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Summary of the Intrusive Lithostratigraphy and Geochronology of the Cupriferous Retreat Batholith, Clermont, Queensland

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Abstract

The Clermont district of Queensland is well-known for historical small-scale copper and gold mining. The Neoproterozoic-Cambrian Anakie Metamorphic Group contain zones of lower greenschist facies metabasite hosting possible VMS copper shows together with limited outcrops of related ultramafic rocks with Ni/Pt/Pd possibilities. The Anakie Metamorphic Group is intruded by the predominantly granodioritic, monzonitic and gabbroic assemblage of the Middle-to-Late Devonian Retreat Batholith. In the study area these intrusive rocks display sporadic, fracture-hosted shows of malachite and azurite with associated “green-rock” alteration along a 14km strike length between the Rosevale and Consols-Savannah areas.

Between 2013 and 2015 Diatreme Resources Ltd, in a joint venture with Antofagasta PLC, carried out a detailed exploration programme involving 1:2000 and 1:5000 geological mapping supported by a limited petrological study, detailed study of approximately 14km of legacy and new diamond drill-core, RC and RAB drilling and geochronological studies along the cupriferous zone within the Retreat Batholith. This project not only has enabled a clear understanding of the timing of intrusion and mineralisation but has also given an indication of the possible sub-surface source for the mineralisation at the Rosevale prospect in this lithostratigraphically complex region. This project consolidated prior regional campaigns of investigations of soil geochemistry, geophysics, prior cored diamond and RC drilling and limited geological mapping by Diatreme Resources and precursor companies.

Introduction

The Clermont district of Queensland is well-known for historical small-scale copper and gold mining across a wide region and in variable settings ranging in age Neoproterozoic-Cambrian to Late Devonian and in style from VMS to intrusive-related deposits (see Withnall 1995; Withnall *et al.* 1995; Lam 2005).

The polydeformed (Wood 2006) basement rocks of the region, the Neoproterozoic-Cambrian (Fergusson *et al.* 2001) Anakie Metamorphic Group, contain zones of lower greenschist facies metabasite (Withnall *et al*. 1995) hosting possible VMS copper shows together with limited outcrops of related ultramafic rocks with Ni/Pt/Pd possibilities; the locally major historic VMS-style copper mine (Peak Downs or South Copperfield Mine) occurs in these rocks 9km south of Clermont (Figure 1). Nearby there occur historic shows of alluvial gold (Palm Trees area; Figure 1) thought derived from fault-controlled reefs in the underlying metamorphic basement rocks.

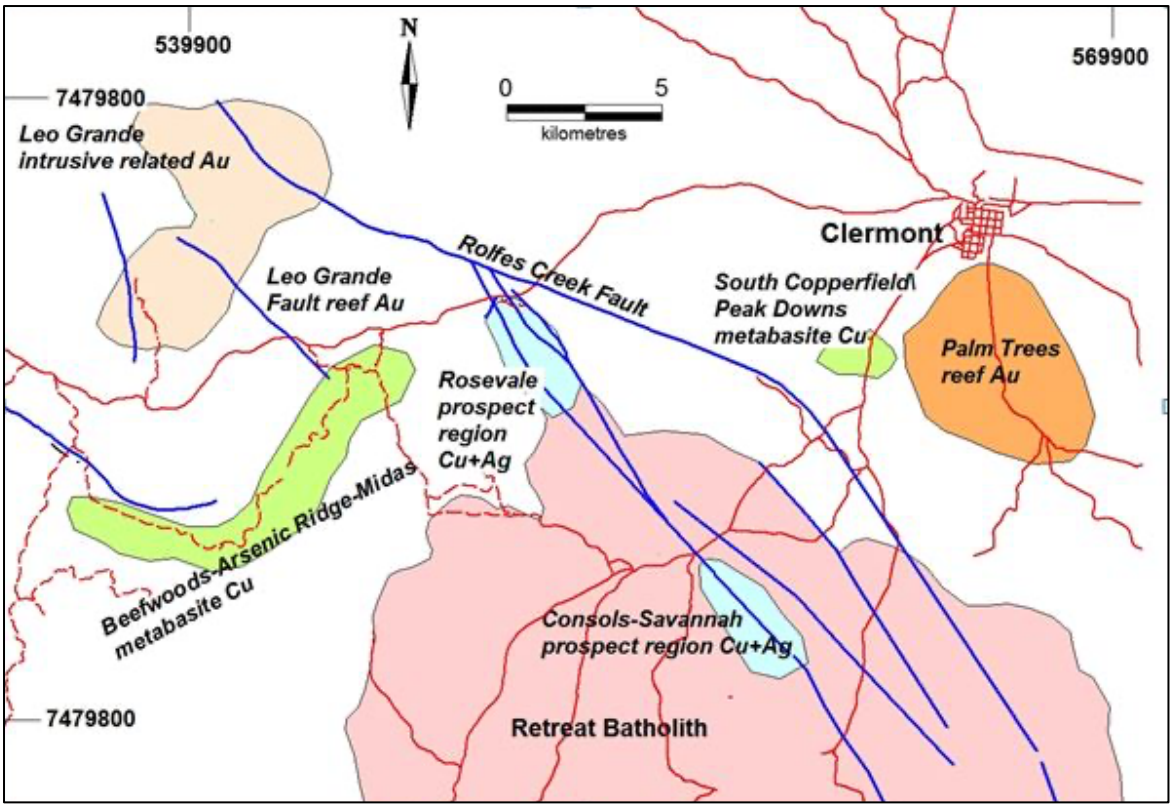

Figure 1. Summary sketch map showing mineralised areas, Clermont district, and types of mineralisation. Solid red lines, roads; broken red lines, tracks; blue faults. Retreat Batholith, solid pink; prospect areas in Retreat Batholith, light blue.

The Anakie Metamorphic Group is intruded by the predominantly granodioritic, monzonitic and gabbroic assemblage of the Middle-to-Late Devonian Retreat Batholith (Withnall *et al*. 1995). In the study area these intrusive rocks display sporadic, fracture-hosted shows of malachite and azurite along a 14km strike length between the Rosevale and Consols-Savannah areas (Figure 1). This cupriferous zone hosts both sericitic ± chlorite ± epidote alteration and, in the south around the Iron Hut Quartz Monzonite (Consols-Savannah prospect area), epidote+chlorite ("green rock") alteration (Figure 2). In addition, small, historically mined, fault-controlled Cu-Zn deposits are located in the Anakie Metamorphic Group adjacent to the batholith (West Copperfield; Figure 2) and in the rhyolitic Devonian Theresa Creek Volcanics (Consols, Savannah; Figure 2) within the boundaries of the batholith.

