



# 34th International Geological Congress (IGC)

**Brisbane Convention and Exhibition Centre, Queensland, Australia**

5 - 10 August 2012

Unearthing Our Past And Future – Resourcing Tomorrow

*Q-2* *11 - 17 August 2012*

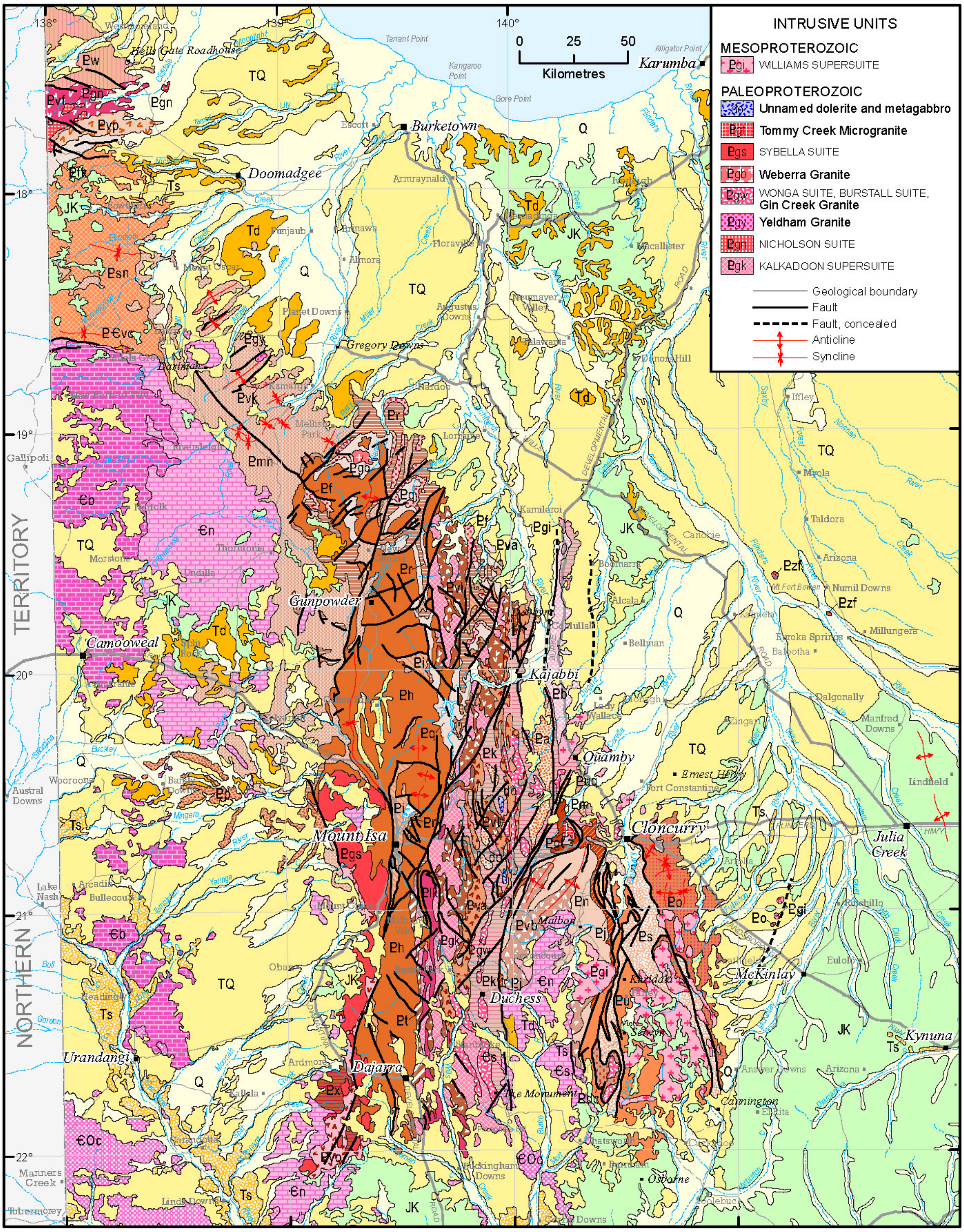
# Mineralisation of the Mount Isa Region

Dr Laurie Hutton, and Dr Geoff Derrick

# Field Trip looking at Mineralisation in the Mount Isa Inlier, north-west Queensland, Australia

L.J.Hutton, G.M.Derrick, with contributions from several exploration companies in the region

Map showing the geological units in the Mount Isa Inlier also showing key localities to be visited during the trip.



# Itinerary:

### *Day 1: 11/8/2012*

Arrive Mount Isa on the flight form Brisbane. Depart from the airport to travel to Adels Grove near Century Mine. On the way we will inspect some Tertiary fossils form the Riversleigh Fossil Park. If there Is time, we will also look at some vein-type mineralisation at the abandoned Lilydale Mine.

Overnight at Adels Grove (camping)

### *Day 2: 12/8/2012*

Depart Adels Grove and travel to the nearby Century zinc/lead mine. There staff from Century will conduct some presentations on the mineralisation and visit the pit. We will depart Century mid-afternoon to visit the beautiful Lawn Hill Gorge in the Lawn Hill National Park.

Overnight at Adels Grove (camping).

### *Day 3: 13/8/2012*

Depart Adels Grove and travel back towards Mount Isa. On the way we will detour to the Lady Loretta Pb/Zn shale hosted Deposit which is undergoing development. We will be escorted around by staff from Xstrata Zn. Returning toward the highway from Lady Loretta, we will inspect the Lady Annie Cu mine, a shale hosted Cu deposit which has similarities to the giant Mount Isa deposit. Return to Mount Isa

Overnight Mount Isa (Motel)

### *Day 4: 14/8/2012*

Today we will visit some exploration and mining camps around Mount Isa. First we will inspect core form the Valhalla U deposit north of Mount Isa. Following this we will move to Xstrata Cu and look at core from the giant Mount Isa Cu deposit. We will also have a presentation form Xstrata Cu geologists. After the Cu core, we will move to the Black Star Mine where shale hosted Pb/Zn is mined. We will have a presentation and tour with Xstrata Zinc geologists.

Overnight Mount Isa (Motel)

### *Day 5: 15/8/2012*

Today we will travel to Cloncurry. En-route to Cloncurry we will visit the Mary Kathleen U and REE mine and some adjacent outcrops. In the afternoon, we will visit the Ernest Henry IOCG deposit. We will be given a presentation and visit some facilities at the mine and look at some core with Xstrata Cu geologists.

Overnight in Cloncurry (Motel)

### *Day 6: 16/8/2012*

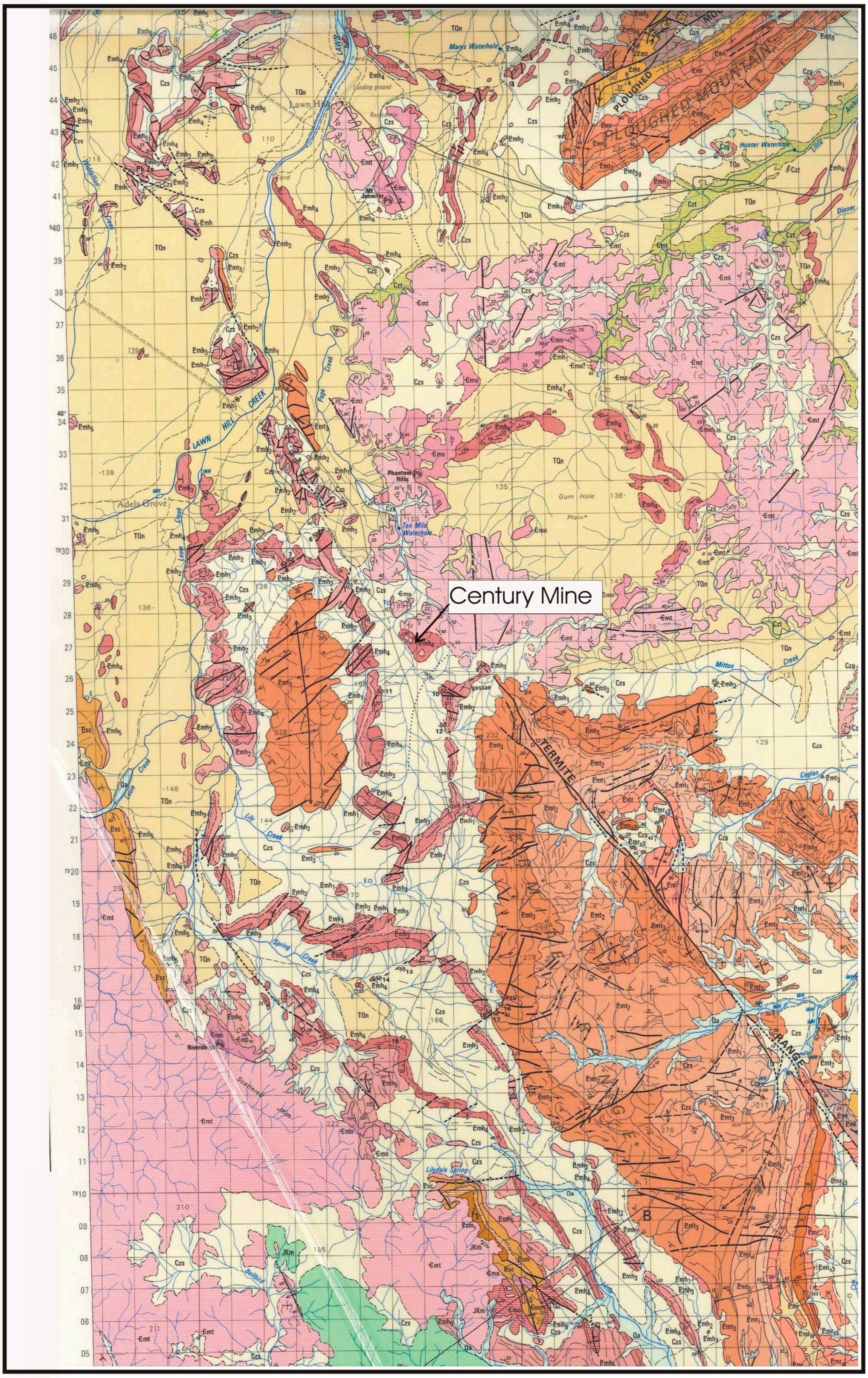
Today we will visit Ivanhoe Australia's exploration around Selwyn and Mount Elliot. Both are mining districts from last century. Recent exploration has identified large Cu/Au reserves as well as the Mo/Rh deposit at Merlin which is under development. We will be accompanied by Ivanhoe Australia geologists. On the way back to Cloncurry (time permitting) we will inspect the old mining camps at Hampden and Kuridala.

