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HEAVY MINERALS IN THE LATE CAINOZOIC SEDIMENTS OF SOUTHEASTERN SOUTH AUSTRALIA

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1. Graphic logs showing carbonate content, and heavy-mineral abundances, and suites in samples in BMR drill holes.

SUMMARY

A study of the heavy minerals in the late Cainozoic sediments of southeastern South Australia has been made using 295 subsurface and surface samples. The nature, abundance and provenance of the suite have been determined and indicate likely source areas of the sediments. In general, concentrations of heavy minerals are low, partly as a result of the high content of locally derived biogenic carbonate in many of the sediments. Concentrations rarely exceed 0.5 percent by weight and commonly are below 0.1 percent. The highest recorded concentrations (up to 1.2 percent total heavies) occur in an unconsolidated calcareous sand unit of probable Pliocene age which underlies the beach and dune deposits. Throughout the region the suite typically consists of between 25 and 45 percent magnetite and ilmenite combined, 5 and 20 percent leucoxene, 5 and 25 percent zircon, 5 and 30 percent tourmaline, and between 0 and 10 percent of amphibole, of epidote, of rutile and of garnet. Andalusite, sillimanite, kyanite and staurolite occur as minor components in many assemblages. Sialic igneous, reworked sedimentary, metamorphic and to a slight extent mafic igneous components are present. Sources include the igneous rocks of the Padthaway Ridge, the volcanic rocks of the Mount Gambier area, the metamorphic and sedimentary rocks of the Fleurieu Peninsula and Kangaroo Island, and reworked Tertiary and other sediments. Intrastratal solution appears to have partly removed chemically unstable heavy mineral components from the relatively old inland beach and dune deposits.

INTRODUCTION

Heavy minerals (specific gravity greater than 2.85) occur as a minor component in the terrigenous fraction of virtually all sediments. This record summarizes an investigation of the nature, abundance, and provenance, of the heavy minerals in 295 samples of the late Cainozoic sediments of southeastern South Australia. The investigation forms part of a joint study of the stratigraphy and sedimentology of the region presently being undertaken by BMR, Flinders University, ANU and the South Australian Department of Mines, and aims to aid the understanding of the provenance and genesis of the sediments, in addition to providing some indication of the region's heavy mineral potential.

During 1974 and 1975 BMR undertook stratigraphic drilling in the Robe-Naracoorte and Bordertown areas. Forty-five holes ranging in depths from 10 to 63 m were drilled through the Quaternary and uppermost Tertiary sediments (Fig. 1).

Previous Work

Aspects of the geology and geomorphology of southeastern South Australia have been described by a number of workers including Tindale (1933, 1947, 1959), Hossfeld (1950), Sprigg (1948, 1952, 1958), De Mooy (1959) and Firman (1967 a & b, 1973). Sprigg's (1952) paper provides the most comprehensive study and includes a discussion of coast-line migrations and modern beach development. A preliminary paper discussing the revised geology of the region following the BMR drilling is presently in preparation (Cook et al., 1977).

Several mineral sand mining companies have held exploration leases over parts of the region at various times but only very limited exploration work appears to have been undertaken to date.

Regional Geology

Generalized cross-sections based on the BMR drilling are shown in Figure 2. Throughout the southern part of the region gently north-westerly dipping Gambier Limestone of Oligocene to Miocene age (Ludbrook, 1969) underlies the Pliocene, Pleistocene and Holocene sediments. However, north of a line approximately between Kingston and Padthaway, early Palaeozoic igneous rocks of the Padthaway Ridge form a shallow basement which crops out west and northwest of Bordertown.

An unconsolidated calcareous sand unit of probable Pliocene age overlies the Gambier Limestone throughout much of the eastern part of the region. This is in turn overlain by Quaternary beach and dune deposits which form a series of 'ranges' parallel to the present coast and separated by estuarine and lacustrine deposits. In the southwestern part of the region the calcareous sand unit is absent and the beach and dune deposits directly overlie the Gambier Limestone. West of Bordertown the beach and dune deposits are draped over granite basement highs.

On the eastern (upthrown) side of the Kanawinka Fault (Fig. 2) the Gambier Limestone is overlain by the Parilla Sand (Firman, 1973), a unit of Pliocene age consisting mainly of clay-rich sand. The Parilla Sand is partly overlain by an unconsolidated, aeolian quartz sand (the Molineaux Sand of Firman, 1973) which extends in some areas to the west of the Kanawinka Fault.

In the south of the region, late Cainozoic volcanics consisting mainly of ejectamenta occur in a trend extending northwest from Mount Gambier to Mount Graham, a distance of approximately 50 km (Fig. 7).

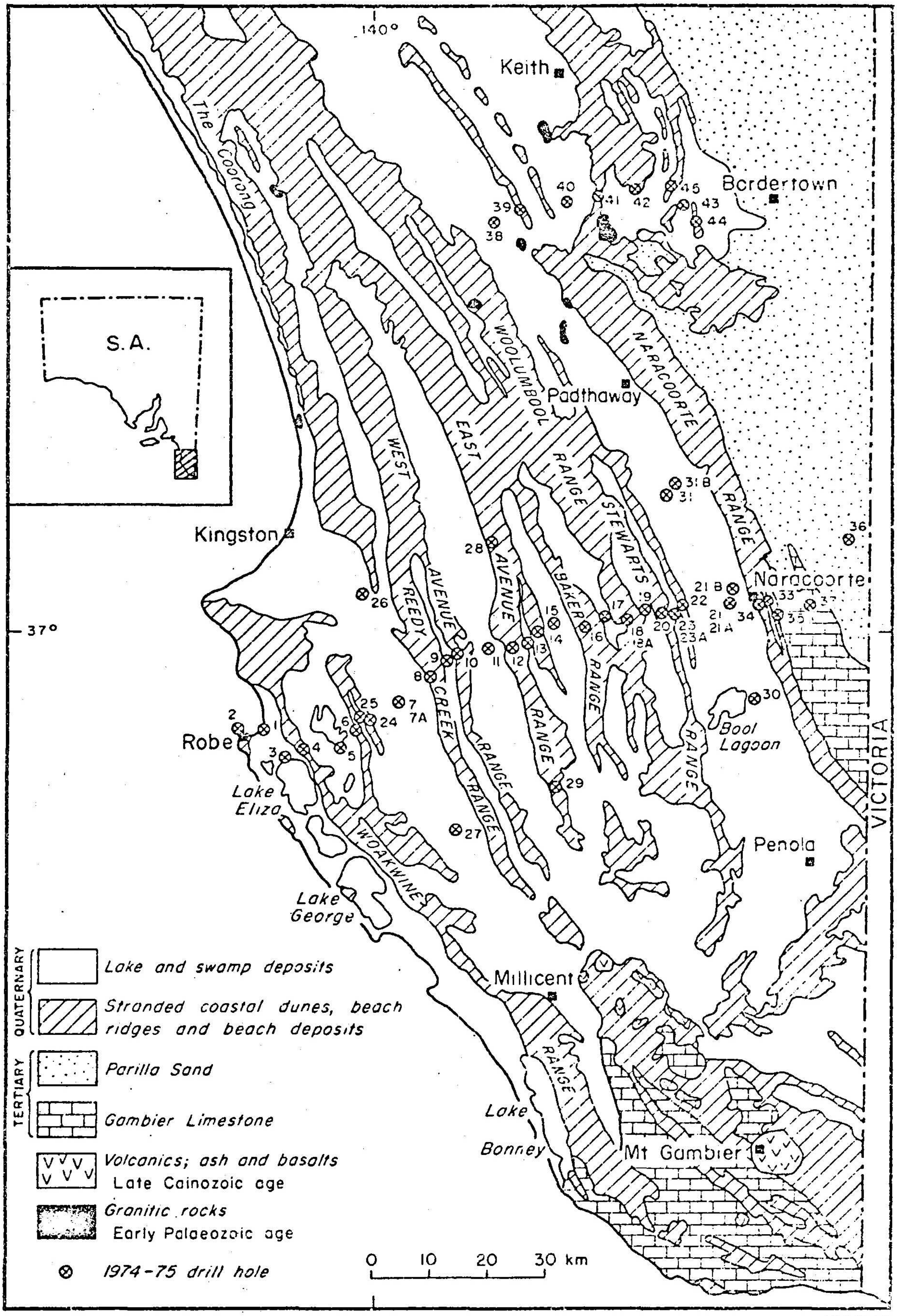

Figure 1. Surface geology and location of drill holes.

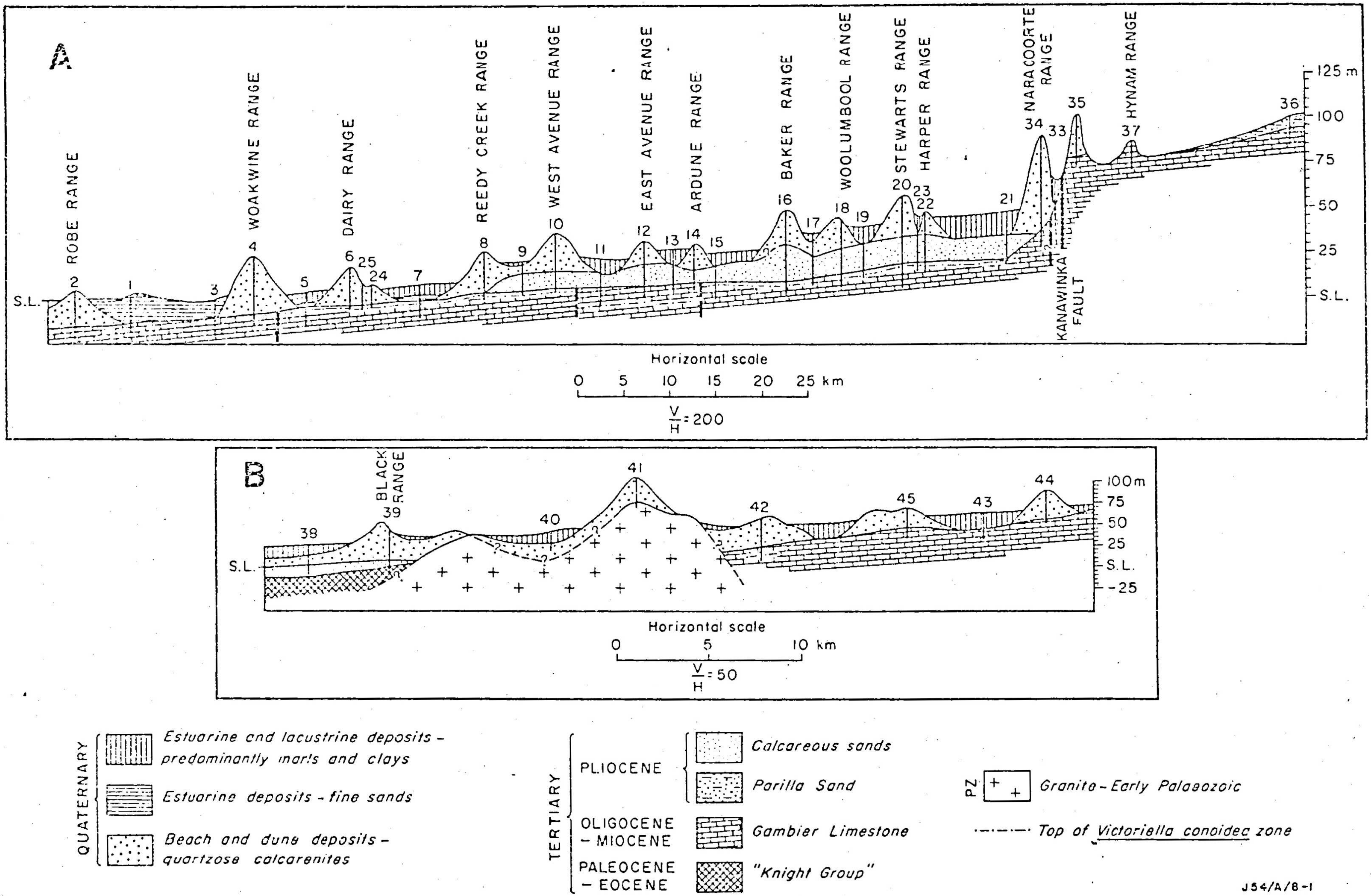

Figure 2. Sections through the late Cainozoic sequence.

FIELD AND LABORATORY PROCEDURES

Sediments

Samples of the late Cainozoic sediments used in this study come mainly from drill-core material and it was therefore possible to cover both the lateral and vertical sequences. Additional samples were collected from exposures in road cuttings and quarries at points along the dunes north and south of the line of drill holes. Several dozen samples of modern beach and stream sediments were also collected.

Drill core samples were selected to include the range of lithologies encountered in each of the holes. Particular attention was paid to horizons in which terrigenous material appeared relatively abundant or in which there was some possibility that the sediments had been reworked. No seams of heavy mineral were encountered in any of the holes drilled.

All samples were oven dried and approximately 200 g split, weighed and treated with dilute hydrochloric acid to remove carbonate cement and biogenic clastic components. Total carbonate content was calculated by weight loss. The non-carbonate residue was split to approximately 20 g, weighed, and the light and heavy minerals separated using bromoform (tribromomethane, specific gravity 2.85). In a small proportion of the samples it was then necessary to treat the heavy minerals with weak (0.2 M) oxalic acid to remove obvious iron oxide components (often iron oxide replacing biogenic carbonate) and surface stains. The heavy-mineral residue was weighed and recorded as a weight percent of both the total sediment and the terrigenous fraction.

The heavy minerals separated from each of the samples were split and then mounted on a glass slide using 'De Pex' mounting medium (R.I. 1.524). Because only a small quantity of heavy mineral was extracted from most of the samples, no attempt was made to sieve-fraction the grains prior to mounting. In any case, only in a very few samples were grains present outside the commonly analysed size range of 0.5 to 0.03 mm. Those grains larger than 0.5 mm were generally garnet whereas those less than 0.03 mm were generally too small for practical study.

The percentage of each mineral in the heavy-mineral suite was determined by counting in 'ribbon' traverses using a mechanical stage. Approximately 300 grains were counted per slide. This number was considered an optimum with respect to accuracy and time involved as the accuracy of the count increases only as the square root of the number of grains counted (Dryden, 1931). The curves of Dryden indicate that for a count of between 300 and 400 grains there is approximately 10 percent error for constituents in amounts of about 10 percent and progressively smaller errors for more abundant components. In a small number of the samples the total heavy-mineral fraction was well below the required number of 300 grains and in these cases no attempt was made at quantitative determinations.

In a few samples mica was present as a minor component. As quantification of mica abundance is difficult owing to its similarity in density to bromoform, counts of mica grains were omitted and percentages recalculated to 100 percent. Weight percentages of the amount of heavy mineral were recalculated accordingly in these cases.

The unmounted portion of the heavy-mineral fraction was examined in reflected light to determine the approximate composition of the opaque fraction. In each sample, more than 100 representative opaque grains were classed either as magnetite or ilmenite, iron oxide (hematite and limonite), leucoxene, or pyrite. The number percentage of each of these classes of opaque minerals in the total heavy-mineral suite was then calculated. For samples containing iron oxide in the opaque fraction (usually in minor amounts after oxalic acid treatment), percentages of the various heavy minerals were recalculated on an iron-oxide-free basis. No attempt was made to distinguish ilmenite from magnetite because of their close similarity in reflected light.

A detailed discussion of the accuracy of heavy-mineral analysis techniques is given by Hubert (1971). Although errors may arise as a result of splitting the bulk samples, separating, micro-splitting and mounting the heavy minerals, and identifying and counting the minerals, the greatest source of error appears to arise from counting a limited number of grains. This error is considered to have been reduced to an acceptable level in this study.

Igneous rocks of the Padthaway Ridge

Samples representative of the several igneous rock types exposed on the Padthaway Ridge were collected. Chips of rock were removed from an area of several tens of square metres or less depending upon the size of the exposure and the uniformity of the rock. Samples were lightly crushed in a jaw crusher and the material split and sieved into three size fractions: 35-80 US Standard Mesh (0.500-0.177 mm); 80-170 mesh (0.177-0.088 mm); and -170 mesh (-0.088 mm).

Heavy minerals in each of the sieved fractions were recovered by heavy-liquid separation. The ferromagnetic components (magnetite and hematite) were then extracted with a hand magnet and the residue mounted on glass slides using 'De Pex' mounting liquid. A semiquantitative abundance notation after Hutton (1950) was used.

Samples of the rock were thin sectioned.

Volcanic rocks of the Mount Gambier area

Samples of the ash and basalt which form the deposits of the Mount Gambier volcanic province were collected from a number of sites between Mount Gambier and Mount Graham. Extraction of the heavy minerals from these rocks was only partly successful due to the difficulty in separating groundmass components. Heavy minerals occurring as phenocrysts (notably olivine) could, however, be readily separated. All samples were thin sectioned.

NATURE OF THE SEDIMENTS

Unlike the Quaternary beach and dune deposits of the eastern coast of Australia which are predominantly quartzose, the sediments of southeastern South Australia are in general calcareous. This difference is important geomorphologically, for the calcareous sands tend to become lithified by carbonate cement to form calcarenite, whereas the quartzose sands remain largely unconsolidated and are therefore relatively susceptible to rearrangement or dispersal by wave and wind action. Depending upon the degree of lithification, the calcareous beach and dune deposits have a relatively good chance of preservation during sea-level change particularly if they are located in a region such as southeastern South Australia which has undergone gentle regional uplift.

The highly calcareous nature of many of the late Cainozoic sediments occurring in southeastern South Australia is shown in Plate 1 (in pocket), and is discussed in the following descriptions of the major sedimentary units.

Calcareous sands

Unconsolidated fine and very fine-grained calcareous sands of probable Pliocene age overlie the Gambier Limestone in the Robe-Naracoorte area east of the Reedy Creek Range and west of the Naracoorte Range (Fig. 2). Similar sands, probably deposited under very shallow marine conditions, overlie Early Tertiary 'Knight Group' (Ludbrook, 1971) sediments on part of the Padthaway Ridge west of Bordertown. The thickness of the sands ranges from 8 m (Hole 14) to 17 m (Hole 16).

The amount of acid-soluble carbonate in these sands varies considerably (Pl. 1). It generally exceeds 40 percent by weight of the material, although in Hole 21 the upper part of the unit contains less than 10 percent carbonate and has a corresponding slight increase in heavy-mineral abundance.

Clay-rich sands (Parilla Sand)

Unlike the majority of the sediments of the region, the clay-rich sands which overlie the Gambier Limestone east of the Kanawinka Fault, are for the most part only slightly calcareous. They were probably deposited under lacustrine and fluvial conditions during the Pliocene (Firman, 1973). Twelve metres of the unit was intersected in Hole 36.

Beach and dune quartzose calcarenites

The beach and dune deposits which form the extensive series of ranges characteristic of the region are predominantly quartzose calcarenites composed of fragmental biogenic carbonate (bivalves, gasteropods, algae, bryozoa, forams, etc.), varying amounts of quartz, and carbonate cement. The deposits, which are in some cases composite, range up to 50 m in thickness (Hole 34).

The farthest inland and presumably oldest beach and dune deposits in the region occur to the west of Bordertown (Hole 38 to 45). In general, carbonate makes up between 30 and 60 percent of these deposits which tend to be moderately to well indurated (carbonate cement) and strongly ironstained.

In the Robe-Naracoorte dune and beach ridge sequence, sediments become slightly more calcareous as the coast is approached (Pl. 1). The calcarenites of the dunes situated well inland rarely contain more than 70 percent-by-weight carbonate whereas those of the Robe, Woakwine and Dairy Ranges invariably contain over 65 percent carbonate. This regional trend probably reflects prolonged leaching of carbonate from the older, more inland deposits.

Much of the upper part of the beach and dune sequences forming the West Naracoorte and Baker Ranges (Holes 34 and 16 respectively) contain particularly low amounts (less than 10 percent) of carbonate and are virtually pure quartz sands. Carbonate increases with depth suggesting that the upper parts have undergone extensive and prolonged leaching.

