

**PETROGRAPHIC REPORT ON SEVENTY-
EIGHT ROCK SAMPLES FROM
CAMBRIAN VOLCANIC AND VOLCANO-
SEDIMENTARY SEQUENCES IN
NORTHERN AND NORTH-WESTERN
TASMANIA**

For

Zinifex Rosebery Mine

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SUMMARY

Introduction

A suite of seventy-eight rock samples from surface outcrops of Cambrian volcanic and volcano-sedimentary sequences in northern and north-western Tasmania, were submitted for petrographic preparation, description and interpretation. The sampled sequences are considered to be correlatives of the Cambrian Mount Read Volcanics of western and north-western Tasmania. A batch of 61 samples from the Castra-Nietta area were initially submitted, but these were shortly followed by a further 17 samples from the region between Sheffield and the Dial Range. The samples were identified in the number series between 378103 and 378189, but with gaps in sequence (i.e. there was no sample 378117, 378122-4, 378134, 378169-72).

Standard thin sections were prepared from each sample and all offcuts from the sections were treated with hydrofluoric acid and sodium cobaltinitrite in order to test for the presence of K-feldspar. This step proved invaluable as many of the altered volcanic and volcano-sedimentary rocks contained fine grained K-feldspar and knowledge about the amount of K-feldspar aided rock classification. Several samples contained carbonate and these were tested with dilute HCl to check for carbonate speciation. All rocks were measured for magnetic susceptibility. Many of the volcanic, epiclastic and possible intrusive rocks in the suite were moderately to strongly magnetic, which, together with the presence of relict clinopyroxene (and rare hornblende), or pseudomorphs thereof, indicate that the magmatic source(s) for the igneous rocks were of I-type.

Microscopic examination of the thin sections was made in transmitted and oblique reflected light and this allowed samples in the suite to be classified into the following major groups: clastic sedimentary, epiclastic, pyroclastic, probable extrusive (lava) and probable intrusive. In the descriptions, the term "epiclastic" denotes a clastic sedimentary rock with a dominant immature volcanic provenance; in the suite, most volcanic material is of intermediate to felsic composition. Many of the interpretations of primary rock type based on petrography vary somewhat from field descriptions, but this is to be expected, based on firmer textural and mineralogical criteria. In the main, the field descriptions are reasonably accurate and most of the interpretative differences lie in the distinction between rocks that might be pyroclastic versus sedimentary (epiclastic) and between sedimentary (epiclastic) and porphyritic coherent volcanics (e.g. lava). In several samples, it has not been possible to unequivocally assign an interpreted origin (e.g. epiclastic versus pyroclastic, or extrusive versus intrusive).

Summary descriptions of each sample are listed below:

378103 **TS**

Summary: Coarse grained lithic-crystal felsic tuff, with abundant tightly packed, angular lithic and mineral grains. There is no diagnostic textural evidence to indicate that the rock represents a reworked pyroclastic, i.e. a coarse epiclastic sandstone. Lithic fragments are dominated by volcanic material (mostly pumice, glassy and porphyritic grains), with a tiny population of fine grained carbonaceous sedimentary material. Individual mineral grains are dominated by volcanic-derived quartz and plagioclase, but there are a few small, altered ferromagnesian grains. The matrix is fine to medium grained and composed of altered pumiceous material. The rock has undergone strong alteration of sodic-propylitic type, with dominant replacement by albite, with patchy chlorite and a little quartz, sericite plus trace leucoxene, pyrite and sphalerite.

378104 **TS**

Summary: Coarse grained lithic sandstone, grading into conglomerate, with a wide variety of lithic and individual mineral grain types. Detrital grains are tightly packed and there is little matrix. Lithic grains include fine grained sedimentary/metasedimentary types (e.g. shale, carbonaceous shale, siltstone, siliceous argillite/chert, marble) and fine to medium grained mafic to intermediate igneous types (e.g. intermediate to mafic porphyritic lava, dolerite). Individual mineral grains include plagioclase, quartz, clinopyroxene, calcite and FeTi oxide. The rock has undergone only weak alteration, with relatively minor replacement by albite, chlorite, carbonate and traces of leucoxene and pyrite.

378105 **TS**

Summary: Coarse grained lithic sandstone, with a wide variety of lithic and individual mineral grain types. Detrital grains are tightly packed with only a little matrix. Lithic grains include fine grained sedimentary/metasedimentary types (e.g. shale, carbonaceous shale, siliceous argillite/chert, recrystallised limestone) and fine to medium grained mafic igneous types (e.g. basaltic porphyritic lava, dolerite). Individual mineral grains include plagioclase, quartz, clinopyroxene, calcite and altered ferromagnesian material. The rock has undergone only weak alteration, with relatively minor replacement by albite, chlorite, carbonate, sericite and traces of leucoxene, sphalerite, pyrrhotite, chalcopyrite and pyrite.

378137 **TS**

Summary: Coarse grained lithic-crystal felsic tuff or derived epiclastic sandstone (grading into conglomerate). Relict textures are not diagnostic to distinguish due to alteration and recrystallisation. The rock has abundant lithic clasts that include volcanic material (pumice and porphyritic grains) as well as fine grained low grade metasedimentary material (mica schist, etc.). There are also individual mineral grains dominated by former volcanic-sources quartz and plagioclase. The matrix interstitial to lithic and mineral grains is composed largely of former fine pumiceous material. The rock has undergone strong alteration of propylitic type, with replacement by albite and lesser amounts of quartz, K-feldspar, sericite and chlorite. A few thin veins cut the altered rock and contain quartz \pm albite, chlorite. The rock has been weakly deformed, with slight development of a foliation defined by preferred orientation of alteration-derived sericite.

378138 **TS**

Summary: Well laminated shale-siltstone, with good preservation of detrital grains and sedimentary bedding. Laminations are planar and sharp to gradational, with detrital grains dominated by plagioclase, K-feldspar, quartz and fine grained lithics. Matrix to the coarser laminae, as well as the finer, shaly laminae, is dominated by chlorite, with patchy development of carbonate. Shaly laminae may contain a little carbonaceous material and traces of pyrite. Alteration in the rock may be due to very low grade metamorphism and is dominated by an assemblage of albite, chlorite and carbonate, with a little sericite.

378139 **TS**

Summary: Coarse grained lithic-crystal felsic tuff, dominated by pumiceous fragments and a minor pumiceous matrix component. There is a minor population of other lithic fragments including foliated carbonaceous shale/siltstone and quartzite, as well as individual mineral grains dominated by volcanic quartz and plagioclase grains. There is little evidence for the volcanic components to have been reworked to form an epiclastic sandstone. The rock has undergone strong alteration that is interpreted to be transitional between propylitic and potassic. There has been replacement of former igneous components by albite, sericite, K-feldspar, quartz, chlorite, carbonate and traces of leucoxene and pyrite.

378148 **TS**

Summary: Altered, moderately porphyritic felsic volcanic rock, probably representing a lava of dacitic composition. The original rock contained phenocrysts of plagioclase, plus a few of biotite, along with microphenocrysts of FeTi oxide and possible pyroxene in a fine grained (aphanitic/glassy) quartzofeldspathic groundmass. There is weak flow alignment of phenocrysts and of quartz-rich alteration patches in the groundmass. Pervasive strong alteration has led to replacement of the groundmass by K-feldspar, with minor quartz, sericite and hematite. Plagioclase has been replaced by variable amounts of quartz, K-feldspar, sericite and albite, with biotite being replaced by sericite ± hematite ± leucoxene, pyroxene by quartz ± hematite, and FeTi oxide by hematite. The alteration may be due to low grade metamorphic effects and is of potassic-phyllitic type.

378149 **TS**

Summary: Altered porphyritic quartz-biotite-pyroxene latite, perhaps representing a former lava. The rock contained scattered phenocrysts of plagioclase and biotite, with a few glomeroporphyritic aggregates of plagioclase-pyroxene-biotite-FeTi oxide-apatite and a few microphenocrysts of FeTi oxide in a fine grained (perhaps aphanitic) groundmass that was rich in K-feldspar, plus minor quartz, plagioclase and ferromagnesian material. There has been moderate to strong pervasive alteration of propylitic type imposed, with partial replacement of igneous minerals by albite, sericite, chlorite, carbonate and trace leucoxene. A few irregular veins cut the altered rock; they range from quartz-rich, with K-feldspar selvages to carbonate-rich.

378150 **TS**

Summary: Medium grained lithic-feldspathic-quartz sandstone, with a mixed felsic to intermediate volcanic and sedimentary provenance. Lithic grains include volcanic material as well as fine grained siliceous and sericitic sedimentary material. The rock has undergone pervasive strong alteration under oxidising conditions to develop an assemblage of albite, quartz, carbonate (e.g. dolomite), sericite and hematite.

378157 **TS**

Summary: Altered porphyritic quartz latite maybe representing a shallow intrusive or less likely, a lava. The original rock contained scattered phenocrysts of plagioclase and a few microphenocrysts of ferromagnesian material and quartz in a holocrystalline, fine to medium grained groundmass of plagioclase, K-feldspar, minor altered ferromagnesian material, quartz and FeTi oxide. The rock contains a few glomeroporphyritic aggregates (?micro-enclaves) of plagioclase-altered ferromagnesian material-FeTi oxide and quartz. There has been pervasive propylitic alteration, probably the result of very low grade metamorphism, with partial replacement by albite, chlorite, sericite and carbonate.

378158 **TS**

Summary: Porphyritic quartz micromonzonite, with scattered small plagioclase phenocrysts set in a fine to medium grained groundmass of plagioclase, K-feldspar, altered ferromagnesian material, minor quartz and FeTi oxide. Pervasive strong propylitic alteration has been imposed, with partial replacement by albite and chlorite, plus minor carbonate and hematite.

378159 **TS**

Summary: Altered porphyritic quartz monzonite. The original igneous rock contained abundant tabular plagioclase phenocrysts, with interstitial medium grained K-feldspar, ferromagnesian material and minor quartz, plagioclase and FeTi oxide (titanomagnetite). There has been moderate to strong imposed alteration of propylitic type. This has led to replacement of some of the primary minerals by albite and chlorite, with minor carbonate, sericite and epidote, plus traces of titanite and leucoxene.

378163 **TS**

Summary: Medium to coarse grained volcanoclastic sandstone with intermediate to felsic volcanic provenance. The rock contains abundant altered lithic detrital grains (fine grained and locally porphyritic and flow-foliated intermediate volcanic material), plus altered plagioclase grains, quartz and a little detrital muscovite. Detrital components occur in a fine grained quartzofeldspathic matrix. The rock has undergone pervasive propylitic alteration to develop an assemblage of dominant albite, with subordinate quartz and chlorite, minor carbonate, a little sericite and trace rutile and pyrite.

378164 **TS**

Summary: Medium grained quartz-lithic sandstone with a mixed provenance dominated by grains of siliceous metamorphic material, possible felsic plutonic, fine grained sedimentary, volcanic and trace ultramafic material. The rock has undergone moderate alteration, with development of chlorite and carbonate, mainly from replacement of volcanic grains, matrix and development of cement. A trace of disseminated pyrite occurs as part of the alteration assemblage.

378165 **TS**

Summary: Medium grained quartz-lithic sandstone containing detrital grains of quartz, subordinate amount of lithic material (quartzite and quartz-muscovite schist), scattered grains of muscovite, a little altered biotite, K-feldspar and carbonate and traces of tourmaline, rutile and chromite. The minor amount of matrix component has been recrystallised as a result of low grade metamorphism and consists of quartz, chlorite, carbonate and a little sericite. Rare pyrite grains might have also formed as a result of matrix alteration. The rock is likely to have had a provenance from a mature silicic metamorphic source, rather than from a volcanic source.

378166 **TS**

Summary: Well laminated carbonaceous shale-siltstone. The rock contains detrital grains of quartz and muscovite, with minor lithics and K-feldspar in a fine grained matrix of chlorite, with minor sericite, quartz and carbonaceous material. The latter might represent former organic material, subsequently matured into a graphite-like substance. It is locally accompanied by traces of fine grained pyrite. The rock may have undergone very low grade metamorphism and the mica flakes display a weak preferred orientation.

378167 **TS**

Summary: Strongly altered medium to coarse grained lithic-crystal felsic tuff. The rock contains tightly packed lithic grains (mostly altered pumice) and altered plagioclase grains, with minor quartz, in a finer grained pumiceous matrix. There has been replacement of the igneous material by albite, quartz, chlorite, K-feldspar, sericite and traces of leucoxene and pyrite, with the alteration assemblage being of propylitic type. There is no textural evidence for the rock to represent reworked volcanoclastic material (i.e. being an epiclastic sandstone).

378173 **TS**

Summary: Coarse grained felsic pyroclastic rock, probably representing a lithic-dominated type, with a small crystal component. There is no textural evidence for the components of the rock to have been substantially reworked so as to form an epiclastic sandstone. The dominant lithic fragments are altered pumiceous material and the small amount of matrix is also

pumiceous, with altered glass shard fragments. Individual mineral grains are represented by a few relict volcanic quartz and altered plagioclase and ferromagnesian grains. The rock has undergone strong, pervasive alteration to an assemblage dominated by albite, quartz and sericite, with minor chlorite and carbonate, plus traces of leucoxene and pyrite. The assemblage is of propylitic type and may have formed by very low grade metamorphism (e.g. attending the formation of a weak foliation) and/or due to fluid interaction.

