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ACCESSORY MINERALS OF SOUTH AUSTRALIAN GRANITES

by

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The data in this report were contained in a thesis for the degree of Master of Science submitted to the University of Adelaide by Mr. Fander in December, 1960.
Apart from some re-arrangement the thesis is presented in its original form.

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FOREWORD

Because of its possible value to our sponsors in the mineral Industries and because much of the work was done in these Laboratories, Mr. Fander's thesis is being reproduced and distributed as an AMDL report.

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SUMMARY

The purpose of the work was to compare and contrast the petrography, accessory minerals, and absolute ages of twenty-five granitic and allied rock samples collected from widely scattered localities in South Australia. The principal areas from which samples were collected are: Encounter Bay, Murray Bridge, Coonalpyn, Flinders Ranges, and Eyre Peninsula, with other samples from Yorke Peninsula, Musgrave Ranges, and the Peake Denison Ranges. The processes necessary to produce pure zircon for age-determinations by the Larsen method also yielded concentrations of accessory minerals not normally seen in thin-section. These mineral concentrations were subjected to detailed study and comparison as a basis for discussions and conclusions.

The thesis is divided into four main sections as follows:-

Section 1.	Comparison of the rock samples on the basis of petrography and accessory minerals.
Section 2.	Age determinations. Method, results, discussinn.
Section 3.	Unusual mineral features.
Section 4.	Conclusions.
Appendix A	Petrography, accessory minerals and other features of each individual rock.

The feasibility of correlating granitic rocks by means of their accessory minerals has been shown to be limited to rocks which are in close proximity to one another. Rocks of the same or similar age but widely separated geographically usually show very little resemblance in petrography and accessory minerals. Accessory minerals can most usefully be compared when two adjacent granitic rocks of similar aspect are suspected to belong to different suites and to be magmatically unrelated. The comparisons will usually show whether the adjacent rocks are in fact co-magmatic or not.

INTRODUCTION

Much of the work described in this thesis was carried out in connection with the determination of the absolute age of granitic rocks in South Australia. The age determination project is currently being carried out at the Australian Mineral Development Laboratories on behalf of the South Australian Government Department of Mines. Of the many samples of granite and allied rocks collected for the project, twenty-five were selected for closer study. The main purpose of this study was to compare and contrast the heavy accessory minerals of the rocks, particularly in relation to the absolute ages of the rocks being considered. As the study proceeded, many other informative and significant facts came to light, and it was decided to incorporate as many of these as possible, since they are of practical and economic value.

GENERAL CONSIDERATIONS

Absolute-age determinations are made at A.M.D.L. according to the method of E.S. Larsen[1]. This method involves the isolation of pure zircon from a granitic or allied rock, and its analysis for uranium and radiogenic lead. In the course of the extraction of the zircon, the other heavy minerals are isolated and concentrated in various fractions. These fractions were studied and the minerals occurring in them were recorded semi-quantitatively. For reasons which will be apparent later, it was not possible to make the study a fully quantitative one.

Previous investigations, notably by A.W. Groves[2], have shown that only a limited number of heavy accessory minerals are suitable for comparison purposes. The main objects of comparing heavy-mineral suites are as follows:

1. To attempt to prove or disprove a genetic relationship between two or more igneous bodies which appear related in some way, e.g. in composition, in space or in time.

2. To attempt to date an igneous body of unknown age by comparing it with one of known age (i.e. age deduced from stratigraphic studies).

3. To determine the degree of contamination of an igneous rock by assimilated material.

4. To determine whether the rock under consideration is of orthodox igneous origin or not.

5. To evaluate the possibility of the occurrence of economically valuable minerals.

An endeavour has been made to study the heavy accessory minerals with these aims in view, and to correlate the facts with other information obtained from petrographic studies and age-determinations.

One of the most important aims in this study is to isolate, purify and examine the zircon contained in the rock sample. Quite apart from its importance as the most suitable mineral for age-determinations, zircon appears to be a fairly reliable indicator of the circumstances of formation of the rock. One of the most detailed studies of zircons in sedimentary and igneous rocks was made by Poldervaart[3], who drew attention to a number of important features of zircons. It is perhaps appropriate at this juncture to present a resume of these features, since they have considerable bearing on the investigations described here.

In regard to sedimentary rocks and the zircons contained in them, Poldervaart makes the following remarks:

1. Finer-grained sediments have more angular zircons than coarser-grained ones. The reason is that fine-grained particles are not abraded in transport to the same extent as medium or coarse-grained particles.
   This statement holds where zircons are of comparable size to the other mineral grains in the sediment.

2. Larger zircons survive longer than smaller ones, and consequently become more rounded.

3. In sedimentary rocks, larger zircons tend to be rounded, small ones are angular. In igneous rocks the reverse is true.

4. Due to the overall stability of zircon, a sediment shows a progressive relative increase in zircon content after each re-working, due to the destruction and removal of the other heavy minerals.

5. The stability of zircon is due to a number of factors, such as the small initial size of the crystals, lack of cleavage, resistance to chemical attack. The more rounded the crystals become, the more inert they are. The abrasive resistance (resistance to abrasion) of zircon however, is fairly low comparable with quartz and apatite. Alkaline solutions appear to attack zircon.

6. Malacons (i. e. metamict zircons) appear to be less stable than zircons.

In regard to igneous rocks, Poldervaart makes the following observations: -

1. Zircons which appear rounded in a thin section of a rock, may actually be completely euhedral. Heavy-mineral concentrations alone reveal with certainty whether the zircons are, in fact, rounded or euhedral. Since a certain amount of contamination and assimilation has occurred in many igneous rocks, rounded zircons may be found, but they generally amount to under 10 per cent. of the total zircon.

2. The majority of medium and large zircons (whose length exceeds 0.05 mm) are euhedral in true intrusive granites. Smaller zircons may have rounded terminations.

3. Zircons are of early crystallization in the sequence of solidification of a magma. They may have acted as nuclei for minerals of later crystallization. They are usually associated with mafic minerals such as biotite, hornblende, opaque minerals.

4. The uniformity of zircons in a rock demonstrates the uniformity of conditions of crystallization.

5. Small zircons are often rounded and corroded, though more often in effusive than intrusive rocks.

6. Granites showing evidence of strong hydrothermal activity (e.g. red or orange potassic granites with abundant fluorite, etc.), may contain dark brown or opaque, closely zoned, altered zircons which may have rounded outlines, often ragged and with small irregularities. Such crystals often have a narrow, colourless outer shell of low-birefringent material.

Poldervaart proposed the following features to aid in the classification of zircons.

1.) Simplicity, complexity, or absence of terminal faces.

2.) Elongation (ratio of length to breadth of crystals).

3.) Colour and inclusions.

He quotes Morgan and Auer (1941) (3a), who have classified zircons on their physical properties :-

Colour	NO	NE	NE-NO	Radioactivity
Normal	1.924 - 1.934	1.970 - 1.977	0.036 - 0.053	low
Hyacinth	1.903 - 1.927	1.921 - 1.970	0.017 - 0.043	medium
Malacon	1.782 - 1.864	1.827 - 1.872	nil - 0.008	high

Malacon is further subdivided into two types by Claus (1936) into-

1) altered, with dull lustre and often with rounded outlines, and
2) metamict, with bright lustre and euhedral outlines.

Both types are brown and opaque. Type 1) is found preferentially in red granite phases (i.e. hydrothermal activity).

All these types and sub-types were found in the present investigation and will be described later, in the descriptive section ("A").

Of further relevance to this thesis, in regard to zircons, is the report by Frondel and Collette[4], describing the synthesis of zircon. These authors describe experiments carried out in "hydrothermal bomb runs", involving varying temperature, pressure, and water vapour conditions. They were able to synthesize crystallized zircon at temperatures as low as 350°C. at about 1000 atm. pressure. However, they did not attempt to actually re-crystallize zircon, and from petrographic evidence one can say that this process would take place at appreciably higher temperature-pressure conditions. Volatiles, or "fluxes", would probably play an important part. After all, many metasediments of the highest metamorphic facies contain well-rounded zircons. Frondel and Collette used ZrO_2 gel, SiO_2 sand, H_2O, and $ZrOF_2.2H_2O$ as starting materials for their experiments.

To refer back to investigations made by A. W. Groves[2] on accessory minerals of the granitic rocks of the Channel Islands, much of this work was severely criticized by A. K. Wells[5], who set up a classification of these minerals, as follows -

a) Normal Accessories: Minerals largely independent of high flux content of a magma. Including minerals such as zircon; magnetite; ilmenite; some of the sphene; xenotime; monazite; perhaps orthite.

b) Pneumatolytic Accessories: Including tourmaline; fluorite; topaz; cassiterite; some of the rutile, anatase and brookite. Generally late-stage minerals, occurring in higher parts of intrusions (i.e. early removal by denudation).

c) Contamination Accessories: Derived from country rock. Including minerals such as cordierite, andalusite, spinel, garnet, sillimanite.

d) Secondary Accessories: Products of late-stage alteration, such as chlorite, zoisite-epidote, etc.
A.K. Wells states that only minerals of class a) may be used for correlation, and points out that even in this class the minerals show insufficient individual characteristics, with the possible exception of zircon.

Whilst the present writer agrees that classes c.) and d.) cannot have any value for comparison purposes (e.g. between two granite masses separated by either time or place), class b.) can have restricted application. Groves, in his reply to Wells's criticisms, points out the lack of beryllium minerals in the Armorican granites, and the presence of these minerals in the Tertiary granites of the Mourne Mountains. Some of the opaque minerals, such as molybdenite, pyrite, pyrrhotite and chalcopyrite, may be of early crystallization and thus be useful for purposes of correlation.

The whole question of definition of the term "accessory mineral" is a debatable one and has been summarized by J.C. Reed[6]. In that paper Reed favours the definition formulated by Holmes[7], namely - "A term applied to minerals occurring in small quantities in a rock, whose presence or absence does not affect its diagnosis". Further subdivision of these minerals on a genetic basis (e.g. that of Wells, see above), or on the basis of physical properties (e.g. heavier than 2.86) or chemical similarities (e.g. sulphides) is possible. In this thesis, Holmes' definition will be used, with the additional qualification that only accessory minerals with specific gravity greater than 2.86 (i.e. that of bromoform) will be considered. As far as comparisons and correlations are concerned, only those minerals will be considered, which in the light of conclusions reached by previous investigations are suitable. However, all minerals of interest will be included in the descriptions; some of them, whilst of little use for correlation, may have economic significance or be of interest for considerations of provenance of heavy minerals in sediments.

SECTION 1.

PETROGRAPHY AND HEAVY ACCESSORIES

COMPARISONS BETWEEN ROCKS

1. Encounter Bay

First and foremost among the suites of co-magmatic rocks are the Encounter Bay intrusives, of which three samples have been studied. This suite was chosen because the results would show whether a.) different samples of one rock-type (collected at different localities) such as V.3 II and V.4, would contain heavy accessories showing a high degree of correspondence, and b.) whether co-magmatic rocks such as V.3 II, V.4, and V.5, representing different phases of the same intrusive complex, also show a high degree of correspondence in their heavy accessories. If both these conditions are fulfilled, then a fairly strong case is established for comparing this suite with other, similar rocks in South Australia which are suspected to be of a similar age. The results, taken in conjunction with the absolute age of the rocks, will indicate whether a comparison of heavy accessories can lead to valid conclusions concerning the relationship between two or more rocks in question.