Lacustrine and estuarine clays and marls

Clays and marls deposited under lacustrine and estuarine conditions are the principal interdune deposits of the region. The amount and composition of the carbonate and the thickness of the deposits vary considerably. Non-calcareous clays commonly alternate with thick sequences of marl. Calcrete occurs as a minor component in many of the deposits and in Hole 43 comprises approximately 25 percent of the sequence.

Estuarine fine sands

Sands of probable estuarine origin are the principal interdune deposits between the Robe and Woakwine Ranges north of Lake Eliza. They are calcareous, fine to medium-grained and largely unconsolidated sands with a thickness of 10 to 15 m. Biogenic carbonate makes up over 70 percent of the sediment.

Aeolian quartz sands (Molineaux Sand)

Aeolian quartz sands occur as minor, unconsolidated, surficial deposits on the flanks (particularly the eastern flank) of many of the 'ranges' as well as extending as a series of sand sheets and east-southeast-trending dunes across much of the eastern part of the region. Carbonate is virtually absent.

NATURE AND ABUNDANCE OF THE HEAVY-MINERAL SUITE

The nature and abundance of heavy minerals in a sediment are functions not only of the geology of the source areas, but also of a number of other factors. These include selective sorting due to different hydraulic equivalent sizes, the size distribution of the heavy minerals in the source rocks, and the chemical and physical stability of the minerals. The effect of these factors in determining the suite present in the sediments examined in this study is discussed in following sections of this report.

Heavy minerals can be classified into four main groups (Folk, 1968):

(i) the opaque heavies - magnetite, ilmenite, leucoxene, hematite limonite and pyrite;

(ii) the ultrastable group - zircon, tourmaline, and rutile;

(iii) the metastable group which includes amphibole, epidote, monazite, kyanite, sillimanite, garnet, apatite, staurolite, olivine and pyroxene;

and (iv) the micas which are generally not included in quantitative studies because complete separation from the light fraction is seldom achieved.

Of these minerals rutile, ilmenite and leucoxene are important sources of titanium, zircon contains zirconium, and monazite contains the rare earths and thorium.

Of the 295 samples examined 261 are from drill cores and 34 from surface sites. Thirty five samples contained insufficient heavy minerals to allow accurate quantitative determination of the composition of the heavy mineral fraction.

Nature of the suite

The same minerals occur as major components in the heavy-mineral assemblages of virtually all of the samples of the late Cainozoic sediments. Most of the variation between samples occurs as variation in the proportions of the major mineral components and in the presence or absence of certain minerals as minor components. Gross variations are rare.

Throughout the region the suite typically consists of between 25 and 45 percent magnetite-plus-ilmenite, 5 and 20 percent leucoxene, 5 and 25 percent zircon, 5 and 30 percent tourmaline, and between 0 and 10 percent of amphibole, of epidote, of rutile and of garnet (Fig. 3). Framboidal pyrite occurs as a major component in a few of the estuarine and lacustrine deposits. Andalusite, kyanite, sillimanite and staurolite are of common occurrence, generally in amounts of one or two percent (Table 1, Fig. 3). Topaz, zoisite, apatite, monaxite, pyroxene, sphene, olivine, fluorite, and ?monticellite occur in some of the assemblages, always in trace amounts.

The full composition of the heavy-mineral assemblage in each sample is given in Appendix A.

Heavy-mineral abundance

In all of the sediment samples examined heavy minerals are present in low or very low concentrations. The heavy-mineral fraction rarely comprises more than 0.5 percent by weight of the sediment and concentrations commonly fall below 0.1 percent (Pl. 1). These low concentrations are partly the result of dilution, by locally derived biogenic carbonate, of a terrigenous fraction which generally contains between 0.1 and 0.7 percent heavy mineral.

Throughout much of the region, the calcareous sand unit contains a slightly higher concentration of heavy minerals than

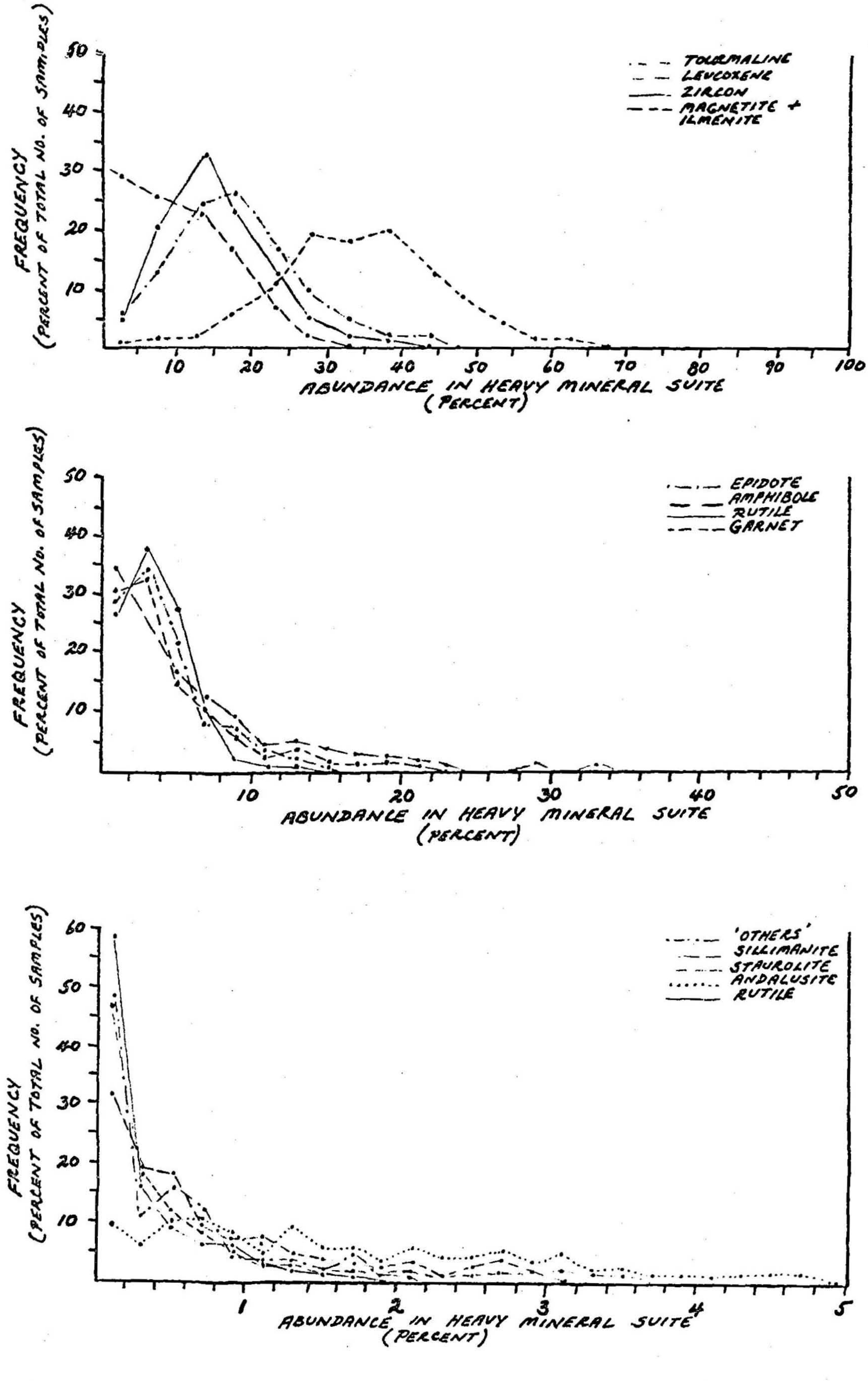

Figure 3. Frequency of abundance of the principal heavy minerals.

Table 1. Number of occurrences of each of the heavy minerals in the total number of samples analyzed.

Mineral	No. of occurrences	% of total no. of samples
Magnetite & Ilmenite	295	100
Leucoxene	295	100
Pyrite	14	5
Zircon	295	100
Tourmaline-brown	295	100
Tourmaline-blue	269	91
Rutile	295	100
Monazite	211	71
Amphibole	260	88
Epidote	285	97
Garnet	286	97
Andalusite	278	94
Sillimanite	216	73
Kyanite	144	49
Staurolite	169	58
Topaz	74	25
Zoisite	82	28
Apatite	49	16
Pyroxene	23	8
Sphene	22	8
Olivine	12	4
?Monticellite	8	3
Fluorite	6	2

the other sedimentary units (Pl. 1). This trend is particularly noticeable in Holes 39, 38, 30 and 20 where heavy mineral concentrations of up to 1.2, 0.5, 0.7 and 0.6 percent respectively, occur. Although in some cases (e.g., Hole 21) the higher values are due partly to a decrease in the amount of carbonate in the sediment, in general they reflect higher concentrations of heavy minerals in the terrigenous fraction and therefore reflect processes operating during transportation, deposition and diagenesis.

Description of the principal minerals

(i) Magnetite and ilmenite occur as the principal opaque heavy minerals in all samples. They are extremely difficult to distinguish petrographically; both occur as irregular submetallic or metallic grains. Partial alteration of ilmenite to leucoxene is commonly observed.

(ii) Leucoxene is a decomposition product of ilmenite and typically occurs either as pseudomorphs after ilmenite or as irregular aggregates. It generally comprises only 10 to 20 percent of the opaque fraction although it does become more abundant in the furthest inland beach and dune deposits.

(iii) Zircon is ubiquitous in the sediments and generally comprises between 5 and 25 percent of the heavy-mineral assemblage. Grains are typically either prismatic bipyramidal forms displaying some rounding of the terminations, or angular fragments. Sharply pointed euhedral crystals are subordinate. The presence of euhedral, subhedral and well-rounded zircons in the one assemblage probably reflects a multiple source including reworked and first-cycle components. Elongation (length/breadth) generally ranges between 1.5 and 2.5. The grains are almost invariably colourless and are commonly zoned. Inclusions of apatite, rutile, zircon, cavities and opaques are observed.

Although not particularly hard (H = 7.5), zircon has a high relative stability due to its resistance to chemical attack, absence of cleavage, and small crystal size.

(iv) Tourmaline occurs as an important component (5 to 30 percent) in all the heavy-mineral assemblages and is particularly abundant in many of the coarser-grained sediments. Of the five main types described by Krynine (1946) (granitic, pegmatitic, sedimentary authigenic, reworked, pegmatized injected in metamorphic terrains), granitic, reworked and pegmatitic types are recognized.

Although having colour and other features consistent with an initial granitic source, much of the tourmaline appears from the degree of fracturing, rounding and refracturing, to be reworked. Prismatic grains are relatively uncommon. Colour ranges from yellow to dark brown, indicating the Fe-dravite or Fe-Mg schorlite varieties. Inclusions are common and are generally cavities and bubbles with minor zircon, rutile and opaques. Rare occurrences of particoloured brown- and green or brown- and blue grains have been notes.

Pegmatitic tourmaline (indicolite) occurs in trace amounts in most of the assemblages. The colour is typically blue with pleochroism in shades of mauve.

Tourmaline of pegmatized injected metamorphic terrains may be present but is indistinguishable from grains of the granitic type.

(v) Rutile. Reddish brown to almost opaque grains of rutile occur as a constant minor (less than 10 percent) component in the heavy-mineral assemblage of all of the samples (Fig. 3, Table 1). Grains occur as either rounded prismatic forms with pyramidal terminations, or as anhedral fragments.

(vi) Monazite has been recognized in approximately two-thirds of the samples, usually making up less than 0.5 percent of the heavy mineral assemblage. It occurs as colourless or pale yellow well rounded 'egg shaped' grains with a very high refractive index.

(viii) Amphibole occurs in varying amounts in the heavy-mineral fraction of most samples. It generally makes up less than 10 percent of the assemblage, although values as high as 33 percent do occur, particularly in the finer-grained sediments. It is almost invariably a brownish-green to bluish-green hornblende which occurs as irregular, angular, elongate grains. Grain shape is determined largely by cleavage and possibly by etching. Pleochroism is variable, and generally weak.

In addition to hornblende, tremolite and actinolite occur in trace amounts in a few samples.

(viii) Epidote occurs in virtually all assemblages. The grains are usually pale yellow to greenish-yellow in colour, irregular and angular. Pleochroism is weak. Partial alteration is common.

Colourless zoisite occurs in trace amounts in some assemblages.

(ix) Garnet. Pale pink (common) to red (rare) grains of garnet occur in almost all samples. The mineral typically comprises less than 10 percent of the heavy-mineral assemblage, although values as high as 40 percent occur in a few of the coarse-grained samples. Generally grains are irregular, fractured, and either subangular or angular. Well-rounded grains are rare. Inclusions (generally bubbles, cavities, opaques, zircon and colourless minerals) are common. Minor pitting and grooving occurs on the surfaces of some grains.

The colour and refractive index (1.75-1.85) indicate a composition close to that of almandine.

(x) Andalusite is a constant minor (less than 5 percent) component in the heavy-mineral assemblage of virtually all samples. Grains are irregular, angular or subangular, and typically contain bubbles, cavities, abundant dust-like particles of carbonaceous matter, and opaques as inclusions. Grains are either colourless or display a pleochroism from pink to colourless.

(xi) Kyanite has been noted in about 50 percent of the samples and generally comprises well below 2 percent of the heavy-mineral assemblage. It varies considerably in appearance, the commonest type being colourless, subangular or subrounded prismatic grains showing traces of cleavage parallel to, and at right angles to, the prism faces.

(xii) Sillimanite occurs as colourless, acicular prisms and fibres making up a very minor component (typically less than 2 percent) of the heavy-mineral assemblage of many of the sediments.

(xiii) Staurolite. Approximately two-thirds of the heavy-mineral assemblages contain staurolite which typically occurs as relatively large, dark brown to brownish-yellow, irregular grains with moderate pleochroism. Inclusions (principally opaques, bubbles and cavities) are common. In general the mineral comprises less than 1 percent of the total heavy-mineral assemblages, rising to 5 to 8 percent in several of the coarser-grained sediments.

(xiv) Pyroxene has been recognized in only 8 percent of the samples and always occurs as a very minor (less than 1 percent) component in the heavy-mineral assemblage. Grains are typically yellowish-green in colour, ragged and clouded by alteration. All the pyroxene appears to be a clinopyroxene, probably augite.

(xv) Olivine appears to occur only in those sediments directly over-lying the volcanic rocks of the Mount Gambier area. It occurs as irregular, altered, yellowish-green grains comprising only a minor part of the assemblage.

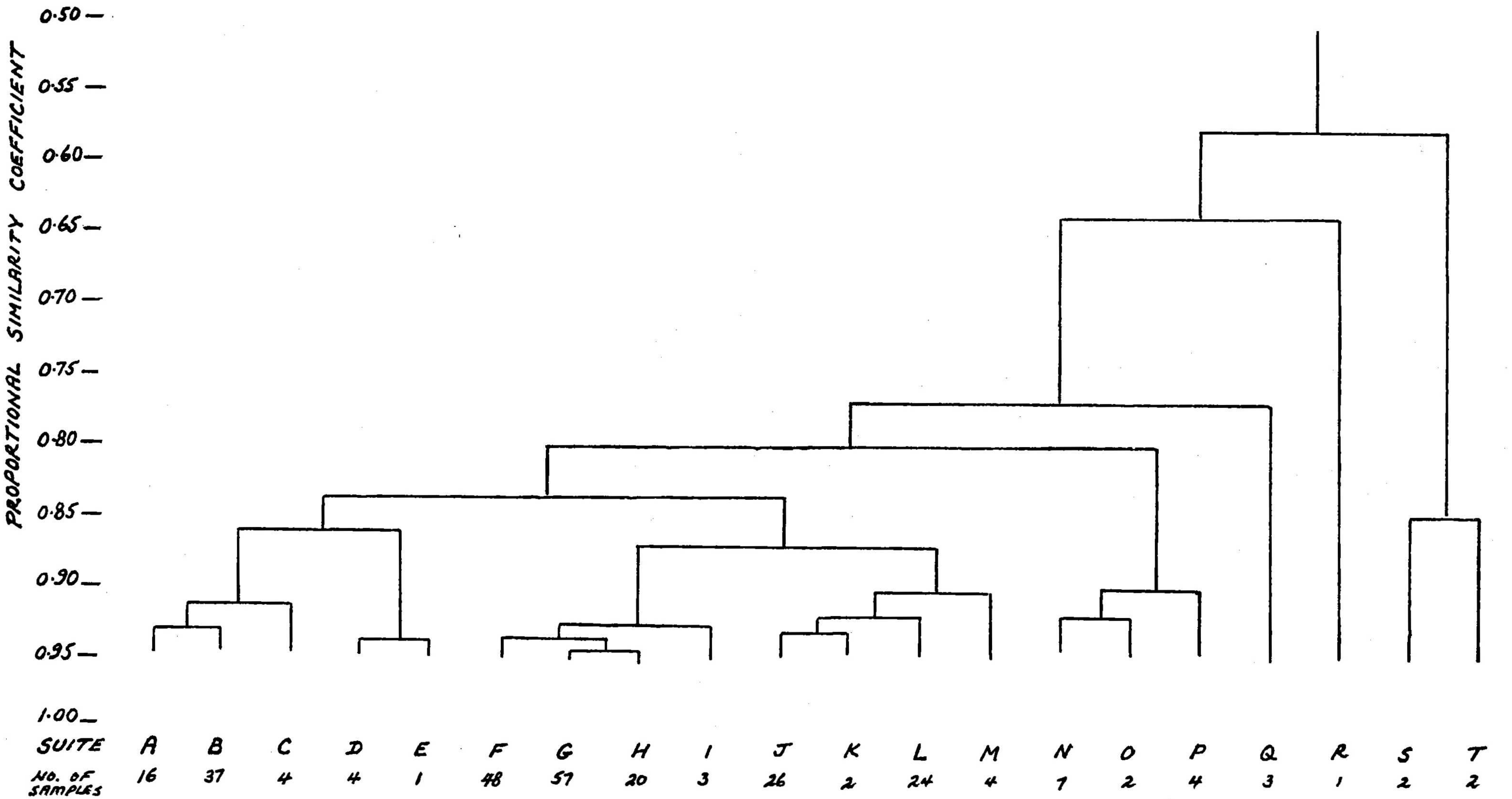

Figure 4. Cluster analysis dendrogram of samples on the basis of heavy mineral assemblages.

Variations in the composition of the suite

Although the same few minerals form the bulk of the heavy-mineral fraction in most samples, significant variations occur both in the proportions of the major minerals and in the nature of the minor mineral components. In order to determine the nature and amount of the variation, trends, and possible controlling factors, cluster and Q-mode factor analyses were undertaken. Only the cluster analysis is discussed in this report.

The BMR Geological Branch CLUSTER program (Mayo & Long, in prep.) was used to compare and classify the large number of sediment samples on the basis of the composition of the heavy-mineral assemblages. The program produced the dendrogram hierarchy shown in Figure 4 in which samples are successively linked on different levels of similarity using the weighted pair-group method. Seven major groups and thirteen minor groups (generally less than 5 samples each) are defined at a similarity level of 0.95.

Examination of the heavy-mineral data of the samples in each group indicates that although intra-group variations occur, they are slight when compared to inter-group variations (Table 2). Each group is characterized by a particular type of heavy-mineral suite. The seven most common suites are*:

(i) Suite A (16 samples) which has relatively high amphibole and epidote contents and a moderately high brown tourmaline component (Table 2);

(ii) Suite B (37 samples) which is similar to Suite A but has lower amphibole and epidote and is very high in brown tourmaline;

*Terms such as "high" and "low" are used only in a sense relative to the generally occurring abundance.

(iii) Suite F (48 samples) - high zircon, moderately high magnetite and ilmenite;

(iv) Suite G - most common suite (57 samples), similar to Suite F but has only slightly high zircon and has moderately high amphibole and epidote;

(v) Suite H (20 samples) - similar to Suite G but has lower amphibole and epidote and high garnet and staurolite;

(vi) Suite J (26 samples) - relatively high leucoxene, slightly high zircon;

(vii) Suite L (24 samples) - high zircon and leucoxene, low ilmenite, magnetite, amphibole and epidote.