378174 TS

Summary: Altered porphyritic quartz micromonzodiorite, with moderately well preserved texture showing abundant plagioclase phenocrysts, a few quartz phenocrysts and glomeroporphyritic aggregates (originally with plagioclase \pm ferromagnesian material \pm quartz \pm FeTi oxide) in a fine to medium grained groundmass of plagioclase, altered ferromagnesian material, interstitial K-feldspar and quartz, and disseminated FeTi oxide. There is no textural evidence to indicate that the rock represents a clastic sedimentary type, e.g. epiclastic sandstone. There has been pervasive strong alteration of propylitic type imposed, with replacement of some of the igneous phases by albite, plus subordinate chlorite and minor sericite, carbonate and hematite. Later weathering effects have caused the development of scattered goethite aggregates.

378187 TS

Summary: Strongly altered, porphyritic intermediate to felsic volcanic rock, perhaps representing a lava. There is no textural evidence for the sample to represent a clastic rock, e.g. epiclastic sandstone. The original rock contained a few phenocrysts of feldspar (probably plagioclase) and a ferromagnesian phase, plus a little FeTi oxide, set in a fine grained, perhaps glassy, quartzofeldspathic groundmass. The latter might contain possible spheroidal devitrification structures. Feldspar and ferromagnesian phenocrysts have been replaced by sericite and quartz, with groundmass material having recrystallised to an assemblage of K-feldspar, quartz, sericite and minor hematite. In places, quartz aggregates form cores to the spheroidal structures. The altered rock has been cut by a few extensional quartz-rich veins containing a few aggregates of sericite. These veins might also have hosted aggregates of pyrite, but the latter has been replaced by goethite as a result of weathering.

The following table provides a summary classification of the samples examined. Many samples are difficult to accurately classify into a genetic type, but the most likely interpretations are displayed.

Clastic sedimentary	Epiclastic	Pyroclastic	Extrusive (lava)	Intrusive
378105	378104	378103	378119	378107
378106	378112	378110	378121	378114
378108	378120	378115	378125	378126
378109	378128	378116	378127	378129
378111	378137	378139	378130	378142
378113	378141	378140	378131	378143
378118	378146	378145	378132	378144
378138	378147	378151	378133	378157
378164	378150	378152	378135	378158
378165	378153	378167	378136	378159
378166	378163	378173	378148	378161
378188	378168	378176	378149	378162
378189	378184		378154	378174
			378155	378177
			378156	378180
			378160	378182
			378175	378183
			378178	
			378179	
			378181	
			378185	
			378186	
			378187	

Interpretation and discussion

The distinction between “clastic sedimentary” and “epiclastic” rocks is based on the proportion of juvenile volcanic detritus versus fine grained sedimentary detritus. Sedimentary bedding phenomena have only been recognised in one or two samples and is not diagnostic. Epiclastic rocks have a preponderance of volcanic detrital grains and in the suite display a range from very immature, e.g. tightly packed, angular grains, with strong preservation of delicate volcanic features such as pumice, and in some samples, preservation of primary igneous minerals, such as clinopyroxene. The clastic sedimentary rocks tend to have a preponderance of fine grained sedimentary detritus, ranging from massive to weakly foliated sericitic shale and siltstone (in places carbonaceous) to siliceous argillite to chert. A few samples have relicts of radiolarians in the fine grained sedimentary detrital grains. Several of the clastic sedimentary rocks, as well as a few of the epiclastics, have evidence of siliceous metamorphic detritus, e.g. quartzite

and muscovite quartzite, with many of these grains being foliated. Detrital muscovite flakes also occur in many of these rocks and may have come from a similar metamorphic source (e.g. from the Rocky Cape or Tyennan regions). Three clastic sedimentary samples (378118, 378163, 378165) contain tiny traces of detrital chromite, with the first sample also containing small lithic clasts with fuchsite alteration. These characteristics are consistent with a small ultramafic provenance component.

The distinction between epiclastic and pyroclastic rocks is based on the lack of textural evidence for any sedimentary transport or depositional processes in the latter. Pyroclastic rocks tend to be dominated by tightly packed volcanic fragments, commonly pumiceous, with a few also containing finer grained matrix material that is also pumiceous and commonly displays small former glass shard fragments. It is possible that one or two of the interpreted pyroclastic rocks may be ignimbritic (i.e. welded texture). In addition to volcanic lithic fragments dominated by pumice, pyroclastic rocks also commonly contain a crystal component, e.g. disaggregated volcanic phenocrysts of plagioclase and/or quartz. Epiclastic rocks commonly have less of a pumiceous lithic component and a higher proportion of other volcanic lithics (e.g. porphyritic lava fragments) and/or crystals; they also may contain a higher proportion of matrix material (generally not former glass shards) and may contain lithic grains of fine grained sedimentary material.

There are relatively numerous samples in the suite that are classified as representing intrusive igneous rocks. Most interpreted intrusives are porphyritic and have scattered to abundant phenocrysts occurring in a fine to medium grained holocrystalline groundmass. One or two, however, are less porphyritic, and more evenly medium grained. The main distinction from interpreted extrusives is the grain size of the groundmass, which in the latter is typically fine grained to possibly glassy in original character. Some of the porphyritic igneous rocks with fine grained groundmass are also amygdaloidal, a common textural characteristic of lavas. However, in the descriptions of several porphyritic igneous samples, the distinction between extrusive and intrusive emplacement modes remains speculative.

In the sample suite as a whole, primary textures are moderately to well preserved, and together with either the preservation of primary minerals (e.g. magmatic minerals) or easily recognisable pseudomorphs thereof, have allowed some degree of certainty about (a) the primary rock types, and (b) their mode of formation. It is likely that there is a large amount of consanguinity between the various igneous rocks in the suite and many of the interpreted epiclastic sedimentary rocks, and that this relationship could extend further into many of the recognised clastic sedimentary rocks, i.e. with decreasing detrital volcanic material and an increasing amount of fine grained sedimentary (or metasedimentary) detritus. Many of the sedimentary rocks

have a clear “mixed” provenance, e.g. with evidence of juvenile volcanic detritus as well as sedimentary or metasedimentary detritus.

The igneous rocks in the suite (i.e. interpreted intrusives, extrusives and pyroclastics) mostly fall into a compositional spectrum from intermediate to felsic. Only one rock with a mafic igneous composition has been recognised (378114). Interpreted intrusive rocks are largely porphyritic and span the compositional range from monzodioritic to granodioritic; some intrusives having finer grained groundmasses are assigned “volcanic” nomenclature such as latite or rhyodacite – perhaps the latter types could be given less genetic terms such as plagioclase-clinopyroxene porphyry or quartz-feldspar porphyry. From the textural characteristics, most of the interpreted intrusives are considered to have been emplaced rather shallowly in the earth’s crust and are likely therefore to represent sub-volcanic masses. Interpreted extrusive rocks span the composition range from latite (or high-K andesite) to rhyodacite, although in a few, the intensity of imposed alteration makes identification of primary rock type rather obscure. Most interpreted pyroclastic rocks are felsic in composition, although a few might tend to grade towards intermediate volcanic composition. Derived epiclastic sedimentary rocks are considered to cover the same composition spectrum as the igneous rocks, i.e. from being dominated by intermediate igneous detritus such as porphyritic latite, to felsic igneous detritus, e.g. porphyritic rhyodacite.

Many of the volcanic and intrusive rocks either preserve primary igneous minerals or contain pseudomorphs that indicate the nature of the primary mineralogy. Most igneous rocks contain evidence of plagioclase crystallisation (commonly as a phenocryst and a groundmass phase) and plagioclase (or its alteration products) is usually the dominant mineral. Quartz occurs as a phenocryst phase in many of the felsic extrusive and pyroclastic rocks, and as a derived detrital grain phase in some epiclastics. In some of the coarser intrusives, it is present as an interstitial, late-magmatic phase. Quartz is also a common groundmass phase in some of the more felsic volcanic rocks. K-feldspar commonly occurs as a fine grained groundmass phase, but in some of the coarser intrusives, it occurs interstitially as a late-magmatic phase. It is probable that ferromagnesian minerals (one or more) occurred in most igneous samples and also occurred in some of the epiclastic rocks as detrital grains. However, except in a few samples, all ferromagnesian phases have been completely altered. Clinopyroxene phenocrysts have been preserved in a few igneous rocks (e.g. porphyritic latite) and detrital clinopyroxene grains occur in one or two of the epiclastics. Brown hornblende and biotite are preserved very rarely, although it is probable that biotite may have been a relatively common ferromagnesian phenocryst phase in several of the more felsic igneous rocks, judging by relict grain shapes. Pyroxene (presumably clinopyroxene) would have also been a common phenocryst phase. Microphenocrysts of FeTi oxide occur in many igneous rocks and

detrital grains occur in many epiclastics. The magnetic characteristics of many samples indicate that this phase is magnetite, or more specifically, titanomagnetite. Other minor to trace accessory minerals noted in the igneous rocks and in derived epiclastics include apatite, zircon and possibly, rare titanite.

A common mineralogical thread through many of the less altered igneous rocks and the derived epiclastics, is the presence of interpreted magmatic K-feldspar. In many rocks containing K-feldspar, there is little or no evidence for this phase to have been formed by hydrothermal replacement (i.e. a form of potassic alteration), notwithstanding the possibility of alkali (e.g. K) mobility during diagenesis, hydrothermal alteration and/or later imposed metamorphism. As a consequence, it is interpreted that the igneous rock suite overall has a probable high-K, calc-alkaline signature. Clearly, the magmatic affinities are of I-type, as indicated by the presence at the magmatic stage of minerals such as clinopyroxene, (titano)magnetite and uncommon hornblende.

All samples in the suite display evidence of alteration. Generally, the effects are pervasive and there is little indication of fracture control on alteration assemblages. The terminology used to describe and classify different alteration assemblages is that used for hydrothermal alteration (e.g. propylitic, phyllic, potassic, sodic), but it is recognised that many of the samples may not have undergone significant hydrothermal alteration, but been subject instead to the effects of very low grade (regional) metamorphism. The mineralogical consequences may ultimately be the same, but there is a difference in fluid:rock ratio and time.

The types of alteration observed fall into the above-mentioned categories, i.e. propylitic, phyllic, potassic, sodic, and there are also transitional varieties. The alteration effects are interpreted to be the result of either, or both, very low grade metamorphism or hydrothermal alteration, with the latter inferring a high fluid:rock ratio and a significant compositional change in relation to primary rock composition. However, it is acknowledged that the two processes overlap, especially in an active volcanic and volcano-sedimentary environment such as in the Mount Read Volcanics, where seawater interaction could have been extensive at the magmatic and diagenetic stages.

Propylitic alteration assemblages typically involve albite and chlorite, with rather common carbonate (ranging from Fe-bearing, e.g. ankerite, siderite to calcite) and sericite, and less common epidote. Leucoxene/rutile and pyrite are common trace to minor accessories and titanite is rare. A few samples demonstrate formation of actinolite and/or pumpellyite as part of this alteration assemblage. Although propylitic alteration could be a result of focussed hydrothermal processes, it more likely reflects widespread very low grade metamorphic effects. Phyllic alteration assemblages are typified by

sericite + quartz, commonly with leucoxene/rutile and a trace of pyrite, but in places they contain carbonate (as porphyroblasts) and grade into propylitic assemblages with increasing chlorite and albite. One sample (378131) has a variant of phyllic alteration in that it contains a few thin tourmaline-quartz-pyrite veins and a trace of alteration-derived tourmaline with sericite. Phyllic alteration more likely reflects focussed hydrothermal processes. Many samples have assemblages that could be viewed as being transitional from propylitic to potassic, or phyllic to potassic, due to the presence of K-feldspar in addition to many of the phases described above. However, it is difficult to distinguish whether much of the fine grained K-feldspar present is actually relict magmatic, or whether it might have replaced earlier phases. From study of the least-altered samples in the suite, the view is taken that much of the K-feldspar encountered may be relict, although there is probably mobilisation of K and formation of "secondary" K-feldspar in some samples. Sodic alteration occurs in a few samples and is manifest by the abundance of albite (e.g. having replaced former feldspars), in places in association with appreciable chlorite. Sodic alteration may reflect stronger focussing of heated seawater into the alteration system. Minor hematite occurs in several samples, generally as part of propylitic or phyllic alteration assemblages (e.g. in 378108, 378127, 378148, 378149, 378189) and reflects alteration occurring under rather oxidising conditions. Transitional alteration assemblages are widespread in the sample suite, with variations between propylitic-phyllic, sodic-propylitic, propylitic-potassic, etc.

