THE GEOLOGY OF THE ANGUS MINE AREA OF THE BARRIER RANGES, NEW SOUTH WALES.

by

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This thesis does not contain any material previously submitted for a degree in any University by me, or by any other person, except where due reference is made in the text of the thesis.

J. B. McMANUS
31st December, 1963

SUMMARY

The "aplites" and concordant pegmatites in the Angus area are considered to be altered sediments; the "aplites" would have been felspathic sands, or arenites with minor clay material; the concordant pegmatites are considered to be similar sediments, with greater amounts of clay material. Major soda metasomation is not invoked to explain the sodic rich nature of the rocks, which are thought to have been sodic rich sediments. Transgressive sodium rich and potassium rich pegmatites have been derived partly by pneumatolytic processes and partly by migration of ions from metasediments into joints and fractures.

The amphibolites are interpreted as having a sedimentary origin, and to have been calcareous - chloritic-siliceous-ferruginous sediments, with minor clays and sericitic material. Iron, aluminium, and magnesium metasomatism is not invoked, and the constituents of the amphibolites were originally present in the sediments. The amphibolites could also have been acidic tuffs.

All rock types have been described in detail, and the genesis of each rock type has been given.

The stratigraphic sequence and sedimentary environment could be explained by regressions and transgressions

of the sea in unstable areas where uplift and subsidence occurred.

The overall structure is a limb structure, with minor folding on the limb. The beds dip steeply in a westerly direction. The overall plunge is northerly.

Metallic minerals in the area have been deposited in a calcic environment within fine-grained sediments, now gneisses, schists, calcic-plagioclase quartzites, quartz-epidote rocks, and in places, amphibolites. The mineralisation has concentrated in small folds within the calcic bearing zones. Potassic felspar associated with the mineralisation is considered to have developed partly as the result of potassium ions being relatively mobile during metamorphism and migrating to areas of lower stress, and partly by potassium ions being "repelled" from calcic environments under metamorphic conditions. A sedimentary origin is favoured for the Broken Hill type mineralisation in the area.

Vegetation-rock type associations and their possible significance have been outlined.

The results of geophysical studies have been applied to the geology.

Economic considerations have been put forward. Surface indications of base metal mineralisation are such that further geophysical (electrical) studies should be carried out before drilling is considered. Consideration could possibly be given to drilling at the Angus mine without further geophysical studies.

Minor beryl occurrences in some of the transgressive pegmatites within an "aplite" zone require investigation by using a Beryllium Detector (berylometer).

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CHAPTER I

I N T R O D U C T I O N

This thesis is being submitted to the Faculty of Science, in the University of Adelaide, for admission to the degree of Master of Science.

The geological field work was commenced in July, 1957, and was completed in March, 1959, while in the employ of The Zinc Corporation Limited, Broken Hill, New South Wales. Laboratory studies have been undertaken in the Department of Economic Geology, at the University of Adelaide, from March 1959 until June 1960.

An area of 18 square miles approximately, situated 22 miles to the south-west of Broken Hill, (Plate 1, Figures 1 and 3), held under an Authority to Prospect, by the Australian Mining and Smelting Company Limited, has been mapped geologically using a scale of 1 inch represents 400 feet.

Aim of Work

The aim of the work was to endeavour to determine the stratigraphy, structure, grade of metamorphism, and origin of rock types, as weak zinc, lead, and copper

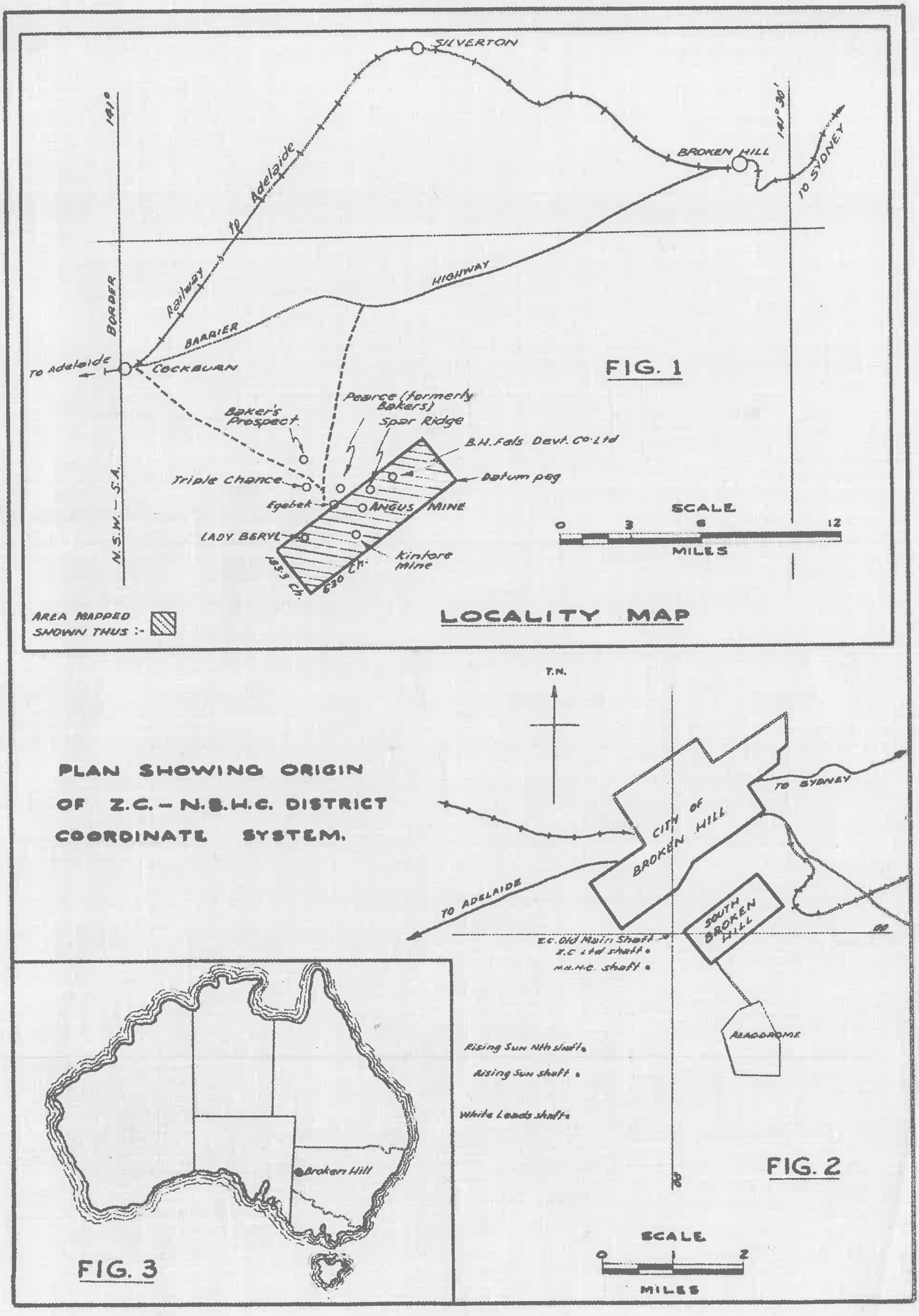

SILVERTON
141°
141° 30'
BROKEN HILL
TO SYDNEY
Railway to Adelaide
HIGHWAY
BARRIER
BORDER
To Adelaide
COCKBURN
FIG. 1
Pearce (formerly Bakers)
Baker's Prospect.
Spar Ridge
B.H. Fels Devt. Co Ltd
Datum peg
Triple Chance
Egebek
ANGUS MINE
LADY BERYL
Kintore Mine
N.S.W. – S.A.
SCALE
0 3 6 12
MILES
AREA MAPPED SHOWN THUS :-
LOCALITY MAP
T.N.
PLAN SHOWING ORIGIN
OF Z.C. – N.B.H.C. DISTRICT
COORDINATE SYSTEM.
TO SYDNEY
CITY OF BROKEN HILL
TO ADELAIDE
SOUTH BROKEN HILL
Z.C. Old Main Shaft
Z.C. Ltd shaft
N.B.H.C. shaft
AERODROME
Rising Sun Nth shaft
Rising Sun shaft
White Leads shaft
FIG. 2
SCALE
0 1 2
MILES
Broken Hill
FIG. 3

PLATE I

mineralisation occurs within the area. The information obtained will be used in considering the possibility of economic deposits in the area and to assist in the search for further economic deposits in the Broken Hill district.

A gravity survey of a portion of the area was carried out by a consultant geophysicist between November 1958 and January 1959. The survey was made to assess the possibility of a large ore-body at a shallow depth, and to help outline the stratigraphy and structure.

Previous Investigations

The Angus Mine was first worked from 1880-1890 by the Angus Smelting and Mining Company, producing approximately 400 tons of "run of mine" ore, which was hand-picked to 184 tons, assaying 35% lead, 40 oz. silver per ton, and an unknown quantity and grade of zinc. The workings reached a depth of 130 feet.

In 1925-26 the mine was re-opened by an Adelaide company, and prospected to the 210' level with poor results.

Many shallow shafts, costeans and pits have been sunk on weak zinc, lead, and copper mineralisation which occurs in the area mapped. No records of these workings were kept, although they were probably prospected in the latter part of the 19th century.

G.L. Baker held a lease of an area around the Angus Mine in 1948, but did not exploit the mine. No detailed geological records have been kept, although some development and assay records of the Angus Mine are held by the Department of Mines, New South Wales. Copies of newspaper cuttings from the "Silver Age" and "Barrier Miner" give progress reports of the development in the Angus Mine.

Felspar, beryl and mica have been won since 1941 from the Egebek, Triple Chance, Pearce's and Baker's quarries, which are situated to the west of the area mapped (Plate 1, Fig.1). Within the area mapped,felspar, beryl and mica have been worked since 1947; tonnages have been obtained from the Lady Beryl, Spar Ridge, and Broken Hill Felspar Development Co.Ltd. (formerly Pearce's) quarries. Geological mapping of an area surrounding the abovementioned quarries with the exception of the Broken Hill Felspar Development Co. Ltd. quarry, had been done using a scale of 1 inch represents 1,000 feet and reduced to 1 inch represents 1,800 feet approximately (Rayner and Hall, 1949).

In 1951-1952 an area (including the Angus Mine area) of 250 square miles was mapped by geologists of Enterprise Exploration Co. Pty. Ltd., using a scale of 1 inch represents 1,000 feet and scaled down to 1 inch represents 2,000 feet. Quoting from Thomson (1952); private report to Enterprise Exploration Co. Pty. Ltd.:

> In April 1951, an application for Authority to Prospect was made by Australian Mining and Smelting Co. Ltd., over an area covering 250 square miles south-west of Broken Hill. This application was made through the direction of Mr. H. F. King, who reasoned that the potential lode-bearing horizons should reach the surface because of the probable north-easterly plunge of the rocks south of the Thackaringa Fault and the presence of Hanging-Wall Gneiss and Broken Hill type mineralisation (The Angus line) in the area.

Williams (1952) in an unpublished thesis, placed the rocks containing the Angus and Pinnacles mineralisation stratigraphically above the rocks containing the mineralisation at Broken Hill. A microscopic study was made of four rock specimens from the Angus area.

Thomson (1955) in an unpublished thesis, also considered the rocks in the Angus area to be within the Pinnacles Group, which is stratigraphically above the Broken Hill Group which contains the rich ore-bodies.

<u>Survey and Mapping Methods</u>

A traverse, which was "run" by the survey staff of The Zinc Corporation Limited, from the Pinnacles Mine (9 miles south-west of Broken Hill) to the authority peg in the north-east corner of the area mapped, enabled a base map to be controlled at 1 inch represents 400 feet. The

Pinnacles Mine has been "tied-in" to a grid system used by The Zinc Corporation Limited.

A base map was prepared from aerial photographs using the radial-line plot method.

A regional grid system with its origin at the Old Main Shaft of The Zinc Corporation Limited, was used for location reference (Plate 1, Fig.2).

A geophysical base line and grid was "laid-out" by The Zinc Corporation Ltd. survey staff in a portion of the area mapped.

An area of 600 feet by 500 feet around the Angus Mine was surveyed using plane table and alidade methods in conjunction with geological mapping at 1 inch represents 20 feet. Members of the New Broken Hill Consolidated Limited Survey Office assisted in the survey.

Accessible underground workings of the Angus Mine were surveyed and mapped with the aid of tape and compass.

Mapping of the area held under authority was carried out with the aid of photographs having a scale of 1 inch represents 400 feet approximately. These photographs were enlarged from aerial photographs having a scale of 1 inch represents 1,000 feet.

During the mapping of the northern portion of the area the author was assisted by two graduate mining engineers, W. J. Hogg and J. G. Tankard. Assistance was given by W.J. Hogg and B.E. Braes while mapping and sampling the underground workings of the Angus Mine. G. Stevens, P. Anthony and D.E. Ayres, geological students, assisted in the field mapping for a few weeks.

Accessibility

Access to the area is good, particularly by way of a track which heads south from the Adelaide Road, at a point 18 miles west of Broken Hill. Most points within the area can be reached when using a four-wheel drive vehicle.

P H Y S I O G R A P H Y

Topography

The western and central portions of the area are moderately rugged, with elongated ridges running in a north-easterly direction in the northern portion of the area and running north-south in the southern portion. The ridges die out to the north and to the south where the country is undulating. In general the relief amplitude in the Angus area is 200-300 feet.

Drainage

In the north-western portion of the area the creeks drain to the north, while the north-eastern sector is drained to the north-east and east. In the south, the creeks mainly drain to the south.

In general the drainage system is subsequent, although insequent drainage occurs in many parts of the areas.

An inch of rain with "follow-up" rain is required before the creeks run. Most of the creeks terminate in outwash fans. As the average rainfall for Broken Hill and district is less than 10 inches, the creeks seldom run.

Climate

Daily temperatures from October to March are warm to hot. From June to August the daily temperatures are generally cool, and occasionally very cold when conditions are dominated by southerly and south-westerly air-streams. Frosts occasionally occur during this latter period. The conditions of humidity during the summer months rarely exceed the human comfort level.

The mean annual rainfall for Broken Hill and district is 9-10 inches, with the highest annual rainfall on record being near 17 inches. The rainfall occurs intermittently throughout the year.

Vegetation

Vegetation in the area was noted in some detail and some chemical analyses have been carried out on a tree (Pittosporum phillyraeoides) and a small annual bush (Sida virgata). Noting the trend of growth of salt-bush (Atriplex vesicaria) and blue bush (Kochia pyramidata and Kochia sedifolia) was an assistance in determining the trend of the under-lying rocks.

In many instances the stands of timber could be related to the texture and amount of soil and its water holding properties. In other instances the topography, nearness of creek beds and rock types determined the vegetation present.

The trees, bushes and grasses that were noted in the area are as follows:

Casuarina lepidopholia Miq. (belah or black oak)
Heterodendron oleifolium Desf. (rosewood, boonery or bullocky bush)
Acacia aneura F.v.M. (mulga)
Geijera parviflora Lindl. (wilga)
Acacia victoriae Benth. (prickly wattle)
Eremophila sturtii R.Br. (turpentine bush)
Acacia tetragonophylla F.v.M. (dead finish)
Pittosporum phillyreoides D.C. (butterbush)
Eremophila duttonii F.v.M.
Eremophila maculata (Ker) F.v.M. (native fuchsia)
Fusanus acuminata (R.Br.) Spr. et Susan (quandong)
Capparis mitchellii Lindl. (native orange)

<u>Eremocitrus glauca</u> Lindl. Swingle (1914) "desert lime wild cumquot)

<u>Prostanthera striatiflora</u> F.v.M. (mint bush)

<u>Sida virgata</u> Hook

<u>Triodia irritans</u> R.Br. (porcupine bush)

<u>Cassia artemisioides</u> Gaudich

<u>Sarcostemma australae</u> R.Br. (milky bush)

<u>Dodonaea species</u> (hop bush)

<u>Asphodelus fistulosus</u> L. (wild onion)

<u>Ptilates obovatus</u> (Gaudich) F.v.M. (lambs tongue)

<u>Atriplex vesicaria</u> Heward ex Benth (bladder salt bush)

<u>Kochia pyramidata</u> Benth (blue bush)

<u>Kochia sedifolia</u> K.v.M. (blue bush)

The four types of vegetation which will be discussed in relation to rock types are <u>Pittosporum phillyreoides</u>, <u>Sida virgata</u>, <u>Kochia sedifolia</u> and <u>pyramidata</u> and <u>Triodia irritans</u>.

<u>Water</u>

Information supplied by T.W. Carne of Hillston Station during 1960, shows that 5 bores and 2 wells are at present in use within a radius of 13 miles of the area mapped; two bores occur near the area.

Bore No.81 described by Kenny (1934) is situated at a position 500 feet south-west of 66,000'S - 74,000'W (district co-ordinates), being near the north-east corner of the area mapped. The hole was rebored or resunk in 1939 to a depth of 200 feet. When pumped the bore can give

200-250 gallons per hour. Kenny listed the salt content as $1\frac{3}{4}$ ounces per gallon, and water was reached at 201 feet; the water level rose to 101 feet. This bore is known as the 12 Mile Hut bore.

Hillston bore is near the Hillston Station homestead, which is situated near the south-eastern portion of the area mapped. This bore was sunk in 1939 to a depth of 275 feet, with water being encountered at 245 feet and 255 feet. The water contains approximately 2 ozs of salts per gallon. Initially the bore supplied 200 gallons per hour when pumped; this rate has now dropped to 125-150 gallons per hour.

If water is required by The Zinc Corporation Ltd., for drilling purposes, T.W. Carne, Hillston Station will permit the company to use water stored in an earth tank near Pearce's quarry (Plate 1, Fig.1) which is 6,500 feet north of the Angus Mine. The track leading to the Angus Mine passes the tank.

No water was encountered in the main shaft at the Angus Mine. The shaft was sunk to a depth of 210 feet. The collar of the shaft would be at least 200 feet above the collars of the two bores described.

GEOMORPHOLOGY

A prominent geological feature which has bearing on the morphology is the Hillston fault which strikes N.E.-S.W. approximately along the eastern side of the area. What may be the fault line is marked by a prominent scarp. The terrain on the east "down-throw" block is flat to undulating, and is capped with siliceous laterite (grey-billy) in places, being evidence of previous peneplanation. West of the scarp the terrain is hilly.

The north-south striking Mundi-Mundi fault is thought to be responsible for the ground gradually flattening in the south-west portion of the area. No direct evidence of this fault was observed in the area mapped.

The Hillston fault and Mundi-Mundi fault give a wedge shape to the outcropping rocks in the southern portion of the area.

The elongated ridges parallel the strike of the beds and consist mainly of pegmatite, "aplite" and amphibolite.

Schists and gneisses have been eroded easily and where these rocks are reasonably thick, valleys have formed.

The flattening of the ground in the north of the area could be partly explained by the rocks plunging in a northerly direction, also partly by the poor development of pegmatites which elsewhere form prominent features.

CHAPTER II

G E O L O G Y

Rock Types

The principal rock types in the area are:

- Pegmatites
- Albite, soda oligoclase, quartz rocks (locally called "aplites")
- Amphibolites
- Schists
- Gneisses
- Quartz-epidote-zoisite rocks
- Felspathic quartzites with garnet

There are very minor occurrences of quartz-magnetite and granitic gneisses in the south-western portion of the area.

Garnet quartzites and garnet granulites ("garnet sandstones") are associated with the weak mineralisation in the area.

Scattered siliceous, lateritic "float" is found in the eastern portion of the area.

Pegmatites

Pegmatite would probably be the most abundant outcropping rock type in the area.

The pegmatites can be divided broadly into three types:

1. Concordant pegmatites
   Concordant pegmatites parallel the bedding or gneissosity of the sediments, although in places near the noses of folds the pegmatites appear to follow pre-existing cleavages for short distances. Very little muscovite is found in these pegmatites.
2. Transgressive pegmatites
   Transgressive pegmatites generally cut the sediments and concordant pegmatites at large angles and are obviously later than the concordant pegmatites.
   They may parallel the bedding or gneissosity for short distances in fold environments.
   Transgressive pegmatites often contain notable amounts of muscovite.
3. A third type of pegmatite has green lead-bearing felspar. This type of pegmatite is rather rare, although important, as it is always associated with the zones of mineralisation.

1. Concordant pegmatites

The widths of the pegmatites vary from less than 1 inch to tens of feet, and are generally interbedded, with schists or albite-soda oligoclase-quartz rocks ("aplites") of sedimentary origin.

The pegmatites occur in zones, up to 600 feet wide, which parallel the sediments often for miles.

Where the pegmatites are the dominant rock type, they resist weathering to a greater degree than the amphibolites, schists and gneisses. The prominent ridges in the area consist of pegmatites, often associated with "aplites".

The colour of the concordant pegmatites varies from whitish to cream, with surface iron-staining in places.

The pegmatites vary from fine-grained (less than 1 mm.) to coarse-grained (having quartz and felspar crystals in excess of 6 inches).

A few concordant pegmatite outcrops show relict bedding.

Felspar and quartz are the main constituents of the pegmatites, with felspar slightly in excess of quartz throughout the area. The minerals have a weakly developed orientation parallel to the foliation of the surrounding rocks.

Muscovite, garnet and tourmaline occur in a few outcrops and can be observed in hand specimen.

Concordant pegmatites are often well developed in fold environments.

Mineralogy

Felspar constitutes approximately 60% of the concordant pegmatites. Albite, An_{4-10}, constitutes 80% of the felspar present, although in some specimens potassic felspar can be as high as 50%. Concordant pegmatites associated with "aplites" of sedimentary origin have very minor potassic felspar present.

In association with optical methods, etching with hydrofluoric acid and sodium cobaltinitrite was carried out to determine the amount of potassic felspar present. Dilute hydrochloric acid removed the greenish-yellow stain produced by any biotite present in the specimens, thus allowing a relatively accurate determination of the amount of potassic felspar present.

Specimen A/180/55, consisting of equal portions of quartz and felspar, with minor muscovite occurring interstitially and sericite developing from the felspars, shows a few specks only of potassic felspar when etched. Chemical assays of the specimen indicated that major amounts of potassic felspar were not being overlooked by etch methods. The assays were carried out by the writer, using a flame photometer, and are as follows:

Na_2O	4.9%
K_2O	1.6%

The xenoblastic grains of felspar vary from less than 1 mm. to several centimeters in length in each specimen, although in the fine-grained concordant pegmatites the felspar and quartz tend to be even-grained and granoblastic.

In general the sodic plagioclase and potash felspar are fresh in appearance, and twinning is clear in the plagioclase. Incipient sericitisation of the potassic and sodic felspars occurs in some localities.

Most of the specimens examined show that the twin planes in the plagioclases are bent slightly, or the plagioclases and the potash felspars show strain shadows.

No zoning was noted in the felspars, nor microcline twinning in the potash felspars.

In specimen, A/180/157, which contains tourmaline crystals up to $\frac{3}{4}$ inch in length, two crystals of felspar show aligned blebs of potash felspar in albite. This specimen was taken near a position where "transgressive" pegmatite occurs indicating that the anti-perthitic texture could have developed in the concordant pegmatite as a result of introduced material from the "transgressive" pegmatite.

Quartz inclusions are common in the plagioclases, and in specimen A/180/123, inclusions of potash felspar are found. Plagioclase inclusions in quartz are not common. Muscovite flakes, from 0.1 mm. to 3-4 mms. in length, are often found as inclusions in the felspars. The flakes are generally oriented parallel to weakly oriented felspar and quartz grains. Sillimanite needles, up to 0.75 mms. in length occur as inclusions in specimen (A/180/157) in which felspars have an anti-perthitic texture.

Quartz

Quartz constitutes approximately 30%-40% of the minerals present in the concordant pegmatites, although in some specimens, quartz content is less than 5%, while in others it can be as much as 70% of the rock.

The quartz grains are transparent to translucent, unlike the quarts in the transgressive pegmatites, which is mostly milky.

The grain size is similar to that of the felspar grains. The grains are xenoblastic, although tend to be granoblastic in the fine-grained pegmatites, associated with "aplites".

Generally several quartz grains occur together, and the felspar grains have a similar occurrence, giving the pegmatites a patchy appearance. Most grains have undulose extinction. Few grains have lines of minute black inclusions. In specimen A/180/123 lines of inclusions intersect at 45° approximately.

Inclusions of muscovite, up to 5 mms. in length, and sillimanite needles, up to 1.0 mm. in length, occur in the quartz in specimen A/180/157, which was collected near a "transgressive" pegmatite.

Most grains are oriented.

Muscovite

Muscovite content can be as much as 5% of the concordant pegmatites, but in most specimens muscovite is only 1%-3% of the rock.

Some flakes are as long as 0.75 mm., and 0.5 mm. wide, ranging down to interstitial flakes less than 0.1 mm. in length.

A feature of the concordant pegmatites is the small grain size, and the small percentage of muscovite present. In the "transgressive" pegmatites the muscovite often occurs in "books" and can be a major constituent.

Minor amounts of muscovite develop from the felspar.

In specimen A/180/159, which is a sheared pegmatite containing tourmaline, the muscovite occurs in bands, also interstitially, and gives the rock a schistose appearance.

Sericite

Sericite is not common, and when present is an alteration product of the felspars.

Biotite

Biotite is a very minor constituent of the pegmatite. When present it is associated with muscovite. The flakes do not exceed 1.0 mm. in length.

Chlorite

Chlorite is found in pegmatised rocks, although the occurrences are rare. In specimen A/180/116, chlorite which appears to have altered from biotite is found in small "knots" up to 0.7 mm. in diameter. Individual flakes range between 0.1 and 0.6 mm. in length.

Chlorite is generally associated with quartz, and the flakes often show a weak orientation with the quartz grains.

Tourmaline

Within the concordant pegmatites tourmaline is rare. When noted it is present within a particular pegmatite band.

The idioblastic crystals are up to 2-3 inches long and $\frac{3}{4}$ inch in diameter.

In specimen A/180/157, tourmaline crystals, up to 5 mms. in length, are partly surrounded by small muscovite crystals. Some crystals show zoning, having a bluish-green core and a yellowish-green outer rim.

Specimen A/180/159, which has been sheared, contains tourmaline crystals, up to 3 mms. in length, which appear to have been rotated; alternatively shearing has caused the muscovite crystals to be displaced around the tourmaline crystals.

Both specimens A/180/157 and 159 were collected near transgressive pegmatites, indicating that material could have been introduced into the concordant pegmatite to form tourmaline. However, other occurrences of tourmaline bearing bands are not associated with transgressive pegmatite.

Garnet

Garnet is another very minor constituent of the concordant pegmatites. Specimen A/180/108 shows cracked, elongated, reddish garnets, up to 3/8 inch in length, with inclusions of quartz, and muscovite filling the cracks. Garnets extracted from specimen A/180/108 were assayed for manganese, giving a value of 3.1% MnO. T.R. Sweatman, Division of Soils, C.S.I.R.O., Adelaide, carried out the assay using an X-ray fluorescent method developed by Dr. K. Norrish. A ratemeter reading for iron, taken while assaying for manganese, indicated that the iron content is high.

One pegmatised rock, specimen A/180/116, contains minor biotite and chlorite; garnets are associated with quartz and show incipient alteration to biotite, and are surrounded by fine-grained muscovite. The garnets appear to have been present before pegmatisation.

A few minute grains of potassic felspar are present in specimen A/180/116, but no potassic felspar occurs in A/180/108. Sillimanite has developed in specimen A/180/108, suggesting that conditions were "dry" (Ramberg, 1956), thus allowing the development of garnet in an almost potassium free environment. Garnets in specimen A/180/108 could have formed during the development of pegmatite.

Sillimanite

In the two specimens A/180/157 and 159, which contain tourmaline some sillimanite is found. In specimen A/180/157, sillimanite needles up to 0.75 mm. occur in the quartz and felspar with no preferred orientation. In specimens A/180/159 and A/180/108 a few sillimanite needles occur in quartz crystals; specimen A/180/108 contains elongated garnets.

Magnetite

Magnetite was found in one specimen only. The specimen was taken where a pegmatite grades-out along strike. The pegmatite specimen is fine grained and tends to be even grained. A few subhedral to euhedral crystals of magnetite, less than 0.5 mm. in length, occur in the quartz grains.

Zircon

Small rounded zircons, 0.05 to 0.1 mm. in diameter, occur in quartz in specimen A/180/116, which is a pegmatised rock.

The coarse grained pegmatites do not contain zircons, but specimen A/180/65, an "aplitic", fine-grained pegmatite, contains minute rounded zircons.

Apatite

Minute grains of apatite are found in the specimens which contain sillimanite. In specimen A/180/108, the small grains are ragged.

Rutile

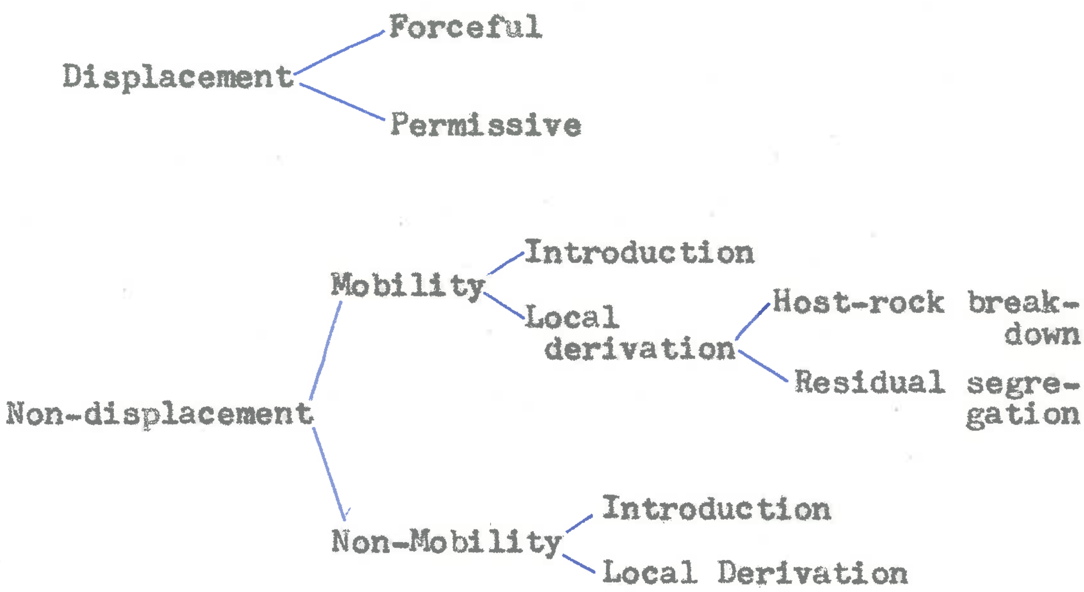
Rutile was found in one specimen A/180/65, an "aplitic" pegmatite which grades into schists. The rutile constitutes 1% of the rock, and occurs as inclusions in the quartz and felspar. Other grains are found along the boundaries of quartz and felspar crystals. The larger grains are 0.2 mm. long, and are angular; smaller grains are rounded.

Genesis of the Concordant Pegmatites

The most exhaustive studies of pegmatites in the Broken Hill district have been made by Mawson (1912) and Andrews (1922). The most recent workers, King and Thomson (1953) concluded that pegmatite replacement of sediment occurs, and the most satisfactory explanation of the large pegmatite bodies is that in the main they represent large scale transformation of pre-existing sediments. King and Thomson also stated that some of the pegmatite is post-Torrowangee in age. Leslie and White (1955) who mapped a portion of the Torrowangee Series, 26 miles north of Broken Hill, noted that there is no evidence of post-Torrowangee igneous activity.

The writer considers the concordant pegmatites in the Angus area to be of a non-displacement type, which have been non-mobile, with the pegmatitic material having a local derivation.

Chadwick (1958) has suggested the following diagram to indicate the mode of emplacement of pegmatites:



The following definitions put forward by Chadwick (1958) will assist in explaining why the writer considers the concordant pegmatites to be of a non-displacement type.

<u>Displacement type pegmatite</u>: "The rock formerly occupying the site of the present pegmatite was moved bodily outward either before or during emplacement to make room for the pegmatite".

<u>Non-displacement type</u>: "Processes that do not involve bodily displacement of the host material from the site of the pegmatite may be termed types of non-displacement".

Within the area mapped observations indicate that the pegmatite is of a non-displacement type. Bands of schists which are interbedded with the pegmatites are not pushed aside by the pegmatites, also the foliation of the wall rocks is not distorted by the pegmatites.

To explain mobility and non-mobility Chadwick's (1958) definitions are quoted.

Mobility

"Material that occupied the site of the present pegmatite, either the original country or some product formed during emplacement, became bodily mobile at some time during the emplacing process, so that mass flowage or movement took place. The presence of a liquid or gas of pegmatitic composition is not necessarily implied. Rather than emphasize the condition of the medium from which the pegmatite developed, the definition is intended to include all processes that could produce certain observable effects - those consequent upon mass movement of the material present. Examples of mobile processes might include stoping of host rock, rheomorphism, consequent on metasomatic transformation, mass melting or solution, and plastic flowage or other localised movement during emplacement that would produce rotation or translation, in masses, of included fragments of the country rock. Solid host rock need not be present; residual crystallisation of pegmatite from a larger magmatic body entails mobility of the material occupying the pegmatitic site before crystallisation of the body".

Non-mobility

"The material at the site of emplacement was never mobile en masse but rather was dissolved and recrystallised or replaced by an intimate, increment-by-increment process. Outlines of the pre-existing texture and structure may or may not be preserved in the resulting pegmatite. Non-mobility might be effected by recrystallisation, crystalloblastic growth in which the host rock is not bodily pushed aside from the site of emplacement, metamorphic differentiation with the same qualification of metasomatism".

Observations in the Angus area indicate "non-mobility" during the emplacement of the concordant pegmatites.

The non-displacement, non-mobile type of pegmatite is sub-divided, according to whether it is introduced or derived locally.

Chadwick (1958) suggested the following reasons for introduced and locally derived material:

Introduction: "At least some of the pegmatite constituents came into the site of emplacement from elsewhere. Possible mechanisms of introduction are: stoping into a chamber below the site of the present pegmatite, assimilation of wall rock by introduced pegmatitic material and metasomatic transformation of country rock".

Local Derivation: "The material composing the pegmatite was derived essentially at the site of emplacement; any solid host rock present was dissolved, differentiated or transformed without additions from beyond the immediately surrounding rocks".

Features of the concordant pegmatites which stand-out after mapping and laboratory studies are: the association of pegmatites with sedimentary, soda rich, "aplites", both across and along strike, and the abundance of sodic plagioclase in the pegmatites. Some fine-grained concordant pegmatites resemble "aplites". Transgressive pegmatites are richer in potassic felspar than the concordant pegmatites.

Browne (Andrews, 1922) noted that the pegmatites are soda rich in the Broken Hill district.

The writer considers that the development of the concordant pegmatites is dependent upon the nature of the pre-existing sediments, as the greater proportion of pegmatite has developed in zones which contain "aplite".

A study of the "Interpretation of Geology" plans (X27/780 and X27/781) when placed over the geological plans (X27/762 and X27/763), shows that the "aplites", which are thought to have a sedimentary origin, are closely associated with the concordant pegmatites. Both rock types are fine-grained when interbedded. The "aplites" which are considered to represent original felspathic sands would have changed along strike to sediments containing increasing amounts of pelitic material, thus becoming felspathic sub-greywackes if up to 10% pelitic material were present (Folk, 1954).

Under metamorphic conditions the grains in the felspathic sands are thought to have developed an even texture during crystalloblastic growth. The ions would have been in an environment of almost "equal-potential" as the original felspathic sand sediments would have tended to be equi-granular, and the quartz and felspar fairly evenly distributed. Any ions could have distributed themselves evenly throughout the rock and did not form blebs.

In the felspathic sand sediments with a proportion of pelitic sediments, ions such as sodium, potassium and silicon were not in an environment of "equal potential" as the quartz and felspar grains were not so evenly distributed throughout the rock. The ions tended to seek nuclei which were randomly spaced, therefore blebs of quartz and felspar began to form. The pegmatites would have been formed by the development of such blebs.

Ramberg (1956) explained many of the occurrences of pegmatite in West Greenland by suggesting a method whereby mobile ions were deposited upon irregular nuclei and formed blebs, and eventually masses of pegmatite.

It is considered that the soda rich concordant pegmatites and soda plagioclase, quartz rocks ("aplites") in the Angus area were derived from soda rich sediments, and not the result of soda metasomation. The pelitic portions of the sediments would have consisted of clays which would not have contained an abundance of hydromica. However sericitic material plus minor hydromica present in the felspathic sands, could have combined with silica under metamorphic conditions and produced potash felspar. Other alumina in the form of Kaolinite ($Al_2O_3\ 3SiO_2\ 2H_2O$), or other clays, would have combined with the abundant sodium ions to form plagioclase.

Throughout the area mapped it has been noted the pegmatites often show a greater development in fold environments, whether the folds are small or large, suggesting movement of ions to such environments.

Apart from being concordant with the sediments, it has been noted that very minor amounts of pegmatites near folds appear to be discordant and could favour a pre-existing cleavage. These pegmatites have the same properties as concordant pegmatites, and are unlike the "transgressive" pegmatites.

Relict bedding is not a prominent feature of the concordant pegmatites and is only noted to a very minor degree in the fine-grained pegmatites which are associated with the "aplites".

Zoning or chilled margins were not noted in the concordant pegmatites.

No wall rock impoverishment was noted when examining rock slides A/180/42 and A/180/180. It was noted in A/180/180 that there is a small pegmatite development in a small fold in the wall rock, also potassic felspar was added to wall rock in specimen A/180/42.

Often the contact between pegmatite and schist is definite, although the pegmatite follows the smaller crenulations in the schist wall rock. The relatively sharp contact is explained by a sharp change between the original sedimentary compositions of the wall rock and the rock now made over into pegmatite.

No acid igneous rocks occur in the area with the exception of the "transgressive" pegmatites and quartz veins.

As stated, the felspars in the concordant pegmatites would consist of approximately 80% sodic plagioclase. 98-100% of the felspars in the "aplites" is sodic. This fact would be in keeping with the pegmatites being derived from sediments which occur in the same zones as the "aplites".

Specimens taken from schist bands occurring inter-bedded with the pegmatites, and a specimen in contact with the pegmatites show that the felspar in them is also mostly sodic with minor potassic felspar.

As the pegmatites are considered to have an origin brought about by a metamorphic-metasomatic process, then diffusional transfer is essential. From the lack of muscovite, and the development of garnet and sillimanite in places, it would appear that the conditions under which the pegmatites were developed tended to be "dry" rather than "wet".

No stoped material (xenoliths) was noted in the concordant pegmatites.

No perthite has been noted, with the exception of the crystals in specimen A/180/157, which was collected near a transgressive pegmatite.

The accessory minerals present, biotite, chlorite, tourmaline, garnet, sillimanite, magnetite, zircon, apatite, and rutile, do not detract from the pegmatites being produced from pre-existing sediments.

The tourmaline could have been introduced into the concordant pegmatites, as transgressive pegmatites occur nearby. Sillimanite also occurs in the specimens which contain tourmaline. It is thought that the sillimanite inclusions were present in the concordant pegmatites, and have been "protected" by the quartz and felspar grains when volatiles from the "transgressive" pegmatites were introduced.

Garnets occur in those specimens which have little or no potash-felspar content. The manganese content of the garnets in the specimen examined is 3.1% MnO. Acid igneous rocks (pegmatites and granites) generally have a higher manganese content in the garnets (Wright, 1938 and Tröger, 1959).

Zircons present are small and rounded. Although minor they were noted in a fine-grained pegmatite, but are rare to absent in the coarse-grained pegmatites. In the "aplites" which often grade into concordant pegmatites, zircon is common. The rounded zircons in the concordant pegmatites are thought to have a sedimentary origin, although it is not overlooked that a minute and a square-shaped zircon crystal was noted in the transgressive pegmatites.

Rutile grains occur in an "aplitic" pegmatite. Most grains are rounded, with one grain being ragged. The rutile grains are presumed to have been deposited as such rather than the growth of rutile from leucoxene which could have been adsorbed on clays.

2. "Transgressive" Pegmatites

These pegmatites are characterised by their "cross-cutting" mode of emplacement. They generally strike in an E-W direction. Notable amounts of muscovite, often occurring in "books", are present. Beryl crystals are found in these pegmatites. The transgressive pegmatites often parallel the bedding for short distances in fold environments.

The rocks resist weathering to some degree, and form ridges with relief of several feet in places.

The widths of the pegmatites vary from a few inches to tens of feet. The thick occurrences have often been worked economically for their potassic-felspar as well as beryl and mica content.

Lady Beryl and Spar Ridge quarries which occur within the area mapped, and Egebek and Triple Chance quarries occurring to the west of the area mapped, have all been opened in the transgressive pegmatites.