In addition to the seven major suites, others occur. Suite C is present in four samples and has a similar composition to Suites A and B but like Suite H has very high garnet and staurolite contents. Suite D (4 samples) is high in leucoxene, amphibole and epidote whereas Suite K (2 samples) is high in leucoxene, zircon and garnet and low in tourmaline. Suite E is low in magnetite-plus-ilmenite, high in leucoxene and relatively high in blue tourmaline. Suite M (4 samples) has a very high zircon content. Suites N, O and P (totalling 13 samples) have high or very high amphibole and epidote contents and are differentiated from each other by the composition of the opaque-mineral fractions. Suite Q (3 samples) has very high ilmenite, leucoxene and magnetite contents and is very low in tourmaline. Suite R (1 sample) has a very high garnet content. Suites I, S and T have pyrite as a major component of the opaque minerals.

The regional distribution of the different heavy-mineral suites is shown in Plate 1 (drill core samples) and Figure 5 (surface samples). From these diagrams it is apparent that a number of general trends occur:

TABLE 2. AVERAGE COMPOSITION OF THE HEAVY-MINERAL SUITES

SUITE	No. of Samples	$\bar{x}$: mean s : standard deviation	Magnetite + Ilmenite	Leucoxene	Pyrite	Zircon	Brown Tourmaline	Blue Tourmaline	Rutile	Monazite	Amphibole	Epidote	Garnet	Andalusite	Sillimanite	Kyanite	Staurolite	Others
A	16	$\bar{x}$	25.95	6.83	0	10.47	23.31	0.85	2.59	0.36	12.31	7.87	3.49	2.83	1.26	0.47	0.67	0.70
		s	4.81	3.41	0	2.45	5.36	0.72	1.32	0.30	2.63	3.05	1.91	1.25	0.83	0.41	0.68	0.67
B	37	$\bar{x}$	28.34	7.87	0	9.50	32.31	0.99	3.46	0.41	3.80	3.31	5.05	2.66	0.55	0.12	0.74	0.70
		s	6.32	4.06	0	4.76	6.72	0.71	1.66	0.44	2.85	1.98	3.37	1.47	0.54	0.25	0.93	0.69
C	4	$\bar{x}$	28.10	5.53	1.11	7.34	20.15	0.60	4.20	0.54	4.86	3.19	17.62	2.39	0.35	0	3.86	0.20
		s	0.74	3.20	2.49	2.87	2.30	0.23	2.18	0.31	3.64	1.00	4.71	0.64	0.23	0	2.57	0.25
D	4	$\bar{x}$	22.66	16.77	0	7.07	16.64	0.90	2.37	0.21	8.80	14.85	4.44	1.13	1.12	0.72	0.53	1.16
		s	3.55	7.22	0	1.36	1.38	0.27	1.10	0.20	3.04	3.83	1.20	0.88	0.13	1.05	0.46	0.44
E	1	$\bar{x}$	15.50	15.28	0	13.62	18.86	6.29	2.11	0	3.16	11.51	6.29	3.16	2.11	1.05	0	1.05
F	48	$\bar{x}$	39.26	6.61	0.12	22.35	13.75	0.60	4.44	0.46	3.65	2.46	3.31	1.39	0.44	0.24	0.40	0.25
		s	5.83	2.81	0.59	5.94	6.27	0.51	2.40	0.39	3.13	1.73	2.37	1.07	0.54	0.39	0.52	0.39
G	57	$\bar{x}$	45.73	7.96	0.11	13.36	10.08	0.43	2.78	0.26	8.59	4.33	3.17	1.19	0.58	0.33	0.39	0.25
		s	8.78	5.00	0.08	3.37	3.73	0.36	1.60	0.22	5.66	2.50	1.91	0.70	0.59	0.53	0.64	0.32
H	20	$\bar{x}$	40.10	6.42	0.26	10.07	15.67	0.55	3.61	0.43	4.79	3.01	10.05	2.20	0.36	0.32	1.98	0.14
		s	4.71	2.64	0.61	3.29	3.07	0.40	1.84	0.32	2.49	1.32	4.48	1.19	0.40	0.39	1.82	0.22
I	3	$\bar{x}$	35.00	7.23	14.07	13.11	13.60	0.24	3.72	0.11	0.92	2.18	6.67	2.07	0	0.42	0.22	0.42
		s	4.66	3.32	2.66	5.44	3.46	0.32	0.84	0.15	1.31	2.14	6.28	2.30	0	0.28	0.38	0.29
J	26	$\bar{x}$	35.47	19.18	0	13.21	17.33	0.64	3.32	0.20	1.67	3.05	3.34	0.91	0.35	0.13	0.17	0.32
		s	4.92	3.60	0	3.37	3.30	0.55	1.39	0.18	1.72	2.10	2.23	0.64	0.36	0.23	0.30	0.30

table 2 contd

K	2	$\bar{x}$	44.42	14.02	0	19.24	7.60	0.43	1.07	0	0.44	0.64	11.34	0.33	0	0.33	0.11	0
		s	13.87	11.30	0	2.86	1.73	0.01	0.89	0	0.62	0.29	1.99	0.47	0	0.47	0.16	0
L	24	$\bar{x}$	24.00	18.96	0	21.70	18.84	1.44	5.16	0.13	1.84	2.57	1.40	1.71	0.58	0.40	0.19	0.82
		s	4.16	4.07	0	3.36	4.28	1.04	2.92	0.21	2.81	2.29	1.40	1.15	0.81	0.47	0.38	0.65
M	4	$\bar{x}$	28.60	5.44	0	40.71	16.12	0.53	4.47	0.38	0.07	1.31	1.40	0.44	0	0	0.03	0.18
		s	2.56	3.52	0	7.15	5.18	0.19	1.65	0.15	0.09	2.35	2.63	0.36	0	0	0.05	0.25
N	7	$\bar{x}$	28.13	17.44	0	8.99	10.05	0.77	2.51	0.28	15.28	8.81	1.64	1.96	1.95	0.89	0.46	0.91
		s	8.35	5.25	0	3.42	1.63	0.34	1.18	0.21	5.77	3.95	0.91	1.16	0.81	0.69	0.44	0.67
O	2	$\bar{x}$	18.54	18.19	0	5.67	10.51	0.25	5.09	0.25	31.28	5.04	3.19	2.67	2.50	0.73	0.24	0
		s	6.42	3.97	0	2.15	0.13	0.35	5.80	0.35	2.36	0.94	1.36	1.83	0.03	0.71	0.01	0
P	4	$\bar{x}$	30.56	3.36	0	11.79	12.01	0.84	1.76	0.36	22.88	8.61	2.07	1.48	2.33	0.70	0.52	0.71
		s	4.88	2.30	0	5.66	3.79	0.58	0.70	0.15	4.75	1.13	1.79	0.57	2.01	0.57	0.45	0.68
Q	3	$\bar{x}$	63.40	14.08	0	11.97	4.46	0.11	1.19	0.05	1.13	2.34	0.77	0.49	0	0	0	0
		s	9.72	2.52	0	3.77	1.79	0.19	0.23	0.08	1.43	1.02	0.50	0.21	0	0	0	0
R	1	$\bar{x}$	18.05	10.31	0	3.09	10.39	0.36	1.07	0.71	0	6.80	44.42	0.36	0.36	0	0.71	0.36
S	2	$\bar{x}$	28.64	4.66	27.58	24.86	2.20	0	1.11	0.68	0.83	0.37	8.69	0.69	0	0.09	0.18	0
		s	3.98	2.54	6.65	8.15	1.33	0	0.52	0.61	1.17	0.52	7.60	0.13	0	0.13	0.26	0
T	2	$\bar{x}$	10.73	1.97	55.00	12.31	9.02	0.24	0.68	0	6.35	0.93	1.96	0.44	0.34	0	0	0
		s	1.28	2.79	0.96	5.73	3.10	0.07	0.13	0	2.31	0.78	0.56	0.62	0.49	0	0	0

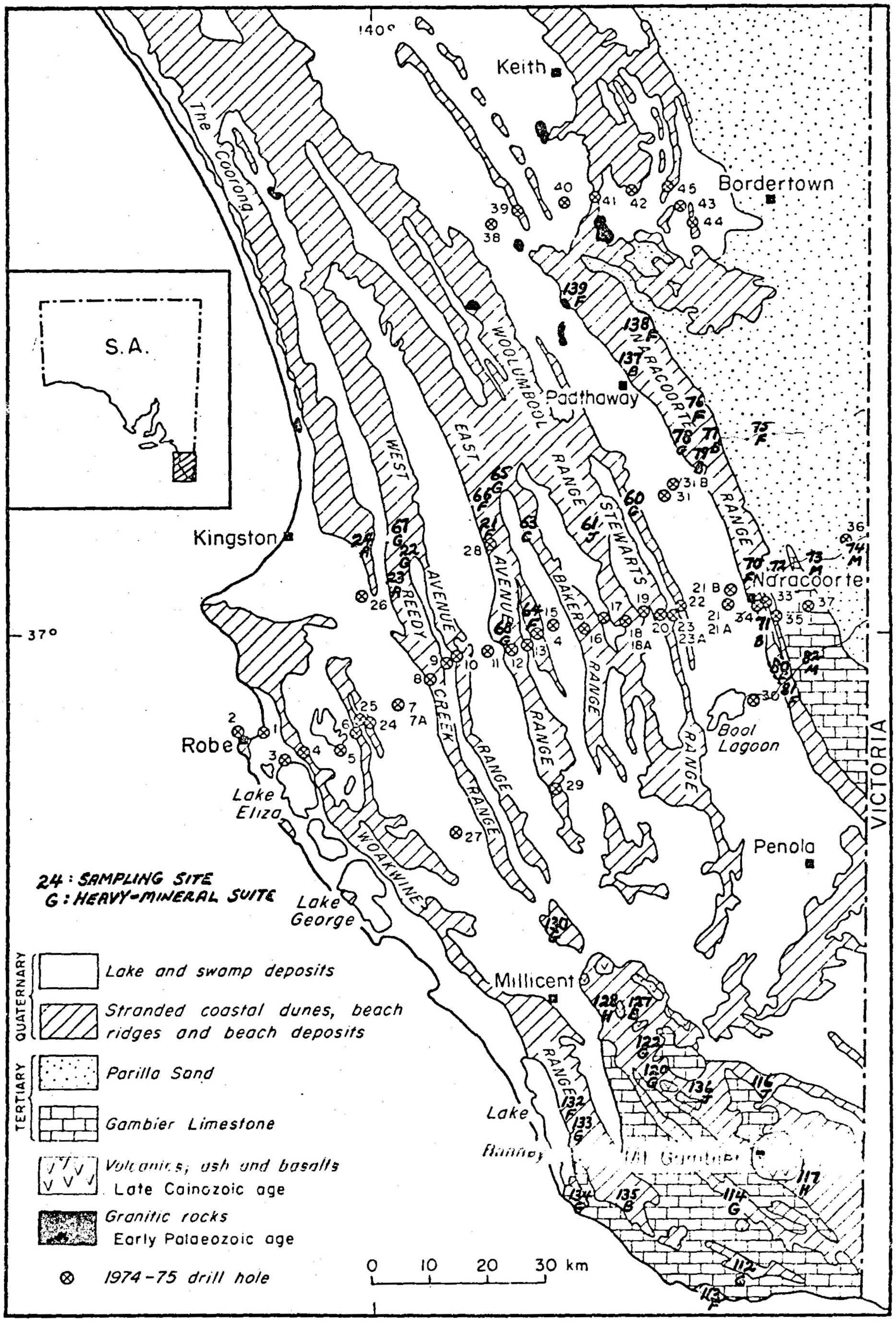

Figure 5. Surface geology, location of surface samples, and distribution of surface - sample heavy-mineral suites.

(1) In the area to the west of Bordertown, the sediments encountered in the holes drilled east of Hole 38 have heavy-mineral assemblages similar to those occurring in the Parilla Sand (Hole 36) east of Naracoorte, in the beach and dune deposits of the West and East Naracoorte Ranges (Holes 34 and 35), and in the interdune deposits between the Naracoorte Ranges (Hole 33). In general the suites (J, B, F, L) are characterized by relatively high zircon and leucoxene contents, and very low contents of amphibole, epidote and the other unstable minerals. Two suites (A B) contain a relatively high tourmaline component.

(2) The interdune deposits and underlying calcareous sands west of the Black Range (Hole 38) differ from the deposits farther to the east in containing relatively high amounts of amphibole and epidote (Suites D, N, G).

(3) The interdune deposits and underlying calcareous sands between the West Naracoorte and Harper ranges (Holes 21, 30, 31b) contain for the most part heavy-mineral suites which are characterized by relatively high zircon and leucoxene contents and low contents of amphibole and epidote (Suites L and J). However in Hole 21, the amount of amphibole and epidote increases substantially in the lower part of the calcareous sand unit (Suites P and N).

(4) West of Hole 21 the calcareous sand unit contains heavy mineral suites which are typically characterized by moderately high to very high contents of amphibole and epidote (Suites G, N, O, D, P). Garnet is relatively high in some samples of the unit (Suite H) and zircon high in others (Suite F).

(5) The beach and dune deposits west of the West Naracoorte Range and east of the Dairy Range commonly contain heavy-mineral suites similar to those occurring in the underlying calcareous sand unit. However, upper parts of the deposits may contain markedly different suites characterized by small amounts of amphibole and epidote and relatively large amounts of either

zircon, garnet or tourmaline (Suites F, H and C, and B respectively).

(6) The beach and dune deposits of the Dairy and Woakwine Ranges have heavy-mineral suites very similar to those occurring in the calcareous sand unit farther to the east.

(7) The beach and dune deposits of the Robe Range and upper part of the West Avenue Range contain a heavy-mineral suite (Suite B) which is characterized by a relatively high tourmaline content.

(8) Heavy-mineral suites with framboidal pyrite as a major component in the opaque fraction (Suites I, S, T) occur in some of the estuarine and lacustrine deposits.

The occurrence and distribution of the various heavy-mineral suites in the sediments of the region appear related not only to provenance and intrastratal solution (which are discussed in later sections of this report) but also to the grain size of the heavy-mineral fraction and of the terrigenous material as a whole. The general relationship of grain size to type of heavy-mineral suite reflects the different hydraulic equivalent sizes of the minerals, the size distribution of the heavy minerals in the source rocks, and the resistance of the minerals to breakage during transport. In the sediment samples examined, heavy-mineral fractions with a high content of zircon, amphibole or epidote tend to be slightly finer grained than those with a relatively high content of tourmaline or garnet. The grain size of the associated light minerals in the terrigenous fraction shows a similar relationship to the type of heavy-mineral suite present.

PROVENANCE

To aid in interpreting sediment provenance, heavy minerals are usually grouped, on the basis of their genetic association, into either 'reworked sedimentary', 'low - or high-rank metamorphic', 'sialic or mafic igneous', 'pegmatitic' or 'authigenic' suites (Table 3) (Hubert, 1971).

Although exceptions occur, in most sediments a mixing of grains from several sources has occurred, complicating provenance studies. In the case of the late Cainozoic sediments of southeastern South Australia the heavy mineral suites appear to contain on the basis of their mineralogy a mixture of sialic igneous, reworked sedimentary, metamorphic and to a slight extent mafic igneous components. Aspects of the geology of the region suggest that the following rocks are probable sources for these components.

1. Igneous rocks of the Padthaway Ridge

Early Palaeozoic igneous rocks crop out in the northern part of the region (Fig. 6). The rocks form part of the Padthaway Ridge which although partly covered by thin sediments of the early and middle Tertiary Knight Group and Gambier Limestone, would have partly remained as a substantial, eroding, topographic high during most of late Cainozoic time.

Descriptions of the igneous rocks exposed on the Padthaway Ridge are given by Mawson & Parkin (1943), Mawson & Dallwitz (1944), Mawson & Segnit (1945 a, b) and Rochow (1971). As shown in Figure 6, six major types of igneous rocks varying from rhyolites and quartz keratophyres to hornblende and biotite granites, occur on the Padthaway Ridge. These rocks appear to have intruded Cambrian sediments and were probably emplaced in the early Ordovician during the final (Delamerian) orogenic phase of the Adelaide Geosyncline (Parkin, 1969). Dating of the Victor Harbour Granite at 415 ± 42 m.y. (Fander, 1960) supports this view.

In the present study samples were collected in the Keith-Padthaway-Kingston area at the sites shown in Figure 6. The heavy minerals were extracted using the method previously outlined. The rocks were examined in thin section and the resulting petrographic descriptions are given in Appendix B.

The heavy minerals present in the various igneous rocks sampled are shown in Table 4. Non-ferromagnetic opaques (mainly ilmenite), magnetite, zircon and apatite are the only accessory minerals occurring in the adamellites and are swamped in the heavy-mineral separation by biotite which commonly contains minute zircon and apatite inclusions. Magnetite is the principal accessory mineral in the granites, microgranites and quartz porphyries and occurs together with abundant biotite and/or hornblende, ilmenite, zircon, apatite, fluorite and in some cases, sphene. Magnetite and non-ferromagnetic opaques are the principal heavy minerals in the rhyolites and quartz keratophyres and occur in the heavy-mineral fraction with abundant, partly chloritized, intermediate groundmass components. These heavy minerals agree closely with those recorded by Mawson and co-workers in petrographic descriptions of similar rocks from the northern part of the ridge.

Zircons occurring in the adamellites appear, on the basis of a study of 200 unbroken grains in each sample, to be more elongate, less euhedral and freer of inclusions than those occurring in the biotite-hornblende granites, microgranites and quartz porphyry. Crystal growth trends as indicated by reduced major axes differ in a similar fashion and it appears unlikely that the adamellites and the hornblende-biotite granites are genetically related to the one magma as suggested by Mawson and co-workers. The similarity of zircon growth trends within granitic bodies derived from the one magma is well established (Spotts, 1962).

TABLE 3. GENETIC ASSOCIATIONS OF THE COMMON HEAVY MINERALS

Reworked sediments	Well-rounded grains of rutile, tourmaline, zircon.
Low-rank metamorphic	Biotite, chlorite, spessartite garnet, tourmaline
High-rank metamorphic	Actinolite, andalusite, apatite, almandine garnet, biotite diopside, epidote, clino-zoisite, glaucophane, hornblende (including blue-green varieties), ilmenite, kyanite, magnetite, sillimanite, sphene, staurolite, tourmaline, tremolite, zircon, zoisite
Sialic igneous	Apatite, biotite, hornblende, ilmenite, monazite, muscovite, rutile, sphene, tourmaline, zircon, magnetite
Mafic igneous	Augite, diopside, epidote, hornblende, hypersthene, ilmenite, magnetite, olivine, oxyhornblende, pyrope garnet, serpentine.
Pegmatites	Apatite, biotite, cassiterite, garnet, monazite, muscovite, rutile, tourmaline (especially indicolite).

Ash falls	Euhedral crystals of apatite, augite, biotite, hornblende, and zircon.
Authigenic	Hematite, leucoxene, limonite, tourmaline, zircon; euhedral crystals of anatase, brookite, pyrite, rutile, and sphene.