Comparison of V. 3 II with V. 4 -

Petrography: Both are strongly porphyritic adamellites, with good agreement between petrographic and mineralogical features. The two rocks are both representatives of the same phase of the igneous complex.

Heavy Accessories: Zircons of the same three types occur in both rocks. Sphene is leucoxenic and altered in both rocks. Other minerals occurring in both rocks are as follows: pyrite, molybdenite, tourmaline, apatite and monazite. Staurolite and garnet occur in V. 4, indicating assimilation of metasedimentary material. Only two minerals occur in V. 3 II which are not found in V. 4, namely gold and rutile; both of these may be of late-stage origin. Thus it may be seen that the two suites of accessories are practically indistinguishable. It may be noted here that fluorite does not occur in these rocks.

Comparison of V. 5 with V. 3 II - V. 4

Petrography: V. 5 is more alkalic than V. 3 II and V. 4. It is even-grained, not porphyritic, and contains more biotite than the other two rocks. From field evidence there is no doubt that V. 5 belongs to the same igneous complex as V. 3 II and V. 4.

Heavy Accessories: The following minerals occur in V. 5 which also occur in the other two rocks: - monazite, zircon (three types), tourmaline, apatite, pyrite, molybdenite. Garnet also occurs, as in V. 4; sphene, however, is absent. This may be due to the more alkalic nature of V. 5. The dominant zircon type is very similar to the dominant type in V. 3 II and V. 4, though there are minor differences (L : B up to 5:1, crystals less altered, overgrowths occur). The other two zircon types are identical to those of V. 3 II and V. 4, in character and amount. The monazite in V. 5 appears slightly more altered than in V. 3 II and V. 4. These minor differences however, do not detract from the high degree of correspondence between the heavy accessories of all three rocks.

Comparison of Encounter Bay Rocks with Others

From a consideration of petrography and heavy accessories, of the Encounter Bay suite and the Murray Bridge-Coonalpyn suite, (represented by C. W. 2 and T. B. 9), these two differ substantially from one another. Age-determinations confirm this, revealing a difference of over 20 MY between the two suites. The Murray Bridge-Coonalpyn suite shows fairly wide variation, particularly in texture, but is nevertheless closely linked. For instance, the "cognate xenoliths" of porphyritic microgranite at Murray Bridge are remarkably similar to the porphyritic microgranite at Cold and Wet. The coarse-grained granite of Murray Bridge (T. B. 9) is seen also in the Kangaroo Flat area east of Meningie. A few "outliers" of Encounter Bay (Granite Island type) granites occur just north of Meningie, but it is thought that they represent the northern limit of this suite.

The heavy accessories of the two suites are quite different. However, the close correspondence found in the accessories of the Encounter Bay suite is not nearly as marked in the Murray Bridge-Coonalpyn suite; notably the types of zircon in C. W. 2 and T. B. 9 show only slight similarity, though the other accessories "match" very well.

The magmatic reddening of C. W. 2 indicates hydrothermal activity. This is confirmed by the zircons in C. W. 2, which are brown, altered malacons. C. W. 2 and T. B. 9 are representative of a wider variation than the Encounter Bay rocks, so that one would not expect to find such a good degree of correspondence in the heavy accessories.

No other rocks, of those here considered, are related in space or time to the Encounter Bay suite, and the present study has revealed no such rocks.

2. Northern Flinders Ranges

It is generally accepted that there are two distinct sets of granitic and allied rocks occurring in the Flinders Ranges. They are usually distinguishable in the field, and are divided into an "older" series (pre-Adelaide System) and a "younger" series (post-Adelaide System). Of the samples described in this thesis, K. 8, K. 10, K. 13, and K. 15 belong to the older series, and K. 12 to the younger series. Age determinations on the rocks have fully confirmed this, the older series being dated from 1645 MY to 1400 MY, and the younger series at 920 MY. If these determinations are substantially correct, then the "older" granites were emplaced over a period of some 245 MY, and the question arises as to what relationship they bear to one another and to the "younger" granites.

Petrographically, the older granites are very similar in their constituents and are biotite granites or adamellites, depending on the ratio of oligoclase to microcline. All are stressed and shattered, with evidence of partial re-crystallization or even conversion to orthogneiss (K. 15).

The only representative of the younger series, K. 12, is classed as a biotite granodiorite, on the grounds that the dominant feldspar is oligoclase. It is however, very sodic, and borders on albite, so that the rock may actually in parts be a strongly sodic biotite granite. The plagioclase is somewhat out of the ordinary in being antiperthitic. The potassic feldspar is orthoclase, not microcline as is the case with the older series.

Comparison of the accessories shows a general agreement between rocks of the older series, though not nearly as convincing as the Encounter Bay suite. The types of zircons show reasonable agreement also, whereas the zircons of K. 12 are different. Apatite is present in K. 12 in traces only, being much more conspicuous in the other rocks. Thus with these rocks, whilst no more than a general agreement can be found between samples K. 8, K. 10, K. 13 and K. 15, it can be said that differences in petrography and accessories between these and K. 12 are quite marked.

3. Eyre Peninsula Rocks

There appear to be few, if any affinities between the various rocks studied from this area. The Moonabie Porphyry is unlike the Gawler Range Porphyry in petrography and heavy accessories. Two samples which are of very similar age are K. 21 and K. 24, but are dissimilar in petrography. This is not really surprising in view of the great distance (about 250 miles) separating them. Also, the difference in age between the two rocks, 20 MY (890 - 870 MY), is probably a real one though covered by the $\pm$ 10 per cent. error.

The most that can be said is that the two granites K. 21 and K. 24 belong to the same phase of igneous activity which was responsible for the emplacement of K. 26 and the "younger" granite series of the Flinders Ranges.

4. Other Rocks

The rocks from Neptune Island and Stenhouse Bay are rather similar Archaean metasediments, and are not true magmatic granites. The Neptune Island augen-gneiss is closely similar to augen-gneisses occurring South of Corny Point, at the foot of Yorke Peninsula As far as heavy minerals are concerned, no great similarity can be expected, unless one knows one is dealing with the same sedimentary horizon (now granitized) over a limited extent. An interesting feature of the Archaean metasediments of the Yorke Peninsula is the universal occurrence of one of the rarer amphiboles, ferrohastingsite. This mineral appears also in the Palmer sample (Mt. Lofty Ranges) and may be characteristic of Archaean rocks in these areas.

The Monarto rock is considered to be a granitized sediment, on petrographic evidence and from the examination of the heavy accessories. However, the presence of fresh, euhedral monazite is a problem; the inference is that this mineral crystallized (or re-crystallized) during granitization and that monazite is not nearly as refractory as zircon. It would be of great interest to determine the age of the monazite, because this should be the age of the granitization.

The Moonta Porphyry appears to be heavily contaminated by sedimentary material, as demonstrated in the study of the heavy accessories, several of which are conspicuously rounded. The main difficulty is the lack of fresh rock material, from which good samples could be obtained. If the intrusion is of a laccolithic nature, as some geologists believe, then contamination would be expected to be fairly severe.

With regard to zircons, a general observation is that the vast majority of the magmatic rocks contain at least three different types of zircon, whereas the granitized rocks usually contain only one type of zircon. This observation is in keeping with observations made by Poldervaart, as already recorded.

SECTION 2.

AGE DETERMINATIONS

Introduction -

This section describes in detail the methods used to prepare samples of zircon and to determine their absolute age. The method was first developed by Larsen, Keevil and Harrison[1], and modified at A. M. D. L. after much experimentation, to suit local working conditions and equipment. A later paper, by Gottfried, Jaffe and Senftle[8], describes the most up-to-date procedures adopted by the U. S. Geological Survey. This paper was first seen at A. M. D. L. in the middle of 1960, and it was interesting to note that practically identical techniques had been evolved at each Laboratory quite independently.

Principles Involved -

The principles involved in using certain accessory minerals for the determination of absolute age are based on three pre-requisites and on geochemical data, as follows, -

1. The accessory minerals must be contemporaneous with the rock under consideration.

2. All the lead (Pb) in the accessory minerals must be radiogenic, resulting from the decay of radioactive elements.

3. No products of radioactive decay must have been lost (or gained) since the commencement of decay at the time of crystallization of the minerals.

The choice of suitable minerals is related to point 2. above, from geochemical considerations. Uranium and thorium can go into ionic substitution for zirconium on a limited scale owing to the similarity in dimensions of ionic radii (Zr - 0.87A, U - 1.05A, Th - 1.10A), whereas lead does not substitute owing to its fairly large radius (Pb - 1.32A). In zircon, therefore, any lead present can be assumed to be radiogenic. Similar considerations apply to xenotime and monazite. Apatite and sphene give erratic results, according to Gottfried et al.[8] At this laboratory (A.M.D.L.), the writer has so far used zircon only, since it is far more widespread in its occurrence than the other two minerals.

The age of the mineral is determined by measuring its alpha-activity (which is a direct measure of its U + Th content) and analysing for lead. The formulae derived by Keevil[9], are as follows: -

$$t = c \frac{Pb}{Alpha}$$ where t = age in millions of years,

c is a constant depending on the ratio of thorium to uranium in the mineral, alpha is the number of alpha-counts per milligramme of sample per hour, and Pb is expressed in parts per million. This formula is applicable to minerals from 0 - 200 million years (MY) old. For the range 200 - 1700 MY, Keevil[9] has modified the formula to correct for errors: -

$$t_o = t - \tfrac{1}{2} k t,$$ where t is the value obtained in the first formula, K is a constant determined by experiment. A further formula must be applied for minerals in the range 1700 - 4000 MY: -

$$T = t_o + 3.4 \times 10^{-9} t_o^3 \quad \text{or}$$

$$T = (t - \tfrac{1}{2} kt^2) + 3.4 \times 10^{-9} (t - \tfrac{1}{2} kt^2)^3$$

The paper by Gottfried et al.[8], goes into very great detail concerning all aspects of this method of age determinations known as the lead-alpha method, and the conclusion is reached that it is a useful, if not very accurate, quick and inexpensive method, and that it usually fulfils the function of resolving questions pertaining to age of intrusion and similar problems.

Preparation of Zircon Sample -

The method presently employed by the writer to prepare a sample of pure zircon (of at least 100 mgm) is as follows:

a) A 10 Kg. sample of fresh rock, as nearly as possible representative of the rock to be dated, is crushed to -40 mesh B.S.S. The zircons do not adhere to other minerals but usually "spring out" during crushing, and remain as whole crystals. Since this is a desirable factor from the point of view of later purification, very fine crushing is avoided as far as possible.

The crushed sample is then passed over a laboratory Wilfley table. This operation serves the twofold purpose of removing slimes and of producing a concentrate rich in heavy minerals. In practice, two concentrates are produced, the second (less rich) one being re-tabled to upgrade it. Great care is taken to avoid contamination by lead compounds (paint, bearing metal, etc.).

b) The two concentrates are separated in bromoform of S.G. 2.85 - 2.90 in a specially-designed separatory funnel. The funnel has a capacity of about 800 ml, is fitted with a wide-bore tap at the bottom to run off the heavy fraction, and is straight-sided with an open top for removal of the light fraction with a small ladle. The separation process is thus semi-continuous, and 1500 gm of concentrates (the two concentrates usually amount to about 15 per cent. of the original sample weight) can be separated in a few hours. about 200 gm of material is added to the funnel for each separation, stirred, allowed to separate, and stirred again. After settling, the heavy fraction is run into a filter funnel below. This operation has the effect of compacting the light-mineral layer, which can then be lifted out piecemeal with a ladle (a bent stainless steel teaspoon!) and placed into a beaker for subsequent recovery of bromoform.

c) The heavy fraction from the bromoform separation is washed with alcohol and dried. A powerful hand-magnet is then used to remove magnetite, stray iron (from the grinding equipment) and other ferromagnetic materials. This is the ferromagnetic fraction. The remainder of the heavy fraction is passed through the Frantz Isodynamic Separator, usually at a fixed slope and tilt, with successive increases in the field strength of the electromagnet by increasing the current passing through its coils. A slope of 20^0 and a tilt of 15^0 have been found satisfactory for almost all separations. (N.B. slope is the inclination of the long axis of the sample chute, tilt is the inclination of the transverse axis of the chute, both measured from the horizontal.) The final fraction which is non-magnetic at almost the maximum setting of the instrument, contains zircon and other non-magnetic minerals. These are usually fluorite, apatite, quartz, feldspar, anatase, some rutile and sphene, pyrite and molybdenite. Of these, anatase is a very rare constituent, and rutile and sphene are usually more magnetic.

