A PETROLOGICAL STUDY OF THE WALLAROO AND MOONTA MINING DISTRICTS

By R.H. Jones.

Honours

?1940

Honours thesis 1940
Supervisor: unknown

Introduction.

Description of the Area.

The country in the neighbourhood of the mines is flat or slightly undulating. On the west coast there is usually a low cliff; the country then rises slowly to the east side of the peninsula. There are almost no lines of drainage and there are no creeks at all.

At the time[10a] when the mines were first discovered the area was covered with scrub, mallee, broombush, sheoak, sandalwood, quondong, saltbush and various grasses and herbage, and was held under pastoral lease. It has now been cleared and is used for farming, mainly wheat.

Deep soil, a light sandy loam, covers the whole district and this is underlain by a layer of travertine of varying thickness.

Except for the coastal cliffs there are no rock outcrops. This made prospecting difficult and has made any detailed geological study of the area impossible.

General Geology.

The rocks of the area are:-

Tertiary limestone
Cambrian siliceous conglomerate
Pre-Cambrian basal complex of metamorphosed sediments with intrusive igneous rocks.

These Pre-Cambrian metamorphosed sediments form the country rock of the Wallaroo Mines. They have apparently been intruded by the feldspar porphyry of Moonta Mines and by granite. This granite outcrops along the coast between Wallaroo and Tickera, and its presence is indicated by granitic stones in the fields about 5 miles east of Arthurton. A similar granite outcrops along the east coast of Yorke Peninsula near Mulcowurtie. There are some small copper mines associated with this.

The conglomerate and some quartzites outcrop at various places along the coast from Port Hughes to Wallaroo and has also been found in prospecting shafts sunk between Wallaroo Mines and Moonta. On top of these rocks is a siliceous quartzite conglomerate. It has not been proved definitely Cambrian in this area but a similar conglomerate is conformably overlain by limestones and shales containing lower Cambrian fossils at Curramulka and along the eastern coast of Yorke Peninsula. Jack[10b] records that "at Port Hughes it lies horizontally upon the tilted Pre-Cambrian schist and upon the edges of the granitic dykes which penetrate the schist, but do not penetrate the quartzite conglomerate". Unfortunately this junction has since been covered by the drifting sand dunes.

Tertiary, algal and polyzoal limestone overlies these older rocks in places. It outcrops in the sea cliffs from Pt. Riley to Tickera where it overlies the gneissic granite. It also covers a considerable area E. and N.E. of Wallaroo Mines.

Source of Specimens.

Since all the mines have been closed down for some time, no specimens of the country rock of the mines could be obtained in situ. Thus the only study that could be made was petrographical. Specimens for examination were obtained from the S.A. Museum from several collections, the main ones being, one presented by H.R. Hancock on behalf of the proprietors of the Wallaroo

10a & 10b. R. Lockhart Jack: Geological Survey of S.A. Bulletin No.6 pp. 9 & 30 respectively.

Mines Limited, and another presented by H. Lipson Hancock. Other specimens were obtained from the University, collected by Professor Howchin and others. Rocks collected by H. Lockhart Jack, and rock slides cut from them, were obtained from the Mines Department Museum. Numerous specimens were collected from the Mine Dumps.

History of the Mines.

R. Lockhart Jack has included a historical review in Bulletin No.6 of the Geological Survey of S.A., published in 1917. The remarks below are mostly about things not recorded by Jack, and they include some post-1917 history.

The Wallaroo Mines were discovered first[1]. Small ~~stones of ore~~ were found by a shepherd on a mound thrown up by a native rat. A hole was dug on the spot, disclosing samples of ore, which warranted further testing. This was in 1860. The Moonta Mine was discovered some months later by another shepherd.

J.B. Austin reported in 1863[2]:- "Before many months had elapsed since the discovery there was a perfect furore for securing 'claims' at Wallaroo. To such an extent did this proceed that to my knowledge persons who had never seen the place went to the Land Office, and, asking to see the plans, indicated two or three spots where they would like to take out claims; and some of these 'dips in the lucky bag' resulted satisfactorily". Some really good discoveries were made by systematic searching. At this time about half a dozen mines showed prospects of proving remunerative and not even half that number were actually paying.

Owing to the absence of water-courses, water caused much trouble. Fresh water was scarce. It was obtained by condensing steam from engines, by distilling sea water, for which purpose there were several stills of considerable magnitude, and by conserving rain from the roofs. There were no natural drains to remove the mine water, and until the Government built drains, this "mad-water" lay about, covering acres to a depth of two or three feet, gradually percolating back into the mines.

By 1863 the Wallaroo Mines had overcome their initial difficulties. The deepest shaft was 240' and the lode had expanded with depth to 30' wide. The ore averaged 15% Cu. At the Moonta Mines the two easterly lode belts had been discovered and worked down to 180'. This was still in the oxidized and secondarily enriched portions of the lode, the ore averaging 25% Cu. Other mines working were the New Cornwall, the prospects of which, however, were not good, the Kurilla Mine, the Duryea Mine, the Yelta Mine and the Karkarilla Mine. The New Devon Mine, which had looked promising in the beginning, had already closed down.

In 1866[3] the grade of the ore at Wallaroo Mines was improving with depth. Wandilta and New Cornwall mines were still working. At the Yelta Mine the ore was averaging 28% Cu. The Euko, Wilkawat and Poona Mines had not yet proved successful and the Karkarilla was not doing very well. The Moonta Mines were working in 20 shafts, the deepest being 330'. The average grade of ore was 21% Cu. Machines for dressing low grade ore were already in operation.

In 1880 H.M. Franklyn reports that the grade of the ore from Moonta Mines had fallen, necessitating dressing before smelting. Hancock Jiggers, which had been developed on the field, were used, the discharge varying from 16 - 25% Cu. The average tenor of the output of Wallaroo Mines was still about 10%, and no dressing was done. The Cementation Process for leaching the tailings dumps ~~were~~ was just being put into operation.

In 1889[4] only the main Wallaroo Mines and the main Moonta Mines were being worked. The two companies had amalgamated into the Wallaroo and Moonta Mining and Smelting Co. In all the others except the Yelta and Paramatta Mines, which have been worked, since, any ore there was had been completely worked out.

---

1. H. Mortimer Franklyn: "A Glance at South Australia in 1880". p.87
2. J.B. Austin: "The Mines of South Australia, 1863" pp 88-97
3. Bailliere's South Australian Gazetter compiled by R.P. Whitworth 1866. pp 261-6
4. The Record of Mines of S.A. for 1899. pp. 31-56

At Moonta the deepest shaft, Taylor's, was down 2,340' on Beddomes, Hogg's, Green's and Fergusson's lodes shafts were down 1,500'. The ore broken averaged 3% Cu. At Wallaroo, Taylor's shaft was 2,070' deep and the grade of ore broken was still about 12%. This figure seems remarkably high.

In 1909[5] the tenor of the ore broken in both mines was 3.9%. This was concentrated to 9% at Wallaroo and 13.5% at Moonta. Wallaroo produced 120,000 tons and Moonta 58,000 tons of ore per annum.

The mines were closed down in 1923, but the deep workings on the Eastern belt at Moonta had been deemed worthless in 1902. Work had been discontinued in the Central belt in 1904. The Western belt was never important as a producer of ore. After 1904 until the mines were closed, the only active mining was in the upper portion of the Eastern belt.