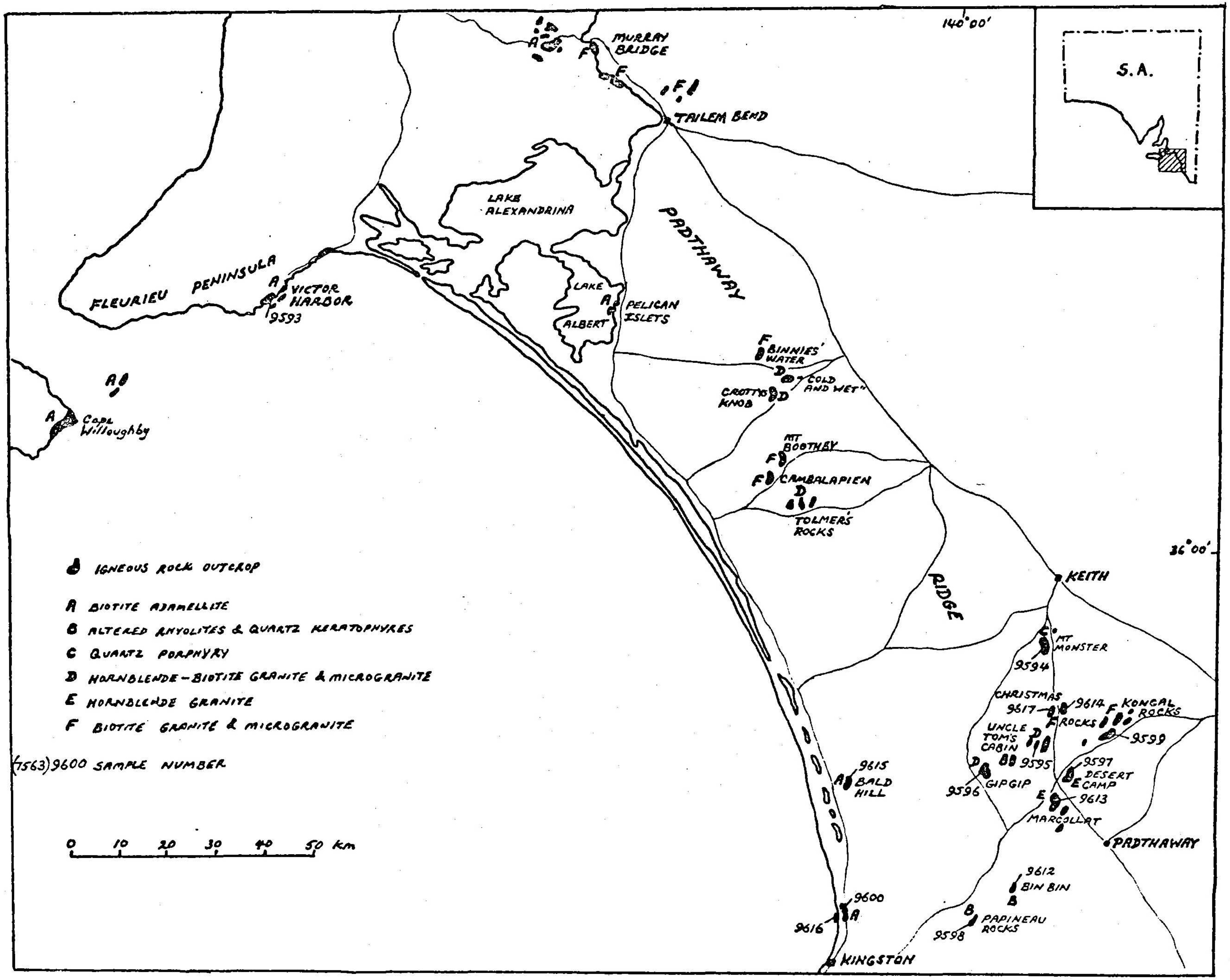

Figure 6. Distribution, lithology, and location of samples of Padthaway Ridge basement igneous exposures.

SAMPLE NUMBER	7563 9593			7563 9616			7563 9603			7563 9615			7563 9594			7563 9595			7563 9596		
ROCK TYPE	A			A			A			A			C			D			D		
SIZE FRACTION	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
% FERROMAGNETIC	0.1	0.1	1	0	0	1	1	3	7	5	12	7	15	38	49	8	9	14	17	16	14
FERRO-MAGNET. MAGNETITE	p	a	p			p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p
FERRO-MAGNET. HEMATITE		a					tr						tr	tr	tr	tr	tr				tr
NON-FERROMAGNETIC MINERALS BIOTITE	p	p	c	p	p	c	p	p	p	p	p	a			tr	p	p	c	c	c	tr
HORNBLENDE																c	tr	tr	p	p	a
OPAQUES	tr		c			a		c	c	c	c	c		c	a	c	c	a	tr	tr	c
ZIRCON		c	a		tr	a		tr	c		c	a		c	a			a		tr	a
TOURMALINE										tr					vr						
APATITE		c	tr		tr	c		c	c		c	tr			tr						
ALLANITE																					
FLUORITE														vr	tr	c	c	c		vr	tr
MONAZITE					vr																
CASSITERITE																					vr
RUTILE																					
SPHENE												tr							tr	c	c
ALTERED INT. GRNDMASS													p	p	c						
EPIDOTE														tr	c					c	c

SAMPLE NUMBER	7563 9599			7563 9614			7563 9617			7563 9597			7563 9613			7563 9598			7563 9612		
ROCK TYPE	F			F			F			E			E			B			B		
SIZE FRACTION	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
% FERROMAGNETIC	31	25	52	50	64	53	25	63	35	41	49	28	13	12	21	10	20	0	10	15	18
FERRO-MAGNET. MAGNETITE	p	p	p	a	p	p	p	p	p	p	p	p	p	p	p	p	p		p	p	p
FERRO-MAGNET. HEMATITE	tr	tr	tr	a	tr	tr	c	c	c	tr		tr	tr	tr	tr		c				
NON-FERROMAGNETIC MINERALS BIOTITE	p	p	c	c	c	tr	c	tr	c	c	c	tr									
HORNBLENDE	tr		tr							p	p	a	c	a	a						
OPAQUES	c	tr	a	p	a	p	p	a	p	c	c	c	p	a	c	a	c	c	p	p	p
ZIRCON		tr	c		c	c	c	a	c	vr	tr	a	tr	tr	c			tr			tr
TOURMALINE																					
APATITE														tr	c						
ALLANITE														tr	tr						
FLUORITE	c	a	a	c	a	a			tr					c	vr						
MONAZITE																					
CASSITERITE																					
RUTILE			vr		tr																
SPHENE																				c	c
ALTERED INT. GRNDMASS													p	p	p				a	a	a
EPIDOTE			vr																		

ROCK TYPE

A Biotite adamellites
B Altered rhyolites & quartz keratophyres
C Quartz porphyry
D Hornblende - biotite granite & microgranite
E Hornblende granite
F Biotite granite & microgranite.

SIZE FRACTION

1 35–80 mesh
2 80–170 mesh
3 –170 mesh

ABUNDANCE NOTATION (after Hutton, 1950)

p	Predominant	>60 %
a	Abundant	20 - 60 %
c	Common	5 - 20 %
tr	Trace	1 - 5 %
vr	Very rare	< 1 %

TABLE 4. COMPOSITION OF THE HEAVY-MINERAL FRACTION IN SAMPLES OF THE PADTHAWAY RIDGE IGNEOUS ROCKS

The igneous rocks of the Padthaway Ridge discussed above probably have been an important source of many of the heavy minerals occurring in the late Cainozoic sediments of the region. Hornblende, biotite, magnetite, ilmenite, zircon, apatite, sphene and fluorite which are the principal heavy minerals in the igneous rocks, commonly occur in the heavy mineral fraction of the sediments. Features of the minerals are generally similar in both cases. In particular, grains of hornblende and biotite occurring in the igneous rocks. Likewise, subhedral and euhedral zircons in the sediments generally have similar colour, inclusion and zoning features to typical zircons of the igneous rocks.

2. Volcanic rocks, Mount Gambier area

Late Tertiary and Quaternary volcanics occur in a SE-NW trend from Mount Gambier to Mount Graham, a distance of approximately 50 km in which at least 16 cone eruptions are known to have occurred (Fig. 7). The vulcanism formed part of a widespread volcanic phase (the Newer Basalts) which is principally represented by basalt flows covering large areas of the Victorian Western District plains and highlands. More than 120 cone eruptions are known to have occurred during this period of activity (Sprigg, 1952).

K-Ar dating of the Newer Basalt lava flows in Victoria indicates ages ranging from 4.5 to 0.57 m.y. (McDougall et al, 1966; Rahman & McDougall, 1972; Wellman, 1974). Many of the eruptive centres are probably substantially younger, and in South Australia, C^{14} dates at Mount Gambier (Gill, 1955; Dury & Langford-Smith, 1968) indicate ages between 1400 and 4800 years B.P. Volcanic activity may have continued in this area until very recent times. Hossfeld (1950) refers to aboriginal legends containing possible references to such activity.

Two distinct periods of volcanic activity are suggested by the physiography and aeolianite stratigraphy surrounding the volcanics in southeastern South Australia (Sprigg, 1952). The earlier Newer Basalts which occur east and southeast of Millicent, include Mounts Burr, Graham, McIntyre, Watch and Muirhead, and The Bluff. Volcaniclastic deposits from these vents have been modified by erosion and are largely covered by quartzose calcarenite beach and dune deposits. According to Sprigg (1952) they were probably erupted in the Late Pliocene or Early Pleistocene. The later Newer Basalts which form Mount Gambier and Mount Schank post-date the local Pleistocene beach and dune deposits, of the high sea levels.

The locations of the sampling sites used in the present study are shown in Figure 7. All major rock types were sampled, thin sectioned, and an attempt made to extract the heavy minerals from them.

Ejectamenta forms the bulk of the volcanic deposits. Ash, scoria, lapilli and volcanic bombs form volcanic cones or subsidence calderas at Mount Schank, Mount Gambier, Lake Leake and Lake Edward. Elsewhere the original form of the pyroclastic deposits has been largely masked by Pleistocene beach and dune deposits. Most deposits have vitric, lithic and crystal components with fragments ranging in size from dust and lapilli to volcanic bombs. Most of the lithic fragments are basalts similar to the associated flows although at Mount Gambier and Mount Schank and possibly elsewhere, fragments of the underlying Gambier Limestone occur.

Partly vesicular basalt flows occur as the initial phase of volcanic activity at most sites and are either K-rich nepheline hawaiites or olivine analcimites (Irving & Green, 1976). Typically the hawaiites consist of olivine phenocrysts set in a fine-grained groundmass of andesine laths, olivine and augite grains, acicular apatite, and opaques. Nepheline is interstitial. The olivine analcimites consist of olivine phenocrysts set in a partly crystalline, partly fluidal groundmass of olivine, augite, opaques, apatite and analcime.

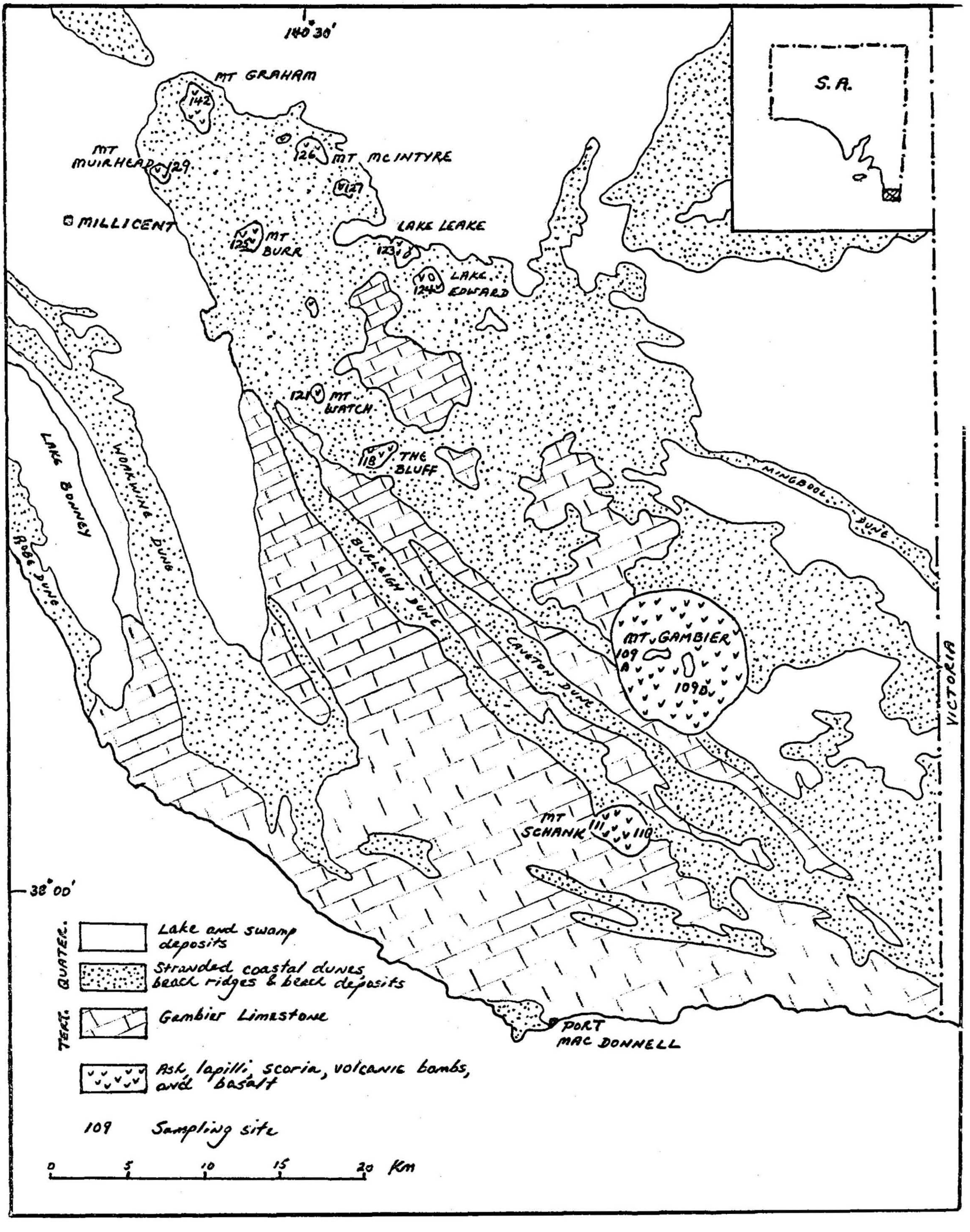

Figure 7. Distribution and sampling sites of volcanic rocks.

Opaques, olivine, augite and apatite appear to be the only heavy minerals in the volcanic rock samples and the contributions of these minerals to the heavy-mineral fractions of the late Cainozoic sediments appears to have been slight. Olivine has been recognized only in those sediments directly overlying the volcanic deposits at Mount Watch, Mount Burr, Mount Muirhead and The Bluff. Pyroxene (probably augite) occurs only in 8 percent of the sediment samples and is always a very minor component of the heavy mineral assemblage. Apatite, which is present in minor amounts in the heavy-mineral suite of some samples may have had either a granitic or volcanic source.

The virtual absence, in most of the sediment samples, of heavy minerals characteristic of a volcanic source, probably reflects not only a relatively minor, essentially localized contribution from the volcanics, but also the chemically and physically unstable nature of minerals such as olivine, augite and apatite. Wherever observed in the heavy-mineral fraction of the sediments, olivine and augite were invariably of ragged appearance and clouded by alteration.

3. Metamorphic and sedimentary rocks of the Fleurieu Peninsula and Kangaroo Island

Along the northern part of the region, relatively unaltered Late Proterozoic sediments, Cambrian metasediments of the Kanmantoo Group, and Archaean inliers of highly altered gneisses and schists, form the Mount Lofty Ranges and extend through the Fleurieu Peninsula to Kangaroo Island. They are partly overlain by Permian glacial and fluvioglacial deposits, by Tertiary sands, and by Quaternary dunes and sand spreads. On parts of the Padthaway Ridge metamorphosed sediments referable to the Kanmantoo Group are known to occur in the subsurface (Rochow, 1971).

Heavy-mineral-rich zones containing zircon, ilmenite, magnetite, rutile, sphene, epidote and actinolite, occur as lenticular bodies within a sequence of the Kanmantoo Group metasediments on the western side of Kangaroo Island. Recent beach and dune deposits on the island, on the other hand, contain opaques, zircon and rutile as the principal heavy minerals, together with significant amounts of kyanite and minor amounts of garnet, staurolite, andalusite, actinolite, monazite, spinel, tourmaline, spidote and apatite (Johns, 1966; Flint, 1976).

The beach sands occurring around the coastline of the Fleurieu Peninsula have been studied by Farrell (1968). The predominant constituents of heavy-mineral fractions of these sands are garnet (usually 30 to 50 percent of the total heavy-mineral assemblage), opaques (20 to 60 percent) and zircon (5 to 15 percent). Staurolite, andalusite, kyanite, sillimanite, rutile, tourmaline, monazite, amphibole, epidote and mica occur as very minor components.

Farrell concluded that the most immediate source of the beach sands around the western Fleurieu Peninsula is the Tertiary sands, whereas the southern coastline of the peninsula receives material mainly from the Cambrian metamorphic terrain and the early Palaeozoic igneous rocks. Contributions to both coastlines appear to come also from the extensive Permian glacials and fluvioglacials and from the Precambrian inliers.

The presence of high-rank metamorphic minerals such as garnet, sillimanite, kyanite, staurolite, andalusite and zoisite in heavy-mineral assemblages of many of the late Cainozoic sediments indicates a contribution from the metamorphic and sedimentary rocks of the Fleurieu Peninsula and Kangaroo Island. However the contribution was slight and continues to be so. Along the modern Coorong beach (Young Husband Peninsula) only those sands within 30 km of the Fleurieu Peninsula contain metamorphic minerals as major components of the Heavy-mineral fraction (see Appendix A).

4. Parilla Sand

The Parilla Sand overlies the Gambier Limestone east of the Kanawinka Fault and may have occupied a similar stratigraphic position west of the fault prior to erosion, and subsequent deposition of the shallow-marine calcareous sand unit. It contains a very mature heavy-mineral assemblage consisting predominantly of opaques, zircon and tourmaline. The zircon and tourmaline grains are generally moderately or well rounded, and commonly fractured.

Modern sediments occurring in Morambro, Mosquito and Naracoorte Creeks which drain areas covered by the Parilla Sand, typically contain very mature heavy-mineral suites, commonly with a high content of well rounded zircons (Appendix A).

It seems highly probable that erosion of the Parilla Sand coupled with the westerly flowing drainage system off the topographically high eastern side of the Kanawinka Fault would have resulted in a significant contribution from this source to the heavy-mineral assemblages of the calcareous sand unit, and the beach, dune and interdune deposits. Many of the moderately and well rounded zircons and the typically fractured and rounded tourmaline grains, probably were supplied to the late Cainozoic sediments via the Parilla Sand as an intermediate source. Tourmaline is almost certainly multicyclic as it is virtually absent in the igneous rocks of the region.

5. Calcareous sand unit

The unconsolidated calcareous sand unit of probable Pliocene age which underlies the Quaternary beach, dune and interdune deposits throughout much of the region, appears on the basis of its irregular upper surface, to have undergone partial erosion. The lack of the unit west of the Reedy Creek Range probably resulted from more prolonged erosion in that area (Cook et al., 1977).

Erosion of the unit would have resulted in the incorporation of heavy minerals present in the calcareous sands into the heavy-mineral fraction of the overlying beach and dune deposits. Both sequences contain broadly similar heavy-mineral assemblages and much of the variation which exists is probably due to selective sorting and the effects of intrastratal solution rather than to differences in provenance.

6. <u>Sediments transported by the Glenelg and Murray Rivers</u>

The Glenelg and Murray Rivers enter the region in the far south and north respectively. Both are sluggish at present and carry little sediment in their lower reaches. However during the Late Cainozoic periods of low sea level the Glenelg River eroded through a sequence of Tertiary and younger sediments, producing gorges extending well below the modern erosion level (Sprigg, 1952). Similarly, the Murray River eroded through a succession of lacustrine and other terrestrial sediments, through Tertiary sandy limestones and fluviatile sediments, and finally into granite bedrock. At Murray Bridge the river eroded granite to form gravels at depths of more than 40 m below present sea level (Sprigg, 1952).

By erosion along their lower reaches, the Murray and Glenelg Rivers would have supplied to areas of Late Cainozoic deposition, heavy minerals mostly reworked from older sediments such as the Tertiary sands and limestones. The Murray River would also have transported heavy minerals such as hornblende, biotite, opaques, zircon and apatite which were derived by erosion of granites. Contributions may also have come via the rivers from distant and now indistinguishable sources.