Veining only occurs significantly in a few samples. Some could have formed hydrothermally at the time of pervasive alteration, but other vein assemblages appear to have been imposed later. Hydrothermal veining occurs in a few samples and could be manifest for example by quartz (-chlorite-carbonate-epidote) infilling (e.g. in 378175) and by tourmaline-quartz-pyrite infill in 378131. Other vein assemblages, although hydrothermal, may be related directly to very low grade metamorphic mobilisation of components, and typified by assemblages containing one or more of the minerals carbonate, chlorite, quartz, albite, sericite and epidote.

As mentioned, some of the alteration observed may be the result of extensive very low grade metamorphism. The propylitic assemblages are essentially consistent with having formed under lower greenschist facies conditions (e.g. chlorite grade), but the presence of pumpellyite in a few samples (378147, 378175, 378176, 378180, 378185) implies that the metamorphic grade may not have attained greenschist facies (at least in some of the sampled areas) but only pumpellyite-actinolite facies.

Penetrative deformation effects are generally not apparent, but in a few samples, the following deformation effects are observed: (a) as foliated metasedimentary lithic grains in clastic sedimentary rocks, and (b) as weak foliation imposed during or following alteration. Obviously in (a), the

deformation in the lithic grains occurred prior to incorporation of the lithic grains into the clastic sedimentary rock and relate to deformation in the source basement terrain. In (b), however, weak deformation effects were imposed after deposition of the rock and are generally indicated by weak foliation defined by preferred orientation of alteration-derived layer silicate phases such as sericite or chlorite. Rarely, thin stylolites occur and are also an indication of penetrative deformation and rock dissolution.

There are few indications of sulphide mineralisation in the sample suite, although traces of fine grained disseminated pyrite occur in many samples. Pyrite is interpreted to have formed as part of the alteration assemblages. Traces of fine grained disseminated sphalerite are recognised in 378103 and 378105, and in the latter sample, there are also traces of fine grained chalcopyrite and pyrrhotite. Again, these latter sulphides are viewed as having formed as part of the respective alteration assemblages.

Since it is understood that the samples in the suite were collected from surface outcrops, it is not surprising that minor effects of weathering are present in many samples. Weathering effects are mainly manifest by the development of a little goethite staining and in the local replacement of minerals such as pyrite and Fe-bearing carbonate by aggregates of goethite. In other samples, there has also been some retrograde degradation of alteration-derived layer silicates. This is commonly expressed in the partial replacement of chlorite by nontronitic clay and by the replacement of sericite by illite or kaolinite. The relatively abundant hematite that occurs in samples 378108, 378127, 378148, 378149 and 378189 is not considered to be due to weathering, but represents a hydrothermal/diagenetic, etc. alteration product.

INDIVIDUAL SAMPLE DESCRIPTIONS

378103 TS

Summary: Coarse grained lithic-crystal felsic tuff, with abundant tightly packed, angular lithic and mineral grains. There is no diagnostic textural evidence to indicate that the rock represents a reworked pyroclastic, i.e. a coarse epiclastic sandstone. Lithic fragments are dominated by volcanic material (mostly pumice, glassy and porphyritic grains), with a tiny population of fine grained carbonaceous sedimentary material. Individual mineral grains are dominated by volcanic-derived quartz and plagioclase, but there are a few small, altered ferromagnesian grains. The matrix is fine to medium grained and composed of altered pumiceous material. The rock has undergone strong alteration of sodic-propylitic type, with dominant replacement by albite, with patchy chlorite and a little quartz, sericite plus trace leucoxene, pyrite and sphalerite.

Handspecimen: The sample is composed of a rather massive, coarse grained lithic-crystal felsic tuff or derived coarse epiclastic sandstone. It is probably of felsic volcanic composition. There are abundant altered lithic clasts of possible volcanic type up to 5 mm across, as well as individual mineral grains up to 4 mm across. The latter are quartz and altered plagioclase. The lithic and mineral grains occur in a finer grained grey matrix. The rock may have undergone some alteration to chlorite and sericite, and testing of the section offcut with sodium cobaltinitrite did not reveal the presence of K-feldspar. The rock is essentially non-magnetic, with susceptibility of $<20 \times 10^{-5}$ SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, relict medium to coarse grained relict clastic texture is moderately well preserved. The rock contains relatively tightly packed individual mineral grains and lithic fragments up to 4 mm across. Interstitially, there is a subordinate fine to medium grained matrix component, now strongly altered. Lithic fragments are angular and dominated by volcanic materials. These include former pumice, vitric material (with rare relict perlitic cracking) and porphyritic material (plagioclase phenocrysts in a fine grained groundmass). There are one or two small fine grained sedimentary lithic grains that are probably carbonaceous shale in composition. Individual mineral grains are dominated by volcanic-derived quartz and altered plagioclase, but there are also a few small grains of altered ferromagnesian material and FeTi oxide. The matrix is apparently composed of small pumiceous fragments, including pseudomorphs after former glass shards. There is no preserved diagnostic texture to indicate sedimentary transport and deposition of components in the sample. Consequently, it is tentatively interpreted that the sample is a pyroclastic, i.e. a coarse felsic lithic-crystal tuff, rather than representing a volcanoclastic sandstone.

b) Alteration and structure: The rock has sustained strong, pervasive alteration, maybe as a result of very low grade metamorphism and/or interaction with heated fluids such as seawater. All plagioclase has been albitised and also slightly flecked by sericite. Most volcanic lithic material and matrix has been replaced by fine to medium grained albite, with minor chlorite, quartz and trace leucoxene, clinozoisite and pyrite. However, some glassy and frothy pumiceous fragments have been largely replaced by chlorite. Former ferromagnesian grains have been replaced by chlorite \pm quartz \pm traces of leucoxene, sphalerite and pyrite, and igneous FeTi oxide grains have been replaced by leucoxene. The alteration is considered to be of sodic type, transitional into propylitic.

c) Mineralogy and paragenesis: The sample contains a trace of disseminated pyrite and sphalerite as part of the alteration assemblage. Largest grains of each sulphide are up to 0.2 mm across.

Mineral Mode: Approximate modal proportions are: plagioclase (albite) 60%, quartz 25%, chlorite 13%, sericite 1% and traces of carbonaceous material, leucoxene, clinozoisite, pyrite and sphalerite.

Interpretation and Comments: It is interpreted that the sample is an altered coarse grained lithic-crystal felsic tuff, with abundant tightly packed, angular lithic and mineral grains. There is no diagnostic textural evidence to indicate that the rock represents a reworked pyroclastic, i.e. a coarse epiclastic sandstone. Lithic fragments are dominated by volcanic material (mostly pumice, glassy and porphyritic grains), with a few grains of fine grained carbonaceous sedimentary material. Individual mineral grains are dominated by volcanic-derived quartz and plagioclase, but there are a few small, altered ferromagnesian grains. The matrix is fine to medium grained and composed of altered pumiceous material. The rock has undergone strong alteration of sodic-propylitic type, with replacement by dominant albite, plus patchy chlorite and a little quartz, sericite plus trace leucoxene, pyrite and sphalerite.

378104 TS

Summary: Coarse grained lithic sandstone, grading into conglomerate, with a wide variety of lithic and individual mineral grain types. Detrital grains are tightly packed and there is little matrix. Lithic grains include fine grained sedimentary/metasedimentary types (e.g. shale, carbonaceous shale, siltstone, siliceous argillite/chert, marble) and fine to medium grained mafic to intermediate igneous types (e.g. intermediate to mafic porphyritic lava, dolerite). Individual mineral grains include plagioclase, quartz, clinopyroxene, calcite and FeTi oxide. The rock has undergone only weak alteration, with relatively minor replacement by albite, chlorite, carbonate and traces of leucoxene and pyrite.

Handspecimen: The sample is composed of a massive, grey coarse grained lithic sandstone, grading into conglomerate. It is dominated by tightly packed angular to sub-rounded detrital grains of fine grained sedimentary material, probably including chert, shale and almost black carbonaceous shale. There may also be a small population of volcanic and carbonate grains. There is little obvious alteration, although a little disseminated pyrite is present. Staining of the section offcut with sodium cobaltinitrite showed that some lithic grains contained a moderate amount of K-feldspar. The rock is weakly magnetic, with susceptibility up to 50×10^{-5} SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, relict detrital grain texture is well preserved. There are abundant tightly packed angular to sub-rounded lithic detrital grains up to 5 mm across and a smaller population of smaller (up to 0.8 mm) individual mineral grains. There is very little interstitial matrix. Lithic grain compositions are diverse. They include fine grained sedimentary and metasedimentary types, e.g. fine grained recrystallised chert, fine to medium grained quartzite (with trace sericite and biotite and locally with quartz veining), fine grained siliceous argillite, grading into shale (composed of quartz, with variable amounts of sericite, K-feldspar, carbonate and carbonaceous material), volcanoclastic siltstone and recrystallised limestone (marble). Lithic grains also include igneous material, e.g. intermediate to mafic porphyritic volcanic rock (maybe latite, andesite and basalt composition, with plagioclase and clinopyroxene phenocrysts) and relatively fresh medium grained dolerite (composed of plagioclase, clinopyroxene and a little FeTi oxide). Individual detrital mineral grains include plagioclase, clinopyroxene and rare quartz, microcline, FeTi oxide and carbonate. The composition of the rock is consistent with it being a coarse grained lithic sandstone, grading to conglomerate. It has a mixed sedimentary/metasedimentary and intermediate to mafic igneous provenance.

b) Alteration and structure: Alteration is relatively weak and may be a consequence of burial metamorphism. Some of the igneous lithic grains contain relatively fresh plagioclase and clinopyroxene. There has been local replacement of igneous lithic grains by chlorite and a little carbonate, with FeTi oxide being partly altered to leucoxene. Igneous lithic grains may have some albitisation of plagioclase and development of sericite. A little carbonate may have formed in interstitial positions between detrital grains. A trace of pyrite has formed as a result of alteration and occurs disseminated within some lithic grains.

c) Mineragraphy and paragenesis: The sample contains a trace of disseminated pyrite as part of the alteration assemblage. Largest grains are up to 0.3 mm across.

Mineral Mode: Approximate modal proportions are: plagioclase (including albite) and quartz each 35%, chlorite 8%, K-feldspar, clinopyroxene, carbonate and sericite each 5%, carbonaceous material 1% and traces of pyrite, leucoxene, biotite and FeTi oxide.

Interpretation and Comments: It is interpreted that the sample is a coarse grained lithic sandstone, grading into conglomerate. It tightly packed detrital lithic and mineral grains and little matrix. Lithic grains include fine grained sedimentary/metasedimentary types (e.g. shale, carbonaceous shale, siltstone, siliceous argillite/chert, marble) and fine to medium

grained mafic to intermediate igneous types (e.g. intermediate to mafic porphyritic lava, dolerite). Individual mineral grains include plagioclase, quartz, clinopyroxene, calcite and FeTi oxide. The rock has undergone only weak alteration, with relatively minor replacement by albite, chlorite, carbonate and traces of leucoxene and pyrite.

378105 TS

Summary: Coarse grained lithic sandstone, with a wide variety of lithic and individual mineral grain types. Detrital grains are tightly packed with only a little matrix. Lithic grains include fine grained sedimentary/metasedimentary types (e.g. shale, carbonaceous shale, siliceous argillite/chert, recrystallised limestone) and fine to medium grained mafic igneous types (e.g. basaltic porphyritic lava, dolerite). Individual mineral grains include plagioclase, quartz, clinopyroxene, calcite and altered ferromagnesian material. The rock has undergone only weak alteration, with relatively minor replacement by albite, chlorite, carbonate, sericite and traces of leucoxene, sphalerite, pyrrhotite, chalcopyrite and pyrite.

Handspecimen: The sample is composed of a massive, grey coarse grained lithic sandstone. It is dominated by tightly packed angular to sub-rounded detrital grains up to 7 mm across of fine grained sedimentary material, probably including chert, shale and almost black carbonaceous shale. There may also be a small population of volcanic and carbonate grains. Alteration is minor apart from possible formation of minor carbonate and chlorite, and the crystallisation of a little disseminated pyrite. Staining of the section offcut with sodium cobaltinitrite showed that some lithic grains contained a moderate amount of K-feldspar. The rock is weakly magnetic, with susceptibility up to 40×10^{-5} SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, relict detrital grain texture is well preserved. There are abundant tightly packed angular to sub-rounded lithic detrital grains up to 7 mm across and less abundant, smaller (up to 1 mm) individual mineral grains. There is only a little interstitial matrix. Lithic grain compositions are diverse. They include fine grained sedimentary and metasedimentary types, e.g. polycrystalline quartz representing fine grained recrystallised chert, fine to medium grained quartzite, locally with quartz veining, fine grained siliceous argillite, grading into shale (composed of quartz, with variable amounts of sericite, K-feldspar, carbonate and carbonaceous material) and recrystallised limestone. There are also igneous derived lithic grains e.g. mafic porphyritic volcanic rock (e.g. basaltic, with plagioclase and clinopyroxene phenocrysts) and relatively fresh medium grained dolerite (composed of plagioclase, clinopyroxene and a little FeTi oxide) and a little altered felsic igneous rock (fine to medium grained, with quartz, plagioclase and K-feldspar). Individual detrital mineral grains include plagioclase, clinopyroxene and rare quartz, altered ferromagnesian material, FeTi oxide and carbonate. The matrix interstitial to the detrital grains is fine grained and perhaps represents former muddy to silty material. It has been recrystallised. The relict texture and grain composition indicate that the rock is a coarse grained lithic sandstone. It has a mixed sedimentary/metasedimentary and mafic to felsic igneous provenance.

b) Alteration and structure: Alteration is relatively weak and may be a consequence of burial metamorphism. Some of the igneous lithic grains contain relatively fresh plagioclase and clinopyroxene, although there has been local alteration to chlorite, albite and sericite. Some igneous lithic grains and former ferromagnesian grains have been replaced by chlorite and a little carbonate, with FeTi oxide being partly altered to leucoxene. Plagioclase grains are partly albitised with minor development of sericite and carbonate. A little carbonate and chlorite may have formed in interstitial positions between detrital grains, with carbonate also occurring as uncommon porphyroblastic masses up to 1 mm across. Rare grains of sulphides occur in the partly altered lithic grains and matrix as part of the alteration assemblage. Sulphides include sphalerite, pyrrhotite, chalcopyrite and pyrite.

c) Mineragraphy and paragenesis: The sample contains traces of irregularly disseminated sphalerite, pyrrhotite, chalcopyrite and pyrite as part of the alteration assemblage. Largest grains (sphalerite) are up to 0.3 mm across.