The reason for closing the mines, as given in Mining Review No.39, was:-"The impoverishment of the Moonta lodes at depth and the decreasing size of the ore bodies in the deeper levels of the Wallaroo Mines together with the heavy expense of mining at nearly 3,000' in the latter mines were all factors which caused the cost of producing copper to exceed considerably the market price, which was about £60 standard at the time of closing down on October 23rd, 1923. The Moonta Mines were the first to give way for the lodes at depth were found to be unproductive, and the deeper levels had long been abandoned, work having been confined to the extraction of whatever ore could be obtained from the 1,800' level upwards.

Taking the entire life of the mines, the following figures give substantially the total output:-

Production of ore	11,581,480 tons
Production of copper	333,599 tons
Value of copper produced	£20,077,652

About 2,000 men were constantly employed at the mines and about 300 at the two smelters, one at Wallaroo and the other at Port Kembla, N.S.W.

Since 1923 the Moonta Copper Recovery Co. have been successfully working over the old dumps recovering copper by the cementation process. They are still working there.

There has also been much prospecting done by diamond drilling, both by the Government and by private companies, but nothing of note has been found.

In 1930[7] the South Australian Government applied to the Commonwealth Government for assistance, from the fund for the relief of unemployment, to reopen a portion of the Moonta Mines. There was known to be 54,000 tons of 4½% ore in crushed ground left by the Wallaroo and Moonta Mining and Smelting Co., and operations of tributers had disclosed good prospects. As a result of a favourable report from Sir Herbert Gepp a grant of £5,000 was made by the Commonwealth and this was supplemented from the State Mining Vote. Work was commenced, under the supervision of the Mines Department, on the southern end of the Eastern belt. Smith's shaft was recommissioned for hoisting

---

5. The Wallaroo and Moonta Mines -- a booklet published by the Company in 1909.
6. S.A. Mining Review No.39 pp.15 & 16
7. Reports of Moonta Mining Scheme are published in S.A. Mining Reviews Nos. 52-69.
   Report by J.L. Pearson (Inspector of Mines) No.53 pp. 130-133

and 16,000 tons of ore carrying 6% Cu. were developed.

In June 1931 Dr. Stillwell visited Moonta and following on his favourable report a further sum of £5,000 was allocated from "unemployment" funds.

Altogether within 300' of the surface over 30,000 tons of 5% ore was developed, with strong prospects of much larger tonnages. Under the special wage conditions arranged, it was found that for successful working at the price that then held for standard copper, £45 per ton, Australian currency, the ore broken needed to contain 5% Cu. This was for a rate of production of 300 tons of ore per week.

A treatment plant for flotation concentration was built, and active mining was carried out until the end of August 1938. The Scheme's operations were then closed owing to complete exhaustion of the known ore reserves. During this time 46,000 tons of crude ore were treated, and the concentrates smelted at Port Kembla. The gross value of the metal produced, 1,103.8 tons of Cu. with some gold, was £59,292. This makes the total output of the mines:

Ore	11,628,000 tons
Copper	334,700 tons
Value of Copper	£20,137,000

The total gross value of the metals produced from the Scheme's operations was £51,477 while the expenditure on production was £60,680. Although the Scheme as a mining venture did not pay, consideration must be given to the fact that the greater number of men employed at Moonta (between 55 and 70 men) would have had to apply to the Government for relief for themselves and their dependents.

Since then some boring[8] has been done and is still being carried on in the Karkarilla lode, which is along the southern extension of Taylor's lode. Some very narrow veins carrying 2.3% Cu. have been cut at depths of about 600'-700'.

Report by Dr. F.L. Stillwell	No.54 pp. 91-98
" " Sir Herbert Gepp	No.57 pp 56-62
Details of concentrating plant	No.58 pp. 42-46
Final Summary	No.69 pp. 74-77

8. S.A. Mining Reviews No. ~~77~~ 70 pp. 46-48 and No.71 pp. 50-53.

The Country Rocks of Wallaroo Mines.

The rocks of this area represent a sedimentary series which has suffered regional metamorphism. They are mainly quartz biotite schists, some of which contain amphibole and scapolite. Some lime silicate rocks are present, consisting of scapolite and diopside, and some rocks consisting almost entirely of hornblende are also present. The grade of metamorphism reached was that of Barrow's biotite zone, and it is probable that stress was deficient in places. During metamorphism there was considerable introduction of chlorides, producing the scapolite. Some retrograde changes have taken place resulting in the conversion of some pyroxene to amphibole and some biotite to chlorite. There has also been introduction of apatite, tourmaline and feldspar, but as these appear to be connected with mineralization they will be discussed later.

The sediments were originally arkoses, slates and calcareous slates, and there were some basic igneous rocks but whether they were intrusive or extrusive cannot be decided. A notable feature of the rocks is the large amount of feldspar present. Both microcline and plagioclase are present, the plagioclase varying from $Ab_{90}An_{10}$ to $Ab_{70}An_{30}$. Distinguishing the quartz and the feldspar in the groundmass of most of the rocks is difficult, but many appear to contain as much or more feldspar than quartz. For convenience the rocks have been divided into two classes:- 1. the metamorphosed arkoses and slates;
2. the metamorphosed calcareous slates.

The Metamorphosed arkoses and slates.

These rocks, which are now represented by quartz biotite schists, ranging from quartz feldspar rocks containing numerous biotite flakes, through quartz biotite schists to rocks consisting almost entirely of biotite, apparently originally ranged from argillaceous arkoses to slates containing but little detrital quartz. Rocks which appeared to have been quartzites in the field were later found to be scapolite-rich rocks.

Rocks 25, 26, 27, 28 are typical of the micaceous quartzites.

The main minerals in order of abundance are quartz, feldspar, biotite (including chlorite). The quartz and feldspar form a fine-grained mosaic, average grain-size .1 mm.

Feldspar constitutes about 30% of the rock. Most of it is untwinned and quite clear but some shows multiple twinning. It is oligoclase varying from $Ab_{90}An_{10}$ to $Ab_{70}An_{30}$. The main distinguishing feature between the quartz and the feldspar is the cleavage of the latter, but sometimes quartz shows cracks resembling cleavage, making distinction difficult.

The biotite occurs in bands, and flakes scattered through the groundmass, all the flakes having similar orientation. It is pleochroic in X = light brown $<$ Y = Z = dark brown. It shows alteration to light green chlorite with the formation of some magnetite.

Pyrite, zircon, apatite and tourmaline are accessory occurring in small idioblastic crystals.

Some of these rocks show marked bands of biotite about ¼" apart, giving the rock a "sheeted" appearance. These rocks may have been something resembling a flagstone before metamorphism. Rock 24 is an example of this rock type which is very common in dumps around the main workings.

Rocks 29, 30, 32, 33, 35, 36, 39 and 40 are quartz biotite schists. These differ from the above group of rocks only in greater richness in biotite or chlorite.

A complete description of Rock 33 is as follows:- The rock consists of biotite with parallel arrangement in a base of quartz

9. A. Harker: "Metamorphism" p. 208.

mosaic ~~consists~~ of very variable grain-size.

The quartz is clear with, at times, strings of dusty inclusions.

The biotite is pleochroic in X = light yellow < Y = Z = dark greenish brown. It contains numerous pleochroic haloes surrounding inclusions.

There is a considerable amount of feldspar as small grains in the rock. It appears to be all plagioclase usually showing albite twinning and containing 5 - 30% An. Some is quite clear but some is full of inclusions.

Apatite and tourmaline are accessories.

In many of these rocks biotite shows alteration to chlorite.

A little microcline is present in some.

Amphibole and scapolite are minor constituents of some, e.g. 29,32, 39. The amphibole is pleochroic in X = yellow < Y = yellow green < Z = bluish green. It has $Z \wedge c = 15^{\circ}$ and is probably an actinolite. The scapolite shows extensive alteration to sericite. These two minerals probably represent some slightly more calcareous parts of the rocks. Cordierite was searched for but none could be found.