7. <u>Aeolian quartz sands (Molineaux Sand)</u>

From a very limited number of samples examined it appears that the aeolian quartz sands present on the flanks of many of the 'ranges' typically contain heavy-mineral assemblages

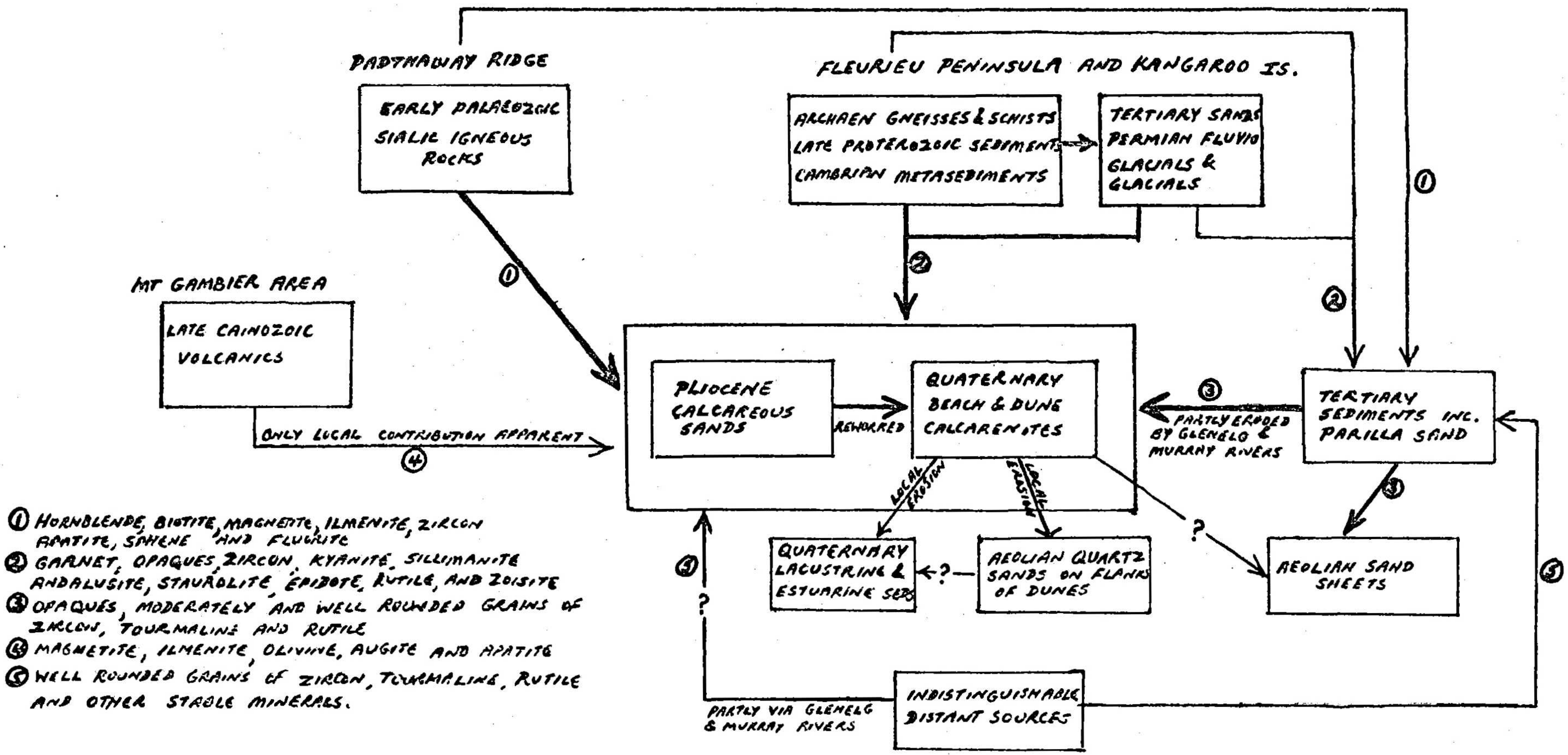

Figure 8. Provenance of the heavy minerals.

with slightly higher proportions of stable minerals than the underlying beach sand dune quartzose calcarenites. This difference probably results from the alteration and partial removal of relatively unstable minerals during minor localized leaching and stripping of the calcareous beach and dune deposits. The degree of rounding and other features of minerals such as zircon and tourmaline are comparable in both cases.

The large-scale sheets of aeolian quartz sand which extend from southeastern South Australia into the Murray Basin are considered by Lawrence (1966) to have been derived by wind erosion of the Parilla Sand and not as Sprigg (1952) suggested, by stripping during an arid period of a quartzose. A horizon developed on the calcareous beach and dune deposits in southeastern South Australia. The very mature heavy-mineral assemblage (predominantly zircon and tourmaline) present in these sand sheets (Lawrence, 1966, p. 546) is similar to that occurring in the Parilla Sand intersected in Hole 36.

From the foregoing discussion it is apparent that the provenance of the Late Cainozoic sediments in southeastern South Australia is complex. Figure 8 summarizes the main points.

THE ROLE OF INTRASTRATAL SOLUTION

The extent to which intrastratal solution is a major geologic process is currently being debated (Hubert, 1971). In some sedimentary sequences, for example in the Pliocene-Pleistocene-Holocene sediments of Baja California (Walker, 1967), its effects are well established due to the presence of etched and skeletal grains and a general downward decrease in unstable heavies. In many other examples, however, its effects have been shown to be minimal (van Andel, 1959).

The degree to which intrastratal solution modifies the heavy-mineral assemblage initially deposited in a sediment is related to the chemical stability of the minerals in the assemblage. Chemical stability ranges from low in the case of olivine, augite and hornblende to very high in the case of rutile, zircon and tourmaline.

In the case of the late Cainozoic sediments in south-eastern South Australia evidence of intrastratal solution of heavy minerals in the older deposits is of two types -

1. Higher proportions of chemically unstable heavy minerals (particularly hornblende and epidote) generally occur in the beach and dune deposits west of the Harper Range than in older beach and dune deposits to the east (Figure 9). It seems probable that many of the secondary iron oxides which are particularly evident in the farthest inland beach and dune deposits result from intrastratal alteration of the unstable iron-bearing minerals such as hornblende.

2. Grains of hornblende, epidote, augite and olivine are commonly of ragged, angular and altered appearance. Although possibly partly resulting from breakage during transport, this appearance is consistant with intrastratal etching and alteration.

CONCLUSIONS

(i) The amount of heavy mineral in the late Cainozoic sediments sampled is generally low. Concentrations rarely exceed 0.5 percent by weight of the sediment and commonly fall below 0.1 percent. The highest concentrations (up to 1.2 percent, of which approximately 20 percent consists of rutile and zircon combined) occur in an unconsolidated calcareous sand unit of probable Pliocene age, which underlies the beach and dune sands and lacustrine deposits throughout much of the region. There is no evidence of enrichment of heavy minerals particular shoreline sequences, but it should be pointed out that the drilling was aimed at establishing the stratigraphic succession in the region, and not specifically at exploration for heavy minerals.

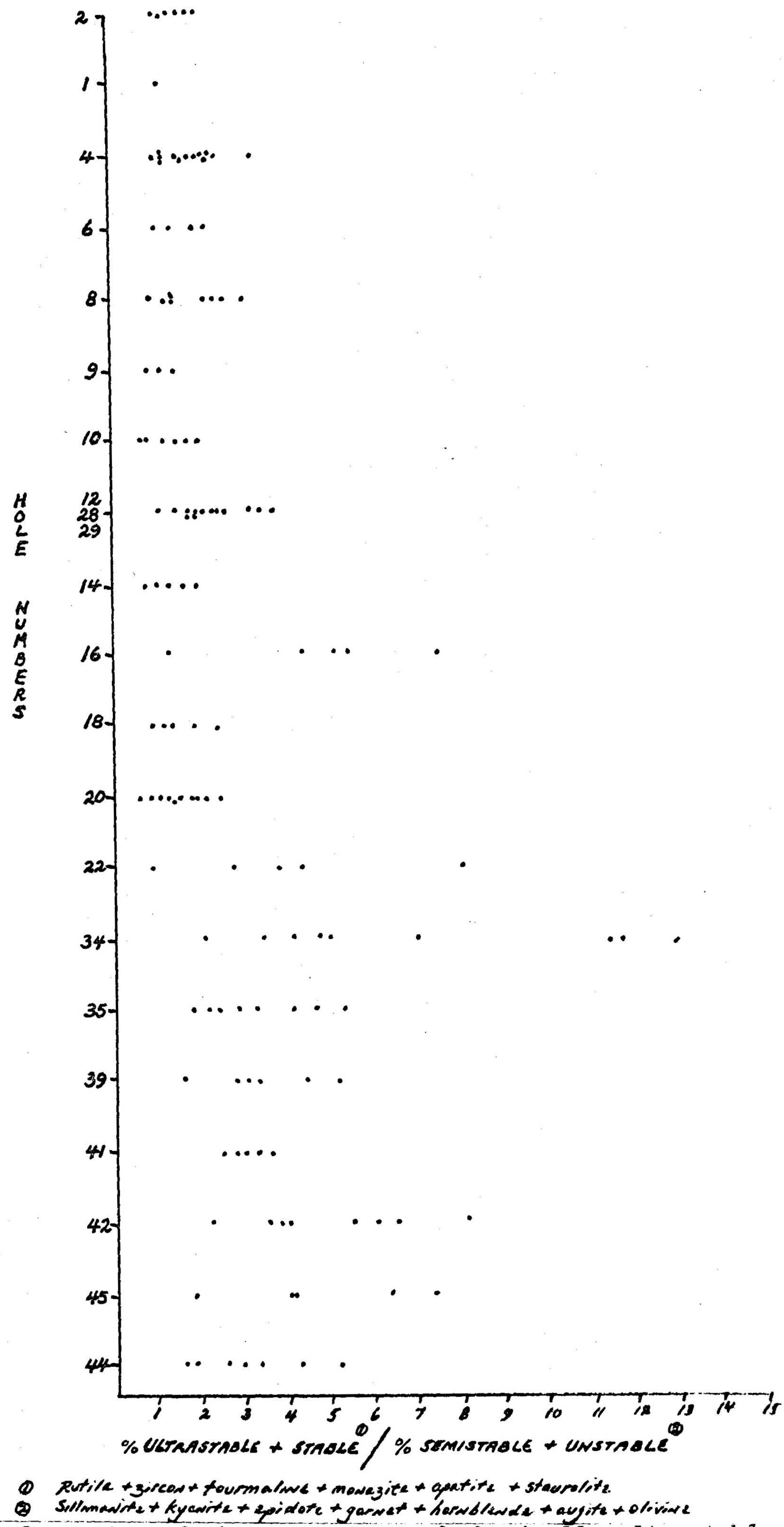

Figure 9. Ratios of the percentage of chemically ultrastable and stable: semistable and unstable minerals in the non-opaque heavy-mineral fraction, beach and dune deposits.

(ii) Heavy minerals appear to have been supplied to sediments from a number of sources. These include the igneous rocks of the Padthaway Ridge, the metamorphic and sedimentary rocks of the Fleurieu Peninsula and Kangaroo Island, reworked Tertiary and other sediments, and the volcanic rocks of the Mount Gambier area.

(iii) Intrastratal solution appears to have partly removed chamically unstable heavy-mineral components from many of the sediments. Its effects have been most pronounced in the relatively old inland beach and dune deposits.

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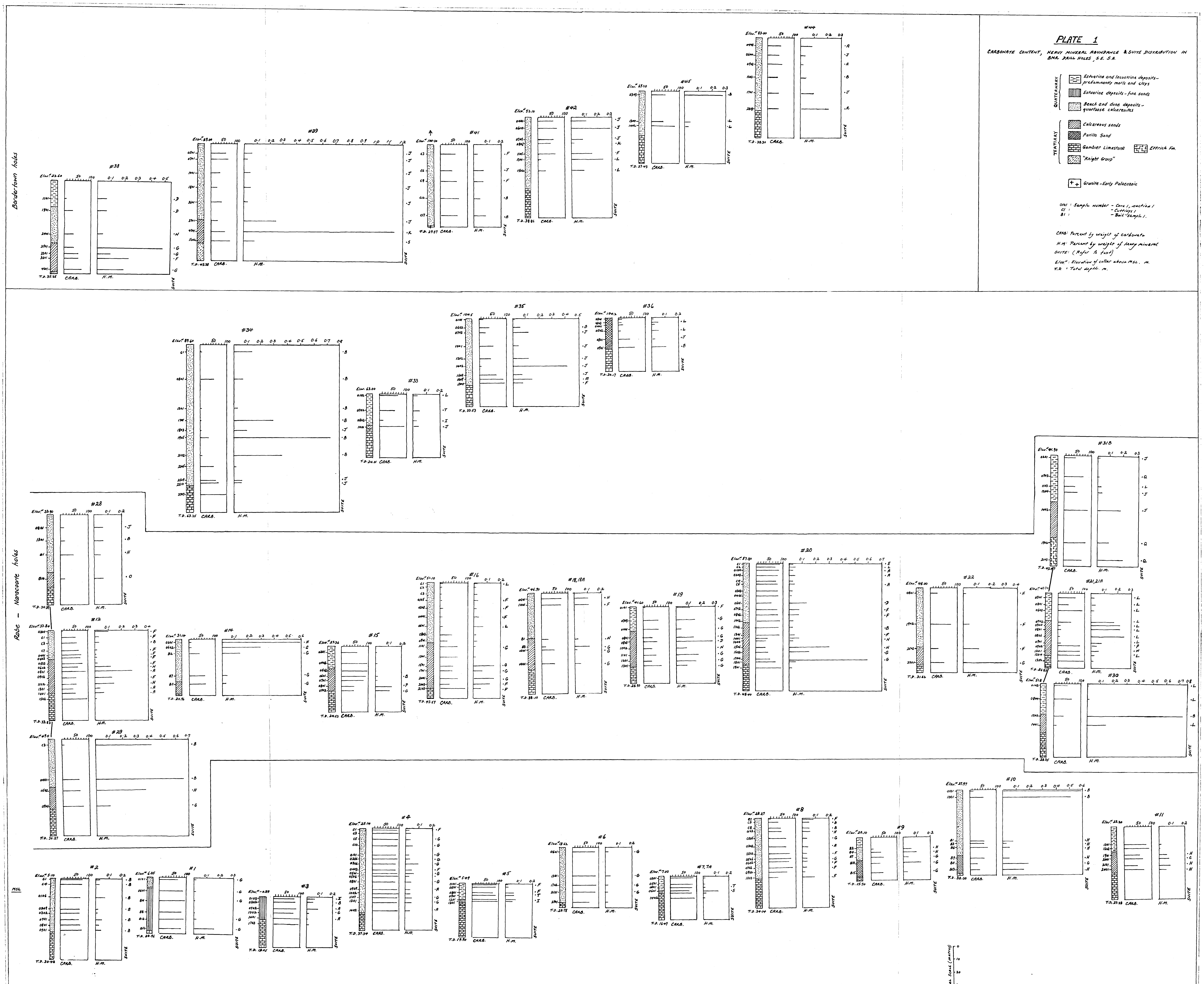
PLATE 1

CARBONATE CONTENT, HEAVY MINERAL ABUNDANCE & SUITE DISTRIBUTION IN BMR DRILL HOLES, S.E. S.A.



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Appendix A

Table listing heavy-mineral assemblage data (Fig A1 - location of modern - beack samples)

SAMPLES FROM DRILL CORE

SAMPLE NUMBER (CORE, SECTION)	MAGNETITE + ILMENITE	LEUCOXENE	PYRITE	ZIRCON	BROWN TOURMALINE	BLUE TOURMALINE	RUTILE	MONAZITE	AMPHIBOLE	EPIDOTE GROUP	GARNET	ANDALUSITE	SILLIMANITE	KYANITE	STAUROLITE	TOPAZ (OTHERS)	APATITE (OTHERS)	PYROXENE (OTHERS)	OLIVINE (OTHERS)	SPHENE (OTHERS)	FLUORITE (OTHERS)	MONTMORILLONITE UNKNOWN	TOTAL %
10101	36.57	16.88	2.81	8.37	15.59	0.38	2.66	0	6.08	5.32	1.52	2.66	0.78	0	0.36	0	0	0	0	0	0	0	99.99
100B4	47.00	20.14	0	6.50	2.53	0.36	1.08	0	13.72	2.89	3.61	1.45	0.36	0.36	0	0	0	0	0	0	0	0	100.00
100B8	47.97	8.47	0	13.33	8.33	0	0.21	0	14.38	5.42	1.46	0.42	0	0	0	0	0	0	0	0	0	0	100.01
10B12	44.46	2.34	0	16.77	12.55	0.48	0.48	0.12	15.32	2.17	3.98	0.72	0.60	0	0	0	0	0	0	0	0	0	99.99
10B16	39.07	15.03	6.01	11.08	9.36	0	0.99	0	6.65	1.97	7.88	0.99	0.49	0	1.23	0	0	0.25	0	0	0	0	100.00
200C1	24.65	3.56	0	4.07	33.18	1.36	6.77	0.67	5.41	2.71	13.55	2.03	0.67	0	0	1.36	0	0	0	0	0	0	99.99
200C4	24.37	14.24	0	5.54	26.76	0	4.15	0	4.61	5.08	10.15	3.23	0.46	0	0.46	0.94	0	0	0	0	0	0	99.99
20106	22.41	10.28	0	7.26	24.05	0.40	1.61	1.21	8.06	14.03	6.45	5.64	1.61	0.40	0.40	0	0	0	0	0.41	0	0.80	100.02
20209	22.14	5.53	0	8.27	42.29	2.37	2.40	0	5.90	3.16	8.09	2.77	0.40	0	0.79	0	0	0	0.39	0	0	0.40	100.00
20701	26.18	12.43	0	7.21	28.85	1.00	1.49	0.25	8.21	4.48	5.97	1.74	0.50	0.24	0.50	0.24	0.50	0	0	0.50	0	0	100.00
20901	29.67	13.71	0	7.92	24.23	0.23	4.43	0.23	8.15	2.33	4.89	3.03	0	0.23	0.47	0.47	0	0	0	0	0	0	100.01
030102	31.70	4.88	12.19	9.26	16.05	0	4.32	0	1.85	3.70	11.11	3.70	0	0.62	0	0.62	0	0	0	0	0	0	100.00
030202	26.80	11.49	0	4.46	35.32	1.86	1.58	0	4.46	2.60	2.97	4.83	1.12	0	0.74	1.47	0	0	0	0	0	0	100.00
30702	25.12	13.52	0	6.79	19.06	0.78	2.09	0.26	15.93	6.27	3.92	2.87	1.83	0.78	0.26	0	0	0.52	0	0	0	0	100.00
31401	40.30	10.75	2.69	12.93	10.54	0	1.02	0.34	1.70	1.70	16.33	0.68	0	0	0.68	0	0	0	0	0.34	0	0	100.00
400C1	40.63	13.54	0	20.63	8.33	0.42	2.71	0.42	6.46	1.66	3.33	0.63	0.20	0.42	0	0.42	0.20	0	0	0	0	0	100.00
0400C5	39.60	12.40	0	15.50	11.50	0.50	3.00	0.50	7.00	3.50	4.50	1.00	0	0.50	0.50	0	0	0	0	0	0	0	100.00
040C10	35.24	11.75	0	15.13	13.11	0.55	3.83	0.27	9.56	3.01	4.37	1.09	0	0.27	0.55	0	0	0	0	0	0	0	100.00
40101	46.03	6.14	0	18.64	8.46	0.21	4.24	0.21	9.52	1.90	2.12	1.06	0.63	0.22	0	0.21	0	0.21	0	0	0	0	100.0[illegible]
040206	34.20	13.71	0	16.59	13.68	0.29	6.11	0.29	6.40	3.49	3.20	0.87	0.87	0	0.30	0	0	0	0	0	0	0	100.0[illegible]
040306	36.88	13.23	0	17.72	9.33	0.70	4.20	0	9.09	3.73	2.56	0.70	0.46	0	0.46	0	0.24	0	0	0	0.6	0.69	99.99
040407	43.39	5.78	0	26.59	5.60	0.93	7.47	0.93	5.13	0.47	3.76	0	0.47	0	0	0	0	0	0	0	0	0	100.02
040501	51.56	3.03	0	14.36	12.74	0	5.75	0.57	2.87	2.59	4.02	1.14	0.57	0	0.29	0	0	0.29	0	0	0	0	100.00
040801	64.68	4.05	0	12.25	4.29	0	4.90	0.62	3.68	1.22	2.45	1.23	0.61	0	0	0	0	0	0	0	0	0	99.98
040909	22.64	7.41	0	6.87	20.61	0.21	5.93	0.94	10.93	4.37	9.36	2.81	0.62	0	2.19	0	0	0	0	0	0	0	99.99
041107	35.59	9.54	0	10.87	12.11	0.87	2.17	0	13.03	5.22	2.60	0.43	2.79	0	0.43	0	0	0	0	0	0	0	100.00
41301	48.85	4.47	0	16.75	4.52	0	2.53	0.50	6.08	1.02	9.13	2.03	0.50	1.52	1.02	0	0.30	0.20	0.52	0	0	0	99.99
041402	28.18	4.96	0	5.38	26.15	0.51	2.31	0.26	13.85	7.18	6.67	2.56	0.51	0.77	0.26	0	0	0	0	0.51	0	0	100.00
050101	39.03	16.73	0	18.59	9.48	0.19	3.53	0.19	5.37	2.41	2.79	1.12	0.56	0	0	0	0	0	0	0	0	0	100.00