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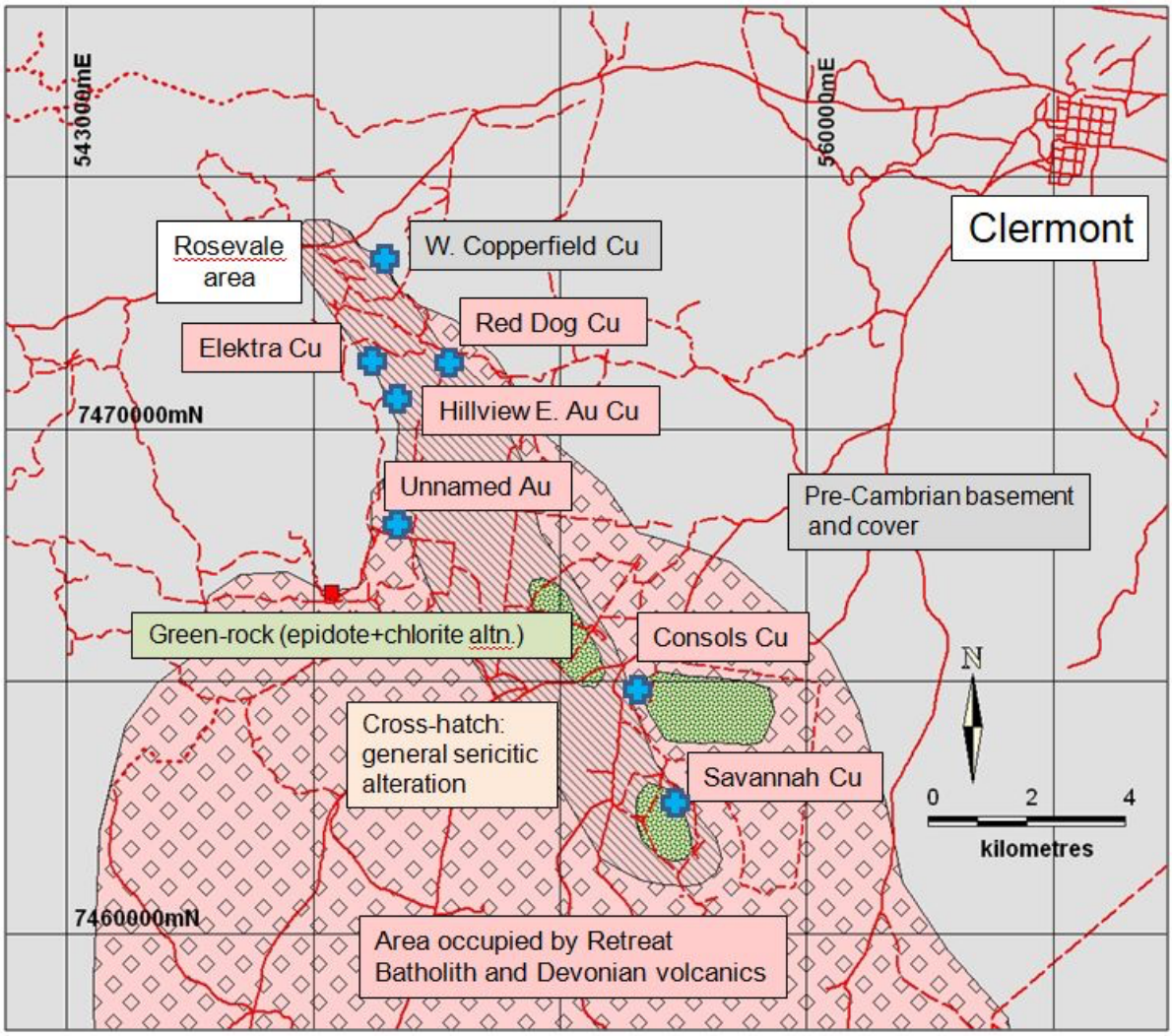

Figure 2. Summary geological sketch map, study region, to show main prospects (blue crosses) and general alteration in Retreat Batholith. Solid red lines, roads; broken red lines, tracks.

Intrusive Lithostratigraphy

The intrusive lithostratigraphy was determined from detailed mapping, re-logging of legacy drill-core, additional diamond drilling and geochronological dating. The intrusive lithostratigraphy is described in Table 1, the summary of geochronological studies in Table 2, and the lithostratigraphic relationships are shown in the geological map of the Rosevale area (Figure 3) and also in the rock-relationship diagram (Figure 4).

Geochronology

Geochronological dating involved U-Pb dating of zircons by the LAICMPS method, SHRIMP U-PB dating of zircons and Re-Os dating of molybdenite which, during the lengthy and intermittent period of exploration, involved four laboratories and the geochronologists acknowledged in Table 2.

Os-Re dating of molybdenite grains proved a key element in dating mineralisation and for indicating the probable source of the mineralisation. Two samples of molybdenite were selected for dating.

Table 1. Lithostratigraphy, northern Retreat Batholith, Rosevale-Savannah prospects region west of Clermont. Unit codes and names are informal with exception of Theresa Creek Volcanics and Silver Hills Volcanics.

UNIT NAME	MAP CODE	AGE	LITHOLOGY	ALTERATION / MINERLISATION	RELATIONSHIP TO OTHER UNITS
Coarsely porphyritic quartz monzonite	SDcm	Devonian	Coarsely porphyritic quartz biotite-hornblende monzonite with coarse red K-feldspar phenocrysts and smaller plagioclase phenocrysts in variably fine to medium grained groundmass.	Sericite-silica-chlorite-haematite variable; magnetite with chlorite in some hornblendes after pyroxenes; pyrite and chalcopyrite with chlorite in other hornblendes. Hosts pyrite, chalcopyrite, bornite and very minor molybdenite in the groundmass as fine intergranular grains and veins.	Intruded by Drrh, Dgd, Ddi and Dda; intrudes Anakie Metamorphic Group.
Dolerite	SDdo	Devonian	Equigranular biotite-bearing dolerite.	Pyroxenes altered to hornblende and chlorite where subsequent alteration occurs; hornblendes may host haematite or pyrite and/or chalcopyrite; in RDD006 haematite alteration of plagioclases, associated with epidote ± calcite veining may colour the rock red.	Intrudes Unit SDcm; intruded by Round Hill rhyolite and dacitic dyke (Unit Dda).
Pink granite	Dgi	Devonian. Pink granitic microdyke containing Mo dated by Re-Os dating as 375 ± 3.0 Ma	Medium grained non-porphyritic K-feldspar + quartz granite with aplitic chilled margin in the east. Outcrop area restricted.	Surface exposures of dyke and microdykes in core contain chalcopyrite in what appear to miarolitic cavities. 1 microdyke contains Mo dated at 375 ± 3 Ma. Similar microdykes dykes carrying Cu and Mo, together with possible yellow sphalerite, cut sericitically altered plagioclases in Unit SDcm.	Intrudes Anakie Metamorphic Group and possibly Unit SDcm; thin microdykes carrying chalcopyrite and rare molybdenite intrude Unit SDcm; thin K-feldspar +quartz dykes carrying chalcopyrite intrude Unit Ddo. Intrudes Units SDcm and SDdo both as dykes and microdykes.
Dacite dykes	Dda	Devonian. SHRIMP age 383 ± 3.3 Ma	Brown-pink fine to glassy plagioclase ± hornblende-phyric dacite dyke; commonly magnetic.	Plagioclase phenocrysts are commonly sericitised; hornblendes may be pseudomorphed pyroxene and are commonly chloritised.	Identical rock-type forms chilled margin of Unit Hillview granodiorite (Unit Ddi) dated at 380.5 ± 3 Ma.
Hillview granodiorite	Ddi	Devonian. SHRIMP age 380.5 ± 3.0 Ma and same as	Brown-pink diorite/quartz granodiorite/diorite with fine pink K-	Plagioclases may be sericitised; hornblendes which may pseudomorph pyroxene are	Intrudes Unit SDcm; may correlate with Unit Dda lithologically and geochronologically; both units

