

THE ZINC-RICH SKARN DEPOSITS IN THE CHILLAGOE DISTRICT OF NORTH-EAST QUEENSLAND

Ian Morrison (Lantana Exploration Pty Ltd), Andrew Beaton (Atherton Resources Ltd)

Abstract

Zinc-rich skarn deposits in the Chillagoe district of north Queensland are hosted by Siluro-Devonian Chillagoe Formation limestone/marble. Brittle faults, possibly reactivated steeply-dipping ductile thrust faults, broadly coincident with Late Carboniferous porphyry intrusions, provided permeability for introduction of the prograde skarn altering fluids. Subsequent metal-bearing fluids resulted in partial replacement and retrograde alteration of the prograde garnet- and pyroxene-dominant prograde assemblage and, in some deposits, replacement of marble with negligible skarn alteration.

Compared to most zinc-rich skarn deposits, the Chillagoe deposits sit comfortably around the median tonnage but contain anomalously high copper and low lead. The deposits also show large variations in Zn:Pb:Cu ratios; these variations are particularly evident between separate lenses in the King Vol deposit and may reflect separate phases of mineralisation.

Deposits can be described as either distal or proximal to the source intrusive. The Griffiths Hill deposit is a clear example of a proximal deposit with the transition from Cu-rich to Cu+Zn-rich to Zn-rich mineralisation occurring over a distance of 300-500 metres from the Red Dome porphyry. A similar style of hybrid mineralisation in the Penzance deposit, one of the Redcap group of deposits, may be a strong indication of proximity to a fertile intrusive – a target for the future.

1. Introduction

In this extended abstract and presentation we will present a snapshot of the key characteristics of the major zinc-rich skarn deposits in the Chillagoe district of north-east Queensland. Included will be a summaries of the geological setting and key structural and lithological controls, skarn and sulphide mineral species and a consideration of the classification of the deposits as either proximal or distal (or ?medial) to the causative intrusive. A brief comparison will be made with “average” zinc-rich skarn deposits from elsewhere. Production and resource figures for Mt Garnet are listed in Table 1 for comparison but the deposit is not discussed in the text.

2. Comparison with the “average” zinc skarn

The zinc-rich skarn deposits, mostly clustered around Chillagoe in north-east Queensland, share many common characteristics with their kin worldwide.

- Zinc skarns are commonly associated with copper skarns and copper porphyries (Ray, 1995); demonstrably true for the Griffiths Hill deposit and reasonably assumed for the others.
- Skarn alteration and mineralisation is typically focussed along structures that commonly define lithological boundaries (Ray, 1995) – a characteristic of the Chillagoe district skarns.
- Zinc skarns vary from skarn-rich to skarn-poor, commonly with skarn content decreasing with increasing distance from the intrusive (Meinert, 1992) – and proximal skarns tend to be richer in copper and distal skarns higher in lead, silver and manganese (Ray, 1995). These observations are consistent with some of the variations noted in the Chillagoe deposits.

- Simplistically, sulphide mineralisation is preceded by prograde garnet-pyroxene dominant skarn alteration and recrystallisation of limestone to marble. Sulphide mineralisation follows accompanied by lower temperature skarn alteration and retrograde alteration of the prograde skarn minerals, commonly to various species of amphibole, ilvaite, epidote, chlorite, quartz and calcite (Lerhman, 2012). Magnetite, wollastonite and bustimite are, in variable proportions, common components of the prograde assemblage (Ray, 1995), a mineralogy shared with the Chillagoe district skarns and documented by Lerhman (2012) who also noted vesuvianite as part of the prograde assemblage in her comparative study of the Redcap, Mungana and Red Dome skarns.

A major departure between most of the Chillagoe zinc-rich skarns and those from elsewhere is they are relatively copper-rich and lead-poor (Table 1). Typically, zinc skarns are referred to as zinc-lead or lead-zinc skarns (eg Meinert, 1992 and Ray, 1995) and tonnage-grade figures, compiled by Mosier (1986) for 34 representative zinc-skarn deposits from several districts around the world, confirm this. Mosier's (*op cit*) median deposit of 1.4Mt grades 5.9% Zn, 2.8% Pb, 58 g/t Ag and only 0.09% Cu for Zn:Pb:Cu ratios of 1 : 0.5 : 0.02. Most of the Chillagoe deposits sit comfortably around the median size and zinc grade but the copper grades are typically an order of magnitude higher and lead grades an order of magnitude lower. Only two of the lenses that comprise a lesser part of the King Vol deposit, with Zn:Pb:Cu ratios of 1 : 0.35 : 0.1, approximate the ratios for the median deposit defined by Mosier, albeit at higher grade.