The length of the transgressive pegmatites can be in excess of 2,000 feet. The high grade potassic felspar portions occur intermittently, although they can be in excess of 300 feet in length and up to 50 feet wide.

Many of the narrow transgressive pegmatites have a "clean" contact along one edge. The contact appears to be a joint face, which dips from 50°-60° southerly to near vertical.

Mapping shows that a possible north-block-west movement has taken place, and offset "aplite" zones occurring to the north of the Angus Mine. Transgressive pegmatites occur in the offsetting fractures.

Along the pegmatite contacts there is often a narrow edge of fine-grained quartz and muscovite, followed by a band of fine-grained quartz, then the coarse-grained pegmatite. Within the centre of the pegmatite there is often a quartz core.

Referring to the diagram on page 22, it is concluded that the transgressive pegmatites are of a displacement type having a permissive emplacement, although the emplacement could be partly forceful.

Definitions are used by Chadwick (1958), and are explained:

Permissive Emplacement: "The pegmatite crystallised passively in an opening formed before or during the ingress of pegmatitic material consisting perhaps of fluid or perhaps constituents diffusing without the movement of a pegmatitic fluid".

Forceful Emplacement: "Growing or crystallising pegmatitic material forced aside the walls of an opening which was perhaps extremely small. This force was either pressure acting from an intrusive or locally derived fluid or force exerted by mineral aggregates growing crystalloblastically in an essentially solid medium and bodily pushing aside the host rock. Regional deformation contemporaneous with emplacement is considered forceful to the extent that the pegmatitic material moved under large-scale forces, exerted pressure upon the surrounding rock and deformed it. The deformation may have occurred during only the final stages of emplacement of a pegmatite which had developed by other processes before that time; however, the classification is necessarily based on the stage or stages from which geologic evidence is preserved, perhaps only the final one."

In the field the transgressive pegmatites are best developed in the competent rocks, especially where these rocks are folded. "Aplites", amphibolites and concordant pegmatites acted competently and the transgressive pegmatites are best developed in these rocks. In places the transgressive pegmatites can be seen to continue into the schists and gneisses, but the development is narrow and dies out. The possibility of the transgressive pegmatites being obscured by alluvium in the easily weathered schists and gneisses is not overlooked, but observations suggest that this is not so.

The pegmatites vary from fine-grained to coarse-grained, with some resembling true aplites. The felspar in the rocks ranges from white to brownish-red in colour.

Graphic pegmatite is common, but perthite was not noted in the specimens collected. Perthitic intergrowths were observed in the felspars at the Triple Chance quarry. (Plate 1, Fig.1).

Edwards and Williams (1959) noted a perthitic intergrowth of microcline and albite of a felspar sample from Baker's Prospect (Plate 1, Fig.1). The specimen has 11.81% K_2O and 3.41% Na_2O present. Rayner and Hall (1949) also noted perthitic intergrowth of felspars in the transgressive pegmatites. An assay of felspar from the Egebek Quarry (Plate 1, Fig.1) gave values of 9.68% K_2O and 3.83% Na_2O.

Etching and staining, and petrological studies of the transgressive pegmatites in the south-western portion of the Angus area, show that potassium felspar is abundant, and can be as much as 95-100% of the felspar present. However, transgressive pegmatites elsewhere in the area contain from as little as a few specks to 50% potassic felspar of the felspar present.

Only 2-3% of the felspar in specimen A/180/63, collected near the Spar Ridge quarry, is potassium felspar.

The quarry was worked for the felspar content.

Another specimen A/180/74 which consists of 50-60% sodic felspar, 5-10% potassic felspar, 20-30% quartz and 5-10% muscovite; was assayed by the writer, using a flame-photometer, gave values of 5.59% Na_2O and 2.02% K_2O. The assays indicate that the staining technique gives a good indication of the sodic and potassic felspar present in rocks.

Where transgressive pegmatites cut amphibolites, biotite is produced consequent upon the introduction of potassium. Specimen A/180/194 shows biotite being produced, also staining reveals that potassic felspar constitutes about 5%-10% of the amphibolite. Biotite is not common in the amphibolites, and staining of amphibolite specimens has shown that no potash felspar is present excepting in specimens which are cut by transgressive pegmatites, or when narrow amphibolites occur in pegmatite zones. At the western end of the Triple Chance quarry amphiboles have been altered to biotite where the large transgressive pegmatite contacts amphibolite. It was noted that the potassic transgressive pegmatite terminated at the amphibolite.

Minerals present in the transgressive pegmatites are: felspars, quartz and muscovite, with minor garnets, sericite, chlorite, biotite, sillimanite,and tourmaline.

Beryl is a major constituent in places. Rayner and Hall (1949) reported the occurrence of several tantalite specimens at Lady Beryl quarry, also some apatite associated with a quartz vein.

In a transgressive pegmatite, approximately 3 miles south of the Adelaide Road, on the track to the Angus area, an occurrence of johnstrupite, a cerium bearing mineral, has been reported (Johnson 1956). Specimens collected recently from the same location by R.V. Harvey, Department of Economic Geology, University of Adelaide, and examined by T.R. Sweatman and J.G. Pickering, Division of Soils, C.S.I.R.O., Adelaide, have strengite and possible frondelite present. These minerals are rare iron phosphates. The occurrences of these minerals are outside the area mapped.

Mineralogy

Felspar

Felspar would constitute approximately 60% of the transgressive pegmatites. In some occurrences the felspar is predominantly sodic (An_{04-12}), while in other occurrences the felspar is predominantly potassic, being orthoclase, and occasionally, microcline. Specimen A/180/74 shows some of the felspar to be anorthoclase. Green felspar, which is potassic rich, will be described under "pegmatites with green felspar".

The proportion of potassic to sodic felspar in both the concordant and transgressive pegmatites in the area mapped would be approximately 35:65; potassic felspar content is greater in the transgressive pegmatites than in the concordant pegmatites.

Twinning in the sodic plagioclases in the transgressive pegmatites is not as well shown as in the sodic plagioclases of the concordant pegmatites.

The twin planes are often bent, and occasionally small fractures offset the twinning.

Carlsbad twinning is not common, but was noted in specimens A/180/202 and A/180/203. Zoning of the felspars was not observed.

Grain sizes vary from less than 1 mm. to feet in length, although the coarseness or fineness of individual specimens is reasonably uniform.

The felspar grains are xenoblastic in the medium and coarse-grained pegmatites, but tend to be granoblastic in the fine-grained pegmatites. The transgressive pegmatites are considered to have been subjected to metamorphism, as the transgressive pegmatites are considered to be pre-Torrowangee. Metamorphic terms are used for the grains in the rock in preference to igneous terms, although no indications of growth were noted, although quartz grains have been strained.

Alteration of felspars is not common, as is the case with the felspars in the concordant pegmatites. Muscovite has developed in cleavages in microcline in specimen A/180/115. Inclusions are not common, although sillimanite occurs as inclusions in specimen A/180/121. Lines of minute black inclusions are found in the felspars in specimen A/180/110.

No perthitic intergrowths occur in the specimens collected, but some were noted in the field. Graphic intergrowth of potassic felspar bands, 1/4 inch wide, and quartz bands, 1/8 inch wide, occur in specimen A/180/123.

<u>Quartz</u>

Unlike the transparent to translucent quartz of the concordant pegmatites, the quartz which often occurs as a core in the transgressive pegmatites, is milky. Most of the quartz not within the core is transparent to translucent.

The quartz shows strain shadows, like all quartz in the area, including the quartz in the lode-horizons.

The quartz content of the pegmatities is 40% or less. Like the felspar grains, the quartz grains are considered to be xenoblastic in the medium and coarse-grained specimens, and tend to be granoblastic in the fine-grained specimens, A/180/118, 196, 198, 199, 202 and 203.

The size of the quartz grains varies from less than 1 mm. to feet in length.

Lines of minute blackish inclusions were not noted in the quartz grains in the transgressive pegmatites, but abundant minute blackish inclusions occur in the quartz in specimen A/180/89, which is in contact with a chlorite rock.

Muscovite

When mapping in the field the muscovite flakes in the transgressive pegmatites can be seen without close inspection, whereas close inspection is necessary to detect muscovite flakes in the concordant pegmatites.

Muscovite can be a major constituent of the transgressive pegmatites, but overall would be approximately 5-10% of the rocks. In the larger pegmatites, "book" muscovite flakes are up to 6 inches square. Often small "books" of muscovite have weathered from quartz crystals leaving a shape which can be confused with the shape a pre-existing beryl crystal would leave.

When "books" of muscovite are abundant it has been noted that beryl is generally present. The "books" of muscovite have no preferred orientation, although the "books" are generally small in the quartz and larger within the felspar.

The greater proportion of muscovite occurs as individual flakes, inclusions in quartz and felspar, and interstitially between quartz and felspar grains.

In the past some muscovite has been won from the quarries.

Garnet

Garnet is a minor mineral, although it occurs in six of the 18 transgressive pegmatite specimens which were collected, thus indicating that garnet is more common in the transgressive pegmatites than the concordant pegmatites.

The largest idioblastic garnet noted would be 1.5 mms., while elongated porphyroblastic garnets reach 0.8 mms, in length. The garnets are reddish in colour. Here again the metamorphic textural terms are used in preference to the igneous textural terms.

Many of the larger, cracked garnets have an iron alteration product.

Quartz inclusions in the garnets are not common, but do occur.

Minor muscovite is sometimes closely associated with the garnets, though the garnets generally develop in the fine-grained transgressive pegmatites, where muscovite is not well developed.

In specimens A/180/196, 198 and 202 which are rich in sodic plagioclase, garnets have developed, and have iron alteration products. Specimen A/180/202 shows a pegmatite-schist contact; no garnets have developed within the schist, but do occur within the pegmatite. Garnets occurring in specimen A/180/203, are minute to 0.2 mms. in diameter.

Garnet can be in equilibrium with potassic felspar if water is deficient. The following equation was put forward by Ramberg (1952):

$$KFe_3Si_3AlO_{10}(OH)_2 + KAl_3Si_3O_{10}(OH)_2 + 3SiO_2 \longrightarrow$$

biotite muscovite quartz

$$2KAlSi_3O_8 + Fe_3Al_2Si_3O_{12} + 2H_2O$$

orthoclase almandine water

To further support the suggestion that "dry" conditions existed in some of the transgressive pegmatites, it has been noted that the pegmatites with garnets are fine-grained and muscovite is poorly developed. Tourmaline has not been observed in the fine-grained pegmatites. Sillimanite has been observed in one fine-grained permatite.

No assays for manganese were carried out.

Sericite

Sericite is a minor alteration product of both the potassic and sodic felspars.

Biotite

In specimen A/180/110, which contains mainly potassic felspar and quartz, biotite is associated with garnets which occur in a band. Specimen A/180/198 contains a cluster, 3 mms. in diameter, of radiating biotite flakes; no potash felspar is present in this rock.

Biotite is rare in the transgressive pegmatites.

Chlorite

A few small occurrences of pegmatite with chlorite have been mapped in the southern portion of the area. The chlorite is in contact with the pegmatite in most cases. The grains often have a "rosette" appearance. In specimen A/180/89, chlorite occurs within quartz in the pegmatite.

The development of chlorite in contact with and within the pegmatites in the southern portion of the area, always occurs near amphibolite. It is thought that fractures have developed in the amphibolites, thus causing hornblende to alter to chlorite. The introduction of pegmatite, into the fractures, has followed. The plagioclase in specimen A/180/89, which contains pegmatite in contact with chlorite, has an An_{35} content. This observation indicates that calcium has probably entered the pegmatite from the pre-existing amphibolite. All other plagioclases in the transgressive pegmatites are sodic.

Minor chlorite is the alteration product of biotite in specimen A/180/198.

Beryl

Field observations have shown that the beryl is associated with transgressive pegmatites which are coarse and uneven grained, and contain notable amounts of muscovite, generally in "book-form". A crystal with measurements of 9 feet 6 inches long and nearly 3 feet in diameter has been reported to have been mined at the Lady Beryl quarry (Rayner and Hall, 1949). The size of the crystals range from a few mms. in length to that of 9 feet 6 inches.

Observations made at the Triple Chance quarry show that beryl develops best in the felspar near the edges of quartz cores; beryl also develops in the quartz.

(Rayner and Hall, 1949), noted that beryl crystals tend to be associated with quartz rather than with felspar.

The colour of the beryl crystals varies but a yellowish variety is most abundant; brownish, greenish and white were noted. Small amounts of beryl at the Triple Chance quarry are gem quality.

At the Lady Beryl quarry some of the crystals have an incipient quartz core; not a well developed quartz core like some specimens from the Olary district in South Australia.

As with the "books" of mica, no preferred orientation of the beryl crystals was observed.

The beryl is not distributed evenly throughout the transgressive pegmatites, but occurs in patches. Field observations indicate that beryl would make up a fraction of 1% of the transgressive pegmatites.

The development of beryl is generally considered to occur at a pneumatolytic stage of the emplacement of pegmatites.

<u>Tourmaline</u>

Tourmaline is a very minor constituent of the transgressive pegmatites. Tourmaline noted in the area, is black, or nearly so, which suggests an iron rich type (schorlite).

In specimen A/180/89, the crystals radiate from a point and occur in quartz; they are up to 3 inches in length with a diameter of 1/16 inch or less.

<u>Sillimanite</u>

Sillimanite also occurs in the transgressive pegmatites.

In specimen A/180/121, sillimanite makes up 45% of the rock, with the sillimanite needles being 0.4 mms. in length. The needles give the rock a herringbone and cone structure. The herringbone structure is seen when viewing the rock in two dimensions, but when viewed in 3 dimensions the needles are seen to radiate from points, and give the rock a cone structure. Most of the sillimanite needles are included in quartz in the specimen, which was taken from within a fine-grained pegmatite, with small amounts of muscovite.

Sillimanite needles also occur within quartz in a fine-grained specimen A/180/199.

The sillimanite has presumably developed under "dry" conditions, in fine-grained pegmatites, with minor muscovite. The quartz grains protect the sillimanite from alteration.

<u>Zircon</u>

Zircons are rare in the pegmatites. A minute grain is associated with plagioclase in specimen A/180/198, a fine-grained pegmatite. Specimen A/180/203, another fine-grained pegmatite, has a minute, square shaped, zircon crystal, occurring between the grain boundaries of quartz and plagioclase.

<u>Apatite</u>

Apatite is rare, although a few ragged grains are found in specimens A/180/196, 198 and 202, along quartz and felspar boundaries.

<u>Genesis</u>

The transgressive pegmatites are younger than most rocks in the area, with the exception of the siliceous lateritic rocks (Grey-Billy) and the possible exception of some of the lode material. The pegmatites have entered east-west striking "fractures", which appear to be joints in places. Movement has occurred in some of the pegmatite localities. The "fractures" are best developed in the competent rocks.

As the pegmatites have been emplaced in "fractures" it is most likely that the material entered at medium to shallow depths during a late stage of a tectonic period. There is no field evidence to suggest strongly that the pegmatites have been subjected to folding since their emplacement, although the strike of outcrops varies slightly in places. Quartz grains show strain shadows under the microscope.

The pegmatites are a displacive type having a permissive emplacement, although partly forceful. The transgressive pegmatites in the south-western portion of the area, where the pegmatites are relatively large, are believed to be "introduced" and contain abundant potassic felspar, large muscovite flakes and very often, beryl crystals. The transgressive pegmatites elsewhere in the area are believed to be partly introduced and partly of "local derivation".

As the transgressive pegmatites are generally best developed in "aplite" zones containing bands of "aplite" and concordant pegmatites, the material for the transgressive pegmatites could be derived from these. Should a fracture develop in the "aplitic" zones, then ions would become mobile and close the openings. Ramberg (1956) noted that pegmatites in West Greenland fill joints, shears, noses of folds and other such structures which produce a "pressure low", thus allowing the ingress of mobile ions from the surrounding rocks. The transgressive pegmatites, excepting those occurring in the south-west portion of the area, are sodic rich and have a similar composition to the concordant pegmatites and "aplites".

Zoning in the pegmatites is observed in the south-western portion of the area. The zoning is thought to be the result of "introduced" material, however, it is possible to have zoning in pegmatites which are derived from the adjoining sediments. Ramberg (1956) envisages the migration of mobile ions into openings, from their "ends". The openings would be expanding joints. The zones crystallise inward from the walls as the joint expands. Chadwick (1958) would agree with the above development of zoning if the shape of the pegmatite is regular.

As the wallrock foliation is not bent to parallel the observed pegmatite contacts, an expanding joint is more likely than force from growing pegmatites expanding the openings. However, in the larger somewhat irregular deposits in the south-west of the area, a combination of both types of openings could exist, with the "expanding joint" mechanism being the major type.

Specimen A/180/202, is a rock showing a transgressive pegmatite-schist contact. The contact is sharp, and the foliation of the schist is not bent to be parallel to the contact. There is no enrichment of felspar in the schist.

The occurrence of antiperthite in the larger deposits in the south-west of the area, indicates that the temperature was near 660°C during deposition (Bowen and Tuttle, 1958).

The presence of abundant muscovite, and very often beryl, in the coarse-grained pegmatites, shows that such pegmatites were deposited under "wet" conditions with possible volatile material, and suggests a "pneumatolytic" stage of deposition. Minor tantalite at the Lady Beryl quarry, suggests a "pegmatitic" stage of deposition. The stages would be, pegmatitic, pneumatolytic and hydrothermal.

The finer-grained pegmatites, minor muscovite, garnets and sillimanite would probably have been deposited at a temperature above the stability of muscovite.

The source of the introduced pegmatites in the south-west of the area is not known.

As soda metasomatism is thought not to have occurred in the Angus area, the source of potassium could not be explained by displacement of potassium from rocks by sodium.

Should some of the pegmatitic material in the beryl bearing pegmatites be derived from the sediments, then the possibility of widespread beryllium occurring in the "aplitic" zones must not be overlooked.

Four specimens were assayed for beryllium by A.B. Timms, Australian Mineral Development Laboratories, Parkside, South Australia, using optical spectrographic methods. The four specimens were collected in the upper "aplitic" zone, which is traversed by several beryl bearing pegmatites. The specimens are:

A/180/64	Banded pegmatitic "aplite" - 800 feet east of Spar Ridge quarry
A/180/65	Fine-grained concordant pegmatite - 800 feet east of Spar Ridge quarry
A/180/67	"Aplite" - 4,800 feet west of Spar Ridge quarry
A/180/165	"Aplite" - 3,000 feet east of Spar Ridge quarry

A/180/64 No detectable beryllium

A/180/65 No detectable beryllium

A/180/67 No detectable beryllium

A/180/165 Detectable - but less than 10 ppm.

Beryl has been won from the Spar Ridge quarry, and it is interesting to note that the specimens taken near the quarry do not contain beryllium whereas Specimen A/180/165 taken 3,000 feet to the east contains a detectable amount.

As a large company could not work economically any of the transgressive pegmatites individually or collectively, for their beryl content, then a Beryllium Detector, (berylometer) should be used to carry out a systematic survey of the upper "aplite" zone to determine if beryllium is widespread in such rocks, which are considered to be altered arkoses or felspathic quartzites.

Kleeman (1944) noted that beryl from Boolcoomatta, South Australia, has a refractive index $\omega = 1.581$ although the beryl was collected from several localities, and the colour varied. He also noted that assays of beryl specimens of different colours, were similar. Edwards and Williams (1959) noted that the refractive index of a beryl specimen from the Broken Hill area is

$\omega = 1.585 \pm 0.002$.

No conclusion is drawn from the results, but if beryllium were concentrated from sediments, perhaps beryls of uniform refractive indices could develop.

3. Pegmatites with Green Felspar

Pegmatite with green felspar is a minor rock type in the Angus area, and is always found in or near the mineralised zones. The long axes of the pegmatites parallel the strike of the foliation.

Stillwell (1959) has outlined the work which has been done on the green felspar in the Broken Hill district. The felspar is considered to be orthoclase, not microcline, and the green colour is attributed to possible minute inclusions, or replacement of potassium ions by lead ions in the lattice of the orthoclase.

A specimen of pegmatite with green felspar, collected at New Broken Hill Consolidated Limited, Broken Hill, was submitted by the writer to Dr. K. Norrish, Division of Soils, C.S.I.R.O., Adelaide, and Dr. J. B. Jones, Department of Geology, University of Adelaide. Drs. Norrish and Jones have noted that rubidium occurs in the green felspar. The presence of rubidium could give the green colour to the felspar by replacing potassium ions.

In the Angus area, pegmatite with green felspar and quartz has been noted only near galena mineralisation.

The green felspar becomes a darker green on exposure to sunlight for several days.

Lead is present within the green felspars in the pegmatites. Green felspars from two specimens, collected at New Broken Hill Consolidated Ltd., were assayed for lead. The values obtained are, 1.85% and 1.98% lead. Selected green felspars from pegmatites in the Angus area were also assayed, with the following results:

Specimen	A/180/39	- near the Angus Mine	- 0.181% Pb
"	A/180/73	- near 65,000'S-79,000'W	- 0.095% Pb
"	A/180/167	- " " "	- 0.11% Pb

The assays were determined by T.R. Sweatman, Division of Soils, C.S.I.R.O., Adelaide by using X-ray fluorescent spectrographic methods.

The important point to determine is whether the lead was emplaced with the pegmatites, or whether the incoming pegmatites entered sediments containing lead.

Near the Angus Mine, two small irregular shaped pegmatites in schists 250 feet north-east and 220 feet east of the main shaft respectively, contain green felspar. Green felspar was also noted to occur on the 190 ft. level of the Angus Mine.

The two small irregular shaped pegmatites in schists occur just to the east of the Angus-Kintore Zone of mineralisation. Biotite, garnet and minor zircons occur in Specimen A/180/39, which was collected 250 feet north-east of the main shaft; these minerals are considered to have been present in pre-existing sediments, as the pegmatite is small and irregular in shape, and muscovite is associated with the garnets. The zircons are minute and rounded. There is no indication to definitely suggest that lead entered with the pegmatite, or that lead was present in the sediments.

Specimen A/180/73, which shows green felspar occurring along the edge of a sodic-rich transgressive pegmatite, was collected at 65,000'S-79,000'W., where narrow transgressive pegmatites cut a mineralised zone. (See Plans Nos.X27/780 and X27/762). Specimen A/180/167, was collected near Specimen A/180/73, while Specimen A/180/74, was collected 250 feet to the east of Specimen A/180/73, in the transgressive pegmatite.

The possibility that the soda rich transgressive pegmatite carried and deposited lead where it cut "favourable" horizons is not favoured as Specimen A/180/73 shows white and green potassic felspar,occurring along its edge. It is more likely that the transgressive pegmatite either cut potassium, lead and rubidium bearing rocks, or potassium, lead and rubidium bearing material was emplaced in its present position later than the transgressive pegmatites.

As the pegmatites, with green felspar, which occur at the Angus Mine and throughout the Broken Hill district, are not transgressive pegmatites, the idea is supported that the green, lead bearing, felspars near the transgressive pegmatite at 65,000's-79,000'W are not genetically related to the transgressive pegmatites.

Genesis of the Pegmatites with Green Felspar

The pegmatites with green felspar are potassium rich, and occur in the mineralised zones which contain more calcium and manganese than most rock type zones in the area mapped.

The small pegmatites with green felspar where observed are always associated with "Broken Hill type" mineralisation in the Broken Hill district. Broken Hill type mineralisation is explained in the section in which mineralisation is discussed (p.215). The genesis of sulphide mineralisation and green felspar are closely associated. In the area mapped the green felspar is found near known lead sulphide mineralisation, in fold environments.

The pegmatites with green felspar are considered to have developed from constituents of the sediments during a period, or periods, of metamorphism, and are thought to have been emplaced, in their final positions, later than the transgressive pegmatites.

Orville (1959) carried out work, as described on page 61 of this thesis, which suggests that potassium ions would be repelled from a calcium environment during regional metamorphism. Such an origin is partly envisaged for the development of the green (potassium and lead bearing) felspars in the pegmatites.

Potassium ions could be very mobile ions during metamorphism and move to fold positions, along with silica, alumina and metallic sulphides. A combination of the idea of concentration of ions in areas of lower stress and the idea of repulsion of potassium ions from calcium environments could explain the development of pegmatites containing green felspar. It is likely that rubidium ions in the felspar gives the green colour and not lead ions.

As the green felspar and mineralisation are associated, the green felspar is again discussed in the section dealing with mineralisation.

Albite-Soda oligoclase-quartz Rocks ("Aplites").

The term "aplite" is a field term used by Broken Hill geologists for even-grained felspar and quartz rocks. Such terms as banded "aplites", siliceous "aplites" and pegmatitic "aplites" are also used. The term is incorrect as the rocks do not have an igneous origin. Where the term "aplite" is used in this thesis, it will imply that the rocks consist mainly of albite, soda oligoclase and quartz.

Next to the pegmatites, the "aplites" are the most abundant rocks cropping out in the area. The "aplites" are always concordant with the foliation of the schists and gneisses.

The zones of "aplites" are best seen by studying the "Interpretation of Geology" overlay sheets, Numbers X27/780 and 781.

The "aplites" are interbedded with pegmatites and schists. "Aplites" and amphibolites have a close association, especially when the two rock types are examined as zones. This association is important when discussing the origin of the amphibolites.

Individual "aplite" beds within the zones are generally only a few inches to a few feet wide, although the zones can be in excess of 1,200 feet wide and up to 5 miles long. There are 3 major zones, the upper and lower containing more "aplitic" rocks than the middle zone. The middle "aplitic" zone grades into pegmatite zones in places.

Tight folding is not a common feature of the "aplites", although it does occur.

The colour of the "aplites" varies; with some iron staining in most outcrops. "Aplites" which contain more quartz than felspar have a glassy, whitish colour, whereas the "aplites" with more felspar than quartz are dull creamish in colour.

The"aplites" tend to be even-grained, although some of the outcrops could be described as fine-grained pegmatitic "aplites", or aplitic pegmatites. In these rocks there are alternating bands of granoblastic grains and xenoblastic grains, often with minor amounts of biotite occurring between the bands.

The felspar and quartz grain size of the various "aplites" varies from approximately 0.3 mms. to 1.5 mms., although when the rocks are pegmatitic the grain size is often slightly in excess of 1.5 mms.

A very striking feature of the"aplites" is that the felspars present are mainly albite-soda-oligoclase (An_{02-14}), having never more than 2% potassic felspar present, excepting the specimens which have been collected near transgressive pegmatites. The felspars were determined optically and by staining methods. Assays have been carried out for sodium and potassium in a few specimens,as a check on the accuracy of the determinations.

The felspar-quartz ratios vary considerably. In some specimens the felspar content is as high as 70% of the rock, while other specimens contain up to 70% quartz; the latter resemble quartzites in the hand specimen.

Minor minerals present are: muscovite, biotite, chlorite, zircon, rutile, magnetite, limonite, apatite, haematite, pyrite, and epidote. Tourmaline is found intermittently in a narrow horizon for over a mile in the middle zone of "aplite" in the southern portion of the area.

Garnets were not observed in the "aplites", although fine-grained "transgressive" pegmatites which resemble the "aplites", often contain garnet. Russell (1957) also noted that garnets do not occur in the Thackaringa, Pinnacles, and Big Hill "aplites".

Mineralogy

Felspar

The grains of felspar tend to be granoblastic, although some of the rocks, which resemble pegmatitic aplites and aplitic pegmatites, have uneven grain sizes. The amount of felspar present varies from 30-70%. The grains of plagioclase show albite twinning, and are fresh in appearance, with very little alteration. The albite twin planes are often bent. Carlsbad twinning was noted in one specimen (A/180/90). Inclusions of quartz are common in the felspars.

Sodic plagioclase, albite-oligoclase (An_{02-14}) constitutes about 98% of the felspar present in the rocks. Potassic felspar when present, occurs as orthoclase, microcline or in antiperthite and generally occurs in the "aplites" with a pegmatitic appearance, such as Specimens A/180/64 and 84.

In Specimen A/180/64 some of the grains up to 1 mm. in length are antipheritic. Aligned potassium felspar blebs, up to 0.05 mm. long, occur within the grains. Another antiperthite grain shows oriented blebs of potassium felspar occurring along its edges. A small grain of microcline is in the specimen. One grain shows possible residual potash felspar in soda felspar. Most of the antiperthite grains occur along the grain boundaries of the soda plagioclase and appear to have developed later than soda plagioclase. Specimen A/180/64 was collected from an area between two transgressive pegmatites near the Spar Ridge quarry.

A specimen with abundant potassic felspar present is Specimen A/180/200, which was collected near a transgressive pegmatite 1,400 feet south-west of Spar Ridge quarry. Staining shows that potassic felspar grains up to 0.5 mms. occur throughout the specimen. Optical properties show antiperthite grains which have been strained like most other grains in the specimen. The antiperthite grains have irregular shape. A microcline grain occurs in the specimen. An antiperthite grain shows a small grain of residual albite which is oriented at right angles to the blebs of potassium felspar in the antiperthite.

Antiperthite and residual felspars have been only observed in the "aplite" specimens which were collected near transgressive pegmatites.

Refractive index measurements made on felspar grains in Specimens A/180/64 and 165, being representative of the "aplites", gave the following results:

Banded "aplite"	A/180/64	$\beta = 1.536$
Siliceous "aplite"	A/180/165	$\beta = 1.537$

The measurements were made by using an oil immersion technique. The refractive indices of the oils were checked by using an Abbe refractometer.

The results again indicate that the plagioclases present are albite-oligoclase.

Grain sizes vary from 0.3 mms. to greater than 1.5 mms.

in length, but generally the grain size is between 0.5 mms. and 1.0 mm.

Quartz

Like the felspar, the amount of quartz present varies from 30% to 70% in the "aplites". Grain sizes vary from 0.3 mms. to in excess of 1.5 mms. although they are generally between 0.5 mms. and 1 mm.

The grains tend to be granoblastic in most specimens, although in the pegmatitic "aplite" the grain sizes vary.

Most quartz grains show undulose extinction although the grains are fresh in appearance.

Minute blackish inclusions are found in some quartz grains. In Specimen A/180/56 minute black inclusions occur in hair-line, parallel fractures in the quartz grains.

Muscovite

Muscovite may be as much as 3% of the "aplites". When the amount exceeds 1%, the muscovite occurs in rough bands, and gives the rocks a weak foliation. Generally the flakes occur interstitially, with a few flakes being present as inclusions in quartz and felspar. Many specimens have only one or two minute muscovite flakes present.

The flakes reach 0.5 mm. in length, and 0.1 mm. wide.

Specimens A/180/54 and 56 taken from an "aplite" which grades into schists, have 5-10% muscovite present.

Biotite

Biotite is normally a minor constituent of the "aplites". The biotite generally occurs interstitially and not as inclusions. Many flakes show incipient or complete alteration to chlorite.

Some aplites have as much as 10%-15% biotite present. The biotite gives a gneissic or banded appearance to the rock (Specimen A/180/87). The flakes of biotite range from less than 0.1 mm. to greater than 1 mm. in length.

The flakes have a pale yellow to dark reddish-brown pleochroism.

<u>Chlorite</u>

Chlorite is an alteration product of biotite. Small amounts of sagenitic chlorite occur in Specimen A/180/85.

Flakes of chlorite are similar to biotite in size. In Specimen A/180/143, pale chlorite flakes, which are nearly isotropic have abundant haematite inclusions.

<u>Zircon</u>

Zircon is present in most specimens, having a grain size from minute to 0.1 mm. The zircons are rounded and are found along grain boundaries and as inclusions, also several occur in lines in some specimens. Some zircon grains are angular. Rounded zircons occur as inclusions in muscovite flakes.

Zircon is as much as 0.5% to 1% of some specimens.

<u>Rutile</u>

Rutile is another common detrital mineral, which occurs in most "aplite" specimens. The rutile and zircon grains are often associated.

Rounded and angular rutile grains do occur in the same specimen. Grain sizes range from minute to greater than 1.5 mms. They are found along grain boundaries and as inclusions.

Sagenitic chlorite contains needles of rutile.

Pegmatitic "aplites" contain less grains of rutile and zircon than the even-grained aplites. Rutile is as much as 2% of Specimen A/180/90.

<u>Magnetite</u>

One grain of magnetite was noted in Specimen A/180/90. The grain is 1 mm. long and 0.5 mm. wide, and is altering to haematite. A few euhedral grains of magnetite altering to haematite are found in Specimen A/180/56.

Limonite

Limonite is a minor constituent, which is found along grain boundaries, also pseudomorphing pyrite crystals.

Haematite

Haematite is often associated with limonite, along grain boundaries, and in cleavages in the felspars. Specimen A/180/143 contains approximately 15-20% haematite which is associated with limonite and possible goethite. Haematite occurs with chlorite and as an alteration product of magnetite. Haematite is a minor mineral in the "aplites".

Apatite

Apatite is rare and where present is found in the pegmatitic "aplites". The grains are minute and angular, although in Specimen A/180/200, apatite has a rounded appearance.

Pyrite

Pyrite has been found in the "aplites" with abundant quartz. The pyrite crystals are up to 1/16 inch in diameter, and are subhedral (Specimen A/180/154).

Limonite after pyrite has been noted.

Observations made indicate that pyrite occurs only in the upper "aplite" zone, although the occurrences are rare.

Epidote

Only one small occurrence of epidote was noted. In Specimen A/180/56, in a small fracture, 1.2 mms. long and 0.3 mms. wide, there is a mineral with optical properties of epidote. The mineral is length fast; only a flash figure could be obtained; it has one prominent cleavage with a weak cleavage at 90° to it; extinction is parallel; appears colourless; birefringence moderate to second order blues; relief high. The mineral appears to be secondary and is surrounded by limonite.

Ilmenite and Leucoxene

Ilmenite is rare in the "aplites". Most grains show alteration to leucoxene. In Specimen A/180/143, biotite is altering to chlorite, and leucoxene and rutile are associated.

Jarosite, Pyrophyllite, Amphibole and Montmorillonite

Jarosite, pyrophyllite, amphibole and montmorillonite are minor and were identified by X-ray methods. Specimen A/180/95 is the only rock in which they were found. Colourless fibrous material (pyrophyllite) gives the specimen a very weakly foliated appearance. Small clusters of jarosite are associated with the pyrophyllite fibres.

The colourless amphibole, which is very minor and associated with the pyrophyllite, has not been identified with certainty.

J.J. Pickering, Soils Division, C.S.I.R.O., Adelaide, examined the X-ray photographs, with the following results:

Material in clusters

jarosite) quartz) felspar)	moderate
pyrophyllite) amphibole)	minor

Fibrous material

pyrophyllite (talc)) quartz) amphibole)	moderate
felspar	minor
jarosite) montmorillonite)	minute

Specimen A/180/95 was collected at 65,100'S-81,400'W approximatimately. Along strike in a northerly direction, costeans and pits containing haematite are found. Jarosite has been identified at the Big Hill workings, some 2½ miles NNE of the Angus area; haematite is common at Big Hill.

The amphibole is probably anthophyllite, as no potassic felspar occurs in the rock. If potassium were present possibly biotite would have developed. The amphibole has straight extinction.

Genesis

Heavy minerals, such as rutile and zircon are rounded, and occur in all specimens. As the rounded zircon grains are up to 0.1 mm. in length, much of the original sediments would probably have been greater than silt size. The grains are not thought to have grown during metamorphism.

The "aplites" are conformable with the sediments throughout the area. No irrefutable sedimentary features were noted.

The zones of "aplites" are closely associated with amphibolite zones. The association will be discussed at length, when the amphibolites have been described.

As the "aplites" are very rich in sodic felspars, and potassic felspar is very minor, and absent in some specimens, the feature must be explained either by soda metasomatism, or by concluding that the original sediments were soda rich. Soda metasomatism is not invoked by the writer, and it is therefore concluded that the original sediments were soda rich.

One specimen, A/180/64, collected near a transgressive pegmatite shows one grain with possible residual potash felspar in an albite grain. Many grains in the specimen are antiperthite. Another specimen, A/180/200, also collected near a transgressive pegmatite shows residual albite in potash felspar. One could not conclude that soda metasomatism has taken place as a result of the observation made in Specimen A/180/64, as the occurrence of potassic felspar and antiperthite in the specimen appear later than albite grains.

No perthitic, antiperthitic or residual textures have been noted in the "aplites" with the exception of those specimens collected very close to transgressive pegmatites.

Orville (1959) has carried out work on two ternary felspar pairs which have different proportions of anorthite in the plagioclase felspar, and which are in close association with the same alkali-bearing solution. He shows that the pairs can approach equilibrium with the solution and each other, by exchange of K and Na ions.

The K ions from the calcic plagioclase-alkali felspar pair, migrate to the less calcic plagioclase-alkali felspar pair, and Na ions from the less calcic plagioclase-alkali felspar pair migrate to the calcic plagioclase-alkali felspar pair.

Orville (1959) suggested that the process is very likely to take place under conditions of regional metamorphism, in which rocks of heterogeneous composition are subjected to elevated temperature and pressure in the presence of a fluid phase. Operating under such conditions it provides a driving force for movement of potassium and sodium. Its effect would be to deplete calcium rich rocks, and enrich calcium poor rocks in potassium, with the reverse being true for sodium.

If soda metasomatism had taken place in the Angus area, it would be expected that the sodium would be "attracted" to the calcic felspars and "repelled" from the potassic felspars. There is no indication whatever, of the calcic plagioclases in the amphibolites, being enriched in sodium. If potassic felspar were abundant originally in the "aplites", it would be expected that the sodium would be "repelled".

The only indication of a more calcic felspar having ever been present in the "aplites", is the presence of a very minor amount of epidote in a small fracture in Specimen A/180/56. The specimen contains 60% quartz, 30% felspar and up to 10% muscovite. The muscovite appears high but the specimen was taken where an "aplite" grades into schists. Assays for sodium and potassium, carried out by the writer, give values of 2.83% Na_2O and 1.30% K_2O. As there is approximately 30% felspar present, the assay indicates that the felspar is sodic. Most of the potassium would be in the muscovite, although minor amounts could be present in the felspar.

Should soda metasomatism of the "aplites", have taken place, there is no indication of displaced potassium, with the exception of the "transgressive" pegmatites.

The writer considers that the sediments have been derived from medium-coarse grained acid rocks,containing abundant sodic plagioclase felspar. Washington (1917) shows analyses of aplites, granite porphyries, soda rhyolites, microgranites, granites, quartz keratophyres, granophyres, and felsites, from various localities throughout the world, which have less than 1% K_2O present, with some aplites and granite porphyries containing no K_2O. Many of the rocks mentioned are not abundant, and are not considered to be possible source rocks of the widespread sediments, now "aplites", in the Broken Hill district. The finer-grained acid rocks mentioned could have been subjected to metamorphism,thus becoming coarser-grained rocks, before being eroded.

Edwards and Baker, (1943) noted that the Jurassic arkose in Southern Victoria contains sodic felspar (oligoclase) which is in excess of potassic felspar. Assays for K_2O, carried out on the Jurassic arkoses, show the values not to exceed 1.98% K_2O, with one as low as 0.98% K_2O.

A typical "aplite" specimen, A/180/165 having approximately 50-55% plagioclase, 40% quartz, and 3-5% muscovite, was assayed, by the writer, for sodium and potassium, giving values of: 5.12% Na_2O and 0.48% K_2O. The assays indicate that possibly all of the potassium would occur in the muscovite, with little or none occurring in the plagioclase. If soda metasomatism had taken place it would be expected that much of the potassium in possible pre-existing felspars, would remain in the rock. This fact is considered to favour the postulate that the sediments were originally sodic rich and not metasomatised, as there is no evidence of widespread displaced potassium in the area. Nor is there any evidence of the "aplites" ever having been more calcic rich.

The "aplites" are thought to have remained equigranular, because the original sediments contained felspar and quartz of a similar grain size, and under metamorphic conditions blebs of quartz and felspar have not formed because mobile ions would be in environments of "equal-potential" and could distribute themselves evenly throughout the rocks. When pelitic material was present in the felspathic sands, mobile ions would not be in an environment of "equal-potential", and would have to seek quartz or felspar. Under these conditions the rocks tend to become fine-grained pegmatitic "aplites" as the grain sizes vary.

Biotite bands, which are not common, but do occur in some aplites, are considered to have developed from sedimentary bands of sericitic and chloritic material.

In the area mapped, the upper zone of "aplite" has minor pyrite; this feature is noted because it may assist workers in Broken Hill to correlate "aplite" zones throughout the area. As the felspathic sands would have been deposited under oxidising conditions, it is likely that the sediments were later subjected to reducing conditions, for the pyrite to form.

A study of the "aplites" in the Broken Hill district has been carried out by members of C.S.I.R.O., Mineragraphic Section, Melbourne, Victoria. The writer has not had the opportunity to study a preliminary report relating to the rocks.

