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Petrological Services for the
Minerals Exploration and Mining Industry

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Petrographic Descriptions for Six Rock Thin Sections

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SIGNED	
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Petrographic Descriptions for Six Rock Thin Sections

SUMMARY

1. Rock Samples

- A collection of 6 thin sections has been studied using optical petrographic methods.

2. Results

- A summary of rock names and mineralogy is provided in TABLE 1.

- *Query 1: Are these intrusive rocks?*

  - In Group 1 samples, two samples display high-intensity alteration which prevents interpretation of the mode of emplacement (2138266, 2138269); 1 sample is interpreted as a schistose meta-sediment (2138268). See TABLE 2 for summary.

  - In Group 2 samples, all are interpreted as having formed as shallow-level intrusive rocks. One sample formed as a holocrystalline syenogranite porphyry (2138292; FIG. 1), and two samples formed as vitrophyric porphyries of likely rhyodacite/syenogranite composition (2138293, 2138300).

- Query 2: *Are there similarities between these thin sections and Gawler Range Volcanics and/or Benagerie Ridge Volcanics?*

  - In Group 1, the felsic character of the protoliths of 2 samples, including presence of large crystals, provides a petrographic link to GRV/BRV rocks. Further comment is precluded by the strong alteration effects.

  - In Group 2, there are numerous petrographic features which provide links to GRV/BRV rocks: large and abundant K-feldspar, plagioclase and quartz crystals; minor ferromagnesian crystals likely ?pyroxene; zircon as discrete crystals and inclusions in ferromagnesians; and general K-rich rhyodacitic/syenogranitic composition.

- Query 3: *Would you agree that there does not seem to be any strong petrological relationship between Group 1 and Group 2 due to the alteration of Group 1 (if both groups are interpreted to be extrusives)? Or could Group 1 possibly be altered Group 2?*

  - It is difficult to draw comparisons between the protoliths of Group 1 and Group 2 samples, and GRV/BRV rocks. In regard to Group 1 samples, the high intensity of alteration of the felsic rocks prevents positive identification of their protoliths, but they contained similar large feldspar and quartz crystals as observed in Group 2, GRV and BRV rocks. In regard to Group 2, all samples are interpreted as shallow intrusive rocks, which are different from the mostly extrusive tuffaceous GRV deposits, but the mineralogies, their large crystal sizes, and the rhyodacitic/syenogranitic compositions of Group 2 are broadly similar to GRV/BRV rocks.

TABLE 1: SUMMARY OF ROCK NAMES AND MINERALOGY

SAMPLE	ROCK NAME	MINERALOGY*			
		Primary**	Metamorphic/ |Alteration	Veinlets	Weath-ering
GROUP 1 (MPI)					
2138266	Thinly anhydrite-opaques fractured and medium-intensity K-feldspar-biotite-opaques-tourmaline (potassic) altered felsic rock	Kf, qtz, zir	Kf, bio, ser, qtz, opq(hem,?mt), tou	Anh, opq(hem)	-
2138268	Hematite stained (weathered), quartz-muscovite-opaques schist (meta-sediment)	-	Qtz, mus, opq(?mt), mon	-	Hem
2138269	High-intensity biotite-sericite-hematite-monazite (potassic) altered felsic rock	Qtz, zir	Qtz, bio, ser, opq(?hem), mon	-	Hem
GROUP 2 (Tillite clasts/lag)					
2138292	Low-intensity chlorite-magnetite-sericite-hematite altered syenogranite porphyry	Kf, qtz, all, zir	Alb, ser, opq(mt), car(cal), hem	-	-
2138293	K-feldspar-chlorite-hematite altered, weakly flow-banded porphyritic rhyodacite vitrophyre	Kf, qtz, opq(FeOx), zir	Kf, alb, ser, chl, hem, car(cal)	-	-
2138300	K-feldspar-chlorite-hematite altered, weakly flow-banded porphyritic rhyodacite vitrophyre	Kf, qtz, apa, zir	Kf, alb, ser, qtz, chl, qtz, hem	-	-

NOTES
*: Minerals are listed in each paragenesis according to approximate decreasing abundance.
**: Only primary minerals currently present in the rock are listed. Others may have been present, but are altered.

Mineral abbreviations
Alb = albite; all = allanite; anh = anhydrite; apa = apatite; bio = biotite; cal = calcite; car = carbonate minerals; chl = chlorite; FeOx = iron oxides; hem = hematite; Kf = K-feldspar; mon = monazite; mt = magnetite; mus = muscovite; opq = opaque minerals; qtz = quartz; ser = sericite (fine-grained white mica); tou = tourmaline; zir = zircon; ?min = uncertain mineral identification.