On the rare occasions when they appear in this fraction due to an abnormally low iron-content, they can be removed by increasing the field-strength to the maximum rating and at the same time reducing the tilt of the chute to 10°. Fluorite, apatite, quartz and feldspar are removed by centrifuging the sample in very pure methylene iodide (S. G. 3. 3). The heavy fraction from this operation contains zircon, pyrite and sometimes molybdenite.

d) Purification of the "zircon fraction" involves the removal of pyrite and molybdenite. Particularly the latter mineral must be removed completely, since it is known to contain up to 1000 p. p. m. lead.

Pyrite may be very effectively removed by rendering it magnetic. This is achieved by roasting the sample in a furnace at 450°C. for about 10 minutes. The pyrite is superficially oxidized to magnetite and haematite and may be removed by passing the sample through the Frantz Separator at a fairly strong current-setting, say 0. 8 Amperes.

Molybdenite is more of a problem, and if too abundant to be hand-picked, must be leached.

Fairly comprehensive tests have been conducted at A. M. D. L. on the effects of leaching the zircon concentrate by boiling in aqua regia for 15 minutes. It was found that, provided the sample was not crushed beforehand (i. e. the crystals of zircon were left unbroken), no preferential leaching of uranium or lead occurred which could result in errors in age. The leaching with concentrated aqua regia has the further advantage of removing any other uranium - or lead-bearing contaminants and of dissolving any stray apatite and fluorite which may have been in the methylene iodide heavy fraction.

The leached and washed final zircon fraction is then examined under a binocular microscope and impurities are removed by hand-picking. The sample is then crushed to minus 200-mesh in a special porcelain mortar and submitted to the Analytical Section for alpha-counting and spectrographic lead analysis.

Analysis for Uranium and Lead -

The finely-crushed zircon is placed in a standard sample holder so as to give an infinitely thick source for counting. This is placed in an ionization-chamber filled with argon and counted for a fixed time.

The sample is then passed on for spectrographic analysis for lead, using known standards for comparison.

Early analyses were unsuccessful, due to insufficiently developed techniques. However, this position has gradually improved and it can be said that a ± 10 per cent. overall accuracy can be expected, taking into account all errors of sampling, purification and analysis.

Contamination, particularly by lead, is a constant hazard. Absolute purity of the zircon sample is very difficult to attain, since lead is ubiquitous in its occurrence. A number of results quoted in this thesis have undoubtedly suffered contamination, as the results clearly show. The source of contamination is difficult or impossible to trace. Molybdenite, which is hard to eliminate and is known to contain lead, is undoubtedly responsible in some cases (T.B.9, V.4), as shown by spectrographic results. Both these samples, which have a lead content quite inconsistent with the expected figure, contain abnormal amounts of molybdenum.

Results -

It was recognized by the initiators of this method (Larsen et al.[1]) that several samples of the same rock should be determined in order to obtain reliable results; a single determination on a single sample of a granitic rock might yield only approximate results. The present determinations at this laboratory were partly aimed at comparing co-magmatic or related rocks, so that in some cases duplicate samples have been determined. So far, an insufficient number of duplicate samples have been determined at A.M.D.L., the present scope of the work being more in the nature of a reconnaisance, to be followed up by more detailed studies as opportunity permits.

So far, fourteen age determinations have been made which can be regarded as reasonably reliable, except for contaminated samples. New determinations on old samples were unfortunately not possible, as earlier methods destroyed the samples.

A list of results to date follows:-

Sample No.	Locality	Absolute Age
V.3 II	Granite Island	415 ± 42 MY.
V.4	Pt. Elliot West	680 ± 68 MY.
T.B.9	Murray Bridge (South)	545 ± 55 MY.
C.W.2	16 miles E. of Meningie	440 ± 44 MY.
K. 8	N. Flinders Ra.	1575 ± 158 MY.
K.10	N. Flinders Ra.	1400 ± 140 MY.
K.12	N. Flinders Ra.	920 ± 92 MY.
K.13	N. Flinders Ra.	1520 ± 152 MY.
K.15	N. Flinders Ra.	1645 ± 165 MY.
K.21	N. Eyre Pen. - Pine Hill	890 ± 89 MY.
K.23	N. Eyre Pen. - Calca Bluff	1660 ± 166 MY.
K.24	N. Eyre Pen. - Tarcoola	870 ± 87 MY.
K.26	Moorilyanna Area	880 ± 88 MY.
K.27	Musgrave Ra.	1770 ± 177 MY.

Discussion of Results -

1. V.3 II. V.4 -

The age determined on V.3 II is regarded as the reliable one, since the V.4 zircon sample appears to have been contaminated, probably after the final purification stage (aqua regia treatment). The Encounter Bay rocks are therefore about 420 MY old.

2. T. B. 9, C. W. 2 -

Significant amounts of molybdenum were detected in the spectrum of the T. B. 9 zircon sample, and this result is therefore open to considerable doubt. C. W. 2, which from field-relationships, associated phases (very similar to T. B. 9), and heavy accessory studies, is regarded as co-magmatic with T. B. 9, is about 440 MY old. This age is probably substantially correct. This suite is then 20 MY older than the Encounter Bay suite.

3. K. 8, K. 10, K. 13, K. 15 -

The "older" series of Flinders granites. The spread of results may not be as drastic as appears at first (1400 - 1645 MY), since the K. 10 age may be incorrect. Mines Department geologists have informed the writer that the K. 10 sample occurred very near a contact with a granite belonging to the "younger" series. This indicates a strong possibility of contamination of the sample by younger material. The spread of results could therefore be lessened to 1520 - 1645 MY. It is interesting to note here that Prof. J. T. Wilson of Toronto has dated the Radium Hill davidite at 1510 $\pm$ 100 MY.

4. K. 12 -

The age for this sample, which belongs to the "younger" series, is thought to be substantially correct. It quite clearly demonstrates the very much later age of the "younger" series.

5. K. 21, K. 24, K. 26 -

These three rocks have very similar ages, which are also fairly close to that of K. 12. However, neither petrography nor heavy accessories show more than a vague general similarity. Apart from being spread over some 50 MY (870 - 920 MY) in time, the rocks K. 12, K. 21, K. 24, and K. 28 are also spread in space, from Pine Hill to Moorilyanna and the Flinders Ranges.

6. K. 23 -

From a consideration of its age, this rock may be related in time to the "older" series of Flinders Ranges granites. No particular affinity between K. 23 on the one hand and K. 8, K. 10, K. 13, K. 15 on the other can be detected as regards petrography and heavy minerals.

7. K. 27

Since this rock is regarded as an Archaean metasediment, the age-determination result is not surprising. It is, of course, impossible to say whether this is the true age of the original zircon or whether the zircon has lost uranium or lead during metamorphism.

SECTION 3.

UNUSUAL MINERALS AND MINERALS OF ECONOMIC INTEREST

It was felt by the writer that brief notes on minerals of scientific or economic interest would be of value if summarized in list form.

1. Gold

Crystallized gold occurs, apparently as a primary constituent, in the Granite Island adamellite. When the gold was first discovered in the concentrate of V. 3 II, a sample of beach sand was collected from the beach on the northern sides of the island. Traces of gold were found in this also. Under favourable conditions of natural concentration, economic deposits of gold may exist in this locality.

2. Molybdenite

This mineral is far more widespread in granitic rocks than is usually suspected. It occurs in minute hexagonal crystals, in the following rocks: -

V. 3II, V. 4, V. 5, K. 24.

There is always the possibility that economic quantities of this mineral occur in the vicinity of these rocks. Its presence as small, well-defined crystals raises the possibility that molybdenite crystallizes early in the magmatic sequence. Some support is lent to this view because of the presence of molybdenite in all the Encounter Bay rocks examined.

3. Chalcopyrite

This mineral is a very rare accessory and was found in only four rocks:

V. 5, T. B. 9, C. W. 2, and M. P. 1,

in each case in trace amount only.

4. Monazite

This is of fairly widespread occurrence. In some of the rocks which are suspected to be granitized sediments, the monazite is probably of detrital origin, as is the case with zircon in these rocks. The mineral occurs in the following rocks: -

V. 3 II, V. 4, V. 5, Mon. 1, K. 15, T. B. 9(trace), K. 22, and K. 24.

It is of interest to note that all three Encounter Bay rocks carry monazite.

The occurrence of monazite in the Monarto rock and in the Encounter Bay rocks is of interest from the point of view of economic beach-sand deposits of this mineral, and in all probability the Monarto area was the source of the monazite in the Moana beach-sand.

5. Fluorite

This mineral has been found in many of the rocks examined, namely:

K. 8, K. 10, K. 13, K. 16, K. 21=, K. 22, K. 23, K. 24=, K. 26, T. B. 9, M. P. 1, C. W. 2.

The two samples marked (=) contain purple fluorite which is anomalously anisotropic, exhibiting faint pleochroism from blue to purple and showing very weak birefringence. In sample K. 21, a few small blue isotropic grains of a mineral, whose R. I. is similar to that of fluorite, may be yttrocerite.

Most of the fluorite is colourless with occasional purple patches. It is conspicuous by its absence in the Encounter Bay suite.

6. Rutile

A far scarcer mineral in granitic rocks than would be supposed, at least in the samples examined. When occurring, it is present in traces only, as in the following rocks:-

V. 3 II, Pal. 1, M. P. 1, K. 8, K. 12, K. 15, K. 16, and K. 24.

In the case of K. 12, the crystals are yellow to amber in colour, and are well-crystallized; they are fairly common in one of the fractions (see Appendix A). In the other rocks, the traces of rutile that are detectable are brown or foxy-red and are poorly crystallized.

7. Anatase

Encountered in only two samples: -

K. 16 and K. 22.

In the former sample the anatase is yellow to greenish-yellow and some is pleochroic in these colours. It occurs as tetragonal bipyramids, with no prism faces and no basal pinacoid. The faces are horizontally striated. In sample K. 22 the crystals are tabular, and are of a conspicuous greenish-blue colour. Anatase is usually regarded as a secondary mineral.

8. Sphene

A ubiquitous mineral, occurring in many of the rocks examined, being especially abundant in K. 29. It is usually amber to brown, faintly pleochroic and sometimes superficially altered to leucoxene. It is a somewhat brittle mineral, fracturing easily; for this reason it is seldom seen as complete, well-defined crystals. In a few cases, the sphene contains so little iron that it is practically non-magnetic. This is the case in samples K. 10 and K. 29, where the separation of the zircon and sphene was achieved by a higher field-strength and/or lower tilt angle setting on the Frantz Separator.