Sample	MAGNETITE + ILMENITE	LEUCOXENE	PYRITE	ZIRCON	BROWN TOURMALINE	BLUE TOURMALINE	RUTILE	MONAZITE	AMPHIBOLE	EPIDOTE GROUP	GARNET	ANDALUSITE	SILLIMANITE	KYANITE	STAUROLITE	TOPAZ	APATITE	PYROXENE	OLIVINE	SPHENE	FLUORITE	? MONTICELLITE & UNKNOWNS	TOTAL %
																OTHERS							
050801	47.87	3.31	3.19	25.53	6.82	0.35	0.70	0.35	3.49	1.93	5.77	0.52	0.17	0	0	0	0	0	0	0	0	0	100.00
050901	11.64	3.95	54.32	8.26	11.21	0.29	0.59	0	4.72	1.49	2.36	0.88	0.29	0	0	0	0	0	0	0	0	0	100.00
051201	43.70	4.85	19.43	10.66	11.54	0.84	0.79	0	1.19	1.57	3.55	0.79	0	0	0.79	0	0	0	0	0	0	0	100.00
060601	47.50	10.00	0	11.50	14.25	0.50	3.75	0.25	5.25	2.75	2.00	1.75	0.25	0.25	0	0	0	0	0	0	0	0	100.00
062101	39.78	7.02	0	13.80	15.55	0.47	2.79	0.31	12.40	3.88	1.55	1.71	0.78	0	0	0	0	0	0	0.16	0	0	100.00
061301	50.00	2.20	0	10.23	15.66	1.46	4.52	0.35	4.98	4.30	3.98	2.02	0.15	0.16	0	0	0	0	0	0	0	0	100.00
061702	53.58	2.82	0	12.33	13.56	0.46	3.54	0.46	4.93	2.62	2.93	2.47	0.15	0.15	0	0	0	0	0	0	0	0	100.00
7A0601	31.46	2.86	22.88	30.63	3.14	0	1.48	1.11	1.66	0.74	3.32	0.18	0	0.18	0.20	0.17	0	0	0	0	0	0	100.01
0800C1	30.07	10.02	0	22.20	18.10	0.22	3.83	1.29	4.09	2.81	2.16	1.94	0.86	0.43	1.51	0	0	0	0	0	0	0	100.02
0800C3	22.50	2.52	0	14.29	27.67	0.89	5.36	0.89	4.46	4.46	8.04	3.57	0.89	0	2.67	0	0	0	0	1.79	0	0	100.00
0800C8	28.53	1.62	0	11.91	25.98	0.58	7.04	1.62	8.12	2.71	6.49	2.16	1.08	0	2.16	0	0	0	0	0	0	0	100.00
080102	36.31	7.32	0	12.61	14.59	0.66	4.64	1.10	7.07	4.42	7.51	2.21	0.24	0.88	0.44	0	0	0	0	0	0	0	100.00
080205	42.74	2.38	0	15.37	12.62	0.28	5.21	0.55	10.15	3.02	3.84	2.46	0.55	0	0.28	0	0	0	0	0	0	0.55	100.00
080302	30.43	3.58	0	11.22	21.10	0	4.28	0.53	11.76	5.34	5.08	3.21	1.07	0.53	1.60	0	0	0	0	0.27	0	0	100.00
080503	44.56	5.55	0	22.40	7.10	1.09	4.92	0.91	6.56	1.82	2.91	1.28	0.55	0.18	0	0	0.18	0	0	0	0	0	100.01
080506	36.27	6.40	0	8.59	11.67	0.22	4.85	0.22	17.18	9.47	1.76	1.32	1.32	0.88	0.44	0	0	0	0	0	0	0	99.99
080602	27.10	9.96	0	17.78	16.16	1.08	4.58	1.08	10.23	3.23	3.77	1.34	0.54	0.81	1.08	0	0.54	0.54	0	0.27	0	0	99
080702	34.28	4.29	0	6.12	13.34	0.66	1.31	0.22	20.34	9.83	4.37	1.31	1.97	0.88	0.44	0.	0	0	0	0	0	0.66	100.02
081003	40.00	7.50	2.50	18.41	12.16	0.17	2.20	0.34	4.56	3.21	6.59	0.84	0.34	0.17	0.84	0	0	0	0	0	0	0.17	100.00
090082	46.46	11.62	0	4.04	17.68	0	0.51	0	2.53	1.52	9.60	3.03	1.01	0	2.02	0	0	0	0	0	0	0	100.02
090084	37.64	2.09	0	7.86	20.06	0.78	0.31	0	4.39	4.55	13.01	3.13	0	0.94	3.13	0	0	0	0	0	0	0	99.99
090087	51.62	5.74	0	11.74	9.28	0.15	1.82	0.33	8.93	4.93	3.47	1.32	0.50	0	0	0	0.17	0	0	0	0	0	100.00
090810	36.45	10.41	0	12.23	14.68	0	2.45	0	17.13	2.45	1.22	2.45	0	0	0	0.53	0	0	0	0	0	0	100.00
090815	37.10	10.20	0	10.71	13.60	0.32	3.94	0.20	12.20	2.10	5.19	3.10	0.31	0	1.04	0	0	0	0	0	0	0	100.01
100101	37.95	4.22	0	2.21	31.93	1.41	2.41	0.40	0.60	6.02	4.62	5.22	0	0	2.61	0	0	0	0	0.40	0	0	100.00
101001	31.70	2.93	0	4.30	29.78	0.56	2.24	0.56	2.24	0.56	4.30	2.99	7.29	3.55	0	0	3.12	0	0	1.50	0	0.19	100.0
100061	42.47	4.72	0	7.87	11.24	0.45	5.39	0.22	1.80	3.82	13.26	4.49	0	0	4.27	0	0	0	0	0	0	0	100.00
100066	38.42	5.45	0	6.88	18.53	0.18	2.64	0.71	4.41	4.06	12.89	1.59	0.53	0.36	3.17	0	0	0.18	0	0	0	0	100.00
100083	40.47	4.75	0	8.38	12.64	0.48	4.42	0.22	2.80	3.99	13.09	4.20	0	0.29	4.00	0	0	0	0	0	0	0.27	100.00

Sample	MAGNETITE & ILMENITE	LEUCOXENE	PYRITE	ZIRCON	BROWN TOURMALINE	BLUE TOURMALINE	RUTILE	MONAZITE	AMPHIBOLE	EPIDOTE GROUP	GARNET	ANDALUSITE	SILLIMANITE	KYANITE	STAUROLITE	TOPAZ	APATITE	PYROXENE	OLIVINE	SPHENE	FLUORITE	MONTICELLITE + UNKNOWNS	TOTAL %
																OTHERS							
100089	33.06	4.40	0	6.05	15.98	0.28	1.93	0.28	8.57	3.86	15.70	2.21	0.28	0.55	6.58	0	0	0	0	0.27	0	0	100.00
100811	48.25	2.84	0	5.79	11.58	0.58	1.45	0.29	13.03	3.18	5.21	0.87	2.61	0.29	4.03	0	0	0	0	0	0	0	100.00.
100813	40.60	7.17	0	10.24	13.65	0.26	3.94	0.26	8.14	2.10	9.19	2.10	1.31	0	1.05	0	0	0	0	0	0	0	100.01
111901	36.50	4.29	0	11.83	17.97	0.88	4.38	0.88	6.14	4.38	7.89	3.94	0.48	0.44	0	0	0	0	0	0	0	0	100.00
112001	28.86	10.30	0	8.25	16.71	0.86	5.69	0.28	2.28	3.70	18.77	2.28	0.28	0	1.42	0	0	0	0	0	0	0.28	100.02
112101	35.95	4.79	0	12.05	12.28	0.24	5.06	0.96	2.65	1.45	18.79	3.13	0.48	0.23	1.93	0	0	0	0	0	0	0	99.99.
112401	40.94	7.22	0	18.57	9.72	0.42	3.67	0.22	1.94	0.65	13.61	0.86	0.43	0.22	1.51	0	0	0	0	0	0	0	99.99
120201	38.76	10.33	0	20.12	15.02	0.51	5.60	0.76	2.29	2.05	2.04	1.27	0	0.26	0	0	0	0.51	0	0	0	0	100.02
1200C1	31.78	7.95	0	17.81	19.86	2.05	4.79	0	2.74	5.48	3.42	2.74	1.37	0	0	0	0	0	0	0	0	0	99.99
1200C3	31.65	6.80	0	10.58	25.01	1.92	3.84	0	2.88	2.89	8.66	2.88	1.92	0.96	0	0	0	0	0	0	0	0	99.99
1200C7	41.85	4.90	0	13.72	15.33	0	4.84	0.81	1.61	1.61	7.27	4.04	2.42	0.81	0.81	0	0	0	0	0	0	0	100.02
120401	42.93	8.05	0	22.39	4.97	0.36	4.26	0.36	2.48	4.97	6.04	2.48	0.71	0	0	0	0	0	0	0	0	0	100.00
120403	34.32	3.43	0	29.41	9.32	0.49	9.80	1.96	2.45	0.50	5.39	2.45	0	0	0.50	0	0	0	0	0	0	0	100.01
120503	32.64	5.02	0	21.08	16.59	0.45	4.48	0.45	6.73	2.24	5.83	2.69	0.45	0.90	0.45	0	0	0	0	0	0	0	100.01
120602	26.82	13.37	0	10.50	9.43	1.08	3.23	0.54	19.93	6.20	1.62	2.70	2.42	1.35	0	0.27	0	0.54	0	0	0	0	100.00
120801	22.44	13.04	0	8.44	17.38	0.68	1.82	0.46	12.31	10.94	1.82	3.42	2.51	1.60	0.46	0.32	0.36	0	0	0	0	0	100.00
120902	31.97	8.03	0	16.36	15.52	0.84	6.30	0.85	8.81	1.68	2.10	4.59	2.10	0.85	0	0	0	0	0	0	0	0	100.00
121102	31.35	2.61	2.60	9.37	18.74	1.45	2.16	0.72	6.85	4.68	11.18	3.97	1.08	1.45	1.08	0.72	0	0	0	0	0	0	100.01
121301	33.21	4.14	0	12.79	22.13	0.69	0.69	0.69	9.68	2.77	6.95	3.80	0.74	0.34	1.04	0	0	0	0	0	0	0.34	100.00
121401	20.51	3.78	0	18.08	22.60	0	2.26	1.13	11.30	5.08	5.65	5.65	2.26	0.56	1.13	0	0	0	0	0	0	0	99.99
140201	43.58	4.89	0	6.11	17.04	0.64	6.75	0.16	1.93	1.29	9.49	1.13	0.16	0.48	5.31	0	0	0	0	0.64	0	0	100.00
140602	27.23	3.03	0	2.61	23.25	0.40	3.01	0.80	4.81	3.61	20.04	3.01	0.40	0	7.82	0	0	0	0.10	0	0	0	100.12
140082	52.74	4.08	0	16.52	11.30	0.29	4.06	0	3.48	2.90	3.18	0.58	0.58	0	0	0	0.29	0	0	0	0	0	99.99
140087	25.68	14.67	0	18.07	16.27	1.09	2.17	0.36	7.95	6.14	1.45	3.26	1.45	0	1.43	0	0	0	0	0	0	0	99.99
140811	40.82	4.53	0	7.88	15.75	0.72	1.19	0	16.71	5.97	3.10	1.43	0.48	0	0.95	0	0.24	0	0	0.24	0	0	100.01.
150601	35.25	6.60	0	11.35	23.17	0	1.82	0	2.73	5.00	6.36	5.91	0.91	0	0.45	0	0	0	0	0	0	0.45	100.00
150801	28.14	1.51	0	11.40	10.60	0.27	1.09	0.27	29.88	7.33	1.90	2.17	2.45	1.36	1.09	0	0	0	0	0	0	0.54	100.00
150902	35.87	4.76	0	15.79	7.34	0	1.78	0	21.36	7.12	1.78	0.89	1.78	1.11	0.44	0	0	0	0	0	0	0	100.01

Sample	Magnetite + Ilmenite	Leucoxene	Pyrite	Zircon	Brown Tourmaline	Blue Tourmaline	Rutile	Monazite	Amphibole	Epidote Group	Garnet	Andalusite	Sillimanite	Kyanite	Staurolite	Topaz	Apatite	Pyroxene	Olivine	Sphene	Fluorite	? Montmorillite ? & Unknowns	Total %
																Others							
160001	33.60	15.51	0	18.29	16.31	0.80	7.16	0.40	0	0.80	1.59	4.78	0.40	0.42	0	0	0	0	0	0	0	0	100.02
160105	35.16	8.71	0	28.22	9.77	0.51	7.23	0.72	1.46	1.82	2.48	2.18	0.37	0.72	0.37	0	0	0	0	0	0	0.72	100.00
160202	32.13	11.74	0	25.20	2.79	0.20	7.40	0.72	1.50	1.78	2.10	2.26	0.37	0.72	0.37	0	0.72	0	0	0	0	0	100.00
160601	26.18	23.59	0	23.17	13.63	0.19	7.40	0.39	0.39	1.17	0.78	1.36	0.78	0.58	0.19	0.19	0	0	0	0	0	0	99.99
161101	40.57	10.80	0	12.67	10.62	0.68	4.80	0.35	5.48	5.13	4.11	2.40	1.38	1.03	0	0	0	0	0	0	0	0	100.03
161501	14.00	21.00	0	7.20	10.42	0.50	0.99	0.50	29.51	5.71	2.23	3.97	2.48	1.24	0.25	0	0	0	0	0	0	0	100.00
161701	31.02	14.32	0	15.57	15.90	1.66	2.65	0.66	2.98	4.31	3.64	5.31	0.99	0.33	0.66	0	0	0	0	0	0	0	100.00
162001	36.47	13.03	0	19.34	6.31	0.40	3.26	0.20	7.74	6.31	2.65	1.84	1.22	0.81	0.41	0	0	0	0	0	0	0	99.99
162003	41.06	10.27	0	26.02	2.89	0	3.37	0.24	6.75	3.37	2.41	0.96	1.20	1.20	0.24	0	0	0	0	0	0	0	99.98
162203	46.21	2.89	0	22.58	9.98	0	2.63	0	5.25	4.19	2.10	3.15	0.52	0.52	0	0	0	0	0	0	0	0	100.02
180602	37.39	8.31	0	11.01	19.35	0.33	5.33	0.33	6.33	4.34	6.00	0.33	0	0	0.96	0	0	0	0	0	0	0	99.99
181001	39.44	6.65	0	21.37	11.98	0	4.93	0.55	3.83	3.56	5.21	1.36	0	0.28	0.83	0	0	0	0	0	0	0	99.99
180081	27.22	27.23	0	3.86	9.81	0.35	1.76	0.35	16.82	4.91	3.15	2.10	2.45	0	0	0	0	0	0	0	0	0	100.01
180083	58.39	7.04	0	13.16	5.73	0.31	1.86	0.15	5.93	4.33	2.17	0.62	0.31	0	0	0	0	0	0	0	0	0	100.00
18A0201	54.64	6.07	0	14.35	9.18	0.24	0.94	0.24	5.65	5.41	1.65	1.18	0.21	0	0	0	0.24	0	0	0	0	0	100.00
18A0401	44.42	4.94	0	13.78	6.87	0.16	0.48	0.32	22.12	4.01	1.60	0.04	0.80	0	0	0	0	0	0	0	0	0	100.00
190101	38.12	10.17	0	19.33	11.35	0.42	7.14	0.43	2.09	2.10	6.30	1.26	0	0.45	0.42	0.42	0	0	0	0	0	0	100.05.
190303	33.16	15.30	0	13.53	8.31	1.19	3.57	0	5.70	11.40	4.51	0.72	0.72	0.72	0.25	0	0	0	0	0	0	0.95	100.03
190401	54.90	4.58	0	11.07	6.12	0.59	2.05	0.29	9.33	6.12	2.05	0.88	0.88	0.29	0.29	0.29	0	0	0	0	0	0.29	100.02
190801	45.96	15.32	0	9.21	7.04	0.28	1.90	0	3.79	10.56	1.90	1.62	0.54	0.82	0.54	0	0	0	0	0	0	0.54	100.02
190803	25.01	10.04	0	9.28	15.07	0.78	1.55	0	11.59	15.84	3.87	1.93	1.16	1.93	0.78	0	0.78	0	0	0	0	0.39	100.00
191002	29.44	21.36	0	10.19	7.51	0.30	0.87	0	12.80	8.44	1.46	2.92	1.75	2.33	0.58	0	0	0	0	0	0	0	100.01
191101	38.43	17.74	0	10.32	5.54	0.26	2.26	0.50	7.55	8.81	3.78	2.02	1.51	1.01	0.26	0	0	0	0	0	0	0	99.99
191201	33.17	18.42	0	11.22	7.69	0	2.56	0.33	9.30	6.41	5.46	2.25	0.96	1.93	0.33	0	0	0	0	0	0	0	100.03
191301	33.37	11.86	0	11.18	7.82	0.75	1.86	0.38	15.27	8.19	2.24	1.86	1.49	2.61	1.12	0	0	0	0	0	0	0	100.00
20001	15.50	15.28	0	13.62	18.86	6.29	2.12	0	3.16	11.51	6.29	3.16	2.11	1.05	0	0	0	0	0	0	0	1.05	99.99.
20002	18.13	18.00	0	20.75	15.34	3.09	3.11	0.76	6.93	9.24	1.54	0.78	0	0.78	0	0.76	0	0	0	0	0	0.76	99.99
200104	29.00	2.90	0	13.83	22.31	0.54	4.26	0	10.8	11.17	2.13	1.60	1.07	0.54	0	0.54	0	0	0	0	0	0	100.05.
200104	34.74	5.69	0	10.56	16.32	2.89	3.52	0	9.60	8.96	2.87	1.61	0.33	0.33	0.96	1.07	0.18	0.36	0	0	0	0	100.01.