TABLE 2: MODE OF EMPLACEMENT

SAMPLE	MODE OF EMPLACEMENT	COMMENTS
GROUP 1 (MPI)		
2138266	Unknown, but likely felsic igneous rock	Strong pervasive alteration has obscured primary textures; Protolith was a felsic rock which contained mostly large crystals (Kf>plag>qtz>>zir).
2138268	Schist	Inferred sedimentary protolith
2138269	Unknown, but likely felsic igneous rock	Strong pervasive alteration has obscured primary textures; Protolith was a felsic rock which contained large crystals (?feld>qtz>>zir).
GROUP 2 (Tillite clasts/lag)		
2138292	Intrusive	Well-preserved massive holocrystalline micrographic igneous groundmass, moderately abundant phenocrysts (Kf >> pla >> qtz = ?pyrox >> zir).
2138203	Likely shallow intrusive	Abundant phenocrysts (Kf = qtz > pla >> ?pyrox >> FeOx, zir) in devitrified and altered glassy groundmass with weak flow banding.
2138300	Likely shallow intrusive	Abundant phenocrysts (Kf = qtz > pla >> ?pyrox >> apa, zir) in devitrified and altered glassy groundmass with weak flow banding.

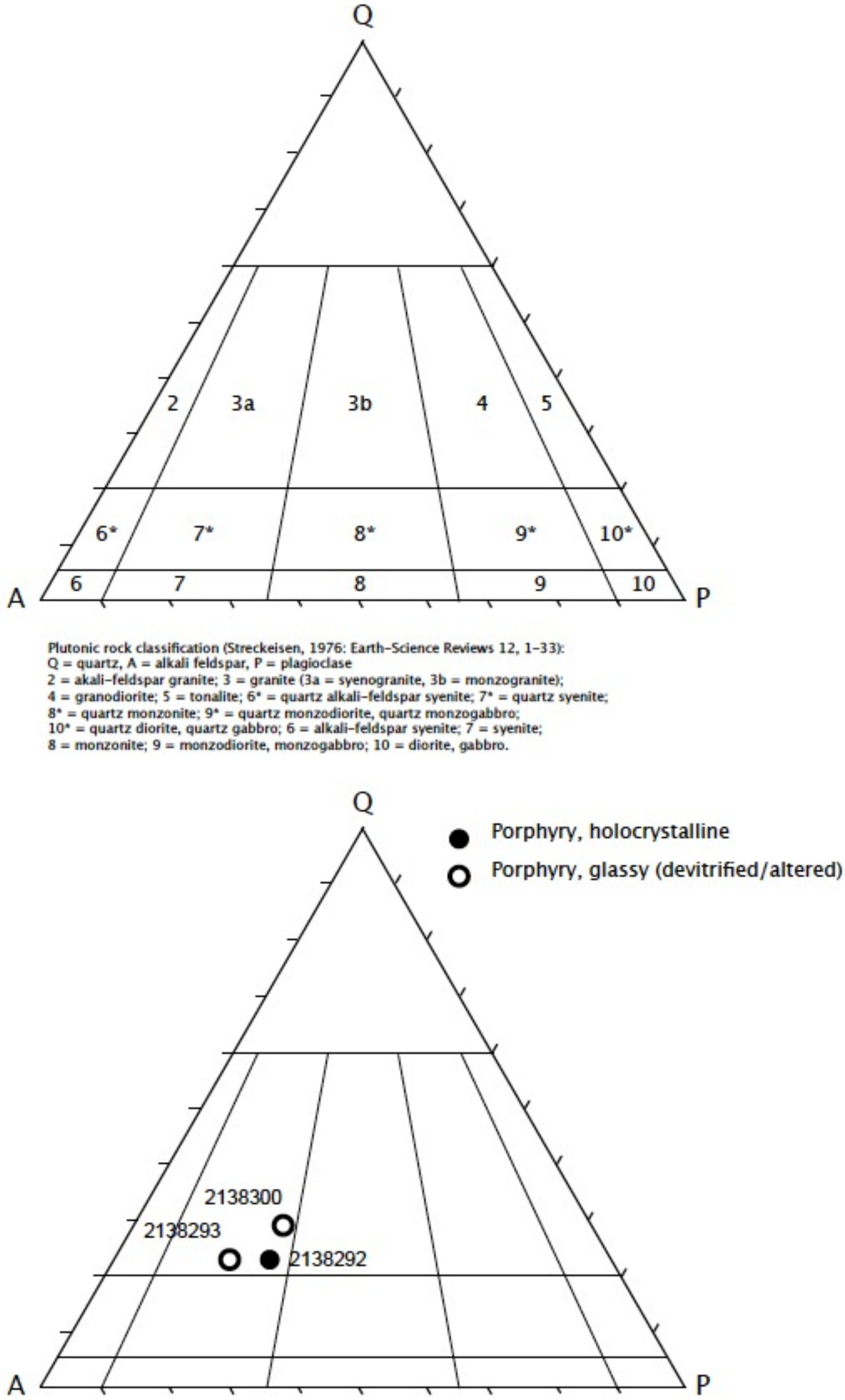

FIG. 1: Q(quartz)-A(alkali feldspar)-P(plagioclase) granitoid classification plot for porphyry samples of Group 2.

1 INTRODUCTION

A collection of 6 thin sections was provided by Mr Stephen Hore, during an office visit to Mason Geoscience on 5 January 2017.