9. Orthite (Allanite)

Observed in only one sample, K. 21, and described in Appendix A above. Other samples could possibly contain this mineral, which on account of its anomalous optical properties and metamictization is easily overlooked and confused with haematite, goethite, etc.

10. Tourmaline

A far less common mineral than commonly supposed, occur only in the Encounter Bay suite, V. 3 II, V. 4, and V. 5, and in K. 8 and M. P. 1. In the last-named sample the tourmaline may well be detritally rounded, being derived from xenoliths. The variety schorl is the only one encountered.

11. Zircon

This note is intended only to draw attention to the yttrium-bearing zircon contained in sample K. 27. The optical properties of the zircon appear to be normal. Significant amounts of hafnium are contained in zircons from samples K. 10 and K. 12.

SECTION 4.

CONCLUSIONS

The conclusions reached as a result of the work described in the foregoing sections may be summarized thus:

1. Various phases of an igneous complex, closely related in space and time, contain closely similar heavy accessories despite differences in petrography. This is exemplified by the Encounter Bay suite of rocks and the Murray Bridge/Coonalpyn rocks.

2. Rocks that are of similar age and belonging to the same phase of igneous activity but not closely related in space may show a general similarity of heavy accessories (as in the "older" series of the Flinders Ra.) or may be quite dissimilar, as seen in the K. 12 - K. 21 - K. 24 - K. 26 series.

3. An examination of the heavy accessories of a rock, together with its petrography and structure (field relationships) will usually show whether the rock is of magmatic origin or whether it is a granitized sediment.

4. The degree of contamination of a magmatic rock by sedimentary material can often be assessed by studying the heavy accessories.

5. Age-determinations by the Larsen or lead-alpha method can only be regarded as reasonably reliable if several determinations are made on a rock or a closely-related suite of rocks. Since the risk of contamination, leading to erroneous results, is very high, it is desirable that age-determination work is done using rooms and equipment reserved only for this purpose, and is carried out by

personnel able to devote all their time to it.

6. Accessory mineral studies are of real value where adjacent rocks of similar aspect are suspected to be unrelated magmatically.

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APPENDIX A

PETROGRAPHY AND HEAVY ACCESSORY MINERALS OF THE GRANITES

In the following pages, descriptions will be given of the twenty-five samples examined. The system adopted for easier reference is as follows: -

1. Sample number

2. Locality

3. Petrography

This is a brief description of the sample examined. It is not necessarily representative of the rock as a whole, nor is it intended as a substitute for the many excellent and detailed petrographic descriptions already available in many cases. Since much care was taken in sampling to obtain fresh, representative material for age determinations, the description of the sample examined will usually coincide with published descriptions.

4. Heavy Accessories

The accessories heavier than bromoform were further subdivided by means of the Frantz Isodynamic Separator, and the minerals in each fraction are listed. Abbreviations: -

Ferromag.	=	Ferromagnetic minerals
Mag.	=	Magnetic, i.e. magnetic at ...... Amps.
Non Mag.	=	Non-magnetic, i.e. non-magnetic at .... Amps.
LF MeI	=	Methylene Iodide light fraction
HF MeI	=	" " heavy fraction

When the final non-magnetic stage in separation is reached, the non-magnetic fraction is centrifuged in methylene iodide. Further details of the whole process are given in the section on age determinations ("2").

5. Features

This heading covers detailed descriptions of special features of minerals in various fractions described under 4.), and includes details of zircons, optically anomalous minerals, minerals with unusual physical or chemical properties, and minerals of economic interest.

6. Absolute Age

Where determined, is given here for completeness, as well as in the section on age determinations.

NOTE ON SPECIMEN PREPARATION

The petrography of the rocks was of course studied by means of thin sections. The various fractions from the crushed granites were produced in the following way: -

1. Granite crushed to minus 40-mesh B.S.S. (5-10 kg material)
2. Concentrate produced by passing crushed rock over a laboratory Wilfley table.

3.) Concentrate 2.) separated in bromoform.

4.) Heavy fraction from 3.) treated with powerful hand-magnet to remove ferromagnetic minerals.

5.) Residue from 4.) passed through Frantz Isodynamic Separator with progressive increase in field-strength (usually 0.1 Amp., 0.2 Amp., 0.5 Amp., 0.8 Amp., 1.4 Amp.).

6.) Final non-magnetic fraction was centrifuged in methylene iodide, yielding a heavy and a light fraction.

The ferromagnetic fraction obtained in 4.) above was mounted in bakelite and polished. Some of the more magnetic fractions in 5.) were treated similarly. The other fractions in 5.) and 6.) were mounted on glass slides, with Canada balsam to make the mounts permanent. They were examined by means of the binocular (steroscopic) and petrographic microscopes. Where necessary, individual fractions were also mounted in refractive-index oils to facilitate identifications of some minerals, e.g. monazite. Polished sections were examined in reflected light by means of an ore microscope.

Numbers are allocated to minerals to indicate their relative abundance in a fraction :

5. = Predominant
4. = Abundant
3. = Common
2. = Uncommon
1. = Rare
Tr. = Trace

1. SAMPLE NUMBER: - K. 8

2. LOCALITY:

N. Flinders Range, 5 miles E. of Mt. Fitton homestead, on Moolawatana road.

3. PETROGRAPHY

A stressed granite, with coarse texture, showing strain and brecciation. Large areas of shattered quartz occur, and show undulose extinction, and there are coarse-grained subhedra of microcline-perthite and a few subhedra of oligoclase which are largely sericitized. Small aggregates of deep-brown biotite are scattered sparingly through the rock. They are interstitial and crystalloblastic, indicating late formation. Veinlets of crushed constituents are common. Stressed microcline-granite.

4. HEAVY ACCESSORIES

Ferromagnetics	: Magnetite;	ilmenite (includes 0.1 Amp. mag.)		
0.5 Amp. Mag.	: Tourmaline	(3)		
0.8 Amp. Mag.	: Tourmaline	(2);	fluorite (2);	apatite (2)
1.4 Amp. Mag.	: Fluorite	(3);	apatite (3);	zircon (3-4)
1.4 Amp. Non. Mag.:	LF MeI -		Fluorite(4);	apatite (4).
Zircon Fraction -	Zircon	(5);	rutile (Tr.).	

5. FEATURES

a. Tourmaline: rough, green fragments.

b. Fluorite: Colourless with purple patches, some very intense.

c. Apatite: Rough, clear, colourless prisms.

d. Zircon: Four distinct types occur, as follows -

I. Zoned, brown crystals with shallow pyramid faces, causing stubby terminations. Metamict or with patchy, low-birefringent material. Ratio length to breadth about normal, averaging 2 : 1.
In 1.4 Amp. mag. fraction and in zircon concentrate common to plentiful.

II. Clear, unzoned, colourless, with variable L : B ratio. Rare.

III. Clear, zoned, with high birefringence - predominates in zircon concentrate.

IV. Rounded, clear, detrital zircon. Rare. Origin from assimilated sediments or metasediments.

6. ABSOLUTE AGE

1575 ± 158 Million Years. (MY).

1. SAMPLE NUMBER - K.10

2. LOCALITY

N. Flinders Ra., Mudnawatana Creek, 7 miles N.W. of Mt. Fitton homestead.

3. PETROGRAPHY

A stressed and brecciated biotite adamellite. Microcline-perthite and oligoclase are present in roughly equal amount, quartz is subordinate to these. These minerals are stressed and shattered, and there are zones and veinlets consisting of mosaics of quartz and feldspars. Re-crystallization is evidenced in the occurrence of late-stage clear microcline and quartz. Biotite, which is seen as undistorted, fresh, dark-brown laths, is also a late-stage (post stress) mineral. Apatite and sphene are the main accessories.

4. HEAVY ACCESSORIES

Ferromags	: Magnetite.
0.35 A. Mag.	: Sphene (2)
0.5 A. Mag.	: Sphene (2)
0.8 A. Mag.	: Sphene (3-4)
1.4 A. Mag.	: Sphene (5); Apatite (4); zircon (Tr.)
1.4 A. Non Mag., MeI LF	: Sphene (2); fluorite (2); apatite (5).
1.4 A. Non Mag., MeI HF	: Zircon (5); sphene (Tr.)

5. FEATURES

a. Sphene: This occurs in earlier fractions (0.35 A. - 0.8 A.) as large, rough amber grains. In the other fractio ns it occurs as very pale (evidently iron-poor) grains and must be separated from zircon by altering the tilt of the Frantz Separator (reduce from 15^0 to 10^0 at 20^0 slope).

\- At 10^0 tilt, 20^0 slope.

b. Apatite: Stubby prisms with prominent basal pinacoids and small truncating pyramid faces. Many elongate inclusions parallel to the c-axis.

c. Fluorite: Colourless with patchy purple.

d. Zircon: Three distinct types -

I. Stubby, clear, colourless, unzoned, with L : B about 1 : 1 (which is unusual). Rare.

II. Zoned, cracked, with inclusions, and with lowered birefringence. Common.

III. Pale-brown, cloudy, altered, zoned malacons, with patchy, low birefringence. L : B normal, about 2 : 1, occur in 1.4 A. mag. fraction.

6. ABSOLUTE AGE 1400 $\pm$ 140 MY.

1. SAMPLE NUMBER - K. 12

2. LOCALITY

N. Flinders Ra., 1 mile along Paralana Hot Springs Creek from Hot Springs.

3. PETROGRAPHY

A biotite granodiorite, consisting of fresh anhedra of quartz, sodic oligoclase and orthoclase, with sutured boundaries. The oligoclase is sodic and slightly antiperthitic, and far exceeds the orthoclase in amount. Large irregular laths of greenish biotite are interstitial to the felsic minerals, and are associated with zircon crystals. Sphene occurs in association with rare opaques. Secondary or late-stage muscovite is present.

4. HEAVY ACCESSORIES

Ferromags	:	Titaniferous magnetite
0.3 A. Mag.	:	Epidote (Tr.)
0.5 A. Mag.	:	Garnet (Tr.) pale brown; epidote (Tr.)
0.8 A. Mag.	:	Epidote (Tr.)
1.4 A. Mag.	:	Rutile (3); Zircon (Tr.)
1.4 A. Non-Mag., LF MeI	:	Apatite (Tr.), colourless.
Pure Zircon	:	Trace of honey-yellow rutile; zircon (5).

5. FEATURES

a. Epidote, garnet: Probably derived from assimilated xenoliths.

b. Rutile: Pale yellow to amber to brown elongate crystals.

c. Zircon: Two distinct types -

I. Small, clear, colourless crystals with faint zoning and basal parting L : B = 3 : 1 or greater.

II. Large, pale mauve, zoned crystals with cloudy, opaque cores. Outlines irregular, due to overgrowths and outgrowths (second generation?). Usually steep pyramid faces. Commonly cracked.

6. ABSOLUTE AGE

920 ± 92 MY.

1. SAMPLE NUMBER - K.13

2. LOCALITY

N. Flinders Ra., Yudnamutana Gorge, B. bank.

3. PETROGRAPHY

A stressed microcline granite with rather heterogeneous, inequigranular texture. Microcline is abundant, with stressed, distorted grid twinning; quartz is also stressed and has a marked bluish tinge. Oligoclase is uncommon, and usually somewhat altered. The conspicuous feature is the occurrence of "clots" or patches of biotite with associated opaques, sphene, and euhedral zircon; the sphene is partly an alteration-product of the opaques. Some myrmekite is present.