Mineral Mode: Approximate modal proportions are: plagioclase (including albite) and quartz each 35%, chlorite 8%, K-feldspar, clinopyroxene, carbonate and sericite each 5%, carbonaceous material 1% and traces of pyrite, leucoxene and FeTi oxide.

Interpretation and Comments: It is interpreted that the sample is a weakly altered coarse grained lithic sandstone, with a wide variety of lithic and individual mineral grain types. Detrital grains are tightly packed with only a little matrix interstitially. Lithic grains include fine grained sedimentary/metasedimentary types (e.g. shale, carbonaceous shale, siliceous argillite/chert, recrystallised limestone) and fine to medium grained mafic igneous types (e.g. basaltic porphyritic lava, dolerite). Individual mineral grains include plagioclase, quartz, clinopyroxene, calcite and altered ferromagnesian material. There has been relatively minor replacement by albite, chlorite, carbonate, sericite and traces of leucoxene, sphalerite, pyrrhotite, chalcopyrite and pyrite.

378137 TS

Summary: Coarse grained lithic-crystal felsic tuff or derived epiclastic sandstone (grading into conglomerate). Relict textures are not diagnostic to distinguish due to alteration and recrystallisation. The rock has abundant lithic clasts that include volcanic material (pumice and porphyritic grains) as well as fine grained low grade metasedimentary material (mica schist, etc.). There are also individual mineral grains dominated by former volcanic-sources quartz and plagioclase. The matrix interstitial to lithic and mineral grains is composed largely of former fine pumiceous material. The rock has undergone strong alteration of propylitic type, with replacement by albite and lesser amounts of quartz, K-feldspar, sericite and chlorite. A few thin veins cut the altered rock and contain quartz \pm albite, chlorite. The rock has been weakly deformed, with slight development of a foliation defined by preferred orientation of alteration-derived sericite.

Handspecimen: The sample is composed of a massive to weakly foliated, coarse grained lithic sandstone, grading to conglomerate. It contains scattered lithic clasts up to 1 cm across and individual grains of quartz and feldspar up to 3 mm across in a finer grained grey matrix. Lithic include fine grained dark grey sedimentary types (e.g. shale, siltstone) as well as volcanic types. The rock may have undergone some alteration to sericite and chlorite. Staining of the section offcut with sodium cobaltinitrite showed that many of the lithic clasts contain significant K-feldspar, but that there is little K-feldspar in the matrix. The sample is essentially non-magnetic, with susceptibility of $<20 \times 10^{-5}$ SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, relict texture is moderately preserved. It is apparent that the rock is clastic, but the preserved textures are not diagnostic as to whether the rock is dominantly pyroclastic or that the components have undergone transport and deposition to form a coarse epiclastic sandstone (-conglomerate). The rock contains abundant lithic clasts up to 1 cm across, as well as individual mineral grains. These are relatively tightly packed, but there is a subordinate amount of fine to medium grained matrix material. Lithic clasts are varied and include elongate, commonly foliated low grade metasedimentary types (e.g. former shale or siltstone that has been metamorphosed into slate or muscovite-quartz schist) as well as volcanic types. The latter were mostly pumice, although some are porphyritic (plagioclase phenocrysts in a fine grained groundmass). Individual mineral grains are dominated by former volcanic-sourced quartz and plagioclase up to 1.5 mm across, plus rare K-feldspar, muscovite, biotite and tourmaline. The matrix is apparently composed of fine to medium grained former pumiceous material, including altered glass shards. From the relict texture, the rock is considered to be a lithic-crystal felsic tuff or derived epiclastic sandstone (-conglomerate).

b) Alteration and structure: The rock has sustained strong and pervasive alteration and minor veining. All volcanic lithic material has been replaced by fine grained albite and lesser amounts of K-feldspar, quartz, sericite and chlorite, although some clasts are dominated by sericite alteration. Low grade metasedimentary lithics are dominated by muscovite/sericite and quartz. All plagioclase grains are altered to albite, with a little sericite and matrix material has been finely recrystallised, with replacement by albite, chlorite, quartz, sericite and traces of leucoxene. The alteration assemblage is consistent with propylitic type. Minor veining has occurred, with emplacement of a couple of irregular veins up to 0.2 mm wide that are dominated by quartz, but also contain minor albite and chlorite. An incipient foliation has formed in the rock, and is defined by preferred orientation of some lithic clasts and by alteration-derived sericite aggregates. Slight weathering effects are indicated by a few small goethite aggregates and staining.

c) Mineragraphy and paragenesis: No sulphides have been observed in the sample.

Mineral Mode: Approximate modal proportions are: plagioclase (albite) 50%, quartz 20%, sericite + muscovite 13%, K-feldspar 10%, chlorite 6% and traces of leucoxene, biotite, tourmaline and goethite.

Interpretation and Comments: It is interpreted that the sample is an altered coarse grained lithic-crystal felsic tuff or derived epiclastic sandstone (grading into conglomerate). Relict textures are not diagnostic to distinguish due to alteration and recrystallisation. The rock has abundant lithic clasts that include volcanic material (pumice and porphyritic grains) as well as fine grained low grade metasedimentary material (mica schist, etc.). There are also individual mineral grains dominated by former volcanic-sources quartz and plagioclase. The matrix interstitial to lithic and mineral grains is composed largely of former fine pumiceous material. The alteration imposed is of strong propylitic type, with replacement by albite and lesser amounts of quartz, K-feldspar, sericite and chlorite. A few thin veins cut the altered rock and contain quartz ± albite, chlorite. The rock has been weakly deformed, with slight development of a foliation defined by preferred orientation of alteration-derived sericite and elongate lithic clasts.

378138 **TS**

Summary: Well laminated shale-siltstone, with good preservation of detrital grains and sedimentary bedding. Laminations are planar and sharp to gradational, with detrital grains dominated by plagioclase, K-feldspar, quartz and fine grained lithics. Matrix to the coarser laminae, as well as the finer, shaly laminae, is dominated by chlorite, with patchy development of carbonate. Shaly laminae may contain a little carbonaceous material and traces of pyrite. Alteration in the rock may be due to very low grade metamorphism and is dominated by an assemblage of albite, chlorite and carbonate, with a little sericite.

Handspecimen: The sample is composed of a well laminated, fine grained shale-siltstone. Paler grey laminae are slightly coarser grained (siltstone) and are intercalated with darker grey shaly laminae. Bedding laminations are planar and on a scale of <0.5 mm to 2 cm. The rock is probably quartzofeldspathic in composition, with shaly laminae possibly have a carbonaceous component. Staining of the section offcut with sodium cobaltinitrite showed that a moderate amount of K-feldspar is present throughout. The sample is essentially non-magnetic, with susceptibility of $<10 \times 10^{-5}$ SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, relict detrital grain texture and sedimentary bedding laminations are well preserved. There are intercalated fine grained shaly laminae with coarser laminae that grade from siltstone into fine sandstone. Laminations are on a scale of <0.5 mm to 2 cm in thickness. The somewhat coarser laminae are dominated by angular detrital grains of plagioclase, K-feldspar, quartz and lithics (probably of fine grained volcanic origin), with traces of detrital biotite, muscovite and leucoxene. Maximum detrital grain size is up to 0.5 mm, but most detrital grains are <0.2 mm across. The matrix interstitial to detrital grains in fine grained and dominated by alteration-derived chlorite, carbonate and a little sericite and trace leucoxene and pyrite. The shaly laminae contain a higher proportion of chlorite and smaller amounts of feldspars and quartz. They are more darkly pigmented by fine carbonaceous material and also contain traces of fine grained disseminated pyrite.

b) Alteration and structure: The rock has undergone moderate alteration, interpreted to be a result of very low grade metamorphism. This has led to albitisation of plagioclase and its further partial replacement by sericite, chlorite and carbonate. Matrix chlorite and carbonate developed during alteration, with some of the siltstone laminae containing considerable carbonate, in places as a replacement of detrital grains. Finer grained laminae have locally developed a weak, bedding plane parallel fissility. Possible former organic material has matured into a carbonaceous substance and traces of fine grained pyrite have formed.

c) Mineragraphy and paragenesis: The sample contains traces of fine grained disseminated pyrite, interpreted to be a product of alteration.

Mineral Mode: Approximate modal proportions are: plagioclase (albite) 30%, chlorite 25%, K-feldspar and carbonate each 15%, quartz 10%, sericite/muscovite 3%, carbonaceous material 1% and traces of leucoxene, biotite and pyrite.

Interpretation and Comments: It is interpreted that the sample is a very low grade metamorphosed, well laminated sedimentary rock, e.g. shale-siltstone, There is strong preservation of detrital grains and sedimentary bedding. Laminations are planar and sharp to gradational, with detrital grains dominated by plagioclase, K-feldspar, quartz and fine grained lithics. Matrix to the coarser laminae, as well as the finer, shaly laminae, is dominated by chlorite, with patchy development of carbonate. Shaly laminae may contain a little carbonaceous material and traces of pyrite. Alteration in the rock is dominated by an assemblage of albite, chlorite and carbonate, with a little sericite and a trace of pyrite.

378139 TS

Summary: Coarse grained lithic-crystal felsic tuff, dominated by pumiceous fragments and a minor pumiceous matrix component. There is a minor population of other lithic fragments including foliated carbonaceous shale/siltstone and quartzite, as well as individual mineral grains dominated by volcanic quartz and plagioclase grains. There is little evidence for the volcanic components to have been reworked to form an epiclastic sandstone. The rock has undergone strong alteration that is interpreted to be transitional between propylitic and potassic. There has been replacement of former igneous components by albite, sericite, K-feldspar, quartz, chlorite, carbonate and traces of leucoxene and pyrite.

Handspecimen: The sample is composed of a massive to weakly foliated coarse grained felsic tuff or epiclastic sandstone. It contains scattered lithic fragments up to 1 cm across as well as individual grains of quartz and feldspar up to 3 mm across set in a grey, finer grained volcanoclastic matrix. The lithic fragments are commonly fine grained and dark grey and may represent a carbonaceous sedimentary type. However, some lithics are also likely to be volcanic fragments. The rock has undergone mild sericite-chlorite alteration and staining of the section offcut with sodium cobaltinitrite showed that a moderate amount of K-feldspar is present throughout. The sample is essentially non-magnetic, with susceptibility of $<10 \times 10^{-5}$ SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, relict medium to coarse grained fragmental texture is moderately well preserved. The rock contains abundant tightly packed angular to sub-rounded lithic fragments up to 5 mm across and less abundant individual mineral grains, set in a relatively minor fine to medium grained matrix component of pumiceous material. Lithic grains are dominated by pumice fragments, with relict frothy and flow foliated textures and there are also a few porphyritic fragments (quartz and plagioclase phenocrysts). There is a smaller population of non-volcanic lithic fragments and these include fine grained foliated carbonaceous shale, grading into siltstone (with conspicuous muscovite) and medium grained muscovite quartzite. Individual mineral grains are dominated by former volcanic phenocrysts of quartz (some embayed) and plagioclase up to 2 mm across, along with rare grains of muscovite, altered ferromagnesian material (probably biotite and pyroxene, judging by relict grain shape), FeTi oxide and zircon. The finer grained pumiceous matrix locally preserves fine glass shard texture. There is little textural evidence for the components of the rock to have undergone sedimentary transport and deposition and hence it is interpreted that the rock is more likely to be a coarse grained lithic-crystal felsic tuff (i.e. a pyroclastic rock).

b) Alteration and structure: The volcanic rock has sustained strong pervasive alteration, maybe due to very low grade metamorphism and/or hydrothermal processes. Pumiceous fragments and matrix have been mostly replaced by fine grained albite, quartz, K-feldspar and less abundant sericite, carbonate, chlorite and traces of leucoxene and pyrite. However, some fragments are dominated by sericite and/or chlorite and a few contain large porphyroblastic aggregates of carbonate. Former plagioclase grains have been albitised and also flecked by sericite and carbonate. Former biotite has been replaced by sericite and leucoxene, pyroxene by carbonate, and FeTi oxide by leucoxene. A weak foliation has been imposed on the rock, defined by slight preferred orientation of elongate lithic fragments and by development of elongate and locally stylolitic masses rich in sericite. Alteration is viewed as being transitional in type between potassic and propylitic. Slight supergene oxidation in the sample is indicated by partial replacement of pyrite by goethite and by local goethite aggregates and staining.

c) Mineralogy and paragenesis: The sample contains traces of fine grained disseminated pyrite, interpreted to be a product of alteration.