Rocks 34 and 38 represent the types very rich in biotite.

Rock 38 comes from 1440' level Taylor's shaft. It consists almost entirely of biotite with some chlorite, a little quartz and a little microcline.

The biotite is pleochroic in X = very light brownish yellow < Y = Z = dark greenish brown, and also contains numerous pleochoric haloes. It shows a tendency towards parallel arrangement, giving the rock a slight schistosity. Some alteration of biotite to chlorite has taken place. This chlorite occurs as light green bands spotted with magnetite within the biotite flakes. Sometimes the chlorite has completely replaced the biotite, forming pseudomorphs after biotite, possibly with just a brown centre of biotite. The chlorite shows ultra-blue interference colours. The change of biotite to chlorite appears to be the result of retrograde metamorphism.

There are also areas of lighter green chlorite aggregates. The shape of these areas suggests that they may represent alteration products of hornblende. This is especially well shown in Rock 40.

<u>The metamorphosed calcareous slates</u>.

There are extensive scapolite-diopside and scapolite-hornblende rocks, and some scapolite-biotite rocks at Wallaroo.

Jack[10] records the presence of scapolite at Wallaroo as "a white to yellowish to purplish mineral aggregate occurring in the lode". The mineral was analysed and Jack concluded that it was "mizzonite".

SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	H_2O+	H_2O-	Total
55.20	26.02	0.32	nil	7.36	4.54	4.81	1.22	.10	99.57

There are two notable features about this analysis. One is the large amount of K_2O present and the other is the absence of CO_2 and Cl. The analysis was done before the true composition of scapolite was realized. Before 1914 [11] it was thought that the composition of marialite was 3 $CaAl_2Si_2O_8.CaO$ and many old

---

10. R. Lockhart Jack: Bulletin No. 6 S.A. Geological Survey p.48
11. Zeitschrift für Krystallographie; Band 76, 1931. p.486.

analyses[12] of scapolites do not show the presence of CO_2 or Cl. Such a large amount of K_2O is unusual, but Hintze[12] quotes a number (18) of analyses of scapolites containing from 2.68 - 8.82% K_2O. Smaller amounts of K_2O in scapolites are very common.

The mineral is definitely scapolite. There is much scapolite in the rocks at Wallaroo, and the slide, made by Jack, of the analysed mineral, shows its optical properties to be those of scapolite. It is uniaxial and optically negative, has scapolite cleavage and has a R.I. about 1.553. Consideration of the analysis and of the R.I. of the scapolites gives a composition of approximately $Ma_{60}Me_{40}$ - ~~dipyrite~~. dipyre

Jack appears to regard the scapolite as a mineral associated with the lode only, for he does not report its presence in the description of the "Pre-Cambrian sediments". However, scapolite seems to be a very common mineral in the region, formed in the metamorphism of original calcareous slates. It does not seem to be connected with the introduction of the lode material but the partial alteration to sericite shown may have taken place then.

Rocks 20, 22, 23 and 64 are typical scapolite-diopside-actinolite rocks. They are greenish-grey in hand specimen, showing light greenish-grey and white, greasy-looking scapolite and dark greenish-grey diopside.

The scapolite is in large individuals (about 5 mm. across). It contains numerous poeciloblastic inclusions, mostly quartz, but some are diopside, sphene, calcite and apatite. The scapolite constitutes 60-70% of these rocks. It is altered in places to sericite and this alteration often seems more intense where pyrite is present, i.e., it may be a result of action of lode-forming solutions.

Diopside occurs as individuals half the size of the scapolite and also as aggregates of small grains. It shows a high relief and medium birefringence (2nd order green) and $Z \wedge c = 40°$. It often has a rim of green actinolite and the two may be intergrown in a manner resembling graphic intergrowth. The actinolite is probably an alteration product of the diopside, a result of retrograde metamorphism. It is pleochroic in X = yellow $<$ Y = yellow green $<$ Z = green.

A little plagioclase and microcline are present in these rocks, but there is not enough plagioclase to determine it.

Scattered through these rocks are numerous small grains of pink mineral, slightly pleochroic with very high relief and birefringence. No satisfactory interference figures could be obtained. Most of the grains are probably sphene but some not quite so pink in colour may be zircon. Garnet was searched for but none could be found. A few small grains of apatite ~~were~~ are also present.

Rock 22 is foliated, consisting of bands of quartz-feldspar-biotite-schist and of scapolite-diopside rock. This definitely gives the scapolite-diopside rock a ~~definite~~ sedimentary origin.

High[9] grade regional metamorphism of impure dolomitic limestone may produce diopside, with scapolite associated. The grade of metamorphism necessary for formation of diopside is equivalent to half way through the garnet zone in argillaceous sediments. These rocks therefore probably represent impure dolomitic limestones or calcareous slates which have suffered regional metamorphism. Judging by the associated argillaceous rocks none of which have reached the garnet zone the formation of diopside has taken place at a lower grade than Harker postulates or the stress was lower than its maximum possible.

---

9. A . Harker; op. cit. p. 260
12. C. Hintze ; Handbuch der Mineralogie ; Band 2 ; 1897, pp. 1575-80

Rocks 51, 54 and 55 are scapolite rocks but here the ferro-magnesian mineral is biotite. The rock consists essentially of black biotite, showing no special orientation, with white porphyroblasts of scapolite in it.

The biotite is pleochroic in X = cream ~~and~~ < Y = Z = dark brown, and shows numerous pleochroic haloes.

The scapolite is in much larger individuals in 55 (2.5 mm) than in 54 (1 mm.), and in the former it also contains numerous inclusions of biotite and quartz, the quartz being in small areas showing a micro-graphic intergrowth with the scapolite. The scapolite is ~~dipyrite~~ dipyre, having R.I. about 1.553, and it shows slight alteration to sericite in places.

There is a little amphibole in the rocks, very light green in colour and probably actinolite.

Sphene and apatite are accessories.

Rock 51 was a biotite-scapolite rock, but has been very extensively altered, the biotite to green chlorite, showing ultra blue interference colours and the scapolite to sericite and calcite and a colourless mineral. This colourless mineral is optically negative, has R.I. less than balsam and shows very low birefringence. It is probably a zeolite. The rock also contains large apatites.

In hand specimen the rock is a green and pink mass. It shows mineralization by chalcopyrite but whether the mineralization caused the alteration cannot be decided. This seems improbable since Rock 55 also shows mineralization but no alteration. However, here a small vein of chalcopyrite microcline and quartz was introduced and it may still be that, at lower temperatures, than those necessary for formation of microcline, ore forming solutions caused the extensive alteration.

These biotite-scapolite rocks probably represent metamorphosed impure limestones, the impurity being large amounts of sericite and chlorite. These together produced biotite and in the reaction freed alumina, which helped to form the scapolite.

Rocks 41 and 42 are scapolite,-hornblende,-biotite schists. They show marked linear schistosity. Here again the scapolite is ~~dipyrite~~ dipyre. It contains numerous poeciloblastic inclusions of quartz, biotite, hornblende and sphene.

The biotite is pleochroic in X = light yellow brown < Y = Z = dark brown.

The amphibole is pl~~ee~~eochroic in X = greenish yellow < Y = yellow green < Z = blue green. It is negative with $Z \wedge c = 15^{\circ}$. It is probably an actinolitic hornblende. It contains poeciloblastic inclusions of quartz. Quartz itself is only a subsidiary mineral in the rock. Accessories are sphene and apatite.