Tourmaline Rock Interbedded with "Aplites"

Tourmaline is a mineral which is not present in the "aplites", however a narrow, intermittent, fine-grained, black tourmaline horizon has been mapped for over a mile along strike in the southern portion of the area. The tourmaline is interbedded with the "aplites". Because of the close association with "aplites" the tourmaline rock will be described before more abundant rock types.

The bands of tourmaline are up to 6 inches wide and a few feet in length, consisting mainly of friable fine-grained tourmaline with minor sodic plagioclase, quartz and sericite. Narrow veins 1/32 inch wide, carrying albite-oligoclase occur in fractures. Specimen A/180/12 is a typical specimen.

The size of the grains vary from 0.2 mm. to 1.0 mm. The grains are roughly rounded and pitted, although fresh in appearance. The pitting and rounding appears to be due to crystalloblastic growth. Few crystals have well formed crystal faces.

Other specimens, A/180/122 and 125, show the tourmaline occurring in alternating bands, 1/64th to 1/8th inch wide, with sodic plagioclase, 1/16th to 1/8th inch wide. These rocks have a gneissic appearance, and when mapped in the field can be mistaken for "aplites" with biotite bands.

The tourmaline shows pale yellow to yellowish-green pleochroism. Most of the grains are poikiloblastic with albite inclusions; there is no lining-up of the long axes of any of the grains. Tourmaline is approximately 40-50% of the banded rocks and 95-98% of the massive tourmaline rocks. The refractive indices of the tourmaline lie either side of 1.640.

Felspar present is albite-oligoclase, with inclusions of tourmaline. The size of felspar grains varies between 0.2 mm. and 1.5 mm. long.

No quartz was observed in Specimen A/180/125, but approximately 3-5% occurs in A/180/122. The quartz grains, 0.1 to 0.3 mm. occur as inclusions in the felspar, also grains occur between the felspar and tourmaline grains. Some of the inclusions in the tourmaline could be quartz, but the grains large enough for optical identification are plagioclase.

Muscovite is present as interstitial flakes up to 0.6 mm. long. About 1-2% would be muscovite.

Haematite occurs throughout Specimen A/180/122, along the boundaries and cleavages of felspar grains, also surrounding tourmaline grains. Limonite occurs with the haematite. Minor magnetite is altering to haematite. Staining revealed a few specks of potassic felspar.

The occurrence of the tourmaline rock within the "aplites" resembles the occurrence of weak mineralisation in the area, that is, as narrow, intermittent bands or blebs, although the tourmaline does not occur in small drag-fold positions. The massive tourmaline rock (A/180/124) was assayed for manganese, lead and zinc, giving the following values:

MnO	0.04%
Pb	119 p.p.m.
Zn	114 p.p.m.

The assays were carried out by T.R. Sweatman, Division of Soils, C.S.I.R.O., Adelaide, by X-ray fluorescent spectrographic methods.

As the tourmaline is present in a narrow horizon, and occurs intermittently for over a mile, it is possible that the tourmaline occurred as a narrow band in felspathic sands.

As the mode of occurrence of the lead and zinc in the tourmaline rock is not known, no conclusion is drawn regarding the origin of the metals.

Amphibolites

The amphibolites range in width from narrow bands a few inches wide to bands 300 feet wide, and occur in zones, which are up to 1,000 feet wide. The individual bands are concordant with the sediments, and lens out along strike. Some zones are over 5 miles in length. They resist erosion to a greater degree than the schists and gneisses, but not as well as the pegmatites and "aplites".

The colour of the rock varies from blackish, greenish black to greyish black, depending on the amount of felspar, quartz, epidote and ziosite present.

Whitish bands in some amphibolites, contain felspar, quartz, or epidote and zoisite. The bands of epidote-zoisite, and bands of quartz, generally do not exceed 1/8th inch wide, but the felspar bands reach 8 feet in width and 60 feet in length. Plate 2, Figures 1 and 2, show narrow felspar bands in amphibolite, while Figures 3 and 4, show broad felspar bands in amphibolites.

Some outcrops have porphyroblasts of amphibole, or large idioblastic garnets, which give the amphibolites a knotted appearance. The development of fine-grained garnets in other outcrops gives the rocks a reddish colour.

Platy weathering is not a feature of the amphibolites, and the only outcrop with platy "igneous type" weathering proved to be the only outcrop with pyroxene present. The outcrop is not foliated, although narrow, parallel bands of felspar, resembling bedding, parallel the outline of the platy weathering.

PLATE 2

1

2

Narrow calcic plagioclase bands (up to 3 inches wide) in amphibolite.

3

4

Broad calcic plagioclase bands (up to 8 feet wide) in amphibolite.

Most outcrops are massive, although most rocks are weakly foliated, or have a gneissic appearance.

The amphibolites have acted competently, and often have milky quartz filling fractures. Tight folding was not observed in the amphibolites.

A study of the "Interpretation of Geology", plans, Numbers X27/780 and X27/781, shows that the amphibolite zones are either just stratigraphically above or below "aplite" or concordant pegmatite zones.

No lava flow structures or chilled margins were observed in the rocks. Weak mineralisation is associated with the amphibolites which are in, or adjacent to, the broader zones of schists and gneisses.

Only one small transgressive amphibolite was observed in the area.

<u>Mineralogy</u>

Before outlining the mineralogy, an idea is given of the type of category into which the amphibolites were placed following a petrological study. The types are as follow, not necessarily in order of abundance:

amphibolites with marked foliation
amphibolites with siliceous bands
amphibolites with abundant garnets (1/8th inch in diameter)
amphibolites with porphyroblasts
amphibolites in contact with translucent quartz
amphibolites with zoisite, clinozoisite, epidote bands
amphibolites with "pegmatitic" bands
amphibolites with garnet sandstone

amphibolites with abundant quartz and garnet
amphibolites with pyroxenes and platy weathering
amphibolites with epidote crystals which weather to give vesicles
amphibolite - transgressive
amphibolites - near fine-grained transgressive pegmatites
amphibolite with copper staining
amphibolite in contact with lode
amphibolite with felspar bands
biotite, garnet, amphibole rock
amphibolite and transgressive pegmatite
amphibolite within pegmatite
tremolite-actinolite rocks
actinolite rocks
garnet, quartz rocks in amphibolites
amphibolite tending to amphibolitic quartzite
epidote rock in amphibolites

As the minerals are described they will be referred to the "amphibolite" category as outlined above.

Hornblende

The amount of hornblende in the amphibolites varies considerably, from as little as 10% in some of the banded epidote rocks, for example Specimen A/180/9, to as much as 90% in Specimen A/180/14, which has a pronounced foliation. In most specimens the hornblende is well developed,although lepidoblastic in the foliated specimens. The hornblende can occur in bands, or within bands of quartz, epidote-zoisite, or felspar.

The size of the grains range between 0.5 mm. and 1.0 mm. long, and between 0.3-0.7 mm. wide. Porphyroblasts, in Specimen A/180/26, reach a length of half an inch, with the matrix grains being 0.4 mm. in length.

The hornblende has yellowish or yellowish-brown to green or dark green pleochroism. Some specimens show yellowish-green to bluish-green pleochroism. The pleochroism was noted to give an idea of the degree of metamorphism, and to obtain an idea of the amount of sodium present. In Specimen A/180/13, which contains bands of zoisite, it is possible that sodium from altering calcic plagioclases (now zoisite) has entered the hornblende, as the grains have bluish-green pleochroism. Hornblende in specimens collected near pegmatites often show bluish-green pleochroism. If large scale soda metasomatism had taken place in the area, it could be expected that most of the specimens could show bluish-green pleochroism in the hornblende. This is not the case.

To assist in determining some of the amphiboles some readings were made, by K.J. Mills, Department of Geology, University of Adelaide, using the universal stage microscope. The readings are as follows:

		Extinction Angles
Specimen A/180/30	amphibole	$11\frac{1}{2}^\circ$ - $13\frac{1}{2}^\circ$
Specimen A/180/38	amphibole	13° - 14°
Specimen A/180/25	amphibole	11° - 19°
Specimen A/180/10	amphibole	$12\frac{1}{2}^\circ$ - 13°
	pyroxene	$41\frac{1}{2}^\circ$ - $43\frac{1}{2}^\circ$
Specimen A/180/193	amphibole	$17\frac{1}{2}^\circ$

From the above readings, plus information obtained by flat-stage microscope readings, the amphiboles present, in Specimens A/180/30, 38, 10 and 193 are hornblende. Specimen A/180/25 has actinolite present. The pyroxene, in Specimen A/180/10, which is altering to hornblende, is diopside.

Cleavage is shown in the hornblende in most specimens.

Apart from Specimen A/180/10, in which pyroxene is altering to hornblende, no other specimens show hornblende being produced in this way. Magnetite is often associated with hornblende, and this could be indicative that pyroxene has altered to amphibole.

Hornblende is altered to biotite, where amphibolites are cut by "transgressive" pegmatites; Specimen A/180/194 is an example.

No variation in grain size of hornblende has been noted near the contact of amphibolites and other rocks.

Hornblende in Specimen A/180/184, which was collected from the only mapped transgressive amphibolite in the area, has a grain size of 0.3-0.4 mm. in length, being less than the average grain size of the hornblende in all other specimens. The outcrop is 3,500 feet to the east of the Angus Mine, and is 200 feet long and 6 feet wide approximately.

Hornblende is often included in garnet, and in Specimen A/180/30, garnet is replacing hornblende. Small inclusions in the hornblende often have pleochroic haloes. The inclusions are thought to be sphene or apatite with uranium in the lattice.

Specimen A/180/208 has 2-3% hornblende present which is altering to chlorite.

Only one specimen, A/180/162, showed twinning in the hornblende.

Felspar

The amount of felspar present in the amphibolites varies from nil to 50%. Bands of calcic plagioclase may be as wide as 8 feet within the amphibolites, and these bands contain 95% plagioclase.

The felspar grains are xenoblastic. The grain sizes vary from 0.3-1.0 mm. in length, and many show that they have been strained.

Maximum extinction angle readings using the flat-stage microscope indicate that the composition of the plagioclases varies between An_{42}-An_{80}. A similar range has been noted for the felspathic garnet quartzites, An_{58}-An_{80}. Amphibolitised felspathic quartzites have plagioclase with a composition of An_{54}, while minor schists and gneisses with calcic plagioclase present have a content of An_{34}-An_{74}. Spotted gneisses, resembling "Potosi" gneiss, have a plagioclase composition of An_{33}-An_{52}.

An amphibolite, 300 feet to the west of the Angus Mine, consists of several bands of amphibolite in contact with each other. The colour and texture of each band differs from that of the next band. Specimens A/180/36, 37,38, taken from the bands have plagioclase An contents of An_{78}, An_{46}, and An_{55} respectively. Specimen A/180/10, which contains altering pyroxene has a plagioclase content of An_{57}.

The extinction angles indicate that the plagioclases in amphibolites are andesine to bytownite.

The extinction angles of albite and parallel twins were carried out by K.J. Mills, Department of Geology, University of Adelaide, using an universal-stage microscope and Tröger's graphs to check the results obtained by the writer, using a flat-stage microscope. Twenty-six amphibolite specimens were examined.

The results obtained by Mills are listed in Table 1.

TABLE 1

THE An CONTENT OF PLAGIOCLASES IN THE AMPHIBOLITES

Specimen No. Prefixed by A/180/	Extinction on	An Content
4	Albite twins	33-35
10	Albite and parallel twins	69-70
18	" " " "	78-84
30	Albite twins	57-58
33	Albite and parallel twins	63-70
36	Albite twins	77-94
37	" "	32-44
38	Albite and parallel twins	69-70
49	Parallel twins	85
50	" "	75-85
57	Albite twins	58
191	Albite and parallel twins	62-67
193	Albite twins	72-76

He found that the range is even greater that that shown by using the flat-stage microscope, the range being An_{32} to An_{94}. Individual plagioclase grains within the same specimen often have different compositions. This variation was also noted in the spotted gneisses, which resemble "Potosi" gneisses, and also in the gneisses with calcic plagioclase. For checking, in Specimen A/180/153, a spotted gneiss, seven plagioclase grains were examined twice and extinction readings were made on the albite and parallel twins in the same grain. The range obtained is An_{33} to An_{48}. A similar examination was made on a schistose gneiss, Specimen A/180/178, with calcic plagioclase; a range of An_{27} to An_{35} was obtained.

Whether the amphibolites were originally basic igneous rocks or sediments, the plagioclase is not in equilibrium. Three specimens A/180/36, 37 and 38 taken from 3 bands of amphibolites in physical contact with each other have plagioclases present with An contents ranging from An_{32} to An_{94}. The flat-stage microscope showed a range of An_{46} to An_{78}.

Wilcox and Poldervaart (1958) found that metadolerites and amphibolites of doubtful origin in the Bakersville-Roan Mountain area of North Carolina, have variable plagioclase present. In the subophitic metadolerites the most calcic plagioclase is An_{50}. The granoblastic amphibolites or metadolerites have oligoclase. The porphyroblastic metadolerites have oligoclase (An_{18}) in the groundmass and andesine (An_{42}) as porphyroblasts. These rocks have been subjected to amphibolite facies grade of metamorphism. Normal unmetamorphosed dolerites have plagioclase which is An_{60-65}.

In the south-eastern portion of the area described by Wilcox and Poldervaart (1958), undoubted para-amphibolites occur. A description of the para-amphibolites of sedimentary origin is to be published by Brobst and Kulp, under the title of "Geology of the Spruce Pine District, North Carolina", in the U.S.Geol. Survey, Professional Papers. Unfortunately, there is no record of this paper as yet, thus the writer is unable to compare the plagioclases of metadolerites, amphibolites of unknown origin, and sedimentary amphibolites, within the same district, and in turn apply the information to the Angus area.

Edwards (1957) noted that amphibolites of sedimentary origin from the Appolyon Valley area, in the Broken Hill district, have labradorite or anorthite present. In the Peak Hill area, Broken Hill district, the plagioclase is bytownite in sedimentary amphibolites. The amphibolites in the Broken Hill basin, considered to have an igneous origin by Edwards, have labradorite felspar present.

The felspars described by Wilcox and Poldervaart (1958) and Edwards (1957) will be discussed when describing the genesis of the amphibolites.

Returning to the amphibolites of the Angus area, most grains of plagioclase are clear, although in some specimens which contain epidote, zoisite or clinozoisite, the plagioclase has altered to these minerals. Sericitisation of felspars is not common, but does occur in Specimens A/180/12, 18 and 24, which have abundant large blebs of quartz present.

A feature of the plagioclases in the amphibolites and other rocks with calcic plagioclase present, is the presence of parallel twinning, apart from the albite twinning. From observations made, it would appear that parallel twinning occurs only in the calcic plagioclase.

Turner (1951) and Gorai (1951) independently arrived at the conclusions that albite and pericline twinning are common in igneous as well as metamorphic rocks; but carlsbad and albite-carlsbad twins are generally found in volcanic and plutonic rocks.

As the amphibolites under study could be either sedimentary or igneous in origin, and have been metamorphosed, the findings of Turner, and Gorai, cannot be applied with certainty.

Carlsbad twinning is found in plagioclase in Specimen A/180/193, which has bands which appear to be pegmatitic, but calcic plagioclase is present. Specimen A/180/184, taken from the transgressive amphibolite has one plagioclase grain which has possible carlsbad twinning; in the same specimen the cores of some plagioclase grains have an An_{30} content and an outer rim of An_{43}, that is, reverse zoning.

Zoning is also shown in one plagioclase grain in Specimen A/180/193; the inner portion is twinned very finely, and the outer portion is untwinned. Specimen

A/180/33 collected near the Angus Mine, and also Specimen A/180/187, show zoning in the plagioclases, with reverse zoning in Specimen A/180/33.

The amount of felspar in the amphibolites is less in the specimens which contain garnet. In Specimen A/180/61, which has no plagioclase present, patches of garnet have developed. The garnets are small and friable like garnet sandstone; but the colour is reddish, not pinkish.

Specimens A/180/15 and 204 were taken from within pegmatite zones; Specimen A/180/15 collected within a fine-grained transgressive pegmatite shows that the plagioclase within the amphibolite is sericitised, with twinning poor to absent. The plagioclase has a content of An_{33}, suggesting the introduction of sodium, although there is no indication of hornblende becoming sodic. In Specimen A/180/204, which was collected from within a concordant pegmatite zone, most of the plagioclases have been sericitised, and the composition of the plagioclase is An_{44}. The hornblende in this specimen shows straw to bluish-green pleochroism, indicating that some sodium may have entered the hornblende. From these observations it would appear that the final stages of the development of pegmatite took place after the deposition or emplacement of the amphibolites.

The composition of the plagioclase in the transgressive amphibolite is An_{46}, with the exception of the grain with reverse zoning (inner An_{30} - outer An_{43}).

An unusual occurrence of plagioclase is found in banded amphibolites in the north-west portion of the area. As shown in Plate 1, the felspar can occur in narrow or broad bands. Specimens A/180/48 and 51 have been taken from broad plagioclase bands, and Specimens A/180/50 and 51 contain alternating bands of hornblende and plagioclase. The plagioclase is fresh with albite and parallel twinning; a few grains are altering to clinozoisite.

Specimen A/180/48 which is mainly plagioclase, was examined for other minerals. The minerals present are:

Magnetite and ilmenite	- abundant accessory
Sphene	- abundant accessory
Rutile	- abundant accessory
Zircon	- rare accessory

Apatite	- rare accessory
Tourmaline	- rare accessory
? Gahnite	- rare accessory
Chlorite	- rare accessory
Biotite	- rare accessory

An elutriation method was used to separate the minerals from the plagioclase rock.

The rock was further examined with the aid of the Franz Isodynamic Separator. In the fraction obtained at 0.7 amps, 15° forward and 15° side tilt, and having a grain size -120 to +240 mesh, one light-dark green, isotropic crystal was observed. The refractive index of the mineral is greater than 1.8. Sufficient grains were not obtained to take X-ray photographs using the powder technique to verify the presence of gahnite.

As the presence of gahnite is suspected, the fraction containing the suspected mineral was assayed, by T.R. Sweatman, Division of Soils, C.S.I.R.O., Adelaide, using X-ray fluorescent spectrographic methods. The values obtained are, 51 p.p.m. zinc and 6 p.p.m. lead. The zinc and lead values are much lower than values obtained for several amphibolite specimens (Table 2, page 98).

As the felspar bands are up to 8 feet wide, the rock could be considered to have been an anorthosite, being a possible segregation from a gabbroic magma, although the number of heavy minerals suggest a sedimentary origin.

Edwards (1957) noted amphibolites of sedimentary origin in the Peak Hill area, with bands of plagioclase with sphene present.

Some of the small bands of plagioclase, in the banded amphibolites in the north western portion of the Angus area, are pegmatitic in appearance, and transgress the amphibole bands to join to plagioclase bands. Specimen A/180/195 is an example. On examination the An content of the plagioclase in the concordant bands is the same as the An content in the transgressive, although the quartz content of the transgressive bands is as much as 25%.

Potassic felspar is found in Speciman A/180/194 and 197, which occur near fine-grained and coarse-grained transgressive pegmatites. Staining shows that the potassic felspars transgress the banding in Specimen A/180/194, and the foliation in Specimen A/180/197.

In a few places the amphibolites grade into rocks with minor amphibole. The plagioclases in such rocks have contents of An_{54-67}.

<u>Quartz</u>

A feature of the amphibolites is that many have as much as 30% quartz present, especially the banded varieties. There is no indication that the quartz has been emplaced following the deposition of the amphibolites. Metamorphic differentiation is not overlooked and will be discussed.

The quartz crystalloblasts are generally xenoblastic, although in the banded amphibolites the quartz tends to be granoblastic and slightly larger in grain size.

The grain sizes vary from 0.2-1.0 mm. Most specimens show the quartz to have undulose extinction.

Minute blackish inclusions are found in quartz in a few specimens. Sphene, hornblende and apatite are other inclusions which occur in the quartz. Quartz is often included in garnets and hornblende.

In the transgressive amphibolite (Specimen A/180/184) 2-5% interstitial quartz is present.

Specimen A/180/14, an amphibolite with a pronounced foliation, has no quartz present, and Specimen A/180/15, has small blebs of quartz within a mosaic of plagioclase. If quartz were to be introduced into the amphibolites, it would most likely enter foliated amphibolite such as Specimen A/180/14, yet no quartz is present.

Specimen A/180/208 was collected by W.N. Thomas, The Zinc Corporation Limited, at a position 3,500 feet to the east of the Angus Mine, in the amphibolite zone above the lower "aplite" zone. The rock has 2-3% altering amphibole, 45% epidote, and 50-55% quartz, plus minor chlorite, magnetite, sphene and apatite. Another specimen, A/180/16, collected by the writer, near Specimen A/180/208, is a banded amphibolite with up to 60% quartz present.

Specimen A/180/18, consists of narrow alternating bands of hornblende and quartz in contact with a 1 inch band of quartz with minor hornblende.

Specimens A/180/12, 24 and 27 contain abundant quartz, and were collected in small fold environments in the amphibolites. The rocks show faint to good banding, although the quartz bands and patches are irregular in shape. The quartz is transparent to translucent, unlike the milky quartz "blows" in the area, which have obviously been emplaced at a late stage. The quartz in the small folds in the amphibolites is considered to have migrated to the noses of the folds.

In the amphibolite (Specimen A/180/10) containing pyroxene, the quartz is present as minor interstitial blebs. Specimen A/180/61, which contains clusters of small friable garnets, resembling garnet sandstone, has minor quartz present as interstitial blebs.

Specimens A/180/57 and 170, which contain abundant garnet, up to 3/16th inch in diameter, have 25% and 5-10% quartz present respectively.

In amphibolite Specimens A/180/193 and 195, which have pegmatitic looking bands present, there is as much as 10% and 25% quartz present respectively.

In the Specimens A/180/9 and 13, which have bands of clinozoisite and zoisite alternating with hornblende bands, the quartz content is 30% and 20% respectively.

Three Specimens, A/180/36, 37, 38, which were taken from lenses of amphibolite, in contact with each other, within a broad zone show that Specimen A/180/36 has approximately 10% quartz, Specimen A/180/37 has 30% quartz, and Specimen A/180/38 has approximately 3% quartz. Percentages of minerals in the rocks have been determined by referring to diagrams prepared by Shvetsov, and described by Terry and Chilingar (1955).

An amphibolite, which is in close association with the lode at the Angus Mine, has 10-15% quartz present in "weak" bands, and also occurring interstitially, and as inclusions.

Specimen A/180/71 has abundant quartz and fine-grained reddish garnets, and minor chlorite altering from hornblende. Specimens A/180/52, 69 and 70, resemble A/180/71, but no chlorite or hornblende is present. Quartz-gahnite is associated with Specimen A/180/70. These fine-grained garnet-quartz rocks, which occur in the amphibolites, tend to be similar to the friable, pinkish garnets and quartz in the lode horizons.

Amphibolites grade into biotite-garnet-amphibole rocks; as the biotite content increases the quartz content decreases. In the amphibolitised felspathic quartzites, the quartz content is as high as 40%; Specimens A/180/60, 117 and 191 are examples. These rocks occur in the same horizons as amphibolites.

An actinolite rock (Specimen A/180/25) with minor plagioclase (oligoclase) and magnetite, and also a tremolite rock, (Specimen A/180/101), clouded with possible graphite, occur approximately 4,000 feet north of the Angus Mine. The rocks contain no quartz, and occur in the same horizon as amphibolites.

Minor quartz, with minute inclusions, is found in garnet-actinolite-calcite rocks, which are found within amphibolite bands. Specimens A/180/28 and 32 are typical of the rocks.

Epidote-quartz blebs, generally not more than a few inches in length, are found within the amphibolites. Specimens A/180/171 and 172 are examples and have 40% and 20-30% quartz respectively. Minor chlorite appears in A/180/171 and minor amphibole altering to chlorite is found in A/180/172.

In the hand specimen, the amphibolites often do not appear to have felspar and quartz present in major amounts. For example Specimens A/180/58 and 104, which have faint gneissic appearance, contain approximately 20% and 30% quartz respectively.

The amphibolite specimens have been taken from most zones in the Angus area, and it is obvious that the quartz content of many of the specimens is far in excess of the amounts which would be present if the rocks were originally gabbros, dolerites, or basalts. Basic tuffs could well explain the amount of quartz, without having to introduce the quartz. If the amphibolites were derived from sediments the high quartz content could be normal.

Stillwell (Andrews, 1922) concluded that the high quartz content of the amphibolites was brought about by the development of garnet.

Stillwell noted that the quartz content of the garnet amphibolites is as high as 34.3%. Also a zoisite amphibolite contains 13.4% quartz, while the combined quartz and felspar contents were noted on other specimens.

In the Angus area, garnet amphibolite Specimens A/180/57, 170 and 61, have 25%, 5-10% and minor interstitial blebs of quartz respectively.

Most of the amphibolites, in the Angus area, with high quartz contents are not rich in, and even lack, garnets.

Very little quartz would be produced if pyroxenes have altered to amphiboles.

Garnet

The percentage of garnet present in the amphibolites ranges from nil to greater than 50%. The garnets are mostly idioblastic, and have an average grain size of 0.3 mm. Larger garnets, up to 1.5 mms. are often cracked and ragged, and have iron alteration products in the cracks. Specimens A/180/24 and 27 have large garnets with pennine alteration.

Quartz is a common inclusion in the garnets, causing them to be poikiloblastic.

The colour of the garnets in the amphibolites is reddish, whereas the lode garnets are pinkish in colour.

Garnets do not occur in the amphibolites which have clinozoisite, zoisite, or epidote banding. When garnets are present, quartz and felspar are present, with the exception of Specimen A/180/61, which has minor blebs of quartz, but no felspar. Specimens contain quartz and felspar in varying amounts, but garnet need not be present, although generally it is present when average amounts of felspar and quartz are present.

Specimens A/180/57, 170 and 201, which have abundant garnets, up to 1/8th inch in diameter, show that the garnets have best developed within the felspar and quartz, although inclusions of hornblende are present within the garnets. In the three specimens small amounts of garnet appear to be replacing the hornblende.

In Specimen A/180/57, large garnets have forced aside the hornblende crystals.

Garnets were extracted from Specimens A/180/33, 38 and 61, and assayed for calcium. Specimen A/180/33 occurs near the mineralisation at the Angus Mine; Specimen A/180/38 was collected 300 feet to the west of the Angus Mine; Specimen A/180/61 was collected at the north end of the area near a mineralised zone.

The assay values are:

garnets in A/180/33 - 3.9% CaO
" " A/180/38 - 4.9% CaO
" " A/180/61 - 4.9% CaO

The assays were carried out by A.B. Timms, Aust. Min. Devel. Laboratories, Parkside, Sth. Australia, using optical spectrographic methods.

Assays for manganese in garnets in Specimens A/180/12 and 33, were carried out, with the following results:

garnets in A/180/12 - 3.65% MnO
" " A/180/33 - 3.53% MnO

These assays were made by T.R. Sweatman, Division of Soils, C.S.I.R.O., Adelaide, using X-ray fluorescent spectrographic methods.

The above assays will be compared with the assays of garnets from the lode horizons, gneisses and pegmatites, when discussing the mineralisation.

Garnets in the amphibolites are concluded to be almandite, although assays show that small amounts of calcium and manganese are present. The refractive index of the garnets in Specimen A/180/38, collected 300 feet to the west of the Angus Mine, is 1.775. Garnets in Specimen A/180/33, collected near the lode, have a refractive index slightly higher than 1.775.

The lode garnets have a higher manganese content, and higher refractive index than the garnets in the amphibolites.

Specimens A/180/25 and A/180/101, collected in the amphibolite zones, which contain actinolite and tremolite respectively, have no garnets present, although fine-grained garnet rocks, such as Specimens A/180/28 and 32, are veined with actinolite and calcite.

An unusual occurrence of garnet is found in Specimen A/180/191, a felspathic-tremolite-diopside-quartz-garnet-magnetite-muscovite rock, which appears to grade into amphibolite. Idioblastic garnets of 0.15 mm in diameter, almost completely rim all tremolite grains which are in contact with plagioclase. Such an association suggests that possible pre-existing pyroxene or amphibole has reacted with the plagioclase to form garnet.

Minor biotite, garnet, quartz, amphibole rocks, which grade into amphibolites along strike, have no plagioclase present. Garnets compose as much as 70% of the rock, and have magnetite, quartz and biotite inclusions, and reach a ½ inch in diameter. When actinolite is present, biotite is minor and the garnet content 20-30%.

Edwards (1957) concluded that garnet developed in the amphibolites in the Broken Hill Basin by the reaction between pyroxene and plagioclase (bytownite).

Browne (Andrews, 1922) suggested that some garnet has developed in amphibolites which were apparently devoid of pyroxenes.

The development of megascopic garnets in the amphibolites could depend upon a higher than normal manganese content. The amphibolites which have megascopic garnets have pale or dark amphiboles present, thus it is not possible to conclude that iron from amphiboles enters the garnets. Mawson (1912) shows two analyses of amphibolites, collected east of Broken Hill on the Broken Hill-Rockwell Road. An amphibolite containing megascopic garnets, assayed 1.33% MnO and the other amphibolite without megascopic garnets, assayed 0.34% MnO. The specimens were collected near the Little Broken Hill line of mineralisation.

Browne (Andrews, 1922) compared an analysis of a non-garnetiferous Black Bluff "gabbro", with two analyses of garnetiferous amphibolites collected near Round Hill and Potosi Mine. The Black Bluff rock has 0.31% MnO present, while the other two specimens, collected near a line of known mineralisation, assayed 0.65% and 0.94% MnO.

Stillwell (Andrews, 1922) shows assays of three garnet amphibolites, taken near, and some distance from the Broken Hill ore-bodies. The manganese assays are 0.72%, 0.95% and 0.70% MnO. The assay values for manganese are higher than manganese values obtained in amphibolites without garnets which were also collected near, and some distance from the ore-bodies. The assay values for the amphibolites without garnets are: 0.52%, 0.15%, 0.45% and 0.35% MnO.

Browne (Andrews, 1922) favoured the opinion that the manganese bearing garnets crystallised from a gabbroic magma, and that the manganese was not introduced.

Amphibolite specimens with megascopic garnets, collected in the Angus area, occur near lines of weak discontinuous mineralisation. Specimens A/180/57, 170 and 201 were collected in the amphibolite zone stratigraphically above the Angus-Kintore (middle) zone of mineralization. Specimens A/180/12, 24 and 27 were collected in the amphibolite zone stratigraphically above the upper zone of mineralisation.

Specimen A/180/57 was assayed for manganese, by the writer, using a spectrophotometer. The value obtained is 0.51% MnO, which is higher than the manganese assays of other amphibolites, as listed:

Specimen	A/180/25 -	Actinolite rock (no garnet)			- 0.33% MnO
"	A/180/30 -	Amphibolite (minor garnet)			- 0.25% MnO
"	A/180/33 -	"	"	"	- 0.39% MnO
"	A/180/38 -	"	"	"	-0.23% MnO

Thus Specimen A/180/33, collected near the manganese rich lode at the Angus Mine, has a manganese assay below that of Specimen A/180/57, which was collected 500 feet west of a possible mineralised zone, 3½ miles to the north east of the Angus Mine.

As Specimen A/180/33 is low in manganese, and yet in contact with a manganese rich lode, it is concluded that the manganese in the amphibolites could well be an original constituent.

If the amphibolites have a sedimentary origin, then the higher amount of manganese present in the megascopic garnet amphibolites presents no problem. If the amphibolites have an igneous origin, it is necessary to explain how a particular lens, or band of amphibolite in an environment of many lenses and bands, has a higher manganese content.

The development of megascopic garnets in the schists and gneisses is attributed to a high manganese content, also to the fact that the particular schists and gneisses have calcic plagioclase present. This statement will be explained when describing the schists and gneisses.

Wright (1938) concluded that garnet may form before biotite in regional metamorphism if the sediment is manganese rich.

Epidote, zoisite, clinozoisite

Bands of zoisite and clinozoisite, with some epidote, up to 3/16th inch wide, are found in some amphibolites, but the occurrences are not numerous.

In Specimen A/180/9, epidote and minor zoisite and clinozoisite are fresh in appearance and do not appear to be altering from plagioclase, however the hornblende shows bluish-green pleochroism, which could be indicative that some sodium entered the hornblende. The sodium could come from the breakdown of plagioclase.

In Specimen A/180/13, which is miles away from Specimen A/180/9, the zoisite and clinozoisite with minor epidote, have a clouded appearance and are altering from felspar. Sericite is also an alteration product of felspar in this specimen.

Sphene is common in both the above specimens.

A specimen, A/180/208, collected from within a narrow amphibolite zone, 3,500 feet east of the Angus Mine and 1,400 feet north-east of Specimen A/180/9, has banding, and approximately 45% epidote present. The rock contains 50-55% quartz and minor amphibole altering to chlorite. Most of the epidote is clear, but several patches contain zoisite, and very minor sericite. The unaltered hornblende shows bluish pleochroic colours, again indicative that sodium could have entered following the break-down of felspars. Rocks such as Specimen A/180/208, with such a high quartz content, and low amphibole content, throw doubt on an igneous origin for the amphibolites.

Specimen A/180/12, 24 and 27 are rocks which contain amphibole with megascopic garnets, small and large blebs of quartz, and minor plagioclase which has slight alteration to epidote and clinozoisite. The garnets are irregular and cracked and there is pennine alteration in Specimen A/180/27. The quartz is transparent to translucent and not banded regularly, and probably has been mobilised.

In the Specimens A/180/48, 49, 50 and 51 which were taken from plagioclase banded amphibolites in the northern portion of the area, only one grain of plagioclase in Specimen A/180/51 shows alteration to zoisite. These specimens do not contain quartz or garnet. Ramberg (1952) states that calcic plagioclase will remain stable if no water, potassic felspar or possibly calcite is present.

Specimens A/180/38 and 187 have minor clinozoisite and zoisite present as alteration products of plagioclase.

Porphyroblasts of epidote are found in Specimen A/180/162 and constitute about 5-10% of the rock. These crystals tend to weather more quickly than the other minerals present. In the hand specimen, some weathering porphyroblasts of epidote resemble olivine or zeolite grains in vesicles.

Specimen A/180/194, which has transgressive potassic felspar associated with it, shows 2-3% epidote and zoisite altering from plagioclase.

From the rock slides studied the bulk of epidote, zoisite and clinozoisite has altered from plagioclase.

Occasionally blebs of epidote are found in the amphibolites. Specimens A/180/171 and 172 are representative of the type of rock. A/180/171 has minor copper staining. These rocks contain "fresh" epidote, although in Specimen A/180/172 it appears to be altering from plagioclase. Minor chlorite is present, and in A/180/172 is altering from hornblende. Quartz is abundant in the rocks; 40% quartz is present in Specimen A/180/171, and 70% quartz in Specimen A/180/172. Magnetite is abundant in Specimen A/180/171, but minor in A/180/172.

In Specimen A/180/184, taken from the transgressive amphibolite, there is a "hair-line" fracture, parallel to the foliation, which contains epidote. The amphiboles are finer grained near the fracture.

<u>Sphene</u>

Sphene is a minor mineral in the amphibolites, but can be as much as 3-4% of the rocks.

In the amphibolites which contain sphene, garnet is absent, with the possible exception of copper stained Specimen A/180/4, which has abundant garnet. Possible sphene grains occur near one garnet in the rock.

Sphene occurs in the amphibolites which have epidote zoisite or clinozoisite bands, or calcic plagioclase bands.

In Specimen A/180/9, which has bands of epidote with minor zoisite and clinozoisite, sphene is an abundant accessory, occurring as elliptical shaped grains, 0.2 mm in length, in narrow intermittent bands. The largest grain is 0.6 mm long and 0.2 mm wide. Some grains are twinned. Some tend to be idioblastic. Other grains occur along boundaries of quartz, epidote, and hornblende grains. In Specimen A/180/13, another banded amphibolite, with bands of zoisite, clinozoisite and minor epidote, sphene grains are abundant (3-4% of the rock), and are up to 0.6 mm in length. Sphene occurs along crystal boundaries, and as inclusions in the zoisite and clinozoisite and in the hornblende.

In the amphibolites with calcic plagioclase bands, such as Specimens A/180/48, 49, 50, 51 and 195, sphene is common. In A/180/48, the sphene is strongly pleochroic, straw to reddish, and the grains range from minute to 0.2 mm. The sphene grains occur along grain boundaries of other minerals, and as inclusions in the plagioclase. In A/180/49, sphene surrounds ilmenite grains, while in Specimen A/180/195, sphene occurs within ilmenite and surrounding ilmenite. In Specimen A/180/50, the sphene grains which are xenoblastic and up to 0.4 mm in length, occur as inclusions in the plagioclase and hornblende,also along grain boundaries. A few rounded grains 0.1 mm are present as inclusions in the plagioclase in Specimen A/180/51.

Foliated Specimens A/180/14 and 15, with faint intermittent plagioclase bands, have a few grains of sphene, minor blebs of quartz, and no garnet. Minute sphene inclusions occur in the hornblende grains in Specimen A/180/37.

Thomson (1955) and Edwards (1957) noted that numerous sphene grains occur in the amphibolites in the western portion of the Broken Hill district. Both workers concluded that the amphibolites in the western portion of the district have a sedimentary origin.

Amphibolites in the Broken Hill Basin, concluded to have an igneous origin (Edwards, 1957) have very minor sphene, which generally surrounds ilmenite.

As sphene is common in the banded amphibolites in the Angus area, it suggests a sedimentary origin for the amphibolites. However, on the other hand rutile generally occurs in the banded amphibolites, and reactions between calcic plagioclase and rutile, or calcic pyroxene and rutile could produce sphene in rocks which have an igneous origin.

Magnetite

The banded amphibolites with zoisite, clinozoisite and epidote have little or no magnetite. The banded amphibolites with plagioclase have some magnetite, but much of the opaque black mineral is ilmenite.

In the epidote-quartz blebs which occur in the amphibolites, magnetite is common. Specimen A/180/171 has 5-10% magnetite present, and the grains are minute to 0.3 mm in length.

In the remainder of the amphibolites, magnetite is present in every specimen, and can be as much as 5% of the rocks. In many specimens the grains "line-up" parallel to the foliation; Specimen A/180/14 is an example where abundant small magnetite grains, averaging approximately 0.03 mm in length, occur throughout the rock, but always parallel the foliation.

Specimen A/180/104 has irregular shaped grains, varying in length between minute and 0.2 mm in length. Grains in Specimen A/180/204 are angular to sub-angular, and up to 0.4 mm in length.

In most specimens the magnetite is associated with hornblende, and garnet if present. The magnetite occurs within the grains and along grain boundaries.

An amphibolite, Specimen A/180/191, containing tremolite, has abundant magnetite present, although in another Specimen A/180/101, which mainly consists of tremolite, magnetite is minor to absent. This specimen is clouded with possible graphite.

Actinolite bearing Specimens A/180/25, 28 and 32 are poor in magnetite. Specimen A/180/25 has minor magnetite, whereas the other two specimens have no magnetite present.

The amphibolite containing altering diopside has very minor magnetite associated with the hornblende which has altered from the diopside.

In the transgressive amphibolite, Specimen A/180/184, abundant magnetite grains occur associated, and within, the hornblende.

Biotite-garnet-quartz rocks, which grade into amphibolites, have little or no magnetite present, but as pale amphibole (actinolite) develops with the rock change magnetite also develops and is associated with the amphibole and garnet. Three specimens numbered A/180/201, show the change from biotite-garnet-quartz rocks to rocks containing amphibole, biotite, garnet and quartz.

Edwards (1957) noted that iron oxides are as common in the amphibolites which are considered to have a sedimentary origin, as in the amphibolites which are considered to have an igneous origin. Thomson's (1955) description of the amphibolites in the western portion of the Broken Hill district showed that iron oxides are notable; the amphibolites have a sedimentary origin.

The magnetite in the amphibolites in the Angus area could have developed as pyroxenes altered to amphiboles, or ferruginous material could have been present in a calcitic-chloritic-ferruginous-siliceous-sediment which was metamorphosed to develop amphibolites.

Ilmenite

Possibly some of the ilmenite has been described as magnetite, as the iron minerals were identified by using a petrological microscope.

Minor ilmenite is associated with hornblende, and the grain sizes and shapes are similar to those of magnetite.

In the zoisite, clinozoisite, epidote banded amphibolites ilmenite is absent, although in the plagioclase banded amphibolites it is a common accessory mineral which is often surrounded, or internally replaced, by sphene.

Biotite

Biotite is a very minor mineral in the amphibolites, excepting where the amphibolites grade into biotite-rich rocks.

Specimens A/180/33 and 36, which were collected near the Angus Mine, contain biotite. Specimen A/180/33 has approximately 1% biotite, which is associated with hornblende. The biotite appears stable and not ragged, with few flakes up to 0.7 mm in length. The biotite has straw-yellow to brownish pleochroism.