Overnight in Cloncurry (Motel)

### *Day 7: 17/8/2012*

This is our last day. We will be travelling back to Mount Isa in time to catch flights back to Brisbane. We will inspect some field sites en-route as time permits.

# *DAYS 1 & 2:*




**Stop 1.1 Geological Map of the Lawn Hill Region showing the location of Century Mine**

# Century Mine:

**Century Deposit** (G. M. Derrick)

1. The Century Zn deposit appears to have formed at 1575 Ma in 1595 Ma host rocks of the Lawn Hill Formation, deposited in the Lawn Hill Platform of the Mount Isa Inlier; as such, it is the youngest of all the sediment-hosted Pb-Zn-Ag deposits located in the Mount Isa Inlier (Mount Isa Hilton, George Fisher, Lady Loretta) and at McArthur River. It is a gently folded open pittable deposit occurring over an area of 1.4 x 1.2km as a 45m thick mineralised interval within a sequence of shale, siltstone, and sandstone mapped as unit $Pmh_4$, and was discovered in 1987-88 by soil and rockchip geochemistry related to the Proterozoic host rocks. Extensive Pb-Zn anomalism in basal units of the overlying Cambrian limestones at first hindered the full appreciation of the soil geochemical results, delaying actual discovery by 2 years. Anomalous geochemistry was found in early 1988, but the discovery drillhole was not made until April 1990.

2. Century contains a resource of 118Mt @ 10.2% Zn, 1.5% Pb, 36g/t Ag, and was commissioned in 2000. It produces per annum from 450,000 to 500,000 t of Zn metal and 45,000t Pb, and is scheduled to close in 2015. Zn and Pb concentrate are transported 300km by pipeline to the Karumba port. The former contains 59% Zn, 2.7% Pb, 440g/t Ag, 0.7% Fe and 3.8% Si, which is the most significant contaminant. The deposit accords with most of the established exploration parameters for this class of ore deposit — stratigraphically above a rifted terrain, proximity to long-acting and reactivated, commonly intersecting fault structures ( e.g Termite Range Fault), fine-grained reduced (carbonaceous) host lithologies in third order basins, and likely presence of oxidised sulphate-bearing metalliferous brines.

3. Bedding-parallel replacement during diagenesis is seen increasingly as the preferred mode of mineralisation at sediment-hosted Pb-Zn-Ag deposits such as Mount Isa and Hilton-George Fisher. Similarly, a ~20 Ma gap between host rock age and mineralisation age at Century suggests that Century may bridge the transition from diagenesis to epigenesis. Century sphalerite is grey and low Fe, and the deposit is a low-pyrite sediment-hosted type.

4. Century mineralisation may coincide with onset of gentle compressive folding forming part of the early Mount Isa Orogen dated approximately 1600 Ma to 1500 Ma. It is a bedding replacive type of mineralisation, the necessary permeability being available through overpressuring of the host sequence, development of intrastratal fluid flow within a quartzose carbonaceous siltstone sequence, and expulsion and depletion of pore-filling bitumen with time.

5. C isotopes vary from $\delta^{13}C$ values from -2.6 to +2.6 per mill, and $\delta^{18}O$ values range from 15 to 25.5 per mil, similar to values in other regional marine sedimentary and diagenetic Proterozoic carbonates in the Mount Isa and McArthur basins of northern Australia.

6. Despite the strongly laminar appearance of the ore at Century, it has formed at considerable crustal depth, from ~500 to 3km depth. It has no connection with synsedimentary exhalative processes. The mineralisation is closely associated with an ankerite-siderite halo controlled regionally by the Termite Range Fault, and since siderite replaces diagenetic silica, the late diagenetic timing of mineralisation is confirmed. Although mineralisation is well laminated, there is considerable bedding plane deformation and extension, boudinage and compaction effects and nodular structures, and low angle replacement fronts of sphalerite and carbonaceous shale. The upper parts of the ore sequence tend to be Pb-Ag (galena) rich, with lower units in the ore sequence more Zn–rich.

7. Current thinking proposes that metalliferous brines rising along fault structures extended laterally into carbonaceous facies fine-grained sediments, focussed by pre-ore stage development of top seal rocks; deposition of sulphides is inferred to have taken place within a gentle anteform containing a pool of gaseous and liquid hydrocarbon formed during ingress of the warm metalliferous brine at temperatures of about 150–200ºC. The host sequence formed an organic-rich source rock which was heated through the oil window to form hydrocarbons, which then experienced cracking and thermal degradation to methane and pyrobitumen. The latter was redeposited within the source rocks (i.e. a source-reservoir) and together with methane and $H_2S$ provided a means of metal precipitation from metalliferous sulphatic brines.

8. The interplay of gaseous and liquid hydrocarbons and Zn-rich metalliferous fluid has determined the nature of the most common sphalerite species present in laminations — an early pyrobitumen-rich species, originally termed ‘porous sphalerite’ and a cogenetic or later translucent bitumen-poor species possibly mediated under gaseous conditions. Both are Fe-poor sphalerite, and are difficult to separate and identify in hand sample. TEM studies show that ‘porous’ sphalerite does not contain pores, but is in fact highly bituminous, and that this phase is transformed to a bitumen-free clear sphalerite possibly by a process known as ‘Ostwald ripening’, whereby bitumen is expelled from the earlier sphalerite by pressure and the passage of time, to produce a bitumen-free recrystallised fine-grained sphalerite aggregate.

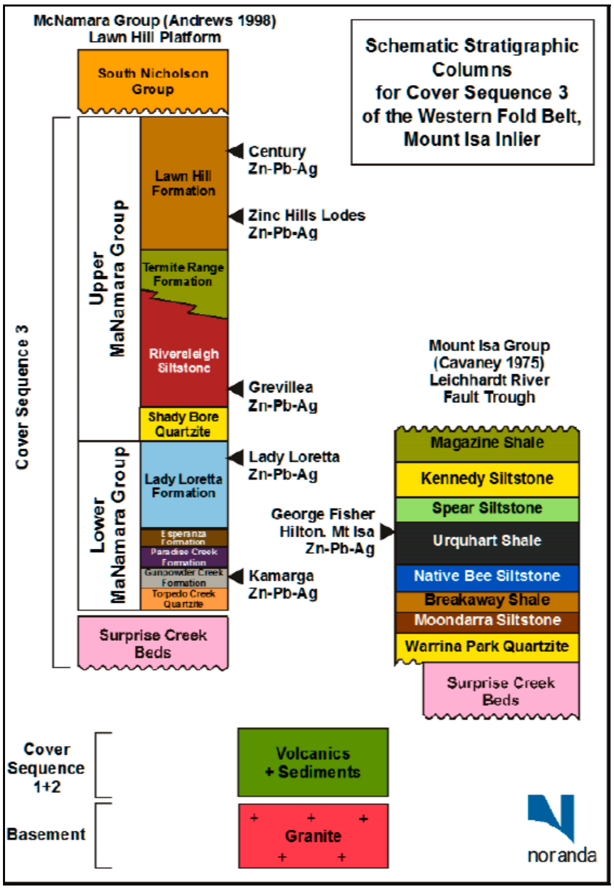
9. The major Fe-bearing phase is siderite, which accompanies mineralisation and also forms extensively in older stratigraphic units adjacent to the Termite Range Fault, i.e. siderite alteration is an important vector towards ore. Together with pyrite, siderite and sideritic siltstone form fringe alteration to the Century deposit, but also form as 1–3m thick barren ribs within the ore sequence, and also display extensive stylolitic development which is overprinted by laminar Zn mineralisation.

10. Sphalerite in sideritic layers and in local veins tends to be straw-coloured to pale yellow and coarse-grained. Some Zn and Pb-rich veinlet zones occur within the deposit, especially towards the SE corner. They resemble the later veinlet mineralisation which crosscuts the main laminated Zn-Pb mineralisation within the deposit.

11. Regional observations and Pb isotopes suggest that Century-style mineralisation evolved with time (over +50Ma) towards the late coarse-grained sphalerite-galena-quartz-siderite vein fill typified by the Silver King-type deposits which formed the basis of all previous historic mining in the Lawn Hill district.