Mineral Mode: Approximate modal proportions are: plagioclase (albite) 40%, quartz 20%, sericite + muscovite and K-feldspar each 15%, chlorite 5%, carbonate 4% and traces of carbonaceous material, leucoxene, zircon, goethite and pyrite.

Interpretation and Comments: It is interpreted that the sample is an altered coarse grained lithic-crystal felsic tuff, dominated by pumiceous fragments and a minor pumiceous matrix component. There is a minor population of other lithic fragments including foliated carbonaceous shale/siltstone and quartzite, as well as individual mineral grains dominated by volcanic quartz and plagioclase grains. There is little evidence for the volcanic components to have been reworked to form an epiclastic sandstone. Strong alteration imposed on the rock is interpreted to be transitional between propylitic and potassic types. There has been replacement of former igneous components by albite, sericite, K-feldspar, quartz, chlorite, carbonate and traces of leucoxene and pyrite.

378148 **TS**

Summary: Altered, moderately porphyritic felsic volcanic rock, probably representing a lava of dacitic composition. The original rock contained phenocrysts of plagioclase, plus a few of biotite, along with microphenocrysts of FeTi oxide and possible pyroxene in a fine grained (aphanitic/glassy) quartzofeldspathic groundmass. There is weak flow alignment of phenocrysts and of quartz-rich alteration patches in the groundmass. Pervasive strong alteration has led to replacement of the groundmass by K-feldspar, with minor quartz, sericite and hematite. Plagioclase has been replaced by variable amounts of quartz, K-feldspar, sericite and albite, with biotite being replaced by sericite \pm hematite \pm leucoxene, pyroxene by quartz \pm hematite, and FeTi oxide by hematite. The alteration may be due to low grade metamorphic effects and is of potassic-phyllic type.

Handspecimen: The sample is composed of a rather sparsely porphyritic, weakly flow foliated, dark brick red coloured felsic volcanic rock. It contains scattered altered feldspar phenocrysts up to 4 mm long set in a fine grained altered groundmass, strongly pigmented by fine grained hematite. The rock has a few aligned aggregates rich in quartz, but it is otherwise feldspar-rich, with sodium cobaltinitrite staining of the section offcut indicating that K-feldspar is abundant. The sample is essentially non-magnetic, with susceptibility of $<10 \times 10^{-5}$ SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, relict porphyritic and flow foliated texture is moderately well preserved. The original rock was evidently moderately porphyritic, with scattered feldspar phenocrysts (probably plagioclase) up to 4 mm long and less common biotite phenocrysts up to 2.5 mm long. There were scattered microphenocrysts of FeTi oxide up to 0.5 mm across and microphenocrysts of another ferromagnesian phase (possibly pyroxene judging by relict grain shape) up to 0.7 mm across, plus rare small grains of apatite and zircon. The phenocrystal phases were set in an originally fine grained (aphanitic to glassy) quartzofeldspathic groundmass containing a few small microphenocrysts of feldspar, biotite and FeTi oxide. In the groundmass, there are a few irregular to elongate, aligned aggregates rich in quartz. These might be due to replacement of former glassy bands. The pseudomorphs after former feldspar phenocrysts also show some alignment, interpreted as due to original flow in the magma. It is considered likely from the relict textures and interpreted primary mineralogy that the rock is an altered porphyritic biotite-pyroxene dacite, representing a lava.

b) Alteration and structure: The rock has been strongly and pervasively altered. This has led to replacement of the original aphanitic to glassy groundmass by fine grained K-feldspar, with minor quartz, sericite and hematite, along with development of elongate to irregular patches of fine to medium grained quartz. Former plagioclase phenocrysts were replaced by quartz, K-feldspar \pm albite, with subsequent variable replacement (of albite) by sericite. Biotite grains have been replaced by sericite \pm hematite \pm leucoxene, pyroxene by quartz \pm hematite and FeTi oxide by hematite. The alteration may be due to low grade metamorphism and occurred under oxidising conditions (presence of hematite). The alteration assemblage is of potassic-phyllic type.

c) Mineralogy and paragenesis: No sulphides are observed in the sample. Minor hematite has formed as a product of the alteration.

Mineral Mode: Approximate modal proportions are: K-feldspar 60%, quartz 25%, sericite 7%, albite 5%, hematite 2% and traces of zircon, apatite and leucoxene.

Interpretation and Comments: It is interpreted that the sample represents an altered, moderately porphyritic biotite-pyroxene dacite, probably emplaced as a lava and having weak relict flow foliation. The rock contained phenocrysts of plagioclase, plus a few of biotite, along with microphenocrysts of FeTi oxide and possible pyroxene in a fine grained

(aphanitic/glassy) quartzofeldspathic groundmass. Pervasive strong alteration has led to replacement of the rock by K-feldspar, quartz, sericite and minor hematite. The alteration may be due to low grade metamorphic effects and is of potassic-phyllic type, occurring under oxidising conditions.

378149 **TS**

Summary: Altered porphyritic quartz-biotite-pyroxene latite, perhaps representing a former lava. The rock contained scattered phenocrysts of plagioclase and biotite, with a few glomeroporphyritic aggregates of plagioclase-pyroxene-biotite-FeTi oxide-apatite and a few microphenocrysts of FeTi oxide in a fine grained (perhaps aphanitic) groundmass that was rich in K-feldspar, plus minor quartz, plagioclase and ferromagnesian material. There has been moderate to strong pervasive alteration of propylitic type imposed, with partial replacement of igneous minerals by albite, sericite, chlorite, carbonate and trace leucoxene. A few irregular veins cut the altered rock; they range from quartz-rich, with K-feldspar selvages to carbonate-rich.

Handspecimen: The sample is composed of a massive brown-grey to pink-grey altered porphyritic, fine grained intermediate to felsic igneous rock. It contains scattered tabular feldspar phenocrysts up to 5 mm across and a few smaller chloritic aggregates that might represent former ferromagnesian phenocrysts set in a fine grained feldspathic groundmass. Staining of the section offcut with sodium cobaltinitrite showed that K-feldspar is abundant in the groundmass. The sample contains minor magnetite as it is moderately magnetic, with susceptibility up to 770×10^{-5} SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, relict porphyritic texture is moderately well preserved. There are scattered, variably altered tabular phenocrysts of plagioclase up to 3 mm across and less common smaller phenocrysts of biotite up to 1 mm across. There are also a few microphenocrysts of FeTi oxide (e.g. titanomagnetite) and a few glomeroporphyritic aggregates up to several millimetres across that are composed of plagioclase-altered ferromagnesian phase-biotite-FeTi oxide-trace apatite and zircon. Relict shapes suggest that the altered ferromagnesian phase was a pyroxene. The phenocrystal phases occur in an altered and partly recrystallised fine grained (maybe originally aphanitic) feldspathic groundmass - rich in K-feldspar, but with minor plagioclase, quartz, ferromagnesian material and trace FeTi oxide. From the relict texture and interpreted primary mineralogy, the rock is considered to represent a porphyritic quartz-biotite-pyroxene latite, perhaps emplaced as a lava.

b) Alteration and structure: The rock has undergone moderate to strong pervasive alteration and minor veining. There has been partial replacement of plagioclase by albite, sericite and carbonate. Most biotite has been replaced by chlorite \pm sericite \pm leucoxene, although minor relict biotite occurs. All former pyroxene has been replaced by carbonate \pm chlorite and igneous FeTi oxide is locally altered to leucoxene. The groundmass has been patchily recrystallised to fine to medium grained inequigranular K-feldspar, but there are considerable less recrystallised and interstitial zones rich in fine grained K-feldspar, albite, sericite, chlorite, carbonate and trace hematite. The altered rock has been cut by a few irregular veins up to 0.4 mm across. Some are quartz-rich, with thin alteration selvages of K-feldspar, sericite and chlorite, whereas other veins are carbonate-rich. The alteration assemblage is considered to be largely of propylitic type.

c) Mineragraphy and paragenesis: No sulphides are observed in the sample. The rock contains a little relict igneous FeTi oxide (titanomagnetite).

Mineral Mode: Approximate modal proportions are: K-feldspar 35%, plagioclase (including albite) 25%, sericite 15%, chlorite 10%, carbonate 8%, quartz 5%, FeTi oxide 1% and traces of zircon, apatite, hematite, biotite and leucoxene.

Interpretation and Comments: It is interpreted that the sample represents a porphyritic quartz-biotite-pyroxene latite, perhaps emplaced as a lava. The rock contained scattered phenocrysts of plagioclase and biotite, with a few glomeroporphyritic aggregates of plagioclase-pyroxene-biotite-FeTi oxide-apatite and a few microphenocrysts of FeTi oxide in

a fine grained (perhaps aphanitic) groundmass that was rich in K-feldspar, plus minor quartz, plagioclase and ferromagnesian material. There has been moderate to strong pervasive alteration of propylitic type imposed, with partial replacement of igneous minerals by albite, sericite, chlorite, carbonate and trace leucoxene. A few irregular veins cut the altered rock; they range from quartz-rich, with K-feldspar selvages to carbonate-rich.

378150 TS

Summary: Medium grained lithic-feldspathic-quartz sandstone, with a mixed felsic to intermediate volcanic and sedimentary provenance. Lithic grains include volcanic material as well as fine grained siliceous and sericitic sedimentary material. The rock has undergone pervasive strong alteration under oxidising conditions to develop an assemblage of albite, quartz, carbonate (e.g. dolomite), sericite and hematite.

Handspecimen: The sample is composed of a massive to weakly foliated, pink-brown, medium to coarse grained sandstone. It has a well preserved relict detrital grain texture, with individual grains up to 2-3 mm across. There may be considerable carbonate interstitial to the detrital grains plus minor hematite pigmentation. Testing of the section offcut with dilute HCl gave little reaction, indicating that the carbonate may be dolomite or ankerite. Likewise, testing with sodium cobaltinitrite did not indicate the presence of K-feldspar. The sample is very weakly magnetic, with susceptibility up to 25×10^{-5} SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, the rock has a moderately well preserved relict detrital grain texture, with abundant tightly packed detrital grains and only a small matrix component. Detrital grains are angular to sub-rounded and are dominated by lithics, altered plagioclase and quartz. Grains of plagioclase and quartz are up to 1 mm across, with probable derivation from a volcanic source. Lithic grains are up to 2 mm across and include a large component of volcanic-derived grains (generally fine grained, locally porphyritic and possibly pumiceous material of felsic to intermediate volcanic composition). There is also a component of lithic grains that are interpreted as sedimentary (or metasedimentary) in origin. These range from polycrystalline quartz-rich aggregates (e.g. metachert, siltstone) to sericite-quartz (perhaps shaly material). In addition, there are a few detrital flakes of muscovite up to 1 mm across along with altered FeTi oxide and a trace of zircon. The minor matrix component may have been muddy to silty material and probably of volcanoclastic derivation. The relict textures indicate that the rock is a lithic-feldspathic-quartz sandstone, with a mixed volcanic and sedimentary provenance.

b) Alteration and structure: The sandstone has undergone strong pervasive alteration, maybe as a result of very low grade metamorphism. Detrital plagioclase has been albitised and also locally replaced by carbonate and sericite. Lithic grains and finer matrix material have been replaced by finely granular albite and minor quartz, in places accompanied by sericite, carbonate, hematite and traces of chlorite. There has been rather abundant growth of irregular porphyroblastic masses of carbonate throughout. Hematite has locally largely replaced lithic grains as well as former detrital FeTi oxide and hematite also occurs as a fine dusting throughout. Weak deformation effects on the rock are indicated by slight development of preferred orientation in sericite masses at detrital grain boundaries and in lithic grains. The alteration assemblage of albite-quartz-carbonate-sericite-hematite (-chlorite) is viewed as having propylitic affinities and occurring under oxidising conditions. Subsequent minor supergene alteration effects have caused local replacement of carbonate by goethite.

c) Mineralogy and paragenesis: No sulphides are observed in the sample. Minor hematite has formed as a product of the alteration.

Mineral Mode: Approximate modal proportions are: plagioclase (albite) 55%, quartz 25%, carbonate (dolomite/ankerite) 14%, sericite/muscovite 3%, hematite 2% and traces of zircon, chlorite and goethite.