These rocks may represent diorites which have suffered regional metamorphism; but the presence of a little scapolite and amphibole in some of the rocks described on page 2, which are definitely metamorphosed sediments, indicates a sedimentary origin for them. They probably represent calcareous slates, with a composition between those of the previous two groups, which have been regionally metamorphosed.

That ~~dipyrite~~ dipyre is the scapolite seems to add weight to the argument for an igneous origin for these rocks, for ~~dipyrite~~ dipyre is usually a product of metamorphism of igneous rocks, mizzonite being the usual scapolite formed in the metamorphism of calcareous rocks. However, the scapolite in all the other rocks is dipyr~~it~~e, and this anomaly may be accounted for by the high feldspar content of the rocks. The rocks described on pages 1 and 2 cont~~in~~ain a considerable amount of albitic feldspar, and a similar content of feldspar in these calcareous rocks could account for the high marialite content of the scapolite.

Basic Igneous Rocks.

Jack records:- "Fragments in several of the old mine dumps indicate the existence of basic igneous dykes, but in no case was such material seen in situ". He describes Rock 14.1.66 as "a coarsely crystalline rock showing abundant hornblende and quartz. Microscopically it is seen to be a coarsely crystalline rock of granitoid texture, composed of quartz, hornblende and magnetite together with some kaolinized plagioclase. The hornblende is deep green to brownish yellow in colo ur and has been much corroded by the quartz which appears to be of later date. The high percentage of quartz in association with large plates of amphibole and plagioclase suggests that the rock is a basic igneous intrusion affected by a subsequent siliceous invasion".

Some rocks very rich in hornblende -- even consisting almost entirely of hornblende -- were found. The origin of these rocks is obscure, and seeing that some may have had an igneous origin they will be discussed here.

Rocks 43, 44, 45, 46, 47 and 48, and 17 from the Mines Department are hornblende rocks. Rock 45 is slightly different from the others which are all very similar, except that 47 contains much chalcopyrite.

Rock 44 will be described as being typical of these rocks. In hand specimen it is seen to consist mainly of coarse hornblende, individuals being about ½ cm. long, with a little coarse biotite. In section the hornblende is seen to contain numerous poeciloblastic inclusions of quartz. It is pleochroic in X = yellow < Y = yellow green < Z = blue green, has $Z \wedge c = 16^{\circ}$ and is optically negative. It also shows slight alteration along cracks. The biotite is pleochroic in X = light yellow brown < Y = Z = very dark brown. It appears to be remnants of partly digested flakes, and it is very extensively altered to chlorite.

A little apatite is present and also some tourmaline.

Rocks 48 and 17 are much coarser, the hornblende being between 1 and 2 cm. long. It does not contain inclusions. In 48 there is an area of quartz and associated with this is some biotite, altered extensively to chlorite. In the quartz is another mineral, feldspar?, which has altered to sericite.

Some relatively large apatites, some siderite and hematite are present.

The origin of the hornblende is problematical. According to Harker,[9a] under regional metamorphism, calcareous grits may produce hornblende. He says:-"In some more impure calcareous rocks, large poeciloblastic crystals of hornblende come to constitute the major part of the rock. The hornblende porphyroblasts, accompanied by biotite and epidote are enclosed in a quartzose or quartzo-feldspathic groundmass with granoblastic structure". Also, under regional metamorphism, ultrabasic rocks produce a hornblende schist.[9b] "With advancing metamorphism these various minerals come to be merged in a green hornblende of complex constitution, adapted to the bulk-composition of the rock. We have then a relatively coarse textured hornblende-schist, or a more massive hornblende rock composed almost entirely of the one mineral".

Either of these explanations may account for the hornblende rocks under consideration. In rock 47 the contact between the hornblende rock and the biotite schist resembles an intrusive contact. It is therefore suggested that some of the hornblende rocks represent basic igneous rocks intruded prior to the period of metamorphism.

9a & 9b. A.Harker op. cit. pp. 269 & 277 respectively.

Jack, who apparently found Rock 17 in situ, giving its occurrence[10] as "a ~~view~~ vein in S. wall at 2,670' level West drive Taylor's shaft", seems to be of the opinion that hornblende was introduced as part of the ore mineral assemblage. Rock 48 also probably represents hornblende introduced at the ore forming time. These two rocks do not show the granoblastic and poeciloblastic structures of the other hornblende rocks.

Rock 45 shows some different features. There appears to be two different parts to this rock, one consisting almost entirely of coarse amphibole with much quartz (more quartz than the above hornblende rocks), and the other being much finer grained. The finer-grained portion resembles rocks described above as definitely sediments, but is richer in hornblende. It contains biotite altered to chlorite, some apatite, calcite and tourmaline. This rock seems more likely to be an amphibolite derived from a sediment.

Mineralization.

From the few specimens now obtainable the complete story of the mineralization at Wallaroo cannot be worked out. Jack has written a little on this. From a study of Jack's slides and from other specimens, some additions and modifications can be made to Jack's findings. He records the following:- "The gangue minerals consist of quartz, coarse plates of biotite, distinct from the fine scales of biotite left in the lode owing to incomplete replacement of the mica schist which the lode traverses, a little feldspar, schorl, apatite, fluorite, amphibole, pyroxene, siderite, calcite, dolomite, rhodochrosite, and mizzonite. Chlorite, muscovite and sericite are also in small amount. Metallic minerals are chalcopyrite, pyrite, pyrrhotite and small amounts of galena, blende, ferberite, scheelite, molybdenite and gold. Smaltite also occurs in the Kurilla lode. The calcite and dolomite appear to have crystallized later than and enwrap chalcopyrite and are in turn surrounded by galena. Both the galena and blende appear to be among the latest metallic minerals deposited".

The mineralization at Wallaroo seems to have been the filling of fissures and replacement of the country rock out from these fissures. The miners divided the ore into two groups, one which they called "veinstuff" and the other "ore". The "veinstuff" consists mainly of chalcopyrite, pyrite, quartz, calcite, ankerite, and siderite with a little fluorite, galena, ferberite, scheelite, hematite, cobaltite and gypsum and is apparently a fissure filling. The "ore" is a replacement of the country rock -- mainly biotite schist -- by chalcopyrite and quartz. The non-metallic minerals introduced during the ore-forming period seem to have been quartz, feldspar, apatite, fluorite, tourmaline, calcite, siderite, dolomite, rhodochrosite, gypsum and possibly amphibole. The biotite associated with the ore seems more likely to be all residual from the biotite schist and the "mizzonite" was also left from incomplete replacement of the country rock. Some of the amphibole may have been introduced during the ore-forming period.

Apatite appears to have been the earliest mineral introduced. It is the chlor-variety. Rocks No.56 and 57 show extensive replacement of biotite schist by quartz and apatite. The apatite shows shadow extinction and is biaxial negative with a very small optic axial angle. The quartz also shows shadow extinction and contains dusty inclusions. The biotite is slightly altered to chlorite. In some places this alteration resembles that shown by the biotite of rocks on pp.2 and 3. Some of the chlorite is in small radiating aggregates and associated with calcite and also some chlorite fills cracks in the apatite. Large crystals of apatite (No.51 and M.D. No.13) and also apatite veins (e.g. M.D.14.1.71) occur in the rocks.

---

10. R. Lockhart Jack: op. cit. p.48

In M.D.No.13 chalcopyrite fills cracks in the apatite, and in M.D. No.26 apatite occurs as inclusions in massive chalcopyrite. Thus it appears that apatite was one of the first minerals introduced.