UNIT NAME	MAP CODE	AGE	LITHOLOGY	ALTERATION / MINERLISATION	RELATIONSHIP TO OTHER UNITS
		molybdenite age dated by Re-Os method	spar phenocrysts and hornblende; commonly weakly magnetic.	commonly ragged and chloritised. Carries fine Cu sulphide.	correlate geochronologically with Mo in pink granitic microdyke intruding SDcm (see following discussion).
Iron Hut Quartz Monzonite	Dgh	Devonian. U-Pb zircon age of 376 ± 4.0 Ma	Coarse to medium biotite-hornblende monzonite generally white but pink hydrothermal alteration noted in marginal areas.	Cut by epidote-bearing veins with narrow pink selvages; local pink alteration in marginal areas	Found adjacent to and south of Savannah and Consols prospects. Dated as synchronous or closely penecontemporaneous with molybdenite and, therefore, regional mineralisation. may have introduced Cu + Ag ± Mo ± Au mineralisation into the fracture-controlled Savannah and Consols prospects
Yellow rhyolite	Dry	? Devonian	Pale yellow weathering almost featureless rhyolite carrying no clasts or phenocrysts; gives rise to distinctive cream soil.	May show local strong haematitic alteration to a chocolate brown colour. may contain sericitic alteration. No mineralisation seen.	Forms what are best interpreted as intrusive rhyolite plugs although some of these units may be flows. Intrudes Unit SDcm (Red Dog 001/ RDD012); mapped outcrop pattern suggests intruded by Unit Ddi; may correlate with intrusive rhyolite Unit DCir.
Unassigned generally rhyolitic volcanics (not shown in Figure 3)	uDfv	? Devonian	Commonly glassy to devitrified rhyolitic and dacitic dykes, may show flow bands and rock and crystal fragments inc. HT quartz phenocrysts. Defined by float and subcrop as forming dykes		Inferred to be dykes of mineralised Round Hill rhyolite intruding Unit SDdo.
Theresa Creek Volcanics	Dt	Devonian, pre-363 Ma; at Consols, SHRIMP age of 388.9 ± 3.5 ma.	Widely variable range of dominantly pyroclastic rocks of rhyolitic, dacitic and andesitic composition. Crystal tuffs, lithic tuffs and crystal lithic tuffs.	Strong 5 sq km epidote alteration zone in Consols and surrounding region to east of Consols and Savannah prospects indicate important underlying hydrothermal system; base-metal sulphides in fractures at Consols. NW-trending epidote + silica alteration in fracture zone at Savannah prospect hosts Cu + Ag ± base metals ± Mo ± Au.	Overlain unconformably by 363 Ma Silver Hills Volcanics; west of Consols may overthrust Silver Hills Volcanics. Intruded by weakly mineralised dyke resembling Unit Ddi in epidote-alteration area of the Savannah prospect.

UNIT NAME	MAP CODE	AGE	LITHOLOGY	ALTERATION / MINERLISATION	RELATIONSHIP TO OTHER UNITS
Round Hill rhyolite	Drrh	? Devonian	Cream coloured rhyolite plug containing clasts of older rocks and carrying Cu, Zn, Pb and Ag sulphides; forms plug; displays autobrecciation	Sericitic alteration; mineralised (Cu, Zn, Pb, Ag).	Intrudes SDcm and Ddo; carries possible clasts of Ddi; may correlate with other rhyolitic units that themselves may correlate with Unit DCir mapped to the east by the Queensland Geological Survey.
Fine granodiorite	Ddg	Devonian. SHRIMP age 389.8 ± 3.1 ma.	White, fine, equigranular hornblende biotite granodiorite	Magnetite in hornblende; haematite staining around epidote vein as seen in Unit SDdo.	Intrudes SDcm; the lack of obvious alteration in hand specimen suggests that it is one of the youngest intrusive units, which conflicts with SHRIMP age. Chronostratigraphic correlate of Theresa Creek Volcanics.
Fine diorite. **(not shown in Figure 3)**	Ddf	? Devonian	Small area of outcrop of fine-grained equigranular diorite dyke with pink tinge to feldspars, weakly magnetic. Contains very sparse plagioclase phenocrysts.	Pink tinge to feldspars may be either haematite alteration, as in the adjacent SDcm, or possibly is K-feldspar. Plagioclases are weakly sericitised. Unknown if magnetite secondary or primary. Hornblendes chloritised.	Intrudes Unit SDcm and is central to a high Cu-in-soil anomaly. Is close to the fault-hosted malachite and azurite in the fracture zone near diamond drill-hole Elektra North 001 (RDD004). Correlation with other intrusives unknown.
Silver Hills Volcanics	DCsi	SHRIMP dating confirms a 363.9 ± 2.8 Ma age. Correlates elsewhere dated by SHRIMP U-Pb at between 357.4 ± 3.3 Ma and 343.7 ± 5.3 Ma (see Perkins *et al*.1995; Henderson *et al*.1998)	Heavily weathered and apparently poorly indurated rhyolitic pyroclastic rocks, commonly with quartz and feldspar phenocrysts and flattened glass shards; may weather red-brown and includes local deposits of volcaniclastic sandstone.	Not recognised	Unconformably overlies Theresa Creek Volcanics with inferred angular unconformity. Overlain unconformably by Permian beds.