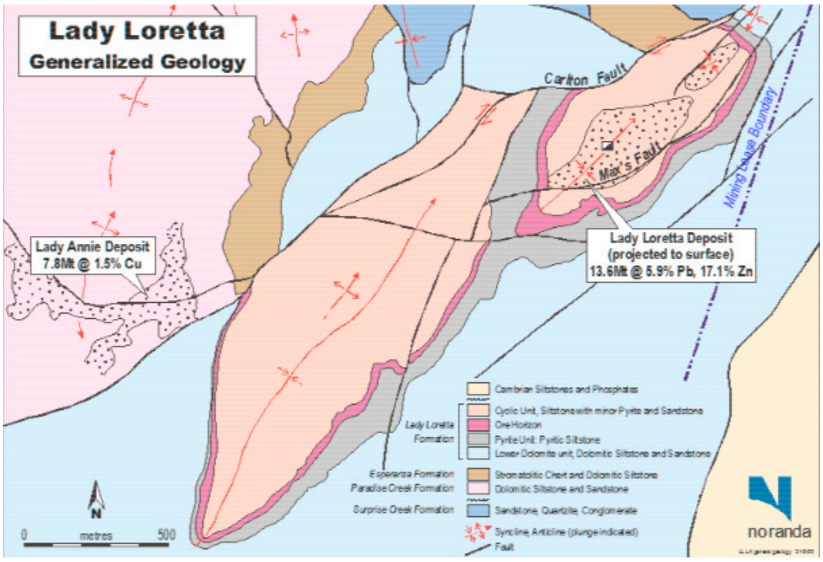
# *DAY 3:*
# Lady Loretta Deposit:

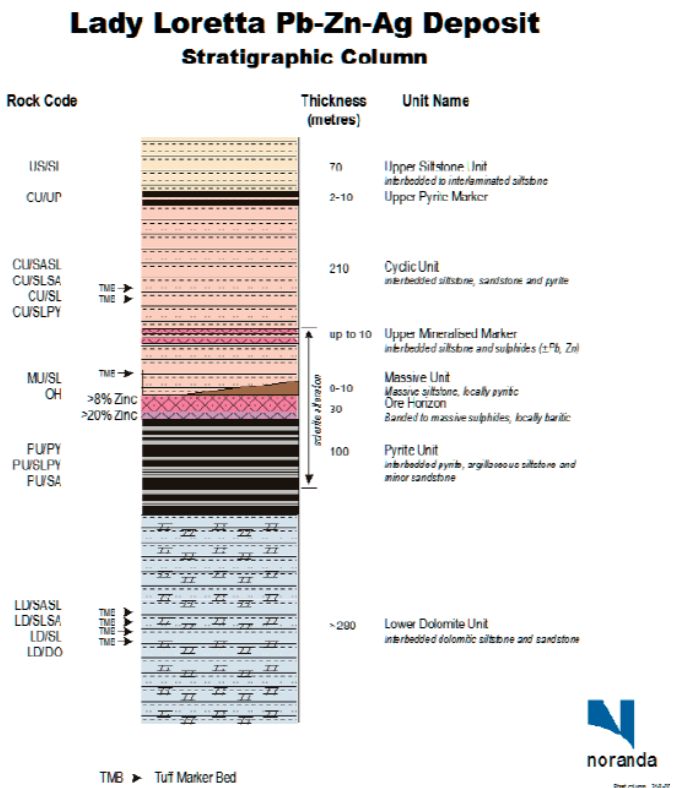
**Lady Loretta Geological overview. (**By A. Campbell, Xstrata)
**Overview**
The Lady Loretta deposit occurs within the Mount Isa Inlier, which consists of a series of north-south trending Proterozoic tectonic terranes. These are divided into three main zones, the Eastern Fold Belt, the Western Fold Belt and the central basement called the Kalkadoon-Leichhardt Block.
The Western Fold belt is tectono-stratigraphically subdivided into the Lawn Hill Platform (host to the Lady Loretta deposit) and the Leichhardt River Fault Trough (host to Urquhart Shale). Both units within the Western fold belt sit on a Granite basement, overlain by Cover Sequence 1 and 2 (volcanics and sediments) and Cover Sequence 3.
Cover Sequence 3 is divided into the Upper McNamara Group (which hosts the Century, Zinc Hills Lodes and Grevillea Zn-Pb-Ag deposits) and the Lower McNamara Group (hosts Lady Loretta and Kamarga Pb-Zn-Ag deposits).
The Lower McNamara Group consists of basal, coarse clastics fining upwards into a thick sequence of dolomitic siltstones and sandstones. Occasional localised phases of non-dolomitic quartz-clastic sedimentation are also present within the Lower McNamara Group. Chert horizons are common and are readily outcropped in underground workings at Lady Loretta.
The boundary between the Lower and Upper McNamara Groups is defined by a distinct change to non-dolomitic clastic facies which are associated with deeper water depositional conditions, sometimes as turbidites, and often associated with localised sub-basins.

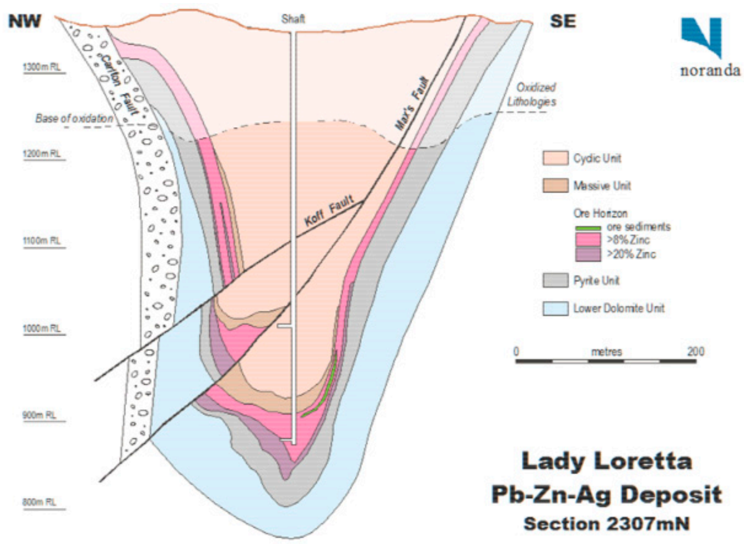



**Local Geology**
The Lady Loretta deposit is considered to be a classic example of sediment hosted Pb-Zn deposit. While it displays many characteristics similar to other deposits within the Mount Isa Inlier, it differs in that it contains a single ore lense, shows exceptionally high grade, and is associated with barite mineralisation on the eastern limb of the syncline. Host rock deposition indicates an age of 1647 Ma. The deposit is hosted in the upper portion of the Lower McNamara Group and is stratiformally bound in a tight, north-east plunging syncline named the Small Syncline. The orebody length along strike is roughly 1.3km. A larger syncline called the Large Syncline occurs to the south-west and is pushed

hard up against the Small Syncline. A small anticlinal fold once separated the two synclines but this has weathered away. A large fault named the Syncline Dividing Fault runs between the synclines and is virtually bedding-parallel. The orebody is truncated to the north by the Carlton fault.
The ore hosting sediments are thought to be variants of a dark grey, massive siltstone unit (the Massive Unit) which marks the base of an interbedded siltstone/lesser sandstone/pyrite unit called the Cyclic Unit. Underlying the orebody is the interbedded pyritic siltstone (the Pyrite Unit) which grades from massive pyrite bedding to dark shale/siltstone.
The Ore Horizon sits conformably between the Massive Unit and the Pyrite Unit and its stratigraphic position is indicative of a major sedimentalogical change. This is expressed by units fining upward towards a period of low energy deposition (the Pyrite Unit and Ore Horizon), then reverting back to high energy deposition, reflected in the interbedded Cyclic Unit.
The Ore Horizon extends into the Large Syncline and is expressed as a chert-barite-pyrite zone between 10m to 30m thick, however the high grade mineralisation is not present.






# Lady Annie Mine:

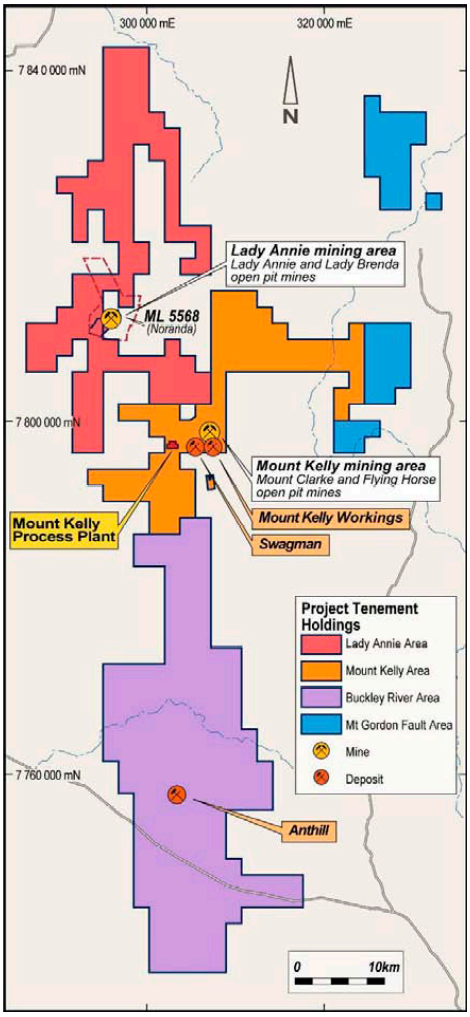
**Geology and mineralisation**

The Lady Annie Project is located within the Mount Isa Inlier, which hosts several known copper oxide and sulphide resources and prospects. The Mount Isa Inlier consists of a north-trending belt of Early Proterozoic basement rocks (the Kalkadoon-Leichhardt Belt) flanked by two belts of Middle Proterozoic rocks, known as the Eastern and Western Fold Belts. The Lady Annie Project tenements occur within the Western Fold Belt. The Western Fold Belt is subdivided by the Mount Gordon Fault into the Lawn Hill Platform in the west and Leichhardt River Trough in the east.