As the mineralised zones contain potassic felspar, potassium could have entered Specimen A/180/33 which was collected near the Angus Mine.

Where transgressive pegmatites cut amphibolites, biotite has developed in the amphibolites.

Amphibolites in a few places grade into biotite-garnet-quartz-rocks, and also banded quartz-biotite-calcic plagioclase-muscovite rocks.

In the biotite-garnet-quartz-rocks the gradation to amphibolite shows pale amphibole developing and then green hornblende, before becoming amphibolite. Biotite can be as much as 50% of the rocks; the flakes being decussate when garnet is abundant. The biotite is pleochroic from light brown to dark brown, and many of the flakes are bent. When pale amphibole is present, it is associated with the biotite.

As the biotite-garnet-quartz-rocks grade into amphibolite, it would be necessary for potassium to have been introduced if the amphibolites were originally basic igneous rocks; this is possible as the best development of biotite-garnet - quartz rocks is 600 feet north of the Angus Mine in an amphibolite zone. It is also possible that calcium poor phases of sediments containing abundant chloritic, and some sericitic material could be metamorphosed to give biotite and garnet. The chlorite could combine with sericite to give biotite, and with quartz to give garnet. If abundant sericitic material were present, potassic felspar would have developed.

The quartz content of the biotite-garnet-quartz rocks is 5-10%, and increases to 30% where the pale and green amphiboles develop along strike.

Chlorite

Chlorite is found in only a few amphibolite specimens, and is an alteration product of hornblende or garnet.

When chlorite is present, either zoisite, clinozoisite, or epidote are present. These minerals are also considered to be alteration products, although they can be present without chlorite.

Specimens A/180/24 and 27, which contain garnets altering to pennine, have plagioclases present which are partly sericitised.

Apatite

Apatite grains are not common in the amphibolites. The grains are minute to 0.2 mm in length, and are rounded, ragged and subhedral to euhedral. Apatite occurs as inclusions in plagioclase, quartz, and rarely in hornblende. In Specimen A/180/50, taken from a banded amphibolite, the apatite grains occur along the boundaries of the plagioclase crystals.

No particular mineral assemblage of the amphibolites appears to have, or not have, apatite present.

Sericite

Specimens A/180/30, 194 and 197 were taken from amphibolites which have transgressive pegmatites cutting them. Staining of the amphibolites show that some potassic felspar has been introduced. The alteration of the plagioclases in the specimens is attributed to the introduction of potassium and hydroxyl ions from the transgressive pegmatites.

Amphibolites occurring in concordant pegmatite zones have sericitised plagioclases present. Specimens A/180/15 and 204 are examples. As the concordant pegmatites are considered to be altered sediments, the alteration of the plagioclases in the amphibolites is attributed to mobile potassium and hydroxyl ions.

Specimen A/180/33 was taken from the amphibolite in contact with the lode at the Angus Mine. The plagioclases are partly sericitised, which is attributed to mobile potassium and hydroxyl ions from the mineralized zone. When felspar is present with mineralisation, it is generally potassic.

Specimen A/180/170, which has megascopic garnets, and which resembles Potosi gneiss, was taken from an outcrop 500 feet south of the Angus Mine, near the Angus-Kintore lines of mineralisation. This specimen shows that the plagioclase crystals have reached an advanced stage of sericitisation. Its position near the line of mineralisation could well explain the alteration.

Three specimens, A/180/12, 18 and 24, have large blebs of quartz present, and each specimen has minor zoisite or clinozoisite. These specimens show sericitisation of the plagioclase. As the quartz appears in large blebs, and zoisite and clinozoisite are produced, the introduction of hydroxyl and possible potassium ions is envisaged.

Where amphibolites grade into quartz-hornblende, garnet-plagioclase rocks, such as Specimen A/180/60, the plagioclase is sericitised. Similarly in a gneissic quartz-biotite-plagioclase-garnet rock, which is in an amphibolite horizon, the plagioclase is sericitised.

An amphibolite Specimen A/180/4, taken from the shear zone striking east-west, just north of the Angus Mine, has malachite staining, and the plagioclases are sericitised. Two factors could account for the sericitisation; being in the shear zone, and also being near a mineralised zone.

The plagioclases in Specimens A/180/187 and 195 have minor sericitisation and alteration to zoisite and clinozoisite.

In the minor transgressive amphibolite, Specimen A/180/184, narrow zones of sericitised plagioclase occur along the edges of the "hair-line" band of epidote filling a fracture, suggesting that the epidote has been formed by the introduction of H_2O and other active volatiles.

In general the plagioclase crystals in the amphibolites are "fresh", and the abovementioned examples are exceptions.

Limonite and Haematite

Limonite and haematite are rare in the amphibolites. In Specimen A/180/101, which contains abundant tremolite with possible carbonaceous material, and possibly some magnetite, limonite staining occurs throughout.

Amphibolites occurring within concordant pegmatite zones, have minor limonite and haematite associated with the hornblende, with some haematite altering from magnetite. Limonite staining is present in Specimens A/180/28 and 32, which contain abundant fine-grained garnets, with actinolite and calcite veins.

Diopside

Pyroxene was noted in only one specimen (A/180/10). The altering colourless, pyroxene (diopside) grains are between 1 and 2 mms in length. The diopside grains have pronounced alteration to hornblende along their boundaries, and some internal alteration. Plagioclase inclusions and very minor iron staining are found in the diopside.

The extinction angle, $Z \wedge C$, is $41\frac{1}{2}^\circ$-$43\frac{1}{2}^\circ$, and 2V is 55°.

Plagioclase grains in the rock are unoriented, and are 0.5 to 0.7 mm in length.

The rock is not foliated, although bands, possibly due to weathering, parallel the surface outline, and give an appearance of folding. The outcrop, from which the specimen was taken, is 3,600 feet north of the Angus Mine.

The texture of the rock, the platy weathering, and the minor quartz, suggest that the rock could have an igneous origin.

If the amphibolites in the Angus area have an igneous origin, then all pyroxenes in the rocks, with the exception of the abovementioned outcrop, have altered to amphibole, unless the original igneous rocks were hornblende gabbros or hornblendites.

Rutile

Rutile is rare, but occurs in the plagioclase banded amphibolites. The grains are small, with some being angular and others rounded, and generally occur in the plagioclase bands. Specimen A/180/48, which was taken from a plagioclase band in the amphibolites was examined in detail for heavy minerals. Iron ore, sphene and rutile are common.

Other amphibolite Specimens A/180/9, 10 and 104, were examined in detail for heavy minerals; in Specimen A/180/10, the amphibolite with altering pyroxene, contains rutile grains.

Several specimens have been assayed for titanium.

Zircons

Zircons are rare, although they occur in the plagioclase banded amphibolites. The grains are minute and rounded, with some being subhedral to euhedral in Specimen A/180/50. In Specimen A/180/49, the grains are associated with iron ore in the hornblende.

Zircons would be rare if the amphibolites have an igneous or sedimentary origin.

Actinolite

Minor actinolite is found in the amphibolite zones. Specimen A/180/25, collected 4,800 feet to the north of the Angus Mine, occurs in an amphibolite horizon. The actinolite flakes are between 1 mm and 3 mms in length, and are not oriented. The extinction angles, using an universal stage microscope, are 11^{o} to 19^{o}, and the pleochroism is straw to greenish, cleavage is well shown.

Interstitial sericitized andesine (An_{34}) is present, and also a few grains of magnetite.

Two specimens, A/180/28 and 32, which consist essentially of fine-grained garnet, contain narrow veins of calcite grading into actinolite. The garnets have a refractive index between 1.78 and 1.79, and have 6.4 MnO present. Minor quartz is present in the rocks. The specimens were collected within amphibolites.

Tremolite

Tremolite is rare in the amphibolites. Specimen A/180/101, was taken from the same zone of amphibolites as the actinolite bearing Specimen A/180/25.

The tremolite is fibrous and not well oriented. Larger flakes up to 1.0 mm in length are clouded with minute black grains, possibly graphite. Magnetite is common throughout the rock, and the irregular shaped grains are up to 0.4 mm in length. Iron staining is common; a few grains of haematite are present.

A polished section, or chemical tests were not made to determine if the "clouds" of minute black grains are graphite or not.

The tremolite and actinolite are not associated with altering pyroxenes.

Other Accessory Minerals

In Specimen A/180/48, a plagioclase banded amphibolite, the following accessory minerals were noted:

iron ore rutile sphene	common
zircon apatite	rare
tourmaline ? gahnite	very rare

Other plagioclase banded amphibolites are expected to have similar accessory minerals present.

A quartz banded amphibolite, Specimen A/180/104; an epidote, zoisite, clinozoisite banded amphibolite, Specimen A/180/9; and the amphibolite with altering pyroxene, Specimen A/180/10, were examined for accessory minerals, but only iron ore, rutile and sphene were found.

Genesis

Apart from petrological studies, partial chemical analyses of some amphibolites have been carried out, as shown in Table 2.

The iron, titanium, strontium, lead, zinc and manganese assays were carried out by T.R. Sweatman, Division of Soils, C.S.I.R.O., Adelaide, using X-ray fluorescent spectrographic methods. As such a method was used, the iron assay obtained is the total iron, expressed as FeO. The cobalt and nickel assays were carried out by C. Moncrieff, The Zinc Corporation Ltd., Broken Hill; the calcium assays of the garnets were done by A.B. Timms, Aust. Mineral Development Laboratories, Parkside, and the calcium assay of the amphibolite was made by A.Blaskett, Division of Biochemistry, C.S.I.R.O., Adelaide. The writer carried out the assay for manganese in Specimen A/180/57.

The amphibolites are considered to be altered chloritic, calcitic, ferruginous, siliceous sediments, which had very minor clay material in places. The reasons for concluding such an origin are listed briefly and then

TABLE 2

PARTIAL ASSAYS OF AMPHIBOLITES AND A GNEISS

Amphibolite Specimen No. Prefixed by A/180/	Rock Type	Total Iron Expressed as % FeO	% TiO_2	ppm Sr.	ppm Pb.	ppm Zn.	% MnO	% Co	% Ni	% CaO
9	Banded epidote, zoisite, clinozoisite, amphibolite	9.03	1.81							
10	Amphibolite with altering pyroxene	10.00	0.73	99	43	146		0.003	0.0073	
13	Banded zoisite, clinozoisite, epidote amphibolite	7.13								
14	Foliated amphibolite with magnetite bands	13.42								
25	Actinolite rock	8.26	0.29	37	21	40	0.33	0.004	0.0376	
30	Amphibolite near trans-gressive pegmatite	9.97	1.04		34	92	0.25	0.001	0.0006	
33	Amphibolite near lode at Angus Mine	14.04	1.81	314	290	256	0.39	0.0035	0.0070	
38	Amphibolite - 350 ft. NNW of Angus Mine	10.10	1.08	259	54	190	0.23	0.0035	0.0036	
49	Plagioclase band in amphibolite	1.22	1.02	613 }	19 }	171 }				8.1 }
49	Amphibole band in amphibolite	9.07	1.45							
184	Transgressive amphibolite	13.12		141	59	281		0.0035	0.0039	
48	Plagioclase band in amphibolite				6	51				
33	Garnets from amphibolite near lode at Angus Mine						3.53			3.9
38	Garnets from amphibolite									4.9
57	Amphibolite with megascopic garnets						0.51			
Gneiss Spec No.A/180/40	Quartz, plagioclase, biotite, garnet, muscovite gneiss	6.66								

described in detail. The reasons are as follow:

(1) The quartz content of many of the amphibolites is as much as 30%.

(2) Banding in many of the amphibolites is considered to represent a bedding feature and not metamorphic differentiation.

(3) The wide range of plagioclases in the amphibolites is explained by differences in the composition of the original sediments, and not by metamorphic differentiation.

(4) The high MnO content in the amphibolites with megascopic garnets is explained by sedimentation, and not by the introduction of manganese.

(5) Accessory minerals in the plagioclase banded amphibolites do not detract from a sedimentary origin.

(6) No chilled margins or flow structures have been observed in the amphibolites.

(7) Hornblende porphyroblasts occur in some outcrops, and could well indicate a sedimentary origin for the rocks.

(8) All amphibolites mapped in the Angus area are conformable with the sediments, with the exception of one outcrop, 250 feet long and 6 feet wide.

(9) In places the amphibolites grade into quartz-

amphibole-plagioclase-garnet rocks, biotite-garnet-quartz-amphibole rocks; and quartz-epidote-amphibole-felspar rocks.

(10) The amphibolite zones are associated with "aplite" zones, or "aplite" and concordant pegmatite zones. The association is possible if the amphibolites are altered sediments.

(11) The stratigraphy suggests that the amphibolites could fit into a sedimentary sequence such as would be expected with transgressions and regressions of the sea.

(12) Pyroxene was found in only one outcrop, and apart from the one occurrence there is no positive proof that the amphibolites have altered from pyroxene bearing rocks.

(13) Gneisses occurring near, or in the same zones as, the amphibolites contain calcic plagioclase and abundant biotite.

(14) Partial analyses for iron, titanium, and strontium do not rule against a sedimentary origin.

(15) The occurrence of actinolite and tremolite in an amphibolite horizon is not common, but could favour a sedimentary origin for the rocks.

(16) Metamorphism of chloritic, calcareous, siliceous, ferruginous sediments could well explain the mineral

assemblage of the amphibolites, although acidic tuffs are not overlooked.

Explaining the reasons in some detail:

(1) Quartz content

The introduction of quartz into the amphibolites is not favoured, as the foliated specimens contain the least quartz. If quartz were to be introduced, it would most likely favour foliation planes.

With a quartz content as high as 30% of the rocks, the amphibolites could have been acidic tuffs. Eruptions would have taken place before, during and after the deposition of arkosic material, as the amphibolite zones are associated with the "aplite" zones, suggesting unstable sedimentary conditions. Such a quartz content can also be explained by the deposition of sediments under fairly stable conditions.

The presence of a high quartz content cannot be adequately explained by the development of garnet, as most of the amphibolites with a high quartz content are not rich in garnet.

(2) Banding in the amphibolites

If metamorphic differentiation had occurred, an increase in the iron content in the amphibole bands could be expected. A representative amphibole band from a plagioclase banded amphibolite, Specimen A/180/48, was assayed for iron, and the value obtained was 9.07% expressed as FeO, as shown in Table 2. This assay is 1.21% FeO less than the average iron content of eight amphibolites assayed excluding the transgressive amphibolite. The assay result could indicate that metamorphic differentiation did not occur.

(3) The wide range of plagioclases

Table 1 shows that the plagioclases in the amphibolites vary from andesine (An_{32}) to anorthite (An_{94}). The range of plagioclases present cannot be explained by original phenocrysts in basic igneous rocks having higher An contents than the ground mass, as porphyroblastic plagioclase is not found in the amphibolites (with the exception of the small transgressive amphibolite).

Normal An contents of plagioclases of rocks, of gabbroic composition, which have been subjected to different grades of metamorphism, have been outlined by Eskola (Barth, et al., 1939) and are as follows:

Pyroxene hornfels facies - An_{40}
Amphibolite facies - An_{43}
Epidote-Amphibolite facies - An_{9}

Edwards (1957) found that the plagioclases in the amphibolites in the Broken Hill Basin have an An_{85-90} content (bytownite), and he considered the rocks to have an igneous origin. The plagioclases in the amphibolites in the western portion of the Broken Hill district have an An_{85} content (bytownite) at Peak Hill, and labradorite, or anorthite, in the Appolyon Valley, and were concluded, by Edwards, to have a sedimentary origin. Edwards described how the bytownite is destroyed as pyroxenes alter to amphiboles.

In the Angus area, the amphibolites do not contain pyroxene, with the exception of one small rounded outcrop. It would be expected that the plagioclase in the amphibolites would not have very calcium rich plagioclases if the hornblende had developed from pyroxene, as calcium would enter the hornblende. However the plagioclases in some of the amphibolites in the Angus area have contents as high as An_{94}. If diopside had not developed regionally, and the amphibolites had an igneous origin, then the rocks could have been hornblende gabbros or hornblendites, although the wide range of the plagioclases must be explained.

The variable An content of the plagioclases in the amphibolites could be explained if the amphibolites have a sedimentary origin. Chloritic, calcareous, ferruginous, siliceous, sediments could have been subjected to metamorphic conditions, which produced hornblende, calcic plagioclase; garnet and diopside locally. The amount of calcium and sodium in the sediments would vary, therefore under metamorphic conditions if sufficient calcium is not available the An content of the plagioclases may not be in keeping with the grade of metamorphism. Similarly, excess calcium could be available and the plagioclases would have a high calcium content, especially if the sodium content was very low to absent.

The felspathic quartzites with garnets, and gneisses with calcic plagioclases in the Angus area, have plagioclases present with An_{35-80} contents. These rocks which are discussed on pages 171 and 126 respectively are altered sediments, and the wide range of plagioclases is explained by available calcium in the original sediments.

Small amounts of calcium are present in the garnet, and the amphibolites with the highest An content in the plagioclases have only small amounts or no garnet present.

As the amphibolites in the western portion of the Broken Hill district have a sedimentary origin, and have plagioclases with high An contents, there should be no objection from this point of view to the Angus area amphibolites having a sedimentary origin.

Specimens (A/180/36, 37 and 38) taken from amphibolite bands in physical contact, the plagioclases in the rocks differ greatly (see Table 1, page 74). The wide range of plagioclases is difficult to explain if the rocks were originally sills or flows, although tuffs could have varying calcium contents. No pyroxene occurs in the three specimens; minor garnet is present, but does not explain the wide range of plagioclases. Soda metasomatism could not be invoked as the hornblende has not been altered, and it is difficult to imagine such selective metasomatism of three amphibolites in physical contact.

The amphibolite with altering pyroxene, Specimen A/180/10, has plagioclase with an An_{69-70} content. As no other pyroxene bearing amphibolite was noted in the area, the plagioclases could not be cross-checked to ascertain if unaltered pyroxene bearing amphibolites have higher plagioclase An contents.

(4) <u>The high manganese content of the amphibolites with megascopic garnets</u>

Assays have shown that amphibolites with megascopic garnets have higher manganese contents than amphibolites with microscopic garnets or without garnets.

The amphibolites with megascopic garnets are not necessarily in very close association with mineralised zones, but they do occur nearby. Gneisses and schists, with megascopic garnets contain higher than normal manganese, and also are found near mineralised zones.

The occurrence of megascopic garnets, should be used to indicate manganese rich areas, which could be associated with mineralised zones.

Amphibolite (represented by Specimen A/180/33) with a minor amount of small garnets occurred near the manganese rich lode at the Angus Mine; the manganese content is not high, being 0.39% MnO. If manganese had been introduced into the amphibolites, then the amphibolites in close association with lode horizons would probably contain greater than normal amounts of manganese. A small amount of manganese could have been introduced into Specimen A/180/33, as assays for MnO of three other amphibolites are 0.33%, 0.25% and 0.23% (Table 2).

An amphibolite with megascopic garnets (Specimen A/180/57) was collected 500 feet stratigraphically above possible lode material, and has 0.51% MnO present.

Average MnO assays of metadolorites, ortho-amphibolites, para-amphibolites, alkali basalts, olivene basalts, and amphibolites are listed by Wilcox and Poldervaart (1958). The average MnO assay for 402 rocks is 0.2% and for 8 other rocks the average MnO assay is 0.3%.

(5) Accessory minerals

As minerals such as rutile, sphene, with rare apatite, zircon, tourmaline, and possible gahnite occur in the plagioclase banded amphibolites, a sedimentary origin is possible.

(6) Chilled margins and flow structures

No chilled margins or differences in grain sizes were noted at the contact of amphibolites and sediments, although in the small transgressive amphibolite the grain size is finer than the grains in the amphibolites which are conformable with the sediments. The transgressive amphibolite has porphyroblasts of plagioclase; this is not a feature of the concordant amphibolites.

No flow structures, vesicles, or relict amygdales were noted in the amphibolites, although in Specimen A/180/162 epidote grains have weathered, giving the appearance of vesicles.

The lack of such features suggests a sedimentary origin for the amphibolites when other factors are considered although does not rule against an igneous origin; especially an origin such as tuffs.

(7) Hornblende porphyroblasts

A few bands of amphibolite contain abundant hornblende porphyroblasts. Edwards (1957) noted that a feature of the sedimentary amphibolites in the Appolyon Valley, is their porphyroblastic texture.

Specimen A/180/26, has a porphyroblastic texture with the crystals of hornblende tending to be idioblastic.

Browne (Andrews, 1922) concluded that the amphibolites with porphyroblastic hornblende crystals were deposited as flows, sills, or tuffs before the first period of metamorphism, then subjected to further periods of metamorphism. Browne also noted that the plagioclases in the rocks have inverted zoning.

Sediments subjected to metamorphism could develop porphyroblastic hornblende crystals, and would be likely to have inverted zoning in the plagioclases. The suggestion that the porphyroblasts of hornblende have been developed in basic igneous rocks would require a history differing from the history of other basic igneous rocks.

(8) Conformable with sediments

In the Angus area the amphibolites are conformable with the sediments (with the exception of one outcrop, 250 feet long and 6 feet wide). The conformable nature does not prove that the amphibolites were sediments, but it is in keeping with sedimentation.

(9) Facies changes along strike

Minor occurrences of such rocks as quartz-amphibole-plagioclase-garnet-rocks; biotite-garnet-quartz-amphibole rocks; and quartz-epidote-amphibole-felspar rocks, grade into, or occur in the same stratigraphic horizons as, amphibolites.

These rocks have a sedimentary origin, and indicate that the amphibolites have a similar origin.

(10) Amphibolite - "aplite", or amphibolite - concordant pegmatite zone associations

Amphibolite zones occur above and below the "aplite" and concordant pegmatite zones. There are minor occurrences of amphibolites within the latter zones.

If the amphibolites were originally basic sills, then the sills have favoured positions near the contact between competent "aplitic" rocks and incompetent schistose rocks.

If the amphibolites were originally flows or tuffs, the eruptions have taken place before, during and after the deposition of felspathic sands and sub-greywackes. This is possible as the sedimentary condition would be slightly unstable.

If the amphibolites were originally sediments, it is necessary to have calcareous, chloritic, ferruginous and siliceous material being deposited near, and within, felspathic sands. Edwards and Baker (1943) studied the widespread Jurassic arkose in Southern Victoria. They noted that the rocks are cemented by chlorite, epidote, zoisite and secondary felspar; also that the Jurassic rocks consist of arkoses and mudstones. The mudstones contain considerable amounts of lime and soda, and the iron in them is chiefly in the ferrous state. The iron appears to occur mostly as more or less colloidal size particles of a mineral which was concluded to be chlorite. An analysis of a composite clay fraction only of the blue mudstones was made. The clay fraction remained in suspension after standing for 12 hours. The assay values for iron are, 1.95% Fe_2O_3 and 13.35% FeO. No indication of the amount of iron in the portion which settled in 12 hours was given.

Total analyses of four shales were carried out, but the specimens were taken from locations near coal seams. A total analysis of a blue mudstone was not carried out.

Edwards and Baker (1943) concluded that the chloritic cement in the Jurassic arkoses appears to have been deposited from the connate waters of the mudstones, which migrated into the arkoses during the compaction of the sediments. They also concluded that the arkosic material had a different source than the shales and mudstones.

As lime rich, chloritic sediments are thus known to be deposited near arkosic sediments, a sedimentary origin for the amphibolites is possible, and readily explains the amphibolite-"aplite"-concordant pegmatite zone associations.

(11) Stratigraphic sequence

When discussing the stratigraphy and environment of sedimentation it will be shown that the stratigraphic sequences into which the amphibolites fit could be explained by transgressions and regressions of the sea.

(12) Pyroxenes

The occurrence of diopside in an amphibolite is more likely to develop as the result of metamorphism of calcium bearing sediments, than the metamorphism of basic igneous rocks. It is a common mineral in the amphibolites of sedimentary origin in the western portion of the Broken Hill district.

Apart from the one occurrence of pyroxene in the Angus area, no observations were made to prove definitely that pyroxenes were ever present in the amphibolites. The association of iron and hornblende is found in the amphibolites of undoubted sedimentary origin, and may not indicate with certainty that iron-bearing pyroxenes were present.

Mawson (1912), Browne and Stillwell (Andrews, 1922), and Edwards (1957) have noted the common occurrence of hypersthene in the amphibolites which occur in the highly metamorphosed areas of the Broken Hill district. Such a pyroxene can develop from chloritic and calcareous sediments at high grades of metamorphism.

(13) Gneisses occurring within, and near, amphibolite zones

Gneiss specimens collected in contact with and near amphibolites, contain calcic plagioclase and often abundant biotite. Schists and gneisses occurring elsewhere in the area contain sodic plagioclase and very minor potassic felspar.

The calcic nature of the gneisses is not thought to have developed as a result of contact metamorphism, and metasomatism, by basic igneous rocks, as felspathic quartzites with garnets contain calcic plagioclase and do not occur in close contact with amphibolites. The gneisses are considered to have been calcic bearing sediments deposited in a similar environment to that of the amphibolites.

The iron content of a gneiss Specimen A/180/40, collected in an amphibolite zone near the Angus Mine, contains 6.66% iron expressed as FeO. The gneisses will be described in detail (p.126).

A gneiss specimen, A/180/177, collected in contact with the lower side of an amphibolite has plagioclase grains present with a core of An_{40} and en outer zone of An_{28}; such an occurrence could favour an igneous origin for the amphibolites.

(14) <u>Partial analyses of the amphibolites</u>

(a) Iron

Edwards (1957) used the notably different chemical assays of the amphibolites in the Broken Hill Basin, to those of the amphibolites in the western portion of the Broken Hill district to assist in determining their origin.

Engel and Engel (1951) and Wilcox and Poldervaart (1958) have noted that chemical assays of ortho- and para-amphibolites are very often similar (Table 3, p.117). Engel and Engel noted that accessory minerals such as Co, Ni, Cr, Sc, and Cu are often higher in the ortho-amphibolites, and Pb, Au, and Ba are often higher in the para-amphibolites. Wilcox and Poldervaart suggested that high titanium and strontium assays could indicate ortho-amphibolites.

The average iron content, expressed as FeO, of the concordant amphibolites in the Angus area is 10.28%. The small transgressive amphibolite has an iron content of 13.12% expressed as FeO.

Using assays taken from Edwards (1957), the average iron content of the sedimentary amphibolites in the western portion of the Broken Hill district would be approximately 5.25% expressed as FeO, while the amphibolites and granulites in the Broken Hill Basin, considered to have an igneous origin, have an average iron content of approximately 17.75% expressed as FeO.

The average assay of iron content of the amphibolites in the Angus area lies between the assay values obtained for amphibolites occurring in the western portion of the Broken Hill district and the amphibolites in the Broken Hill Basin. It is not considered necessary to invoke iron metasomatism of the original chloritic, calcitic, ferruginous siliceous sediments, as a gneiss occurring near the amphibolites has as much as 5.55% iron expressed as FeO.

It is possible that iron has entered the amphibolites. Williams (1952) and Thomson (1955) concluded that the amphibolites are altered impure limestones. Thomson invoked varying degrees of metasomatism, with the introduction of Fe, Mg, and Al, into impure limestones to explain the development of amphibolites throughout the Broken Hill district. Thomson also noted the development of pegmatitic and aplitic rocks near the amphibolites, thus supporting a metasomatic theory. The soda rich nature of the "aplites" and many pegmatites in the Angus area would probably be explained by Thomson by the transfer of sodium ions from limy sediments to nearby sediments as Fe, Mg and Al ions entered the limy sediments.

As the grade of metamorphism reached in the Broken Hill Basin is greater than the grade reached in the Angus area, which in turn appears to have a higher grade than certain areas of the western portion of the Broken Hill district, it is possible that the iron content of the amphibolites is proportional to the grade of metamorphism, thus lending some weight to Thomson's idea of varying degrees of metasomatism.

On studying various chemical analyses of Broken Hill amphibolites of sedimentary origin (Edwards, 1957), it is found that Na_2O content does not exceed 0.87%, whereas the Broken Hill amphibolites of igneous (Edwards, 1957) or sedimentary (Williams, 1952 and Thomson, 1955) origin have as much as 2.28% Na_2O present. If Fe ions entering original lime rich sediments were inversely proportional to the Na ions remaining in the sediments it is found that the reverse would be the case in the Broken Hill district, although the writer has not overlooked the fact that the original iron and sodium content of limy sediments would vary throughout the field.

(b) Titanium

The TiO_2 content of several amphibolites is shown in Table 2.

The highest TiO_2 assays of the amphibolites in the Angus area, are obtained in the banded amphibolites, and also in the amphibolite near the lode at the Angus Mine. The values obtained lie between 0.29% and 1.81% TiO_2, and have an average TiO_2 assay of 1.32%.

The assays are compared with assays of ortho-amphibolites, para-amphibolites, metadolerites, basalts, and amphibolites, taken from Wilcox and Poldervaart (1958), and shown in Table 3.

From the above assays it can be seen that three known para-amphibolites have a TiO_2 content of 0.6%.

The 200 amphibolites of doubtful origin have an average TiO_2 content of 1.6%, and another 89 amphibolites of doubtful origin either have no TiO_2 or the assays were not carried out. Metadolerites, ortho-amphibolites, and basalts have average TiO_2 contents between 2.4% and 3.0%.

As the average TiO_2 assays for the Angus area

TABLE 3

AVERAGE ASSAYS: BASALTS AND AMPHIBOLITES

Index	A	B	C	1	2	3	4	5	6	7
SiO_2	47.9	48.7	49.7	46.1	47.1	51.2	50.3	50.3	49.9	50.5
TiO_2	2.9	2.4	0.6	2.6	3.0	0.6	1.6	-	-	-
Al_2O_3	14.0	15.7	15.5	14.8	15.1	15.0	15.7	16.6	16.4	16.7
Fe_2O_3	3.8	2.6	1.7	3.2	3.7	2.0	3.6	3.7	3.7	3.7
FeO	11.3	10.4	8.5	8.8	8.1	9.3	7.8	8.9	12.1	7.8
MnO	0.3	0.2	0.2	0.2	0.2	0.2	0.2	-	-	-
MgO	6.4	6.2	10.0	9.4	7.9	8.8	7.0	6.9	6.2	7.2
CaO	9.2	9.6	11.1	10.8	10.9	9.8	9.5	10.0	8.6	10.5
Na_2O	2.9	2.8	2.3	2.7	2.7	2.2	2.9	2.9	2.4	2.9
K_2O	0.9	1.1	0.3	1.0	1.0	0.8	1.1	0.7	0.7	0.7
P_2O_5	0.4	0.3	0.1	0.4	0.3	0.1	0.3	-	-	-
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

A - Average 8 Bakersville-Roan Mountain metadolerites

B - Average 8 Toecane ortho-amphibolites

C - Average 3 Roan para-amphibolites

1 - Average 96 alkali basalts

2 - Average Pacific olivine basalt

3 - Average 5 Quad Creek para-amphibolites

4 - Average 200 amphibolites

5 - Average 89 amphibolites

6 - Type ortho-amphibolite

7 - Type para-amphibolite

amphibolites is 1.3%, and the average TiO_2 content of the amphibolites of unknown origin is 1.6%, it is possible that the Angus area amphibolites had a sedimentary origin if the TiO_2 content is considered.

Edwards (1957) listed 5 TiO_2 assays of amphibolites and granulites from the western portion of the Broken Hill district. The TiO_2 values for the Broken Hill Basin rocks are: 1.32%, 1.44%, 0.75%, 0.55% and 2.35%. The TiO_2 values for the rocks from the western portion of the district are: 0.72%, 0.34%, nil, 0.30% and 0.25%. As the highest TiO_2 assay listed by Edwards (1957) is not as high as the lowest average TiO_2 content of known igneous rocks shown by Wilcox and Poldervaart (1958), it is not possible to conclude from the TiO_2 content that the amphibolites in the Broken Hill Basin have an igneous origin.

(c) Strontium

Strontium as a trace element could give an indication of the origin of the amphibolites, as shown on a portion of a table taken from Wilcox and Poldervaart (Table 4, p.119).

The transgressive amphibolite (Specimen A/180/184), and the amphibolite with altering pyroxene (Specimen A/180/10), have 141 p.p.m. Sr and 99 p.p.m. Sr respectively. These two rocks could be thought to have

TABLE 4

STRONTIUM ANALYSES

Group	Strontium (p.p.m.)	Mean	Standard Deviation
Metadolerites	384	338	112.7
	211		
	300		
	242		
	370		
	521		
Toecane type amphibolites	524	478	64.8
	606		
	424		
	445		
	495		
	397		
	457		
	480		
Roan para-amphibolites	315	144	87.0
	133		
	117		
	56		
	37		
	90		
	133		
	270		

an igneous origin yet the strontium assays fall into a para-amphibolite group in Table 4.

Strontium assays of the actinolite rock (Specimen A/180/25) indicate that the rock could have a sedimentary origin. Two Specimens A/180/33 and 38 collected near the lode at the Angus Mine have 314 p.p.m. and 259 p.p.m. of Sr respectively, indicating a possible sedimentary or igneous origin. The highest assay for strontium of the known sedimentary amphibolites in Table 4, is 315 p.p.m. The p.p.m. of strontium for the metadolerites and the para-amphibolites have an overlapping range.

Specimen A/180/49, which is a plagioclase banded amphibolite, has 613 p.p.m. strontium present. Such an assay would place the rock in the Toecane type amphibolites, which have an unknown origin.

Strontium assays (Table 2 p.98) of 6 amphibolites from the Angus area do not enable conclusions to be made regarding the origin of the rocks.

(d) Cobalt and nickel

Trace elements, cobalt and nickel, in the Angus area amphibolites do not appear to assist in determining the origin of the rocks. Table 2 shows that the amphibolite with the least cobalt and nickel was collected near a transgressive pegmatite, so the possibility exists that

Co and Ni have migrated to the fracture containing the transgressive pegmatite, or even away from the fracture, depending on whether the pegmatitic material was derived from sediments or from a deep seated magmatic source.

The relatively high assay for nickel, 0.0376% in Specimen A/180/25, an actinolite rock, is not sufficient evidence from which to draw conclusions.

Wilcox and Poldervaart (1958) used a diabase (altered dolerite) rock as a standard when comparing cobalt and nickel assays of metadolerites, amphibolites and para-amphibolites. The standard contained 0.0039% cobalt and 0.007% nickel, and assays of the metadolerites, amphibolites and para-amphibolites were near these values, so no distinction could be made between amphibolites of igneous or sedimentary origin, using cobalt and nickel assays.

(e) Lead and zinc

Lead and zinc assays of 7 amphibolites, and lead and zinc assays of a plagioclase band in an amphibolite, are shown in Table 2. The zinc assays in each case are much higher than the lead assays, with the exception of the amphibolite occurring near the lode at the Angus Mine. The assay for lead in the amphibolite taken from near the mine suggests that lead has been introduced into the rock.

The amphibolite, Specimen A/180/30, taken from near a transgressive pegmatite is not high in lead or zinc.

The transgressive amphibolite (Specimen A/180/184) has a relatively high zinc assay of 281 p.p.m.

No conclusions relating to the origin of the amphibolites are drawn from the assays, but should geochemical studies of the amphibolites in the Broken Hill district be made, the presence of higher than normal lead in the amphibolites, could indicate sulphide mineralisation nearby.

(15) Actinolite and Tremolite in Amphibolite Zones

The presence of actinolite and tremolite in amphibolite horizons, suggests that the amphibolites could have a sedimentary origin.

(16) Metamorphism of Chloritic-calcareous-siliceous-ferruginous Sediments to develop Amphibolites

Harker (1932) describes the green beds which constitute a group in the Dalradian sequence. The green beds are considered to be originally chloritic rich sediments with calcareous material present. The beds can be "followed" through every grade of metamorphism. Garnetiferous and non-garnetiferous amphibolites are found. Harker points out that biotite is not common as the original sericitic material would be scanty. He stated that the bulk-composition of the sediments is that of material derived directly from the waste of basic igneous rocks; he also noted that quartz is often abundant. In the highest grades (cyanite and sillimanite zones) the plagioclase is mostly andesine, with biotite and potash felspar absent.

An example such as this indicates that metasomatism is not essential for the development of amphibolites from sediments.

The development of amphibolites from sediments could be explained by the following equations:

Calcite + chlorite → hornblende + zoisite + carbon dioxide + water

Some ferruginous material could be present to assist in developing the hornblende if the chlorite is not very iron rich.

If actinolite is developed then this reaction could take place at higher temperatures:

Calcium carbonate + actinolite + quartz → diopside + carbon dioxide + water

If talc were present in the sediments then:

talc + calcium carbonate + quartz→tremolite +

water + carbon dioxide

If kaolinite were present, the reaction,

Kaolinite + calcite ⟶ epidote + water + carbon

dioxide, could take place.

Garnet development could be explained by:

Fe.Mg chlorite + quartz ⟶ Fe.Mg garnet + water, or

the garnet could be produced from hornblende.

Epidote at higher temperatures would go to anorthite:

Epidote + carbon dioxide ⟶ anorthite + calcium carbonate + water

or

Epidote + kyanite + quartz ⟶ anorthite + water

The development of biotite was outlined when discussing the mineralogy of the amphibolites.

The above equations were suggested by Ramberg (1952) to explain the development of various minerals at different grades of metamorphism.

For all the above reasons the amphibolites occurring in the Angus area are concluded to have a sedimentary origin.

Schists and Gneisses

Schists and gneisses are probably very abundant in the area but are eroded easily, and do not crop-out especially when not near competent rocks.

Schists are more abundant than gneisses, however the gneisses will be described before the schists, as the calcic plagioclase bearing gneisses are generally associated with the amphibolites.

The schists and gneisses have acted incompetently during folding.

The schists are interbedded with "aplites", pegmatites, and to some extent, amphibolites.

Within the broader zones of schists and gneisses the beds do not crop-out continuously for distances greater than a few hundred feet.

Weak mineralisation in the area occurs within zones of schists and gneisses which occur near amphibolite zones.

Sodic plagioclase is the common plagioclase in the schists, and potassic felspar is lacking. Many of the gneisses have calcic plagioclase present.

Garnets mainly develop in the schists and gneisses when sodic and potassic felspar are absent.

Minor sillimanite has developed in shear zones, in tight folds, in small faults, also where schists and gneisses are in contact with competent rocks.

Some zoning has been observed in the calcic plagioclases in the gneisses.

Gneisses

The gneisses are best explained under the following headings:

(1) gneisses with calcic plagioclase
(2) gneisses (with calcic plagioclase) which somewhat resemble Potosi gneiss
(3) schistose gneisses, and gneisses without calcic plagioclase.
(4) pegmatitic and granitic gneisses
(5) gneisses with abundant potassic felspar

(1) Gneisses with calcic plagioclase

The gneisses with calcic plagioclase occur near, or in contact with, amphibolites, and contain calcic plagioclase, quartz, biotite, garnets, muscovite, sericite and sillimanite. One specimen, A/180/185, occurs in a possible lode horizon, but between amphibolite zones 400 feet apart.

The rocks do not show clear cut gneissic bands, as the biotite generally occurs in rough zones, rather than in bands. Porphyroblastic garnets which have developed often force aside the biotite flakes.

The gneisses are crystalloblastic with much of the quartz and felspar tending to be granoblastic, and the biotite lepidoblastic. The garnets may be idioblastic with few or no inclusions, or porphyroblastic with inclusions giving the garnet a poikiloblastic appearance.

Mineralogy

Staining of the rocks, and microscopic study has shown that potassic felspar is not present, with the exception of a few minute grains.

The calcic plagioclase has albite and parallel twinning, a feature of the plagioclase in the amphibolites.

The An content of the plagioclases varies as shown in Table 5.

The plagioclases are andesine to labradorite, with the exception of Specimen A/180/188, which contains oligoclase, with refractive indices less than quartz. Specimen A/180/188 was collected in contact with the upper side of an amphibolite, while all other specimens were collected within the amphibolite zones or in contact with the lower side of the amphibolites.

Although Specimen A/180/188 should not be included under the heading of "Gneisses with Calcic Plagioclase", it is important and convenient to point out that if the calcic plagioclase in the gneisses was produced by contact metamorphism of basic igneous rocks, it would be expected that the gneisses on upper and lower sides of introduced basic rocks would develop calcic plagioclase. Basalts would not explain the occurrence, as basalts have a "free" upper surface.

Sediments grading across into sediments which are now amphibolites could explain why calcic plagioclase is present on the lower side of the amphibolites. The sedimentation of the "amphibolites" could cease abruptly

TABLE 5

THE An CONTENT OF CALCIC PLAGIOCLASES IN GNEISSES

Specimen No. Prefixed by A/180/	Using Flat-stage Microscope	Using Universal-stage Microscope
40	An_{54}	
41	An_{70}	An_{74} (albite twins)
46	An_{36}	An_{36} (albite twins)
177	An_{54}	
178	An_{34}	An_{27-35} (albite and parallel twins)
185	An_{33}	
188	An_{17}	

and then non-calcareous sediments could be deposited; this could explain the oligoclase content of the gneisses in contact with the upper surface of the amphibolites. In the case of Specimen A/180/188, the rock was collected 4,100 feet S.S.W. of the Angus Mine. The sediments above the particular amphibolite are now pegmatitic grading into "aplitic" rocks.