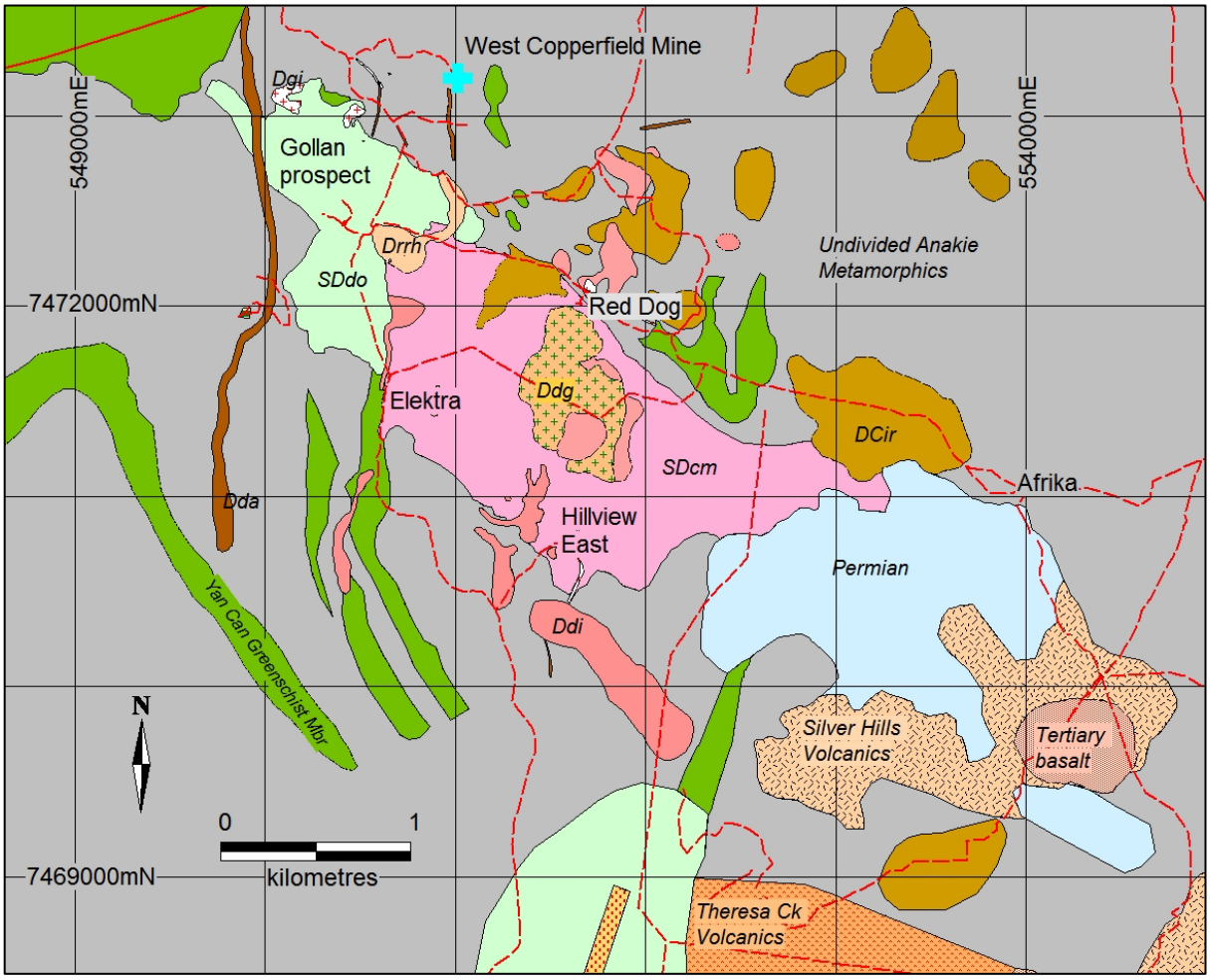

Figure 3. Solid geology of the Rosevale prospect region based on 1:2 000 mapping by author. Unit Drrh is the Round Hill rhyolite at Round Hill. Broken red lines are farm tracks. See Table 1 for explanation of rock-name codes (italicised text) and rock-type. Upright type, company names for local prospect area.

Molybdenite was found in a quartz-filled miarolitic cavity within a thin pink granitic microdyke in drill core into the regional coarse quartz monzonite unit, Unit SDcm (Table 1). This important sample yielded an age of 375 ± 3 Ma, some 20 - 30 million years younger than the preferred age of 405-395 Ma for the quartz monzonite (Unit SDcm; see below and Table 2). This dated granitic microdyke is similar in style to cupriferous microdykes found in thin sections (Figure 5) to intrude Unit SDdo, which has been dated at 410 - 400 Ma (Table 2) by the LAICPMS U-Pb method on zircon. This granitic microdyke is also to similar cupriferous and other molybdenite-bearing granitic microdykes intruding the slightly younger Unit SDcm (Table 2); and it is similar in petrographic composition to cupriferous granite dykes (Unit Dgi; Figure 3 and Table 1) found on the surface to intrude both Unit SDdo and Unit SDcm.

The second sample of molybdenite dated came from a fracture within a chlorite-altered zone in Unit SDcm (Figure 5) and adjacent to a 2cm-thick quartz vein containing chalcopyrite. Post-mineralisation oblique strike-slip movement on this fracture is indicated by slickenlines across the molybdenite coating of the fracture; the age obtained for the molybdenite is 380 ± 3 Ma (Table 2).