	MAGNETITE + ILMENITE	LEUCOXENE	PYRITE	ZIRCON	BROWN TOURMALINE	BLUE TOURMALINE	RUTILE	MONAZITE	AMPHIBOLE	EPIDOTE GROUP	GARNET	ANDALUSITE	SILLIMANITE	KYANITE	STAUROLITE	TOPAZ	APATITE	PYROXENE	OLIVINE	SPHENE	FLUORITE	? MONTICELLITE + UNKNOWNS	TOTAL %
																	OTHERS						
200203	28.54	6.35	0	9.39	17.78	1.68	5.37	0.35	11.41	10.47	3.02	3.02	1.01	0.68	0.35	0	0	0	0	0	0	0.68	100.00
2000C5	18.46	7.38	0	12.79	25.57	1.32	3.09	0	8.82	12.35	4.41	2.64	0.44	0.28	0.28	0	0.89	0	0	0	0	1.33	100.05
200601	18.57	15.87	0	6.84	17.69	1.21	3.62	0.40	9.25	18.09	3.62	1.21	1.22	0	0.81	0.34	0	0.34	0	0	0	0.68	100.01
200702	36.61	2.82	0	20.07	15.44	0.77	6.17	0	2.70	3.86	8.87	0.77	0.76	0	0.40	0	0	0	0	0	0	0.77	100.01
200802	30.86	3.08	0	15.03	15.04	1.58	13.06	0.41	5.94	2.77	7.92	2.79	0.38	0	0	0	0	0	0	0	0	1.19	100.05
201102	25.75	2.15	0	16.74	25.75	2.15	3.86	0.44	8.59	5.15	6.01	0.86	0.86	0	0.44	0	0	0	0	0	0	1.29	100.04
201301	36.19	5.25	0	27.74	6.20	0.65	1.64	0	7.83	4.90	5.87	0.33	0.98	0.33	0.66	0	0	0	0	0	0	0	100.02
201401	23.75	11.06	0	14.15	11.02	0.95	2.20	0	19.84	6.93	1.26	3.47	1.26	1.58	1.26	0	0	0	0	0	0	1.26	99.99
201506	28.57	16.67	0	7.17	12.17	0.72	1.07	0.36	18.62	5.38	0.72	2.87	1.79	1.43	0.72	0	0	0	0	0	0	1.79	100.05
201704	43.64	20.07	0	16.12	3.23	0.27	2.15	0	4.03	6.18	1.61	0.54	0.54	0.81	0.27	0	0.20	0	0	0	0	3.34	100.00
210602	18.35	22.83	0	21.15	19.07	2.06	7.31	0.50	0.52	1.56	1.55	2.57	0.52	1.54	0	0	0.52	0	0	0	0	0	100.05
210702	23.29	23.34	0	13.63	18.85	2.03	11.30	0.29	0.29	1.74	0.87	2.61	0.29	0.87	0	0	0.29	0	0	0	0	0.29	99.98
210704	17.48	17.47	0	25.02	20.01	2.67	8.01	0	0	2.00	0.34	4.00	0.34	0.67	0.34	0	0.67	0	0	0	0	1.30	100.22
210801	19.93	27.36	0	22.30	16.18	1.5[illegible]	6.90	0.17	0	2.40	0	2.10	0.31	0.31	0		0	0	0	0	0	0.61	100.05
210806	21.18	21.18	0	21.41	19.63	2.52	7.56	0	0.77	2.02	0.25	2.02	0.25	0.25	0	0	0.25	0	0	0	0	0.74	100.03
210901	18.34	27.50	0	16.26	20.84	2.50	7.50	0	0	0	0	4.17	0.42	0	0.84	0	0.41	0	0	0	0	1.25	100.03
210902	24.86	6.19	0	19.59	7.62	1.64	2.62	0.55	19.59	8.05	0	1.64	4.90	0.55	0.55	0	0.56	0	0	1.08	0	0	100.00
211201	19.98	19.97	0	6.62	9.84	1.11	4.69	0.28	15.98	14.88	0.55	0.55	2.83	0.83	0.28	0.28	0	0.28	0	0	0	1.11	100.00
211204	21.71	16.20	0	24.16	10.47	0	6.04	0.05	6.85	5.23	2.01	1.21	1.62	1.21	0.81	0.40	0.41	0	0	0.40	0	1.21	100.00
21A0301	23.35	18.68	0	22.30	12.51	4.08	5.99	0.08	3.81	3.54	1.09	2.18	0.27	0.27	0.22	0.54	0.27	0	0	0	0	0.82	100.00
21A0801	29.82	14.91	0	21.60	22.05	0.76	6.35	0	0	0.76	0.38	2.25	0	0	0	0	0	0	0	0	0	1.12	100.00
220801	51.09	8.51	0	8.74	16.92	0.55	3.27	0.55	1.64	2.19	4.36	1.64	0.55	0	0	0	0	0	0	0	0	0	100.01
223201	44.65	4.16	0	10.83	10.02	0.26	0.53	0.13	16.38	8.81	1.45	0.79	0.92	0.26	0	0	0	0	0	0	0	0	99.99
221902	39.20	2.81	0	17.84	25.25	0.50	0.99	0	2.99	2.97	4.46	0.50	0.99	0	1.49	0	0	0	0	0	0	0	99.99
222502	43.30	10.82	0	15.06	23.47	1.40	1.05	0.18	0.35	0.35	1.75	2.28	0	0	0	0	0	0	0	0	0	0	100.01
280801	34.43	11.48	0	16.77	16.14	0.21	5.87	0.21	3.56	2.31	4.61	3.35	0	0	0.84	0	0	0	0	0	0.21	0	99.99
281301	36.73	5.65	0	8.17	24.05	0.88	2.65	0.22	6.85	3.97	5.74	2.86	0.21	0.46	1.32	0.23	0	0	0	0	0	0	99.99
280061	42.56	5.33	0	11.44	16.57	0.46	4.66	0.71	5.14	3.51	4.91	2.13	0	0	2.34	0	0	0	0	0	0.23	0	99.99

	MAGNETITE + ILMENITE	LEUCOXENE	PYRITE	ZIRCON	BROWN TOURMALINE	BLUE TOURMALINE	RUTILE	MONAZITE	AMPHIBOLE	EPIDOTE GROUP	GARNET	ANDALUSITE	SILLIMANITE	KYANITE	STAUROLITE	OTHERS: TOPAZ	OTHERS: APATITE	OTHERS: PYROXENE	OTHERS: OLIVINE	OTHERS: SPHENE	OTHERS: FLUORITE	? MONTICELLITE + UNKNOWNS	TOTAL %
280810	23.09	15.39	0	4.15	10.60	0	0.92	0	32.95	4.38	4.15	1.38	2.53	0.23	0.23	0	0	0	0	0	0	0	100.00
290003	29.11	15.68	0	10.77	26.86	0.41	5.32	0.41	1.64	2.45	4.50	1.23	0	0	0.80	0.82	0	0	0	0	0	0	100.00
290401	36.38	12.12	0	11.53	17.69	0.32	5.37	0.32	4.27	3.79	5.69	1.26	0.16	0.16	0.79	0.16	0	0	0	0	0	0	100.01
290502	38.86	9.71	0	12.19	13.87	0.90	5.02	0.18	4.48	2.15	9.68	0.80	0	0	2.08	0	0	0	0	0	0	0	100.02
290901	27.89	3.72	5.58	9.07	20.02	0.68	0.91	0.45	1.81	2.04	21.09	1.36	0.45	0	4.92	0	0	0	0	0	0	0	99.99
300102	22.20	17.98	0	25.00	25.07	1.00	4.88	0.16	0.32	0.70	1.53	1.01	0	0	0.16	0	0	0	0	0	0	0	100.01
300804	36.95	15.83	0	23.33	18.33	0	1.11	0	1.67	0	1.66	0	0	0	0.56	0.56	0	0	0	0	0	0	100.00
301202	35.30	11.76	0	9.03	27.09	0.71	4.07	0.35	3.90	1.76	3.19	1.77	0	0.17	0.71	0	0	0	0	0.17	0	0	99.98
301401	23.38	16.79	0	26.23	23.84	0.85	4.93	0.16	0.32	0.80	1.43	1.61	0	0	0.16	0	0	0	0	0	0	0	100.00
3180201	46.35	5.80	0	18.89	17.64	0	3.78	1.26	0	5.04	0	1.26	0	0	0	0	0	0	0	0	0	0	100.02
3180903	73.59	11.33	0	7.62	3.21	0	1.46	0.14	0.64	1.40	0.20	0.40	0	0	0	0	0	0	0	0	0	0	99.99
3181103	26.84	18.83	0	25.56	21.39	0.96	3.85	0	0	1.44	1.92	0.72	0.24	0	0	0.24	0	0	0	0	0	0	99.99
3181204	32.55	21.70	0	15.86	19.08	0.46	5.52	0.46	0	0.23	0.69	2.30	0.23	0.69	0	0.23	0	0	0	0	0	0	99.99
3181402	42.00	18.00	0	22.00	15.00	0	0.50	0	0	0.50	1.50	0.50	0	0	0	0	0	0	0	0	0	0	100.00
3181902	62.51	14.45	0	14.26	3.66	0	1.10	0	0	2.19	1.10	0.73	0	0	0	0	0	0	0	0	0	0	100.00
3182103	54.21	16.29	0	14.07	6.52	0.34	1.03	0	2.74	3.43	1.03	0.34	0	0	0	0	0	0	0	0	0	0	100.00
330102	29.14	14.61	0	18.22	25.37	0.64	5.20	0	0	1.29	1.63	2.27	0	0.98	0	0.64	0	0	0	0	0	0	99.99
330702	9.82	0	55.68	16.37	6.83	0.19	0.78	0	7.99	0.38	1.56	0	0.39	0	0	0	0	0	0	0	0	0	99.99
330803	38.30	9.58	15.96	16.96	11.16	0.45	3.13	0.22	0	0.67	2.23	0.45	0	0.22	0.45	0.22	0	0	0	0	0	0	100.0
331001	41.81	13.94	0	11.21	21.26	0.86	3.45	0.29	1.72	1.15	2.59	0.57	0.29	0	0.86	0	0	0	0	0	0	0	100.0
340001	33.33	9.10	0	15.58	33.76	0.64	3.68	0.71	0	0.64	0.86	1.29	0	0	0.42	0	0	0	0	0	0	0	100.01
340801	29.39	7.36	0	16.42	27.89	1.97	6.47	0.99	0	0.48	4.48	1.58	0.48	0	2.48	0	0	0	0	0	0	0	99.99
341301	33.56	6.11	0	19.12	31.87	0.85	3.68	0.28	0.24	0.30	1.82	0.91	0.44	0.82	0	0	0	0	0	0	0	0	100.0
341701	34.20	13.69	0	12.27	27.30	0.75	3.00	0	1.08	1.00	3.75	1.24	0	0.75	0.24	0.49	0	0	0	0	0	0.24	100.0
341803	33.65	22.43	0	16.22	19.73	0.14	4.32	0.14	0.14	1.09	1.08	0.81	0	0	0	0.27	0	0	0	0	0	0	100.0
341905	27.40	13.69	0	9.40	31.33	0.42	4.18	0	3.55	2.51	6.27	0.84	0	0	0	0.41	0	0	0	0	0	0	100.0
342102	34.90	12.46	0	8.38	28.42	0.93	3.73	0	0	0.93	7.45	2.79	0	0	0	0	0	0	0	0	0	0	99.9
342509	50.11	13.45	0	17.44	8.99	0.51	3.24	0.65	0	2.60	1.40	0.97	0.22	0.32	0.10	0	0	0	0	0	0	0	100.0

	MAGNETITE + ILMENITE	LEUCOXENE	PYRITE	ZIRCON	BROWN TOURMALINE	BLUE TOURMALINE	RUTILE	MONAZITE	AMPHIBOLE	EPIDOTE GROUP	GARNET	ANDALUSITE	SILLIMANITE	KYANITE	STAUROLITE	TOPAZ (OTHERS)	APATITE (OTHERS)	PYROXENE (OTHERS)	OLIVINE (OTHERS)	SPHENE (OTHERS)	FLUORITE (OTHERS)	MONTILLITE + UNKNOWNS (OTHERS)	TOTAL
342510	40.96	17.55	0	14.52	15.15	1.04	2.70	0.41	0.21	3.31	2.49	1.24	0	0	0.21	0.21	0	0	0	0	0	0	100.
350602	21.91	14.61	0	4.78	34.13	0	4.78	0	0	7.51	10.92	0.68	0.68	0	0	0	0	0	0	0	0	0	100.0
350703	39.52	25.14	0	15.21	10.30	0	2.81	0.24	0.71	4.45	0.69	0.47	0	0	0	0.47	0	0	0	0	0	0	100.0
351001	41.51	19.68	0	14.78	13.34	0.24	1.67	0.24	0.47	5.00	2.15	0.71	0.24	0	0	0.47	0	0	0	0	0	0	100.0
351202	30.54	19.06	0	15.79	15.42	0	3.00	0.38	3.00	6.00	4.13	0.77	1.13	0	0	0.75	0	0	0	0	0	0	99.9
351402	28.87	18.38	0	9.79	19.58	1.36	2.99	0.27	0.27	4.35	13.32	0.27	0.27	0	0	0.27	0	0	0	0	0	0	99.9
351603	35.91	17.97	0	11.85	16.09	1.26	4.24	0	1.70	5.50	3.80	0.42	0.84	0	0	0.42	0	0	0	0	0	0	100.
351609	27.71	10.65	0	32.80	14.67	0.34	2.76	0.18	0	4.84	5.35	0.52	0	0	0	0.18	0	0	0	0	0	0	100.
351704	38.35	10.98	0	35.00	4.54	0.23	3.50	0.68	0	2.95	4.31	0.23	0.23	0	0	0	0	0	0	0	0	0	100.0
360303	31.80	13.63	0	22.85	23.66	0.81	3.49	0	0	0	1.61	1.34	0.27	0	0	0.54	0	0	0	0	0	0	100.0
360502	25.38	19.75	0	25.62	25.31	0.52	0.78	0	0	0	0.26	1.56	0	0.26	0	0.52	0	0	0	0	0	0	100.0
360801	29.72	24.32	0	12.50	19.42	0.58	3.65	0	1.54	3.26	2.31	0.96	0.58	0.58	0	0.38	0.19	0	0	0	0	0	99.9
360901	31.76	17.10	0	11.73	21.38	1.30	1.95	0.33	0	3.26	3.91	0	0.98	0.65	0.33	0	0.33	0	0	0	0	0	100.0
381101	33.96	22.64	0	6.31	15.49	0.96	2.87	0.19	1.91	8.03	6.12	0.38	0.57	0	0	0.38	0.19	0	0	0	0	0	100.0
381901	24.40	24.39	0	7.00	17.15	0.72	1.93	0.24	5.56	10.63	5.82	0.24	0.97	0.24	0	0.72	0	0	0	0	0	0	100.
382401	24.62	18.46	0	11.48	11.02	0.72	2.76	0.46	11.94	12.85	2.30	0.45	2.30	0	0	0	0.45	0	0	0	0	0	100.
382901	32.25	10.75	0	9.90	16.04	0.34	2.05	0.34	13.31	10.24	3.07	0	0.68	0	0	1.02	0	0	0	0	0	0	99.1
383301	35.11	11.70	0	14.21	15.30	0.55	1.64	0.18	6.92	9.66	3.46	0	0.36	0	0.18	0.36	0.36	0	0	0	0	0	99.9
383601	33.71	5.62	0	31.19	7.90	0	2.14	0	8.54	8.12	2.35	0.21	0	0	0	0.21	0	0	0	0	0	0	99.
384201	47.84	11.04	0	16.35	10.90	0.49	0.49	0.75	3.22	4.71	3.72	0	0	0	0	0	0.49	0	0	0	0	0	100.
390501	36.85	19.84	0	7.76	21.71	0.68	2.55	0	0.85	1.02	5.95	1.19	0.17	0.34	0.34	0.51	0	0	0	0.17	0	0	99.
390701	38.02	16.30	0	12.59	19.51	0.49	4.44	0	1.73	0.74	4.20	1.48	0.25	0	0.25	0	0	0	0	0	0	0	100.
391001	29.56	24.18	0	13.80	17.47	0.29	2.35	0.44	3.67	3.38	2.94	0.88	0.44	0.29	0.15	0.15	0	0	0	0	0	0	99.
391801	31.60	13.54	0	10.86	18.55	0.29	3.43	0	4.57	3.43	12.29	0.29	0.29	0	0.57	0	0	0	0	0.29	0	0	100
392601	31.92	15.96	0	21.74	13.49	0	3.39	0	5.25	3.75	4.50	0	0	0	0	0	0	0	0	0	0	0	100.0
393701	34.32	18.48	0	13.87	13.46	0	5.18	0.41	3.31	5.38	3.52	0.41	0.42	0.62	0	0.41	0	0	0	0	0	0	99.
394301	54.23	6.03	0	17.22	8.83	0.44	0.44	0	0.88	0.44	9.93	0.66	0	0.66	0.23	0	0	0	0	0	0	0	99.
395002	25.83	6.46	22.22	19.10	[illegible]	0	0.75	0.25	0	0	14.07	0	0	0	0	0	0	0	0	0	0	0	100

…ACE SAMPLES

	MAGNETITE +ILMENITE	LEUCOXENE	PYRITE	ZIRCON	BROWN TOURMALINE	BLUE TOURMALINE	RUTILE	MONAZITE	AMPHIBOLE	EPIDOTE GROUP	GARNET	ANDALUSITE	SILLIMANITE	KYANITE	STAUROLITE	TOPAZ	APATITE	PYROXENE	OLIVINE	SPHENE	FLUORITE	? MONTICELLITE +UNKNOWNS	TOTAL
																OTHERS							
24	23.88	10.24	0	11.76	22.35	0.94	2.82	0.47	13.88	6.12	1.18	2.82	1.41	0.47	1.18	0.24						0.24	100.00
23	25.29	4.46	0	6.14	31.86	0.77	0.77	0.38	13.28	6.34	3.65	4.03	0.38	0	2.30	0	0	0	0.19	0	0	0	99.99
22A	35.48	3.94	0	13.49	16.18	0.41	6.02	0.41	9.96	5.60	4.15	1.87	0.62	0.41	0.83	0	0.21	0	0	0.41	0	0	99.99
21A	44.41	5.54	0	24.21	8.14	0.18	3.80	0.36	6.15	4.34	1.27	0.72	0.36	0.18	0	0.14	0	0	0	0	0	0	100.00
66	32.18	2.92	0	24.27	11.82	0.31	3.11	0.31	14.94	4.99	3.27	0.62	0.62	0.16	0.16	0	0.32	0	0	0	0	0	100.0
65	37.74	4.45	0	11.46	15.16	0.88	5.11	0.71	15.68	4.94	2.12	0.71	0.17	0.35	0.17	0	0	0.35	0	0	0	0	100.0
67	38.01	3.30	0	11.53	13.72	0.44	4.53	0.58	14.60	7.44	3.07	0.29	0.58	0.44	0.88	0.15	0.15	0	0	0.15	0	0.15	100.0
68	34.56	5.31	0	15.84	14.33	0.19	2.83	0.19	16.41	5.28	3.40	0.76	0.76	0	0.15	0	0	0	0	0	0	0	100.0
63	28.88	3.21	0	9.91	20.08	0.74	5.46	0.25	4.46	2.23	18.84	2.23	0	0	2.97	0	0	0	0	0	0	0.74	100.0
61	34.96	1.45	0	10.05	16.49	0.80	2.03	0.40	21.73	9.25	2.03	0.80	0	0	0	0	0	0	0	0	0	0	99.99
60	37.54	3.00	0	16.64	15.22	1.07	2.83	0.36	9.91	4.25	5.30	1.07	0.71	0	1.05	0	0	0	0	0	0	0	100.0
80	45.36	8.24	0	9.61	17.85	1.38	2.47	0.27	8.51	2.74	1.92	1.65	0	0	0	0	0	0	0	0	0	0	100.0
79	38.92	5.99	0	6.95	31.28	0.91	4.57	0.36	3.10	1.84	1.83	2.74	0.18	0	0.78	0.37	0.18	0	0	0	0	0	100.0
76	41.62	4.62	0	22.57	17.26	0.66	4.65	0.22	1.11	3.76	1.33	1.33	0.44	0.22	0.22	0	0	0	0	0	0	0	100.0
78	48.95	6.91	0	16.79	13.74	0.76	1.91	0.19	4.58	3.05	2.29	0.95	0	0.19	0.38	0.77	0	0	0	0	0	0	99.98
137	40.94	10.22	0	7.88	25.01	0.92	2.78	0.47	4.17	3.48	1.62	2.09	0	0.21	0.21	0	0	0	0	0	0	0	100.0
138	42.62	10.65	0	21.94	12.05	0.48	5.78	0.72	1.93	1.44	2.18	0	0	0	0	0	[illegible]	0.21	0	0	0	0	100.0
139	33.56	5.60	0	23.66	24.45	0.78	3.90	0.26	2.35	2.07	1.81	1.55	0	0	0	0	0	0	0	0	0	0	99.99
112	49.18	8.68	0	11.14	9.61	0.87	3.49	0.22	6.99	4.56	1.75	1.31	0.44	0.44	0.66	0	0	0.44	0.22	0	0	0.22	100.
113	42.33	5.64	0	34.16	7.45	0	1.59	0	4.77	0.78	1.19	0.79	0	0	0.38	0	0.40	0	0	0	0	0	100.0
114	38.76	4.31	0	19.71	14.60	1.46	3.65	0	9.49	2.90	2.92	1.46	0	0	0.74	0	0	0	0	0	0	0	100.
116	43.03	6.14	0	37.40	2.86	0	2.81	0.40	2.04	2.46	0	1.64	0.81	0	0	0	0.20	0.40	0.21	0	0	0	99.99
117	40.81	4.53	0	11.86	15.11	0.54	5.43	0.27	6.79	3.89	5.70	2.71	0.36	0.45	1.18	0	0.18	0	0.09	0	0	0.09	99.9
120	38.17	7.62	0	14.04	12.02	0.22	3.03	0.11	7.19	4.71	4.16	1.46	0.45	0.33	0.90	0.22	0.22	0.88	4.12	0	0	0	99.9
122	53.61	2.84	0	17.43	7.47	0.36	3.20	0.36	4.26	2.84	3.20	1.42	0	0	0	0	0.15	0.30	0.90	0	0	1.65	99.
127	23.09	15.39	0	13.33	35.76	0.61	5.15	0.30	0.91	0.91	2.60	3.03	0	0	0.31	0	0	0	0	0	0	0.60	99.
126	36.91	2.07	0	14.48	18.03	0.77	8.54	0.38	3.37	1.90	6.65	2.09	0.57	0.38	2.28	0	0.56	0.30	0.70	0	0	0	99.
130	43.35	4.82	0	17.70	12.40	0.41	4.55	0.21	7.64	3.10	2.48	1.65	0.21	0.21	1.24	0	0	0	0	0	0	0	100.
132	50.35	2.65	0	22.61	7.36	0.32	3.47	0.32	5.26	2.72	2.05	0.63	0.10	0.42	0.74	0	0	0	0	0	0	0	100.