Table 1. Resources and production figures for NE Queensland zinc skarns and “median” skarn

Deposit	Category	Tonnes	Zn%	Pb%	Cu%	Ag g/t	Au g/t
King Vol (1)	Indicated	1,045,000	14.7	0.7	0.9	37	0.0
	Inferred	1,943,000	10.4	0.5	0.7	26	0.0
Montevideo (2)	Inferred	720,000	7.7	0.2	0.0	7	0.0
Queenslander (1)	Inferred	1,570,000	4.4	0.2	0.5	12	0.0
Morrison's (1)	Inferred	1,930,000	5.4	0.3	0.6	21	0.1
Victoria (2)	Inferred	3,440,000	5.1	0.0	1.0	22	0.1
Inc Victoria – high grade (3)	Inferred	948,000	7.3	0.0	1.6	30	
Penzance Zn (1)	Inferred	85,000	6.2	0.2	0.7	19	0.1
Penzance Cu (1)	Inferred	228,000	1.3	0.0	3.2	58	0.2
Griffiths Hill Zn (2)	Inferred	58,000	6.9	0.0	0.3	12	0.0
Griffiths Hill Cu (2)	Inferred	1,011,000	0.4	0.0	3.1	61	0.6
Total Zn Resources (6)		10,791,000	7.1	0.3	0.7	21	0.1
Mungana (4)	Probable	1,130,000	10.2	0.8	1.7	122	1.04
	Indicated	230,000	13.3	5.1	2.5	173	1.21
	Inferred	180,000	16.8	0.0	1.7	108	0.7
2009 FYr production	Production	156,625	15.9	1.6	2.1	?122	?1.04
Total Mungana		1,540,000	11.84	1.37	1.85	127	1.03
Mt Garnet (pre-mining) (5)	Proven open pit	646,000	6.3		0.5	20	
Mt Garnet U/ground (4)	Production	71,000	9.5		0.5	?15	
	Probable	827,000	7.5		0.3	15	
	Indicated	544,000	6.7	0.1	0.4	18	
	Inferred	136,000	8.6	0.4	0.4	49	
Total Mt Garnet (8)		1,264,000	8.35		0.45	19	
The “Median” skarn (7)		1,400,000	5.9	2.8	0.09	58	

Notes

- (1) 2012 JORC compliant – source: Mungana Goldmines Ltd ASX release 16 April 2015
- (2) 2004 JORC compliant – source: Kagara Mining Ltd (Administrators Appointed), 2013. Kagara North Queensland asset overview.
- (3) 2004 JORC Compliant – source: von Gnielinski, F., 2014.

- (4) 2004 JORC Compliant – source: Kagara Ltd Annual Report, 2009 (Mungana and Mt Garnet reserves and resources remained in a state of flux over the life of the underground mining operations (2008-2012))
- (5) Kagara Annual Report, 2003
- (6) Excludes Penzance and Griffiths Hill Cu-rich resources
- (7) Mosier, 1986 – median of 34 representative deposits from several countries
- (8) Resource and production figures for Mt Garnet are included for comparison but not discussed

3. Geological Setting

Zinc skarn deposits in NE Queensland are hosted by limestone/marble beds of the Siluro-Devonian Chillagoe Formation. The formation occupies a five to ten kilometre wide north-westerly trending belt that extends for over 150km from Mt Garnet in the south-east to 70km north-west of Chillagoe where the belt, and bounding Palmerville Fault, changes to a northerly trend and extends for a further 120km where it disappears beneath the Mesozoic Laura Basin (Figure 1). The formation comprises fossiliferous limestone, calcareous sediments, chert, basalt and siliciclastic units juxtaposed against Proterozoic rocks to the west along the Palmerville Fault. To the east, the Chillagoe Formation is in contact with Devonian Hodgkinson Formation. The contact is marked by a structural discontinuity along the Mitchell and Walsh faults. However, in the Mt Garnet district, Chillagoe Formation strata are in apparent conformable contact with the Hodgkinson Formation (Henderson et al, 2013).