The geology of the area surrounding the Lady Annie Project is dominated by marine carbonate and clastic sedimentary sequences of the Proterozoic Lower McNamara Group. The Lady Annie Project overlies the north-south trending Lady Loretta High Strain Zone, which is characterised by tight, upright folding along major north-south trending faults. The project area is structurally complex, with multiple generations of folding and faulting. Major, deep-seated faults that cut or bound basement rift blocks of volcanics are considered to be important for targeting copper mineralisation. Extensive weathering has produced a base of complete oxidation at around 80 m, although there are areas with oxidation down to 300 m associated with fault zones.

The known copper mineralisation within the majority of the project area is hosted in dolomitic, carbonaceous and argillaceous sandstones and siltstones. Oxidation of these units has removed the dolomitic material leaving behind ferruginous silty sandstones or kaolinitic sandy siltstones.

Mineralisation in the oxide zone is comprised predominantly of malachite, cuprite, chrysocolla, chalcocite and tenorite with relatively rare native copper. The oxide zone mineralisation appears to be controlled by the in-situ oxidation of pre-existing primary copper sulphide species. The primary copper sulphide mineralisation at depth is dominated by chalcocite and chalcopyrite, and appears to be structurally controlled.




Map showing Location of the Mineral Resources within the Lady Annie Project tenements

# *DAY 4:*
# Mount Isa Uranium Project:

**Paladin Energy Mount Isa uranium project geology summary (**by J. Jory)

Paladin Energy, through its 82% interest in Summit Resources (Aust) Pty Ltd (SRA) and 100% interest in Fusion Resources, is exploring for uranium on 1,772 km² of tenements near Mount Isa in north-west Queensland (Figure 1). Paladin's core objectives are to conduct feasibility studies at Valhalla-Odin and to expand its uranium resources in the region, located 30 to 100 km north of Mount Isa. SRA has a joint venture agreement with Aston Metals, which is exploring for copper. Valhalla pre-feasibility and scoping studies have been conducted for environmental baseline work, mineralogical studies, metallurgical test work, geotechnical evaluation, and preliminary mine and infrastructure design. Project economics are challenged by refractory metallurgy, high processing costs and weak uranium prices.

The project contains uranium resources at Valhalla, Odin, Skal, Bikini, Mirrioola, Andersons, Watta, Duke Batman and Honey Pot. Drilling totals 216,000 metres in almost 1,200 holes. Uranium resources under Paladin's management in the Mount Isa region total 146.7 M lb $U_3O_8$; grades range from 410 to 1,050 ppm. Most (58%) of these resources are contained in the Valhalla deposit, with 76.2 M lb $U_3O_8$ @ 790 ppm. Valhalla is the sixth largest uranium deposit in Australia. Other important resources occur at Odin (17.5 M lb), Skal (21.8 M lb) and Bikini (13.6 M lb). The blind Odin deposit was discovered by drilling a magnetic high and lineament 1 km north of Valhalla in March 2010.

Uranium mineralisation mostly occurs in albite-calcite-dolomite-chlorite-quartz-hematite-magnetite-rich albitites surrounded by chlorite-carbonate alteration haloes. This alteration is marked by grain size reduction, a distinctive red to maroon colour from hematite dusting, and the replacement of quartz and FeMg-silicates by albite and carbonate. Sub-vertical alteration zones are characterised by intense foliation, which rapidly weakens with distance from the mineralised shear zones. Accessory minerals are zircon, apatite, sphene and rutile. Uranium mineralogy includes brannerite, coffinite, uraninite and fine-grained intergrowths.

These deposits are classified as **albitite-hosted metasomatites**. Key features are:

- Albitite-hosted uranium deposits are focused within mafic rocks of the Western Succession of the Mount Isa Inlier. The main uranium district is only about 60 $km^2$.

- Albitite-hosted uranium deposits are hosted within the basalt-rich Cromwell member of the Eastern Creek Volcanics of the Lower Proterozoic Haslingden Group.

- Regional proximity of uranium deposits to strongly foliated rocks within dilation zones along the north-east margin of the Sybella granite (about 10 km).

- Strong structural controls to mineralisation, expressed as brecciation, foliation and carbonate-quartz veins, along N20°W to N40°E fabrics.

- Proximity to magnetic highs and steep gravity gradients. Shear zones are expressed as discrete lineaments oblique to stratigraphy in magnetic data.

- The deposits occur as *en echelon* lenses of uranium mineralisation in steeply dipping zones of strong foliation slightly oblique to bedding; tonnage is enhanced by rheological contrasts along basalt-siltstone contacts.

- Pervasive Na, Ca and $CO_3$ metasomatism, expressed as albite, calcite and dolomite with fine-grained hematite inclusions (albitite).

- Chlorite-rich alteration haloes as proximal products of metasomatism, which overprint earlier greenschist carbonate-chlorite-epidote metamorphism.

- Geochemical signatures of the mineralisation include enrichment of U, Na, Ca, Sr, Zr, Th, V, Pb, Hf and P, and depletion of K, Rb, Ba and Cs. Uranium deposits are close to copper deposits, but do not overlap them (Figure 2). Minor copper occurs at Skal.

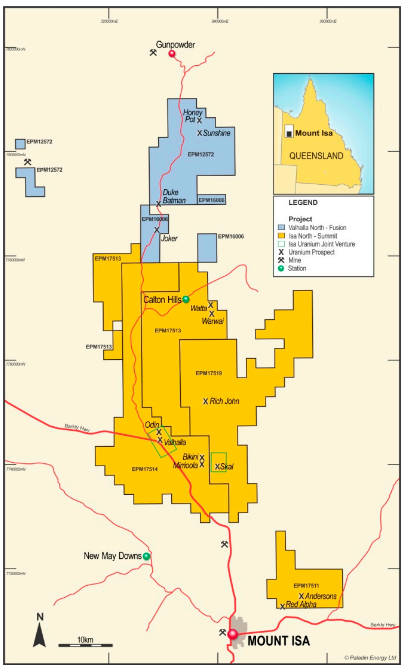



Figure 1. Map of Summit and Fusion Resources tenements and uranium deposits

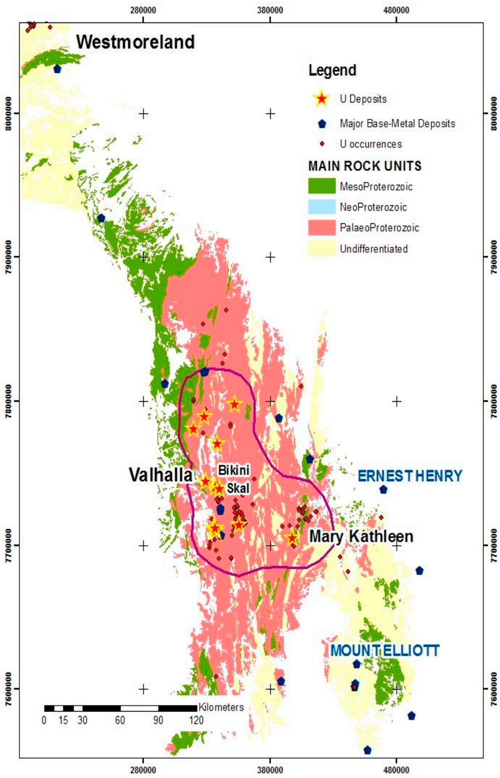



Figure 2. Map of Mount Isa Inlier main rock units and uranium deposits; uranium district is outlined in purple.