The amount of plagioclase in the calcic gneisses, varies between 30% and 70%.

In Specimen A/180/177, which was collected in contact with the lower side of an amphibolite near the Angus Mine, several grains of plagioclase are zoned; one grain with a core of andesine (An_{40}), and an outer zone of oligoclase (An_{28}). This observation could indicate that the amphibolites have an igneous origin, and produced zoned plagioclases in the gneisses.

Specimen A/180/41, collected 400 feet north of the Angus Mine, and in the zone of mineralisation, has several grains with myrmekitic texture. The grains appear to consist of plagioclase with worm-like quartz inclusions. The texture could be brought about by eutectic unmixing, but some of the grains appear to show quartz replacing plagioclase. The specimen was not in contact with an amphibolite, but was collected from a lode zone and the presence of myrmekitic texture could be produced by incoming mineralising material.

Many of the plagioclase crystals show strain features, especially in Specimen A/180/41.

The size of the plagioclase grains varies between 0.3 mm and 2 mms.

Quartz

In most specimens the quartz shows undulose extinction. The amount of quartz varies from 10-20% to 40%.

Like the plagioclase the quartz grains tend to be granoblastic, but are often xenoblastic.

The grain sizes range from .3 mm to 3 mms in length.

Minute blackish inclusions are found in the quartz in Specimen A/180/46; silliminite inclusions occur in Specimen A/180/188.

Biotite

Biotite forms as much as 25-30% of the gneisses, but is generally 10-15%. The biotite occurs in zones, which are often 2 mms. apart. Many decussate flakes occur within the zones. Crenulated bands occur in Specimen A/180/177.

Pleochroism is very marked, from straw to reddish brown. In most specimens the biotite flakes have inclusions with haloes. In the hand specimen the biotite flakes are black.

Specimen A/180/40, which was collected near an amphibolite at the Angus Mine, when assayed for iron gave a value of 6.66% expressed as FeO. As porphyroblastic garnets occur in the specimen, it was not possible to estimate the iron content of the biotite.

As amphibole has not developed in the gneisses with calcic plagioclase, it is considered that sericitic material in the original sediments has combined with chlorite to form biotite. If potassium bearing material were absent, the chloritic material could have combined with calcareous material to develop aluminous actinolite or hornblende.

Garnet

Megascopic garnets have developed in many of the gneisses with calcic plagioclases. Also the manganese content of these rocks is higher than the schists or schistose gneisses, which rarely contain megascopic garnets.

Table 6 shows some manganese assays of gneisses and schists, and an assay for manganese of garnets removed from a gneiss.

TABLE 6

MANGANESE ASSAYS OF GNEISSES, SCHISTS AND GARNETS

Specimen No. Prefixed by A/180/	Rock or Mineral	% MnO
41	Megascopic garnets from calcic plagioclase gneiss	5.06
41	Calcic plagioclase gneiss with garnets removed	0.23
44	Schistose gneiss, with few megascopic garnets, and no felspar	0.14
45	Schist with minor microscopic garnet, and no felspar	0.19
46	Gneiss with megascopic garnets and calcic plagioclase	1.88

The assays were carried out by T.R. Sweatman, Division of Soils, C.S.I.R.O., Adelaide, using X-ray fluorescent spectrographic methods.

Table 6 shows that the higher manganese assays are obtained in gneisses containing calcic plagioclase.

The nearness of the lode horizons does not always appear to be associated with the higher manganese assay values, as Specimen A/180/46 was collected in the northwest portion of the area, 2,800 feet from known mineralisation. Specimens A/180/41, 44 and 45 were collected near the Angus Mine.

The porphyroblastic, and large idioblastic, garnets are generally cracked, while the small idioblastic garnets are fresh in appearance. The porphyroblastic garnets are up to $\frac{1}{8}$" to $\frac{1}{4}$" in diameter in hand specimen.

The garnets occur within the biotite, and within the quartz and felspar, and are best developed in the calcium bearing gneisses. No garnets developed in the gneiss, Specimen A/180/188, which was collected in contact with the upper side of an amphibolite. The specimen contained sodic plagioclase (oligoclase).

Even though known mineralisation does not occur near the location of Specimen A/180/46, which has a high manganese content, the type of rock could indicate the nearness of mineralisation, as the amphibolites with a high manganese content do not occur in contact with mineralisation, but are found near zones of mineralisation.

Many of the underwall gneisses of No.3 lens at New Broken Hill Consolidated Ltd. mine, have megascopic garnets. Should these rocks be rich in manganese then the occurrence of such rocks in the Broken Hill district would indicate a manganese rich area, as the known conformable ore-bodies in the Broken Hill district are rich in manganese. The presence of rocks with megascopic garnets could be an indicator of mineralisation.

<u>Muscovite</u>

Muscovite is a minor constituent of the gneisses with calcic plagioclase, although some specimens contain 5-10%. When present it is generally associated with the biotite, but can occur interstitially throughout the rocks.

Sericite

Most specimens have sericite present as an alteration product of the plagioclases.

Some of the minor sillimanite is altering to sericite.

Sillimanite

Sillimanite occurs in Specimen A/180/77, which was collected in contact with an amphibolite.

Sillimanite in the Angus area has only developed in shears, small faults or tight folds. The sillimanite in A/180/177 is considered to have developed as the result of movement between a competent amphibolite and a relatively incompetent gneiss.

The sillimanite occurs as decussate needles, up to 0.75 mm in length, within quartz and plagioclase. Other sillimanite occurs in narrow bands, and is associated with biotite. The sillimanite in the bands is altering to sericite. Sillimanite needles have been forced aside where garnet has developed, indicating that the garnet was developed later than the sillimanite.

Heavy Minerals

No heavy minerals were observed in the gneisses with calcic plagioclase.

Genesis

Gneisses with calcic plagioclase are considered to have been siliceous-chloritic-calcareous-sericitic sediments, with minor amounts of aluminous clays.

Similar sediments, with little or no sericitic and clay material, are thought to have been metamorphosed to amphibolites.

Garnet has been able to develop in the gneisses, as potassic felspar is absent and the sericitic material would have combined with chlorite to form biotite.

Heavy minerals are lacking in the gneisses with calcic plagioclase, thus indicating that the original sediments were fine-grained. Such a sediment would be expected, of calcareous material were being deposited.

The variable composition of the calcic plagioclases is explained by the variable amounts of calcium in the original sediments.

(2) <u>Gneisses with Porphyroblastic Garnets and Calcic Plagioclase</u>

Gneisses with porphyroblastic garnets and calcic plagioclase resemble Potosi gneisses which have been described by Browne (Andrews, 1922).

These rocks crop out, intermittently, in a narrow band within an amphibolite zone, stratigraphically above the upper zone of weak mineralisation. The rock type has been used to assist in the stratigraphic and structural interpretation of the area, as the intermittent outcrops can be followed for over 4 miles within the zone of amphibolite.

Isolated outcrops of a similar rock are found in the amphibolite zone which is stratigraphically above the Angus-Kintore zone of mineralisation. The outcrops occur half-way between the Angus Mine and the Kintore mine.

The rocks were not observed to grade into amphibolites, either along or across strike. They appear to be in a definite bed or beds.

In hand specimen the rocks have an equigranular ground mass of quartz and felspar, with prophyroblastic garnets which are rimmed by biotite and chlorite. The rocks resemble Potosi gneisses.

In thin section the rocks have a crystalloblastic texture with granoblastic quartz and plagioclase, and porphyroblastic garnets.

Staining shows that the rocks contain only a few minute grains of potassic felspar.

Rounded zircons, up to 0.04 mm in length, are found in the rocks.

The rocks contain quartz, calcic plagioclase,garnet biotite, chlorite, sphene, ilmenite, zoisite, zircon and apatite.

Mineralogy

Quartz

Quartz comprises approximately 40% of the rocks,and the quartz has undulose extinction.

In Specimen A/180/88 the quartz and plagioclase grain size is 0.5 mm approximately, but in Specimens A/180/92 and 153, the grain size of the quartz and plagioclase is near 1 mm.

Thin lines of minute blackish inclusions occur in the quartz in Specimen A/180/153.

Plagioclase

The An content of the plagioclase in the rocks is variable, even the grains within the same specimen have different calcium contents.

Table 7 (p.135) shows the An content of the plagioclase in the three specimens.

K.J. Mills, Department of Geology, University of Adelaide, carried out the universal stage study to check the results of the writer, who used a flat-stage microscope to determine the types of plagioclase present in the rocks.

From the table it can be seen that the An content of the plagioclases varies from rock to rock and from grain to grain. The specimens were collected in the amphibolite zone, above the upper zone of weak mineralisation. The specimens were collected several miles apart. The varying An content of the plagioclases could well be explained by slight variations in the original sediments.

The plagioclase content is between 30-40% of the rocks, and the grain size is similar to that of the quartz grains.

Albite and parallel twinning occurs in the calcic plagioclase. Most of the plagioclase grains show some alteration to sericite.

As these rocks are very closely associated with the amphibolites, and have calcic plagioclase (andesine to labradorite) present, they fit well into a calcic environment of deposition. The small rounded zircons, suggest that sedimentary conditions were not as quiet as the conditions for the deposition of most of the material which was later metamorphosed to develop amphibolites.

TABLE 7

THE An CONTENT OF THE GNEISSES (WITH CALCIC PLAGIOCLASE) WHICH RESEMBLE POTOSI GNEISS

Specimen No. Prefixed by A/180/	Using Flat-stage Microscope		Using Universal-stage Microscope
88	An_{35}		An_{36} (albite twin)
92	An_{42}		An_{41} (albite twin)
			An_{35} (" ")
153	An_{52}		An_{42} (albite twin)
			An_{42} (" ")
			An_{37} (parallel twin)
			An_{49} (" ")
		same grain	(An_{33} (" ")
			(An_{33} (albite twin)
		same grain	(An_{40} (parallel twin)
			(An_{39} (albite twin)

Garnet

Garnet can make up as much as 10% of the rocks. The garnets are porphyroblastic and in Specimen A/180/88 are up to $\frac{1}{8}$ inch in diameter; Specimens A/180/92 and 153 have garnets up to $\frac{1}{4}$ inch in diameter.

All garnets have altered to some degree to pennine or biotite, and are cracked.

Quartz inclusions occur in some garnets.

No assays have been carried out on the garnets. The refractive index is less than 1.82 in Specimen A/180/53, but no other readings were made.

Biotite and Chlorite

Biotite and chlorite are generally associated with the garnets, although some flakes of biotite, altering to chlorite, are associated with the quartz and felspar. Inclusions with haloes occur in the biotite in Specimen A/180/88.

Sphene

Minor sphene is associated with ilmenite and also with altering plagioclase. Minute inclusions of sphene occur within the plagioclase.

Ilmenite and Magnetite

Ilmenite and magnetite grains are irregular in shape, and up to 0.7 mm in length. The ilmenite and magnetite are associated with the biotite, chlorite, and garnet. 1-2% ilmenite occurs in Specimens A/180/88 and 153.

Zoisite

Zoisite is a rare mineral in the rocks, and occurs as an alteration product of a plagioclase grain in Specimen A/180/92.

Zircon and Apatite

Rounded zircons, up to 0.04 mm in length, occur as inclusions and along quartz and plagioclase grain boundaries.

Apatite inclusions are common in Specimen A/180/92. The grains vary from minute to 0.1 mm. The larger grains tend to be idioblastic.

Genesis

The rocks were originally fine-grained, siliceous-calcareous with minor chloritic-sericitic and kaolin, sediments. The grain size would have been similar to that of clay-silt.

If the original sediments had more chlorite and ferruginous material present the sediments could well have altered to amphibolites.

The rocks have properties similar to those of the felspathic (calcic plagioclase) quartzites, with garnet, which will be described.

Under metamorphic conditions it is suggested that most of the quartz has become crystalloblastic, while other quartz has combined with the calcium and minor sodium to give relatively calcic plagioclase. Sericitic and chloritic material have given rise to biotite, or some of the minor chlorite and calcite could have produced very minor hornblende which has altered to biotite. Chlorite and quartz would produce garnet.

Retrograde metamorphic conditions have allowed the garnets to alter to biotite and chlorite. Most plagioclase grains are sericitised. This is not a feature of the quartz-epidote rocks and is explained by the lack of original potassic and sodic material in the sediments. The quartz-epidote rocks, to be described, are considered to have a similar origin to that of the gneisses resembling Potosi gneisses, and to that of the felspathic garnet quartzites.

Analyses of "footwall gneiss" and Potosi gneiss (Andrews, 1922) from the Broken Hill district, show that Potosi gneiss has more MnO than the "footwall gneiss", yet the rocks are in the same stratigraphic horizon. Potosi gneiss is characterised by large garnets with biotite haloes. Another feature of the Potosi gneisses is that the CaO content is higher than the CaO content of the sillimanite gneisses. A particular sillimanite gneiss with garnet present, has three times as much CaO present as a particular sillimanite gneiss without garnet (Andrews, 1922).

Stillwell (1924) concluded that the Potosi gneiss was originally a sediment. Workers since then have agreed with this conclusion.

(3) Schistose Gneisses

The schistose gneisses differ from the other gneisses, in that felspar is generally absent.

Schistose gneisses collected near the mineralised zones do not contain potassic or sodic felspar. One schistose gneiss specimen, A/180/134, collected near a sheared amphibolite and mineralised zone north of the Angus Mine, contains much altered calcic plagioclase (Andesine = An_{33}). As the specimen is a schistose gneiss it was not included with the gneisses with calcic plagioclase. The properties of the rock again point out that calcic plagioclase is found in the gneisses near amphibolite or mineralised zones.

Gneisses occurring near "aplites" and pegmatites are not common, but Specimen A/180/183 occurred in contact with a pegmatitic "aplite", and has sodic plagioclase (oligoclase - An_{12}) present, amounting to approximately 25% of the rock.

When sodic plagioclase is a major constituent of the schistose gneisses, the rocks are found away from mineralised zones. Specimen A/180/83 has approximately 40% sodic plagioclase (albite-oligoclase-An_{10}) present, and was collected 100 feet stratigraphically above an amphibolite zone to the south of the Egebek Felspar Quarry.

No mineralised zone was noted.

Potassic felspar is almost lacking in the schistose gneisses and was detected by staining methods.

In the schistose gneisses, and schists (p.152), garnets rarely develop if sodic felspar is present, whereas in the gneisses with calcic plagioclase garnet develops. The biotite content in the schistose gneisses is higher in the specimens with sodic plagioclase, that is the specimens without garnet.

Muscovite only forms up to 10% of the schistose gneisses when sodic plagioclase is present.

The schistose gneisses and gneisses with calcic plagioclase, although poor in potassic felspar, are not considered to have been soda metasomatised.

The minerals present in the schistose gneisses, and gneisses without calcic plagioclase are: quartz, sodic plagioclase, biotite, muscovite, sericite, garnet, sillimanite, magnetite, apatite and zircons. Minute grains of potassic felspar were detected by staining methods.

Heavy minerals are lacking in most specimens, although minor heavy minerals were noted in the specimens collected near aplitic zones.

Mineralogy

Quartz

Quartz is a major constituent of each rock, being 30-50%. It occurs in bands as the only mineral, or with muscovite, and sometimes plagioclase.

Most specimens show that the quartz is strained.

Bands within the same rock often have different grain sizes. Specimen A/180/83, has granoblastic quartz and plagioclase in a band, with grains sizes between 1 and 2 mms., while another band has granoblastic quartz and plagioclase with grain sizes of 0.5 mm. approximately. In other specimens the grain size of quartz varies from 0.1 mm to 1 mm in the same band when muscovite is present.

Inclusions of sillimanite needles are found in quartz grains in specimens, which have been taken from shear zones or tight folds.

Plagioclase

With the exception of the specimen collected near the sheared amphibolite and mineralised zone, the plagioclase in the rocks is albite to oligoclase (An_{10-13}).

When present the sodic plagioclase may be as much as 40% of the rock. The grains show some degree of sericitisation and twinning is very faint.

The texture and grain size is similar to that of the quartz grains.

Biotite

The biotite content is between 10 and 30% of the rock.

The flakes are generally 1 mm in length, being larger than most of the muscovite flakes which range from 0.1 to 0.7 mm., although in some specimens the muscovite flakes reach a length of 3 mms.

Biotite occurs in rough bands, and the flakes have a preferred orientation, excepting where garnets develop, or shearing about garnets has taken place.

The pleochroism is straw, to reddish brown or yellowish to brown. Inclusions with haloes are not as common as in the gneisses with calcic plagioclases.

Muscovite

Unlike the biotite flakes, the muscovite flakes are often decussate within a band, although the band as a whole gives the rock a foliated appearance. Some muscovite appears to have recrystallised from sericite. The bands often thin and thicken.

Muscovite may be as much as 40% of the rock, and flakes occur interstitially as well as in bands. When biotite occurs within the muscovite bands, the flakes are small.

Sericite

Sericite is found in all specimens as an alteration product of plagioclase. Few specimens have sericite occurring in bands, but when present in such a manner, the sericite is as much as 30% of the rock. In Specimen A/180/134, which contains the calcic plagioclase, sericite is 30% of the rock, and much of it is altering from sillimanite.

Sillimanite may be present without sericite, but when sericite occurs in bands, sillimanite is present.

Garnet

The garnet content of the schistose gneisses is nil when sodic plagioclase is present, and from 1% to 15% in the rocks without sodic plagioclase.

The garnets are generally associated with biotite, although in Specimen A/180/182, which was taken from near an amphibolite, the garnets occur in the quartz bands and are 15% of the rock.

The garnets, when less than 0.6 mm in diameter, are either idioblastic or rounded, and not cracked. The elongated, porphyroblastic garnets, and clusters of garnets, are cracked and altered. The porphyroblastic garnets in Specimen A/180/160 are up to 3/16th inch in diameter, and have quartz inclusions. This rock occurs near the upper zone of mineralisation, in the northern portion of the area; no assay for manganese was carried out, however, it is another example of megascopic garnets occurring near mineralised zones.

Sillimanite

Three specimens have sillimanite present. In Specimen A/180/134, sillimanite is found in sericite bands. The rock is crenulated, and the altering sillimanite needles follow the crenulations and micro folds. Some needles transgress quartz grains, and also occur as inclusions in quartz. The specimen was collected in a well marked shear zone.

Specimen A/180/160, which was collected in a tight fold position, has sillimanite needles and grains present. The grains are associated with quartz, and often occur in clusters, although the grains are oriented. Sillimanite is 5% of the rock. Some sillimanite needles have developed in the biotite, and are not oriented.

Small needles of sillimanite occur as inclusions in some quartz grains in Specimen A/180/44 which was collected 20 feet to the east of the Angus Mine. No sillimanite occurs in the sericite bands in this specimen.

Magnetite and Ilmenite

Magnetite is found in a few specimens, but when present can be up to 7% of the rock. It is generally associated with biotite.

The grains are up to 0.4 mm in length, and irregular in shape.

Minor ilmenite in Specimen A/180/134, is altering to leucoxene.

Apatite and Zircon

Apatite and zircon are uncommon in the schistose gneisses and gneisses.

In Specimen A/180/183, which was collected near a pegmatitic "aplite", apatite and zircon are present. Approximately 1% of the rock is apatite, with grains of an average length of 0.1 mm; some reach 0.2 mm. The grains are not rounded and are associated with the biotite flakes. A few minute rounded zircons, 0.03 mm in length, occur throughout the rock.

A minute zircon was noted in Specimen A/180/182 which was collected near an amphibolite.

Genesis of the Schistose Gneisses

The schistose gneisses are considered to have been fine-grained (clay-silt) sediments, consisting of siliceous, felspathic, chloritic, sericitic and clay material. Calcareous material must have been present in some of the sediments which are now schistose gneisses with calcic plagioclase.

The grain size of the sediments occurring near the pegmatitic and "aplitic" zones, would possibly have been silt size, as the minor rounded zircons indicate a larger original grain size.

Soda metasomatism is not invoked to explain the absence of potassic felspar, but the sediments are considered to have been relatively soda rich.

(4) Pegmatitic and Granodioritic Gneisses

Pegmatitic and granodioritic gneisses are very minor rocks in the Angus area and crop-out in only a few places in the southern portion of the area. The outcrops are small, up to 20 feet in length, and up to 3 feet wide. The granodioritic gneiss is not as coarse-grained as the granite gneiss at Broken Hill, nor does it show platy or tor-like weathering.

Banding is pronounced in some outcrops, while other outcrops with garnet present are poorly banded.

The pegmatitic gneisses have narrow pegmatite bands alternating with very narrow intermittent bands of biotite and muscovite. The granodioritic gneisses have quartz felspar and garnet, with biotite and muscovite which occur randomly.

As the rocks occur in a small area they cannot be used as marker beds.

The most notable feature of the rocks is that the plagioclase is calcic oligoclase to andesine, with some potassic felspar present.

Only two specimens were collected and both occurred near amphibolite. Specimen A/180/112 resembles a Potosi gneiss, with porphyroblastic garnets, up to 1/8th inch in diameter, showing biotite alteration. Although the rock resembles a Potosi gneiss, it is also granodioritic in appearance.

In Specimen A/180/107, a pegmatitic gneiss, potassic felspar is approximately 2% of the rock, whereas in Specimen A/180/112, potassic felspar is 3-5% of the rock. No properties were noted to suggest that the potassium had been introduced.

The occurrence of calcic plagioclase in the gneisses near amphibolites, again supports the conclusion that amphibolites are associated with calcium bearing rocks.

Minerals present in the rocks are: quartz, felspar, biotite, muscovite, garnet, magnetite, and minor zircon and apatite.

Mineralogy

Quartz

Quartz grains have undulose extinction, and a grain size of 0.5-1.0 mm. The grains of quartz tend to be granoblastic.

Quartz is 70% of the banded pegmatitic gneiss, and 35% of the Potosi-like, granodioritic gneiss.

Plagioclase

Plagioclase is 10% of the banded pegmatitic gneiss, and 55% of the Potosi-like, granodioritic gneiss.

The plagioclase is on the border between oligoclase and andesine in one specimen, and is oligoclase in the other. In the pegmatitic gneiss the grain size varies between 0.2 and 0.8 mm; the grains have quartz and muscovite inclusions and show very faint twinning as most grains are sericitised. The granodioritic gneiss has clear plagioclase grains ranging between 0.5 and 1.0 mm in length.

Potassic Felspar

Potassic felspar grain sizes are similar to those of the plagioclase grains. There is no obvious indication that the potassic felspar has been introduced.

In the granodioritic gneiss specimen, the potassic felspar is in the rough bands, which contain garnet, and is 3-5% of the rock. The potassic felspar in the pegmatitic gneiss is 2% of the rock, and is evenly distributed.

Biotite

The pegmatitic gneiss has biotite occurring in intermittent bands, with minor amounts altering to chlorite. The biotite flakes have a preferred orientation.

In the granitic gneiss specimen, the biotite flakes are poorly oriented, and up to 0.75 mm in length. Inclusions with pleochroic haloes occur in this specimen. Some biotite flakes have a myrmekitic texture.

The biotite has yellow to brown pleochroism.

Muscovite

Muscovite is not present in the granitic gneiss; but occurs interstitially in the pegmatitic gneiss, and is 3% of the rock.

Garnet

No garnet is present in the pegmatitic gneiss,although 3-5% of the granitic gneiss is garnet. The garnets are porphyroblastic, up to 1/8th inch in diameter. All garnets show biotite alteration about their peripheries.

Inclusions of quartz up to 0.6 mm and biotite inclusions, 0.1 mm., are found in the garnets. The garnets are cracked, and reddish in colour.

Magnetite

Magnetite is associated with biotite. Subhedral grains in the pegmatite gneiss reach 2 mms in length. In the granitic gneiss, the grains are found along the grain-boundaries of quartz and felspar, and are generally 0.15 mm in length.

Zircon and Apatite

Minor rounded zircons, 0.01-0.05 mm are found in the quartz and felspar grains.

Minor apatite in the pegmatitic gneiss, is 0.05 mm in length, and occurs in the quartz.

Genesis

The pegmatitic gneisses are considered to have been derived from siliceous-sericitic-chloritic-felspathic-calcareous sediments. The zircons indicate that the grain size could be near silt to sand size.

The pegmatitic bands probably developed from the sediments as the zircons in the bands are rounded.

The sediments would probably have been desposited in an environment in which minor calcium was able to be precipitated.

The granodioritic and pegmatitic gneisses are considered to have a similar origin, but the problem is to decide whether the 3-5% potassic felspar has been introduced or not. If the material has not been introduced, then "dry" conditions prevailed during metamorphism for garnet and potassic felspar to exist together. The suggestion of "dry" conditions is favoured.

(5) Gneisses with Abundant Potassic Felspar

Only one Specimen, A/180/22, of this type of rock was collected. It occurred near narrow pegmatite bands, 400 feet south of the minor quartz-magnetite rocks in the southern portion of the area.

The rock contains 10-15% potassic felspar, occurring in bands parallel to the gneissosity of the rock. The potassic felspar is intimately associated with sodic plagioclase which is 5-10% of the rock. Potassic felspar also occurs in the fractures, nearly at right angles to the gneissosity.

The rock appears to have acted competently during folding.

Quartz is a major mineral in the hand specimen.

Minerals present in the rock are: quartz, potassic felspar, plagioclase, muscovite, biotite altering to chlorite, garnet and zircon.

Mineralogy

Quartz

The percentage of quartz in the rock is 60-70%. The grains are xenoblastic and have undulose extinction.

They are elongated parallel to the gneissosity of the rock, and the grain size varies from 0.3-1.0 mm.

Potassic Felspar

All grains are sericitised and are associated with the sodic plagioclase in the rock. 10-15% of the rock is potassic felspar, which occurs in diffuse bands parallel to the gneissosity. The grain size does not reach the maximum size of the quartz, and is between 0.3 and 0.6 mm. The grains are xenoblastic.

Staining techniques show that potassium felspar also occurs in the fractures.

Sodic Plagioclase

Sodic plagioclase has a similar grain size and association as the potassic felspar. All grains show alteration, but faint twinning is seen. 5-10% of the rock is sodic plagioclase (An_0). Like the potassic felspar the grains are xenoblastic and size varies from 0.3 to 0.6 mm.

Muscovite

Muscovite forms 2-3% of the rock, and occurs as oriented flakes in small intermittent bands, and also interstitially throughout the rock.

The grain size varies from sericitic grain size to 0.4 mm in length and 0.3 mm wide.

Sericite

Sericite is mainly an alteration product of the felspars, although minor amounts are associated with the muscovite.

Biotite

Biotite has an occurrence similar to that of muscovite. Most flakes are oriented, although some flakes occur along grain boundaries of quartz and felspar, and these are often not oriented. Small clusters of decussate flakes are present. The flakes are up to 0.4 mm in length.

Much of the biotite is altering to chlorite.

Garnet

Garnet constitutes less than 1% of the rock. The garnets are rounded to idioblastic, with some cracks and minor chlorite alteration. In the hand specimen they are not readily seen.

Zircon

A few rounded zircons, up to 0.05 mm in length, are found. One crystal shows zoning, with an inner zone bounded by angular faces in contrast to the weathered, rounded outer surface.

Genesis

The gneisses with abundant potassic felspar are considered to have been siliceous-felspathic sediments, with minor sericitic and chloritic material.

The grain size of the zircons suggests that the original grain size of the sediments could have been silt to sand size.

The material for the rock would have been derived from the same source which supplied material to the rocks which are now concordant pegmatites. The specimen was collected near concordant pegmatites.

As the potassic felspar occurs in the fractures in the rock as well as in the bands parallel to the gneissosity, it is concluded that some of the potassic felspar was introduced.

Schists

The schists in the Angus area can be divided broadly into two groups for the purpose of description. One group has a pronounced foliation and does not appear to contain abundant quartz in the hand specimen; the other group is not so well foliated and abundant quartz can be seen in the hand specimen.

(1) The Well Foliated Schists

The schists have properties which can often be explained by their relationship with other rocks.

Felspar when present is generally sodic plagioclase (An_{10}), or potassic felspar. However, Specimen A/180/205, a fine-grained pegmatitic schist, was collected near an amphibolite contains oligoclase (An_{25}). Like the gneisses near the amphibolites, the schists near amphibolites have a higher calcium content. This fact is again considered to be a sedimentary feature and not developed by contact metamorphism.

Another feature of the schists is the occurrence of sillimanite in some specimens. When sillimanite is present, sodic plagioclase and potassic felspar are absent. Sillimanite occurs in three schist specimens and in each case the specimens were collected in tight folds or obvious shears.

Chlorite has developed from biotite in shear environments, but only minor chlorite has developed from biotite in fold environments.

Potassic felspar, which is not common in the gneisses, is also not common in the schists, with the exception of one specimen, which has 20% potassic felspar present. Many specimens have no potassic felspar present; some have no sodic felspar and no potassic felspar. In the specimens with felspar present, Table 8 shows amounts of sodic and potassic felspar present.

TABLE 8

AMOUNTS OF SODIC PLAGIOCLASE AND POTASSIC FELSPAR IN THE WELL FOLIATED SCHISTS

Specimen No. Prefixed by A/180/	% Sodic Plagioclase	% Potassic Felspar
42	5-10	2-3
45	few grains	20
47	few grains	5-10
53	5-10	few grains
82	25	5
114	25-30	2-3
133	5-10	few grains
179	30	2
180	5-10	1-2

Although the well foliated schists do not appear to contain abundant quartz in the hand specimen, some specimens contain as much as 60% quartz when examined in thin section. In Specimen A/180/68, 90% of the rock is quartz, as a vein of quartz with malachite staining is present. Most specimens contain less than 50% quartz.

Mineralisation occurs in some of the well foliated schists, but not in the poorly foliated schists.

Garnets develop in the schists which occur near the mineralised zones.

Minerals present in the schists are: quartz, felspar, muscovite, biotite, chlorite, sillimanite, sericite, haematite, limonite, rutile, magnetite, ilmenite, garnet, apatite and zircons.

Mineralogy

Quartz

Quartz occurs in all specimens. Most specimens have 30-50% quartz present, with the percentage being as low as 20% in one specimen, and as high as 60% in another. The specimen with 90% quartz was collected from quartz vein occurring in a pronounced shear.

The elongated quartz grains are between 0.2-1.2 mms in length. The elongation parallels the foliation of the rocks. The quartz is found in bands as the only mineral, or in bands and associated with any or all of the minerals present. The elongated crystalloblasts are generally xenoblastic. Often the bands of quartz have different grain sizes.

Sillimanite, muscovite, minute black grains, biotite and very minor apatite and zircon, occur as inclusions in the quartz.

All specimens show that the quartz has been strained.

No observations suggest that quartz has been introduced, excepting in Specimens A/180/68 and 133 which were taken from shear zones.

Felspar

Only one specimen, A/180/205, has plagioclase present with refractive indices greater than quartz. The An content of the plagioclase is An_{25} (oligoclase). The plagioclase is 5-7% of the rock. The grains are not sericitised, but show strain shadows. Grain size varies from 0.2 mm to 0.7 mm., and the plagioclase is more prominent in some bands than others. No potassic felspar is present in the specimen.

Sodic plagioclase (albite to oligoclase) is the most abundant felspar present and can be as much as 30% of the rock, although in some specimens only a few grains are present as shown in Table 8. Several specimens have no sodic or potassic felspar present.

The grain sizes in some specimens vary from 0.3-0.5 mm., and in other specimens, 0.3-1.0 mm.

In Specimen A/180/133, which was taken from a shear environment, several large sodic plagioclase crystals, up to 4 mms long and 1.5 mm wide, are elongated at right angles approximately to the foliation. On examining the hand specimen, it can be seen that two pegmatite veins have developed.

Most grains of sodic plagioclase show incipient or well advanced sericitisation. Strain shadows are common in the grains, and occasionally the albite twins show slight bending, or offsets.

Potassic felspar is present when sodic plagioclase is present, and the content varies from a few grains to 20%.

As most grains are sericitised to some degree, staining techniques were necessary to determine the amount and associations of the potassic felspar.

The schist (Specimen A/180/45) with the most potassic felspar present was collected 100 feet to the west of the Angus Mine workings. As potassic felspar is associated with the mineralisation throughout the area, it was thought that potassium could have been introduced into rocks near lode horizons. However Specimen A/180/44, a schistose gneiss, which was collected 10 feet to the east of the Angus Mine workings, contains a few minute grains only of potassic felspar, thus indicating that the potassic content of Specimen A/180/45 could be an original constituent.

The potassic felspar grains are elongated parallel to the foliation and have a similar grain size to that of the sodic felspar.

Schists in contact with concordant pegmatite, such as Specimens A/180/42 and A/180/180, do not contain unusual amounts of sodic or potassic felspar. The rocks contain 5-10% sodic plagioclase and 1-3% potassic felspar.

A schist band occurring between two concordant pegmatite bands is slightly pegmatitic in appearance and contains 30% sodic plagioclase and 2% potassic felspar.

Muscovite

The muscovite content of the schists varies from 5-40%. The bulk of the muscovite occurs in bands which are continuous or intermittent; some flakes occur interstitially. Flakes within the bands are often decussate, and the interstitial flakes have a similar occurrence.

The flakes within bands of muscovite reach a length of 1.0 mm., whereas the muscovite in bands of other minerals only reach lengths of 0.4 mm.

Biotite and chlorite are often associated very closely with muscovite. Small amounts of iron staining of the muscovite are observed in these associations.

In some specimens, sericite grades into muscovite, although the sericite is found mostly in separate intermittent bands.

Crenulations and micro folds are well shown by muscovite bands. In Specimen A/180/180, the folds in the muscovite bands appear to be produced by cleavage.

Biotite and Chlorite

Biotite and/or chlorite are found in most schists, although some specimens have no biotite or chlorite. The biotite content can be up to 30% of the rock, and chlorite as much as 10%. The two minerals occur together, as chlorite is the alteration product of biotite. The minerals are generally oriented and help give the rocks a pronounced foliation. The chlorite occasionally occurs in "knots", with the flakes unoriented and of various sizes. The grain size reaches 1 mm in length, although the average length is 0.3 to 0.7 mm.

The biotite is pleochroic from straw to reddish brown. Minor inclusions, with pleochroic haloes, occur in the biotite.

Muscovite and sericite bands in some specimens are in contact with the biotite and chlorite bands.

The specimens which show shearing and others which are lineated, generally have little biotite, as chlorite has developed under the shearing conditions with the possible introduction of volatile material.

There is no indication that biotite and chlorite are more abundant in some rock type associations than in other associations.

Sillimanite

Sillimanite is a minor mineral in the schists, although in Specimen A/180/190, it is 2% of the rock. In this specimen the sillimanite has developed around an elongated, sheared garnet. Some of the sillimanite has altered to sericite.

Sillimanite when present in the schists, is often found as inclusions in quartz grains.

In Specimen A/180/186, collected in a fold environment similar to Specimen A/180/190, the sillimanite needles occur in a small elliptical knot, 4 mms long and 1.5 mms wide. The knot occurs within biotite and muscovite. Sillimanite needles also occur as inclusions, in elongated quartz grains near the knot.

Specimen A/180/132, taken from a sheared zone, has unoriented sillimanite needles in quartz grains, and also some needles within sericite which is approximately 15% of the rock.

Sericite

Sericite is an alteration product of the felspars in the schists, and has also altered from sillimanite. Minor sericite occurs in the muscovite bands of some schists. Sericite fills the cracks in the sheared garnets in Specimen A/180/132.

Haematite and Limonite

Haematite and limonite are minor minerals in the schists. The sheared Specimen A/180/68, which is copper stained and was collected in the northern portion of the area, has irregular haematite masses, up to ½ inch in length, associated with the quartz. The quartz grains parallel the shear planes of the rock.

Limonite, with minor haematite, is 4-5% of Specimen A/180/190. The minerals are elongated parallel to the foliation planes.

Minor iron staining is found in Specimen A/180/133, which was collected in a shear zone.

Magnetite is altering to haematite and limonite in Specimen A/180/114, which has abundant micro-folds.

Haematite and limonite occur in sheared rocks, and in rocks which are tightly folded.

Rutile

Sagenitic rutile needles, up to 0.2 mm in length, are found in most chlorite flakes. The rutile would have developed during the break down of biotite.

Magnetite and Ilmenite

Many minute black grains, and grains up to 0.5 mm in length, occur with the chlorite flakes, and much of the material is thought to be magnetite and ilmenite.

Several small grains of magnetite are altering to haematite in Specimen A/180/114, also very minor ilmenite is altering to leucoxene.

A few small magnetite grains are associated with biotite in Specimen A/180/181.

Garnet

Garnets when present in the schists are generally small and difficult to see in the hand specimen. Specimen A/180/181, occurring near the Angus Mine has megascopic reddish garnets, up to 1/8th inch in diameter. The garnet is 4% of the rock. No assay for manganese was carried out. However, Specimen A/180/45 which was collected near the Angus Mine, assayed 0.19% MnO. The garnets in this specimen are fine-grained.

Garnets in the schists are often elongated parallel to the foliation and show slight iron alteration in cracks.

In some specimens small garnets form clusters, up to 5 mms across.

Quartz and biotite are found as inclusions in the megascopic garnets.

The schists with garnets generally occur near mineralised zones.

Apatite and Zircon

Apatite and zircon are rare in the well foliated schists. Apatite occurs as small inclusions, 0.03 mm in length, in quartz and felspar grains.

Zircon was noted in only one schist Specimen A/180/180, which was collected in contact with a concordant pegmatite. The zircons are up to 0.03 mm in length, and occur as rounded inclusions within the quartz grains.

Genesis

The schists were developed from fine-grained siliceous-chloritic-sericitic-sediments with minor clays and possible felspathic material.

Heavy minerals such as zircon are absent, excepting in the sediments deposited near coarser grained sediments which have been altered to pegmatites.

The sillimanite has developed in the schists which do not contain felspar. The sillimanite is considered to have developed in shear zones and tight folds, and is not developed as a regional metamorphic mineral in the Angus area.

Garnet has best developed in the zones in which manganese is thought to have been present in the sediments, and not introduced.

The schist specimen, collected near an amphibolite, has a higher plagioclase An content than the other schists, and such schists are considered to have been sediments which were deposited in a calcic environment, such as the conditions under which the "amphibolitic" sediments were deposited.

(2) Schists with Abundant Quartz

The schists with abundant quartz generally have a slight greenish appearance, as most of the minor biotite has altered to chlorite.

The rocks are common in a zone occurring between the two felspathic-garnet-quartzite, and quartz-epidote rock zones, as shown in cross-section A-B-C, plan No.X27/782. Other occurrences have been noted in association with "aplites".

Iron staining of the exposed portions of the rocks is a common feature.

The outcrops are up to 300 feet in length and 30 feet wide, and are best seen approximately 1,400 feet north-east of the Kintore mine.

The beds have acted relatively competently during folding.

A specimen, somewhat typical, taken from an outcrop 2,700 feet N-NE of the Kintore mine, contains 85-90% quartz and in the hand specimen resembles a quartzite.

The amount of quartz occurring in the rocks is between 50-90%, although one Specimen A/180/147 which has a pronounced foliation, contains only 25% quartz.

Felspar is a minor constituent of the rocks, although reaching 10% in some specimens. The felspar is sodic plagioclase, with only two specimens showing potassic felspar by staining methods.

Four "quartzitic" schists with sillimanite present were taken from tight fold, shear and fault environments, again strongly indicating that sillimanite in the Angus area has not developed as a result of regional metamorphism, but developed in environments of excessive strain.

Heavy minerals are not common in the schists with abundant quartz. A specimen, A/180/66, taken from near an "aplite", 3,100 feet NNE of the Angus Mine has more heavy minerals, such as zircon, than the "quartzitic" schists collected between the two zones of felspathic, garnet quartzites, and quartz-epidote rocks.

Micaceous minerals are generally less than 30% of the rocks.

Mineralisation was not observed to occur in the rocks.

Minerals present in the rocks are: quartz, muscovite, sericite, felspar, chlorite, sillimanite, garnet, limonite, rutile, ilmenite, magnetite, apatite and zircon.

Mineralogy

Quartz

All specimens show that the quartz has been strained.

The percentage of quartz present, is from 25% to 90%.

The quartz grains are elongated parallel to the weak foliation in the rocks. The crystalloblasts of quartz, generally tend to be granoblastic, but in some specimens are xenoblastic.

The grain size is between 0.2 mm-1.0 mm in length, although in Specimen A/180/72, the grains reach 1.5 mm in length in one band, with finer-grained bands occurring in the same rock.