The feldspar is microcline. No.37 is a feldspathized biotite schist. The rock is a quartz biotite schist in which there are small porphyroblasts of microcline. The average grain size of the quartz base of the schist is .2 mm. and the length of the microclines are about 2 mm. These porphyroblasts show cross-hatching and contain numerous very small inclusions of biotite and chlorite. Also some pyrite is associated with them. Some light green chlorite is present in the rock and appears as though it may be pseudomorphs after hornblende for it shows strands of parallel fibres in directions resembling hornblende cleavage set in a base of radiating aggregates. The presence of similar light green chlorite as inclusions in the porphyroblasts of feldspar seems to indicate that this chloritization of hornblende (?) was caused by the feldspathization. Rock No.59 shows large crystal of microcline as part of the lode. Here the microcline was determined from crushed fragments. It did not show microcline twinning but its extinction angles determined it as microcline. No.55 shows introduction of a small vein of quartz and orthoclase with some chalcopyrite. Here chalcopyrite fills cracks in orthoclase and was therefore introduced later. Quartz and chalcopyrite usually seem to be associated but some of the chalcopyrite seems to have been formed after the calcite. It is found coating calcite crystals. (Rocks V, 55 and 56 of Cloud's set, all at the S.A. Museum).

Tourmaline occurs in most of the rocks. In many it is just as a few small grains (e.g. 64 and 33) and could be accounted for as detrital tourmaline, but others are quite rich in large idioblastic tourmalines often occurring in bands in the rock e.g. 29, 30 and 31. These rocks are chlorite schists and quartz chlorite schists. The tourmaline is pleochroic in ω = dark bluish black > ϵ = pinkish grey. They contain numerous poeciloblastic inclusions of quartz and chlorite. In these cases the tourmaline is a result of boric emanations acting on the chlorite of the rock[9]. Rock No.30 shows that some quartz and calcite were also introduced with the tourmaline. Tourmaline was also apparently introduced bodily as vein filling with calcite. This association of calcite and tourmaline is strange for when limestone suffers boron pneumatalysis axinite is the mineral usually produced. The way in which the calcite fills the spaces between idioblastic tourmaline crystals seems to indicate quite definitely that the tourmaline and calcite were formed together. Some calcite does fill cracks in the tourmaline but this could easily be explained as something which took place much later owing to the mobility of calcite. Rocks 58, 59 and 60 show this coarse intergrowth of calcite and tourmaline. Rocks 59 and 60 show this intergrowth grading into quartz biotite hornblende schist which has been partially replaced by tourmaline and calcite. Here the tourmaline is xenoblastic and contains inclusions and also numerous dusty inclusions of biotite and chlorite. All the observable features seem to indicate that the tourmaline and calcite were formed together. This would mean that the tourmaline was formed at quite a low temperature.

A little gypsum seems to have formed probably as the last mineral precipitated from the ore-forming solutions. Introduction of the ore seems to have caused some alteration of biotite and hornblende in the country rock to chlorite and also of scapolite to sericite and a very pale green chlorite.

---

9. A. Harker op. cit. p.118.

The order of mineral formation seems to have been:-

apatite hornblende	orthoclase quartz most of chalcopyrite	tourmaline calcite some chalcopyrite	galena blende	gypsum

Summary.

The rocks of Wallaroo thus represent a Pre-Cambrian -- probably Archaeozoic -- sedimentary series of argillaceous quartzite slate and argillaceous limestone, with probably some intrusion of basic igneous rock. The area then suffered regional metamorphism up to the biotite grade. The metamorphism converted the sediments into quartz-biotite schists, biotite schists, scapolite-diopside and scapolite-hornblende rocks and scapolite-biotite schists. Then the ores were introduced -- probably following fairly close on the metamorphism for it seems that the granite intrusion which either caused or accompanied the metamorphism was the source of the ore solutions. The temperature conditions of ore formation probably correspond to Lindgren's[13] mesothermal deposits. The presence of tourmaline superficially indicates higher temperature but its association with chlorite and calcite show that the temperature of formation of the tourmaline is this case was exceptionally low. Then the area suffered erosion and Cambrian sediments were laid on top.

---

13. Waldemar Lindgren "Mineral Deposits".

The Country Rocks of Moonta Mines.

The lodes occur in an area of feldspar porphyry. This forms the basal rock over an area of approximately 17 square miles. Jack[10] reports that:-

"In no instance is it possible to see the actual contact between the feldspar porphyry and the surrounding sediments, and the boundary can only be approximately laid down on the evidence afforded by scattered workings and occasional field stones".

The rock is dark red in colour and shows light pink phenocrysts of feldspar. It varies in the extent of development of phenocrysts, some is not porphyritic, and in the amount of biotite it contains. With increasing content of biotite the rock becomes darker in colour. Even when the rock contains only a little biotite, this biotite seems to show a parallel orientation in the fine-grained feldspar quartz groundmass, and with increasing content of biotite still showing parallel orientation, the rock develops a schistose character.

Rocks 72, 73, 74, 90 and 91 are specimens of the porphyritic kind not very rich in biotite. Rock 74 differs from the others in its slightly lighter colour. It is dark pink while the others are dark red.

The phenocrysts are almost all plagioclase but a few of the smaller ones ~~might be~~ are microcline, and some plagioclase ones contain inclusions of microcline. Sometimes the rocks are glomeroporphyritic. The composition of the plagioclase is variable, ranging from $Ab_{80}An_{20}$ to $Ab_{70}An_{30}$.

The groundmass consists of quartz and feldspar. The groundmass is noticeable for its variable grain-size, and the pronounced allotriomorphic granular texture. In some areas of the rock slides the grain-size of the groundmass is very fine (0.2 mm.) while in other areas the grain-size is relatively coarse (1 mm.). The texture of the groundmass resembles very much a granoblastic texture. The feldspar of the groundmass is both microcline and plagioclase. Most of the individuals are too small to show recognisable twinning and so the relative quantities of each in the mode are not determinable. The norm of the rock, which shows 28.91% Orthoclase and 22.04% Plagioclase indicates that there ought to be a little more orthoclase than plagioclase in the groundmass. The quartz of the groundmass is quite clear and some of the larger grains show shadow extinction.

The feldspar is slightly cloudy.

Other minerals present are biotite and chlorite, magnetite, apatite, chalcopyrite and zircon.

The biotite is always partially, and often completely, altered to chlorite. It is pleochroic in X = golden yellow < Y = Z = dark greenish brown. The chlorite is pleochroic in X = yellow < Y = Z = green and shows purple interference colours. It is usually cloudy with fine spots of black Fe-ore (magnetite). These two are usually scattered through the groundmass, but are sometimes segregated into very thin lenses. However, the flakes always have a parallel orientation.

Numerous small magnetite crystals and a few small zircons are scattered through the groundmass.

Apatite occurs as large round grains showing a medium relief and low double refraction. It seems unusual to have such large grains of apatite in a very fine-grained rock but since most of these rocks show at least slight mineralization by chalcopyrite this apatite may have been introduced at the ore-forming time.

The rocks are often traversed by small quartz veins, but, since these are not associated specially with the chalcopyrite, it is probable that they are pre-ore, having formed either just

---

10. R. Lockhart Jack: op. cit. p.24.

after the rock solidified or during the time of metamorphism.

Rock 85 is an example of the non-porphyritic variety. The groundmass of the rock is exactly the same as that of the above class. The only difference between the two rock types is the absence of phenocrysts in one.

Rocks 86, 80, 79 and 78A are examples of rocks richer in biotite (or chlorite). Here also the biotite is extensively altered to chlorite, dusty through magnetite inclusion.