	Magnetite + Ilmenite	Leucoxene	Pyrite	Zircon	Brown Tourmaline	Blue Tourmaline	Rutile	Monazite	Amphibole	Epidote Group	Garnet	Andalusite	Sillimanite	Kyanite	Staurolite	Topaz	Apatite	Pyroxene	Olivine	Sphene	Fluorite	[illegible]	Total %
																OTHERS							
133	49.54	5.82	0	17.67	7.83	0.91	5.65	0.36	3.28	2.01	5.46	0.73	1.19	0.36	0.18	0	0	0	0	0	0	0	100.01
134	54.75	2.88	0	20.72	6.07	0.12	4.67	0.62	2.96	3.89	1.56	0.31	0.31	0	0.47	0	0	0	0	0.16	0	0	99.99
135	32.72	3.75	0	8.44	29.28	0.74	3.97	0.50	7.69	2.95	3.23	4.71	0	0	0.74	0.25	0	0	0	0	0	1.00	100.00
136	33.13	11.38	0	18.68	22.80	1.05	3.77	0.21	0	0.63	0.21	1.67	0.21	0	1.26	0.20	0.60	0.20	4.00	0	0	0	100.00

MOLINEAUX SAND SAMPLES FROM FLANKS OF DUNES

	Magnetite + Ilmenite	Leucoxene	Pyrite	Zircon	Brown Tourmaline	Blue Tourmaline	Rutile	Monazite	Amphibole	Epidote Group	Garnet	Andalusite	Sillimanite	Kyanite	Staurolite	Topaz	Apatite	Pyroxene	Olivine	Sphene	Fluorite	[illegible]	Total %
220	33.54	5.92	0	21.55	20.13	0.63	5.23	0.16	3.65	2.06	2.54	2.38	0.63	0.32	1.11	0.16	0	0	0	0	0	0	100.01
218	33.15	8.28	0	24.97	21.66	0.69	5.02	0	0.69	1.90	1.38	1.56	0	0.17	0.52	0	0	0	0	0	0	0	99.99
68A	36.12	6.37	0	25.19	20.82	0.76	5.89	0.19	1.05	0.86	1.14	0.95	0	0	0.67	0	0	0	0	0	0	0	100.01
64	43.53	7.68	0	17.64	20.48	0.14	5.26	0	1.56	0.57	1.00	1.14	0.12	0.16	0.71	0	0	0	0	0	0	0	99.99
61C	28.69	19.12	0	13.39	26.10	1.39	4.39	0.46	0.69	1.38	0.92	2.54	0.23	0	0.69	0	0	0	0	0	0	0	99.99
70	53.33	5.92	0	14.76	19.81	0.78	3.11	0.38	0.58	0.39	0.19	0.55	0.19	0	0	0	0	0	0	0	0	0	100.00

CREEK SEDIMENT SAMPLES

	Magnetite + Ilmenite	Leucoxene	Pyrite	Zircon	Brown Tourmaline	Blue Tourmaline	Rutile	Monazite	Amphibole	Epidote Group	Garnet	Andalusite	Sillimanite	Kyanite	Staurolite	Topaz	Apatite	Pyroxene	Olivine	Sphene	Fluorite	[illegible]	Total %
79 MB	33.61	3.73	0	16.89	40.33	0.20	2.44	0	0	0	1.31	1.50	0	0	0	0	0	0	0	0	0	0	99.99
81 MO	46.23	2.43	0	37.64	9.20	0.48	2.59	0.48	0.19	0	0.29	0.38	0	0	0.10	0	0	0	0	0	0	0	100.01
82 MO	32.31	3.59	0	41.11	16.38	0.43	3.69	0.54	0.11	0.22	0.11	0.87	0	0	0.11	0.54	0	0	0	0	0	0	100.01
73 NA	27.94	3.10	0	50.07	11.16	0.57	6.58	0.43	0	0	0.14	0	0	0	0	0	0	0	0	0	0	0	99.99
74 NA	26.45	4.41	0	38.88	23.49	0.77	4.86	0.38	0.19	0.19	0	0.38	0	0	0	0	0	0	0	0	0	0	100.00
75 MB	44.67	5.18	0	19.14	22.85	0.62	4.32	0.62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100.00
77 MB	27.64	6.91	0	4.29	52.36	1.83	1.50	0	0	0.21	1.07	3.00	0	0	0.64	0	0	0	0	0	0	0	99.99

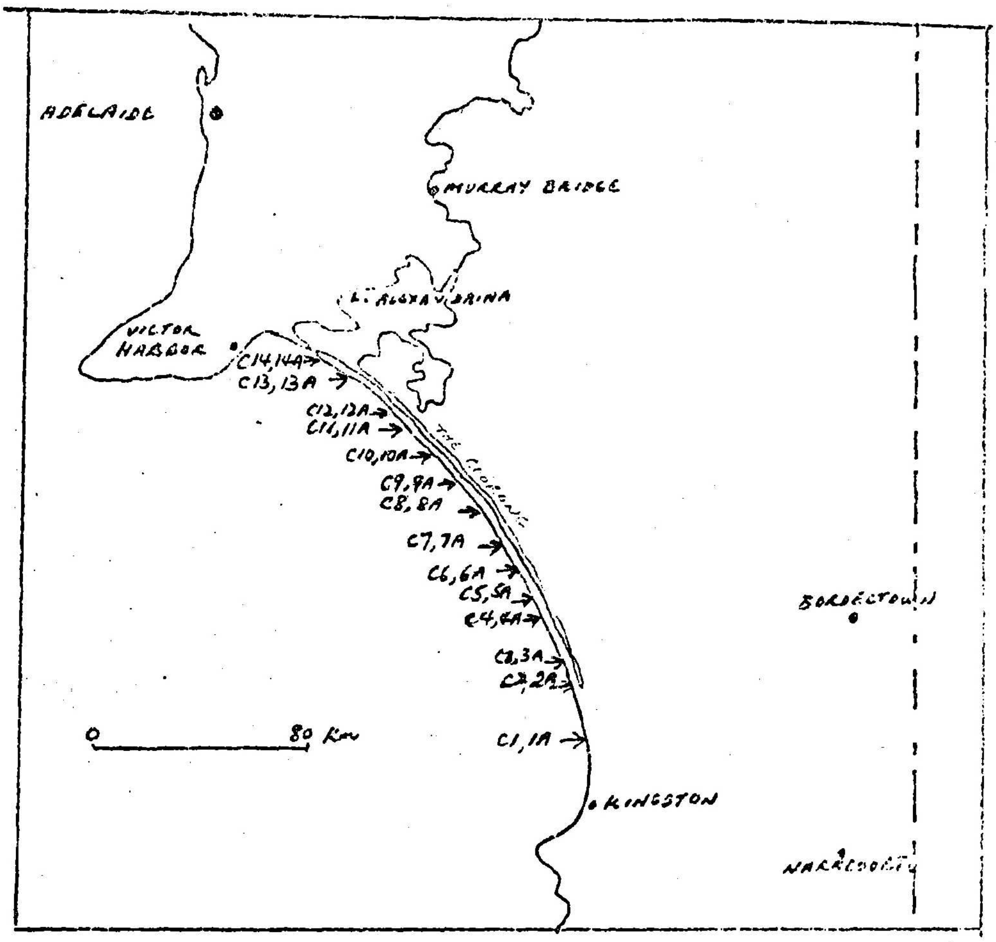
NA NARACOORTE CREEK

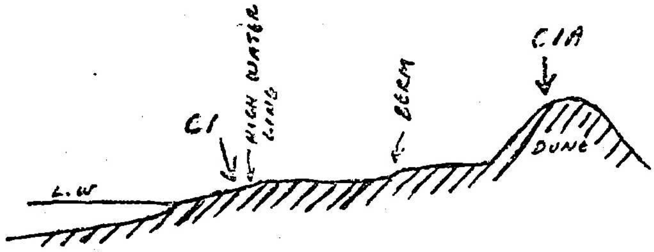
MO MOSQUITO CREEK

MB MORAMBRO CREEK

MODERN COORONG BEACH (YOUNGHUSBAND PEN.) SAMPLES

	MAGNETITE + ILMENITE	LEUCOXENE	PYRITE	ZIRCON	BROWN TOURMALINE	BLUE TOURMALINE	RUTILE	MONAZITE	AMPHIBOLE	EPIDOTE GROUP	GARNET	ANDALUSITE	SILLIMANITE	KYANITE	STAUROLITE	TOPAZ	APATITE	PYROXENE	OLIVINE	SPHENE	FLUORITE	MONTICELLITE + UNKNOWNS	TOTAL %
C1	37.98	16.27	0	8.32	13.02	0.36	0.72	0.18	15.91	2.35	3.07	0.54	0.54	0.36	0.18	0.18	0	0	0	0	0	0	99.98
C1A	38.84	16.64	0	7.76	16.21	0	1.83	0.23	12.56	2.51	2.05	0.46	0.46	0	0.23	0	0.23	0	0	0	0	0	100.01
C2	30.11	16.70	0	19.19	13.78	0.49	2.21	0	3.68	3.20	1.72	0.99	0.74	0	0.25	0.25	0	0	0	0	0	0	100.00
C2A	34.69	20.81	0	11.77	16.19	0.18	2.63	0.18	5.00	2.50	1.62	1.08	0.71	0	0.74	0.36	0.53	0	0	0	0	0	99.99
C3	38.97	15.58	0	5.77	22.37	0	1.44	0.71	5.05	7.22	2.16	0	0	0	0	0.71	0	0	0	0	0	0	99.98
C3A	29.24	14.62	0	7.77	26.14	2.46	2.47	0	7.77	3.18	2.82	1.76	0.70	0.36	0.36	0.36	0	0	0	0	0	0	100.01
C4	41.64	11.92	0	11.89	14.59	0.54	1.62	1.07	8.10	6.48	0.54	0	0.54	1.07	0	0	0	0	0	0	0	0	100.00
C4A	37.36	12.48	0	10.95	20.38	1.28	1.53	0.51	6.37	4.83	3.05	1.01	0	0.25	0	0	0	0	0	0	0	0	100.00
C5	22.12	16.64	0	24.38	20.42	1.32	1.92	1.32	3.30	5.28	1.32	0	0	0	0	0.80	0	0	0	0	0	1.18	100.00
C5A	38.55	15.43	0	12.43	5.95	0.42	3.73	0	8.28	1.87	2.07	0.63	0	0.21	0.21	0.21	0	0	0	0	0	0	99.98
C6	33.01	8.29	0	11.91	18.73	0.85	2.55	0	7.65	6.80	0.85	1.70	3.40	0.85	0.85	0.85	0	1.00	0	0	0.70	0	99.99
C6A	44.93	11.25	0	4.83	18.29	0.69	1.72	0.34	9.32	4.83	0.69	1.38	1.38	0.34	0	0	0	0	0	0	0	0	99.99
C7	35.99	15.44	0	3.24	15.38	0.80	1.62	0	8.90	10.52	1.62	3.24	2.42	0	0	0	0	0	0	0.82	0	0	99.99
C7A	37.35	16.01	0	6.28	22.87	1.79	0	0.45	5.83	7.62	0.45	0	0	0.45	0	0	0	0	0	0	0	0	100.00
C8	40.78	16.31	0	6.26	18.80	0.88	2.68	0	5.37	7.16	0.88	0	0.91	0	0	0	0	0	0	0	0	0	99.98
C8A	42.79	28.52	0	4.22	14.77	0.84	0	0.42	0.38	3.37	0	0.84	0.84	0	0	0	0	0	0	0	0	0	99.99
C9	39.04	19.54	0	9.20	17.48	0.92	0.92	0	6.44	3.69	0	1.84	0.92	0	0	0	0	0	0	0	0	0	99.99
C9A	48.40	20.74	0	9.14	11.43	0.57	1.14	0	2.86	1.43	2.00	0.86	0.86	0.29	0	0	0	0	0	0.29	0	0	100.00
C10	29.46	23.60	0	6.99	19.01	0.77	1.17	0	3.87	5.42	6.20	0.77	0.77	1.17	0.40	0.40	0	0	0	0	0	0	100.00
C10A	50.19	14.34	0	8.35	12.87	0.34	1.04	0.34	1.74	2.79	5.56	0.32	0.91	0.73	0.50	0	0	0	0	0	0	0	100.02
C11	30.73	12.25	0	11.80	23.58	0.99	1.96	0	6.89	5.42	2.95	1.47	1.47	0.49	0	0	0	0	0	0	0	0	100.00
C11A	42.44	12.14	0	12.97	15.97	0	3.00	0	5.98	3.00	2.50	0	0.50	0	1.00	0.	0.50	0	0	0	0	0	100.00
C12	31.57	23.69	0	5.70	19.53	0.41	1.22	0	8.14	5.29	2.03	1.22	0.82	0	0.38	0	0	0	0	0	0	0	100.00
C12A	38.67	20.53	0	12.87	13.27	0.20	1.58	0	4.95	4.16	1.78	0.40	0.40	0	0	0.59	0	0	0	0	0	0	100.00
C13	36.00	4.00	0	6.00	10.00	0.75	2.25	0.50	0.25	3.75	31.50	0.50	0.50	0.75	2.50	0.75	0	0	0	0	0	0	100.00
C13A	34.32	3.81	0	6.00	12.71	0.24	1.44	0	0.72	3.60	33.57	0.96	0.24	0	1.20	1.20	0	0	0	0	0	0	100.01
C14	30.93	3.43	0	2.76	18.71	0.61	0.92	0.31	0	2.76	29.14	3.07	0.31	2.15	0.61	0	0	0	0	1.53	0.31	2.45	100.00





LOCATION OF SAMPLES ALONG THE MODERN COORONG BEACH (YOUNGHUSBAND PENINSULA)

APPENDIX B - PETROGRAPHIC DESCRIPTIONS OF SAMPLES OF THE PADTHAWAY RIDGE IGNEOUS ROCKS

75639593 - Biotite adamellite, Victor Harbour

This is a porphyritic biotite adamellite. Quartz (35%), perthitic potassium feldspar (30%), oligoclase (20%), and biotite (15%) are the principal constituents. Perthite phenocrysts contain inclusions of quartz, oligoclase and biotite. Biotite occurs as large stout laths containing opaques, zircons (surrounded by pleochroic haloes) and apatite prisms. Biotite is pleochroic α= pale yellowish brown, $\beta = \gamma$ = dark brown. Zircon and opaques are the predominant accessory minerals.

75639600 and 75639616 - Biotite adamellite, north of Kingston

This rock is almost identical to that occurring at Victor Harbor. It is a biotite adamellite composed of quartz, microcline-perthite, oligoclase and biotite. Apatite, zircon and opaques are the principal accessory minerals. Myrmekitic intergrowths and exsolution of plagioclase in microcline are common in parts of the rock. Biotite is pleochroic α= pale brown-colourless, $\beta = \gamma$ = dark brown, and commonly contains minute zircons and prisms of apatite.

75639615 - Porphyritic biotite adamellite, Bald Hill

Perthitic microcline, plagioclase (oligoclase-andesine) and quartz are the main constituents. Biotite is the only ferromagnesium mineral present and contains zircon and apatite as inclusions. Although not observed in the sample examined, blue tourmaline (indicolite) is recorded in the accessory phase of the rock at this locality (Rochow, 1971).

75639598 - Rhyolite, Papineau Rocks

The rhyolite which crops out at Papineau Rocks is highly altered. Plagioclase (albite) phenocrysts up to 4 mm in length are set in a minutely crystalline, altered groundmass of feldspar, quartz, chlorite, sphene and sericite. Phenocrysts make up about 5 percent of the rock.

75639612 - Altered quartz keratophyre, Bin Bin

The rock is highly altered and consists of a mosaic of minute quartz and feldspar grains. Relict phenocrysts form approximately 5 percent of the rock and consists of chlorite, potassium feldspar and quartz. Opaques are the main accessory mineral.

75639594 - Quartz porphyry, Mount Monster

Euhedral and corroded phenocrysts of quartz, sanidine, microperthite, non-perthitic potassium feldspar, and sodic plagioclase are set in a groundmass mosaic of quartz and potassium feldspar. The phenocrysts range in size from 0.5 to 4 mm and make up about 50 percent of the rock. Ferromagnesian minerals are absent. Principal accessory minerals are magnetite and zircon.

75639595 - Hornblende-biotite granite-microgranite, Uncle Toms Cabin

The rock has quartz, antiperthite, zoned (albite-oligoclase) plagioclase and perthite as its major constituents. Biotite and minor amounts of hornblende make up about 5 percent of the rock. The biotite usually occurs as aggregates and is pleochroic α = golden brown, $\beta = \gamma$ = dark brown. Hornblende is pleochroic x = greenish brown Y = Z = very dark greenish brown. Fluorite, zircon and opaques are accessories which often accompany biotite.

75639596 - Hornblende-biotite granite, Gip Gip

Grain size is generally 0.5 to 4 mm. Quartz is slightly less abundant than the feldspars. Potassium feldspar is the major mineral present and is strongly perthitic. Ferromagnesian minerals make up about 5 percent of the rock. Biotite is subordinate to blue-green hornblende. Magnetite, zircon and sphene are accessory minerals.

Although Rochow (1971) records pleochroic red-green cassiterite occurring in the accessory phase of this rock, it was not observed in the thin section examined in this study.

75639597 - Hornblende granite, Desert Camp

Grain size varies between 2 and 10 mm. Perthitic potassium feldspar, antiperthite, plagioclase and quartz are the principal constituents. The small amount of plagioclase not in perthite and antiperthite is interstitial between grains of those feldspars. Hornblende is the dominant ferromagnesian mineral, biotite is rare. Opaques, zircon and ?allanite are accessory minerals.

75639613 - Hornblende granite, Marcollat Rocks

This rock is very similar to that occurring near Desert Camp. Perthitic potassium feldspar, quartz and plagioclase are the main components. The plagioclase in this rock has either exsolved from or been incompletely replaced by potassium feldspar. Blue-green to yellowish green hornblende is the principal ferromagnesian mineral present and makes up about 5 percent of the rock. Biotite is very rare. Magnetite, zircon and apatite are the main accessory minerals.

75639599 - Biotite granite, Kongal Rocks

This granite is made up of quartz, perthite, anti-perthite, and relatively minor amounts of oligoclase with biotite as the only ferromagnesian mineral. The biotite is pleochroic α = yellowish brown $\beta = \gamma$ = greenish brown and comprises about 3-5 percent of the rock. Opaques and fluorite are the principal accessory minerals.

75639614, 75639617 - Biotite microgranite, Christmas Rocks

The microgranite of the Christmas Rocks area has a grain size between 0.1 and 4 mm. Perthite and quartz are the major constituents. Plagioclase makes up less than 10 percent of the rock and biotite, 2 to 5 percent. Myrmekitic intergrowths are common. Hornblende was not observed. The biotite varies in colour from brown to greenish brown. Opaques, zircon and fluorite occur as accessories.