# *DAY 5:*

# Field Points between Mount Isa and Cloncurry:

(By G.M.Derrick)

**Day 5: Wednesday 15th August - start Mount Isa 8.30am: Highway traverse from Mount Isa east to Cloncurry**

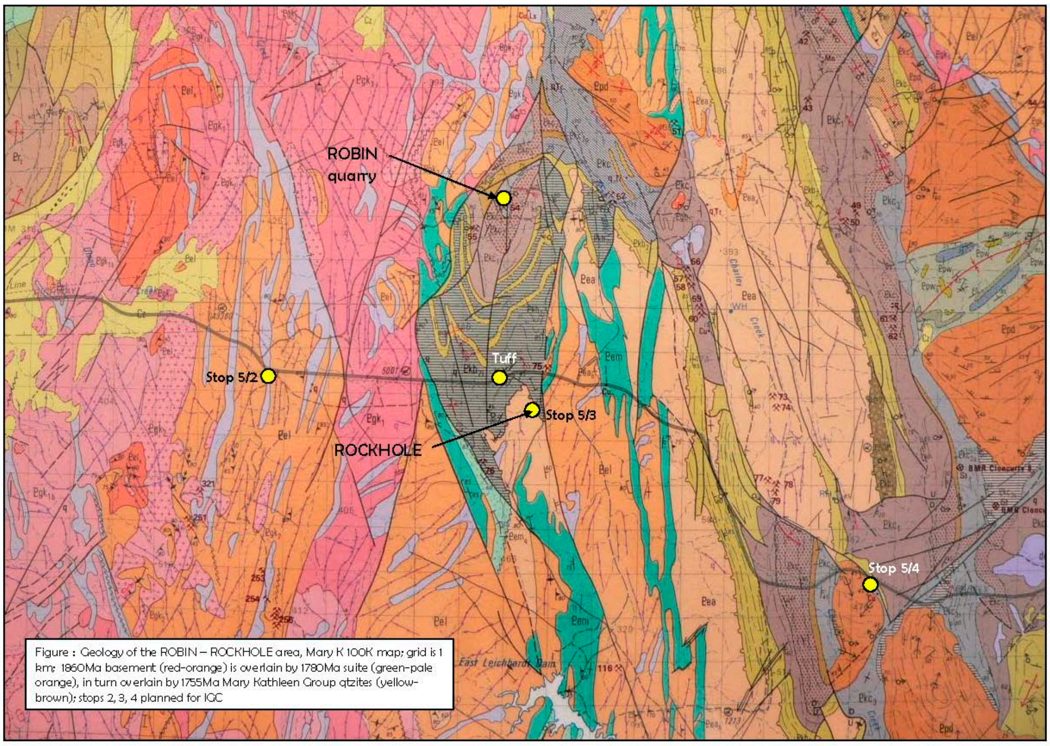



Figure : Geology of the ROBIN – ROCKHOLE area, Mary K 100K map; grid is 1 km; 1860Ma basement (red-orange) is overlain by 1780Ma suite (green-pale orange), in turn overlain by 1755Ma Mary Kathleen Group qtzites (yellow-brown); stops 2, 3, 4 planned for IGC

**Stop 5/1 – Sedimentary interbeds in basalts of the Eastern Creek Volcanics, Leichhardt River Fault Trough -** arrive 8.45am

Rationale: Fluvial interlude in major subaerial basaltic rifting event, 1770–1780Ma

Park 300m west of stop in safe gate entrance; cross road to south, climb through fence and walk east along strike of sediments within basalts to best exposure.

Magnificent exposure of high energy ?fluvial sediments interlayered with basalt, dipping north and striking E-W. Note unimodal cross bedding (??north-directed current), extensive trough structure and channel scour, heavy mineral banding, rip-up clasts of purple-grey mudstone. Sediments are also calcareous, with typical carbonate weathering visible throughout, and many beds are highly magnetic. Walk down section to south and minor outcrop of thin flows of ECV – marked by flow brecciated tops and massive basal parts, about 3–5m thick.

Sediments may be part of a longitudinal braided stream system developed on a basaltic substrate within the developing basalt-filled rift, fed from the east and south by active rift fault margins.

Depart 9.45am

Drive eastwards and enter the Kalkadoon-Leichhardt basement block (1860–1780Ma) – notable change of topography as tour exits the LRFT and enters the volcanic/plutonic basement block.

**Stop 5/2: Basement volcanics: probable ash flow tuff or crystal tuff –** arrive 10.00am

Rationale: Leichhardt Volcanics: Example of continent-scale felsic to dacitic volcanics, dated 1860Ma

Park safely beside highway, cross road to gate on south side. Walk 40m through gate:

A few bouldery outcrops of 1860Ma Leichhardt Volcanics are most likely ashflow crystal tuffs which display a strong steep foliation, fine but convincing beta quartz phenocrysts plus feldspar phenocrysts in a dacitic groundmass with some biotite etc.and fine siliceous groundmass. Dark xenolithic material may be fiamme, or flattened pumiceous fragments. The volcanics are showing moderate recrystallisation here because of proximity to the co-magmatic Kalkadoon Granite (also 1860Ma). This suite may be of vast extent, as they are the same age as similar tuffs in the Whitewater Volcanics of the Kimberley region i.e possibly evidence of a vast array of coalescing caldera fields erupting huge quantities of rhyolitic and rhyodacitic ash flow and tuff across northern Australia at this time — the basal crustal bulwark of the North Australian craton.

Depart 10.30am.

**Stop 5/3: Rockhole exposure - Argylla Fmn and overlying Cover Sequence 2**

Rationale: Important contact between basement and Mary Kathleen Group, a major 1755Ma sag-cover sequence which extended across most of the inlier, allowing good correlation between eastern and western successions. Equivalents of this Group overlie Myally Subgroup in the Western Succession.

Turn off just west of East Leichhardt river crossing; open gate and travel in bus south 800m to rock pavement and waterhole. Arrive 10.45am

Argylla Fmn volcanics are the felsic+sediment component of the bimodal 1790/1780Ma suite of volcanics which overlie the Leichhardt/Kalkadoon basement (1860Ma). The Argylla Volcs are largely subaerial ignimbrites, commonly pinkish and quartz-phenocrystal. They are regionally magnetic, probably more so than the associated and contemporaneous Magna Lynn Metabasalt. At this locality, they are overlain unconformably by the basal calcareous arkosic facies of the Ballara

Quartzite, basal unit of the Mary Kathleen Group, with 1755Ma sediments overlying 1780Ma volcanics.

Geochronology shows that the u/c represents about 25 to 30 Ma of missing time, and that this period was about the period of time taken to deposit the Haslingden Group in the major Leichhardt River Fault Trough to the west. Note a myriad of small N-S axial plane faults. There is poikiloblastic scapolite developed in some of the biotitic sediments, and abundant calcite microveining results in a pock-marked weathering surface on the Ballara sediments.

The contact is fully exposed on the eastern edge of the rock pavement; lack of any soil or prominent weathering profile at the unconformity suggests aridity at about 1755Ma. Look for derived rocks of arkosic character.

Depart 11.30am – drive 10km east across type section of Mary Kathleen Group

**Stop 5/4: Scapolitic calcareous granofels and marbles of Corella Fmn. – arrive** 11.45am

Park bus in roadcut through Deighton Quartzite – walk 150m carefully along road verge to small track to south of road – climb through fence, walk south 150m

This exposure juxtaposes Corella Fmn west of the track with older quartzites of the basal Mary Kathleen Group (Ballara Quartzite) east of the track, separated by an east block up reverse fault. The excellent tight folding in the highly scapolitic bedded calc-silicate and calcareous granofels is directly attributable to drag along the fault zone. The more calcareous marble layers display extensive subhedral to euhedral scapolite crystals 1 to 5mm matchstick shapes

Along the fault zone a further 100m large calcite masses are likely to develop during the D2/D3 deformations, forming large calcite bodies that were mined for flux purposes at the Mount Isa smelters. The cigar-shaped calcite bodies commonly contain splashes of sulphides — coarse py, cpy and pyrrhotite. We may see large calcite rhombs along the track

Return to bus; depart 12.30pm

Drive to Cloncurry: lunch on bus OR at Corella river crossing east of Mary Kathleen. Drive to Ernest Henry mine, via Cloncurry. Arrive Cloncurry 1.30pm, arrive minesite 2pm.

# Ernest Henry Mine:

**Ernest Henry mine (hosts Xstrata – Mick Hawtin, Matt Clifford et al)**

**Induction and talk, Core examination, view open pit and examine ROM pad re sample material**

History: (This contains no information from the Xstrata period of ownership.)

Savage Resources acquired 11 mining leases north of Cloncurry in 1974 following an airborne geophysical survey of the area by government in 1973. Initial follow-up of magnetic anomalies was directed to discovery of a viable magnetite resource to be mined for coal washing purposes. Their focus was on "Savage 26", or ML8856 at Fort Constantine. ML8868 (to be renamed later as ML2671), on which Ernest Henry occurs, is about 10 km to the ENE of Fort Constantine.

BHP undertook a large regional program of airmag. and follow-up drilling in 1985–1990. BHP recognised two broad target types - high amplitude linear magnetic features, typical of, say, Selwyn-type iron formation-related Cu-Au mineralisation; and strong, non-linear magnetic anomalies close to granite margins, prospective for Cu/Au/U in skarns. BHP recognised 7 high priority targets, including one which fell on Savage's ML2671. BHP's drilling of targets on their ground produced disappointing results; no deals were done with Savage Resources, and BHP's program was terminated.

From 1990, Hunter Resources and Western Mining obtained exploration tenements over much of the same ground formerly held by BHP, with all of Savage's leases excised. In mid-1991, WMC/Hunter entered an option agreement with Savage Resources on ML2671, and in December 1991 the JV announced significant Cu-Au intersections. In June 1992, the JV gave notice that they wished to exercise the option on 6 of the 11 Savage leases. Savage were to retain a royalty on production, and retain rights to any magnetite produced. Savage rescinded the option agreement and commenced court action in October 1992, alleging trespass by WMC on ML2671. The subsequent court case was won by Savage Resources, and WMC/Hunter relinquished any claims to the Ernest Henry discovery.

During 1993 MIM successfully reached agreement with Savage for 51% of Ernest Henry (cost $75 million) and WMC/Hunter consented to Savage Exploration (now Ernest Henry Mining) being allowed to mine that part of the orebody identified as extending outside the lease.

Results of the early Hunter/WMC drilling include supergene zone intercepts of 84 m @ 3.47% Cu, 1.1 g/t Au, and primary zone intercepts of 92 m @ 1.65% Cu, 0.94 g/t Au.