Rocks 86 and 80 are non-porphyritic kinds while 79 and 78A show porphyritic feldspars (oligoclase). The texture of the quartz-feldspar groundmass, except for the biotite flakes is similar to the above i.e. it very much resembles granoblastic texture.

The biotite is scattered envenly, with parallel orientation of the flakes, through the groundmass. Rock 80 very much resembles, especially in the slide, a metamorphosed sediment -- an argillaceous arkose. In Rock 86 biotite as well as being scattered evenly through the groundmass occurs as discontinuous bands, with coarse quartz. Some of this biotite may be of later introduction.

Rock 79 does not show such a well developed schistosity as the others, and appears to contain altered hornblende. Pseudomorphs apparently after hornblende, formed of a yellow-green alteration product, are found in the rock. This mineral has R.I. and colour similar to chlorite, but is not pleochroic and has a much higher birefringence -- about same birefringence as biotite.

Rock 80 is rather more strongly mineralized than the others and also contains tourmaline. This occurs as numerous small crystals scattered through the rock and was probably introduced during the ore-forming period. What appears to be the remains of completely kaolinized feldspar phenocrysts are shown by this rock.

Samples of the normal feldspar porphyry and the biotite-rich varieties have been analysed by W.S. Chapman.[10]

	Normal Feldspar Porphyry of Moonta	Schistose Felsite of Moonta	Paney Bluff Feldspar Porphyry Dark-grey Var.	1mile W of Paney Bluff Feldspar Porphyry Reddish Var.	Near Corunna Stn. Feldspar Porphyry Reddish Var.
SiO_2	73.02	62.87	72.22	71.48	68.90
Al_2O_3	13.39	13.97	14.35	14.73	14.43
TiO_2	0.52	0.68	0.42	0.35	0.69
Fe_2O_3	1.87	3.38	1.22	1.14	1.91
FeO	1.40	5.92	1.69	1.16	2.80
MgO	0.55	4.49	0.30	0.25	0.33
CaO	0.42	0.15	1.22	0.54	0.92
Na_2O	2.38	1.26	2.50	2.74	3.07
K_2O	4.89	4.12	5.12	5.68	5.70
H_2O+	0.70	1.94	0.68	1.08	0.87
H_2O-	0.06	0.30	0.12	0.32	0.29
CO_2	nil	0.22	0.22	0.12	0.23
P_2O_5	0.07	0.10	0.07	0.04	0.19
Cl	0.03	0.10	0.02	0.05	0.03
FeS_2	0.20	0.05	0.06	0.14	0.15
MnO	0.02	0.04	0.02	0.10	0.03
BaO	nil	nil			
CuO	0.05	0.01			
Total	99.57	99.60	100.23	99.92	100.54
Norm					
Quartz	38.58		34.92	31.80	25.92
Or	28.91		30.02	33.92	33.92
Ab	20.44		20.96	23.06	26.20
An	1.96		5.56	2.78	3.34
Co	3·37		2·65	2·96	1·84
Hy	1·40		2·15	1·26	3·18
Il. + Mag.	3·84		2·62	2·23	4·59

10. R. Lockhart Jack: op. cit. p.26.

The biotite-rich variety is notably richer in Fe_2O_3, FeO & MgO. Stillwell[7] writes that "examination of thin sections shows that biotite is often accompanied by occasional crystals of tourmaline and usually large crystals of apatite. While, therefore, the development of biotite and its resulting schistosity may be due partly to dynamic metamorphism, it may also be partly a result of pneumatolytic action following on the intrusion and consolidation of the feldspar porphyry".

I think that the tourmaline and apatite are more likely to have been introduced at the ore-forming time. Most of the extra biotite in the biotite-rich rocks is more likely to be due to a variation in the composition of the magma, but some, especially that producing the bands with coarser quartz as in Rock 86, could have been introduced more metasomatically than pneumatolytically, following intrusion and consolidation of the feldspar porphyry.

Jack[10] regards the rock as intrusive, but such a large intrusive body would be expected to be coarser-grained. The texture of the groundmass is more that of a dyke rock than an extrusive rock, but the rock has definitely suffered dynamic metamorphism, if not low grade regional, and the texture may therefore be a result of recrystallization under metamorphism. He compares the Moonta porphyry with the Gawler Ranges porphyry. The chemical compositions of the two are very similar and therefore they may have originated at the same time. However, this evidence is not sufficient to make this necessary for the two are 100 miles apart. The Gawler Ranges porphyry is an oligoclase porphyry, but the texture of the groundmass in the one specimen I could obtain was vastly different. It is bright red in hand specimen and in the slide the feldspar of the groundmass is extensively altered to a brownish product. The alteration made determination of the feldspar impossible. The grain-size, averaging 1 mm., is coarser than that of the groundmass of the Moonta porphyry. Most of the feldspar is in subhedral grains but some shows micrographic intergrowth with quartz.

A more instructive comparison is with a porphyry at Port Victoria, about 20 miles away. This porphyry is slightly lighter in colour than the Moonta porphyry. The porphyritic feldspar is oligoclase.

The groundmass consists of quartz and feldspar. The grain-size is the same as the Moonta porphyry. The texture is the same, a very fine-grained allotriomorphic granular texture, resembling a granoblastic texture. Most of the groundmass feldspar is microcline.

The ferromagnesian mineral is biotite pleochroic in X = yellow $< Y = Z$ = greenish brown. The biotite shows extensive alteration to chlorite. A little green hornblende is also present. This shows extensive alteration to chlorite and calcite. The amount of biotite present varies considerably and in the biotite-rich rocks this biotite shows parallel orientation of the flakes.

Accessory minerals are Fe-ores, sphene, calcite and apatite, which here is only in small individuals comparable in size with the rest of the groundmass.

The rock resembles very much the Moonta porphyry both macroscopically and microscopically.

This porphyry seems to have intrusive relations with the surrounding rocks. The surrounding rocks are metamorphosed sediments and basic lavas. The sediments are now mica schists and the lavas are amphibolites containing amygdules of quartz. The feldspar porphyry seems to form a series of dykes, almost parallel to the coast. These dykes vary in width from a few feet up to 30 yards or 40 yards.

---

10. R. Lockhart Jack: op. cit. pp. 24-27.
7. Dr. F.L. Stillwell op. cit. p.26.

This similarity between the textures of the Moonta and Pt. Victoria porphyries is evidence in favour of an intrusive origin for the Moonta porphyry, but since both the textures may be partly due to metamorphism the evidence is by no means conclusive.

Granitic Rocks of the Area.

Point Riley - Tickera Granite.

Along the coast north of Wallaroo granite has been exposed. It forms a wave cut platform and sea-cliffs (photograph), but inland it is covered by Miocene limestone and Recent sands. The outcrops begin about 2 miles N. of Wallaroo (section 928 Hundred of Wallaroo) and extend to Tickera, about 17½ miles along the coast. In places the Miocene limestone, which often forms the cliff tops extends down below sea-level and obscures the granite. Often what is now the top of the granite was exposed in pre-Miocene time, and in no place was the granite now outcropping probably more than 30 feet below the surface. Thus the extremely weathered nature of most of the rock is not surprising.

At Point Riley, about 4½ miles along the coast N. of Wallaroo the granite is quite gneissic and the feldspar is mainly oligoclase. It is all very weathered and therefore it was hard to get satisfactory specimens. However, No.14 is a typical specimen. The gneissic structure shows up much better in the field than in hand specimen. The direction of the gneissic banding is S.80°W. and is almost vertical.

The rock consists of quartz and pink feldspar with some biotite which has been bleached by weathering to a brassy colour. The texture is markedly allotriomorphic, resembling xenoblastic. The boundaries of individual grains are exceedingly irregular and there are numerous smaller grains interstitial between the larger ones.