Minute black inclusions in quartz are found in many specimens. Sillimanite inclusions in quartz are not oriented, and in Specimen A/180/147, swarms of sillimanite occur within quartz grains. Muscovite flakes also occur as inclusions.

<u>Muscovite</u>

All the weakly foliated schists with abundant quartz contain muscovite; most specimens have 5-10% present, although the content varies between 5-30%.

Most of the muscovite and chlorite flakes are oriented and give the rocks their schistose appearance. Other flakes occur interstitially and have random orientations.

The flakes have lengths up to 0.3 mm., but when occurring as inclusions in quartz, do not exceed 0.1 mm.

Muscovite bands show the folding in Specimens A/180/72 and 146.

Sericite is associated with muscovite in some bands.

<u>Sericite</u>

When sillimanite is present, sericite can be as much as 30% of the rocks. In Specimen A/180/147, sericite appears nematoblastic, as it is an alteration product of sillimanite. It also has a "herringbone" type structure, probably produced by a cleavage.

In Specimens A/180/140 and 146, sericite is 5-10% of the rocks.

Most of the sericite is the alteration product of sillimanite, which has developed in strain environments.

Sericitisation of the minor felspars in the rocks has taken place.

Felspar

Felspar is a minor constituent of the weakly foliated schists.

Sodic plagioclase (An_9) is as much as 5% in two specimens. The grains occur with the quartz and reach 1 mm in length in one specimen, but do not exceed 0.4 mm in other specimens. The grains are generally altered, although Specimen A/180/66, taken from near an "aplite" has mostly clear grains, with some bending of the twin planes.

Potassic felspar is rare, with 1-2% in Specimen A/180/145 and a few grains in Specimen A/180/66. The grains, 0.3 mm in length, are sericitised, and are associated with quartz.

Chlorite

Chlorite is present in most specimens, being 5% of some rocks.

The flakes are generally oriented and occur in intermittent bands. Most flakes are ragged with some tending to be fibrous. Average grain size is 0.4 to 0.5 mm.; some reaching 1.0 mm.

Small black inclusions, possibly magnetite or ilmenite, are common in the chlorite flakes. Sagenitic needles of rutile also occur as inclusions.

Muscovite and sericite are associated with the chlorite in bands in some specimens.

Specimen A/180/140 has biotite with inclusions which are surrounded by pleochroic haloes and chlorite.

Specimen A/180/140 has biotite altering to chlorite. Inclusions with pleochroic haloes are present.

Sillimanite

Most of the oriented sillimanite in bands in the schists with abundant quartz, has altered, or is in an advanced stage of alteration to sericite. The sillimanite needles in the quartz grains are "fresh" in appearance and are not oriented. In Specimen A/180/147, swarms of sillimanite needles occur in the quartz. The sillimanite needles reach length of 1 mm.

Sillimanite is a minor constituent of the rocks.

Garnet

Garnet is another minor mineral, although as much as 2-3% of one rock.

The larger garnets, up to 0.7 mm are cracked, subhedral, and have limonite or chlorite alteration. The smaller garnets are often idioblastic.

In Specimen A/180/147 a few garnet grains occur in the same band.

No megascopic garnets occur in the rocks.

Limonite

Minor limonite staining is found in Specimens A/180/78 and A/180/79. Limonite is associated with garnet in some specimens.

Rutile

Rutile occurs as small, unoriented needles in some chlorite flakes, being developed as a result of biotite altering to chlorite.

Rutile grains, up to 0.03 mm were noted in two specimens, A/180/66 and 147.

Ilmenite and Magnetite

The small blackish inclusions in the chlorite are probably ilmenite and magnetite.

A few grains of magnetite, are found with muscovite in Specimen A/180/79.

Apatite and Zircon

Like the well foliated schists, the weakly foliated "quartzitic" schists do not contain many heavy minerals.

Apatite occurs as inclusions in quartz, either as rounded or subhedral grains. Apatite was noted in six thin sections, although some thin sections have only one or two grains present. The grain size is up to 0.05 mm.

Zircon was noted in four specimens, occurring in quartz. The grain size reached 0.05 mm., and the grains are rounded. Only a few grains are found in each specimen.

Genesis

The grain size of the minor rounded zircons indicates that the original sediments were silt to sand size.

The schists are thought to have been siliceous sediments, with minor felspathic, chloritic, sericitic and clay material.

Quartz-epidote Rocks

Quartz-epidote rocks are associated with felspathic quartzites with garnets. The rocks crop out intermittently in two zones, one being stratigraphically above the lower zone of mineralisation and the other stratigraphically below the middle (Angus-Kintore) zone of mineralisation (See Cross-section A-B-C, Plan No.X27/782). The rocks are best developed in the lower zone, and crop out intermittently for 4,800 feet. The individual outcrops are up to 150 feet in length and 3 feet wide. In the upper zone, the rocks are poorly developed, and only rare outcrops are found with the felspathic quartzites with garnet.

Some of the outcrops within the zone could occupy similar stratigraphic horizons to those of the weak mineralisation.

The rocks should not be compared with the small blebs of quartz-epidote which occur within the amphibolites; however, a similar rock (Specimen A/180/208) was collected in an amphibolite horizon and contained quartz, epidote and minor amphibole altering to chlorite.

Schists are interbedded with the quartz-epidote rocks and the felspathic quartzites with garnet.

The rocks are light green in colour. Minerals present in the rocks are: quartz, epidote, sphene, chlorite, garnet, magnetite, ilmenite, limonite, haematite, apatite and plagioclase.

Quartz

As in all rocks, including lode quartz, the quartz in the quartz-epidote rocks, has undulose extinction.

Quartz is 45-70% of the rocks and is granoblastic. Grain size varies between 0.15 and 0.9 mms. In Specimen A/180/127 the grain size varies between 0.2 and 0.35 mm.

Rough bands often have abundant quartz, with minor epidote and, similarly, rough bands of epidote have minor quartz. The rough bands can be distinguished in the hand specimen, but not well seen in thin section.

Inclusions of epidote are found in the quartz grains.

Epidote

Optical properties indicate that no zoisite or clino-zoisite is present in the rocks. The optical sign is negative, with a 2V of approximately 75°.

The epidote content is as high as 60% in some specimens and as low as 25% in other specimens.

The grains have a fresh appearance, and the epidote does not appear to alter from calcic plagioclase.

Most of the epidote grains have a ragged appearance. The grain size varies from 0.1 to 1.0 mm.

Small grains of epidote, 0.1-0.2 mm occur between the quartz grains, while the larger grains are xenoblastic, and occur in patches. Some grains have quartz and sphene inclusions.

Sphene

In the four specimens collected, three from the lower zone and one from the upper zone, sphene is present.

In Specimen A/180/144, collected in the upper zone, sphene is 3% of the rock. The grains are up to 0.3 mm long and 0.15 mm wide.

The sphene grains are either rounded or irregular in shape, and are always within or along the grain boundaries of epidote crystals. The grain size varies from minute to 0.3 mm.

The grains often occur in lines with 4 or 5 grains in contact.

Chlorite

Chlorite is a minor mineral in the quartz-epidote rocks, and when present it often partly rims epidote grains, or occurs between them.

Limonite and a little haematite are found in association with the chlorite flakes. The chlorite associated with epidote has an irregular shape, and is not fibrous. Pleochroism is pronounced, whereas the epidote is very feebly pleochroic.

No amphibole was observed to be associated with the chlorite.

Some chlorite rims a few of the garnets in the rocks.

Garnet

Garnet occurs in two specimens, A/180/81 and 144, taken from the lower and upper zones respectively. A few grains develop along grain boundaries of quartz and epidote and tend to occur in bands. The garnets are subhedral to rounded and up to 0.15 mm in diameter. Chlorite is an alteration product of some of the garnets.

Magnetite and Ilmenite

Magnetite altering to haematite is found in Specimen A/180/144. Two euhedral crystals of ilmenite, one small and the other 0.25 mm in length, were found in association with an irregular blob of magnetite altering to haematite. Also minute black grains, possibly ilmenite, occur within a cluster of 3 to 4 sphene grains in the rock.

In Specimen A/180/103 small ilmenite grains are altering to leucoxene.

Limonite and Haematite

Limonite apart from being associated with the minor chlorite, occurs in small fractures in Specimens A/180/81 and 127. Haematite is also an alteration product of the minor magnetite present.

Apatite and Zircon

Rare apatite grains, 0.02 mm in length are found as inclusions, and along grain boundaries. Possible zircons, 0.03 mm in length, occur in Specimen A/180/81.

Plagioclase

Three or four grains of altering plagioclase occur in Specimen A/180/144. The grains have irregular shape, and are up to 0.5 mm in length. The grains are sericitised with some possible muscovite developing. The refractive indices are greater than the refractive indices of quartz.

Genesis

The rocks have a similar origin to that of the felspathic (calcic plagioclase) quartzites with garnet. Both rock types occur in the same zones. The felspathic quartzites with garnet will be described subsequently.

The rocks are concluded to have a sedimentary origin. Little or no sericitic material would have been present in the original sediments.

Minor heavy minerals occur in the rocks, and also in the felspathic quartzites with garnet.

Fine-grained siliceous-calcareous sediments with minor chloritic and kaolin material are considered to have produced the quartz-epidote rocks. Although they are quartzitic in appearance, the original grain size would have been of clay to silt dimensions, with some calcareous material being deposited from solution.

Similar sediments with abundant chlorite and ferruginous material were concluded to have been metamorphosed to form amphibolites.

If major amounts of plagioclase developed in the rocks it must have been extremely calcic, as there is little evidence of sodic material being displaced when the calcic plagioclase has altered to epidote.

Sphene would have developed from original titanium (possibly rutile) and calcareous material in the rocks.

The rocks occur stratigraphically above and below amphibolites in schistose sediments.

The sediments are considered to have altered to felspathic quartzites with garnet, and minor biotite or actinolite or hornblende. Under retrograde conditions the rocks have altered to quartz, epidote, garnet, chlorite rocks.

Felspathic Quartzites with Garnet

The felspathic quartzites with garnet are often associated with the quartz-epidote rocks.

The rocks occur in a zone stratigraphically below the zone of mineralisation extending from the Kintore mine to the Angus Mine where it is offset by a shear zone to the east. The mineralised zone then extends to the north-east of the shear. The rocks are also found stratigraphically above the lower zone of weak, intermittent, mineralisation which is approximately 2,650 feet stratigraphically below the Angus-Kintore line of mineralisation. These rocks crop out intermittently for 4,800 feet approximately, and are then terminated by the E-W striking shear zone. Minor outcrops are also found in a broad schist zone, which contains the upper zone of very weak, intermittent, mineralisation.

Individual beds are up to 700 feet in length and 3 feet wide, with most of the outcrops being tens of feet or feet in length. The rocks have a massive, darkish appearance with the small reddish garnets just visible.

Schists are the common rocks surrounding the felspathic quartzites, and as mentioned quartz-epidote rocks occur in two of the zones.

Minor, pyrrhotite, chalcopyrite, pyrite mineralisation is found in one of the two specimens which were collected.

Faint banding is seen in the rocks.

Minerals present in the rocks are: quartz,plagioclase, garnet, hornblende, biotite, chlorite, magnetite, rutile, muscovite, sericite, zoisite, apatite, zircon, pyrrhotite, chalcopyrite and pyrite.

Mineralogy

Quartz

The quartz grains have undulose extinction, and constitute 70-80% of the rocks. The grains vary between 0.15 and 0.6 mm in length.

The grain sizes of quartz grains often varies from band to band in the rocks.

Plagioclase

Plagioclase is approximately 25% of Specimen A/180/80, and 5-10% of A/180/126. The An contents of the plagioclase are:

Specimen A/180/80 - An_{58}

" A/180/126 - An_{80}

The plagioclase grains vary between 0.05 and 0.3 mm and are xenoblastic.

Very minor zoisite alteration is seen in Specimen A/180/80 and minor sericitisation occurs in Specimen A/180/126.

The small plagioclase grains appear to occur between the quartz grains. Similarly small epidote grains in the quartz epidote rocks occur between the quartz grains.

Albite and parallel twinning occurs in the plagioclase; this is a feature of all the rocks containing calcic plagioclase in the area.

Garnet

Garnet is 2-3% of the rocks. The grains have irregular shape and develop in bands. They are often elongated, parallel to the faint banding in the rocks. The grains are up to 0.6 mm in length, with minor cracks developing.

Quartz, and possibly plagioclase, inclusions are found in the larger garnets. Minute blackish inclusions occur in some garnets in Specimen A/180/80.

The garnets could contain some manganese, as an assay for manganese in Specimen A/180/80 gave a value of 0.27% MnO. The manganese value will be discussed again when describing the mineralisation.

Alteration of the garnets is rare.

Hornblende

Hornblende is found in Specimen A/180/80, and is 2-3% of the rock.

The hornblende has a fresh appearance and is pleochroic from straw to green. The grains are very ragged and range in size from less than 0.1 mm to 0.7 mm.

The grains are oriented and occur throughout the rock.

Biotite

In the other Specimen A/180/126, biotite occurs and not hornblende.

It is 5% of the rock and the flakes are oriented. Pleochroism is from straw to brown.

Inclusions of minute to small grains of an iron-bearing mineral are found in the flakes, which are ragged and reach a length of 0.35 mm.

Chlorite

Chlorite occurs in a rough band in Specimen A/180/126. The flakes reach a length of 0.3 mm. Garnet and sericitised plagioclase is found in the same rough band.

Magnetite and Rutile

Magnetite is a minor mineral in the felspathic quartzites.

The grains reach a length of 0.2 mm., and are associated with the garnets, hornblende, biotite and chlorite, with some grains developed along the grain boundaries of quartz and plagioclase. The interstitial grains have a preferred orientation, although an irregular shape.

Minor iron-rich rutile was noted in a mineragraphic briquette Specimen A/180/80.

Muscovite and Sericite

Very minor muscovite occurs in Specimen A/180/126 in the rough band containing chlorite. Sericite is a very minor alteration product of the plagioclase in the same band.

Zoisite

A few grains of plagioclase in Specimen A/180/80, show very minor alteration to zoisite.

Apatite and Zircon

Apatite is more common than zircon. Some apatite grains are rounded and others have well-defined crystal faces. Apatite is found in the quartz and plagioclase and between the grains. The grains reach 0.03 mm in length.

Zircon grains have a similar occurrence, but are rare. The grains are rounded and are up to 0.25 mm in length.

Pyrrhotite and Chalcopyrite

Pyrrhotite and chalcopyrite are found in Specimen A/180/80. They are minor in amount, and are oriented parallel to a very weak foliation. The minerals are accociated and occur in small blebs up to 2.0 mms in length and 0.3 mm wide. A little limonite staining is associated with the minerals. Mineragraphic studies show chalcopyrite and pyrrhotite grains up to 0.5 mm long and 0.2 mm wide. The grains appear to be original; they are not replacing other minerals, or being replaced.

Genesis

The rocks are concluded to have a similar origin to that of the quartz epidote rocks and the amphibolites.

The appearance of hornblende in the rocks, gives some proof that the rocks could grade into amphibolites.

In Specimen A/180/126, which has minor biotite and muscovite, it is concluded that sericitic material was present in the original sediments. Potassic bearing material would have been absent in Specimen A/180/80.

The rocks are thought to have been fine-grained sediments, clay to silt size, consisting of siliceous and calcareous, with minor sericitic and clay, material.

The heavy minerals, such as zircon, indicate that the grain size of the sediments would have been clay to silt size.

<u>Quartz-magnetite Rocks</u>

Only two narrow outcrops of quartz-magnetite were observed within the area mapped. The outcrops occur in the southern portion of the area. Each is 10-20 feet in length and 6 inches to 2 feet wide, and concordant with the sediments.

A small quartz outcrop, 1 mile north of the Angus Mine in an"aplite" zone, contains abundant magnetite, but the rock is coarse-grained, whereas the outcrops in the southern portion of the area are finer grained.

As this rock type is minor there is no possibility of using it as a marker bed, as is possible in other parts of the Broken Hill district.

The two small outcrops occur in a fold environment.

A striking feature of the specimen collected,A/180/113, is the amount of apatite in the rock. The rock contains 5-10% apatite, and in some bands the percentage would be 10%. Edwards (1953) noted 7% apatite in a quartz-magnetite specimen from near the Allendale mine, Broken Hill District.

"Aplite" is generally associated with quartz-magnetite outcrops, but in the Angus area the outcrops in the southern portion of the area are associated with concordant pegmatites, which grade into "aplite", as indicated by structural interpretation and petrological studies.

The minerals present in the rocks are: quartz, magnetite, haematite, apatite, garnet, and limonite.

Mineralogy

Quartz

Quartz is approximately 50% of the typical specimen collected, and the grain size varies from 0.03 mm to 0.6 mm.

Iron staining is common along the boundaries of the crystalloblasts of quartz.

Fine parallel lines, which are oriented from grain to grain, have minute black inclusions. The grains have undulose extinction.

Quartz is found as small inclusions in the magnetite and in the garnets.

Magnetite and Haematite

Magnetite and haematite are 35% of the rock. The grain size varies from 0.02 mm to 1.0 mm. Some grains are idioblastic, while most have irregular shapes. Haematite is a common alteration of magnetite.

Apatite and quartz inclusions are found in some of the larger magnetite grains.

There is a rough banding in the rock and the magnetite grains are oriented weakly. The banding in the rock as a whole is best seen in thin section by holding the slide up to a light source.

Apatite

The grains vary from minute inclusions in the quartz to 0.5 mm when it tends to occur granoblastically with the quartz.

Some grains have haematite in cracks which have developed. Inclusions of apatite are found in some magnetite grains.

A few elongated grains reach 0.5 mm in length, and are oriented parallel to the rough banding.

Garnet

Five percent garnet is found in the rocks, and in one narrow band, 1/16th inch wide, garnet is very abundant.

In the garnet band the rounded and irregular shaped garnets are up to 0.3 mm in diameter; throughout the rock garnets reach 0.25 mm in diameter.

Small cracks have developed in the garnets in the band, and in the garnets throughout the rocks, cracks and iron alteration are present.

Some garnets are surrounded by magnetite.

Limonite

Limonite staining is associated with the haematite.

Possible Copper Staining

A green stain 0.5 mm in length can be seen in the thin section, and could be copper staining.

Genesis

Andrews (1922) regarded the quartz-magnetite rocks as an expression of early iron-rich mineralisation.

King and Thomson (1953) suggested that the quartz-magnetite rocks were originally ferruginous sediments.

Thomson (1955) concluded that the quartz-magnetite rocks and Banded-Ironstone-Formation rocks are altered chemical sediments.

Russell (1957) concluded that B.I.F. rocks were originally chemically precipitated oxides and hydroxides of iron and manganese, along with some clay minerals, sand and lime.

The high apatite content of the specimen collected would support a sedimentary origin for the rocks.

Siliceous Laterite - "Grey-Billy"

Siliceous lateritic material, known as "Grey-billy", is found on the eastern side of the N.E.-S.W. striking Hillston Fault, as float material. In the Angus area the rock was not found in situ, although occurrences of "grey-billy" and iron lateritic material are found elsewhere in the Broken Hill district as cappings.

All rocks described in the foregoing pages are Archaean rocks, whereas the grey-billy is of possible Tertiary age (Kenny, 1934).

The rock is greyish and appears cryptocrystalline in hand specimen. Rayner (1949) described it as a form of porcellaneous secondary quartzite.

As the grey-billy is found only on the eastern side of the Hillston Fault it is indicative that movement on the fault has occurred following the deposition of the siliceous laterite.

Mineralogy

Only one typical specimen was collected and the minerals present are: quartz, sericite, muscovite, and possible limonitic clay mineral.

Quartz

Quartz is approximately 40% of the rock, with the large grains reaching 0.1 mm in length and most grains being much smaller. The grains are distributed throughout the rock, although some cracks, 0.15 mm wide, contain quartz grains only.

The quartz has slight undulose extinction.

Sericite and Muscovite

Associated with the quartz grains are sericite and muscovite, which would be approximately 30% of the rock. Quartz is abundant where associated with sericite, and less abundant where muscovite develops. The muscovite flakes reach 0.15 mm in length.

Limonitic Clay

Approximately 30% of the rock is a material which is thought to be a limonitic clay. The grains occur throughout the rock, and have a preferred orientation. Some grains reach a length of 0.05 mm.

The grains are pale yellowish in transmitted, reflected, and polarised light.

Haematite

Haematite is altering from an irregular shaped bleb of magnetite, which is 0.3 mm in length.

STRATIGRAPHY AND SEDIMENTATION

Stratigraphy, sedimentary environment and metamorphism will be discussed before describing the mineralisation.

Thomson (1955) placed the Archaean rocks in the Angus area stratigraphically above the rocks which contain the large ore-bodies at Broken Hill. The Angus area rocks were placed in the Pinnacles Group.

Thomson (1955) proposed a scheme such as the following for the Archaean rocks:

Group Name	Range
Pinnacles Group	Top of group not known
Broken Hill Group	Top of granite gneiss formation. Base of limey sediments and amphibolites
Redan Group	Base of Redan Group not known

Thomson considered that there was one granite gneiss horizon; Broken Hill geologists now accept two granite gneiss horizons in the mine area, mainly as a result of Lewis' (1957) re-interpretation of the Broken Hill mine area.

B. R. Lewis, Chief Geologist, Broken Hill South Ltd., has re-interpreted the stratigraphy and structure of the Broken Hill district, but the information has not been made known outside the company.

W. N. Thomas of the Zinc Corporation Ltd. will, or has, put forward a Generalised Reconstruction of the Broken Hill Basin of Sedimentation. The reconstruction at the time of preparing this thesis is not known to the writer.

As a relatively small area of approximately 18 square miles has been mapped and discussed in this thesis, no attempt will be made to place the Angus area rocks in stratigraphic horizons on a regional scale. Before attempting such an interpretation it would be necessary to examine the sparse outcrops north of the Angus area. Geophysical work carried out prior to 1949 by The Zinc Corporation Ltd., indicates that the rocks north of the area mapped could strike in a north-easterly direction. Observations made by the writer indicate that the rocks strike in a north-easterly direction for at least 12,000 feet north of the Angus area. The observations will be listed when discussing structure.

In the southern portion of the Angus area the rocks strike in a westerly direction, and appear to be stratigraphically above a granite gneiss horizon which is

$2\frac{1}{2}$-3 miles south of the area mapped.

Cross-section A-B-C (Plan No.X27/782) shows the stratigraphy of the rocks in the Angus area. The section line is shown on Plan Nos. X27/780 and X27/781. The rock types have been divided into zones. The zone is named by the dominant rock type present, although other rock types occur within the zone. For example within the "aplite" zones, pegmatite, schists and minor amphibolite are found, and similarly within the amphibolite zones, schists are found.

If the "Interpretation of Geology" plans (Nos.X27/780 and X27,781) are placed over the"Geological Plans - Angus Area - sheets 1 and 2" (Nos. X27/762 and X27/763) the zones can be seen to contain a dominant rock type.

All beds have a steep westerly dip, and no bed is repeated in the cross-section, showing that the beds are on a limb structure.

If the cross-section is studied it can be seen that the rock types and their sequence could be explained by transgressions and regressions of the sea.

The lowest zone of rocks, the "aplite" zone, outcropping in the eastern portion of the area could indicate a possible regression of the sea, probably caused by uplift of the land. Felspathic sands and sub-greywacke sediments were probably deposited in shallow water, although no definite shallow water sedimentary features were observed. The source beds are thought to have been sodium rich medium-coarse-grained rocks. Minor amphibolites in the "aplitic" zone are considered to have developed from calcareous-chloritic-siliceous-ferruginous sediments.

The "aplites" would have been deposited under oxidising conditions with a low pH and a relatively more positive Eh, as the sediments are thought to have been deposited in shallow water.

The next zone containing schists and pegmatites, indicates the beginning of transgression of the sea. The pegmatites are considered to be altered felspathic sands and pelitic sediments, and thus the schists and pegmatites were originally interbedded fine-grained and coarse-grained sediments.

A zone of amphibolite follows. These rocks were originally sediments deposited as the sea transgressed further. Such factors as pH would have probably increased slightly, Eh relatively more negative, and the water far deeper and quiet for the deposition of calcareous material in the chloritic and ferruginous sediments. Gneisses and schists near the amphibolites have calcic plagioclase present, indicating deposition of sediments in a calcareous environment.

Felspathic quartzites with garnet and quartz-epidote rocks are in the next zone. Deposition of siliceous-calcareous sediments, with minor chloritic kaolinite and sericitic material, occurred to form these rocks.

Further subsidence probably caused the next zone of sediments to be deposited in deeper water. These form the zone of schists. Shallowing of the basin of deposition or increased supply of terrigenous material, could have taken place, as the weakly foliated quartzitic schists originally had a slightly larger grain size than the well foliated schists. Such a situation could be likened to a minor regression of the sea.

The sequence of zones is then repeated in the reverse order (the pegmatite zone which grades into an "aplite" zone is treated as an "aplite" zone). This indicates a renewed uplift of the source area.

Minor fluctuations then occurred until after the deposition of sediments which are now of pegmatitic character, shown at B on the cross-section. Following these minor movements of the sea, further subsidence allowed the deposition of sediments, now schists and gneisses, and also sediments now metamorphosed to amphibolites.

Above the amphibolite zone with minor spotted gneiss (resembling Potosi gneiss), a pegmatite and "aplite" zone with minor amphibolite occurs. Another uplift of the source area is indicated, as the deposition of felspathic sands would probably have taken place.

Stratigraphically above the upper "aplite" zone (point A) there are more amphibolites, schists and pegmatites which have been mapped in the north-western portion of the area.

If treated as zones, the rocks fit a type of cyclic sedimentation.

As soda metasomatism is not invoked to explain the sodic nature of the sediments, then the source material for the "aplites", pegmatites and many of the schists was soda rich.

Chloritic sediments would probably have been derived from basic rocks. Calcareous and ferruginous material would have been deposited from solution under favourable conditions.

Thomson (1955) in his thesis "Tectonics and Archaean Sedimentation of the Barrier Ranges, N.S.W.", has outlined the environment of sedimentation of the Broken Hill Archaean rocks as a whole. Thomson concluded that the environment could have ranged from miogeosynclinal to the

the N.W. of Broken Hill, through unstable shelf to intra-cratonic basin conditions to the S.E. of Broken Hill.

Thomson also concluded that the amphibolites have a sedimentary origin, and showed how the original limy sediments fitted into sedimentary and tectonic environments.

Lewis (1957) by his interpretation of the structure in the Broken Hill mine area, showed that the rock sequences to some extent were repeated in a reverse order on a limb structure. Russell (1957), having knowledge of Lewis' findings made a systematic petrological study of the rocks between the two granite gneiss horizons, and also studied the granite gneisses. Russell concluded that the amphibolites have an igneous origin, thus these rocks were not fitted into a sedimentary origin. Should the amphibolites in the Broken Hill area have a sedimentary origin, then a type of cyclic sedimentation could be possible.

W. G. Burns, The Zinc Corporation Ltd., (personal communication) has noted that zones of rocks are repeated in a reverse order on a limb structure, in the Pinnacle's mine area.

The thicknesses of the various zones, in the Angus area, vary greatly, and are best seen by studying the cross-section A-B-C (Plan No.X27/782), and the Interpretation of Geology plans (Nos. X27/780 and 781).

A study of the plans and section will show that the weak mineralisation is associated with calcium rich zones.

METAMORPHISM

The grade of metamorphism of the rocks in the Angus area is considered to be Amphibolite Facies, under Eskolas, (1939) classification, and the Almandine Amphibolite Facies, under Turner's (1955) classification. Using Turner's classification, the rocks are considered to fit a grade of metamorphism between the staurolite-quartz sub-facies and the sillimanite-almandine sub-facies, of the almandine-amphibolite facies.

The reasons for these conclusions are outlined below.

(1) Pelitic and Quartzo-Felspathic Assemblages

In the pelitic and quartzo-felspathic assemblages only minor potash felspar has developed, yet muscovite is abundant. There is no indication that the biotite is of a magnesian type.

Minor sillimanite has developed in shear and tight fold environments, but no kyanite was observed. The lack of kyanite, and minor sillimanite could be explained by the original kaolinite having combined to form other minerals, leaving no excess alumina to develop kyanite or sillimanite at higher grades of metamorphism. The writer considers that the temperatures and pressures were not high enough to develop kyanite and sillimanite from muscovite on a regional scale. Any kaolinite in a calcareous sediment would have given rise to epidote initially. Kaolinite may have been lacking in the pelitic sediments as staurolite is absent, meaning that chlorite has developed biotite, and no such reaction as chlorite + kaolinite $\longrightarrow$ staurolite would have taken place. The development of staurolite would also depend upon the Fe^{++}/Fe^{+++} ratio, and also the amount of iron present.

The garnet in the pelitic and quartzo-felspathic assemblages is almandine, with minor calcium and manganese present. Garnets removed from a gneiss, Specimen A/180/41, near the Angus Mine, have a refractive index between 1.783 and 1.792, and have 2.09% CaO, and 5.06% MnO present.

Plagioclase present in the pelitic and quartzo-felspathic assemblages ranges from andesine to bytownite. The assemblages in the staurolite-quartz subfacies generally have oligoclase or andesine present. This subfacies lies between the staurolite-quartz subfacies and sillimanite-almandite subfacies, but only the pelitic assemblages have been described by Fyfe, Turner and Verhoogen (1955). Assemblages in the sillimanite-almandine subfacies, generally have anorthite or bytownite present.

Plagioclases in the pelitic and quartzo-felspathic assemblages in the Angus area, would lie between the kyanite-muscovite-quartz subfacies and the sillimanite-almandine subfacies.

Such rocks as "aplites" have not had calcium available to develop plagioclase with a higher An content than An_{14}, similarly with the schists not deposited in calcic environments.

(2) Calcareous and Magnesian Assemblages

In the calcareous and magnesian assemblages the plagioclase is labradorite to bytownite, indicating that the grade of metamorphism is near, or has probably reached, the sillimanite-almandine subfacies. Some epidote in the calcareous assemblages has altered from calcic plagioclase while other epidote appears to have developed as a result of progressive metamorphism, again indicating that the rocks in the Angus area reached a grade of metamorphism between the kyanite-muscovite-quartz subfacies and the sillimanite-almandine subfacies.

Diopside has not developed in the calcareous and magnesian assemblages, but minor hornblende occurs. Diopside and hornblende may develop in the kyanite-muscovite quartz subfacies or the sillimanite-almandine subfacies. Tremolite is found in the calcareous assemblages, and Williams (1952) reported cummingtonite; these minerals may occur in both the above mentioned subfacies.

(3) Basic Assemblages

In the basic assemblages only one specimen collected contained diopside, all other rocks having hornblende present. The hornblende gives no indication of having altered from pyroxene, again indicating that the grade of metamorphism reached lies between the subfacies stated.

Plagioclase in the basic assemblages of the rocks in the Angus area is andesine to anorthite. Such a range would indicate that the grade of metamorphism is near the sillimanite-almandine subfacies.

Garnets in the basic assemblages are concluded to be almandine rich. Garnets extracted from an amphibolite, Specimen A/180/38, have a refractive index of 1.775 and 4.87% CaO present. Garnets extracted from amphibolite Specimen A/180/33, have a refractive index of 1.776, and

3.9% CaO and 4.5% MnO.

Minor biotite in the Basic assemblage would also indicate that the grade of metamorphism would lie between the staurolite-quartz-subfacies and the sillimanite-almandine subfacies.

The lack of perthitic structures in the felspars indicates that the grade of metamorphism has not reached the granulite facies.

Hornblende in the amphibolites is greenish, with minor bluish-green grains. No greenish-brown hornblende was noted to suggest a grade of metamorphism as high as the sillimanite-almandine subfacies or granulite facies. The bluish green hornblende grains were noted in some of the amphibolites containing epidote, suggesting that soda has entered the hornblende when plagioclase altered to epidote, zoisite or clinozoisite.

Zoning in the plagioclases was observed in some amphibolites and gneisses with calcic plagioclase.

Some zoning is normal, while in Specimens A/180/184 and 33 the zoning is "reverse". Specimen A/180/184 was taken from the narrow transgressive amphibolite in the area. In a zoned plagioclase in the rock, the core is An_{30} and the rim is An_{43}. If the rock were of igneous origin, it would be expected that the core of the plagioclase would be greater than An_{30}. The rock under metamorphic conditions has developed plagioclase with an An_{43} content, which suggests that the rocks have been subjected to the grade of metamorphism stated.

Indications of retrograde metamorphism have been observed. The specimen containing diopside shows the diopside altering to hornblende.

Calcic plagioclase grains in some specimens have altered to epidote, zoisite and clinozoisite.

Biotite has altered to chlorite in many rocks in the pelitic and calcareous assemblages.

Garnets in all assemblages have minor biotite and chlorite alteration.

Many of the felspars have been sericitised; probably with some sericitisation produced by retrograde metamorphism.

Much of the very minor sillimanite developed has altered to sericite.

The study of the metamorphism supports the conclusion that the amphibolites could be altered sediments.

METASOMATISM

No large scale soda metasomatism is suggested to explain the sodic nature of the "aplites", concordant pegmatites or many of the schists.

Should such a process have taken place it would be expected that the calcic plagioclases in the calcareous and basic assemblages would show many blebs of albite within their structures. The An content of the calcic plagioclase is normal, or even higher than normal, and there is no indication of sodium having relatively lowered the calcium content.

If wide-spread soda metasomatism occurred, it could be expected that the amount of displaced potassium would be great. Some displaced potassium could be thought to occur in the transgressive pegmatites, but the amount is small in relation to the amount of "aplitic" rocks.

In rocks collected near transgressive pegmatites it was noted that one small albite grain in one specimen had possible relict potash felspar present. This is the only indication of possible soda metasomatism. Several other grains in the specimen are antiperthite. Relict, or included, albite occurs in a potash felspar grain in another specimen collected near transgressive pegmatites;

this occurrence would suggest that potash felspar from the transgressive pegmatite entered the specimen.

In all other specimens collected and examined there is no indication to suggest soda metasomatism.

There is no indication that a more calcic plagioclase existed in the "aplites". The only occurrence of calcic bearing minerals in the "aplites" (with the exception of the plagioclases) is a very narrow vein of epidote.

There is no indication that other than minor amounts of sodium have entered the hornblende grains in the amphibolites.

Orville (1959) has shown that calcium rich environments will repel K^+ to more alkaline environments and at the same time attract Na^+. If soda metasomatism has taken place in the Angus area, then the reverse process has occurred, which is unlikely in the light of Orville's study.

When discussing the "aplites" it was shown that a typical "aplite" assayed 5.12% Na_2O, 0.48% K_2O. The sodium-potassium ratio certainly suggests the possibility of soda metasomatism. However, such rocks as aplite, granite porphyry, soda rhyolite, microgranite, granite (albite pegmatite), quartz keratophyne, granophyte and felsite can have less than 1% K_2O. Washington (1917) has shown 14 analyses of such rocks, with three of them having no K_2O present, and not one having greater than 1% K_2O. Therefore, sediments derived from such rocks would be soda rich. In the Angus area, such an origin is envisaged for the soda rich rocks.

As the amphibolites are considered to be of sedimentary origin, iron, magnesium and aluminium would be required if the sediments were originally calcareous.

No large metasomatism is considered for these rocks, as the amphibolites are considered to be metamorphosed chloritic-calcareous-ferruginous sediments with minor sericitic and kaolinite material.

Structure

Folding

If the reduced "Interpretation of Geology" plan (scale 1 inch represents 800 feet) is studied it can be seen that the overall structure is a limb structure with two pronounced anticlinal folds developed, and a pronounced synclinal fold in the southern portion of the area. One anticlinal fold has developed in the area near the Egebek Felspar quarry, while the other fold has developed in the area surrounding the Angus Mine. Shearing has accentuated the width of the noses of the anticlinal folds.

The beds strike in a westerly direction in the southern portion of the area, and north-easterly in the northern portion of the area.

The axial planes of the folds are considered to be near vertical, as small drag folds have axial planes near vertical; minor cleavage observed is near vertical; a petrofabric study of Specimen A/180/82, indicates that the axial plane could dip east steeply.

The plunges of the folds and lineations in the area are closely related although the plunge is variable.

In most of the area, with the exception of the north-eastern portion and the area on the eastern side of the Hillston Fault, the plunge direction of folds and lineations varies between 10° west of north and 5° east of north, and the plunge is between 10° and 70°. Minor southerly plunges of 5° to 85° have been noted. The southerly plunges occur in a broad zone south of the section line A-B-C to the Kintore mine. The zone parallels the section line. Only 6 southerly plunges were noted. The plunge directions are near the reciprocals of the northerly plunges, indicating minor pitch reversals, and not another period of folding. Although the southerly plunges are minor, they are considered to be important and will be discussed in relation to mineralisation (p.216).

In the north-eastern portion of the area, the plunge directions of folds and lineations vary between 5° east of north and 40° east of north. The plunge is between 35° and 70°.

On the eastern side of the Hillston Fault the plunges vary between 20° and 65°, and the direction varies between just west of north to east.

The plunge readings in the north-eastern portion of the area are important as they assist in determining if the beds keep striking in a north to north-easterly direction under the alluvium. As the plunge directions vary between 5° east of north and 40° east of north, it is indicative that the beds will tend to turn in an easterly direction and not a westerly direction, although the Hillston Fault could truncate the beds. However, the following observations have been made, which support the conclusion that the beds continue to strike north-easterly to the north of the area mapped:

(1) Geological mapping and interpretation indicates that the beds turn north-easterly.

(2) Alluvium covered ridges viewed from the air turn north-easterly.

(3) Salt bush and blue bush boundaries turn north-easterly. The boundaries are not shown on the plans which

accompany this thesis, but were mapped on the aerial photographs.

(4) A study of regional geological maps prepared by Geologists of The Zinc Corporation Ltd., shows sparse "aplite" outcrops striking in a north-easterly direction up to 12,000 feet to the north of the Angus area. The sparse outcrops of "aplites" north of the "aplites" on the eastern side of the Hillston Fault strike in a N.N.E. direction.

(5) A Gravity Survey which was extended 2,400 feet north of the area mapped, indicates that the beds turn north-easterly, and the contours could also indicate that the Hillston Fault exists and is truncating the north-easterly striking beds. The gravity survey will be discussed (p.264).

(6) The slightly converging strikes of the sparse "aplite" outcrops could indicate that the Hillston Fault persists to the north of the area.

Near a shear with copper staining, at 61,700'S-77,400'W, lineations and small folds, plunge 35° north, 12° N.E. and 45°-80° S.W. As these readings were taken within a few square yards and near an obvious shear, no overall structural significance is placed on them.

The beds in the Angus area generally dip steeply, from 60° to near vertical, in a westerly direction.

Overturning of beds, dipping steeply to the east, has been observed, but is very minor.

Tight folding within the schists and gneisses is common. Drag folds in these rocks have been used to determine that the beds in the area are not overturned, and all occur on a large limb structure. No irrefutable sedimentary structures were observed to indicate the attitude of the beds.

Crenulations are not common, but when observed appear to be caused by cleavage.

Ptygmatic folding is very rare. Minor slump structures in schists with associated garnet granulites ("garnet sandstone") were observed underground at the Angus Mine, and also in schists in a creek bed, ½ mile to the south.

The schists and gneisses have acted incompetently during folding.

Folding in the "aplites" is relatively open, although tight folding does occur. The "aplite" is often fractured with slight shearing near the noses of tight folds. Such fracturing may explain a 5° south plunge of a small fold in "aplite" 5,000 feet S.S.E. of the Egebek Felspar quarry. However as other minor southerly plunges have been noted the 5° southerly plunge could be normal. In general, tight drag folding is not a feature of the "aplites".

Tight folding has been observed in the gahnite-garnet sandstone rocks. The folds observed are tectonic and not slumping.

Folding in the amphibolites is open, and these rocks have acted competently. Quartz filled fractures are small, but common in these rocks, especially near the noses of folds. If these rocks were of igneous origin, the competent nature is easily explained, however as they are here thought to have a sedimentary origin the rocks must have been metamorphosed, at least prior to the last period of folding, if two or more periods of folding occurred.

The zones of pegmatites are relatively open-folded, with some tight folding within the zones.

As the concordant pegmatites are considered to be altered felspathic sands and pelitic sediments, it is concluded that these rocks were metamorphosed prior to the folding in its present form.

The pegmatites have acted relatively competently, and fractures have developed, often filled with milky quartz.

All folding observed in the Angus area is of the similar type and no undoubted parallel folding was noted, indicating that confining pressures were large and the deforming forces were applied slowly during a long period of time (Nevin 1949).

Lineations in the rocks are best seen in the schists which have abundant quartz present. Lineations are rarely seen in the other rock types. Lineations observed in the rocks in the Angus area appear to have developed as the result of cleavage being superimposed on bedding planes. Some lineations brought about by macroscopic mineral elongations in the concordant pegmatites were noted.