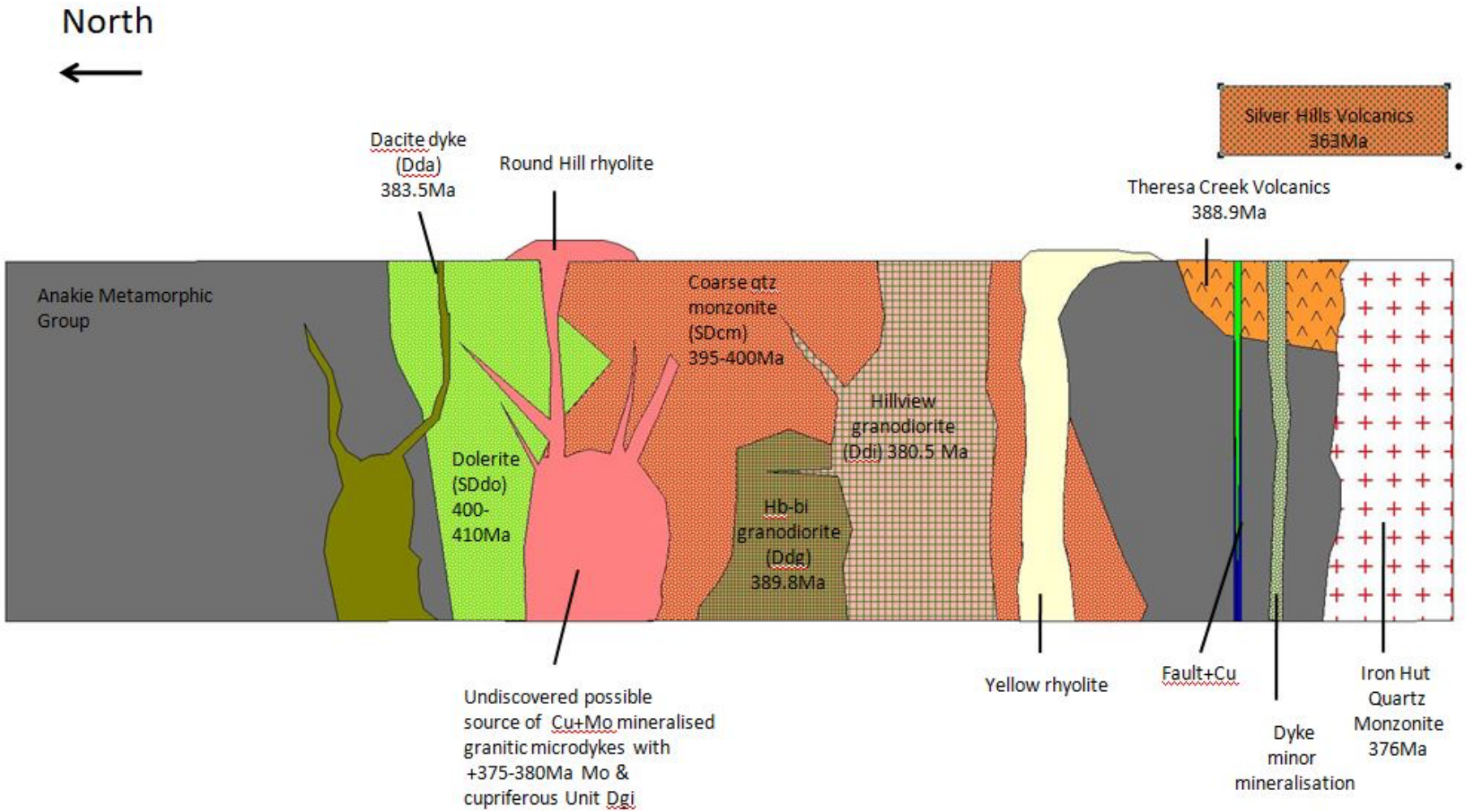

Figure 4. Diagrammatic north south rock relationship diagram of pre-Permian units, northern part of Retreat Batholith. Iron Hut Quartz Monzonite is in the south.

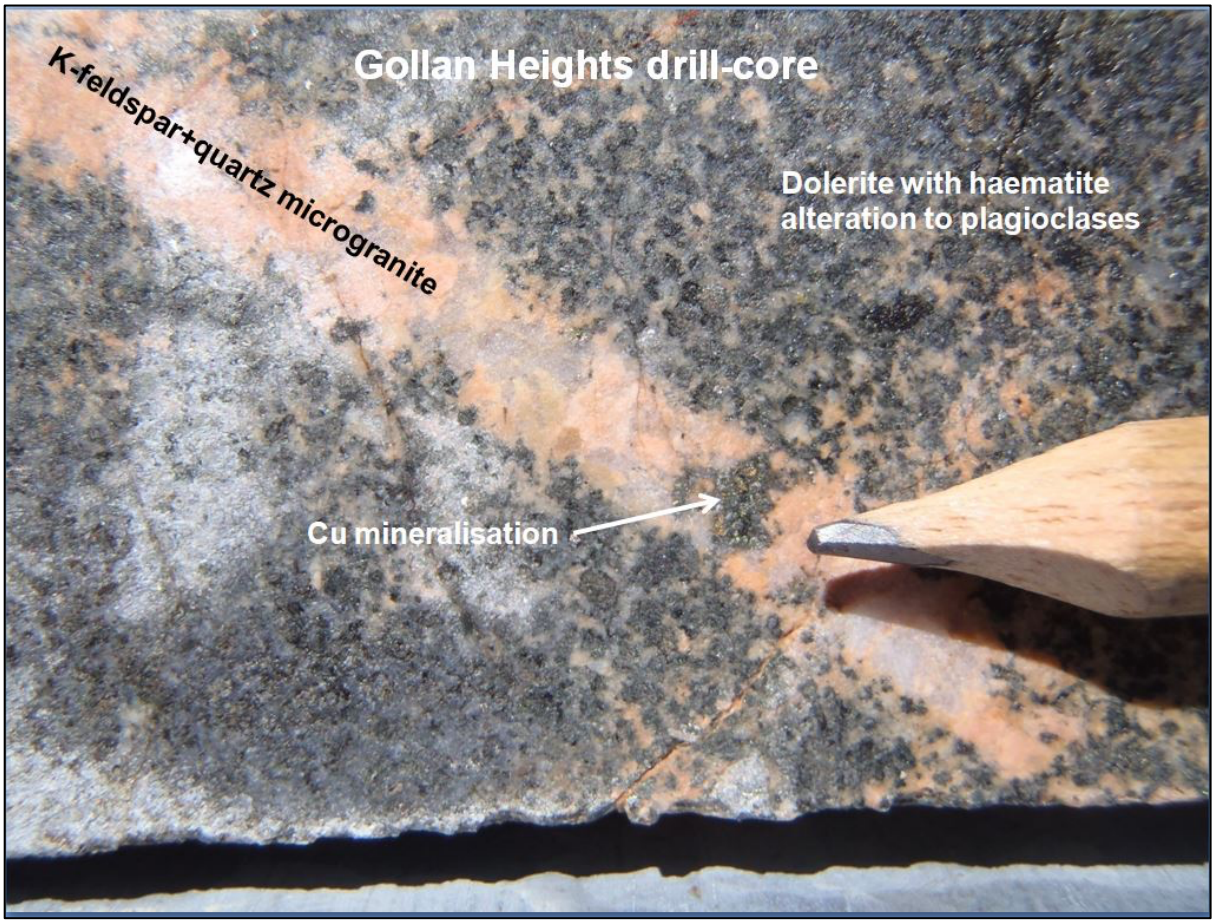

Figure 5. Cupriferous granitic microdyke in haematite-altered dolerite, Unit SDo.

Generally in unit SDcm, primary hornblendes are altered to chlorite and primary biotite grains altered variably to chlorite. Epidote ± chlorite alteration and bleaching occur around some fractures, the alteration diminishing away from such fractures. In other sections of drill-core the otherwise commonly light-pink K-feldspars show a brick-red colour (e.g. Figure 6) and the plagioclases may be rimmed with red, indicating haematitic alteration. In these samples the primary biotite appears unaltered to the eye. Hydrothermal brecciation in hand specimen scale, with attendant chlorite + quartz ± iron oxide (presumably derived from pyrite) alteration is known in some drill-core from Unit SDcm; chlorite veining with arsenopyrite and pyrite is common. Additionally, quartz ± chlorite veins, calcite ± epidote veins and very late, fine calcite-filled tension fractures are also common. No veins carrying biotite or adularia were recognised in this unit, which is clearly a passive host and not the progenitor for the introduced mineralisation.