Background notes on the thin sections, and spider plot from geochemistry (FIG. 2), were provided by the client:

> 'Group 1: 3 thin sections for petrology (MPI). 2138266, 2138268, 2138269.
> Group 2: 3 thin sections for petrology (Tillite clasts/lag). 2138292, 2138293, 2138300.
>
> Q1: Are these extrusive rocks? – attached spider plot related with GRV and Benagerie Ridge Volcanics (BRV).
>
> Q2: In general terms, and with your petrological experience, could there be similarities drawn with these TSs with the GRV and/or BRV?
>
> Q3: There does not seem to be any strong petrological relationship between Group 1 and Group 2 due to the alteration of Group 1 (if both groups are interpreted to be extrusives). Would you agree? Or could Group 1 possibly be altered Group 2?
>
> Work by Stephen Hore on these samples:
>
> Group 1 geochronology gives ~1580 Ma zircon age and ~500Ma monazite age.
>
> Group 2 geochronology gives ~1590Ma zircon and no monazites were gained from separation.'

Excerpts from this report were provided by email to Mr Hore on 1 February 2017. This report contains the full results of this work.

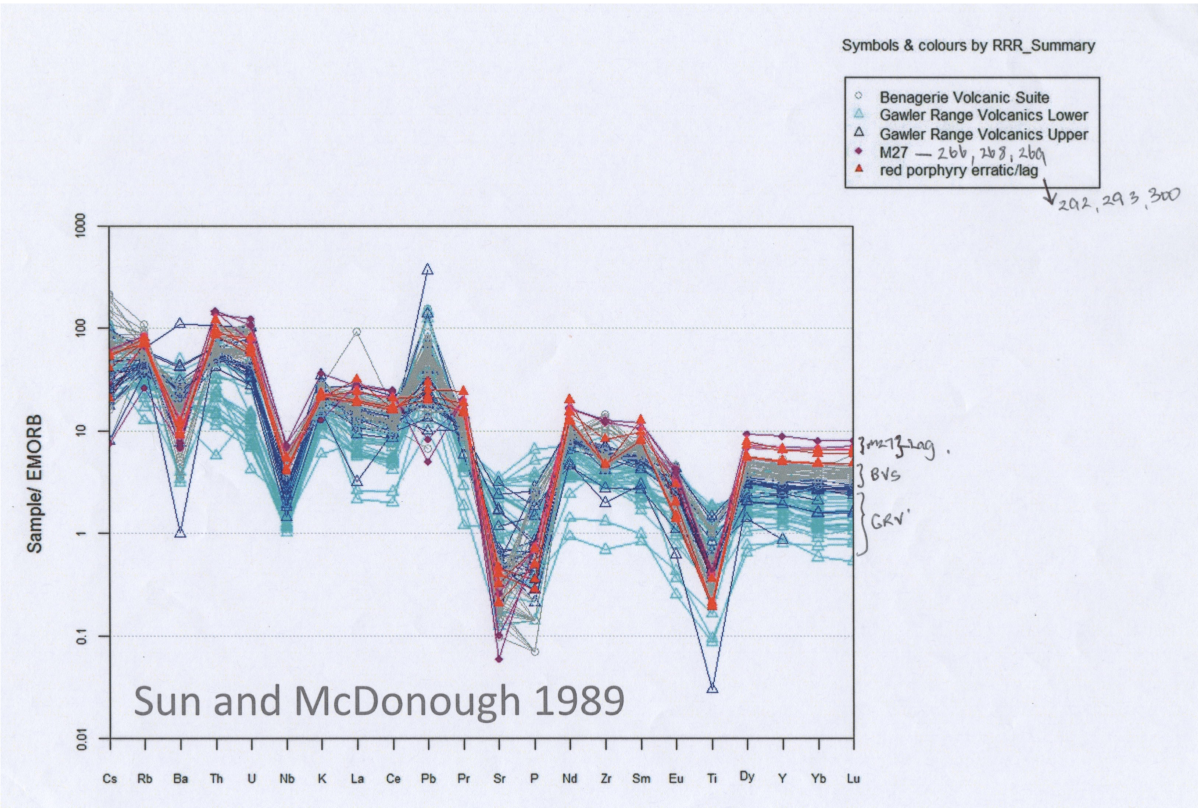

FIG. 2: Spider plot from geochemistry of petrology samples and relevant rock groups (courtesy of Stephen Hore, Geological Survey SA)

2 METHODS

At Mason Geoscience Pty Ltd conventional transmitted polarised light microscopy was used to prepare the routine petrographic descriptions. Modal mineral abundances are optical estimates, and are considered to have approximate absolute errors as follows: ±~5 vol.% at an abundance of 20 vol.%, ±~3 vol.% at 10 vol.%, and ±~2 vol.% at 5 vol.%. Paragenetic stages of development of each rock are indicated in the mineral modal list, where each mineral is assigned to a numerical paragenesis (paragenesis 1 is earliest; paragenesis 2 overprints 1; paragenesis 3 overprints both 2 and 1; etc). **The paragenetic stages display relative timing insofar as they can be determined within each sample**, and are not meant to be directly equated between samples although this may be correct for some samples.