Ernest Henry Mining released an Environmental Impact Assessment Study in early 1994. It described host rock geology as being felsic volcanics and minor carbonaceous siltstone, and a felsic volcanic-dolomite breccia. The host unit trends NE to ENE and dips 30°-40° to the south-east, and is cut (almost at right angles) by the structurally controlled mineralised breccia zones, which strike NNW. They appear to plunge subparallel to the broad lithological layering, but steepen in plunge to the south-east below about 400m depth. The report notes that the deposit contains 90Mt of ore reserves, mineable at 6mtpa for 15 years, from an open pit eventually 450m deep and 1100m diameter.

The volcanics are brecciated and "digested" by mineralising fluids. Magnetite, calcite, chalcopyrite and pyrite are the main ore/gangue minerals, and are associated with anomalous Au, Co, Mo, REE, and U. Footwall and Hanging wall zones are marked by zones of ductile shearing, below which is a zone of carbonate-rich breccia. The basic deposit geometry is two subparallel stacked lenses that merge to the west, with dimensions 250m thick, 300m wide and tested to 900m depth and still open.

The deposit bears all the attributes of a magnetite-rich breccia-hosted deposit in brittle 1730–1740Ma volcanics with some calcareous units (?Corella Formation, Soldiers Cap Group) in the near-vicinity. This sequence was invaded by Cu-Au bearing fluids, probably of high salinity, during a moderately high T shearing event in late ?D3 time which was accompanied, or post-dated by intrusion nearby of fertile fractionating U-Mo rich 1500Ma granites (the latter evident in the subsurface by circular magnetic lows) of the Williams/Naraku Batholith. F and Ba are also anomalous. Some Ar work suggests mineralisation may be as young as 1480Ma. The slight difference in dates throws up the possibility that the mineralisation is not DIRECTLY related to the granite (1480 vs 1500Ma respectively), but that residual heat from a high-U granite has been sufficient to still drive hot fluids and contained metals at an appropriate time into an appropriate structure.

The early geophysical interpretation by Craske for WMC (Craske, AIG Bulletin 16, 1995, 95–109) was based on a Starra model viz. folded BIF or structural ironstones as host to Cu-Au. Figure 3 shows a diagrammatic cross section of the breccia zones developed in the brittle volcanics. While the FW and HW limits are probably shear-controlled, the E and W limits may also be a shear-controlled making the overall structure a plunging box-like feature.

Ernest Henry open pit is now exhausted, and extension underground to exploit the deeper resource was approved in December 2009. Xstrata 3.12.2009 announced that the mine would continue as an underground operation, on reserves of 72Mt @ 1% Cu, 0.5g/t au, and 22% magnetite. This reserve is a 600% increase on previous published underground reserves. Production will be 50,000tpa Cu and 70,000 ozs pa Au, with minelife extended to about 2024. An additional flowsheet will produce magnetite as a saleable by-product.

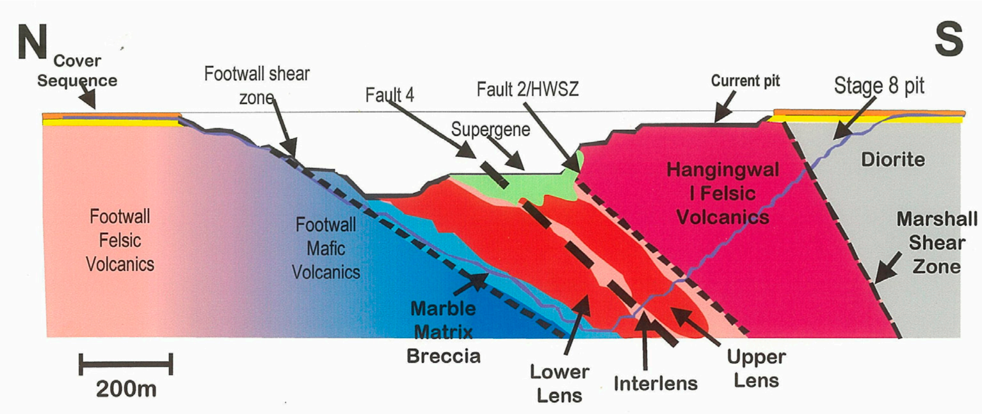



Figure 3. Diagrammatic section through the Ernest Henry Deposit

**Ernest Henry Volcanics + magnetite at Fort Constantine – possibly optional**

This is the site of an old quarry, probably worked for magnetite, but now used in part for road metal. The magnetite is hosted in schistose acid volcanics (?); the latter where fresh are pink to grey siliceous crystal tuffs or lavas, with only moderate preservation of volcanic textures; some trachytic breccias from just north of the quarries have been dated at about 1730–1740Ma, the same age as the Wonga Batholith well to the west. Albitic and actinolitic alteration is abundant in the volcanics.

In the quarries the felsic 'schist' and volcanics are altered and weathered. This degree of weathering has affected the magnetite quality, with a subsequent downgrading of the ironstone resource here as a viable product for coal washing purposes. The magnetite appears to vein the metavolcanics in a coarse stockwork style. Calc-silicate patches (cpx-amphibole-epidote) are present in parts of the massive magnetite.

There may be similarities with the Kiruna iron ores, insofar as the magnetite may be of magmatic origin (magnetite "dykes"), or of moderately high temperature metamorphic origin (magnetite veins in shear zones), near elements of the Naraku Granite. The latter is favoured.

It is now established that these 1730Ma–1740Ma volcanics are the same volcanics which host the Ernest Henry mineralisation a few km to the ENE, and are similar in age to the Wonga-Burstall suite at Mary Kathleen.