4. HEAVY ACCESSORIES

Ferromags	: Titaniferous magnetite; pyrrhotite (Tr.)
0.1 A. Mag.	: Ilmenite (3); sphene (3-4); Staurolite (3); apatite (Tr.); zircon (Tr.)
0.2 A. Mag.	: Ilmenite (5); haematite (Tr.); sphene (2-3); zircon (1-2)
0.5 A. Mag.	: Sphene (2); staurolite (3); zircon (2-3).
0.8 A. Mag.	: Sphene (4); staurolite (2-3); zircon (2).
1.4 A. Mag.	: Sphene (4); zircon (3)
1.4 A. Non-Mag., LF MeI:	Apatite (4); fluorite (3); zircon (1).
Pure Zircon	: Mainly type III zircon.

N.B. Zircon occurs to the extent of 0.07 per cent. in this granite.

5. FEATURES

a. Ilmenite; Shows twinning and orientated exsolution bodies of haematite and magnetite.

b. Staurolite: Deep reddish brown, with many inclusions.

c. Apatite: Clear and colourless

d. Fluorite: Colourless with purple patches.

e. Zircon: Divisible into three types -

I. Zoned, clear, amber coloured. Uncommon.

II. Very coarse and large, rough, cracked, amber coloured and with many inclusions. Types I and II common in earlier Frantz Separator fractions.

III. Lightly zoned or unzoned, clear, colourless, sharply crystallized, with inclusions of opaques and ? apatite. Slightly biaxial anomalous interference figure.

6. ABSOLUTE AGE 1520 - 152 MY.

1. SAMPLE NUMBER - K.15

2. LOCALITY

N. Flinders Ra., Blue Mine Creek, Camel Pad Track. 6 miles E.N.E. of Umberatana homestead.

3. PETROGRAPHY

A mica-orthogneiss. The fabric of the rock is definitely gneissic, and is accentuated by the sub-parallel arrangement of the muscovite and biotite laths. Relict phenocrysts of microcline are present, but the other constituents are very fresh and evidently re-crystallized. They are medium-grained, mosaics of quartz, microcline and albite-oligoclase, with porphyroblasts of microcline and albite. Occasional euhedra of zircon occur.

4. HEAVY ACCESSORIES

Ferromags. + 0.1 A Mag: Ilmenite; goethite/limonite; pyrite/ilmenite.
0.3 A. Mag. : Sphene (Tr.); monazite (Tr.)
0.5 A. Mag. : Monazite (Tr.);
0.8 A. Mag. : Pyrite (2-3); sphene (Tr.); monazite (4); zircon (Tr.)
1.4 A. Mag. (roasted): Rutile + Ilmenorutile (1); monazite (2); apatite (2); zircon (3-4).
1.4 A. Non-Mag: (roasted), LF MeI: Apatite (Tr.-1); zircon composites (1).

Zircon fraction : Types II and IV zircons.

5. FEATURES

a. Ilmenite: contains exsolution lamellae of haematite.

b. Monazite : stubby, pale yellow crystals.

c. Ilmenorutile: Dark green to brown pleochroism.

d. Zircon: Four distinct types -

I. Small, clear, colourless crystals. Rare

II. Large, rough cracked crystals, often cloudy and opaque, and with inclusions. Over and out-growths common.

III. Small, metamict malacons, almost completely opaque.

IV. Large, clear, colourless, rough crystals. Unzoned or only faintly zoned; bubbles and inclusions common - small brown ones may be sphene, colourless rods are possibly apatite. Crystal-faces appear etched, which may be a result of re-crystallization of the rock.

6. ABSOLUTE AGE

1645 ± 165 MY.

1. SAMPLE NUMBER - K. 16 ("Gawler Ra. Porphyry")

2. LOCALITY

Northern Eyre Peninsula, 6 miles W. of Corunna homestead.

3. PETROGRAPHY

A strongly reddened granophyre, with almost unrecognizably altered phenocrysts of albite/oligoclase set in a groundmass of micrographically intergrown quartz and reddened feldspar. Occasional pseudomorphs of chlorite with opaques indicate the former presence of ferromagnesian minerals. Abundant late-stage and secondary material is present - rosettes of chlorite, patches of fluorite and calcite, and secondary quartz as euhedral crystals.

4. HEAVY ACCESSORIES

Ferromags	: Titaniferous magnetite.						
0.2 A. Mag.	: Ilmenite/leucoxene.						
0.5 A. Mag.	: Fluorite (2)						
0.8 A. Mag.	: Fluorite (4); anatase (2); apatite (3).						
1.4 A. Mag.	: Fluorite (3-4); apatite (4); anatase (2).						
1.4 A. Non-Mag:	LF MeI;	Fluorite	(4);	apatite	(4).		
1.4 A. Non-Mag.,	HF MeI:	Rutile	(1);	apatite	(2);	fluorite	(2);
		anatase	(4);	zircon	(4).		

5. FEATURES

a. Fluorite: Colourless with deep purple patches.

b. Anatase: Yellow-green, striated horizontally, with sharp terminations and steep pyramid faces. Sometimes faintly pleochroic yellow to greenish. Some with opaque centres.

c. Apatite: Ranges from bluish, smoky, almost opaque, through brown, smoky, to colourless, clear. Small square prisms with many inclusions parallel to the c-axis.

d. Rutile: Brown, vertically striated crystals.

e. Zircon: Most of it is rounded and fractured, with outgrowths and overgrowths. Often cloudy or opaque, metamict. Contributory evidence of strong hydrothermal activity.

6. ABSOLUTE AGE

Zircon sample too small for determinations.

1. SAMPLE NUMBER - K. ~~20~~ ("Moonabie Porphyry")

2. LOCALITY

N. Eyre Peninsula, 35 miles SW. of Whyalla on Lincoln Highway.

3. PETROGRAPHY

A porphyritic microgranite. Fairly closely-packed phenocrysts of altered albite are set in a fine-grained groundmass of quartz, alkali-feldspar, green biotite, opaques, and chlorite. The groundmass is an even-grained mosaic. The albite phenocrysts are largely altered to kaolin, sericite and zoisite-clinozoisite. Occasional large grains of opaques occur and are commonly mantled by sphene.

4. HEAVY ACCESSORIES

Ferromags : Titaniferous magnetite
0.1 A. Mag. : Silicate/magnetite composites.
0.2 A. Mag. : Ragged ilmenite with lamellar twinning.
0.5 A. Mag. : Apatite (1-2); epidote group (2).
0.8 A. Mag. : Apatite (1-2); epidote group (3); zircon (Tr.)
1.4 A. Mag. : Apatite (3); epidote group composites (4); zircon (Tr.-1).
1.4 A. Non-Mag., LF MeI : Apatite (4-5).
1.4 A. Non-Mag., HF MeI : Pure Zircon

5. FEATURES

a. Magnetite : Contains orientated exsolution-plates of haematite.

b. Apatite : Crystals often poor, being strongly corroded and etched, some have cloudy centres due to inclusions.

c. Zircon: Very scarce in this rock. Three types are distinguishable -

I. Small, clear, unzoned, colourless or faint pink, fresh crystals. No inclusions. Uncommon.

II. Medium to large, zoned, faintly coloured crystals with inclusions. Most common.

III. Rounded, cracked, altered, detrital grains.

6. ABSOLUTE AGE

Insufficient zircon for determinations.

1. SAMPLE NUMBER - K. 21 ("Charleston Granite")

2. LOCALITY

N. Eyre Peninsula; Pine Hill, 46 miles SW. of Whyalla.

3. PETROGRAPHY

A coarse-grained microcline granite, consisting of very large subhedra of microcline-perthite, smaller subhedra of quartz, and small amounts of zoned oligoclase tending to albite. Occasional patches of rather altered biotite occur in association with opaques, apatite, fluorite, zircon and epidote.

4. HEAVY ACCESSORIES

Ferromags : Titaniferous magnetite; pyrite (composites).
0.2 A. Mag: Ilmenite; martitized magnetite.
0.5 A. Mag: Hornblende (3-4); opaques (2); epidote group (1); orthite (2).
0.8 A. Mag: Orthite (4-5); fluorite (Tr.)
1.4 A. Mag: Orthite (5); fluorite (Tr.)
1.4 A. Non-Mag: Apatite (3-4); fluorite (3-4); orthite (Tr.); zircon (2-3).

5. FEATURES

a. Magnetite : titaniferous, with orientated inclusions of haematite.

b. Martitized magnetite: with orientated plates of ilmenite.

c. Hornblende : mentioned here only because it was not detected in thin-section.

d. Orthite : Deep red-brown. Strongly zoned, whitish opaque zones alternating with clear brown zones. Uniaxial to biaxial positive, with 2V up to 45^{0}. Dispersion : r greater than V, distinct to strong. Birefringence moderate to high. Pleochroism weak, in browns. Some cleavage seen.

e. Fluorite : Intense purple colour. Weakly pleochroic, purple to bluish, and weakly birefringent. A few blue fragments, very similar to fluorite, may be yttrocerite.

f. Apatite : Some crystals have elongate inclusions parallel to the c-axis, some perpendicular to the c-axis; the cores are almost opaque.

g. Zircon: Very small amount only, considering original weight of rock sample (5 Kg.). Large crystals, pale-brown to amber, strongly zoned, with outgrowths. L : B up to 5 : 2.

6. ABSOLUTE AGE

890 $\pm$ 89 MY.

1. SAMPLE NUMBER - K. 22

2. LOCALITY

N. Eyre Peninsula; Carippie Hill, 6 miles NE. of Darke Peak.

3. PETROGRAPHY

A muscovite-biotite gneiss, produced by the dynamic metamorphism and partial re-crystallization of a granitoid rock. Relict phenocrysts (or porphyroblasts) of microcline, large patches of coarse-grained quartz, and some albite, remain in a rock with pronounced flaser-structure. Fine - to medium-grained mosaics of quartz and microcline occur as elongate lenses following the structure. Biotite occurs both as re-crystallized laths and poikiloblasts and as relict, bent and altered laths. There has been an influx of abundant muscovite and traces of fluorite. Small zones of stress contain sheared quartz, and sub-parallel laths of biotite and muscovite. From evidence afforded by accessory minerals, it is concluded that the rock is a twice-metamorphosed metasediment.

4. HEAVY ACCESSORIES

0.3 A. Mag:	Hornblende (1).		
0.5 A. Mag:	Fluorite (Tr.);	brown garnet (Tr.);	apatite (1)
0.8 A. Mag:	Pyrite (1);	fluorite (1-2);	monazite (4).
1.4 A. Mag:	Fluorite (1);	zircon (3-4)	
1.4 A. Non Mag., LF MeI :	Fluorite (1-2);	apatite (4-5);	zircon (Tr.)
1.4 A. Non Mag., HF MeI :	Anatase (1-2);	zircon (5).	

5. FEATURES

a. Fluorite: Purple colour.

b. Monazite: Small, rounded altered and discoloured grains.

c. Apatite: Large, rough, colourless grains with poor crystal faces.

d. Anatase: Blue-green small tabular crystals.

e. Zircon: Conspicuously rounded and subrounded detrital grains, all of very similar size. Dark, heavily zoned, altered and with low birefringence. Metamict or nearly metamict zircons are definitely more magnetic than clear, fresh zircons.

6. ABSOLUTE AGE

No determinations made.