3 PETROGRAPHIC DESCRIPTIONS

The petrographic descriptions are provided in the following pages.

SAMPLE # : **2138266**

SAMPLE GROUP : Group 1 (MPI)

SECTION NO. : 2138266

HAND SPECIMEN : Not available.

ROCK NAME : **Thinly anhydrite-opaques fractured and medium-intensity K-feldspar-biotite-opaques-tourmaline (potassic) altered felsic rock**

PETROGRAPHY :

A visual estimate of the modal mineral abundances gives the following:

Mineral	Vol %	Origin
K-feldspar (orthoclase, microcline)	30	Relict primary crystals 1 / alteration 2
Quartz	1	Primary crystals 1
Zircon	Tr	Primary crystals 1
K-feldspar	48	Alteration 2 (after matrix 1)
Quartz	2	Alteration 2 (after matrix 1)
Biotite	10	Alteration 2 / fracture seals 2
Sericite	4	Alteration 2 (after primary crystals 1)
Opaques (hematite, ?magnetite)	3	Alteration 2
Tourmaline	<1	Alteration 2
Anhydrite	<1	Veinlet fillings 2
Opaques (hem)	Tr	Veinlet fillings 2

In thin section, this sample displays a partly preserved primary porphyritic or phenoclastic texture, severely modified by subsequent thin fracturing and pervasive alteration effects.

Primary crystals were moderately abundant, and different types are identified:

i) K-feldspar formed large euhedral blocky prisms, intergrown crystals, and possible magmatically resorbed crystals. They are ~4-10 mm in size. Most are optically homogeneous and therefore appear to be orthoclase, but most display partial replacement to ‘tartan’ twinned microcline around crystal margins and along thin microfractures. Trace biotite occurs as small replacement flakes along minor thin microfractures.

ii) Plagioclase is considered to have been present in minor amount, forming subhedral blocky to anhedral grains generally smaller (~2-4 mm) than the K-feldspar grains. All have suffered complete replacement by fine-grained dense mats of colourless white mica (sericite), accompanied in places by small poorly-formed biotite flakes. Many of the grains display a weak preferred orientation of primary origin (flow structure).

iii) Quartz occurs as minor large clear crystals ~2 mm in size. They display magmatically corroded crystal margins; little or no fracturing is event.

iv) Zircon is observed as uncommon small stumpy prisms discretely in the groundmass, and also included in some large K-feldspar crystals. The zircon displays its typical prismatic crystal form, colourless to off-pink colour, high relief, and high birefringence.

Matrix dominates the rock. It displays a heterogeneous, inequigranular texture. In places, indistinct patches display a poorly-preserved micrographic texture (intergrown K-feldspar and lesser quartz), suggesting it formed as a coherent igneous groundmass. Most of the matrix, however, lacks that texture and is dominated of abundant small anhedral K-feldspar grains. Biotite is moderately abundant, forming tiny poorly-shaped flakes ~20-50 µm in size, pleochroic from pale tan brown to pale yellow. Opaques are distributed throughout, including small euhedral cubic crystals (likely hematite-altered magnetite) and tiny reddish specks (hematite). Tourmaline occurs locally as anhedral large spongy porphyroblastic grains which have partly replaced margins of some of the large feldspar crystals; it is absent from most of the matrix.

Cutting the rock are minor thin fractures:

i) Minor thin discontinuous fractures are sealed by fine-grained biotite identical to the biotite which is more abundant in the enclosing matrix.

ii) A single thin planar fracture cuts the rock, and is sealed by small anhedral anhydrite grains (colourless, high birefringence, cleaved), minor quartz, and minor subhedral bladed opaque grains (hematite).

INTERPRETATION :

This sample displays minerals and textures which are interpreted in the following stages, from earliest to latest:

1. Formation of felsic rock

A felsic rock formed with moderately abundant large crystals (K-feldspar > plagioclase > quartz >> zircon) in fine-grained matrix. Notably, most of the crystals are euhedral or magmatically corroded rather than fragmented; this supports a coherent igneous origin, composed of large phenocrysts in groundmass. In the matrix, development of micrographic patches of intergrown K-feldspar and quartz suggests that the matrix may have formed by igneous crystallisation. Either the rock formed as a coherent igneous rock (eg shallow intrusion or thick flow), or it formed as a thick ignimbritic deposit in which high-temperature pseudo-igneous micrographic texture formed by annealing at elevated temperature of the primary vitric groundmass. Given that primary textures of the groundmass/matrix have been severely obscured by subsequent alteration (see next), the mode of formation of the rock may be better interpreted from field relationships of the rock unit.

2. Thin fracturing and potassic alteration

The rock suffered thin fracturing and infiltration by hydrothermal fluid at moderately high temperature. Particular results included the following:

i) Thin fractures were sealed either by fine-grained biotite, or by anhydrite + opaques (hematite). The presence of anhydrite and hematite indicates that the hydrothermal fluid was oxidised and contained dissolved SO_4, Ca, and Fe.

ii) The groundmass suffered pervasive replacement by the characteristic potassic-type alteration assemblage of fine-grained K-feldspar + biotite + opaques (?magnetite, hematite).

iii) The plagioclase crystals were completely replaced by fine-grained sericite ± tourmaline ± biotite.

iv) The K-feldspar crystals mostly survived, but inverted to microcline near margins and along fractures, and trace biotite formed along fractures.