## *Day 6*:

**Thursday 16th August - Cloncurry - Mount Elliot, Selwyn, Kuridala region - Cloncurry**

# Selwyn Area

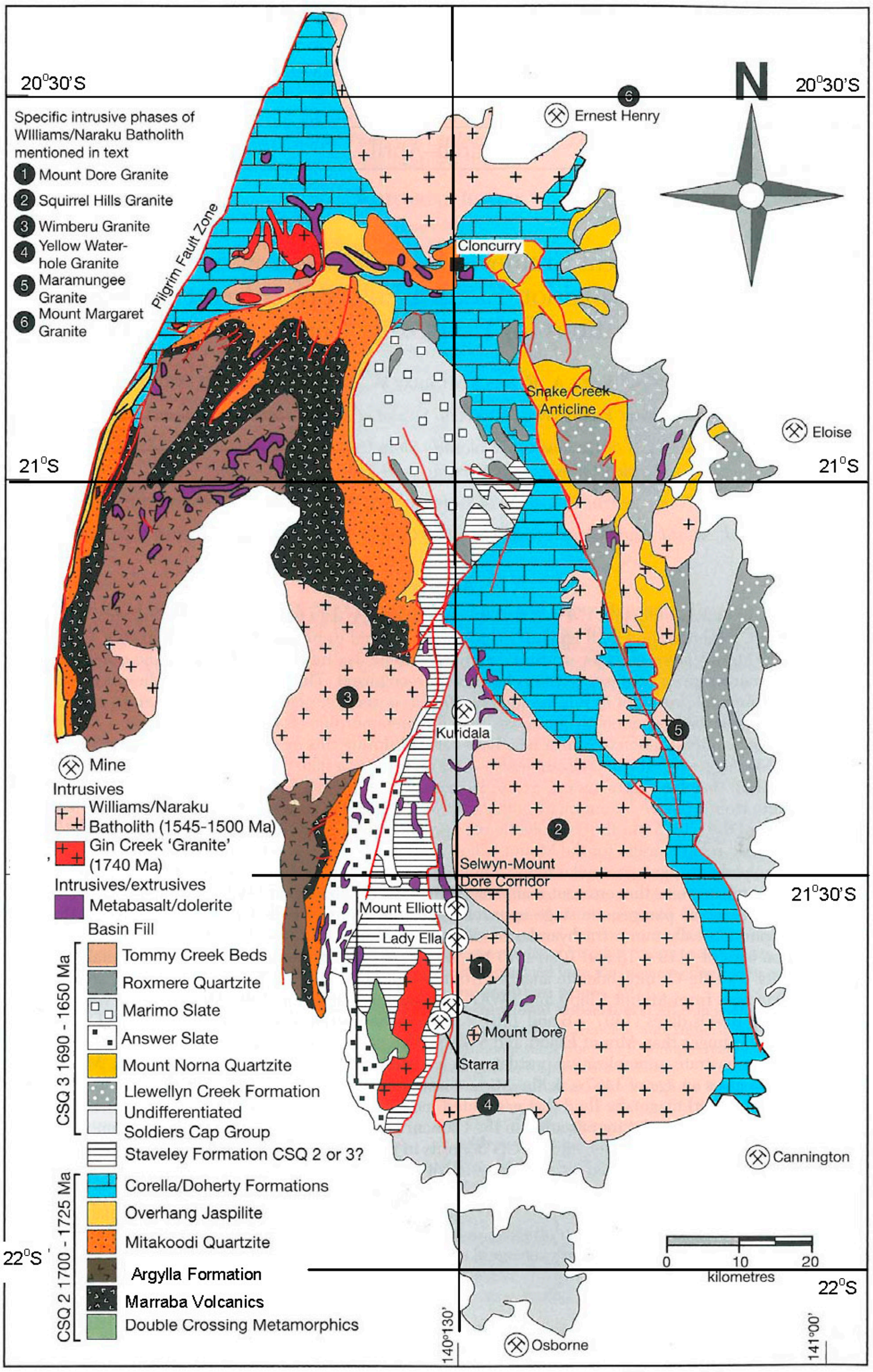



Figure 4. Generalised geological map of the Eastern Fold Belt

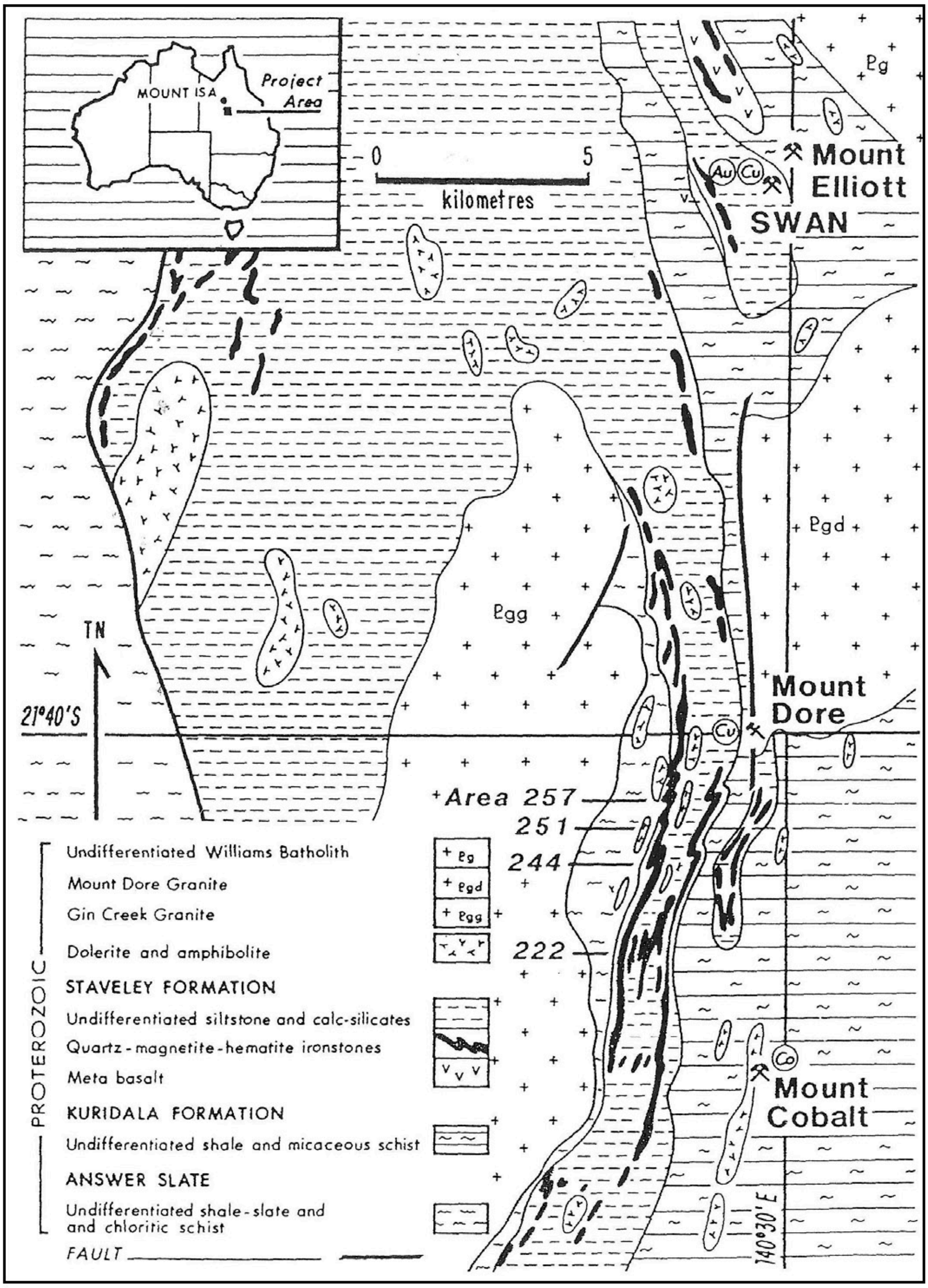



Figure 5. Geological map of the Starra district, showing Selwyn ironstones and numbered small mining operations

# Geological setting and mineralisation

The Selwyn region and Starra line occur within the Eastern Fold Belt of the Mount Isa Inlier, see Figure.4. The project area stratigraphy is part of the Soldiers Cap Group and Young Australia Group (which are lateral facies equivalents), and which are part of regional Cover Sequence 3. The depositional age for these Groups is 1712–1654 Ma, while the main phase of deformation and metamorphism is considered as equivalent to the Isan Orogeny at 1530–1480 Ma, associated with the Williams-Naraku Batholith.

## Regional Geology

The majority of the copper-gold deposits in the area (e.g. Merlin, Mount Dore, Starra and Mount Elliott) belong to the Iron Oxide Copper-Gold (IOCG) style of mineralisation and tend to focus on geological and structural elements, namely being in close proximity to:

- the contact of the Kuridala and Staveley Formations
- regionally extensive north-south trending shear and fault zones (long-lived faults that have been the principal conduits for fluid flow and alteration)
- late north-east and north-west trending structures
- proximity to a Williams-Naraku Batholith intrusion.

The whole metasedimentary package is buttressed either on one or both sides by granites, generally in close proximity to the major prospects.

### Stratigraphy

Proterozoic lithologies of interest in the project area are the Staveley Formation and the Kuridala Formation. The Staveley Formation, occurring WEST of the Mount Dore fault, comprises a >2000 m thick linear belt of shallow water, well-bedded to brecciated variably calcareous, ferruginous, feldspathic, micaceous, and siliceous sandstone, siltstone, and phyllite, impure limestone (marble), and lenses of breccia, together with schist and banded calc-silicate rocks (mainly near granite), and minor basalt lava, conglomerate, and banded quartz + hematite +/- magnetite rock. The Stavely Formation has a depositional age of <1720 ± 20 Ma.

The Kuridala Formation, occurring mainly EAST of the Mount Dore Fault) is a tightly folded package of moderately deep-water turbiditic sediments (schistose greywacke, siltstone and shale) with quartzite, carbonaceous and pyritic slate and calc-silicate rocks. The thickness of this sequence is >2000 m, although neither the top nor the base of the Kuridala Formation is well established. The Kuridala Formation has a depositional age of <1681 ±5 Ma.

### Intrusives

The series of linear batholith scale granitic intrusives are significant lithologies in the Mount Elliott to Mount Dore district. These include the Wonga Granite (Gin Creek Granite ) (1760–1730 Ma) which was emplaced contemporaneously (into Cover sequence 2), and the Williams-Naraku Batholiths (Mount Dore, Squirrel Hills, Yellow Waterhole, Wimberu Granites and SWAN Diorite) (1556–1504 Ma) outcrop over a large area in the EFB and were emplaced in late syn- to post-Isan Orogeny time.

Several dykes and sills intrude the Kuridala and Staveley Formations. At Mount Elliott, distinct bedding concordant basalt intrusives (metamorphosed to amphibolite) are present in the host Kuridala Fm. The same concordant dykes and/or sills also occur near the Mount Cobalt, Lady Ella, and Starra deposits.

### Tectonics

A complex regional metamorphic history (comprising six sequences) and peaking prior to the emplacement of Williams-Naraku intrusives has been proposed. The Mount Elliott - Mount Dore district has been mapped at greenschist facies to amphibolite facies metamorphism. The basement and cover sequences were deformed and metamorphosed by the Isan Orogeny (ca 1600–1500 Ma). Up to seven deformational events in the Eastern Fold Belt have been postulated. Of these deformation events four major events impact on the project area:

- D1: Early thrusting
- D2: Upright north–south large scale folding synchronous with the peak of metamorphism
- D3: Folding of D2 folds. Brittle-ductile deformation with intrusion
- D4: Upright north-south folding. Brittle events producing north-east–north-west faults are integral to the formation of many of the deposits in the region.

**Structure**
District structure is dominated by the regional-scale Starra, Selwyn and Mount Dore shear and thrust zone, which runs through the core of the district. These north-south striking structures host a number of deposits and include:

- Mount Dore Fault Zone (MDFZ): A north-south striking deep seated structure along the limb of two major regional folds, resulting in sheared sub-parallel series of faults which host a number of prospects including Marilyn, Mount Dore, Merlin, Flora, Busker and Metal Ridge
- Mount Dore Silicified Zone (MDSZ): A north–south striking silicified ridge that extends for at least 10 km both north and south of Mount Dore, and broadly marks the western limit of the MDFZ. This forms the footwall to the Merlin and Mount Dore
- The Starra Shear Zone is located 2 km west of and parallel to the MDSZ
- The Selwyn Line comprises an intensely alkali-iron-silica-carbonate altered section of the Starra shear zone, which is host to multiple high grade gold-copper shoots.
- The Selwyn Shear Zone runs parallel to the Starra Shear and the Starra deposits area. It essentially marks the Eastern Haematites, a line of ironstones.

Brecciation is a feature of many deposits in the district. Both hydrothermal (Amethyst Castle) and faulted and crackle (Mount Elliott) breccias are represented as well as combinations and overprints of the all styles throughout the region. The abundance of late brittle fractures may have also contributed to the development of secondary copper enrichment as noted in the Mount Elliott, Mount Dore, Victoria and Lady Ella. The newly discovered Merlin Mo deposit is strongly fracture-controlled in altered fine-grained metasediments.