The Palmerville Fault is interpreted by Henderson et al (2013) as a long-lived fault initiated as a “first-order” normal fault controlling basin development in the early Palaeozoic Mossman Orogen; the fault was subsequently reactivated as a thrust fault during the Late Devonian Tabberabberan Orogeny that transported the Silurian-Devonian strata westwards onto the adjoining Proterozoic craton. South-east of Mt Garnet, the trace of the fault has been obscured by extensive Carboniferous-Permian Kennedy Province intrusive and extrusive events but Henderson et al (2013) consider the fault takes a sharp turn to the south-west and continues as the Burdekin River Fault.

Deformation within the Chillagoe Formation is dominated by a series of steeply-dipping strike parallel faults that have dismembered the formation into a series of imbricate thrust sheets (Henderson et al, 2013) with lithologic units typically discontinuous along strike. In the Mungana area, at least 12 thrust-induced repetitions of stratigraphy have been identified (Nethery and Barr, 1998, citing Fordham, 1990). These thrust faults are characterized by commonly intense foliation development consistent with ductile deformation and probably coincide, broadly, with the Late Devonian thrusting along the Palmerville Fault. It is speculated that some of these faults were reactivated as brittle structures providing fluid pathways and sites for skarn alteration and metal deposition broadly coincident with the intrusion of Late Carboniferous high-level felsic porphyry stocks.

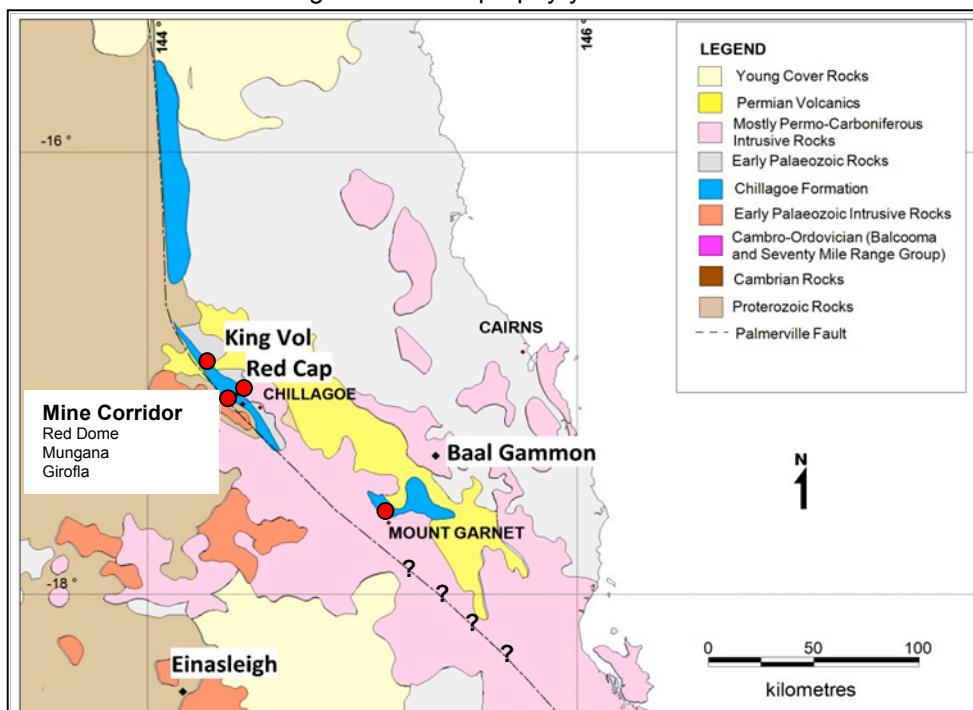


Figure 1. Regional geology and key deposit areas

4. The Zinc Skarn Deposits

4.1 Mine Corridor Deposits

Zinc-rich skarn deposits along the Mine Corridor are: Griffiths Hill, Mungana and Girofla all with very individual characteristics. Griffiths Hill and Mungana zinc-rich skarn deposits, respectively, are intimately associated with the Red Dome porphyry-related Au-Cu skarn deposit and, about 3km to the NW, the Mungana porphyry- and skarn-hosted Au-Cu deposit. The Au-Cu deposits are similar grade and comprise a total resource of 131Mt at 0.21% Cu, 0.65 g/t Au and 8.1 g/t Ag (Mungana Goldmines Ltd 2015) with about 60% of the resource reporting to Red Dome.