The quartz shows a shadow extinction.

The feldspar has suffered much alteration. It is almost all plagioclase, an oligoclase $Ab_{85}An_{15}$. Albite twinning is usually not shown; but the composition was determined by extinction angles perpendicular to X or Z. It has a R.I. $>$ the balsam, thus distinguishing it from microcline which is present in small amounts. The plagioclase is zoned and sometimes shows antiperthitic inclusions of microcline. The rest of the microcline present is confined to the finer-grained portions.

A little muscovite is present but the slide does not show any of the biotite.

Numerous veins of red aplite and pegmatite are present, generally being more or less parallel to the schistosity. Most of the veins are about 1' wide but some are as wide as 3'. No.11 is typical of the red aplites. In the hand specimen the rock shows quartz with red and white feldspar in about equal amounts. A very little muscovite and biotite are present. It is medium- to fine-grained with average grain-size 1.5 mm.

In thin section the rock shows an allotriomorphic texture, the outlines of the grains being again exceedingly irregular.

The quartz shows very marked wavey extinction and is biaxial, probably due to strain.

The red feldspar is microcline which is quite fresh and the white feldspar is plagioclase. This latter is very extensively altered to a brownish product, preventing accurate determination but it appears to be oligoclase with 25 - 30% An.

Some of the pegmatites are just coarser phases of the red aplite e.g. No.10 whereas others show graphic intergrowth between quartz and microcline e.g. No.11. They show large red microcline crystals up to 6" across intergrown graphically with quartz. A little white feldspar, extensively altered, is also present. This rock forms small veins about 1' wide and 6 - 8' long.

About 600 yards north of Pt. Riley itself some white aplite occurs (photograph). The mode of occurrence of this white aplite is different from that of the red aplite. It forms a zone about 70 yards wide and more or less parallel to the gneissic structure. The boundary of the zone is quite sharp but irregular, following the gneissic banding for a short distance and then cutting across it. It is intruded by the red pegmatite. A few hundred yards further north another narrower zone occurs but no more of this white aplite was found.

No.12 is a typical example of this rock. It consists of feldspar and quartz with a little zircon, a brown mineral, a little biotite and muscovite.

The feldspar is mainly plagioclase which constitutes about 65% of the rock. It occurs as large individuals about 2.5 mm. across, sometimes enclosing microcline antipathitically, with finer-grained allotriomorphic microcline and plagioclase interstitially. A few individuals show albite twinning but most are untwinned. It has R.I. balsam but it usually shows cleavage which differentiates it from orthoclase. It is an oligoclase 25% An. Alteration is much less advanced than in the plagioclase of the other rocks. The microcline shows cross-hatching and shows no alteration.

The quartz shows dusty inclusions arranged in approximately parallel lines and also marked shadow extinction.

There appears to have been some ilmentite in the rock but it is now completely altered to a brownish opaque material, possibly limonite and a brown transparent mineral with high relief, high double refraction and positive optical sign, possibly sphene.

A little muscovite and a little biotite are present and also a number of small zircon grains scattered through the rock.

A feature of the feldspar of these rocks is that the microcline is red and usually unaltered whereas the plagioclase is white or pinkaand usually very much altered. Another feature is the absence of albite twinning in the plagioclase. According to Alling[14] plagioclase without twinning is not uncommon but strain -- even that of slide making, is likely to produce the twinning. Thus it is strange that these rocks which have definitely undergone strain should contain untwinned plagioclase unless the stress had fallen off before the temperature had fallen off sufficiently that strain necessarily produced twinning in the plagioclase.

In the direction of ~~Going towards~~ Wallaroo, i.e. S. from Point Riley one approaches the edge of the batholith. The rock remains slightly gneissic and both inclusions and pegmatite veins become more and more frequent. The first inclusions found are dense biotite amphibolites, probably representing igneous rocks in the sediments intruded bu the granites. Being denser they have probably resisted feldspathization better than the sediments and thus have been preserved as inclusions. Nos. 8E and 8H and 9 are examples of these inclusions.

---

14. R.A. Alling: Quarterly Journal of the Geological Society Vols. 29, 31 & 34.

No.9 is a plagioclase amphibolite showing a slight foliation in hand specimen. The rock is fine-grained, average grain-size .5 mm, but the grain-size is variable. It consists of hornblende and plagioclase with magnetite, some quartz and a little apatite.

The plagioclase is mostly untwinned, distinguishable by its .R.I. balsam, but some shows twinning giving composition oligoclase $Ab_{72}An_{28}$. It shows alteration to sericitic material and in some spots it is inclined to be glomeroporphyritic.

The hornblende is pleochroic in X = yellow < Y = green < Z = dark bluish green and $Z \wedge c = 15^{o}$. It tends to develop porphyroblastic individuals enclosing quartz poeciloblastically.

The quartz occurs as inclusions in the hornblende and in the rock itself.

Black opaque Fe-ore, magnetite or ilmenite is quite common.

The rock appears to be a metamorphosed Micro-diorite.

8E and 8H are biotite plagioclase amphibolites.

About ¾ mile S. of Pt. Riley sedimentary inclusions become common and the gneiss becomes richer in microcline. No.8F is typical of this microcline-rich gneiss. It does not show quite such a marked gneissic structure.

These sedimentary inclusions are now represented by biotite sericite schists. They are red, grey and white in colour. They consist of quartz biotite muscovite (sericite) microcline and a little tourmaline. Probably much of the microcline has been introduced from the magma. The inclusions are crossed by numerous quartz feldspar veins about 1" wide both parallel to and across the schistosity.

The inclusions become more and more numerous passing gradually from inclusions in gneiss to granitized country rock. Here there are bands of schist, which appear to have suffered metasomatic introduction of feldspar components, about 100 yards wide separated by bands of gneiss, where there appears to have been almost bodily injection of magna into the country rock. The feldspar in all of these rocks is microcline, and the whole is crossed by pegmatite veins 1" - 3' wide parallel to the schistosity.

Nos. 8A & 8B are specimens of the schist. These are quartz biotite sericite schists containing much microcline and a little tourmaline.

8D is a specimen of the gneiss.

8C probably represents a feldspathized quartzite, part of the feldspathized country rock. In the field it occurs between 8B & 8D and has suffered more feldspathization than 8B.

Between 1½ and 2 miles south of Pt. Riley these rocks are covered by the sandhills of the low-lying country just north of Wallaroo.

Going north of Pt. Riley, beyond the white aplite zone, a seemingly uniform red gneissic granite outcrops for 3 miles, except for one part where the Tertiary limestone comes down to sea-level and obscures the granite for ½ mile and another dyke (?) of white aplite a few yards wide at 2.4 miles. The red gneiss appears uniform in hand specimen. It varies somewhat in the extent of development of the gneissic structure and examination of crushed fragments indicates that the relative amounts of the two feldspars present varies.

In specimen 14A representing gneiss 1 mile N. of Pt. Riley the feldspar is mainly microcline and in 14C ~~there~~ (2.8 miles N. of Pt. Riley) there is more microcline than plagioclase present. The plagioclase is much more altered than the microcline. The quartz shows marked shadow extinction and is markedly xenomorphic. It seems to occur somewhat interstitially between the feldspar and it seems partially crushed.

Over this length no signs of inclusions could be found but there were numerous pegmatite dykes.

Three miles N. of Pt. Riley more signs of inclusions are found. Here there is an inclusion of fine-grained amphibole schist (No.14E). It consists mainly of hornblende with plagioclase and epidote and some blastoporphyritic (?) biotite flakes altered to chlorite. This appears to be the remnant of a much larger inclusion for the rock seems to pass gradually into a biotite plagioclase schist containing less and less biotite and then it merges into the red gneiss.