Interpretation and Comments: It is interpreted that the sample is a medium grained lithic-feldspathic-quartz sandstone, with a mixed felsic to intermediate volcanic and sedimentary provenance. Lithic grains include volcanic material as well as fine grained siliceous and sericitic sedimentary material. The rock has undergone pervasive strong alteration of

propylitic type under oxidising conditions to develop an assemblage of albite, quartz, carbonate (e.g. dolomite), sericite, hematite and trace chlorite.

378157 TS

Summary: Altered porphyritic quartz latite maybe representing a shallow intrusive or less likely, a lava. The original rock contained scattered phenocrysts of plagioclase and a few microphenocrysts of ferromagnesian material and quartz in a holocrystalline, fine to medium grained groundmass of plagioclase, K-feldspar, minor altered ferromagnesian material, quartz and FeTi oxide. The rock contains a few glomeroporphyritic aggregates (?micro-enclaves) of plagioclase-altered ferromagnesian material-FeTi oxide and quartz. There has been pervasive propylitic alteration, probably the result of very low grade metamorphism, with partial replacement by albite, chlorite, sericite and carbonate.

Handspecimen: The sample is composed of a massive, dark grey porphyritic fine grained igneous rock, perhaps of intermediate composition. It contains scattered feldspar phenocrysts up to 2-3 mm across in a fine grained feldspathic groundmass, but which also contains significant chloritised ferromagnesian material. Staining of the section offcut with sodium cobaltinitrite showed that the groundmass contains abundant K-feldspar. The sample contains minor magnetite and is moderately to strongly magnetic, with susceptibility up to 1500×10^{-5} SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, relict porphyritic texture is moderately well preserved. There are scattered partly altered tabular plagioclase phenocrysts up to 1.5 mm across and a few microphenocrysts of quartz and pseudomorphs after former ferromagnesian material. The larger grains occur in a holocrystalline, fine to medium grained groundmass (maximum grain size 0.3 mm) of small plagioclase laths, K-feldspar, minor interstitial quartz and altered ferromagnesian material and a little disseminated FeTi oxide (e.g. titanomagnetite). There are several glomeroporphyritic aggregates (maybe micro-enclaves) up to 1 cm across of medium grained plagioclase-altered ferromagnesian-FeTi oxide-quartz. The relict texture and interpreted primary mineralogy indicate that the rock represents a porphyritic quartz latite, maybe emplaced as a shallow intrusive and less likely as a lava.

b) Alteration and structure: The igneous rock has undergone pervasive moderate to strong alteration, maybe due to very low grade metamorphism. Plagioclase has been partly altered to albite and minor amounts of sericite, carbonate and chlorite. K-feldspar has also been flecked by sericite, chlorite and carbonate. All former ferromagnesian material has been altered to chlorite, carbonate and trace leucoxene, and igneous FeTi oxide has been slightly altered to leucoxene. The rock contains a few alteration patches up to 2 mm across of medium grained chlorite-carbonate-quartz, a single thin stylolitic veinlike aggregate of leucoxene, with a little chlorite and trace pyrite, as well as a few thin shear veins containing chlorite ± sericite. The alteration assemblage is consistent with propylitic type.

c) Mineralogy and paragenesis: The sample contains minor relict igneous FeTi oxide (titanomagnetite) as well as a trace of pyrite as part of the alteration assemblage.

Mineral Mode: Approximate modal proportions are: plagioclase (including albite) 40%, K-feldspar 30%, chlorite 13%, quartz 8%, sericite 5%, carbonate and FeTi oxide each 2% and traces leucoxene and pyrite.

Interpretation and Comments: It is interpreted that the sample is a porphyritic quartz latite with moderate to strong propylitic alteration, perhaps caused by very low grade metamorphism. The original igneous rock may have been emplaced as a shallow intrusive or less likely, a lava. It contained scattered phenocrysts of plagioclase and a few microphenocrysts of ferromagnesian material and quartz in a holocrystalline, fine to medium grained groundmass of plagioclase, K-feldspar, minor altered ferromagnesian material, quartz and FeTi oxide. The rock contains a few glomeroporphyritic aggregates (?micro-

enclaves) of plagioclase-altered ferromagnesian material-FeTi oxide and quartz. Alteration has led to partial replacement of igneous minerals by albite, chlorite, sericite and carbonate.

378158 TS

Summary: Porphyritic quartz micromonzonite, with scattered small plagioclase phenocrysts set in a fine to medium grained groundmass of plagioclase, K-feldspar, altered ferromagnesian material, minor quartz and FeTi oxide. Pervasive strong propylitic alteration has been imposed, with partial replacement by albite and chlorite, plus minor carbonate and hematite.

Handspecimen: The sample is composed of a massive, fine to medium grained, weakly porphyritic intermediate igneous rock. It is brown-grey in colour although the groundmass has a pinkish tinge. There are scattered feldspar phenocrysts up to 2 mm across as well as small dark greenish altered ferromagnesian grains up to 1-2 mm across. The latter appear to have been chloritised. Staining of the section offcut with sodium cobaltinitrite showed that K-feldspar is abundant in the groundmass. The sample contains minor magnetite and is moderately magnetic, with susceptibility up to 740×10^{-5} SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, relict porphyritic texture is well preserved. The rock contains scattered altered tabular phenocrysts of plagioclase up to 1.5 mm long and they are set in a fine to medium grained, holocrystalline groundmass of smaller plagioclase laths, rather abundant small grains of K-feldspar, altered ferromagnesian material, minor quartz, forming interstitial masses up to 1 mm across and a little disseminated FeTi oxide (e.g. titanomagnetite). Relict shapes in some of the altered ferromagnesian material suggest that at least some represents former pyroxene grains. Relict textures and inferred primary mineralogy of the rock indicate that it represents an altered porphyritic quartz micromonzonite.

b) Alteration and structure: The original igneous rock has undergone pervasive strong alteration of propylitic type, perhaps as a result of very low grade metamorphism. All plagioclase has been albitised and also locally replaced by fine grained chlorite and carbonate. K-feldspar is slightly altered to carbonate and also lightly dusted by fine grained hematite. All ferromagnesian material has been replaced by chlorite, with a little carbonate and traces of leucoxene. Igneous FeTi oxide is partly altered to hematite. The groundmass contains one or two porphyroblastic alteration masses of carbonate up to 1.5 mm across.

c) Mineragraphy and paragenesis: No sulphides have been observed in the sample. The rock retains minor igneous FeTi oxide (titanomagnetite).

Mineral Mode: Approximate modal proportions are: plagioclase (albite) 50%, K-feldspar 30%, chlorite 10%, quartz 5%, carbonate 3%, FeTi oxide and hematite each 1% and a trace of leucoxene.

Interpretation and Comments: It is interpreted that the sample represents an altered porphyritic quartz micromonzonite. It contained scattered small plagioclase phenocrysts set in a fine to medium grained groundmass of plagioclase, K-feldspar, altered ferromagnesian material, minor quartz and FeTi oxide. Pervasive strong propylitic alteration has been imposed, with partial replacement by albite and chlorite, plus minor carbonate and hematite.

378159 TS

Summary: Altered porphyritic quartz monzonite. The original igneous rock contained abundant tabular plagioclase phenocrysts, with interstitial medium grained K-feldspar, ferromagnesian material and minor quartz, plagioclase and FeTi oxide (titanomagnetite). There has been moderate to strong imposed alteration of propylitic type. This has led to replacement of some of the primary minerals by albite and chlorite, with minor carbonate, sericite and epidote, plus traces of titanite and leucoxene.

Handspecimen: The sample is composed of a massive, medium to coarse grained, slightly porphyritic, intermediate igneous rock. It is mostly dark green-grey in colour, but contains minor pink feldspar. The rock is rich in feldspars and altered ferromagnesian minerals, with the latter having been replaced by chlorite. Staining of the section offcut with sodium cobaltinitrite showed that there is a moderate amount of K-feldspar, interstitial to dominant plagioclase. The rock contains minor disseminated magnetite as it is moderately to strongly magnetic, with susceptibility of up to 1300×10^{-5} SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, relict porphyritic texture is moderately well preserved. The rock contains abundant altered tabular phenocrysts of plagioclase up to 4 mm across, with interstitial medium grained K-feldspar, altered ferromagnesian material, minor plagioclase, quartz, disseminated FeTi oxide (e.g. titanomagnetite) and a trace of apatite. K-feldspar and quartz grains are up to 1 mm across and FeTi oxide grains up to 0.5 mm across. There are no diagnostic shapes recognisable in the altered ferromagnesian material. The relict texture and interpreted primary mineralogy indicates that the rock represents a former porphyritic quartz monzonite.

b) Alteration and structure: The igneous rock has undergone pervasive moderate to strong alteration of propylitic type, perhaps as a result of hydrothermal and/or very low grade metamorphic processes. All plagioclase has been albitised and also locally replaced by fine grained sericite, epidote, chlorite and carbonate. In contrast, K-feldspar is rather fresh, with only slight alteration to carbonate. All ferromagnesian material has been altered to chlorite \pm carbonate \pm titanite \pm leucoxene. In places, there has been development of a weak network of thin irregular chlorite veins and there is a trace of finely dispersed hematite.

c) Mineragraphy and paragenesis: No sulphides have been observed in the sample, but there is disseminated relict igneous titanomagnetite.

Mineral Mode: Approximate modal proportions are: plagioclase (albite) 55%, K-feldspar 20%, chlorite 10%, quartz 5%, sericite and carbonate each 3%, FeTi oxide (titanomagnetite) 2%, epidote 1% and traces of hematite, titanite, leucoxene and apatite.

Interpretation and Comments: It is interpreted that the sample represents an altered porphyritic quartz monzonite. The rock has undergone pervasive propylitic alteration that has developed albite and chlorite, with minor carbonate, sericite and epidote. The original rock has plagioclase phenocrysts and interstitial medium grained K-feldspar and ferromagnesian material, plus minor plagioclase, quartz and FeTi oxide.

378163 TS

Summary: Medium to coarse grained volcanoclastic sandstone with intermediate to felsic volcanic provenance. The rock contains abundant altered lithic detrital grains (fine grained and locally porphyritic and flow-foliated intermediate volcanic material), plus altered plagioclase grains, quartz and a little detrital muscovite. Detrital components occur in a fine grained quartzofeldspathic matrix. The rock has undergone pervasive propylitic alteration to develop an assemblage of dominant albite, with subordinate quartz and chlorite, minor carbonate, a little sericite and trace rutile and pyrite.

Handspecimen: The sample is composed of a massive, dark grey medium to coarse grained volcanoclastic rock, e.g. tuff or epiclastic sandstone. It contains abundant grains of plagioclase and lithic material up to a few millimetres across in a finer grained dark matrix. Testing of the section offcut with sodium cobaltinitrite did not reveal the presence of K-feldspar. The sample is essentially non-magnetic, with susceptibility of $<10 \times 10^{-5}$ SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, it is apparent that the rock is a medium to coarse grained volcanoclastic. It contains a moderate to well preserved relict texture, with abundant angular lithic grains up to several millimetres across, plus scattered detrital altered grains of plagioclase up to 2 mm across and smaller and less common grains of quartz, a few small flakes of muscovite and traces of detrital carbonate, FeTi oxide (now altered) and a single small grain of chromite. Lithic grains are dominated by fine grained, locally flow-foliated and porphyritic (plagioclase-phyric) intermediate volcanic rock, but with rare small quartzite grains. Detrital grains dominate, but there is a small interstitial matrix component, composed of smaller detrital grains and finely recrystallised feldspar and quartz. From the relict texture and inferred primary mineralogy, it is interpreted that the rock represents a medium to coarse grained volcanoclastic sandstone, with a dominant intermediate to felsic volcanic provenance. However, the grain of chromite indicates a local ultramafic source of detritus.

b) Alteration and structure: The rock has undergone pervasive moderate to strong alteration. All plagioclase (as detrital discrete grains and as a component of the lithic grains) has been replaced by albite, with local development of carbonate, chlorite and a little sericite. The finer grained matrix component has been replaced by fine grained albite and quartz, with minor chlorite and traces of sericite, carbonate, rutile, pyrite and possible carbonaceous material. The rock contains a few irregular alteration patches up to a few millimetres across composed largely of carbonate and/or chlorite, with local traces of pyrite. It is possible that scattered small aggregates of fine grained metamorphic biotite developed in the rock as a result of alteration (metamorphism), but if so, biotite has subsequently been replaced by fine grained retrograde chlorite. The rock exhibits uncommon irregular discontinuous veinlets of carbonate. The alteration assemblage is consistent with propylitic type, but could simply be the result of very low grade metamorphism.

c) Mineragraphy and paragenesis: A few irregularly disseminated grains of pyrite up to 0.1 mm across occur as part of the alteration assemblage, mostly in association with the carbonate-chlorite patches. A single grain of detrital chromite has been observed.

Mineral Mode: Approximate modal proportions are: plagioclase (albite) 60%, quartz 25%, chlorite 10%, carbonate 3%, sericite and muscovite 1% and traces of rutile, chromite, pyrite and ?carbonaceous material.