As most of the weak mineralisation in the area is found in fold environments within particular horizons it suggests that material has moved to positions of relatively lower stress, although Broken Hill type mineralisation is not found in shears, faults or fractures in the Angus area.

A study of the larger folds indicates that there is no pronounced attenuation of limbs and broadening of noses of folds, although concordant pegmatites are often well developed in the noses of folds.

Petrofabric Study

To endeavour to determine if two or more periods of folding occurred, a petrofabric study of a lineated Specimen A/180/82, collected 1,000 feet south of the

Egebek Felspar quarry, was made. Details of the observations made in the field are listed in Plate 3.

Dr. A. W. Kleeman, Department of Geology, University of Adelaide, supervised the petrofabric study.

Plate 3 shows the diagram to have a pronounced a-c girdle, and that only one lineation occurs in the rock, with no suggestion of a second lineation which could indicate another deformation.

In the diagram in Plate 3,

S_1 represents the megascopic foliation, striking 348°M.

S_2 represents the microscopic foliation, striking 006°M.

P_1 is the pole of the megascopic foliation which is striking 348°M, and has been tilted to the vertical.

P is the pole of the megascopic foliation dipping at 69° E, prior to tilting to the vertical for examination.

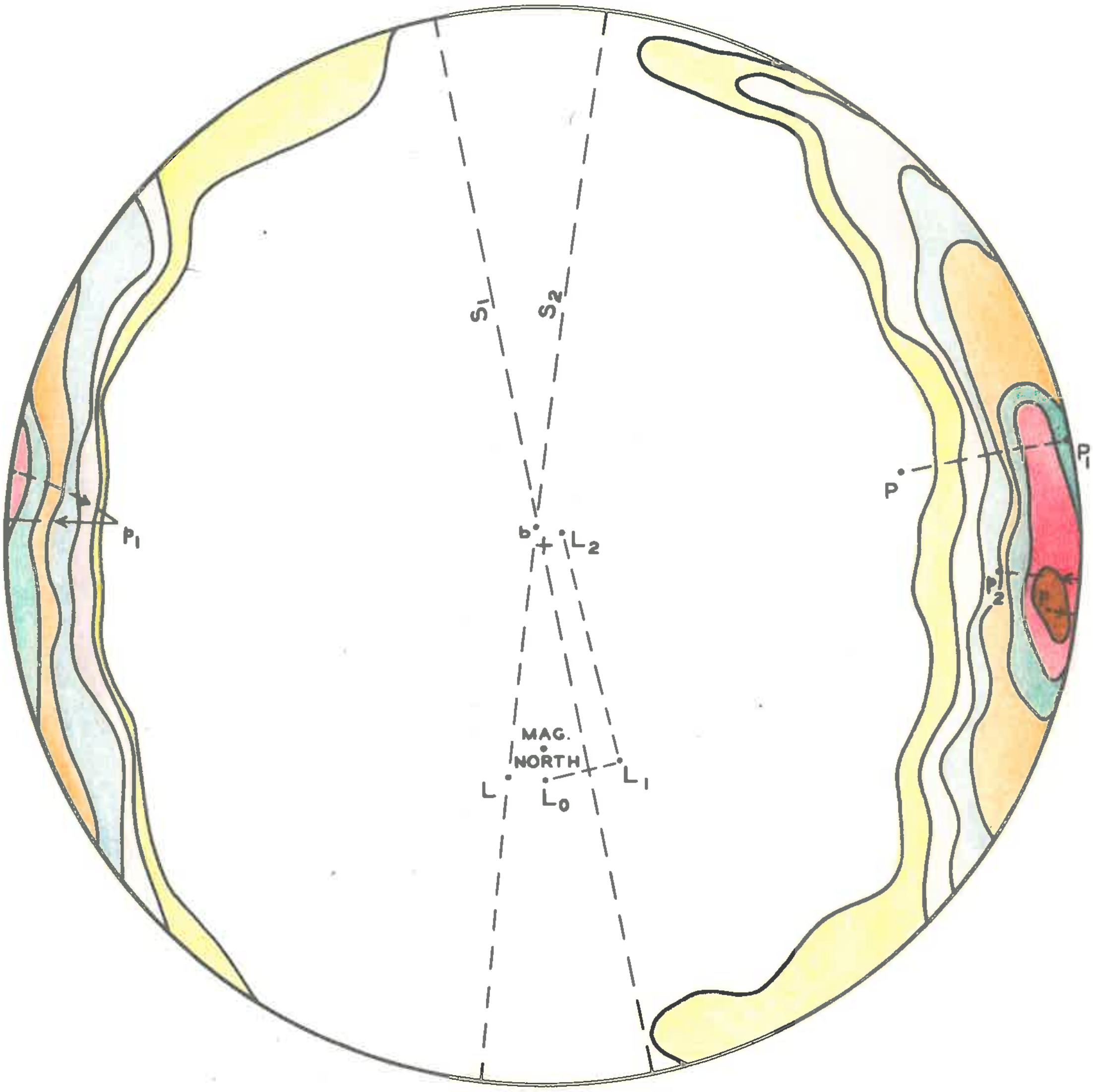
L_o is the plot of the lineation, plunging 42° on a bearing of 000°M, as measured in the field.

L_1 is the plot of the lineation when the megascopic foliation is tilted to the vertical.

L_2 is the plot of the lineation when the lineation is rotated to the vertical.

p is the pole of the microscopic foliation as determined in the petrofabric study.

203A



PLOT ON THE UPPER HEMISPHERE
OF 255 POLES OF 001 CLEAVAGE FLAKES OF MUSCOVITE,
USING AN EQUAL AREA NET

CONTOURED AT INTERVALS OF:

< 1 %	5 — 10 %
1 — 2 %	10 — 15 %
2 — 5 %	15 — 20 %
	> 20 %

SPECIMEN No. A/180/82 — QUARTZ, MUSCOVITE, FELSPAR SCHIST. LINEATION MEASURED IN THE FIELD PLUNGES AT 42° ON A BEARING OF 360° MAGNETIC. FOLIATION STRIKES 348° MAGNETIC AND DIPS 69° E. SLIDE WAS CUT NORMAL TO THE LINEATION.

PLATE 3

A.M.C.S.

p_1 is the plot of the pole of the microscopic foliation after the foliation plane has been rotated back 48° to assume a 42° plunge of any lineations which may be in the plane.

p_2 is the plot of the pole of the microscopic foliation after the plane has been tilted 21° to assume 69° easterly dip.

Using the above information, p_2 being the pole of a microscopic foliation as it would have occurred in the field, the attitude of the microscope foliation can be determined. The attitude of the plane is, strike 002°M and dipping 82° east.

As the megascopic foliation is probably bedding, striking 343°M and dipping 69°E., the microscopic foliation would probably represent a cleavage, striking 002°M and dipping 82°E. The information would indicate that the beds are not overturned in the locality examined, also that the axial plane may have a slight easterly dip on a bearing near (002°M - 6½°E., variation), 355½°T which is in the range of the considered attitudes of the axial planes, strike between 10° west of north and 5° east of north, and the dip is near vertical. These readings apply for most of the area, with the exception of the north-east portion and the area on the eastern side of the Hillston Fault.

Referring to Plate 3, the petrofabric diagram, the point L_o was determined by reasoning that the lineation observed in the field was developed by the intersection of a bedding plane and cleavage. On plotting the megascopic foliation, which was thought to be bedding (strike 348°M, dip 69°E) and the determined microscopic foliation, (cleavage) with a field attitude of strike 002°M, dip 82° east, the lineation obtained has a plunge of 42° on a bearing of 010°M.

The field observation for the plunge of the lineation is 42° on a bearing of 000°M.

The difference in the bearing of the plunge is attributed to an error in field reading. Thus L represents the plot of a lineation as determined in the laboratory, and L_o is the plot of the observed lineation.

The points b, L_2 and + on the petrofabric diagrams, would probably coincide if the specimen had been cut exactly at right angles to the lineation and field measurements were exact.

This laboratory study and field observations in the Angus area do not indicate two or more periods of deformation due to folding, although previous structures could have been obliterated by later structures.

Foliation (Bedding Cleavage or Bedding Schistosity)

Foliation of the rocks in the Angus area appears to parallel the strike and dip of the bedding in limb positions and in fold positions. This type of foliation has been described by Billings (1955) as a particular type of bedding cleavage or bedding schistosity. Billings also describes bedding cleavage which parallels the strike and dip of the limbs, but transgresses the noses of folds. The bedding cleavage in the Angus area is thought to be the mimetic type. Bedding fissility in the rocks would probably have controlled, to a large degree, the direction of recrystallisation of minerals to produce the bedding cleavage.

The "aplites" are very weakly foliated, but the concordant pegmatites are foliated noticeably. Some amphibolites are well foliated, although the texture of most of the amphibolites is gneissic in hand specimen. Foliation (probable bedding cleavage) in the concordant pegmatites appears to be produced by flow and recrystallisation, similarly with the weakly foliated "aplites". The schists and gneisses have a foliated (bedding cleavage) which most probably developed as the result of mimetic recrystallisation, controlled by bedding fissility. The similar type folding suggests that the confining pressures could have been large and deforming forces were applied slowly.

Fracture Cleavage

Fracture cleavage is not well developed in the Angus area, although it is observed in the synclinal fold environments. The strike of the cleavage parallels or nearly parallels the directions of the plunge of folds. The cleavage is vertical, or nearly vertical.

Unlike the bedding cleavage, the fracture cleavage is seen to cut the bedding and associated foliation at acute angles in the noses of folds. Minor bedding-cleavage relationships observed indicate that the beds are not overturned.

Specimen A/180/82, treated in the petrofabric study, was taken from a fold environment where a northerly striking, vertically dipping cleavage is developed, 1,000 feet south of the Egebek Felspar quarry.

There is no evidence to suggest that slaty or flow cleavage was developed due to tight folding, as the overall structure appears relatively open, although Thomson (1955) has interpreted tight folding in the granite gneisses, 3 miles to the south of the Angus area.

During the final stages of folding, fracture cleavage is thought to have developed in the small tight fold environments.

If the direction of deforming stresses were known, a better understanding of the bedding cleavage and fracture cleavage might be possible; similarly with the faults which occur in the area.

Joints

The larger joints in the Angus area are filled with pegmatite. The joints strike in an east-westerly direction, and where the dip is observed, generally in the fine-grained pegmatites, it is 50°-60° south, or near the vertical.

As the joints strike E-W, and most of the observed dips are southerly, it is indicative that the joints are tension joints at right angles to the axial surfaces of the folds. Many of the lineations would be normal to the joint planes.

In the southern portion of the area the joints strike E-W or a few degrees south of east thus the direction is at approximately right angles to the direction of the plunging folds and lineations. In the northern portion of the area the joints strike in an E.S.E. direction, again at right angles to the plunging folds and lineations which strike east of north.

Small joint systems in quartz outcrops are numerous, and no attempt is made to correlate the systems with the overall structure.

The larger joints are best developed in the "aplite", amphibolite and pegmatite zones; that is, in the more competent rocks.

Four thousand feet to the north of the Angus Mine, the joints appear to have a north block west movement of 200-300 feet in places as the "aplite" zones are offset. The joints have thus developed into small faults in this area.

At the Angus Mine, the measured plunge of a lineation is 53° northerly and the major joint system strikes east-westerly and dips to the south at 35°, again indicating that the joints are associated with the expressed folding.

Faults and Shears

Within the area mapped the Hillston Fault strikes N.E.-S.W. on the eastern side of the area; a shear zone strikes east-westerly just north of the Angus Mine, and a gentle scarp strikes N-S in the south-western portion of the area. A small north-south striking fault occurs near the Angus-Kintore (middle) zone of mineralisation.

(1) Shear Zone

The shear zone, striking east-westerly, north of the Angus Mine, has accentuated the anticlinal fold near the Egebek Felspar quarry, and also the anticlinal fold near the Angus Mine.

The shearing has offset beds as much as 2,000 feet, that is a north block east movement, which is the opposite movement to the suspected movement on joints 4,000 feet north of the Angus Mine.

Interpretation of regional mapping, at a scale of 1 inch represents 1 mile, of the Sentinel and adjacent areas by Enterprise Exploration Co.Pty.Ltd., shows the shear to extend westward to the Mundi-Mundi Scarp, and eastward beyond the Hillston Fault (Thomson, 1952).

It is concluded that the shear was controlled along the noses of the anticlinal folds near the Egebek quarry and the Angus Mine. "The Interpretation of Geology" plans (Nos. X27/780 and 781) show that the concordant pegmatite and amphibolite have "flowed" before rupturing, while the "aplite" being relatively more competent has given a relatively cleaner break. The schists and gneisses would have flowed considerably before rupturing.

The shearing preceded the development of the Hillston Fault which did not displace the shear laterally.

The outcrop of "aplite" on the eastern side of the Hillston Fault scarp is sparse and only a few inches to a foot above the surrounding ground, indicating that the "aplite" has been down-faulted following the north block east movement on the shear.

(2) Hillston Fault

The Hillston Fault cuts-off the structures in the southern portion of the area, but in no place can the fault actually be observed. The scarp is pronounced. In the northern portion of the area it runs parallel to the strike of the rocks. The gravity contours at the northern and southern extremities of the gravity survey give an indication that the fault persists past its mapped limits.

The east block has been down-faulted, but no indication of horizontal movement has been observed.

The fault could have developed as a strike fault in the northern portion of the area.

(3) Mundi-Mundi Scarp

The Mundi-Mundi scarp strikes north-south in the south-west portion of the area. No indication of faulting was observed with the exception of the gentle scarp. The scarp is pronounced in the northern portion of the Broken Hill district and is considered to be produced by a zig-zag fault system (Thomson, 1952). Thomson noted that the Mundi-Mundi scarp dies-out to the south of the Angus area.

The Mundi-Mundi Scarp extends for some 40 miles in a north-south direction, with less than a mile of a gentle portion of the scarp occurring in the area mapped.

(4) Fault parallel to Angus-Kintore Zone of Mineralisation

A narrow iron-stained fault zone, up to 5 feet wide, has been mapped intermittently for a distance of 6,000 feet. The fault strikes parallel to, and to the east of, the Angus-Kintore (middle) zone of mineralisation.

The horizontal movement on the fault is less than 5 feet where an observation was made near the Angus Mine. An east block north horizontal movement was noted. Vertical movement on the fault is unknown. The fault dies out toward the folded concordant pegmatite just north of the Angus Mine, and also dies out toward the Hillston Fault.

As the fault direction is parallel to the strike of the poorly developed fracture cleavage, it is thought that the cleavage controlled the fault. The dip of the fault is considered to be near vertical like the cleavage.

(5) Minor Faults and Shears

Small E-W striking, iron-stained faults and shears have been mapped in the schists and gneisses. The strike of the faults is parallel to the strike of the major shear zone.

A small fault, striking parallel to the bedding and dipping 80°-85° E was mapped in a pit to the south of the Clarke shaft at the Angus Mine. The strike and dip of fault would indicate that it was controlled by fracture cleavage.

CHAPTER III

MINERALISATION

(1) Broken Hill type mineralisation is found in three pronounced zones, which will be known as the lower, middle and upper zones in this thesis. A fourth zone occurs above the upper zone, and is associated with amphibolite in the north western portion of the area mapped.

Broken Hill type mineralisation is concordant with the bedding, and contains quartz-gahnite, pinkish friable garnet granulite ("garnet sandstone") and blue quartz, or any of these rocks or minerals.

(2) Very minor Thackaringa type mineralisation has been noted. The gangue is calcite and siderite with minor lead sulphide. Typical Thackaringa type mineralisation is transgressive and generally contains siderite gangue, but there is no proof of the minor occurrence in the Angus area being transgressive.

(3) Copper staining has been mapped in two small shear zones.

(4) Isolated beryl crystals have been noted in some of the transgressive pegmatites.

(1) Broken Hill Type Mineralisation

(a) The Lower Zone of Mineralisation

In the lower zone of mineralisation, which is stratigraphically above the lowest amphibolite zone, quartz-gahnite mineralisation crops out intermittently for 1,000 feet, with the northerly outcrop near the E-W striking shear zone. Approximately 3,000 feet to the south of the southernmost intermittent outcrop, and in the same stratigraphic horizon, a small occurrence of gahnite was noted.

The intermittent outcrops are narrow, from a few inches to a foot in width, and from a few feet to 20 feet in length.

The mineralisation is mainly gahnite, with garnet sandstone, quartz, and copper staining. A few well developed apatite crystals were found. No lead and zinc sulphides were observed. The garnet sandstone is friable and pinkish, and occurs in bands within massive, fine-grained, gahnite rocks.

The lower zone of mineralisation is cut-off by the E-W striking shear zone. However, 6,500 feet N-E of the shear zone, on the eastern side of the Hillston Fault, the lower zone of mineralisation is represented by a small outcrop of quartz-garnet-chlorite-magnetite rock with copper staining. The lower zone of mineralisation is approximately 500 feet structurally above the lowest "aplite" zone.

The mineralisation is associated with small plunging drag-folds. One such fold, in the lower zone of mineralisation, plunges 5° in a southerly direction; other folds have a northerly plunge.

(b) The Middle (Angus-Kintore) Zone of Mineralisation

Approximately 2,000 feet stratigraphically above the lower zone of mineralisation is the middle (Angus-Kintore) zone of mineralisation, which has been mapped from the Hillston Fault in the south, for over 4 miles along strike in a northerly direction. The bands of mineralisation within the zone vary from a few inches thick to 10 feet thick, and from a few feet to tens of feet in length. The mineralisation is mainly gahnite, although minor lead and zinc sulphides occur at the Angus Mine, Kintore Mine, and at a position where a transgressive pegmatite cuts the zone of mineralisation at 65,100'S-79,000'W. Minerals associated with the lead and zinc sulphides are chalcopyrite, anglesite, covellite, pyrite, marcasite, pyrargyrite, rutile, ilmenite and haematite.

The mineralisation is always found in small fold environments in the middle zone of mineralisation. This zone of mineralisation is very closely associated with an amphibolite zone.

Pits, costeans and shafts are found along the middle zone of mineralisation. Most shafts are shallow, up to 50 feet in depth, but the main (engine) shaft at the Angus Mine was mapped to a depth of 209 feet. The depth of the Kintore shaft is unknown, but mullock on the surface would indicate that the shaft would be about 100 feet in depth.

(i) The Angus Mine within the Angus-Kintore Zone of Mineralisation

The Angus Mine was surveyed and mapped geologically. Surveying and mapping, at a scale of 1 inch represents 20 feet, of the accessible underground workings was carried out with the aid of tape and compass. An area of 600 feet by 500 feet, surrounding the mine, was "plane-table" surveyed in conjunction with geological mapping.

The Angus Mine is situated at approximately 69,000'S, 88,800'W, and the Kintore Mine is at 74,800'S, 89,000'W, (see Plan X27/763).

The following plans and sections will be referred to when discussing the Angus Mine workings and mineralisation:

X27,739	Surface Geological Plan
X27/746	Level Plan
X27/747	Cross Sections
X27/750	Longitudinal Section
- -	Isometric Block Diagram
X27/751	Composite Plan

Mapping at the Angus Mine has shown that there are at least four narrow lenses of lode material, which lens out along strike and down dip. Maximum width of the lode material is approximately 10 feet. (See Plans X27/746, 747 and 751). The lenses occur within a stratigraphic thickness of 30-35 feet.

Approximate length of a lens is 100 feet, while the depth is unknown. These weakly mineralised lenses show a concentration of mineralisation in anticlinal noses of drag folds within the lenses. (See Longitudinal Section X27/750 and Composite Plan X27/751). The drag folds are small and plunge at 50^{o} - 60^{o} in a northerly direction, while the dip of the lenses is 70^{o}-80^{o}W. In the lowest lens, one small shoot in a pitching drag fold has been worked to a depth of over 190 feet. Another small drag fold in the upper lens has a concentration of garnet sandstone and minor amounts of lead and zinc sulphides.

Lode material consists of transparent-translucent quartz, gahnite, garnet, pinkish "garnet sandstone",and copper staining associated with quartz. The galena, sphalerite, chalcopyrite, and pyrargyrite are concentrated in the drag folds with the lode material.

The width of the high grade ore in the worked out shoot in the bottom lens is only 2 feet, while the length is 6 feet approximately. The dimensions of the worked out shoot would be 2 feet by 6 feet by at least 200 feet. Records indicate that the lens was worked to a depth of 28 feet below the 190 feet level by means of a winze. The shoot of ore lensed out at 25 feet below the 190 foot level.

The shoot pattern of concentrated mineralisation is controlled by the number of drag folds which are imposed on the lode lenses. The direction of plunge of the shoots of ore is at an angle of 20° approximately to the strike of the lode lenses. (See Composite Plan No.X27/751).

Assays of the 190 foot level underground workings at the Angus Mine are shown on the Isometric Block Diagram. A portion of the rich shoot in the lower lens remaining in a small pillar on the 190 foot level, gives an assay, over a width of 2 feet of 26% lead, 32 ozs silver per ton, 16.5% zinc, 0.24% copper.

(ii) <u>Tonnage Removed from the Angus Mine</u>

Mine records, held by the Department of Mines, Broken Hill, N.S.W., show that approximately 400 tons of "run of mine" ore were removed from above the 130 foot level and handpicked to 184 tons assaying 35% Pb., 40 ozs Ag/ton. This ore was obtained from a north pitching shoot. The shoot has since been worked to the 190 foot level and the writer estimates that another 100 tons of "run of mine" ore has been removed and possibly handpicked to 50 tons with an assay similar to that of the ore occurring in the pillar on the 190 foot level. Records also indicate that a winze was sunk below the 190 foot level to a depth of 28 feet, thus another 50 tons could be added to the "run of mine" ore.

Further reference will be made to the Angus-Kintore zone of mineralisation, when discussing the mineralogy, origin of the mineralisation, and economic considerations.

(c) <u>The Upper Zone of Mineralisation</u>

The upper zone of mineralisation is stratigraphically below the amphibolite zone with the associated spotted gneiss which resembles Potosi Gneiss.

Mineralisation in this zone is found over a distance of 2,000 feet in the northern portion of the area. The zone is broad, up to 300 feet, but mineralisation is weak and the individual lenses are narrow, a few inches to 2 feet wide, and occur intermittently for lengths up to 300 feet. The mineralisation is gahnite, occurring with transparent to translucent quartz, and is found in a broad schist zone.

In the same broad schist zone in the southern portion of the area several narrow lenses of quartz gahnite occur. The lenses in the southern portion of the area can be mapped for over 1½ miles, that is including the folded lenses south of the Egebek Felspar quarry.

A few grains of galena were noted to occur with the tremolite at 70,700'S-94,500'W, south of the Egebek quarry.

Small quartz lenses are found at 71,200'S-92,100'W and 73,200'S-92,600'W. These lenses, although in the same broad schist zone as the other lenses, are stratigraphically lower than the main zone of mineralisation. The lenses occur near amphibolites.

Similar to the lower and middle zones of mineralisation, the gahnite with quartz is found in fold environments.

No friable "garnet sandstone" has been observed within the upper zone of mineralisation. Iron staining is common in this zone of quartz-gahnite.

The weak mineralisation in the upper zone occurs in a calcic environment, and a gneiss collected near the mineralisation in the northern portion of the zone, has megascopic garnets, which indicates that manganese is present, even though friable garnet granulite ("garnet sandstone") does not occur.

(d) Mineralisation within the Zone of Amphibolite with Associated Spotted Gneiss which resembles Gneiss

Some mineralisation occurs within the amphibolite zone which has associated spotted gneiss resembling Potosi gneiss. This mineralisation occurs in the northern portion of the area; minor gahnite and copper staining is associated with quartz and small reddish garnets.

The intermittent copper staining, and one outcrop with gahnite, occur over a distance of 2,100 feet. The lode is narrow, up to 1 foot in width, and individual lenses are up to 50 feet in length.

The quartz associated with the copper staining is milky, unlike the transparent to translucent quartz in the other zones.

Milky quartz is not common near the mineralisation, but does occur near the Angus and Kintore Mines.

Mineralogy of the Broken Hill Type Mineralisation

The assays shown in Tables 9 and 10 (pp.223-24,236-37) will be referred to here and when discussing the mineralogy and the origin of the Broken Hill type, and other, mineralisation.

The assays in Table 9, with the exception of the last two,

TABLE 9

ZINC AND LEAD ASSAYS OF VARIOUS ROCK TYPES

Specimen No. Prefixed by A/180/	Rock Type	Zn	Pb
2	Gahnite-"garnet sandstone" rock	15%	60 ppm
25	Actinolite rock	40 ppm	21 ppm
30	Amphibolite (near "transgressive pegmatite)	92 ppm	34 ppm
33	Amphibolite (near lode)	256 ppm	290 ppm
38	Amphibolite	190 ppm	54 ppm
44	Schistose gneiss	725 ppm	370 ppm
45	Schist	250 ppm	850 ppm
124	Tourmaline rock	114 ppm	119 ppm
168	Wall-rock at Angus Mine	2110 ppm	2050 ppm
48	Felspar band in Amphibolite	51 ppm	6 ppm
184	Amphibolite (transgressive)	281 ppm	59 ppm
10	Amphibolite with pyroxene	146 ppm	43 ppm
49	Amphibolite with felspar bands	171 ppm	19 ppm
73	Transgressive pegmatite with green felspar	Not assayed	0.095%

Table 9 (Continued)

Specimen No. Prefixed by A/180/	Rock Type	Zn	Pb
74	Transgressive pegmatite	Not assayed	0.024%
167	Transgressive pegmatite with green felspar	"	0.11%
39	Pegmatite with green felspar	"	0.181%
78	Schistose quartzite	Not assayed	5 ppm
181	Gneiss with megascopic garnets	"	570 ppm
180	Schist near pegmatite	"	33 ppm
199	Fine-grained transgressive pegmatite	"	44 ppm
203	Fine-grained transgressive pegmatite	"	50 ppm
98	Quartz-calcic plagioclase-biotite-garnet rock	0.05%	0.1%
196A	Brownish "garnet sandstone"	0.2%	0.4%

were determined by T.R. Sweatman, Division of Soils, C.S.I.R.O., Adelaide. The last two assays were determined by The Zinc Corporation Ltd.

The iron and manganese assays in Table 10 were determined by T.R. Sweatman, C.S.I.R.O., Adelaide. The calcium assays, with the exception of Specimen A/180/23, were determined by A.B. Timms, Aust. Mineral Development Laboratories, Parkside, South Australia. The calcium assay of Specimen A/180/23, was determined by A. Blaskett, Division of Biochemistry, C.S.I.R.O., Adelaide. The writer determined the potassium and sodium assays.

Minerals present in the Broken Hill type mineralisation zones, apart from gangue minerals are: gahnite, galena, sphalerite, chalcopyrite, haematite, limonite, magnetite, pyrrhotite, pyrite, marcasite, rutile, pyrargyrite, anglesite, covellite, ilmenite. The minerals are minor, with the exception of gahnite, limonite and haematite. Copper staining is found occasionally, mainly in the form of malachite and azurite.

The gangue minerals will be discussed as the occurrences of the above minerals are described.

"Garnet sandstone" has been mapped as lode material, because lead, silver and zinc are generally present in minor amounts.

TABLE 10

PARTIAL ASSAYS OF ROCKS AND MINERALS

Specimen No. Prefixed by A/180/	Rock or Mineral Type	Assays				
		Total Fe Expressed as % FeO	% MnO	% CaO	% K_2O	% Na_2O
1	Garnets	19.21	11.8	1.7		
2	Garnets		8.29	2.5		
2	Gahnite	9.17	0.35			
5	Quartz-gahnite-garnet rock		0.22			
20	"Garnet sandstone"		11.86			
21	"Garnet sandstone"		10.22			
23	Brownish "garnet sandstone"	18.14	14.47	1.3		
41	Garnets in gneiss		5.06	2.1		
41	Gneiss with garnets removed		0.23			
44	Schistose gneiss		0.14			
45	Schist		0.19			
46	Gneiss with megascopic garnets		1.88			
52	Garnet-quartz rock		12.76			
69	Garnet-quartz-with amphibole rock		8.84			
70	"Garnet sandstone"-quartz rock		10.10			

Continued over page

Table 10 (Continued)

Specimen No. Prefixed by A/180	Rock or Mineral Type	Assays				
		Total Fe Expressed as % FeO	% MnO	% CaO	% K_2O	% Na_2O
80	Felspathic, garnet quartzite		0.27			
124	Tourmaline rock		0.04			
158	Iron stain quartz-gahnite		0.08			
168	Wall rock at Angus Mine		0.40			
122	Tourmaline-"aplitic" rock	5.18				
74	Transgressive pegmatite		0.03			
146	Quartzitic schist with sillimanite		0.61			
8	Quartz-gahnite-felspar rock				2.87	1.40
174	Quartz-gahnite-felspar rock				0.68	2.26
59	Felspathic "garnet sandstone"			10.5		
61	"Garnet sandstone" in amphibolite			4.9		
96	Garnets in a quartz-garnet-felspar-zoisite rock			3.5		
152	Garnets in a quartz-garnet-chlorite-rock			7.0		
32	Garnets in a garnet rock with actinolite and calcite veins			6.4		

Gahnite

In the Angus area, gahnite is generally associated with strained, transparent to translucent quartz. Blue quartz is rare to absent in the mineralised zones. The gahnite generally occurs in bands, with quartz, or with pinkish garnet or "garnet sandstone".

When felspar is present with the quartz-gahnite rocks, the greater proportion of the felspar is potassic.

In the lower zone of mineralisation quartz is not common, and the gahnite grains form a massive rock, with bands of garnet, which has been folded in Specimen A/180/3. The massive gahnite rock in hand specimen, resembles an amphibolite.

The gahnite grains in the lower zone of mineralisation vary from 0.1 to 3.0 mms., in size, with an average size of 0.2 to 0.4 mm. Most grains are idioblastic. In Specimen A/180/2, many of the gahnite grains have blackish centres, which resemble inclusions but could be zoning indicating an iron rich core. Assays for iron and manganese of the gahnite removed from Specimen A/180/2, are 9.17% iron expressed as FeO, and 0.35% MnO. Specimen A/180/2 which contains a band of fine-grained pinkish "garnet sandstone" with minor apatite, was assayed for zinc and lead, giving values of 15% zinc and 60 p.p.m. lead.

The iron content indicates that the mineral could be kreittonite, a variety of gahnite. The colour of the gahnite in the lower zone of mineralisation is greenish-black to almost black.

Where idioblastic gahnite and garnet grains form a mosaic texture, as in Specimen A/180/19, the garnet has exhibited greater crystalloblastic force; it is possible that garnet and gahnite were developed contemporaneously. The garnets are generally smaller in size than the gahnite.

Inclusions are not common in the massive gahnite, although minor quartz and muscovite occur as inclusions. Some grains appear to have "negative" crystals within them rather than inclusions.

Gahnite in the middle (Angus-Kintore) and the upper zones of mineralisation is not massive, but occurs in weak, although definite, bands within quartz. Garnet sandstone often is associated with the gahnite in the middle zone of mineralisation.

The colour of the grains is dark green.

The grain size varies from 0.05 to 1.25 mms with crystals reaching ½ to ¾ inch in Specimen A/180/102, which was collected 1,000 feet to the west of the Kintore Mine.

Idioblastic gahnite is not common in the middle and upper zones of mineralisation; most grains have an irregular shape, and many are elongated, parallel to the banding. Piokiloblastic gahnite is rare, but quartz inclusions are found in some grains.

Most specimens collected in the middle and upper zones have some gahnite crystals which are rimmed by muscovite. The deposition of galena and sphalerite is later than the gahnite and muscovite, as galena and sphalerite enclose both minerals.

Gahnite grains occur mostly between quartz grains, with some grains occurring within the quartz. In Specimen A/180/5, the gahnite appears to be replacing quartz.

In Specimens A/180/7 and 8, which contain biotite, the gahnite grains force the biotite flakes aside.

When garnet sandstone is present, the average size of the gahnite is larger than the average size of the garnet grains.

Many of the larger gahnite crystals are cracked and often filled with limonite and haematite, which is found in most specimens.

In the specimens examined for gahnite it would appear that the minerals were emplaced in the following order: biotite, quartz, gahnite, garnet, muscovite and galena and sphalerite.

Possible gahnite was noted in a calcic plagioclase band in an amphibolite. The properties of the mineral were described when discussing the amphibolites. The mineral occurred in Specimen A/180/48. The likelihood of the mineral being gahnite is not great, as an assay for zinc in Specimen A/180/48, is the lowest assay obtained from the several amphibolites which were assayed for zinc (Table 9).

Galena and Sphalerite

No galena or sphalerite were noted in the lower zone of mineralisation. In the Angus-Kintore (middle) line of mineralisation, three occurrences were mapped, with the best development at the Angus Mine. A few crystals of galena were noted in the upper zone of mineralisation, occurring with a quartz-garnet-tremolite-felspar rock.

Specimens from the Angus Mine were examined to determine the relationship of galena and sphalerite to the rocks containing them.

Specimen A/180/1, a transparent quartz rock with narrow bands of pinkish garnet sandstone, has small galena and sphalerite veins transgressing quartz, garnet, and muscovite grains. Galena and sphalerite enclose muscovite and gahnite. A polished section shows that garnet is surrounded by galena.

The curvature of crystal boundaries of galena and sphalerite, indicates that sphalerite was deposited before galena, although the time-gap would be small.

Specimens A/180/6 and 7, are siliceous schists, with galena and sphalerite present. A thin section shows galena and sphalerite replacing garnet and biotite, also replacing and surrounding quartz. Some galena and sphalerite grains occur interstitially. Small amounts of galena are found within felspar grains. Polished sections show galena and sphalerite occurring between the gangue crystals. In Specimen A/180/7, small blebs of ex-solution chalcopyrite are found in a sphalerite crystal indicating that the temperature was in excess of 350°-400° C during deposition (Buerger, 1934).

Galena in the Specimen A/180/29, was observed in the hand specimen, and staining with nitric acid and potassium iodide shows minute grains of galena occurring along the edges of quartz blebs in the specimen.

By treating Specimen A/180/75, a banded quartz-gahnite-"garnet sandstone" rock, with 1:1 HNO_3 and KI, lead was detected in the "garnet sandstone" band.

Williams (1952) described four polished sections of rocks collected in the Angus area. The writer has examined the polished sections and does not agree in some details with Williams' descriptions. Williams polished sections are held by the Department of Economic Geology, University of Adelaide.

Specimen A/5f, collected by Williams at 65,000'S-79,000'W approximately, and examined by the writer, shows galena altering to anglesite, and chalcopyrite altering to covellite. Williams noted that the minerals filled fractures in cummingtonite.

Specimens A/9a and 10b, were collected at the Angus Mine by Williams. In A/9a, galena, haematite, minor sphalerite, rutile, pyrite, chalcopyrite and pyrargyrite are present. Galena, haematite and chalcopyrite surround and fill spaces between garnets. One observation of curvature of crystal boundaries was made by the writer in Specimen A/9a, indicating that sphalerite and chalcopyrite preceded the deposition of galena.

In Specimen A/10b, minerals present are galena, ilmenite, haematite, pyrite, rutile, sphalerite, and marcasite. Sphalerite is a minor mineral, although some grains of haematite resemble sphalerite. Pyrargyrite is attached to a galena crystal, but no ex-solution properties were noted.

<u>Chalcopyrite, Pyrrhotite, Pyrite and Marcasite</u>

Chalcopyrite has been noted in the Angus area where galena and sphalerite occur, although an occurrence of chalcopyrite was found in the lower zone of felspathic quartzites with garnets, without galena being present.

Minor ex-solution chalcopyrite in sphalerite was noted in Specimen A/180/6, collected at the Angus Mine.

Williams' (op.cit.) specimens collected at the Angus Mine, show rutile intergrown with chalcopyrite in Specimen A/10b, and minor chalcopyrite is associated with sphalerite in Specimen A/9a. Williams' Specimen A/5f collected at 65,000's-79,000'W, in the middle zone of mineralisation shows chalcopyrite almost completely altered to covellite. As the chalcopyrite and galena in the Specimen A/5f has altered and limonite is common, it suggests that pyrite could have been present and altered to give solutions which in turn altered galena and chalcopyrite. The depth of weathering is not great in the mineralised portions of the Angus area, as sulphides were observed in a pit 25 feet south of the Clarke shaft at the Angus Mine. No water was encountered in the Mine.

Chalcopyrite and pyrrhotite grains in a garnetiferous-felspathic quartzite, Specimen A/180/80, are elongated and oriented parallel to the weak foliation in the rock. The grains of chalcopyrite and pyrrhotite are up to 0.5 mm in length and 0.2 mm wide. The grains appear original; they are not replacing minerals or being replaced.

In Specimen A/10b, marcasite surrounds, and is associated with, pyrite grains. Minor pyrite is found in Specimen A/9a. Pyrite is rare in the Broken Hill type mineralisation in the Angus area.

Limonite, Haematite, Magnetite and Jarosite

In the specimens containing galena and sphalerite, limonite and haematite are not common. Minor magnetite grains, up to 0.1 mm in length, occur with quartz and garnet.

Tremolite specimens occurring in the zones of mineralisation have limonite, haematite and magnetite present.

"Garnet sandstone" specimens have minor magnetite, and limonite present.

Most specimens containing gahnite have limonite occurring in fractures; haematite is less common and magnetite is rare. In Specimen A/180/189, collected in the upper zone of mineralisation, limonite is as much as 10% of the rock. The limonite occurs along crystal faces of the quartz and in large patches, often surrounding gahnite crystals.

The massive gahnite-garnet rocks in the lower zone of mineralisation, have iron staining between the gahnite and garnet grains. Limonite, haematite and magnetite occur in fractures in Specimen A/180/17, a massive gahnite-garnet rock.

Possible jarosite is found associated with limonite in Specimen A/180/189, taken from the upper zone of mineralisation. The mineral is yellowish, with high birefringence. A similar mineral, occurring in the "aplites" was checked by X-ray methods and found to be jarosite.

Rutile and Ilmenite

Rutile and ilmenite are rare in the lode material.

In the lower zone of mineralisation, a few grains of ilmenite have sphene associated with them as an alteration product. A polished section of the felspathic quartzite with garnet rock, Specimen A/180/80, show that a few grains of iron-rich rutile are present.

Quartz-gahnite Specimen A/180/34, collected in the middle (Angus-Kintore) zone of mineralisation, has minor ilmenite present. The ilmenite is associated with chlorite, which has altered from biotite. A few elongated grains parallel the bands of quartz, gahnite and minor "garnet sandstone".

Williams' Specimens A/9a and A/10b, collected at the Angus Mine, and examined by the writer show minor rutile in A/9a and minor ilmenite intergrown with haematite in A/10b.

Pyrargyrite

Pyrargyrite was noted by the writer in Williams' Specimens A/9a and A/10b. In Specimen A/10b the pyrargyrite is attached to a galena crystal and in Specimen A/9a a few grains of pyrargyrite show red, internal reflection.

No other silver minerals were noted, so probably the silver occurs within the galena, as high values were obtained in the narrow, high-grade ore on the 190 foot level of the Angus Mine.

Anglesite and Covellite

Galena altering to anglesite and chalcopyrite altering to covellite were noted by the writer in Williams' Specimen A/5f.

Cobalt and Nickel

A specimen, A/180/1, collected at the Angus Mine, and another Specimen A/180/2, collected in the lower zone of mineralisation were assayed for cobalt and nickel. The amounts present are as follows:

	Co %	Ni %
Specimen A/180/1	0.001	0.0003
Specimen A/180/2	0.0095	0.0032

The assays were carried out by C. Moncrieff, The Zinc Corporation Ltd., Broken Hill.

The mode of occurrence of the minor amounts of cobalt and nickel was not observed in the thin, or polished, sections.

Tremolite and Actinolite

Tremolite and actinolite in the mineralised zones are considered to be phases of the amphibolites, as amphibolites are often closely associated with the mineralisation.

In the middle zone of mineralisation, at 65,000'S-79,000'W fibrous, interlocking tremolite was noted. Haematite and limonite, and minor quartz and felspar are associated with the tremolite. Williams reported the occurrence of cummingtonite with galena at the same locality.

Tremolite and actinolite occur with a few crystals of galena in the upper zone of mineralisation, approximately 3,000 feet south of the Egebek quarry. The rocks are considered to be phases of an amphibolite as the rocks grade into, and are in physical contact with, amphibolites.

Calcite

Calcite veinlets occur in the garnet sandstone rocks. The veins transgress banding in the rocks, and also occur interstitially. Specimens A/180/59 and 86, show veinlets, in the hand specimen, which effervesce readily with acid.