SAMPLE # : 2138268

SAMPLE GROUP : Group 1 (MPI)

SECTION NO. : 2138268

HAND SPECIMEN : Not available.

ROCK NAME : Hematite stained (weathered), quartz-muscovite-opaques schist (meta-sediment)

PETROGRAPHY :

A visual estimate of the modal mineral abundances gives the following:

Mineral	Vol %	Origin
Quartz	57	Metamorphic 2 (after precursor 1)
Muscovite	35	Metamorphic 2
Opaques (hematite after ?magnetite)	5	Metamorphic 2 / oxidised 3
Monazite	Tr	Metamorphic 2
Hematite	3	Weathering 3

In thin section, this sample displays a strongly foliated granoblastic metamorphic texture with indistinct mineralogical banding, modified by subsequent oxidation (weathering).

Quartz is abundant, forming uniformly small equant anhedral grains mostly ~0.1 mm in size. They form a granoblastic metamorphic mosaic throughout the rock, and are more abundant in some horizons ~1-2 mm thick.

Muscovite is similarly abundant. It forms small colourless flakes ~0.1-0.2 mm long, with strong preferred orientation defining a penetrative metamorphic foliation. Although it is distributed throughout the rock, the muscovite tends to be more densely concentrated in particular laminae, and is the sole mineral to the exclusion of quartz in some thin laminae ~1-2 mm thick (inferred mudstone laminae).

Opaque crystals ~0.1-0.2 mm in size are distributed in minor amount throughout the rock, but are more abundant in quartz-rich laminae than in the muscovite-rich laminae. The cubic morphology of these crystal sites suggests they were magnetite (now replaced by hematite).

Monazite occurs in trace amount as subhedral blocky prisms up to ~0.2 mm in size, aligned in the trace of the metamorphic foliation. They display the crystal form, pale off-yellow colour, and moderately high birefringence typical of this mineral. They contain tiny ovoid to lobate inclusions (?fluid or ?mineral inclusions).

Hematite occurs throughout the rock. Most has formed as diffuse staining in the muscovite, but some appears to have formed by selective replacement of the ?magnetite crystals.

INTERPRETATION :

This sample is considered to have initially formed as a fine-grained sandy sediment, originally composed of abundant clastic quartz grains accompanied by lesser clays. Primary layering was defined by varied abundances of clastic quartz and clays, with minor thin muddy laminae composed completely of clay.

The rock suffered ductile deformation and recrystallisation in response to a regional metamorphic event, producing a strongly foliated metamorphic assemblage of quartz + muscovite + minor opaques (?magnetite) + trace monazite. Foliation developed subparallel to primary layering. The presence of ?magnetite and monazite suggest that synmetamorphic fluid infiltrated the rock, and its contained dissolved Fe, REE and P.

No specific grade indicator minerals are identified, but the degree of recrystallisation suggests that P-T conditions at least reached the middle greenschist facies.

At a later time, circulation of near-surface meteoric waters generated new hematite, as stainings in the muscovite flakes and as selective replacements of the ?magnetite.

SAMPLE # : **2138269**

SAMPLE GROUP : Group 1 (MPI)

SECTION NO. : 2138269

HAND SPECIMEN : Not available.

ROCK NAME : High-intensity biotite-sericite-hematite-monazite (potassic) altered felsic rock

PETROGRAPHY :

A visual estimate of the modal mineral abundances gives the following:

Mineral	Vol %	Origin
Quartz	3	Primary crystals 1
Zircon	Tr	Primary crystals 1
Quartz	48	Alteration 2 (after matrix 1)
Biotite	29	Alteration 2
Sericite	12	Alteration 2 (after ?crystals 1, ?lithics 1)
Sericite	5	Alteration 2
Opaques (mainly ?hematite)	<1	Alteration 2
Monazite	Tr	Alteration 2
Hematite	2	Weathering 3

In thin section, this sample displays a strong pervasive massive alteration texture, with indistinctly preserved textural elements of a primary coarse-grained porphyritic or porphyroblastic texture.

Most of the rock is composed of a uniformly fine-grained massive alteration mosaic of small anhedral quartz grains, small randomly oriented biotite flakes pleochroic from pale tan brown to very pale yellow, tiny colourless sericite flakes, and minor scattered ragged opaque grains (hematite). This fine-grained mosaic is readily interpreted as completely altered precursor matrix.

Zircon is observed as rare but relatively large crystals ~0.3 mm long, one with thin growth zoning. The crystals occur discretely in the (now-altered) fine-grained matrix, and display the typical optical properties of this mineral including high relief, very pale pinkish colour, high birefringence, and micro-cracking.

Monazite is observed as a single relatively large grain ~0.4 mm in size, with subhedral rhombic crystal form and moderately high birefringence.