1. SAMPLE NUMBER - K.23

2. LOCALITY

N. Eyre Peninsula; Calca Bluff, 12 miles SE. of Streaky Bay.

3. PETROGRAPHY

A porphyritic microgranite. Large phenocrysts of strongly altered microcline, with corroded and fragmented appearance, are set in a fine-grained groundmass consisting of completely altered, reddened feldspar crystals enclosed in areas of quartz with simultaneous extinction. There is some indication of late-stage quartz and albite mantling earlier phenocrysts. Small amounts of hornblende occur, appearing poikiloblastic. Euhedral epidote is conspicuous. Opaques are rimmed with sphene, patches of chlorite contain traces of fluorite, and euhedral zircon is seen. The rock gives the impression of being a hybrid, the phenocrysts and groundmass having different derivation. Deuteric effects are marked.

4. HEAVY ACCESSORIES

Ferromags : Titaniferous magnetite.
0.3 A. Mag: Opaques (3-4); sphene (1); zircon (1-2); contains magnetite.
0.5 A. Mag: Opaques (2); sphene (1); staurolite (1-2); epidote (2-3), zircon (Tr.).
0.8 A. Mag: Sphene (2-4); fluorite (Tr.); staurolite (2), epidote (3-4); zircon (1).
1.4 A. Mag: Sphene (4); fluorite (1-2); apatite (2); staurolite (2); epidote (2); zircon (1).
1.4 A. Non Mag: Fluorite (2-3); apatite (3); zircon (4).

5. FEATURES

a. Magnetite: Titaniferous, with orientated inclusions of haematite and ilmenite.

b. Sphene: Amber to brown grains.

c. Staurolite: Large, rough, brown grains.

d. Fluorite: Mainly colourless, with purple patches.

e. Apatite: Some crystals are nearly opaque, due to inclusions.

f. Zircon: Two types occur -

I. Brown, nearly opaque malacons. Rare.

II. Pale amber, clear to cloudy, zoned, euhedral. Contains oblong transparent inclusions and small square opaque inclusions, presumed to be magnetite to account for the unusually magnetic nature of some of the zircon.

6. ABSOLUTE AGE

1660 ± 166 MY.

1. SAMPLE NUMBER - K. 24

2. LOCALITY

N. Eyre Peninsula, 10 miles E. of Wilgena.

3. PETROGRAPHY

A rather kaolinized, coarse-grained granite with typical granitic texture. Orthoclase-perthite is in excess of oligoclase, and both feldspars are kaolinized and in places almost opaque. Quartz occurs as anhedral areas. Ragged, large laths of dark brown biotite show incipient alteration, and contain small lenses of purple fluorite along cleavages. Larger areas of colourless fluorite also occur. The biotite also contains many small zoned, euhedral zircons; small crystals of apatite are associated with the biotite.

4. HEAVY ACCESSORIES

Ferromags:	Titaniferous magnetite.		
0.1 A. Mag:	Haematite-limonite; traces of pyrrhotite.		
0.3 A. Mag:) 0.5 A. Mag:)	Biotite only, no accessories		
0.8 A. Mag:	Fluorite (2-3);	monazite (3-4);	zircon (2).
1.4 A. Mag:	Fluorite (3);	apatite (2);	zircon (4).
1.4 A. Non Mag., LF MeI:	Fluorite (4-5);	apatite (1).	
1.4 A. Non Mag., HF MeI:	Molybdenite (Tr.);	rutile (Tr.);	
	fluorite (Tr.);	zircon (5).	

5. FEATURES

a. Fluorite: mainly colourless, but some is faintly pleochroic blue/purple, and weakly birefringent.

b. Monazite: shows surface alteration; yellow.

c. Zircon: Almost opaque, metamict. Zoned, twinned, and with outgrowths and overgrowths. Poor crystal faces.

6. ABSOLUTE AGE

870 ± 87 MY.

1. SAMPLE NUMBER - K. 26

2. LOCALITY

Moorilyanna Soak, 30 miles W. of Granite Downs.

3. PETROGRAPHY

A very coarse-grained, leucocratic, granitoid rock. All the main minerals are stressed, fractured, and peripherally granulated. Large, irregular areas of quartz and microcline predominate, and small patches of completely saussuritized plagioclase are present. Aggregates of contorted biotite are associated with fragmented opaques, apatite and sphene. Occasional? rounded grains of zircon occur. On the whole, the rock may be termed a crushed microcline-granite.

4. HEAVY ACCESSORIES

Ferromags: Titaniferous magnetite
0.1 A. Mag: Sphene/leucoxene.
0.3 A. Mag: Sphene (1); epidote group (1); opaques (4).
0.5 A. Mag: Opaques (2); sphene (1); epidote group (4).
0.8 A. Mag: Sphene (1-2); primary uranium mineral (Tr.)
1.4 A. Mag: Sphene (4); fluorite (Tr.-1); apatite (2); U-mineral (Tr.)
1.4 A. Non Mag: Fluorite (2); apatite (4); zircon (3-4); U-mineral (Tr.)

5. FEATURES

a. Magnetite : Titaniferous, with orientated inclusions of ilmenite.

b. Sphene : Dark amber in colour.

c. U-Mineral : A few grains of a black, opaque mineral with veinlets of a yellow secondary uranium mineral through them. U : Th about 2 : 1. Greasy appearance. Probably a thorian uraninite.

d. Fluorite : Bluish-purple fragments.

e. Apatite : Clear, colourless, no inclusions.

f. Zircon : Two types -

I. Faintly pleochroic, brown, zoned. Subhedral to anhedral. Some crystal faces seen.

II. Pale, unzoned, euhedral.

6. ABSOLUTE AGE

880 $\pm$ 88 MY

1. SAMPLE NUMBER - K. 29

2. LOCALITY

Musgrave Ra., 6 miles E.N.E. of Ernabella Mission.

3. PETROGRAPHY

The texture of this rock is granulitic rather than granitic. Subhedral to euhedral granular aggregates and mosaics of quartz, perthite, microcline and microcline-perthite and oligoclase constitute the bulk of the rock. Areas or patches of poikiloblastic green hornblende enclose quartz, feldspars, large grains of apatite, opaques and zircon. The zircon is unusual and problematical; it appears euhedral and poikiloblastic, cracked and coarse-grained in thin-section. This rock is regarded as a metasediment belonging to the amphibolite facies, and the zircon may be of late-stage formation or reconstituted from earlier material.

4. HEAVY ACCESSORIES

Ferromags :	Titaniferous magnetite.		
0.1 A. Mag:	Ilmenite.		
0.3 A. Mag:	Opaques (3).		
0.5 A. Mag:	Apatite (Tr.-1);	epidote group (1).	
0.8 A. Mag:	Apatite (4);	epidote group (2);	zircon (Tr.)
1.4 A. Mag:	Sphene (Tr.);	apatite (4-5);	zircon (Tr.)
1.4 A. Non Mag., LF MeI :		Apatite (4-5);	zircon (Tr.)
1.4 A. Non Mag., HF MeI :		Pyrite (Tr.-1);	zircon (5).

5. FEATURES

a. Magnetite : Titaniferous, slightly anisotropic (pink to grey)

b. Apatite : Clear, colourless, with elongate inclusions and voids parallel to c-axis.

c. Zircon : Two types -

I. Pinkish-brown euhedral crystals - occur in 0.8 A. Mag. fraction. Rare.

II. Large, pale-brown crystal fragments; unzoned, fresh, clear. R.I. normal for zircon, but x-ray fluorescence shows significant yttrium. Complete crystals are very rare, though most fragments show prism-faces.

6. ABSOLUTE AGE

1770 ± 177 MY.

1. SAMPLE NUMBER - K. 29

2. LOCALITY

Peake and Denison Ra., 8 miles SE. of Edwards Creek railway station.

3. PETROGRAPHY

A rather unusual rock, containing very little quartz. The main minerals are coarse-grained, anhedral, strongly kaolinized orthoclase-perthite, and stout laths of zoned plagioclase in the oligoclase range. Quartz occurs as small interstitial patches. Green hornblende is common, as large anhedra and small euhedra. Sphene is very conspicuous, as well-formed large and small crystals. Corroded, euhedral, prismatic crystals of diopsidic augite are sporadically distributed, being quite abundant in some areas. Patches of massive epidote occur, and contain acicular actinolite. Biotite is present in small amount. On the balance of the evidence, it would be appropriate to term this rock a quartz monzonite, though it may be a hybrid rock.

4. HEAVY ACCESSORIES

Ferromag. + 0.1 A. Mag: Titaniferous magnetite.
0.3 A. Mag: Augite (4); sphene (1); epidote (1-2).
0.5 A. Mag: Augite (4-5); sphene (1); epidote (1-2).
0.8 A. Mag: Augite (5); sphene (1); epidote (Tr.)
1.7 A. Mag: Augite (Tr.) sphene (4-5)
1.7 A. Non Mag: Apatite (4); zircon (Tr.)

5. FEATURES

a. Magnetite : Titaniferous, with orientated plates of ilmenite.

b. Augite : Pale green, diopsidic, with (+)2V about 60°.

c. Sphene : Very well-developed, pale amber crystals, Fe-poor.

d. Apatite : Clear, colourless, with prominent pyramid faces.

e. Zircon : Rare, pink crystals, with subrounded to rounded appearance.

6. ABSOLUTE AGE

Insufficient zircon for determination.

1. SAMPLE NUMBER - V. 3 II

2. LOCALITY

Granite Island, Encounter Bay.

3. PETROGRAPHY

Large phenocrysts of microcline-perthite are conspicuous, as is the bluish, opalescent quartz. The phenocrysts show strain-extinction, have inclusions of quartz, biotite and sodic oligoclase, and are often surrounded by sodic plagioclase. This is similar to Rapakivi-structure. There are also subhedral to euhedral plates of sodic oligoclase - to calcic oligoclase. The quartz is stressed. Large, stout laths of greenish biotite contain zircons (surrounded by pleochroic haloes) and prisms of apatite. This may be termed a porphyritic biotite-adamellite.

4. HEAVY ACCESSORIES

Ferromags. + 0.1 A. Mag. : Magnetite, haematite, martite, limonite, pyrite.
0.3 A. Mag : Opaques (4); epidote group (Tr.); apatite (Tr.); zircon (Tr.)
0.5 A. Mag : Opaques (1); epidote group (2-3); apatite (Tr.); zircon (Tr.); tourmaline (Tr.)
0.8 A. Mag : Monazite (Tr.); epidote group (4); apatite (Tr.); apatite (Tr.); zircon (Tr.)
1.4 A. Mag : Pyrite (1); sphene (3); monazite (Tr.); rutile (Tr.); apatite (1); zircon (3).
1.4 A. Non Mag., LF MeI : Apatite (4); zircon (Tr.-1);
Zircon Concentrate : Rutile (Tr.); sphene (Tr.); molybdenite (Tr.); pyrite (3); gold (Tr.); zircon (4).

5. FEATURES

a. Apatite : Some clear crystals, some with fine, black elongate inclusions parallel to c-axis.

b. Monazite: Pale yellow well-defined crystals.

c. Gold : Occasional arborescent crystals. Also found in Granite Island beach-sand.

d. Zircon : Three types -

I. Rounded, detrital - rare.

II. Clear, unzoned colourless; occasional parallel twins. Rare.

III. Cracked, cloudy, colourless, zoned. Whitish surface coating, patchy birefringence. Well crystallized, squat. L : B - 2 : 1.

6. ABSOLUTE AGE 415 ± 42 MY.

1. SAMPLE NUMBER - V. 4

2. LOCALITY

West side of bay at Port Elliot.