15 and 15A show this hybrid biotite schist.

The plagioclase which is a light pink colour is the main mineral of the rock and with this are biotite flakes with a more or less parallel orientation. In thin section the plagioclase is in subhedral individuals with little or no albite twinning. It is an oligoclase with 27% An.

The biotite is pleochroic in X = light brownish yellow < Y = Z = greenish brown.

The quartz shows shadow extinction and with a little microcline occurs interstitially between plagioclase individuals.

A little apatite and black opaque Fe-ore are present.

The formation of biotite from hornblende in a xenolith included in granitic magma is the normal thing. Also introduction of feldspar metasomatically would be expected.

3.4 miles N. of Pt. Riley there is a zone of feldspathized quartzite in the gneissic granite. The transition between the quartzite and the gneissic granite was quite gradual, the quartzite becoming more and more feldspathized.

From here on to Tickera the Miocene limestone formed the cliffs, the granite forming only a platform at sea-level. What is now exposed was exposed in Pre-Miocene time and as a result the granite is very much weathered. The rock appears to remain uniform and dark red all the way. It is cut by a few pegmatite dykes.

Some rock also outcrops in a water-course in Tickera township. This is much less weathered than the rocks on the coast.

No.18 is typical of the rock here.

This rock consists of large light pink feldspar phenocrysts up to 1 cm. across in a dark reddish brown groundmass of quartz and biotite. It appears to be a porphyritic granodiorite.

Most of the phenocrysts of feldspar are plagioclase $Ab_{70}An_{30}$ i.e. an oligoclase-andesine. These phenocrysts show some alteration to sericitic material. They usually do not show albite twinning but they have R.I. balsam. A few phenocrysts are microcline.

The interstitial matter is quartz, plagioclase and biotite with a little microcline and apatite. These constituents are all markedly anhedral and some seem to be due to breaking up of the phenocrysts around their edges. Some of the plagioclase in the groundmass is considerably more altered than that in the phenocrysts. The biotite is also considerably altered to chlorite. The darker colour of the groundmass, which gives the rock a hybrid look, seems to be due only to more complete alteration.

The rocks thus represent an adamellite or granodiorite magma which crystallized under stress. Oligoclase had crystallized and then the magma chamber was stressed resulting in squeezing out of most of the quartz and potash feldspar in the liquid. This squeezed out liquid has formed pegmatites in the outer parts of the batholith and has intimately invaded the country rock as is shown in the area between Pt.

Riley and Wallaroo. The respective amounts of the two feldspars present are very variable;in some parts the feldspar is almost entirely oligoclase and in others almost entirely microcline. This variation may be due to original variations in composition of the magma so that the feldspar crystallized before plagioclase feldspar and also some portions, especially around the outside, may have crystallized further before the stress became strong enough to force out the residual liquids.

Arthurton Granite.

Jack records the following:-

"The main massif of granite in the region, and that which is believed to have been responsible for the mineralization of the region is exposed to the south-eastward of Arthurton, in the Hundred of Tiparra. Here an area of seven and a quarter square miles is occupied by the granite, and the presence of an extensive metamorphosed aureole, penetrated by numerous granite, pegmatite and aplite dykes, indicates a considerably larger subterranean occurrence of granite.

"Exposures of the rocks constituting the metamorphic aureole are practically non-existent, their presence being indicated by abundant feldspar in the soil and by scattered field stones. These and occasional shallow pits afford a clue to the general character, though not to the structure of the underlying rocks. Granitic and pegmatitic stones are abundant throughout the area of the metamorphic aureole and are derived from apophyses from the deep-seated granitic magma.

"The Arthurton granite varies in habit from coarsely crystalline to fine-grained and is essentially a microcline granite. Muscovite is the predominant mica and schorl is present in amounts recognizable in hand specimens".

The only specimens obtainable were stones in the fields. None of these appeared to be normal granite. Rocks Nos. 2 - 6 are typical specimens.

Rocks Nos. 2 and 3 are coarse-grained consisting of quartz and feldspar. The feldspar crystals are up to 2 mm. across. Rock No.2 consists of pink feldspar and quartz. The feldspar is microcline and is quite fresh.

Rock No.3 consists of white feldspar and quartz. The feldspar is plagioclase but is too weathered to determine. It is probably an oligoclase.

Rocks 4, 5 and 6 are representatives of the fine-grained aplitic type. The average grain-size of the quartz is twice that of the feldspar, 2 and 1 mm. respectively. No.4 will be described in detail.

The rock shows an allotriomorphic texture. The quartz contains numerous dusty inclusions and shows a wavey extinction. The feldspar is microcline and plagioclase in about equal amounts. The microcline forms smaller individuals showing typical cross-hatching and is quite fresh. The plagioclase is extensively altered to a micaceous product. It has a composition of approximately $Ab_{70}An_{30}$ i.e. an oligoclase or an andesine.

Some primary muscovite is present and some biotite was present but is now altered to chlorite.

Some black opaque Fe-ore is present. Some seems primary and other fine-grained Fe-ore seems secondary.

Going E.from Arthurton first, in section 351, the coarse pegmatites were found. Rock No.1 was also found here. This is a foliated scapolite microcline hornblende diopside rock. It appears to represent a metamorphosed sediment.

Then in sections 352, 353 and 358 granitic rocks 4, 5 and 6 were found. The outcrop of these rocks was not a typical granite outcrop. There were only numerous pebbles in the fields, most of which had been collected into heaps.

It appears that here erosion has uncovered the outer portion of a batholith of stressed granite similar to that shown along the coast from Pt. Riley to Tickera. Only the very outermost part where there has been intesne invasion of the country rock by aplitic veins has been exposed. Such aplite veins in a matrix of feldspathized rock would be expected to weather into a soil containing pebbles of the aplite. A notable feature on the sea-coast just south of Pt. Riley is the relative rapidity with which the feldspathized sediment has weathered, leaving the harder aplite veins standing up.

Going further east into the Hundred of Clinton the granitic rocks vanish beneath the Cambrian basal conglomerate.

More granite outcrops south of Ardrossan in the Hundred of Muloowurtie. Here similar red aplitic granite outcrops in sections 49, 1 & 2 along the sea coast. Pegmatitic dykes are very common further inland. Also there are some small copper mines e.g. the Hillside Mine and Hart's Mine around the periphery of this granite outcrop.

Possible relations between the two granites and the ores.

Jack considers that the Arthurton granite is younger than the Pt. Riley - Tickera granite because it does not show the effects of stress that the latter does. This may be so, but it seems to me more likely that the two granitic intrusions were contemporaneous or part of the same large batholith, but in the former case erosion has not yet exposed the stressed granite.

It seems, therefore, that the granite responsible for, or accompanying, the metamorphism of the area was also responsible for the introduction of the ore materials. The ores were probably introduced a little time after the culmination of the metamorphism.

The nature of the Pt. Riley - Tickera granite, especially its stressed features suggest a correlation with the granite-gneisses of the Flinders series.[15] This would mean that the metamorphosed sediments were probably the equivalent of the Hutchison series.

About the age of the porphyry intrusion of Moonta, little can be said. Since it has suffered some dynamic metamorphism at least it was definitely intruded before the time of metamorphism i.e. before the time of the granite intrusions.

---

15. C.E. Tilley: Quarterly Journal of the Geological Society Vol. 77 p.75.

The Wave-cut Platform of Gneissic-granite at Pt. Riley.

The Zone of White Aplite 600 yards N. of Pt. Riley.