Scattered through the rock are features of primary origin:

i) Minor large quartz crystals ~3 mm in size are sparsely scattered through the rock. They display magmatically corroded crystal margins, indicating an origin as phenocrysts or clastic crystals derived from a volcanogenic phenocrystic source.

ii) Minor large ragged patches ~2-4 mm long have suffered complete replacement by fine-grained dense sericite. They are aligned in a structure, possibly a primary structure such as flow banding or compaction in ignimbrite. These possibly represent completely altered primary crystals (eg feldspar) or altered lithic fragments (eg fiammé).

INTERPRETATION :

This sample has suffered strong pervasive potassic-type alteration, producing a fine-grained massive alteration assemblage of quartz + biotite + sericite + minor opaques (hematite) + trace monazite. The alteration is considered to have formed in response to infiltration of the protolith by moderately high-temperature hydrothermal fluid containing, amongst other components, dissolved REE and P.

Accurate identification of the protolith is not possible, owing to the high intensity of the alteration event and consequent loss of primary minerals and textures especially in the matrix. However, some primary minerals and textures were preserved, which allows some comments on the protolith:

i) The presence of minor large quartz crystals with magmatic corrosion indicates that the protolith was a quartz-phyric or quartz-porphyroblastic rock of acid bulk composition.

ii) The presence of millimetre-sized sericite-rich alteration patches suggests that these may have been ?feldspar crystals or lithic fragments (possibly ?fiammé).

SAMPLE # : **2138292**

SAMPLE GROUP : Group 2 (Tillite clasts/lag)

SECTION NO. : 2138292

HAND SPECIMEN : Not available.

ROCK NAME : **Low-intensity chlorite-magnetite-sericite-hematite altered syenogranite porphyry**

PETROGRAPHY :

A visual estimate of the modal mineral abundances gives the following:

Mineral	Vol %	Origin
K-feldspar	24	Igneous phenocrysts 1
Zircon	Tr	Igneous (inclusions in phenocrysts 1)
Quartz	5	Igneous phenocrysts 1
K-feldspar (with hematite staining)	29	Igneous groundmass 1
Quartz	15	Igneous groundmass 1
Allanite	Tr	Igneous groundmass 1
Chlorite	5	Alteration 2
Opaques (magnetite)	1	Alteration 2
Albite-sericite	10	Alteration 2 (after plagioclase phenocrysts 1)
Albite-sericite	10	Alteration 2 (after plagioclase groundmass 1)
Carbonate (calcite)	Tr	Alteration 2

In thin section, this sample displays a well-preserved massive porphyritic igneous texture, modified by minor alteration effects.

Phenocrysts were abundant, and different types are identified:

i) K-feldspar forms large subhedral prisms ~3-5 mm in size.

ii) Plagioclase formed subhedral prisms ~2-3 mm in size. All have been replaced by optically continuous albite clouded by tiny sericite flecks.

iii) Quartz formed smaller euhedral crystals mostly ~0.5-1.0 mm in size. They remain clear.

iv) Minor blocky ferromagnesian crystals have suffered complete replacement by fine-grained green chlorite, small ragged calcite grains, and euhedral cubic opaque crystals (magnetite). The identity of this ferromagnesian phase remains uncertain; it may have been ?pyroxene, as supported by its blocky prismatic crystal forms (ie more like pyroxene than amphibole which has a more elongated prismatic form and stronger development of {110} form faces.

v) Zircon is observed as small stumpy terminated prisms, some with growth zoning, which occur as inclusions within (now-altered) ferromagnesian crystal sites and rarely as inclusions in the large K-feldspar phenocrysts.

Groundmass encloses the phenocrysts, and displays a massive micrographic texture defined by abundant anhedral K-feldspar grains intergrown with randomly oriented thin quartz crystals and micrographic patches. Minute red hematite specks cloud the K-feldspar grains. Angular interstitial patches are scattered through the groundmass, and are filled mostly by fine-grained massive green chlorite, locally accompanied by cubic opaque crystals (magnetite) and small calcite grains. Allanite is observed as uncommon small subhedral grains in the late interstitial areas. They display the typical brown to pale yellow pleochroism and anomalous interference colours of this mineral.

INTERPRETATION :

This sample displays minerals and textures which are interpreted in the following stages, from earliest to latest:

1. Crystallisation of syenogranite porphyry

Acid magma crystallised as massive porphyritic igneous rock composed of moderately abundant phenocrysts (K-feldspar >> plagioclase >> quartz = unknown ferromagnesian possibly ?pyroxene >> zircon) in well-crystallised micrographic groundmass (K-feldspar >> plagioclase = quartz >> allanite). Zircon formed as small but well-crystallised inclusions in ferromagnesian and some K-feldspar phenocrysts. Small vughy cavities formed in the groundmass during final consolidation. A syenogranitic composition is indicated by quartz : alkali feldspar : plagioclase ratios (FIG. 1). An intrusive mode of emplacement is supported by particular petrographic observations:

i) Texture of groundmass (moderate grain size, micrographic texture, minor small vughs) indicates moderately slow cooling;

ii) Moderately high abundance of phenocrysts (which limited the ability of viscous acid magma to extrude as lava);

iii) Massive texture (more likely in acid magma in intrusive environment than extrusive environment).