3. PETROGRAPHY

A porphyritic adamellite, very similar to the Granite Island material, though the plagioclase shows strong zoning. In one crystal, each successive zone is bordered by minute microcline crystals. Microcline-perthite is coarse enough to enable the plagioclase component to be recognized as oligoclase. The zoned plagioclase ranges from andesine (core) to albite (mantle). Biotite occurs as ragged green laths, with pleochroic haloes surrounding zircon which is often mantled with apatite.

4. HEAVY ACCESSORIES

Ferromags: Magnetite; martite; pyrrhotite.
0.3 A. Mag: Pyrrhotite (4); tourmaline (Tr.); apatite (Tr.)
0.5 A. Mag: Sphene (2); garnet (Tr.); tourmaline (Tr.); staurolite (Tr.-1).
0.8 A. Mag: Sphene (4); tourmaline (Tr.); monazite (1); apatite (Tr.-1); staurolite (Tr.); zircon (Tr.)
1.4 A. Mag: Pyrite (1-2); sphene (4); monazite (Tr.); apatite (1); zircon (2-3)
1.4 A. Non Mag: Pyrite (2-3) molybdenite (Tr.-1); apatite (3); zircon (4).

5. FEATURES

a. Tourmaline : Strongly pleochroic, pink to green or black.

b. Sphene : Altered, cloudy, poorly-defined, leucoxenic.

c. Garnet : Angular and rounded. Derived from metamorphics.

d. Staurolite; Brown, strongly pleochroic. Derived from metamorphics.

e. Monazite : Pale yellow, well-defined crystals.

f. Apatite : Many elongate inclusions, arranged on trigonal pattern and parallel to c-axis.

g. Zircon : Same three types as in V. 3 II, with Type III predominating.

6. ABSOLUTE AGE

680 ± 68 MY. This result is incorrect; contamination has probably occurred. See Section 2.

1. SAMPLE NUMBER - V. 5

2. LOCALITY

Port Elliot, 1/4 mile east of Bay, in old quarry.

3. PETROGRAPHY

An even-grained biotite granite. Anhedral quartz and kaolinized microcline are the main constituents, with small amounts of zoned oligoclase (with some albitic peripheries), and brownish-green biotite altering to chlorite. Slight stress is evident in the minerals. Sphene, apatite and zircon are the accessories; some pyrite occurs also.

4. HEAVY ACCESSORIES

Ferromags	:	Magnetite; pyrrhotite.
0.1 A. Mag.	:	Pyrrhotite; ilmenite; chalcopyrite; haematite;
0.2 A. Mag.	:	Ilmenite; pyrite; pyrrhotite; chalcopyrite.
0.5 A. Mag.	:	Opaques (3); monazite (3); tourmaline (1); garnet (Tr.); zircon (Tr.)
0.8 A. Mag.	:	Oxidized pyrite (4); tourmaline (1); monazite (1); zircon (Tr.)
0.8 A. Non Mag.	:	Pyrite (4); molybdenite (1); apatite (1); zircon (4-5)

5. FEATURES

a. Monazite: Small, rough, cloudy; euhedral to subhedral.

b. Garnet : Pale pink, rounded, detrital grains.

c. Molybdenite : Small, hexagonal, lamellar crystals.

d. Zircon : Three types -

I. Clear, colourless, unzoned, small. L : B normal (2 : 1 or 3 : 1) but can be up to 5 : 1. Rare.

II. Well-rounded, of sedimentary origin. Rare.

III. Usually small and even-sized. Clear to cloudy, pale mauve; some show overgrowths. L : B normal, but up to 5 : 1 observed. Predominant.

6. ABSOLUTE AGE

Insufficient zircon for determinations.

1. SAMPLE NUMBER - T.B.9

2. LOCALITY

Murray Bridge; West bank of R. Murray, South of the bridge, in old quarry.

3. PETROGRAPHY

A coarsely-crystalline microcline-granite with characteristic granitic texture. Slightly stressed microcline-perthite, subhedral quartz, and lesser amounts of oligoclase are the principal minerals. Small patches of brownish-green biotite are associated with fluorite, opaques, sphene and zircon. This rock contains "cognate xenoliths" of microgranite, some of it porphyritic and carrying zoned microcline. Other parts of the outcrop show "basic clots" - concentrations of ferromagnesian minerals (hornblende and biotite) and accessories.

4. HEAVY ACCESSORIES

Ferromags : Titaniferous magnetite.
0.1 A. Mag. : Ilmenite; traces of chalcopyrite.
0.5 A. Mag. : Apatite (Tr.); ? monazite (Tr.); zircon (Tr.).
0.8 A. Mag. : Sphene (4-5); apatite (Tr.)
1.4 A. Mag. : Sphene (Tr.); apatite (1); fluorite (1); zircon (1).
1.4 A. Non Mag., LF MeI : fluorite (4).
Zircon : Pure zircon of two types.

5. FEATURES

a. Magnetite : Titaniferous, with orientated plates of ilmenite.

b. Apatite : Some crystals have dark centres and are more magnetic than the colourless ones.

c. Fluorite : Colourless to pale purple, occasionally bright purple.

d. Zircon : Three types -

I. Yellow to brown, zoned crystals. Occur in 1.4 A. Mag. fraction.

II. Clear, faint yellow to colourless, zoned. Sharply-defined faces, L : B up to 6 : 1, commonly 5 : 1. Inclusions random, and also parallel to c-axis.

III. Large, cloudy, pinkish. Cracked, with incipient alteration, lowered birefringence. Outgrowths and overgrowths not rare.

6. ABSOLUTE AGE

545 ± 55 MY. This result is unreliable, due to probable contamination. See Section 2.

1. SAMPLE NUMBER - C. W. 2

2. LOCALITY

Binnie's Water, 16 miles E. of Meningie, N. of Meningie-Coonalpyn road.

3. PETROGRAPHY

A reddened, medium-grained granite, consisting of reddened, altered microcline, fresh intermediate oligoclase (less than 1/3 of microcline) and quartz. Occasional laths of dark, brownish-green biotite occur. A rock devoid of unusual features, though the various outcrops in the whole area show much textural and some mineralogical variation. A common feature is the magmatic reddening.

4. HEAVY ACCESSORIES

Ferromags ! Titaniferous magnetite; trace of chalcopyrite.
0.1 A. Mag. : Ilmenite; minor amount of chalcopyrite.
0.3 A. Mag. : Fluorite (Tr.)
0.5 A. Mag. : Zircon (Tr.)
0.8 A. Mag. : Zircon (2).
1.4 A. Mag. : Zircon (3).
1.4 A. Non Mag., LF MeI : Fluorite (4-5); apatite (Tr.); zircon (Tr.)
1.4 A. Non Mag., HF MeI : Fluorite (Tr.); zircon (5).

5. FEATURES

a. Magnetite : Titaniferous, with orientated plates of ilmenite.

b. Fluorite : Mainly colourless, some is patchy and purple.

c. Zircon : Three types -

I. Small, euhedral malacons; brown, altered, metamict, with low birefringence and often with opaque cores. Abundant.

II. Medium to small, euhedral. Cracked, zoned, with lowered birefringence. Uncommon.

III. Colourless, zoned, altered, with opaque cores. Some parallel twins. ? Related to type I. Rare.

6. ABSOLUTE AGE

440 ± 44 MY.

1. SAMPLE NUMBER - M. P. 1 (Moonta Porphyry)

2. LOCALITY

Bald Hill, 3 miles E. N. E. of Moonta.

3. PETROGRAPHY

A porphyritic rhyolite or toscanite, though the grain size is on the border line between the fine-grained and medium-grained rocks, so that the terms microgranite or micro-adamellite could be applied. The glomeroporphyritic crystals of sodic oligoclase, albite, and albite-microcline antiperthite are set in a groundmass consisting of granular quartz and alkali feldspar, and of micrographic intergrowths between these. Wispy biotite, chlorite and opaques occur in the groundmass. Magmatic reddening is conspicuous.

4. HEAVY ACCESSORIES

Ferromag	:	Magnetite
0.1 A. Mag.	:	Magnetite; ilmenite; haematite; trace of chalcopyrite.
0.3 A. Mag.	:	Opaques (4); tourmaline (Tr.)
0.5 A. Mag.	:	Opaques (4); tourmaline (Tr. -1); epidote group (Tr.)
0.8 A. Mag.	:	Tourmaline (3-4); apatite (Tr.); zircon (Tr.); fluorite (Tr.)
1.4 A. Mag.	:	Tourmaline (1); fluorite (1); zircon (2).
1.4 A. Non Mag.	:	Pyrite (1); fluorite (2); apatite (3-4); rutile (Tr.) zircon (3).

5. FEATURES

a. Tourmaline : Variety schorl. Many well-rounded grains occur.

b. Fluorite : Patchy purple colours.

c. Apatite : Large, rough grains with many inclusions

d. Rutile : Rounded brown-red grains

e. Zircon : Three types -

I. Euhedral, colourless, clear.) uncommon.
II. Anhedral, colourless, clear.)

III. Yellowish or pinkish, translucent, altered, rounded. Abundant. Heavy minerals indicate strong contamination by sediments with detrital zircon, rutile, and tourmaline.

6. ABSOLUTE AGE

Insufficient zircon for determination.

1. SAMPLE NUMBER - St. 1

2. LOCALITY

Stenhouse Bay, Yorke Peninsula.

3. PETROGRAPHY

A quartzo-feldspathic paragneiss with heteroblastic texture. Large, sub-to anhedral areas of quartz, microcline, orthoclase-microperthite, and oligoclase, are in contrast to interstitial, medium - to fine-grained mosaics of the same minerals. The "dark" minerals are usually associated in groups - aggregates of reddish biotite with opaques, apatite, poikiloblastic sphene, rounded zircon, and occasional green hornblende. This rock is an Archaean metasediment.

4. HEAVY ACCESSORIES

Ferromags : Titaniferous magnetite
LF MeI : Apatite (Tr. -1).
HF MeI : Pyrite (3); hornblende (3-4); sphene (2); apatite (2); zircon (2-3).

NOTE - The bromoform concentrate was not passed through the Franz Separator because the rock, being a metasediment, was not considered suitable for determination of absolute age.

5. FEATURES

a. Hornblende : 2V = 0 or very small; blue-green/yellow-green pleochroism strong, probably closely related to arfvedsonite or ferrohastingsite. Characteristic of Archaean meta-sediments of Yorke Peninsula, from Pt. Victoria to Stenhouse Bay. Especially common in Brutus Castle hornblende gneiss.

c. Zircon : Three types, all detrital -

I. Rough, ragged, metamict, altered, with patchy birefringence. Abundant.

II. Brownish, zoned, subhedral, clear to cloudy. Common.

III. Unzoned, clear, sub - to anhedral. Rare.

6. ABSOLUTE AGE

See note above.

1. SAMPLE NUMBER - Nep. 1

2. LOCALITY

Harbours Board jetty piling bore, offshore from Neptune Island.

3. PETROGRAPHY

An augen-gneiss. Phacoids of strained quartz are flanked by medium-grained, anhedral, sutured aggregates of quartz, orthoclase, microcline and plagioclase (albite to andesine, but mainly calcic oligoclase). Thin layers of lineated brown biotite and green hornblende have grains of apatite and zircon in association. Myrmekite is common. This rock is a gneissose metasediment.

4. HEAVY ACCESSORIES

Ferromag : Magnetite, with orientated plates of ilmenite.
0.5 A. Mag. : Opaques (3); garnet (3); zircon (Tr.)
0.7 A. Mag. : Sphene (Tr.) garnet (1-2); apatite (1); zircon (2-3).
1.0 A. Mag. : Apatite (2-3); zircon(3-4).
1.4 A. Mag. : Apatite (2-3); zircon (4).
1.4 A. Non Mag., LF MeI : Apatite (4); zircon (Tr.)
Zircon fraction : Zircon (5).