Griffiths Hill

The Griffiths Hill skarn deposit is a steeply SW-dipping tabular body along a marble-sandstone contact that extends south-easterly from the southern side of the Red Dome porphyry and related envelope of Au-Cu skarn, has been tracked along strike for 500m and down-dip for up to 300m and typically varies from 2-5m thick. Most of the defined resource is Cu-rich with appreciable Au and Ag and moderately elevated Zn (Table 1). However, about 300m from the main porphyry body, drill intercepts reveal hybrid moderate- and high-grade Cu+Zn mineralisation as follows: **hole 1040 with 2.1m at 6.8% Cu, 6.12% Zn** and **hole 1040W1 with 9.2m at 3.2% Cu and 4.84% Zn**. A further 100m to the SE, drilling intersected high-grade Zn mineralisation with **hole 1056 intersecting 9.9m at 13.5% Zn and only 0.5% Cu**.

This could be a type example of a proximal zinc skarn deposit with a clear transition from Cu-rich to Cu+Zn-rich to Zn-rich skarn mineralisation occurring over a distance of roughly 300-500m from the mineralising porphyry.

Mungana

The Mungana zinc-rich polymetallic skarn deposit, located about 3km north-west of Red Dome, comprises one main steeply south-west dipping tabular body concentrated along the faulted and skarn-altered contact between limestone and clastic sedimentary rocks. The sulphide-rich skarn lens typically varies from 2-5m thick, locally exceeds 10m thick and has been tracked down-dip for about 700m and along strike for around 500m. Skarn alteration is garnet-dominant with subordinate clinopyroxene and wollastonite with retrograde phases including actinolite, iron carbonate, quartz, calcite and ilvaite with more advanced retrogression characterized by chlorite (Lerhman, 2012). Sulphide ore is commonly brecciated but also comprises the matrix phase in brecciated skarn.

The zinc-rich skarn mineralisation is intruded by a “finger” of porphyry, crudely circular and around 30 to 50 metres in diameter. This timing is in accord with previous workers including Nethery and Barr (1998), Georgees (2007) and Hodkinson et al (2009). Skarn alteration associated with the porphyry typically occupies a narrow annulus of endo- and exoskarn. The porphyry body is the locus for Au-Cu-(Mo) mineralisation and probably resulted in the remobilisation of, and/or introduction of metals into the pre-existing mineralised basemetalskarn body. The porphyry body terminates about 260m below surface in a narrow inverted cone of intense brecciation and alteration interpreted by Nethery, Barr and Woodbury (1994, cited by Nethery and Barr, 1998) as a phreatic breccia. Details of the breccia cone are outside the objectives of this presentation.

Girofla

The Girofla deposit is the oddball amongst all the known zinc skarns in the Chillagoe district with historic production and scant modern drilling revealing Pb>Zn mineralisation concentrated in skarn-altered breccia pipes or chimneys and associated with intense

retrograde chloritic alteration. The sub-vertical pipes evidently branch and coalesce within an area of about 100 by 100 metres with the main pipe reaching a diameter of around 30m. Grades of historical production of 224,000t at 13% Pb, 2.5% Cu and 250 g/t Ag are consistent with the one deep drill hole that intersected a breccia pipe (?the main pipe), hole 666 with 45m from 432m depth at 8.3% Pb, 4.5% Zn, 0.4% Cu and 125 g/t Ag. Subsequent drilling, stepped-out along strike to test for a tabular body, intersected only weakly mineralised intense chlorite alteration. This deposit is akin to the famous chimney deposits of Mexico and, as such, could link at depth to a tabular sulphide body or extend to a source mineralising porphyry.

The Dunter prospect located just beyond the NW end of the Queenslander deposit returned spectacular grades in hole 1203 of 5m at 31.6% Zn, 29.1% Pb and 302 g/t Ag. This may represent another pipe or chimney-style deposit. Further drill-testing was designed principally to test for a tabular body. This is a prospect that should be re-visited.

4.2 Redcap Deposits

The Redcap group of deposits, namely, Queenslander-Morrisons (essentially one deposit), Victoria and Penzance, lie along three separate NW-trending “lines of lode”, spaced about 400-500m apart across strike. There are several prospects prospects along these lines of lode that remain to be adequately tested.

Queenslander-Morrisons

The Queenslander and Morrisons lodes lie along the Redcap Fault, a moderately SW-dipping (approximately 50°) thrust fault along which steeply-dipping Siluro-Devonian Chillagoe Formation strata are juxtaposed against Late Carboniferous dacitic ignimbrites of the Redcap Volcanics. The fault has created a wedge of limestone that terminates against a steeply SW-dipping contact with a siltstone and conglomerate unit to the SW.