2. Alteration

During a late stage of cooling, a small volume of hydrothermal fluid circulated through the rock. This produced new chlorite + albite + sericite + calcite. In more detail:

i) Small interstitial cavities (vughs) were filled mainly by fine-grained chlorite ± magnetite;

ii) Ferromagnesian crystals were replaced by chlorite + magnetite ± calcite.

iii) Plagioclase (both phenocrysts and groundmass) was replaced by albite + sericite.

iv) The relatively low intensity of this alteration event has resulted in good preservation of most primary minerals and textures.

SAMPLE # **: 2138293**

SAMPLE GROUP : Group 2 (Tillite clasts/lag)

SECTION NO. : 2138293

HAND SPECIMEN : Not available.

ROCK NAME **: K-feldspar-chlorite-hematite altered, weakly flow-banded porphyritic rhyodacite vitrophyre**

PETROGRAPHY :

A visual estimate of the modal mineral abundances gives the following:

Mineral	Vol %	Origin
K-feldspar	20	Igneous phenocrysts 1
Quartz	20	Igneous phenocrysts 1
Opaques (Fe-Ti oxide)	Tr	Igneous phenocrysts 1
Zircon	Tr	Igneous 1 (inclusions in phenocrysts 1)
Albite-sericite	12	Alteration 2 (after plagioclase phenocrysts 1)
K-feldspar	41	Alteration 2 (after groundmass 1)
Chlorite	3	Alteration 2 (after groundmass 1)
Hematite	1	Alteration 2 (after groundmass 1)
Chlorite-calcite	2	Alteration 2 (after ferromagnesian phenocrysts 1)
Goethite	Tr	Weathering 3

In thin section, this sample displays a massive porphyritic igneous texture, with weak locally developed flow banding in groundmass, modified by devitrification and weak alteration effects.

Phenocrysts are abundant:

i) K-feldspar forms prismatic crystals ~3-5 mm long, most displaying some degree of smooth magmatic resorption (not fragmentation) of their faces. Most display slight patchy turbid alteration.

ii) Quartz occurs in moderate amount as equant crystals ~2 mm in size, but some range down to ~0.4 mm and some range up to ~4 mm in size. All remain clear, and all display a significant degree of magmatic resorption of their crystal margins.

iii) Plagioclase occurs in moderate amount as prismatic crystals ~1-2 mm long. Like the K-feldspar and quartz, all display modification of the primary crystal shape by magmatic resorption. All of the crystals have suffered complete replacement by optically continuous albite clouded by tiny sericite flecks.

iv) Ferromagnesian crystals occurred as minor small prisms <1 mm in size. Locally they formed small glomerocrystic clusters. All have suffered complete replacement by turbid fine-grained chlorite and calcite. The blocky prismatic crystal forms suggest this was pyroxene, not hornblende, but none is preserved for confirmation.

v) Opaques occur in trace amount as small elongate crystals (possibly ?ilmenite).

vi) Zircon occurs as small stumpy prisms up to ~0.4 mm in size located in some of the altered ferromagnesian phenocryst sites, and also as discrete crystals in the groundmass. They display the typical high relief, lack of colour and high birefringence of this mineral.

Groundmass is composed mostly of tiny equant anhedral K-feldspar grains, through which are distributed tiny green chlorite flakes and small diffuse clouds and patches of brick red hematite. The uniform very fine-grained texture of this assemblage suggests it formed by devitrification and alteration of an originally glassy groundmass. In a small proportion of the groundmass, local discontinuous flow bands are composed of slightly coarser-grained intergrown K-feldspar and lesser quartz, with blocky shapes of K-feldspar suggestive of late-magmatic crystallisation.

Minor goethite occurs as diffuse yellow-brown stains along and near fractures, locally in some phenocryst sites.

INTERPRETATION :

This sample displays minerals and textures which are interpreted in the following stages, from earliest to latest:

1. Consolidation of vitrophyre

A crystal-bearing acid magma consolidated to form a vitrophyre composed of abundant randomly-oriented phenocrysts (K-feldspar = quartz > plagioclase >> ferromagnesian possibly ?pyroxene >> Fe-Ti oxide, zircon) in quenched glassy groundmass. A rhyodacitic composition is inferred from the mineral assemblage, and a syenogranitic composition is indicated on the granitoid Q-A-P classification diagram (FIG. 1). During uprise and emplacement, all of the felsic phenocrysts (K-feldspar, quartz, plagioclase) suffered magmatic corrosion of their crystal margins. Local weak magmatic flow produced minor thin discontinuous flow bands, in which crystallisation of magma produced K-feldspar + quartz. An intrusive mode of emplacement is supported by particular petrographic observations:

i) High abundance of phenocrysts, which would have mitigated flow as extrusive lava;

ii) Euhedral but magmatically corroded form of K-feldspar, quartz and plagioclase phenocrysts. Lack of fragmentation of the crystals suggests it did not form as a tuffaceous deposit.

iii) Local weakly developed flow banding (likely to be much more strongly developed in an extrusive lava of this composition).

