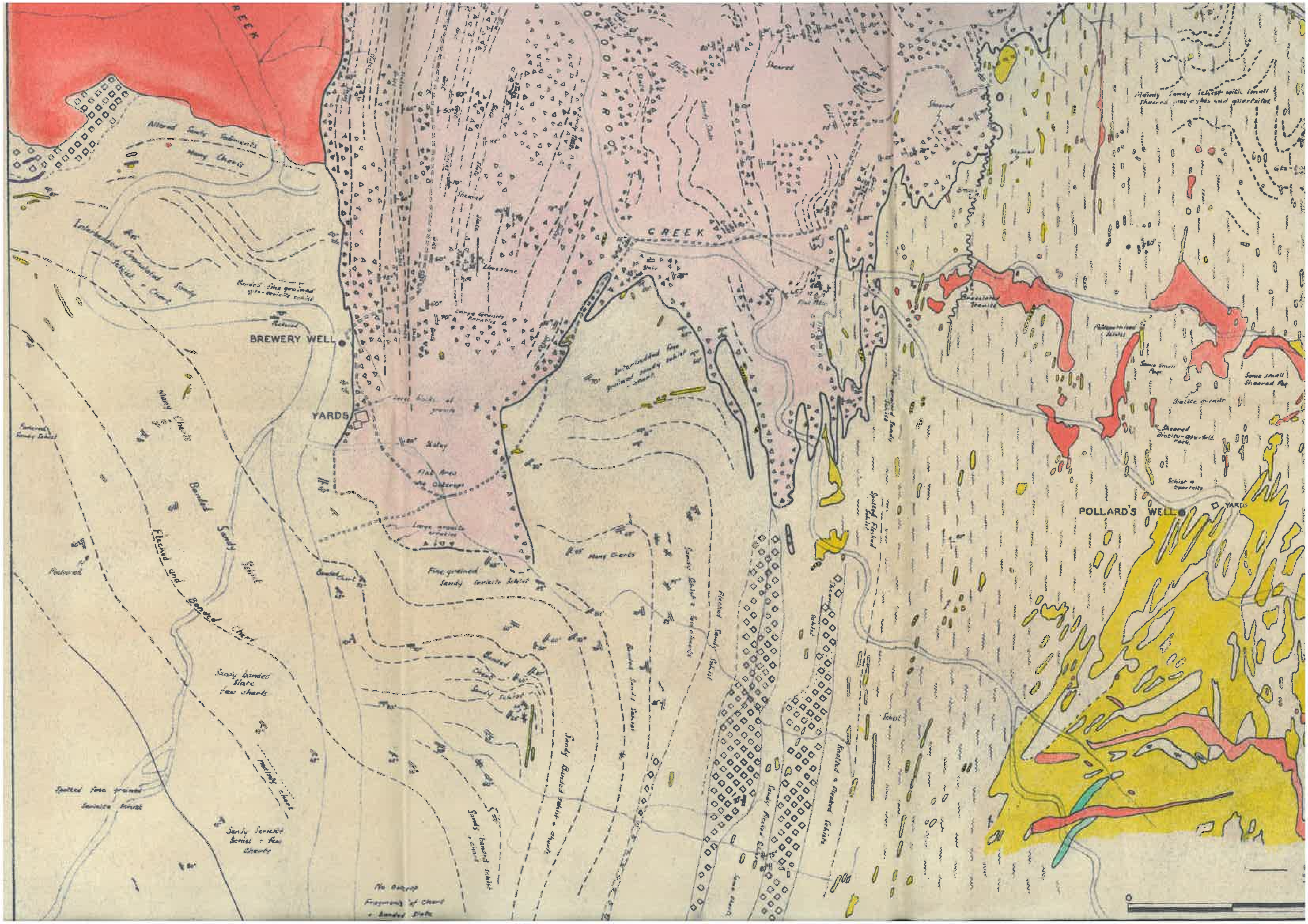
PEGMATITE
BASIC ROCK
TORROWANGEE SERIES
STRUCTURE LINES
STRUCTURES INFERRED
FAULTS
BEDDING
CLEAVAGE
PITCH
POLLARD'S WELL
SCALE
0
¼
½
¾
1 MILE
SECTION X-X
WOOKOOKAROO CREEK
A.J.R. White
R.B. Leslie
Dec 1952