Dating (LAICPMS U-Pb, zircon) of Unit SDcm, SDdo and from a dacitic dyke (Unit Dda) had been carried out before the present project and had included three samples of SDcm showing varying styles of alteration (Figure 7 and Table 2).

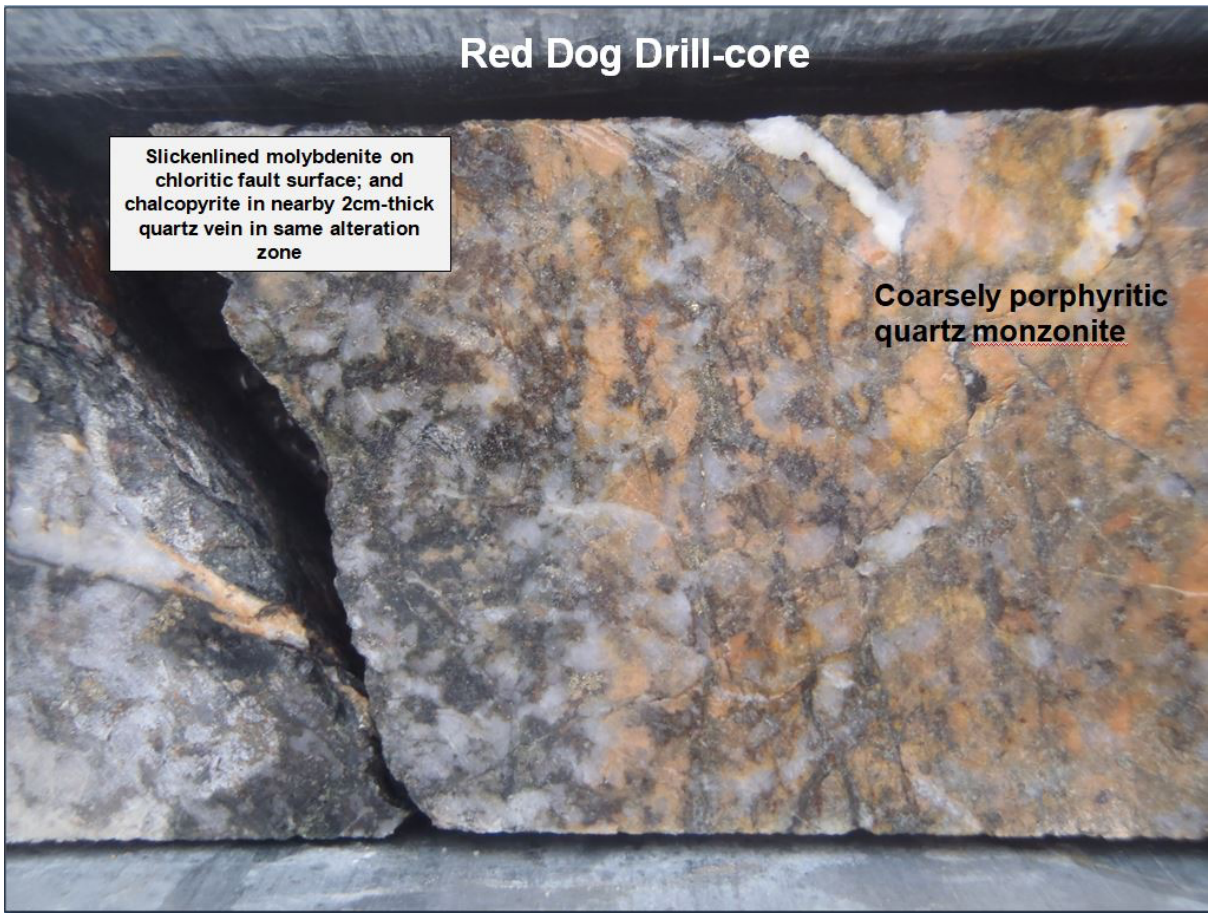

Figure 6. Chloritic alteration zone carrying molybdenite on fracture surface in otherwise haematite altered. Unit Dcm (coarse quartz monzonite). Core size NQ.

The samples of SDcm dated from drill-core are shown in Figure 7 with the bar-charts showing the range of ages determined. The least altered sample (Sample 01) shows zircon maxima spanning the range 395-405 Ma; sample 06, which shows clearly the haematitic alteration, has a sharp high peak at 400 Ma and also 9 zircons scattered in the range 405-445 Ma, perhaps indicative of relative enhancement of radiogenic lead. The bleached, epidote-altered Sample 04 shows a scatter of ages from 395 Ma to 345 Ma with a peak at 380 Ma, indicating variable lead loss due hydrothermal activity. Samples 01 and 06 are taken as indicating igneous closure of the zircon system at 395-405 Ma; it is interesting to note that the peak result for zircons from the epidote-altered sample 04 gives an age reasonably coincident with the molybdenite ages of 375-380 Ma and that epidote alteration together with secondary calcite and galena are evident in the locally epidotised drill core from Unit SDcm at Round Hill.

In the southern, the Consols-Savannah, part of region (Figure 2), a large pluton known as the Iron Hut Quartz Monzonite intrudes the rhyolitic-rhyodacitic volcanics of the Theresa Creek Volcanics. According to the orientation of flow-banding in some outcrops the Theresa Creek Volcanics dip steeply. These rocks show epidote + chlorite + haematite alteration around the broad contact region with the pluton; the alteration occurs both within the groundmass, commonly affecting plagioclase phenocrysts, and also on joint faces further suggesting deformation before intrusion of the monzonite. LAICPMS U-Pb dating of zircons from fresh monzonite of the Iron Hut Quartz Monzonite gave a good age of 376 ± 4 Ma, which clearly coincides with the age of the molybdenite from further north and, by association, the Cu and other mineralisation.