Skarn alteration and mineralisation has been traced along strike for approximately 1.6km and is expressed on surface as a prominent ridge of ferruginous and siliceous breccia and localized garnet skarn – mineralisation remains open along strike. The deposits are named after the historic Morrisons workings and, to the north-west, Queenslander workings which were active early last century. Although essentially one mineralised zone, the central portion of the deposit is typically oxidized and only extends for about 100m down-dip, offering a natural break for differentiation.

Mineralisation occurs in a single lens with down-dip extent, below base of oxidation, of up to 300m. In longitudinal section, the base of the mineralised lens is arcuate, extending down-dip to over 400m at either end and to about 100 metres down-dip in the centre of the deposit, notionally between the Morrisons and Queenslander lodes. This termination describes the contact along the fault between the wedge of limestone, host to the skarn alteration and mineralisation, with a steeply SW-dipping siltstone and conglomerate unit.

Mineralisation, comprising sphalerite with lesser chalcopyrite, pyrrhotite and minor galena replaces prograde garnet-pyroxene-magnetite skarn with associated retrograde alteration of the prograde skarn assemblage.

Victoria

The Victoria deposit comprises two steeply SW-dipping lenses, Victoria Main and the less extensive Victoria South zones, which, respectively, lie along the contact between limestone and the thick unit of siltstone and conglomerate to the NE and the contact with a thin sandstone unit to the SW. The zones are about 30m apart across strike.

Mineralisation extends for about 700m along strike and 400m down-dip and typically ranges from 1-5m thick, locally 10-12m thick, and comprises sphalerite and chalcopyrite which replaces prograde skarn of garnet-pyroxene-magnetite and locally significant wollastonite.

Higher grade mineralisation in the Main Zone is interpreted to occupy a steeply SE plunging domain. This interpretation is supported by recent assays from holes drilled by Kagara Ltd, just prior to going into liquidation, with high-grade zinc-copper intercepts from the core of the deposit including:

- 3.7m at 8.7% zinc and 2.1% copper from 326m in hole 1208 (Victoria Main)
- 3.0m at 20.5% zinc and 2.9% copper from 289.7m in hole 1208W1 (Victoria Main)
- 5.0m at 9.4% zinc and 0.9% copper from 268.4m in hole 1226 (Victoria Main)

Gold-copper mineralisation occurs down-dip of the Main Zone zinc domain, has been tracked along strike for about 300m, about 100m down-dip beyond the zinc domain and appears to mimic the interpreted steep SE plunge assigned to the higher grade portion of the zinc mineralisation; mineralisation remains open. Gold-copper mineralisation is typically associated with similar skarn minerals to the zinc zone but with an increase in pyrrhotite and highly elevated bismuth and molybdenum, a metal association typical of the porphyry mineralisation at Mungana and Red Dome. Gold-copper intersections include:

- Hole 952: 23.4 metres from 565 metres @ 0.82 g/t Au and 0.34% Cu, including 13.3 metres from 575.1 metres @ 1.25 g/t Au and 0.8% Cu
- Hole 971: 7.7 m from 271 m @ 2.23 g/t Au, 0.96% Cu and 2.57% Zn

Penzance

Several small historic pits mark the surface expression of the Penzance deposit about 50m SW of the more substantial main Penzance pit. Mineralisation is a hybrid Cu-Zn to Zn-Cu deposit developed within massive garnet skarn localized along a steeply SW-dipping contact between marble and, to the NE, basalt. The deposit is roughly equidimensional as currently defined, extending 200m down-dip from the base of oxidation and 200m along strike and is characterized by semi-massive sulphides comprising chalcopyrite-sphalerite with variable pyrrhotite and pyrite. High grade copper mineralisation with relatively low zinc occupies a moderately SE-plunging core with more zinc-rich mineralisation peripheral to the core.

Mineralisation at Penzance is very similar to the Griffiths Hill Cu-rich and Zn-rich skarn mineralisation immediately along strike from the Red Dome porphyry and related Cu-Au skarn. There has been much speculation by colleagues that the marked increase in copper grades evident at Penzance, and increasing copper and gold down-dip of Victoria zinc skarn, are vectors to the related causative intrusive(s). There may be justification for further detailed geological, geochemical and geophysical investigations before targeting a drill hole to test this, or perhaps the best course of action would be to bite the bullet, step back from Penzance and target a hole several hundred metres below Penzance and Victoria.