Interpretation and Comments: It is interpreted that the sample represents a medium to coarse grained volcanoclastic sandstone with intermediate to felsic volcanic provenance. The rock contains abundant altered lithic detrital grains (fine grained and locally porphyritic and flow-foliated intermediate volcanic material), plus altered plagioclase grains, quartz and a little detrital muscovite. Detrital components occur in a fine grained quartzofeldspathic matrix.

The rock has undergone pervasive propylitic alteration to develop an assemblage of dominant albite, with subordinate quartz and chlorite, minor carbonate, a little sericite and trace rutile and pyrite.

378164 **TS**

Summary: Medium grained quartz-lithic sandstone with a mixed provenance dominated by grains of siliceous metamorphic material, possible felsic plutonic, fine grained sedimentary, volcanic and trace ultramafic material. The rock has undergone moderate alteration, with development of chlorite and carbonate, mainly from replacement of volcanic grains, matrix and development of cement. A trace of disseminated pyrite occurs as part of the alteration assemblage.

Handspecimen: The sample is composed of a relatively massive, grey medium grained sandstone, probably with a significant amount of detrital lithic grains and quartz, and also with scattered muscovite flakes. There are a few fine grained dark grey lithic grains that might be composed of carbonaceous sedimentary material. Largest detrital grains are up to 1-2 mm across. The rock may have undergone mild chloritic alteration and testing of the section offcut with sodium cobaltinitrite did not reveal the presence of K-feldspar. The sample is essentially non-magnetic, with susceptibility of $<10 \times 10^{-5}$ SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, the sample has a moderately well preserved relict detrital grain texture. Detrital grains are sub-rounded to angular and although most are <0.5 mm across, a few grains are up to 2.5 mm across. Individual grains of quartz are the most abundant detrital grain type, but there is a significant population of lithic grains, plus scattered muscovite flakes, rare grains of altered plagioclase, carbonate, FeTi oxide, zircon, tourmaline, biotite and chromite. Lithic grains are dominated by fine to medium grained quartzite, some of which is foliated and some containing a few grains of muscovite. There is a minor proportion of fine grained carbonaceous grains - probably sericitic and shaly in composition, but darkly pigmented by fine carbonaceous material. There are also a few possible altered fine grained volcanic lithic grains. Larger detrital grains occur in a relatively minor matrix component of smaller grains, plus minor cement, mainly carbonate and chlorite. The rock is considered to be a quartz-lithic sandstone, based on relict texture and compositions of the lithic grains. Provenance is mainly siliceous metamorphic material, possible felsic plutonic, fine grained sedimentary, volcanic and trace ultramafic material (e.g. the latter indicated by the presence of a trace of detrital chromite).

b) Alteration and structure: The rock has undergone moderate pervasive alteration, maybe due to very low grade metamorphism. Very weak foliation is present and manifest by slight preferred orientation of elongate lithic grains and muscovite flakes. Alteration is mainly indicated by replacement of fine grained volcanic lithic grains by chlorite \pm carbonate \pm leucoxene \pm pyrite, and FeTi oxide by leucoxene, as well as by development of cement of chlorite and carbonate, with traces of leucoxene, pyrite and hematite. The alteration assemblage is considered to be of propylitic type. Slight weathering effects imposed on the sample are demonstrated by partial replacement of pyrite grains by goethite.

c) Mineragraphy and paragenesis: A few irregularly disseminated grains of pyrite up to 0.1 mm across occur as part of the alteration assemblage. Rare detrital chromite has been observed.

Mineral Mode: Approximate modal proportions are: quartz 70%, chlorite 15%, carbonate 9%, muscovite + sericite 3%, ?carbonaceous material and plagioclase each 1% and traces of biotite, zircon, tourmaline, chromite, pyrite, goethite, hematite and leucoxene.

Interpretation and Comments: It is interpreted that the sample is a medium grained quartz-lithic sandstone with a mixed provenance dominated by grains of siliceous metamorphic material, possible felsic plutonic, fine grained sedimentary, volcanic and trace ultramafic material. The rock has undergone moderate alteration, with development of chlorite and carbonate, mainly from replacement of volcanic grains, matrix and development of cement. A

trace of disseminated pyrite occurs as part of the alteration assemblage which is interpreted to be of propylitic type and may be due to very low grade metamorphism.

378165 TS

Summary: Medium grained quartz-lithic sandstone containing detrital grains of quartz, subordinate amount of lithic material (quartzite and quartz-muscovite schist), scattered grains of muscovite, a little altered biotite, K-feldspar and carbonate and traces of tourmaline, rutile and chromite. The minor amount of matrix component has been recrystallised as a result of low grade metamorphism and consists of quartz, chlorite, carbonate and a little sericite. Rare pyrite grains might have also formed as a result of matrix alteration. The rock is likely to have had a provenance from a mature silicic metamorphic source, rather than from a volcanic source.

Handspecimen: The sample is composed of a relatively massive, medium grained, grey sandstone. It is rather quartz-rich, with largest grains up to 2 mm across. There are also a few scattered muscovite flakes and possible lithic grains. Weak fracturing has occurred and some fractures are coated by weathering-derived goethite. Testing of the section offcut with sodium cobaltinitrite revealed a few small K-feldspar grains. The sample is essentially non-magnetic, with susceptibility of $<10 \times 10^{-5}$ SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, relict detrital grain texture is well preserved and it is clear that the rock is a medium grained sandstone. There is a dominance of tightly packed detrital grains, with only a minor matrix component. The rock contains angular to sub-rounded detrital grains up to 1.5 mm across, with quartz being abundant. There is a subordinate population of lithic grains (mostly fine grained quartzite and quartz-muscovite schist), with scattered detrital muscovite flakes up to 1 mm across, and a few altered biotite flakes, carbonate grains, rare chlorite, K-feldspar and traces of tourmaline, rutile and chromite. The matrix has been altered and is fine grained, consisting largely of quartz and chlorite, with minor carbonate, a little sericite and traces of pyrite and dark ?carbonaceous material. It is interpreted that the sandstone has a provenance from a silicic, metamorphic source (with trace chromite also implying some ultramafic rock input), rather than a volcanic source.

b) Alteration and structure: The rock has undergone low grade alteration, probably as a result of incipient metamorphism. It has also been weakly deformed, with a slight preferred orientation of detrital grains, e.g. the phyllosilicates. Detrital biotite grains have been replaced by chlorite and sericite and the matrix has been replaced by fine grained quartz, chlorite, carbonate and a little sericite. It is possible that a few small pyrite grains grew in the matrix as a result of alteration. The rock has been slightly affected by later supergene oxidation, with pyrite grains having been partly replaced by goethite.

c) Mineragraphy and paragenesis: A few irregularly disseminated grains of pyrite up to 0.1 mm across occur as part of the alteration assemblage, with subsequent partial replacement by supergene goethite. Rare grains of detrital chromite have been observed.

Mineral Mode: Approximate modal proportions are: quartz 80%, chlorite 10%, muscovite + sericite 5%, carbonate 4% and traces of K-feldspar, tourmaline, rutile, chromite, pyrite, goethite and ?carbonaceous material.

Interpretation and Comments: It is interpreted that the sample is a quartz-lithic, medium grained sandstone that has been derived largely from a silicic, metamorphic source, rather than a volcanic source. It contains detrital grains of quartz, subordinate amount of lithic material (quartzite and quartz-muscovite schist), scattered grains of muscovite, a little altered biotite, K-feldspar and carbonate and traces of tourmaline, rutile and chromite. The minor amount of matrix component has been recrystallised as a result of low grade metamorphism and consists of quartz, chlorite, carbonate and a little sericite. Rare pyrite grains might have also formed as a result of matrix alteration.

378166 TS

Summary: Well laminated carbonaceous shale-siltstone. The rock contains detrital grains of quartz and muscovite, with minor lithics and K-feldspar in a fine grained matrix of chlorite, with minor sericite, quartz and carbonaceous material. The latter might represent former organic material, subsequently matured into a graphite-like substance. It is locally accompanied by traces of fine grained pyrite. The rock may have undergone very low grade metamorphism and the mica flakes display a weak preferred orientation.

Handspecimen: The sample is composed of a well laminated, dark grey fine grained sedimentary rock, probably a type of carbonaceous shale. Laminations are generally planar and on a millimetric scale, with slight variations from lighter to darker colour. The paler laminae may be slightly coarser grained and contain more quartz and feldspar, whereas the darker laminae are finer grained and more carbonaceous. Small flakes of muscovite can be seen on the bedding planes. Staining of the section offcut with sodium cobaltinitrite indicated that minor K-feldspar is present, mainly in the paler laminae. The sample is essentially non-magnetic, with susceptibility of $<20 \times 10^{-5}$ SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, relict sedimentary bedding laminations and detrital grain texture are well preserved. Planar bedding laminations are on a scale of ~0.2 mm to 3 mm in thickness, with variations in grain size and in the relative proportion of detrital quartz and muscovite grains, and also in the proportion of dark carbonaceous pigmentation. There is a range from shale laminae (grain size typically <0.05 mm) to siltstone laminae (detrital grain size up to 0.3 mm) with some laminae showing slight grading of grains. Detrital grains are angular to sub-rounded and are dominated by quartz and muscovite, with minor fine grained lithics (sericite-rich), K-feldspar, chlorite and traces of biotite, leucoxene and tourmaline. Quartz is more abundant in the silty laminae and muscovite in the shaly laminae. Interstitial to the detrital grains is a fine grained matrix dominated by chlorite, with minor sericite, quartz, carbonaceous material and a trace of pyrite. The carbonaceous material is probably a graphitic substance and tends to be more abundant in the shaly laminae. The characteristics of the rock indicate that it is a laminated carbonaceous shale-siltstone.

b) Alteration and structure: The rock has undergone low grade alteration, probably as a result of incipient metamorphism. It has also been weakly deformed, with a slight preferred orientation of detrital muscovite grains that is parallel with the bedding laminations. Matrix material may have initially been clayey and has been replaced by chlorite, with minor sericite and quartz. Former organic material has been matured into a graphitic substance and there is a trace of pyrite.

c) Mineralogy and paragenesis: The rock contains traces of finely disseminated pyrite up to 0.05 mm across as part of the alteration assemblage.

Mineral Mode: Approximate modal proportions are: muscovite + sericite 35%, quartz 30%, chlorite 25%, K-feldspar 7%, carbonaceous material 2% and traces of biotite, leucoxene, tourmaline and pyrite.

Interpretation and Comments: It is interpreted that the sample is a well laminated carbonaceous shale-siltstone. The rock contains detrital grains of quartz and muscovite, with minor lithics and K-feldspar in a fine grained matrix of chlorite, with minor sericite, quartz and carbonaceous material. The latter might represent former organic material, subsequently matured into a graphite-like substance. It is locally accompanied by traces of fine grained pyrite. The rock may have undergone very low grade metamorphism and the mica flakes display a weak preferred orientation.

378167 TS

Summary: Strongly altered medium to coarse grained lithic-crystal felsic tuff. The rock contains tightly packed lithic grains (mostly altered pumice) and altered plagioclase grains, with minor quartz, in a finer grained pumiceous matrix. There has been replacement of the igneous material by albite, quartz, chlorite, K-feldspar, sericite and traces of leucoxene and pyrite, with the alteration assemblage being of propylitic type. There is no textural evidence for the rock to represent reworked volcanoclastic material (i.e. being an epiclastic sandstone).

Handspecimen: The sample is composed of a massive, grey, medium to coarse grained tuff or epiclastic sandstone. It contains tightly packed lithic grains up to 4 mm across as well as abundant smaller grains of feldspar. The rock may have undergone moderate chlorite alteration. Staining of the section offcut with sodium cobaltinitrite indicated that a moderate amount of K-feldspar is present. The sample is essentially non-magnetic, with susceptibility of $<20 \times 10^{-5}$ SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, it is apparent from moderately well preserved relict texture that the rock is most likely a lithic crystal felsic tuff of felsic composition. There is little textural evidence of reworking to form an epiclastic sandstone. There are abundant lithic fragments up to 3 mm across and also abundant altered plagioclase grains up to 2 mm across, along with less common quartz grains up to 0.8 mm across and rare grains of muscovite and altered FeTi oxide. Most lithics represent former pumice fragments, with relict frothy and flow-foliated textures. There are one or two lithic fragments that represent altered fine grained porphyritic volcanic rock (plagioclase phenocrysts in fine grained groundmass) as well as rare lithics composed of fine grained (muscovite) quartzite. In-between the lithic and crystal components there is a minor matrix component, composed of finer grained pumiceous material, including tiny altered glass shard fragments. The relict textures suggest that the fragments are very largely of volcanic origin, but that there is a small proportion of metamorphic (?basement) fragments (e.g. quartzite and rare muscovite grains).

b) Alteration and structure: There has been pervasive strong alteration, maybe due to very low grade metamorphism and/or hydrothermal processes. Plagioclase grains have been replaced by albite and subsequently, abundant sericite. All volcanic lithic fragments have been replaced, mainly by fine grained assemblages of albite, chlorite, K-feldspar, quartz and trace leucoxene and pyrite. Rare porphyritic volcanic fragments show replacement of groundmass material by chlorite. Former igneous FeTi oxide grains have been replaced by leucoxene. The alteration assemblage is considered to be of propylitic type. Later, there has been incipient weathering, leading to local slight goethite staining.

c) Mineralogy and paragenesis: The rock contains a few aggregates of disseminated pyrite up to 0.4 mm across as part of the alteration assemblage.