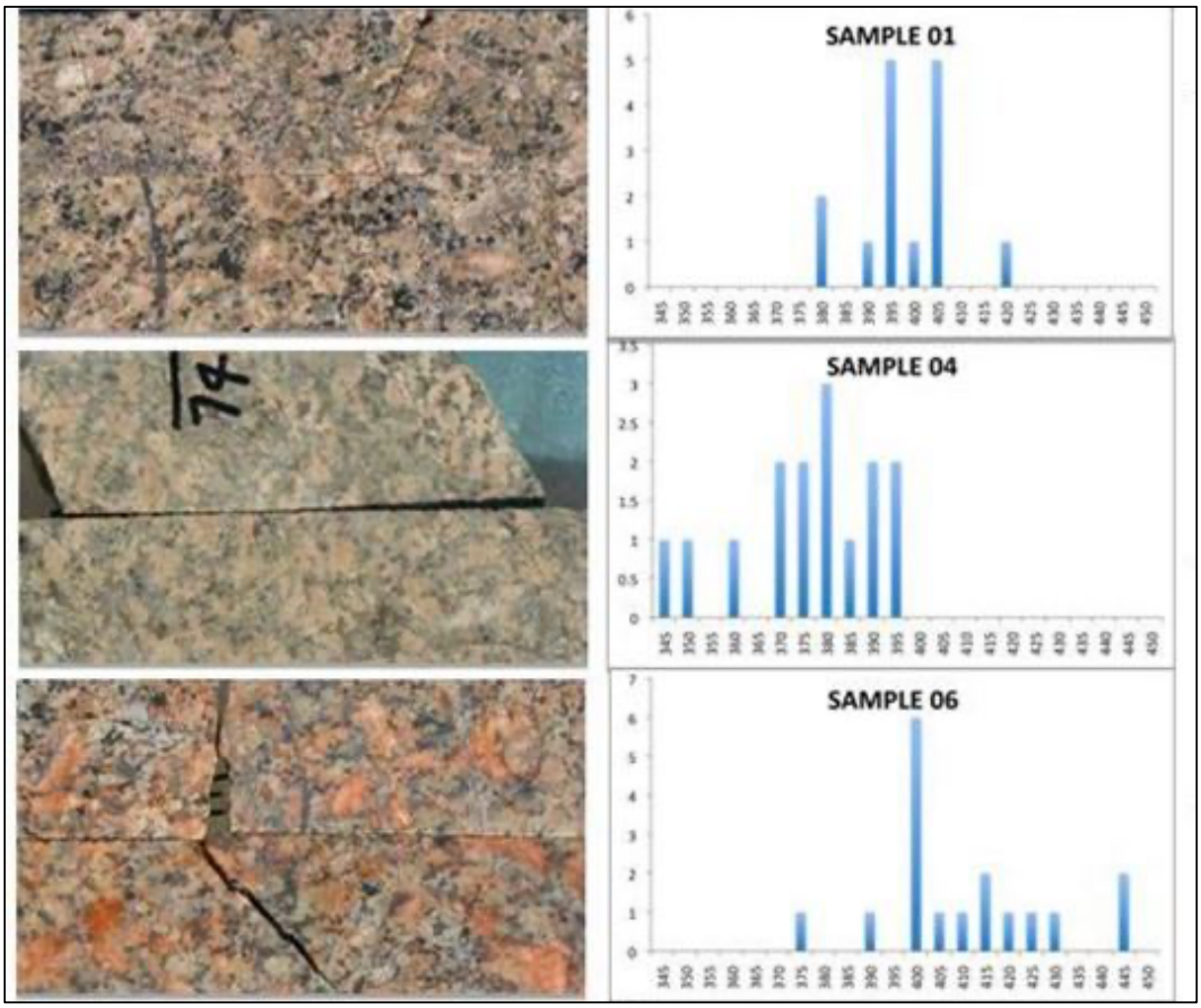

Figure 7. Dated samples from Unit SDcm. Top; sample 01 showing generally unaltered Unit SDcm (inspection by eye). Middle; sample 04, epidote-alteration in plagioclases and bleaching. Bottom; sample 06 showing haematitic alteration. Core size NQ.

Additional dating by the SHRIMP U-Pb method was carried out on Unit Dda (dacitic intrusive), Unit Ddi (Hillview granodiorite; informal company name), Unit Dgd (hornblende granodiorite) and on the Theresa Creek and unconformably overlying the Silver Hills Volcanics. The age of the Hillview granodiorite lies within the age-range of molybdenite mineralisation and the age of Unit Dda is close to this age-range. Unit Dgd and the Theresa Hills Volcanics have matching ages of 389 Ma (Table 2) and, geochronologically, are co-magmatic. The Silver Hills Volcanics date at 363 Ma Table 2), further confirming the widespread distribution of this ignimbritic event across Queensland (see Henderson and Davis 1995).

One Proterozoic (1453 Ma; Table 2) zircon core was found in the Theresa Creek Volcanics and one Archaean (3171 Ma; Table 2) zircon core was found in Unit Dgd. Clearly, these units have sampled zircons from older rocks such as the Anakie Metamorphic Group in the basement. If derived from the Anakie Metamorphic Group, the 3171 Ma-old zircon would appear to be the oldest known from these rocks (Fergusson *et al.* 2001).

Towards a Paragenetic History of Mineralisation

Copper mineralisation is common in the pink granitic microdykes cutting Units SDdo and SDcm. Molybdenite occurs in identical microdykes in Unit SDcm, as well as in fractures within this unit. Chalcopyrite is noted as formed interstitially in both units SDcm and SDdo and is thought to be a late replacement mineral. Arsenopyrite and pyrite is common on chloritic fractures cutting these two units and may also fill small voids. Arsenopyrite and pyrite have been noted in quartz + calcite veins in Unit SDdo and in Unit SDcm chalcopyrite + pyrite is known in quartz veins related to narrow zones of strong, fracture-related chloritic alteration; one such zone (Figure 6) hosts molybdenite in a fracture.

The rhyolitic plug at Round Hill in the Rosevale prospect (Figure 3) area forms a small, important but undated outcrop cutting Unit SDcm from which rhyolitic dykes extend to intrude Unit SDdo. This Round Hill rhyolite (informal name) was drilled during the prior stages of exploration and hosts chalcopyrite, arsenopyrite, sphalerite, and galena with minor silver; similar assemblages, together with some gold, are known from the green-rock alteration zone southwest of the Savannah prospect where they occur in a narrow, silicified zone in the Theresa Creek Volcanics on the western side of the Iron Hut Quartz Monzonite and also in a nearby dyke correlated lithologically with the 380 Ma Hillview granodiorite.

In the drill-core of Round Hill rhyolite, galena occurs together with late, possibly post-sericitic, carbonate alteration; the same style of calcite alteration, together with epidotisation of plagioclases (as in the dated sample 04 from Unit SDcm (Figure 7)) occurs in an adjacent drill-core cutting the coarse quartz-monzonite of Unit SDcm (Figure 8). Chalcopyrite is noted in what may have been gas voids around basement clasts in the rhyolite. Sphalerite in the Round Hill rhyolite overgrows pyrite and arsenopyrite, both of which form chloritic fracture coatings as well as forming interstitially in Unit SDcm.