Quartz-gahnite Specimens A/180/8 and 34 have minor calcite present. In Specimen A/180/34, the calcite occurs in small cavities. The specimens were collected in the middle and upper zones of mineralisation.

A Specimen A/180/173, collected from the Mullock dump at the Angus Mine contains coarse-grained calcite with chlorite and as much as 3% hornblende. The chlorite occurs as decussate flakes and in rosettes.

Apatite

Minor well developed apatite crystals occur in the massive gahnite-garnet sandstone rocks in the lower mineralised zone. The crystals are up to ½ inch in length and 1/16th inch in diameter. Quartz is associated with the crystals.

Apatite inclusions are found in the quartz associated with "garnet sandstone" in the Angus-Kintore (middle) zone of mineralisation. The inclusions are up to 0.25 mm in Specimen A/180/20, and 0.075 mms in Specimen A/180/23. The grains are not rounded. Apatite occurs in a massive "garnet sandstone" rock, A/180/86, as an idioblastic crystal amongst the idioblastic garnets.

Apatite is very rare in the quartz-gahnite rocks, and is only found where the quartz-gahnite occurs with banded "garnet sandstone".

Copper Staining

Apart from copper staining which is found associated with two small shears, and will be discussed under copper mineralisation, minor copper staining is also found associated with calcium bearing rocks near the zones of mineralisation.

Copper staining is found in the amphibolites near the zones of mineralisation, also in quartz-epidote, or quartz-zoisite, rocks which are associated with amphibolites. An epidote rock, Specimen A/180/171, collected within an amphibolite in the north-western portion of the area has copper staining present, but no known mineralisation occurs nearby.

Felspar

When felspar is present in the quartz-gahnite rocks it is mainly potassic, although minor sodic felspar is present when narrow bands of quartz-gahnite occur with muscovite, biotite and chlorite.

Potassic felspar is not common in the Angus area and is best developed in the transgressive pegmatites of the south-western portion of the area. If the quartz-gahnite rocks have a hydrothermal origin the presence of the potassic felspar is readily explained. If the quartz-gahnite rocks have been derived from the sediments the presence of potassic felspar is not as readily explained.

A Specimen A/180/174, collected by W.G. Burns from the Pinnacles mine area to the north-east of the area mapped, and examined by the writer, shows the felspar present in the quartz-gahnite rock to be predominantly potassic, with minor albite-oligoclase.

Quartzitic schists (Specimens A/180/6 and 7) containing galena and sphalerite, show that the felspar present is mainly potassic.

In the banded garnet quartzite rocks, resembling garnet sandstone, the plagioclase is calcic (An_{50}). The banded garnet quartzite occurs in the zone of mineralisation at the northern end of the area.

Quartz

Unlike many occurrences of quartz-gahnite in the Broken Hill district, blue quartz is rare in the Angus area.

The quartz in the quartz-gahnite rocks is transparent to translucent and often contains minute black inclusions in thin lenses, and fractures. Undulose extinction of the quartz grains was noted in most specimens.

The grain size is variable; generally ranging from 0.2 mm to 5 mms. Often the small grains are associated with the gahnite.

Quartz occurs as inclusions in the gahnite crystals.

Muscovite and Biotite and Sericite

Muscovite and biotite bands are found in the banded quartz, gahnite-garnet sandstone rocks. although biotite is not common.

Muscovite in the quartz, gahnite rocks often rims the larger gahnite crystals and not the smaller crystals. Potassic felspar is generally present when the gahnite is rimmed by muscovite.

In Specimen A/180/1, a quartz rock with bands of "garnet sandstone", galena and sphalerite, the biotite is reddish in colour. The colour could be due to the presence of manganese rather than alteration. In Specimen A/180/77, a quartz-gahnite rock, a few small flakes of biotite have yellow to reddish-brown pleochroism.

Where biotite is enclosed in gahnite, such as in Specimen A/180/17, the biotite is fresh in appearance, whereas other biotite is altering.

Minor sericite occurs as an alteration product of the felspar

Garnet Granulite ("Garnet Sandstone")

A rock type which is often associated with Broken Hill type mineralisation, is an aggregate of incoherent garnet grains. The rock is considered to have a metamorphic origin, and is a garnet granulite. The field term used in Broken Hill is "garnet sandstone". If the grains are cemented by quartz, the rock tends to have a garnet quartzite appearance.

"Garnet sandstone" has been mapped as lode material as small amounts of lead and zinc are present in such rocks.

The "garnet sandstone" is generally friable, and pinkish in colour, although some bands are brownish in colour. The "garnet sandstone" is often banded with quartz-gahnite, sericite, calcic plagioclase and quartz. The grain size varies from 0.2 to 2 mms with the size being generally 1 mm or less.

Outcrops of "garnet sandstone" are generally less than 2 feet wide, although in the pits south of the Clarke shaft at the Angus Mine, the "garnet sandstone" and quartz-gahnite band is between 2 and 5 feet wide.

"Garnet sandstone" is found only in the lower and middle zones of the mineralisation, and not in the upper zone. However, in the amphibolite above the upper zone of mineralisation at the northern end of the area, fine-grained reddish-brown garnets occur with quartz. The garnets are not friable, but the rock is not far removed from a garnet sandstone in appearance. Minor copper staining and gahnite is associated with the rocks.

At the Angus and Kintore Mines and half-way between the two mines, brownish, friable "garnet sandstone" is found associated with milky, lineated quartz, stratigraphically above the narrow bands of pinkish "garnet sandstone".

The manganese content of the garnet in the brownish "garnet sandstone" is greater than the manganese in the garnets in the pinkish garnet sandstone. Table 10 shows that Specimen A/180/23, (brownish "garnet sandstone") has 14.47% MnO present, while garnets from pinkish "garnet sandstone" Specimens A/180/1, 2, 20 and 21 have 11.8%, 8.29%, 11.86% and 10.22% MnO respectively.

Iron and calcium contents of garnets from Specimens A/180/1 and 23 show that brown and pinkish garnets have similar iron and calcium contents.

An assay for lead and zinc of a Specimen A/180/196 A, which consists of brown garnets mainly, gave values of 0.4% Pb and 0.2% zinc. The pinkish "garnet sandstone" is generally associated with gahnite, galena and sphalerite, so lead and zinc values would be obtained, if the pinkish "garnet sandstone" were assayed.

Garnets in the "garnet sandstone", associated with gahnite, often exert their crystal shape and appear to replace the gahnite crystals. In other places the contact between gahnite bands and garnet bands is "clean", with both minerals being idioblastic.

"Garnet sandstone" is very closely associated with amphibolites and in places fine-grained, friable garnets develop within the amphibolites. Specimen A/180/61, collected at the north end of the area in the amphibolite associated with the middle zone of mineralisation, is an amphibolite with many patches of fine-grained, friable, reddish, and pinkish, garnet developing. The CaO content of the garnets is 4.9% but no assay for manganese was carried out. However, in Specimens A/180/69 and 70, which are associated with amphibolite in the middle zone of mineralisation at the northern end of the area, the manganese assays of reddish garnets, tending to be friable in places, are 8.84% and 10.10% MnO respectively. Milky quartz occurs near the specimens, but translucent to transparent quartz occurs within the specimens.

Garnets from a fine-grained reddish garnet rock, with bands of actinolite grading into calcite, and possible siderite, assay 6.4% MnO. The refractive index of the garnet is 1.75, indicating that the garnet is almandine with manganese present.

A banded fine-grained garnet, calcic plagioclase-quartz rock, Specimen A/180/59, has garnets present with a CaO content of 10.5%. The rock has ½ inch bands of fine-grained garnets, with bands of calcic plagioclase and quartz containing abundant garnet. Narrow bands of sphene and sphene veinlets occur in the rock. The rock occurs in the middle zone of mineralisation.

"Garnet sandstone" is found in physical contact with amphibolite on the 130 foot level at the Angus Mine, apart from occurring within the schists.

Calcite veinlets and apatite crystals are often associated with the "garnet sandstone".

Like the quartz-gahnite rocks, the "garnet sandstone" is best developed in small drag-fold environments, and the nearby rocks are calcium rich.

Genesis of the Broken Hill Type Mineralisation

The origin of the garnet granulites ""garnet sandstone") will be considered first.

(a) Genesis of the Granulite ("Garnet Sandstone")

Both the "garnet sandstone" and quartz-gahnite are found in zones which have calcium bearing rocks associated with them, although the quartz-gahnite is not always found in a manganese environment.

Mapping in the Angus area indicates that iron and manganese have migrated to small folds where "garnet sandstone" and associated rocks have been formed.

The problem is to determine if manganese and iron have been introduced into the sediments or whether they have been concentrated from the sediments.

An assay of a transgressive pegmatite, which could be expected to carry manganese gave a value of 0.03% MnO. The specimen (A/180/74) was collected at the contact with a mineralised zone. A quartzitic schist with sillimanite in a shear zone (Specimen A/180/146) has 0.61% MnO present. Such a high value could indicate that manganese has entered along the shear.

It has been shown that amphibolites, schists and gneisses with megascopic garnets have higher than normal manganese contents. In the case of the amphibolites, it was concluded that the high manganese content was due to a high manganese content in the original sediment. A similar origin is suggested for the manganese in the schists and gneisses with megascopic garnets.

The only evidence suggesting that the "garnet sandstone" has been formed as the result of the introduction of iron and manganese into sediments, is the presence of milky quartz near the brownish, friable "garnet sandstone".

The banding in the "garnet sandstone", and the conformable nature of the rocks suggests a sedimentary origin.

The iron and manganese in the "garnet sandstone" are considered to have a sedimentary origin, and were deposited in a calcic environment.

Krumbein and Garrels (1952) have shown that haematite, limonite, manganese oxides, silica and chamosite, with minor calcite and phosphorite can be deposited from solution at pH between 7.0 and 7.8, and Eh > 0. If the pH is increased slightly above 7.8, calcite is deposited freely, and haematite, limonite, manganese oxides, chamosite, phosphorite and silica are deposited in minor amounts. If the Eh is slightly less than 0, with the pH still 7.0 to 7.8, chamosite, siderite, glauconite, rhodochrosite, silica and calcite can be deposited.

As the "garnet sandstone" is associated with amphibolite, slight changes in pH and Eh would have allowed deposition of calcareous and ferruginous sediments which have been metamorphosed to form amphibolites.

Under metamorphic conditions, the minerals in the iron and manganese bearing horizons are considered to have migrated to positions of relatively lower stress, such as the noses of drag-folds within the horizons. In such positions garnet has formed, as alumina and silica would be available within the iron and manganese horizons, and also abundant within the surrounding sediments.

The fine-grained garnet, resembling "garnet sandstone", which has developed in amphibolites; felspathic-garnet rocks, quartz-garnet-felspar rocks, and in quartz-garnet-chlorite rocks, have a calcium content which is higher than the pinkish "garnet sandstone".

Specimens A/180/1 and 2, which contain pinkish "garnet sandstone", have calcium assays of 1.7% and 2.5% CaO respectively. Specimen A/180/23, a brownish "garnet sandstone" rock, has 1.3% CaO present. The garnets in the calcic bearing rocks, Specimens A/180/59, 61 and 96 and 152, were assayed for calcium, and contain 10.5%, 4.9%, 3.5% and 7.0% CaO respectively.

Garnets removed from amphibolite Specimens A/180/33 and 38, have 3.9% and 4.9% CaO present respectively. The garnet in Specimen A/180/33 has 3.5% MnO present.

A gneiss Specimen A/180/41, collected near the Angus Mine, has 2.1% CaO and 5.6% MnO present in the garnet.

The assays show that the amounts of calcium and manganese are proportional to amounts of calcium and manganese that would be expected in the rocks if they have a sedimentary origin. For example in the "garnet sandstone" horizons, iron and manganese would have been the principal minerals deposited, with minor amounts of calcium. The amphibolites are considered to have been calcium rich sediments, and would have had small amounts of manganese present. The calcium bearing rocks such as Specimen A/180/59, 61, 96 and 152 have notably higher amounts of calcium in the garnet. The gneiss Specimen A/180/41, which has calcic plagioclase and megascopic garnet, has calcium and manganese present in proportion which would be expected for such rocks deposited in an intermediate environment between a calcium rich environment and a manganese rich environment.

As "garnet sandstone" in the middle zone of mineralisation outcrops intermittently near the base of, and within, an amphibolite zone for over 4 miles, a sedimentary origin is suggested. Similarly, garnet "sandstone outcrops" intermittently in the lower zone of mineralisation which is stratigraphically above an amphibolite zone.

(b) <u>Genesis of the Mineralisation</u>

The Broken Hill type mineralisation in the Angus area is considered to have a sedimentary origin; the evidence obtained does not allow conclusions to be drawn which are beyond doubt, but the evidence does not favour an hydrothermal origin. The points in favour of an origin from a deep-seated magnetic source are: (1) some of the transgressive pegmatites contain much potassic felspar and so is much of the felspar in the lode lenses. (2) a myrmekitic texture in a few grains in a gneiss specimen collected in a lode zone could be indicative of incoming solutions from a magmatic source.

Cross-section X27/782 shows that the mineralised zones fit into stratigraphic zones which could be considered cyclic, suggesting that metallic ions were deposited when conditions were favourable.

Field mapping has shown that the conformable, mineralised lenses occur in narrow, well-defined zones. One zone has been mapped for over 4 miles.

Petrological and mineragraphic studies have shown that the galena, sphalerite and chalcopyrite were emplaced in their present position later than the lode garnets, quartz-gahnite and the sericite surrounding the gahnite. The gahnite is generally rimmed by sericite when galena is present.

The gahnite-garnet relationship in the massive gahnite-garnet rocks is such that the garnet exerts a greater crystalloblastic force than the gahnite in places. In the quartz-gahnite rocks, gahnite has forced biotite flakes aside, and in some specimens gahnite appears to replace quartz.

The presence of potassic felspar and green potassic felspar is explained by segregation in calcic environments.

Segnit (1959) suggested that the zinc in the gahnite was deposited as a sediment, and adsorbed in the clay minerals. Segnit suggested the following equation:

$$2Al_2\,Si_2\,O_6\,(OH)_2 + ZnO \longrightarrow$$

$$Zn\,Al_2\,O_4 + Al_2\,SiO_5 + 3\,SiO_2 + H_2O.$$

He noted that gahnite occurs in sillimanite bands in the area he examined.

Segnit pointed out that gahnite could be prepared in an hour or less by solid reaction of kaolin and zinc oxide at 1300°C. He suggested that by heating for prolonged periods the gahnite would form at far lower temperatures. Segnit further noted that gahnite would be unstable in the presence of water and alkali, as evidenced by the muscovite veins around gahnite.

During metamorphic conditions in the Angus area the writer considers that zinc, iron and manganese ions moved to structural positions and combined with alumina and silica to form such rocks as the massive gahnite-"garnet sandstone" rocks found in the lower zone of mineralisation. 9.17% iron expressed as FeO is present in the gahnite in Specimen A/180/2. The gahnite formed contemporaneously with the development of lode garnet.

In the quartz-gahnite rocks with large sporadic gahnite crystals, a process similar to the development of the concordant pegmatites is considered. Sporadic zinc in the original sediments would have become mobile as ions under metamorphic conditions, and sought like ions, because the ions would not be in environments of equi-potential. Such a process would explain the growth of large gahnite crystals in quartz with minor potassic felspar. In the massive gahnite specimens, zinc is thought to have been abundant in the original sediments, and during metamorphism the ions would have been in environments of equipotential, causing the growth of much smaller crystals.

The relative lowering of stress in the drag-fold environments would probably have allowed the irons to migrate to such areas.

Pyrrhotite and chalcopyrite in a felspathic quartzite with garnet rock, Specimen A/180/80, appears original, as they are not replacing minerals, or being replaced by minerals.

Assays for lead and zinc of amphibolites, schists, gneisses, transgressive pegmatites are shown in Table 9. A schist specimen, A/180/180, which was collected away from the zone of mineralisation near concordant pegmatite, was assayed for lead and the value is 33 p.p.m. There is no reason to suspect that the lead was introduced. The wall rock, Specimen A/180/168, at the Angus Mine has high lead and zinc values, but no observations were made which indicate that lead and zinc had been introduced into the other rocks.

Lead is present in all specimens assayed, but is rarely seen in the hand specimen, or under the microscope. When observed in hand specimen it occurs as the sulphide.

The minor sulphide minerals, sphalerite, chalcopyrite, and galena are later in the paragenetic sequence than gahnite or garnet. Potassic felspar and muscovite would have been emplaced after the gahnite, but before the sulphides.

The writer considers that the minor potassium segregated from the calcic bearing sediments during metamorphism. As the quartz-gahnite, "garnet sandstone", and sulphides occur in calcic environments, it is considered that the potassium in the original sediments is repelled and concentrated with silica and alumina to form potassic felspar or muscovite in fold environments. Such a process could well explain the rimming of the early formed gahnite by sericite and muscovite, instead of postulating recurrent waves of hydrothermal solutions, under which conditions the gahnite would probably have not been stable.

Wall-rock alteration does not occur near the mineralisation in the Angus area, and indicates that the mineralisation probably was not emplaced by solutions from a magmatic source.

The deposition and formation of metallic minerals is thought to have occurred in the following manner:

As outlined on page 242 of this thesis Krumbein and Garrels have shown how pH-Eh conditions have influenced the deposition of iron and manganese bearing minerals. Rankama and Sahama (1949) pointed out that in oxidate sediments, such as manganese-rich lake and bog ores, significant amounts of zinc and cadmium are adsorbed. They also point out that zinc in sea-water is deposited in carbonate sediments.

Under the conditions described by Krumbein and Garrels and having knowledge of points made by Rankama and Sahama, manganese, iron, zinc and silica could have been deposited, along with clay material, to be later metamorphosed to give garnet, gahnite, and quartz in a calcium-bearing zone.

To explain the sulphide mineralisation which is associated in places with the quartz-gahnite-garnet rocks in the middle (Angus-Kintore) zone of mineralisation, a slight change in Eh conditions, without change in pH, could bring about the deposition of metals if they occur in solution. If the Eh is below -0.1, sulphates or sulphides can be precipitated along with manganese carbonate, silica and calcite.

As the amount of observed sulphide mineralisation in the Angus area is not great, it is possible that semi-reducing to reducing conditions were operating when the sulphides in the Angus-Kintore line of mineralisation were deposited. During the deposition of metals in the other mineralised zones where only one occurrence of sulphide mineralisation was noted, probably semi-reducing to oxidising conditions prevailed, thus not allowing the deposition of metals as sulphides, but as oxides, carbonates, silicates or hydroxides.

The relatively mobile sulphide bearing minerals and potash felspar are considered to have formed in their present positions as the result of migration of ions during metamorphism. The minerals surround and transgress earlier formed gahnite and garnet in similar horizons, thus giving the possible false impression of being deposited by later waves of mineralising hydrothermal solutions.

Lead and zinc sulphides generally occur with "garnet sandstone", although a small occurrence of galena with tremolite in the upper zone of mineralisation is not associated with "garnet sandstone".

The sulphide minerals were emplaced in the following manner; sphalerite and chalcopyrite together, with galena being emplaced later. The time gap was small, as grain curvatures are not pronounced. The sulphide minerals are considered to have migrated to the noses of drag-folds, as they were the last minerals emplaced, whereas the gahnite occurs on the limbs of the drag-folds, as well as in the noses.

Potassic felspar and muscovite rimming of gahnite, occurs in the quartz-gahnite specimens collected near known lead and zinc sulphide mineralisation.

The small irregular shaped pegmatites with green felspar, 220 feet east, and 250 feet north east of the main shaft at the Angus mine and the green felspar in the mine workings, are considered to have developed as the result of potassium ions, with minor lead ions concentrating near a fold position in a calcic environment during metamorphism and not by incoming ions from a deep seated magmatic source.

The final emplacement of some of the potassium and lead could have occurred after the emplacement of the transgressive pegmatites. At the northern end of the middle zone of mineralisation, two narrow fine-grained soda rich transgressive pegmatites have green felspar developed along their contacts where they cut the mineralised zone. The green felspar is not found elsewhere in, or near, transgressive pegmatites which occur in an E-W striking zone. The green felspar is thought to have developed following the emplacement of the transgressive pegmatite, although the potassium and lead ions would have been present in the mineralised zone before the emplacement of the transgressive pegmatites.

Lead assays of the fine-grained transgressive pegmatites, occurring in the same zone as the pegmatite cutting the lode horizons, are 44 p.p.m. and 50 p.p.m. respectively, in Specimens A/180/199 and 203. These assays are not high when compared with other rocks in Table 9. The lead is not considered to have concentrated where the transgressive pegmatites cut the calcium bearing zones.

The transgressive amphibolite, Specimen A/180/184, has a higher lead value than the transgressive pegmatites. The assay values are, 59 p.p.m. lead and 281 p.p.m. zinc.

A schist with abundant quartz, Specimen A/180/78, has only 5 p.p.m. lead present. This specimen was collected between the lower and middle zones of mineralisation and not near rocks with relatively high calcium. The metals in the Angus area are considered to have been deposited with calcareous sediments, and also sediments now amphibolites, and concentrated during metamorphism in fold environments.

On the 190 foot level at the Angus Mine, the lode material grades into amphibolite with garnet.

As lead and zinc sulphides have been emplaced after the gahnite, the search for sulphides should be made in the area with the "most severe" folded structure, in broad calcium bearing horizons known to contain gahnite. A drag-fold is a pitch-reversal environment would make possible the concentration of sulphides in mineralised zones. Microscope studies would often be necessary to determine the calcic plagioclase bearing rocks.

(2) <u>Thackaringa Type Mineralisation</u>

Minor siderite and calcite occur within amphibolite in the shear zone, striking east west, north of the Angus Mine. At 68,750'S - 82,450'W, coarse grained galena is associated with siderite and calcite.

The minerals often occur within small fractures in the amphibolites. Calcite occurs in the centre of the fracture, with siderite on either side of the calcite, and in contact with the fracture walls. Specimen A/180/106 shows the calcite-siderite association.

The length of the outcrops does not exceed 15 feet, and the width is generally less than 3 feet.

Williams (<u>op.cit</u>.) prepared a polished section (A/7f), and noted that quartz with comb structure was present, also galena veined the siderite and calcite.

As the siderite and calcite veins are found in the amphibolite, it is possible that retrograde alteration of actinolite has developed calcite, siderite, quartz and water, near fractures in the shear zone. The lead could also have been derived from the amphibolites. The minor outcrops in the Angus area could well have such an origin, but Thackaringa type mineralisation, occurring north of the area mapped, near the Adelaide Road, appears to have been deposited by mineralising solutions, in transgressive fractures and joints.

(3) Copper Staining in Shears

Copper staining (malachite and azurite) occurs in small shears at 61,650'S - 77,400'W and 67,000'S - 85,300'W.

The shears occur in pegmatite zones, above the middle zone of mineralisation.

The copper staining in the southern occurrence is associated with shearing in a fold environment. The east-west striking portion of the shear has been worked to a depth of 20 feet. The staining was mapped intermittently for a distance of 400 feet, and the width did not exceed 4 feet. Minor amphibolite is found near the north-south striking portion of the shear. Malachite and azurite were noted, but not sulphides or oxides.

The northern occurrence of copper staining is found in a small north-east striking shear, 30' in length. The copper staining is associated with quartz blebs. Malachite and minor azurite are present. Lineations, and small folds plunge in northerly and southerly directions. The opposing plunge directions are attributed to the shearing.

Quartz and copper are thought to have been introduced into the shears, but as the occurrences are small, no source is suggested.

(4) Other Mineralisation

Beryl mineralisation has been discussed when describing the transgressive pegmatites and "aplites".

Sequence of Events

The following sequence of events is suggested:

1. Deposition of Willyama sediments. Metals were deposited in some horizons.
2. Initial folding, accompanied by metamorphism - initial development of amphibolites, "aplites", pegmatites, and concentration of metallic ions, silica, alumina, and potassium.
3. Further folding, and regional metamorphism
   (a) further development of amphibolites, "aplites", pegmatites, gahnite and "garnet sandstone", and emplacement of potassium, silica, alumina and sulphides
   (b) shearing developed at a late stage of folding
   (c) emplacement of transgressive pegmatites (derived partly by pneumatolytic processes, and partly by migration of ions from the metasediments into

joints and fractures) emplacement of transgressive amphibolite.

(d) further movement of metallic ions towards fractures which intersected the lode horizons.

The above events would probably have taken place during Archaean, or possibly Lower Proterozoic time (Gustafson, et al. 1952).

As the Torrowangec rocks, of Proterozoic age, in the Broken Hill district have been folded, there is a possibility that the folding has been impressed on the Archaean rocks in the Angus area. The folded unconformity between Willyama and Torrowangee rocks has been mapped in the northern portion of the Broken Hill district (King & Thomson, 1953).

Final movement on the Hillston Fault in the Angus area would have probably taken place after Tertiary time, as the occurrence of grey-billy on the eastern side of the fault suggests such a late movement.

Pleistocene sediments have been noted by Thomson (1952) in an area near the Angus area.

CHAPTER IV

SOME VEGETATION-ROCK TYPE RELATIONSHIPS

(1) *Pittosporum phillyreoides*

Butterbush trees (*Pittosporum phillyreoides*) have been noted to grow near, or in, the middle zone of mineralisation and near "transgressive" pegmatites in the Angus area.

A tree growing near the Clarke shaft, at the Angus Mine, was assayed for manganese, zinc, potassium and sodium. A similar tree growing near the Spar Ridge felspar quarry was assayed for the same elements.

The assays are shown in Table 11.

The manganese and zinc assays were determined by T.R. Sweatman, C.S.I.R.O., Adelaide, by using X-ray fluorescent spectrographic methods; the potassium and sodium assays were determined by the writer with the aid of a flame photometer.

The specimens were threshed by D. Harvey, Government Analysts' Department, Adelaide.

TABLE 11

PLANT ASSAYS

Locality	MnO %	ZnO %	K_2O %	Na_2O %
Butterbush tree at the Angus Mine	0.10	0.039	1.59	2.37
Butterbush tree at Ridge quarry	0.013	0.002	2.41	0.63

The assays do not allow definite conclusions to be made regarding the growth of the trees, but it is suggested that the presence of manganese and zinc is not the reason for the growth of the trees in their particular environments. The presence of potassium is suggested as a possible reason for the growth of the trees, as potassium is not common in the area, although potassic felspar is often found associated with the mineralisation, and some transgressive pegmatites.

There is a possibility that birds have deposited seeds near the mine workings, but this does not explain the growth of trees near transgressive pegmatites. Water holding properties of the rocks does not appear to explain the growth of the trees.

The writer realises that an exhaustive study would have to be made before drawing definite conclusions; however, the presence of the trees in the Broken Hill district could indicate sulphide mineralisation, which is often associated with potassic felspar. Beryl mineralisation is often associated with potassium bearing transgressive pegmatites; here again the presence of the tree could indicate possible transgressive pegmatites under soil cover.

As the assays in Table 11 show that the tree near the Angus Mine contains eight times more MnO, and twenty times more ZnO, than the tree near the felspar quarry, the conclusion is drawn that chemical analyses of butterbush trees could assist in geochemical prospecting for hidden ore bodies.

(2) <u>Sida virgata</u>

<u>Sida virgata</u> is a small, annual, bush which is often found growing on banded amphibolites, and iron stained aplites and schists in the Angus area.

By noting the growth of the bush, a non-outcropping bed can be mapped with some degree of certainty for some distance beyond a point where the outcrops of the above rocks are observed.

As the plant grows well on banded amphibolites, calcium could promote the growth of the bush, although the calcium content of iron-stained aplites and schists is poor.

Assays of the plant, for calcium and phosphorus, growing on the banded amphibolite, are shown in Table 12.

A banded amphibolite, and an iron-stained quartz, biotite, muscovite, sodic-plagioclase schist were assayed for calcium and phosphorus. These are also shown in Table 12.

The calcium assays of the plant, and the banded amphibolite, and the phosphorus in the plant, were carried out by A. Blaskett, Division of Biochemistry, C.S.I.R.O., Adelaide. The calcium assay of the iron-stained schist was made by A.B. Timms, Aust. Mineral Development Laboratories, Parkside. The phosphorus assays of the rocks were done by the writer.

As no specimen of the plant growing on the iron-stained schist was collected, the study of the calcium and phosphorus content in the rocks and plants is incomplete. The data are listed, although no conclusions are made.

Iron could promote the growth of the bush, but iron in calcium environments is generally not available to plants.

TABLE 12

PLANT AND ROCK ASSAYS

Plant and Rock Specimens	CaO %	P %
Sida virgata (growing on amphibolite from which rock Specimen A/180/49 was collected)	4.76	0.11
Banded amphibolite Specimen A/180/49	8.1	0.07
Iron-stained schist Specimen A/180/192	0.35	0.03

(3) Atriplex vesicaria (salt bush), Cockia setafolia, (blue bush), and Cockia pyramidata (blue bush)

The growth of salt bush and blue bush in the northern portion of the area, has been used to assist in determining the trend of the underlying rocks. A marked boundary of the growth of salt bush and blue bush gradually turns in an easterly direction towards the Hillston Fault. Outcrop is absent to scarce, and the bushes grow on an imperceptible ridge which also turns in an easterly direction.

(4) Triodia (Porcupine Bush)

Porcupine bush grows best on the concordant pegmatites to the south west of the Angus Mine. Generally the outcrop is obvious when the growth is present, thus not assisting greatly in the geological mapping. Porcupine bush is found in pockets of soil within the concordant pegmatites which would have good water holding properties.

Other features have been noted, regarding the relationships of growth to aspect, soil, and rock types, but are not considered to assist greatly in solving geological problems of the area.

CHAPTER V

GEOPHYSICAL STUDIES

Prior to 1949, The Zinc Corporation Ltd., carried out an aerial magnetic survey, which included the Angus area. The survey was flown at 1,000 feet. Plans held by The Zinc Corporation Ltd., show the magnetic contours to be elongated in a N.E.-S.W. direction in the northern portion of the Angus area, and trending in an E-W direction in the southern portion of the area. The overall structural trends in the Angus area are similar to the magnetic contour trends.

During 1957, Broken Hill South Ltd., carried out an airborne electro-magnetic survey, but results have not been published.

A gravity survey of portion of the Angus area was carried out between November, 1958 and January, 1959 by I.M. Sefton of L.A. Richardson and Associates for The Zinc Corporation Ltd.; a Worden gravity meter was used. The survey covered the lower and middle zones of mineralisation. The gravity contours are shown on the "Interpretation of Geology" overlay plans (X27/780 and 781), and the geophysical base line, and traverse lines are shown on the geological plans (X27/762 and 763).

The amphibolites give pronounced gravity anomalies and could obscure anomalies arising from mineralisation, as mineralisation is associated with the amphibolites.

Three small anomalies which could indicate mineralisation were noted by the geophysicist (Sefton, 1959). The writer considers the type of anomaly to be due to iron and manganese bearing horizons. A minor positive anomaly was noted by Sefton to extend along the lower zone of mineralisation, between 69,000'S - 85,100'W and 71,300'S - 86,350'W. In this zone manganese and iron rich garnets and gahnite form narrow massive rocks which have a high specific gravity. The presence of sulphides is possible in such horizons. Another small positive anomaly was noted at 64,100'S - 76,650'W, being near a garnet bearing outcrop with copper staining. Structural interpretation has shown that the rocks would occur in the lower zone of mineralisation which has been offset by the E-W shear. The outcrop occurs on the eastern side of the Hillston Fault, and contain iron and manganese in the garnet.

A third minor anomaly was noted by Sefton at 58,000'S - 73,100'W. This anomaly occurs near a fine-grained garnet rock tending to garnet sandstone within the middle zone of mineralisation. The density of such rocks would be greater than the surrounding rocks, owing to the iron and manganese in the garnets.

Although the geophysical traverses do not extend far enough to the east in many places to verify the existence of the Hillston Fault, a study of the southern "Interpretation of Geology" overlay plan (X27,781) shows the possible existence of a fault 450 feet south of the Kintore Mine, as the direction of the gravity contours changes abruptly, and there is a rise in gravity values.

Sefton (1959) suggested that electrical methods of exploration should be used in localities of known mineralisation in the Angus area, if further geophysical studies are carried out.

CHAPTER VI

ECONOMIC CONSIDERATIONS

Weak mineralisation in the Angus area is known to occur within calcic bearing zones of gneisses, schists, calcic plagioclase quartzites, and amphibolites and associated rocks. The manganese content of the rocks within the calcic bearing zone is generally higher than the surrounding rocks. The mineralisation is considered to have been concentrated from the sediments in the calcic zones. The paragenesis of the principal lode minerals is: gahnite and garnet, potassic felspar and muscovite, sphalerite and chalcopyrite, and galena. Biotite, when present, preceded the development of gahnite, and could be a wall rock mineral, rather than lode material. Quartz is considered to have been deposited throughout the sequence. The lode has concentrated in the noses of small drag-folds.

If the above conclusions are correct then the search for sulphide mineralisation in the Angus area, and in the Broken Hill district could be carried out in the following manner.

(1) Further Search in the Angus Area

(a) Sulphide Mineralisation

If a further search for sulphide mineralisation is carried out in the Angus area, it should include the electrical geophysical methods, as recommended by Sefton (1959) and the survey should cover the middle (Angus-Kintore) lower and upper zones of mineralisation.

As the middle mineralised zone is the broadest and contains the most outcropping mineralisation, generally as quartz-gahnite, with three known occurrences of sulphide mineralisation along its length, the zone is considered to be the most likely to contain economic concentrations of base metals, although only one small gravity anomaly was outlined.

As known mineralisation occurs in small folds, and the sulphides were emplaced last, such areas as the noses of folds in calcic zones would be the locations in which sulphides would concentrate if present.

The largest fold, in the middle zone of mineralisation, is 500 feet north of the Angus Mine. The size of the fold is accentuated by shearing.

Consideration could be given to drilling the lode horizons and ore shoots at depth and down pitch at the Angus Mine, but preferably the electrical work should be carried out before a decision is made.

In the absence of electrical geophysical studies the following localities are listed as the most likely to contain sulphide mineralisation:

(i) Angus Mine

(ii) 500 feet to the north of the Angus Mine in the sheared fold environment.

(iii) Halfway between the Angus and Kintore Mines where the mineralised zone is folded.

(iv) Kintore Mine.

(v) In the middle zone of mineralisation at 64,400'S-78,600'W where a fold has been mapped and very weak sulphide mineralisation has been noted.

(vi) The lower zone of mineralisation along which gravity anomalies were detected.

The writer realises that the observed mineralisation in the Angus area is weak and narrow, but for a relatively small cost the electrical geophysical studies, followed by possible drilling, could be carried out with results which would indicate definitely if the area should be "held" or "surrendered". The cost of additional geophysical surveys plus drilling is considered to be relatively small, when compared with the amount of money expended during the present period of holding the lease, and regional work done previously by Enterprise Exploration Co.Pty.Ltd. workers.

Water for drilling purposes is available in the area. Accessibility to the proposed drilling sites at the Angus Mine, Kintore Mine, and half-way between the two mines, could be managed without great difficulty. Accessibility to the northern (locality (v) above), and least favoured target, is not good, owing to water courses cut deeply into the alluvium. Access to the lower zone of mineralisation is fair to good.

Should drilling be considered without further geophysical studies priority should be given to the Angus Mine, and the fold 500 feet to the north of the mine.

(b) Beryl Mineralisation

Should a search for beryllium be considered, the upper zone of "aplite" and transgressive pegmatites should be traversed systematically with a beryllium detector.

(2) Further Search in the Broken Hill District

During a search for ore in the Broken Hill district it is considered that broad calcic bearing zones should be located. Microscopic studies may be necessary to determine the nature of the plagioclase in the sediments.

The presence of megascopic garnets in rocks could indicate a calcic zone, and also indicate the presence of manganese.

To determine the possibility of base metal mineralisation occurring within calcic zones, the rocks within the zone, and nearby amphibolites if present, should be assayed for lead and zinc by an accurate method, such as X-ray fluorescent spectrographic methods.

The presence of sericite rimming gahnite in any weak gahnite mineralisation found in the zone, would assist in selecting the target, as gahnite with sericite, found in the Angus area, occurred near sulphide mineralisation.

Although structure does not "make" ore, economic concentrations occur in fold environments in the Broken Hill district. If the presence of base metals is known to occur in a calcic zone, the most "severe" folded structure within the zone should be located, as the metallic ions will concentrate in areas of relative stress relief. A large drag-fold in an anticlinal pitch-reversal or domal environment would be an ideal structural position for the concentration of metallic ions, whether the mineralisation has a sedimentary or hydrothermal origin.

The anticlinal pitch-reversal or domal areas should be sought and the areas then examined for folds in calcic bearing zones, and geochemical and petrological studies made on the rocks within the zones.

Areas containing anticlinal pitch-reversals in the Broken Hill district have been outlined (McManus, 1958).

The growth of butterbush trees (*Pittosporum phillyreoides*) could indicate the presence of sulphide mineralisation in the Broken Hill district.

Electrical geophysical studies should be carried out if zones and areas such as the above are outlined.

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APPENDIX I

LIST OF SPECIMENS COLLECTED

Localities of specimens are shown on Plans numbered X/27/780 and X27,781.

A/180 is The University of Adelaide accession number.

* denotes that a thin section has been made.

o denotes that a polished section has been made.

780 and/or 781 following the specimen number, indicates the plan on which the specimen locations may be found.

The rock specimens, thin sections and polished sections are held by the Department of Economic Geology, University of Adelaide, South Australia.

A/180/1	*o	780 & 781	A/180/13	*	781
2	*	780	14	*	781
3	*	780	15	*	781
4	*	780	16	*	780
5	*	781	17	*	780
6	*o	780 & 781	18	*	781
7	*o	780 & 781	19	*	780
8	*	780	20	*	781
9	*	780	21	*	781
10	*	780	22	*	781
11	*	781	23	*	780 & 781
12	*	780	24	*	781

Appendix I (Contd)

A/180/25	*	780
26	*	781
27	*	781
28	*	780
29	*	781
30	*	780
31	*	780
32	*	780
33	*	780 & 781
34	*	780 & 781
35	*	780
36	*	780 & 781
37	*	780 & 781
38	*	780 & 781
39	*	780 & 781
40	*	780 & 781
41	*	780 & 781
42	*	780 & 781
43	*	780 & 781
44	*	780 & 781
45	*	780 & 781
46	*	780
47	*	780
48	*	780
49	*	780
50	*	780
51	*	780
52	*	780
53	*	780
54	*	780
A/180/55	*	780
56	*	780
57	*	780
58	*	780
59	*	780
60	*	780
61	*	780
62	*	780
63	*	780
64	*	780
65	*	780
66	*	780 & 781
67	*	780 & 781
68	*	780
69	*	780
70	*	780
71	*	780
72	*	780
73	*	780
74	*	780
75	*	780
76	*	781
77	*	781
78	*	781
79	*	781
80	*o	781
81	*	780 & 781
82	*	781
83	*	781
84	*	780 & 781

Appendix I (Contd)

A/180/85	*	780 & 781	A/180/115	*	781
86	*	780	116	*	781
87	*	780	117	*	781
88	*	781	118	*	781
89	*	781	119	*	781
90	*	780	120		781
91		780	121	*	
92	*	780	122	*	781
93			123	*	781
94		780	124		781
95	*	780	125	*	781
96	*	781	126	*	781
97		781	127	*	780 & 781
98		781	128		780 & 781
99		781	129	*	780 & 781
100		780	130	*	780 & 781
101	*	780	131	*	780 & 781
102		781	132	*	780
103	*	780	133	*	780
104	*	780	134	*	780
105		780	135	*	780
106		780	136		780
107	*	781	137		780
108	*	781	138		780
109	*	781	139		780
110	*	781	140	*	780 & 781
111		781	141	*	780
112	*	781	142	*	780
113	*	781	143	*	780
114	*	781	144	*	780

Appendix I (Contd)

A/180/145 *	780
146 *	780 & 781
147 *	780
148	780
149	780
150 *	780 & 781
151	780 & 781
152 *	780
153 *	780
154	780
155 *	780
156	781
157 *	780
158 *	780
159 *	780
160 *	780
161	780
162 *	
163 *	780
164	780
165 *	780
166	780
167 *	780
168 *	780 & 781
170 *	780 & 781
171 *	780
172 *	780
173 *	780 & 781
174 *	Pinnacles Mine
175 *	780
176 *	780 & 781
A/180/177 *	780 & 781
178 *	780 & 781
179 *	780 & 781
180 *	780 & 781
181 *	780 & 781
182 *	780 & 781
183 *	780
184 *	780
185 *	781
186 *	781
187 *	781
188 *	781
189 *	781
190 *	781
191 *	781
192 *	781
193 *	781
194 *	781
195 *	780
196 *	780
196A	780
197 *	780
198 *	780
199 *	780
200 *	780
201 *	780
202 *	780
203 *	780
204 *	780
205 *	780
208 *	780