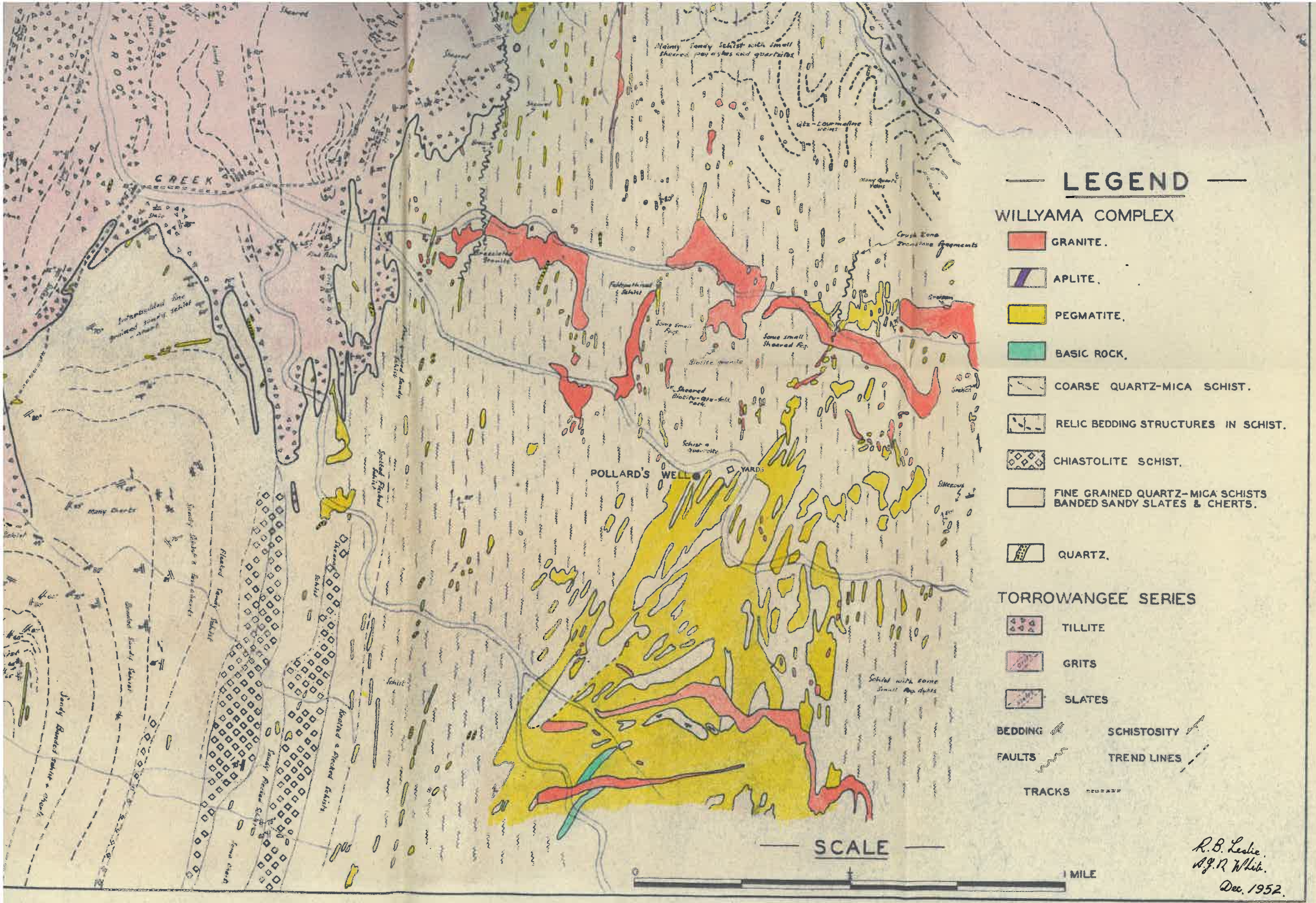
BREWERY CREEK
CREEK
GATE
Altered Sandy Sediments
Many Cherts
Mainly Sandy Schist with small sheared peg dykes and quartzites
Shattered quartzites
Sheared
Limestone



N.
TRUE
GATE
Mainly quartzite Erratics
Shattered quartzites
Sheared
Slate
W O O K O O K A R O O
C R E E K
Mainly Sandy Schist with small sheared peg dykes and quartzites
Qtz-Tourmaline Veins
LEGEND
WILLYAMA COMPLEX
GRANITE.



CREEK
Altered Sandy Sediments
Many Cherts
Interbedded Crenulated Sandy Schist + Chert
BREWERY WELL
YARDS
Sheared
Limestone
Large Granite Erratics
CREEK
Interbedded fine grained sandy schist + chert
Many Cherts
Fine grained Sandy sericite Schist
Banded Sandy Schist
Flecked and Banded Chert
Sandy banded Slate few cherts
mainly chert
Spotted fine grained Sericite Schist
Sandy Sericite Schist - few cherts
No Outcrop
Fragments of Chert + banded Slate
Sandy Banded Schist + chert
Sandy banded Schist + chert
Banded Sandy Schist
Flecked Sandy Schist
Spotted Flecked Schist
Knotted + Flecked Schists
Schist
Mainly Sandy Schist with small Sheared pegmatites and quartzites
Some small Peg.
Some small Sheared Peg.
Sheared Biotite-qtz-fels rock
Schist + Quartzite
POLLARD'S WELL
YARDS


LEGEND
WILLYAMA COMPLEX
GRANITE.
APLITE.
PEGMATITE.
BASIC ROCK.
COARSE QUARTZ-MICA SCHIST.
RELIC BEDDING STRUCTURES IN SCHIST.
CHIASTOLITE SCHIST.
FINE GRAINED QUARTZ-MICA SCHISTS BANDED SANDY SLATES & CHERTS.
QUARTZ.
TORROWANGEE SERIES
TILLITE
GRITS
SLATES
BEDDING
SCHISTOSITY
FAULTS
TREND LINES
TRACKS
KAROO
CREEK
POLLARD'S WELL
YARDS
Mainly Sandy Schist with small sheared peg-s and quartzites
Many Cherts
Sheared Biotite-qtz-feld. rock
Biotite granite
Some small Sheared Peg.
Schist with some Small Peg. dykes
SCALE
0
1 MILE
R.B. Leslie.
A.J.R. White.
Dec. 1952.