Although in the eastern sector of the study area other rhyolitic bodies occur consisting of a prominent brown-to-yellow weathering rhyolite (informal name “yellow rhyolite”) and also those mapped further east by the Queensland Geological Survey (Withnall *et al.* 1995) as “Intrusive Rhyolite” (Unit DCir) none of these are known to carry mineralisation. Clearly the Round Hill rhyolite would appear to be unique and as such might be related to the proposed hidden intrusive that is responsible for mineralisation.

In the Savannah prospect, the narrow quartz + epidote reef west of the Iron Hut Quartz Monzonite has demonstrated in analyses Cu, Mo, As, Ag, Au and Pb.

The psammites and pelites of the Anakie Metamorphic Group host stratabound arsenopyrite, pyrite and pyrrhotite around which the bedding parallel schistosity has been flattened and which may form a mineral lineation. These occurrences are seen as not related to the 375-380 Ma mineralising event but as the result of earlier metamorphism leading to recrystallisation of authigenic sulphides. However, this mineralisation has produced IP and magnetic anomalies.

Discussion

Copper mineralisation in the northern part of the Retreat Hills Batholith was preceded by gabbroic and monzonitic intrusions and, according to dating of molybdenite, occurred some 20my later in early Late Devonian times (375-380 Ma) together with further granitic and monzonitic intrusion and local rhyolitic magmatism. The current copper (+/-Zn, Pb, Ag, Au, Mo, As) shows, some mined, occur in fault-prepared ground indicative of Middle Devonian deformation (post-389 Ma), as determined from the age of the Teresa Creek Volcanics.

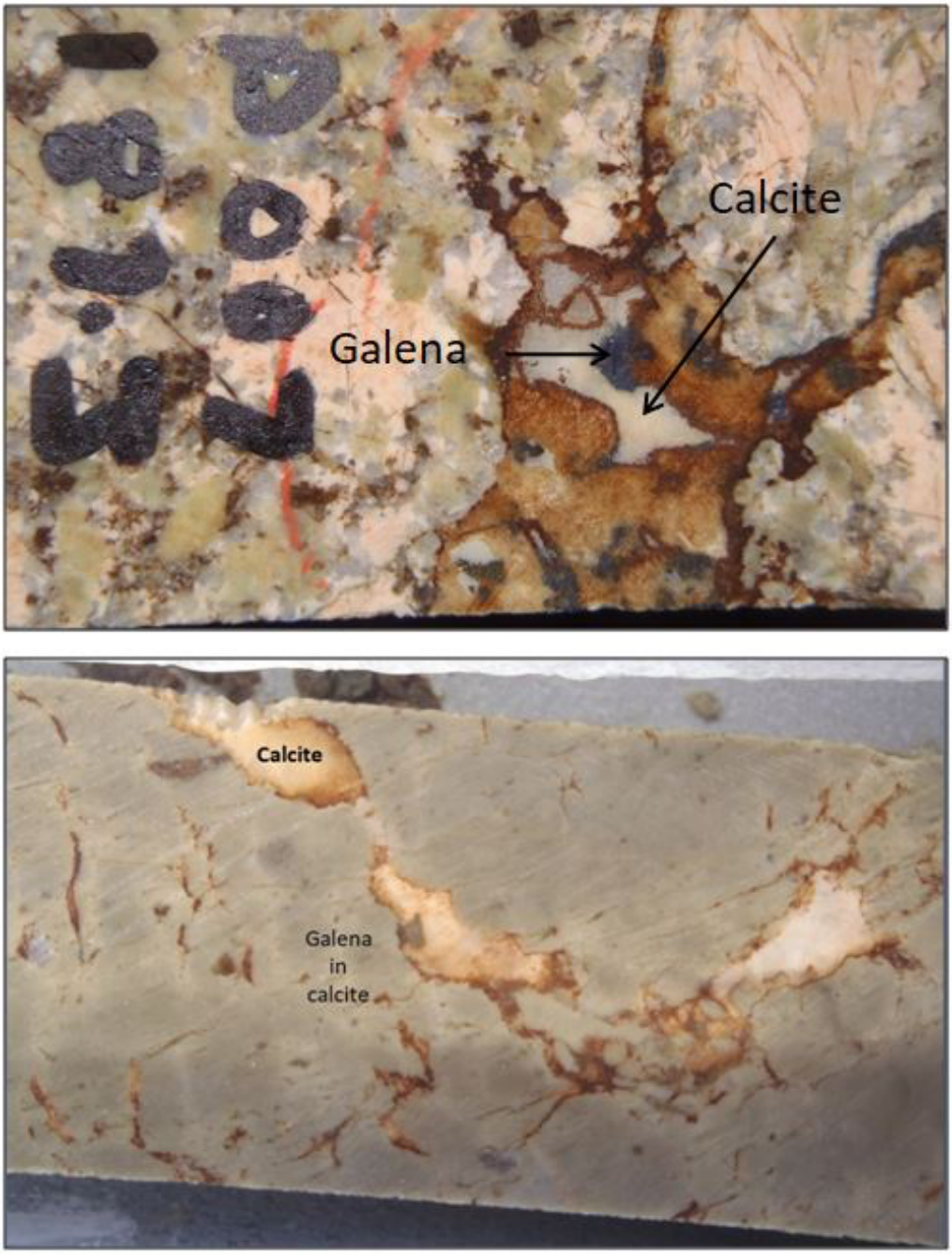

Figure 8. Top: epidote-altered plagioclases and galena-bearing calcite+siderite-filled voids in Unit SDcm. Bottom: galena-bearing calcite+siderite-filled voids in sericitised Round Hill rhyolite. Core sizes NQ.

The mineralisation is attributed to a regional thermal event at about 380-375 Ma, which produced the Iron Hut Quartz Monzonite, the Hillview granodiorite, the undated granitic cupriferous dykes of Unit Dgi and the undated Round Hill rhyolite. By inference from cupriferous microgranitic dykes intruding the doleritic Unit SDdo and the coarse quartz monzonite SDcm, together with surface exposures of cupriferous granite dykes (Unit Dgi) it is considered that the Rosevale area hosts a deep granitic body that carries copper and other mineralisation; this could also explain the small Cu-Zn mine at Copperfield West on the east side of the Rosevale prospect area (Figure 3) and the red-rock (haematitic) alteration seen in drill core from the eastern side of the outcrop of the dolerite here (Unit

SDdo) (see Figure 5). It is envisaged that the Round Hill rhyolite could have been derived from this purported hidden granitic pluton (see Figure 4).

Discussion

380 - 375 Ma is also the age of mineralisation at Mt Morgan (Golding *et al.* 1994), allegedly formed in an island-arc environment (Messenger 1997). This raises the possibility that, in terms of the plate tectonic setting, intrusive-hosted mineralisation in the Clermont district occurred in an extensional region of continental crust subject to high heat-flow, possibly related to distant island-arc activity and presumably subduction in what is now the Mt Morgan region (see review by Kositcin *et al.* 2009).

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