Mineral Mode: Approximate modal proportions are: plagioclase (albite) 40%, chlorite 23%, quartz 20%, K-feldspar 10%, muscovite + sericite 6% and traces of leucoxene, pyrite and goethite.

Interpretation and Comments: It is interpreted that the sample represents a former medium to coarse grained lithic-crystal felsic tuff. The rock originally contained tightly packed lithic grains (mostly altered pumice) and altered plagioclase grains, with minor quartz, in a finer grained pumiceous matrix. Strong propylitic alteration has led to replacement of the igneous material by albite, quartz, chlorite, K-feldspar, sericite and traces of leucoxene and pyrite. There is no textural evidence for the rock to represent reworked volcanoclastic material (i.e. being an epiclastic sandstone).

378173 **TS**

Summary: Coarse grained felsic pyroclastic rock, probably representing a lithic-dominated type, with a small crystal component. There is no textural evidence for the components of the rock to have been substantially reworked so as to form an epiclastic sandstone. The dominant lithic fragments are altered pumiceous material and the small amount of matrix is also pumiceous, with altered glass shard fragments. Individual mineral grains are represented by a few relict volcanic quartz and altered plagioclase and ferromagnesian grains. The rock has undergone strong, pervasive alteration to an assemblage dominated by albite, quartz and sericite, with minor chlorite and carbonate, plus traces of leucoxene and pyrite. The assemblage is of propylitic type and may have formed by very low grade metamorphism (e.g. attending the formation of a weak foliation) and/or due to fluid interaction.

Handspecimen: The sample is composed of a weakly foliated, pale yellowish-grey, strongly altered medium to coarse grained felsic pyroclastic or epiclastic rock. It has a vaguely preserved fragmental texture and contains a few small relict quartz grains. The rock appears to have undergone sericite-quartz alteration, with possible formation of a few small carbonate aggregates. Testing of the section offcut with sodium cobaltinitrite did not reveal the presence of K-feldspar. The sample is essentially non-magnetic, with susceptibility of $<10 \times 10^{-5}$ SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, moderately preserved relict texture implies that the rock is a type of rather coarse grained pyroclastic of felsic volcanic composition. There are abundant, tightly packed, angular to irregular volcanic lithic fragments up to 5 mm across, with a small population of individual mineral grains and rare altered fine grained sedimentary lithic grains (e.g. siltstone). The volcanic lithic fragments are composed of pumiceous material (preserving flow foliation, elongate bubble textures) and there is a small amount of matrix material that is dominated by small, altered pumiceous fragments including altered glass shards. Individual mineral grains are dominated by volcanic-derived quartz grains up to 1 mm across (former phenocrysts) along with a few altered plagioclase and ferromagnesian grains also up to 1 mm across, and a trace of FeTi oxide. The tightly packed lithics exhibit a weak foliation due to alignment of elongate fragments. There is no diagnostic evidence for the components of the rock to have undergone sedimentary transport and deposition, i.e. there is little to indicate that the rock represents an epiclastic sandstone.

b) Alteration and structure: The interpreted pyroclastic rock has undergone strong and pervasive alteration, with almost complete recrystallisation (except for relict quartz grains). The dominant volcanic lithic and matrix material has been replaced by fine grained albite and quartz, with subordinate amounts of sericite, minor chlorite and carbonate and traces of leucoxene and pyrite. However, some volcanic fragments have been replaced more strongly by sericite or by chlorite, and in places there are a few carbonate porphyroblasts up to 2 mm across. Uncommon plagioclase grains have been replaced by albite, ferromagnesian grains by carbonate \pm chlorite, and FeTi oxide by leucoxene. Weak deformation effects may have been imposed during or after alteration, as alteration-derived sericite locally displays a weak foliation. The alteration assemblage is considered to be of propylitic type and it was later affected by slight weathering, leading to a small amount of goethite forming by alteration of carbonate (presumably Fe-bearing) and pyrite.

c) Mineragraphy and paragenesis: The sample contains traces of pyrite as part of the alteration assemblage. Largest grains are up to 0.1 mm across.

Mineral Mode: Approximate modal proportions are: plagioclase (albite) 40%, quartz 35%, sericite 14%, chlorite and carbonate each 5% and traces of leucoxene, pyrite and goethite.

Interpretation and Comments: It is interpreted that the sample represents a coarse grained felsic pyroclastic rock. It is lithic-dominated, with a small crystal component. There is no diagnostic textural evidence for the components of the rock to have been substantially reworked so as to form an epiclastic sandstone. The dominant lithic fragments are altered pumiceous material and the small amount of matrix is also pumiceous, with altered glass shard fragments. Individual mineral grains are represented by a few relict volcanic quartz and altered plagioclase and ferromagnesian grains. The rock has undergone strong, pervasive alteration to an assemblage dominated by albite, quartz and sericite, with minor chlorite and carbonate, plus traces of leucoxene and pyrite. The assemblage is of propylitic type and may have formed by very low grade metamorphism (e.g. attending the formation of a weak foliation) and/or due to fluid interaction.

378174 TS

Summary: Altered porphyritic quartz micromonzodiorite, with moderately well preserved texture showing abundant plagioclase phenocrysts, a few quartz phenocrysts and glomeroporphyritic aggregates (originally with plagioclase \pm ferromagnesian material \pm quartz \pm FeTi oxide) in a fine to medium grained groundmass of plagioclase, altered ferromagnesian material, interstitial K-feldspar and quartz, and disseminated FeTi oxide. There is no textural evidence to indicate that the rock represents a clastic sedimentary type, e.g. epiclastic sandstone. There has been pervasive strong alteration of propylitic type imposed, with replacement of some of the igneous phases by albite, plus subordinate chlorite and minor sericite, carbonate and hematite. Later weathering effects have caused the development of scattered goethite aggregates.

Handspecimen: The sample is composed of a massive, medium grained, apparently porphyritic intermediate igneous rock. It is speckled dark brown-pink to green-grey in colour, with abundant feldspar and altered ferromagnesian material. Staining of the section offcut with sodium cobaltinitrite indicated that there is a moderate amount of K-feldspar present. Alteration of the rock has led to chloritisation of ferromagnesian material, with subsequent weathering having caused the formation of scattered small goethite aggregates. The sample is moderately magnetic, with susceptibility up to 240×10^{-5} SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, relict porphyritic (igneous) texture is moderately well preserved. There is no textural evidence for the rock to represent a clastic sedimentary type, e.g. an epiclastic sandstone. The rock contains abundant pseudomorphs after former tabular to blocky plagioclase phenocrysts up to 3 mm across, as well as rare quartz phenocrysts up to 1.5 mm across, enclosed in a fine to medium grained, holocrystalline groundmass consisting of abundant plagioclase, altered ferromagnesian material, interstitial K-feldspar and quartz, disseminated FeTi oxide (e.g. titanomagnetite) and a trace of apatite. The sample also contains a few glomeroporphyritic aggregates up to 5 mm across (micro-enclaves) that contained medium to coarse grained plagioclase \pm ferromagnesian material \pm quartz \pm FeTi oxide. The relict texture and interpreted primary mineralogy of the sample imply that it represents an altered porphyritic quartz micromonzodiorite, likely to have been emplaced as a shallow intrusive.

b) Alteration and structure: The rock has sustained strong pervasive alteration of propylitic type, maybe as a result of very low grade metamorphism and/or interaction with fluids such as heated seawater. All plagioclase has been replaced by albite, with further minor flecking by chlorite, sericite and carbonate. Groundmass K-feldspar is slightly altered to chlorite and sericite. All ferromagnesian material has been altered, mostly to chlorite, although some patches are largely replaced by sericite. A little carbonate and traces of leucoxene and hematite also occur at altered ferromagnesian sites. Igneous FeTi oxide has been partly replaced by hematite \pm leucoxene. The sample has been affected by later imposed weathering effects, causing much of the alteration-derived carbonate (presumably Fe-bearing) to have been replaced by goethite.

c) Mineralogy and paragenesis: No sulphides have been observed. The sample contains traces of relict igneous FeTi oxide (titanomagnetite).

Mineral Mode: Approximate modal proportions are: plagioclase (albite) 60%, chlorite 12%, quartz and K-feldspar 10%, sericite 3%, goethite 2%, carbonate and hematite each 1% and traces of FeTi oxide, leucoxene and apatite.

Interpretation and Comments: It is interpreted that the sample represents an altered porphyritic quartz micromonzodiorite, probably emplaced as a shallow intrusive. There is no textural evidence for the rock having had a clastic sedimentary origin and that it represents an epiclastic sandstone. The rock has abundant altered plagioclase phenocrysts, a few quartz

phenocrysts and glomeroporphyritic aggregates (originally with plagioclase \pm ferromagnesian material \pm quartz \pm FeTi oxide) in a fine to medium grained groundmass of plagioclase, altered ferromagnesian material, interstitial K-feldspar and quartz, and disseminated FeTi oxide. There has been pervasive strong alteration of propylitic type imposed, with replacement of some of the igneous phases by albite, plus subordinate chlorite and minor sericite, carbonate and hematite. Later weathering effects have caused the development of scattered goethite aggregates.

378189 TS

Summary: Coarse grained lithic sandstone, grading to conglomerate (or could be termed a sedimentary breccia), with abundant fine grained sedimentary lithic clasts (finely recrystallised chert and siliceous argillite), cemented by fine grained hematite and minor fine to medium grained crystalline quartz. There is no evidence that the hematite has replaced former pyrite or Fe-bearing carbonate. Subsequent to hematite deposition, there has been minor veining by carbonate. The sample differs from 378109 in the fact that it contains less diversity in lithic grains, has essentially no individual detrital mineral grains and has abundant hematite cement.

Handspecimen: The sample is composed of a dark red-brown, hematite cemented coarse grained sandstone, grading to conglomerate. There are scattered angular to sub-rounded clasts up to 1.5 cm across, plus many smaller grains (typically <5 mm across) of pale brown to dark red-brown fine grained cherty or siliceous argillite composition, enclosed in a fine grained matrix of hematite. The rock is relatively massive, but very inequigranular and displays no bedding laminations. Testing of the section offcut with sodium cobaltinitrite did not reveal the presence of K-feldspar. The sample is very weakly magnetic, with susceptibility up to 30×10^{-5} SI units.

Petrographic Section:

a) Primary mineralogy and textures: In the section, it is evident that the rock is a coarse sedimentary clastic type, with rather tightly packed angular to sub-rounded clasts up to 1.5 cm across, although most clasts are <5 mm across. Most clasts are composed of massive, fine grained, recrystallised chert (i.e. dominated by finely recrystallised, relatively equigranular quartz), but a minority of clasts are composed of weakly laminated and/or foliated siliceous argillite. The latter have fine grained detrital grain texture and contain a minor amount of sericite; one or two also contain tiny recrystallised radiolarians. In-between the clasts, there is very little matrix (maybe some fine grained clasts), but there is about 20-30 volume % of cement. The latter is dominated by fine grained hematite, with later infilling by fine to medium grained crystalline quartz. The rock is interpreted to be a hematite-cemented and impregnated coarse grained lithic sandstone, grading to conglomerate. It could also be termed a sedimentary breccia. The clasts are entirely composed of fine grained sedimentary material.

b) Alteration and structure: The rock has undergone probable diagenetic cementation under oxidising conditions. Fine grained hematite has partly infilled between clasts and also impregnated and partly replaced many clasts. Later infilling between clasts has been by fine to medium grained crystalline quartz. There is no evidence that the hematite formed by weathering (e.g. of former interstitial pyrite or Fe-bearing carbonate). Subsequently, there has been emplacement of a few anastomosing veins of carbonate up to 0.3 mm across, that cut across hematite aggregates.

c) Mineragraphy and paragenesis: No sulphides have been observed in the sample. There is abundant fine grained hematite as cement and impregnation of lithic clasts.

Mineral Mode: Approximate modal proportions are: quartz 80%, hematite 15%, sericite and carbonate each 1%.

Interpretation and Comments: It is interpreted that the sample is a coarse grained lithic sandstone, grading to conglomerate (or could be termed a sedimentary breccia), with abundant fine grained sedimentary lithic clasts (finely recrystallised chert and siliceous argillite), cemented by fine grained hematite and minor fine to medium grained crystalline quartz. There is no evidence that the hematite has replaced former pyrite or Fe-bearing carbonate. Subsequent to hematite deposition, there has been minor veining by carbonate. The sample may have vague similarities with sample 378109, but differs in containing much less diversity in lithic grains and having essentially no individual detrital mineral grains (e.g.

378109 contains significant detrital quartz grains). Likewise, 378109 does not contain nearly as much hematite.