2. Devitrification and alteration

The rock suffered devitrification and alteration, producing new K-feldspar + chlorite + calcite + hematite. In more detail:

i) The glassy groundmass devitrified to form uniformly fine-grained massive K-feldspar + chlorite + hematite.

ii) Ferromagnesian phenocrysts were replaced by chlorite + calcite.

iii) Plagioclase phenocrysts were replaced by albite + sericite.

iv) The relatively low intensity and selectivity of the alteration effects results in good preservation of primary textures.

SAMPLE # : **2138300**

SAMPLE GROUP : Group 2 (Tillite clasts/lag)

SECTION NO. : 2138300

HAND SPECIMEN : Not available.

ROCK NAME : **K-feldspar-chlorite-hematite altered, weakly flow-banded porphyritic rhyodacite vitrophyre**

PETROGRAPHY :

A visual estimate of the modal mineral abundances gives the following:

Mineral	Vol %	Origin
K-feldspar	15	Igneous phenocrysts 1
Quartz	15	Igneous phenocrysts 1
Apatite	Tr	Igneous microphenocrysts 1
Zircon	Tr	Igneous microphenocrysts 1
Albite-sericite	15	Alteration 2 (after plagioclase phenocrysts 1)
Chlorite-calcite	2	Alteration 2 (after ferromagnesian phenocrysts 1)
K-feldspar	30	Alteration 2 (after groundmass 1)
Chlorite	5	Alteration 2 (after groundmass 1)
Quartz	15	Alteration 2 (after groundmass 1)
Hematite	2	Alteration 2 (after groundmass 1)

In thin section, this sample displays a strongly porphyritic igneous texture which is mostly massive but with weak localised flow banding, modified by selective alteration effects.

Phenocrysts are abundant, uniformly distributed, and display random orientation:

i) K-feldspar forms blocky prisms ~2-6 mm in size, modified by magmatic corrosion around margins. Most crystals remain fresh but display incipient clouding in patches around margins.

ii) Quartz is moderately abundant, forming equant crystals mostly ~2-4 mm in size, but some range down to ~0.4 mm. All display a significant degree of magmatic corrosion, producing convolute lobate margins.

iii) Plagioclase formed moderately abundant prismatic crystals ~1-5 mm long. All have suffered some degree of magmatic resorption around margins. All have suffered complete replacement by optically continuous twinned albite clouded by minute sericite flecks.

iv) Ferromagnesian crystals formed minor small phenocrysts ~1.0-1.5 mm in size. Their blocky shapes suggest they were ?pyroxene, but all have suffered complete replacement by fine-grained chlorite and intergrown small ragged calcite grains and cryptocrystalline red hematite.

v) Zircon occurs in trace amount as small but well-crystallised terminated stumpy prisms up to ~0.2 mm in size. They are colourless and display the typical high birefringence and parallel extinction of this mineral. Some occur discretely in the groundmass, and some formed as inclusions in (now-altered) ferromagnesian phenocrysts.

vi) Apatite is observed as uncommon small colourless prisms located in some of the feldspar phenocrysts.

Groundmass encloses the phenocrysts. Most occurs as a uniformly very fine-grained massive felsic mosaic of tiny K-feldspar grains and lesser tiny quartz grains. Minute red hematite specks are sprinkled through the K-feldspar grains. Small ragged pleochroic green chlorite flakes are scattered sparsely but uniformly through the felsic mosaic. Indistinct thin flow-banding is evident in places through the groundmass, and local larger patches up to several millimetres long are aligned in the flow bands: these patches are composed of slightly coarser-grained K-feldspar (with reddish hematite clouding), quartz and interstitial chlorite flakes.

INTERPRETATION :

This sample displays minerals and textures which are interpreted in the following stages, from earliest to latest:

1. Consolidation of vitrophyre

Acid magma consolidated as abundant phenocrysts (K-feldspar = quartz > plagioclase >> ferromagnesian possibly ?pyroxene >> apatite, zircon) in weakly flow-banded glassy groundmass. A rhyodacitic composition is inferred from the mineralogy, and a syenogranitic composition is indicated from quartz : feldspar ratios (FIG. 1). The magma is considered to have consolidated in a shallow intrusive environment, as supported by particular textural features:

i) The high abundance of total phenocrysts (~57%) is likely to have prevented flow as an extrusive lava.

ii) The phenocrysts display euhedral crystal forms (ie non-fragmented) modified by magmatic corrosion.

iii) The vitric groundmass was weakly flow-banded; it is likely to have been more strongly flow-banded if it had extruded as a lava.

2. Devitrification and alteration

The rock suffered devitrification and low-intensity alteration. This generated new K-feldspar + chlorite + minor calcite + hematite. In more detail:

i) The glassy groundmass suffered devitrification and alteration, forming a fine-grained mosaic of K-feldspar + quartz + chlorite + hematite.

ii) The plagioclase phenocrysts were replaced by albite + sericite.

iii) The ferromagnesian phenocrysts were replaced by chlorite + calcite + hematite.