4.3 King Vol

Located about 40km NW of Chillagoe, the King Vol deposit contains a total resource of 3Mt grading 11.9% Zn, 0.8% Cu, 0.6% Pb and 30 g/t Ag comprising approximately 35% Indicated and 65% Inferred resources (see Table 1). Current extension drilling, which is ongoing, has intersected high-grade mineralisation that will extend the resource with intersections including:

- KVD125: 2.4m at 17.4% Zn
- KVD129: 6.95m at 13.8% Zn (Mungana Goldmines, 2015)

Local stratigraphy dips steeply to grid west and comprises, from west to east, a thick unit of limestone with intercalated basalt (the Western Limestone), 20-40m thick arkosic sandstone, 40-70m thick limestone (the Eastern Limestone), 5-20m thick unit of highly disrupted and brecciated siltstone, a thin chert unit followed by a thick sequence of interbedded siliciclastics. Lenses of mineralised skarn are sub-parallel to parallel to stratigraphy.

Three main lenses of skarn alteration and variably coherent mineralisation, typically 1-5m thick and up to 10-12m thick, are focussed along faults that either define stratigraphic contacts or lie adjacent to stratigraphic contacts. From west to east these are the Western Contact Zone (WCZ) which occurs along the eastern contact between arkose and the Eastern Limestone, the Eastern Replacement and Eastern Contact zones (ERZ and ECZ) which lie, respectively, adjacent to and along the Eastern Limestone contact with footwall siltstone. Typically, the ERZ and ECZ zones are separated by 5-10m of barren marble, but locally coalesce into a single mineralised zone. A locally mineralised zone of skarn alteration, referred to as the King Vol Zone (KVZ) and the focus for historic small scale mining of secondary lead, is focussed along the western contact between the arkose unit and the Western Limestone.

Mineralisation has been tracked for about 400m along strike and to 700m deep with the bulk of the mineralisation occurring in a high-grade, steeply south-plunging domain along the ERZ/ECZ with a strike extent of around 50-100m. Pending results from current drilling, this could change significantly. Dominant sulphides are sphalerite, pyrite, marcasite, arsenopyrite, chalcopyrite and galena. Retrograded prograde skarn alteration is most evidently associated with the KVZ and ECZ lenses. In comparison, the ERZ, in particular, commonly occurs as marble replacement with alteration of the host limestone restricted to recrystallisation to marble and weak pale brown carbonate (?ankerite).

To further characterize the King Vol deposit, the eastern two lenses (ERZ and ECZ), which comprise the bulk of the body, carries elevated copper and low levels of lead, whereas the western two lenses that occur along the arkose contact (WCZ and KVZ) carry much higher lead. Based on grades for each of the lenses estimated by Hodkinson (2009), ratios for Zn:Pb:Cu for the eastern lenses are, notionally, 1 : 0.02 : 0.05 compared to 1 : 0.35 : 0.1 for the western lenses. This invites speculation that mineralisation occurred in two discrete phases related to episodic pulses of hydrothermal activity coincident with discrete advances of the causative intrusive.

If the interpreted timing is correct with zinc-rich polymetallic skarn mineralisation effectively representing a phase of distal skarn mineralisation initiated during a pause in magma ascent, the unknown is whether or not the ascending magma left a metal footprint during this hiatus.

5. Conclusions

1. Brittle reactivation of early ductile thrust faults may be an important ingredient in providing a focus for mineralising fluids.
2. The two highest grade deposits, Mungana and King Vol, show evidence for two pulses of intrusive activity. This is quite evident at Mungana, where the Cu-Au mineralised porphyry stock clearly cross-cuts high-grade distal-style zinc-rich skarn mineralisation. It is speculated for King Vol based on large variations in Zn:Cu:Pb ratios between separate lenses that comprise the deposit. The question is raised – did these fertile porphyries leave a metal footprint behind at depth during a hiatus period?
3. Zn-rich skarn mineralisation is an expression of metal deposition at some unknown distance from the source – the causative intrusion. Mineralisation at Griffiths Hill is clearly proximal to the Red Dome Cu-Au porphyry-related skarn deposit and transitions from Cu-rich to Cu-Zn-rich to Zn-rich over a distance of roughly 300 to 500 metres from the porphyry body. This could be used as a guide to predict the distance to fertile intrusions related to similar deposits. A similar style of hybrid mineralisation in the Penzance deposit, one of the Redcap group of deposits, may be a strong indication of proximity to a fertile intrusive and presents as a target worthy of drilling.

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