5. FEATURES

a. Apatite : Most grains and fragments are colourless, but some in each fraction are a pale yellow colour.

b. Zircon : These are all conspicuously rounded or well - rounded. They are very variable in shape and size. Zoning is prominent. Alteration is extensive, the grains showing patchy, low birefringence. Overgrowths are common.

6. ABSOLUTE AGE

Though the rock is a metasediment, an attempt was made to determine the age of the zircon. However, the techniques of preparation and analyses of zircons were faulty in the early stages (when the determination was made) and the results were quite erroneous.

1. SAMPLE NUMBER - Pal. 1

2. LOCALITY

Palmer Granite, Mt. Lofty Ranges.

3. PETROGRAPHY

A medium grained quartzo-feldspathic rock of granitoid aspect but of sedimentary origin. Very poorly-twinned subhedral, poikiloblastic oligoclase with well-developed cleavage, and anhedral, stressed quartz are the two most abundant minerals. Microcline is scarcer, and it is often seen as anhedral grains surrounding the oligoclase; myrmekite is common at the boundaries of the two feldspars. Biotite occurs as large green laths, and green hornblende is sometimes seen. Opaques are surrounded by sphene, which also occurs as large, rough, poikiloblastic grains. Apatite is present, and grains of zircon are well-rounded.

4. HEAVY ACCESSORIES

Ferromag : Magnetite
0.5 A. Mag: Opaques (2); hornblende (3); sphene (3); epidote group (3); rutile (Tr.) zircon (1-2).
1.2 A. Mag: Sphene (5); zircon (Tr.); epidote group (Tr.)
1.4 A. Mag: Sphene (5).
1.4 A. Non Mag. : Zircon (5).

5. FEATURES

a. Hornblende : Very dark green, strongly pleochroic olive/dark green/nearly black. 2V is very small, nearly 0° in some cases. (see remarks under St. 1)

b. Sphene : Pleochroic from colourless to pale yellow, sometimes yellow to amber. Far less magnetic than normal (usually magnetic at 0.8 A.).

c. Zircon : Two types -

I. Cracked, zoned, colourless to mauve, with uneven birefringence. Well-rounded, with rare subhedral grains.

II. Clear, colourless, with cavities and inclusions. Some subhedral overgrowths over rounded core are seen.

6. ABSOLUTE AGE

Incorrect results.

1. SAMPLE NUMBER - Mon. 1

2. LOCALITY

Monarto Granite, Mt. Lofty Ranges.

3. PETROGRAPHY

A granitoid rock, consisting of approximately equal proportions of sub - to anhedral quartz, microcline and oligoclase. The microcline shows sieve-texture, enclosing blebs of quartz. Laths of green biotite are randomly distributed and are generally poikiloblastic. Opaques, zircon, apatite and monazite are associated with the biotite. Since the zircon is well-rounded, a sedimentary origin for the rock is favoured; it could well be a rheomorphic rock, perhaps approaching the magmatic stage.

4. HEAVY ACCESSORIES

Ferromag : Titaniferous magnetite; martite.
1.0 A. Mag. : Monazite (5); apatite (Tr.); zircon (Tr.)
1.0 A. Non Mag. : Apatite (3-4); zircon (1-2).

5. FEATURES

a. Monazite : yellow, tabular, well-formed crystals. Faint zoning is sometimes seen.

b. Apatite : is sometimes seen as overgrowths on monazite. Good crystals and grains.

c. Zircon : Conspicuously well-rounded, usually small. Zoned, colourless to pale mauve. A few grains show striated prism faces.

6. ABSOLUTE AGE

Not determined; insufficient zircon.

1. SAMPLE NUMBER - I. Q. S. 1

2. LOCALITY

Iron Queen South (near Mines Department camp), Middleback Ra., Eyre Peninsula.

3. PETROGRAPHY

A sheared, granitoid rock. The constituent minerals show strain and peripheral granulation. Quartz occurs in areas of interlocking grains with undulose extinction, microcline is altered and distorted, and small amounts of altered calcic oligoclase are seen. Secondary, fresh and unstressed microcline occurs interstitially, and there are traces of secondary (or late-stage) muscovite. The rock contains practically no ferromagnesian minerals or accessories, and it may be more in the nature of a pegmatite or a quartzofeldspathic metasediment. Heavy-mineral studies favour the latter alternative.

4. HEAVY ACCESSORIES

Ferromags : Haematite; limonite.
HF Bromoform : Pyrite, haematite (3); sphene/leucoxene (3); zircon (1-2)

5. FEATURES

The main feature of the heavy accessories is their great scarcity. Consequently no attempt was made to further separate the bromoform heavy fraction. The zircons are white, opaque and metamict, and are anhedral. Whether the anhedral nature of the grains is due to detrital rounding or is a tendency inherent in metamict zircons is difficult to determine in this particular case. The great lack of heavy minerals of any type is significant, and in the writer's opinion favours a sedimentary origin for the rock.

6. ABSOLUTE AGE

Insufficient zircon for determinations.

Sample Number	Pyrite	Molybdenite	Rutile	Sphene	Monazite	Fluorite	Apatite	Zircon	Tourmaline	Others
K. 8	-	-	x	-	-	x	x	x(3)	x	-
K. 10	-	-	-	x	-	x	x	x(3)	-	-
K. 12	-	-	x	-	-	-	x	x(2)	-	-
K. 13	-	-	-	x	-	x	x	x(3)	-	Staurolite
K. 15	x	-	x	x	x	-	x	x(4)	-	-
K. 16	-	-	x	-	-	x	x	x(1)	-	Anatase
K. 20	-	-	-	-	-	-	x	x(3)	-	-
K. 21	x	-	-	-	-	x	x	x(1)	-	Orthite
K. 22	x	-	-	-	x	x	x	x(1)	-	Anatase
K. 23	-	-	-	x	-	-	x	x(2)	-	Staurolite
K. 24	-	x	x	-	x	x	x	x(1)	-	-
K. 26	-	-	-	x	-	x	x	x(2)	-	(Uranium (Mineral
K. 27	x	-	-	x	-	-	x	x(1)	-	-
K. 29	-	-	-	x	-	-	x	x(1)	-	-
V. 3 II	x	x	x	x	x	-	x	x(3)	x	Gold
V. 4	x	x	-	x	x	-	x	x(3)	x	(Staurolite (Garnet
V. 5	x	x	-	-	x	-	x	x(3)	x	Garnet
C. W. 2	-	-	-	-	-	x	x	x(3)	-	Chalcopyrite
T. B. 9	-	-	-	x	-	x	x	x(2)	-	Chalcopyrite
M. P. 1	x	-	x	-	-	x	x	x(3)	x	-
St. 1	x	-	-	x	-	-	x	x(3)	-	-
Nep. 1	-	-	-	x	-	-	x	x(1)	-	Garnet
Pal. 1	-	-	x	x	-	-	x?	x(2)	-	-
Mon. 1	-	-	-	-	x	-	x	x(1)	-	-
I. Q. S. 1	x	-	-	x	-	-	-	x(1)	-	-

MAGNETIC DATA ON MINERALS

using the

FRANTZ ISODYNAMIC SEPARATOR

The following table gives an indication of the magnetic characteristics of mineral grains in the Frantz Isodynamic Separator. Normally, the separations are done with the chute set at the following angles :

slope 20^0
tilt 15^0

where the "slope" is the inclination of the long axis of the chute to the horizontal and the "tilt" is the inclination of the transverse axis of the chute to the horizontal. Unless otherwise stated, the above settings were used. Many of the minerals listed here were not specifically examined for magnetic susceptibility, the idea being more to find field-strength settings on the instrument which would progressively remove minerals other than zircon and other non-magnetic minerals, with maximum efficiency. Too high a current-setting at the outset of a series of passes, would cause such a flood of material on the magnetic side that much valuable zircon would be entrapped. In any case, from the point of view of age-determinations, it may be necessary to use monazite, or even sphene or apatite, if the zircon sample is too small for analytical work.

The table lists the minimum and maximum current-settings at which a mineral occurs in a fraction, and also the normal range for that mineral. These data apply to the fractions prepared and described in this thesis.

Mineral	Min. Amps.	Max. Amps	Normal Amps.
Allanite	0.5 A	1.4 A +	0.8 - 1.4 A
Anatase	0.8 A	1.4 A +	1.4 A +
Apatite	0.8 A (0.3 A with inclusions)	1.4 A +	1.4 A +
Biotite	0.2 A	1.4 A (phlogopite)	0.3 - 0.5 A
Chalcopyrite	0.1 A - probably contains inclusions	0.2 A	0.1 A
Epidote	0.3 A	0.8 A	0.5 A
Fluorite	0.8 A	1.4 A +	1.4 A +
Garnet	0.3 A +	0.5 A	0.5 A
Gold	Non-magnetic at highest setting		
Hornblende	0.3 A	0.7 A	0.3 - 0.5 A
Molybdenite	Non-magnetic at highest setting		
Pyrite	Non-magnetic at highest setting		
Rutile	1.0 A Amber to brown	1.4 A + yellow	1.4 - 1.4 A +
Sphene (See note on sphene in Section 3)	0.3 A	1.7 A	0.8 - 1.4 A
Staurolite	0.1 A (with inclusions)	1.4 A	0.5 - 0.8 A
Tourmaline	0.5 A	0.8 A	0.8 A
Zircon	Normally non-magnetic at highest setting, but altered and metamict varieties are magnetic at 1.4 A or lower settings (down to 0.8 Amp.).		

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LOCALITY INDEX

Sample		Locality
K. 8	N. Flinders Ra.,	5 mi. of Mt. Fitton H. S.
K. 10	" " "	7 mi. NW. of Mt. Fitton H. S.; Mudlawatana Creek.
K. 12	" " "	1 mi. along Paralana Hot Springs Creek from Hot Springs.
K. 13	" " "	Yudnamutana Gorge, E. bank.
K. 15	" " "	Blue Mine Creek, Camel Pad track. 6 miles E. NE. of Umberatana H. S.
K. 16	N. Eyre Peninsula	6 miles W. of Corunna H. S.
K. 20	" " "	35 miles SW. of Whyalla on highway.
K. 21	" " "	Pine Hill, 46 miles SW. of Whyalla.
K. 22	" " "	Carippie Hill, 6 miles NE. of Darke Peak.
K. 23	" " "	Calca Bluff, Baird Bay, 12 miles SE. of Streaky Bay.
K. 24	" " "	10 miles E. of Wilgena.
K. 26	Moorilyanna Soak	30 miles W. of Granite Downs.
K. 27	Musgrave Ra.,	5 miles E. NE. of Ernabella Mission.
K. 29	Peake and Denison Ra.,	8 miles SE. of Edwards Creek R. S.
V. 3 II	Encounter Bay	Granite Island
V. 4	" "	Pt. Elliot West
V. 5	" "	Pt. Elliot East
T. B. 9	Murray Bridge	W. Bank of R. Murray, south of town.
C. W. 2		16 miles E. of Meningie along Coonalpyn road N. side.
M. P. 1	Bald Hill	Section 1732 e miles E. NE. of Moonta.
St. 1	Stenhouse Bay	Yorke Peninsula
Nep. 1	Neptune Island	Offshore Bore (for jetty pilings)
Pal. 1	Mt. Lofty Ra.	Monarto Granite
I. Q. S. 1	Iron Queen South	Eyre Peninsula