**Alteration**
In the Southern Cloncurry District metasomatic alteration events play a fundamental part in the formation of the majority of deposits within the belt, by either being directly associated with carrying mineralisation or by rheologically preparing rocks for brittle fracture or ductile shearing. There are two main regional scale alteration events:

- The first event is regional Na-Ca metasomatism.
- The second regional alteration event consists of large scale K-Fe-Mg alteration.

Both these alteration assemblages are commonly found associated with mineralisation within the region. Specific alteration types and episodes noted in the district and deposit related are:

- Iron-oxide alteration early — shear hosted (Starra) magnetite or hematite rich
- Iron-oxide alteration later — veined replacement (Mount Elliott) magnetite
- Sodic alteration (widespread) — replacement, veined, stockworking and brecciation (Mount Elliott)
- Sodic-calcic alteration — banded, veined, massive and breccia replacement and infilled (Starra, SWAN and Mount Elliott)
- Potassic alteration (widespread) — veins and breccia clasts replacement and matrix infill K-feldspar, carbonate and biotite veining (Mount Dore, Merlin, Lady Ella and Starra)
- At least four fluid sources have been proposed as being involved in the regional alteration, metasomatism and formation of ore deposits.

# DAY 7:

**Day 7: Friday 17 August 2012**

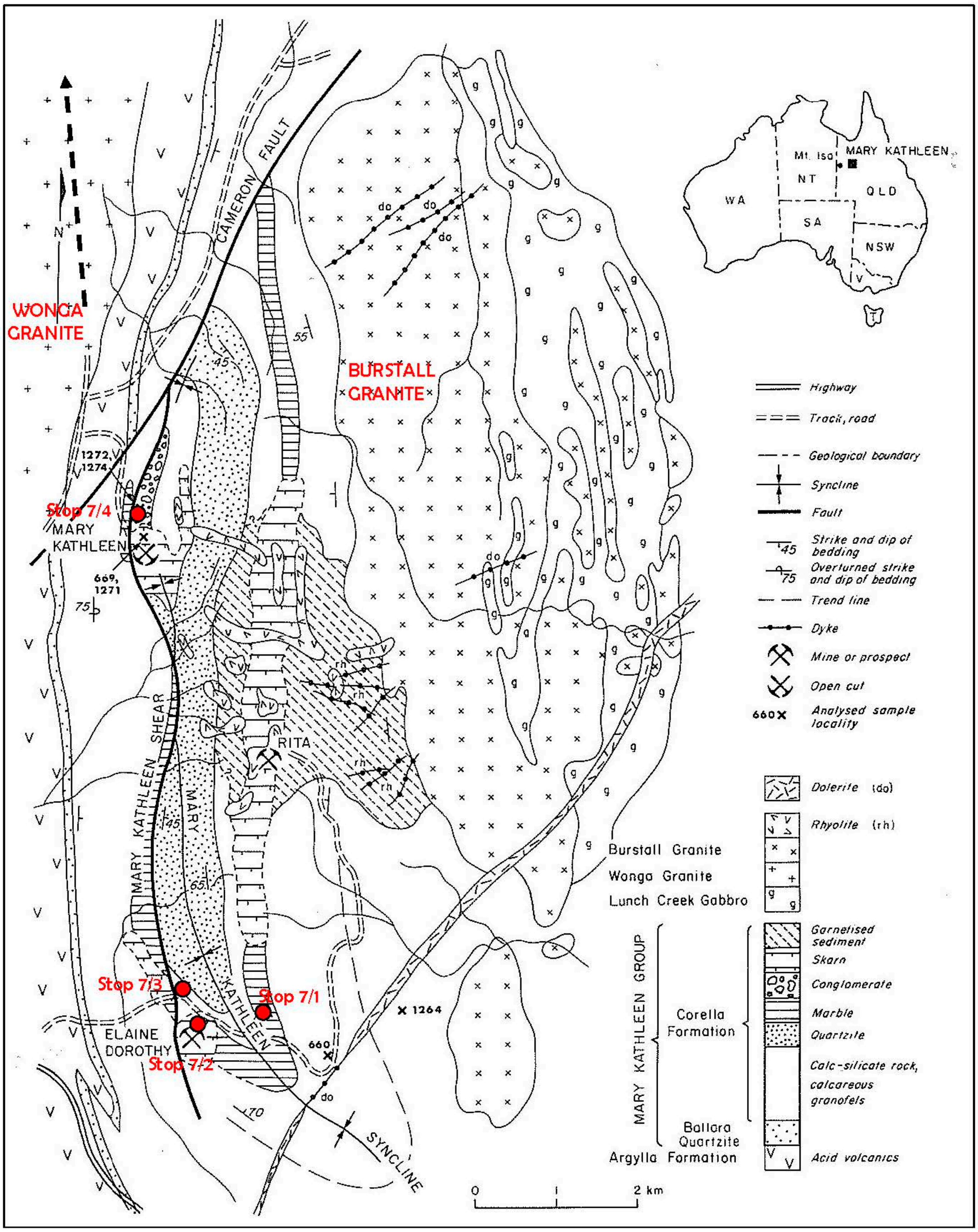



Figure: Geology of the Mary Kathleen syncline, with stop locations *(from Derrick , 1977, BMR Journal)*

Depart Cloncurry 8.30am for return to Mount Isa, via stops in the Mary Kathleen region, examining high temperature low pressure contact metamorphic rocks in the aureole of the 1740 Ma Burstall Granite.

**Stop 7/1: Wollastonite marbles and calc-silicate rocks, axial zone, Mary Kathleen syncline**

***Rationale***: examine calcareous sediments of the Corella Formation (Mary Kathleen Group), intruded by 1740Ma granite, and which are host to the Mary Kathleen Uranium deposit 5km to the north.

Turnoff highway approx. 60km from Cloncurry along access track to a microwave tower and Cu and U prospects at Mount Colin and Elaine Dorothy; drive 2km into east limb of Mary Kathleen syncline, an upright D2 structure (1550–1500Ma) — arrive 9.30am.

Examine high-grade Corella Fmn. wollastonite and vesuvianite marbles, calc-silicate granofels with 2-8mm grossular garnet porphyroblasts, and interbedded f.g. cherty ?albitic, diopsidic and scapolitic granofels, all part of high-grade (high T, low P) metamorphism in the Wonga belt. The degree of strain in these high temperature marbles (T = +600°C?) is low, given that cross-bedding is still preserved in some of the "sandy" marbles, with correct facing evident. Wollastonite forms as fibrous hemispherical masses in bedding planes, and is best seen on weathered surfaces.

**Little or no hammering would be appreciated, except on already broken pieces.**

This marble unit is extensively skarn-altered directly along strike to the north, where the microwave tower can be seen in the far distance. The source of fluids and heat is taken to be the 1740Ma Burstall Granite, which is a thick sill dipping westwards under this sequence, but this entire area has probably undergone major D2 metamorphism as well. The effects of postulated late metamorphism D2 and D3 are not well understood, but resetting of 1740Ma U and skarn at Mary K open pit is one possible example of a D2 overprint on a 1740Ma metamorphic and skarn event.

Depart 10.15am

**Stop 7/2 — optional: Andradite – diopside skarn overprinting calc-silicate rocks**

Examine pavement exposure near creek of folded calc-silicate granofels with some skarn alteration.

Drive up exploration tracks to recent drill pads etc. Examine reddish-brown andradite skarn replacement of high-grade calc-siilicate granofels, in a flexure of the Mary Kathleen shear. Recent drilling of gossans in this area has identified a massive sulphide body at depth containing extensive pyrrhotite, green diopside, red andradite, calcite and some pyrite and chalcopyrite. Drill intercepts include 346m @ 0.28% Cu, 220 ppm Co from 263m, and 123m @ 0.56% Cu, 317ppm Co from 487m.

**Stop 7/3 — drive back to heritage outcrop of folded marbles on west limb of syncline; also visit blue Caesar prospect**

**Heritage site: NO HAMMERS PLEASE!!**

Spectacularly D2-folded vesuvianite and grossular marbles of Corella Fmn deformed adjacent to the Mary Kathleen shear, which is located at or about the fenceline and track to the east. The folding is a tectonic phenomenon, and is not, as one visitor once proposed, a stromatolite mound. Note strongly disharmonic folds with thickened hinges and attenuated limbs; grossularite is colourless to pale grey, and vesuvianite forms small pale olive green matchsticks 1mm to 0.5mm long. Vesuvianite identifies these marbles as high temperature (600°C) low pressure types, and wollastonite appears to be absent (compare with east limb mineralogy). Hills to the south are massive uraniferous andradite skarn at the Elaine Dorothy prospect.

Walk NW 100m to meet coach near gate. There is further massive skarn to the west containing cpx (salite/diopside), andradite garnet and secondary hastingsite, epidote etc. Near the gate and fence, a cupriferous gossan ("Blue Caesar") and old diggings with massive coarse calcite rhombs is possibly a late effect (D3). Alteration around this gossan contains calcite-scapolite masses with rare 1mm to 1cm crystals of pale green **apatite**. Apatite is a moderately common associate of late D2/D3 mineralisation in the Wonga belt, indicating high P levels in fluids, or perhaps a carbonatitic association.

Depart 11.30am

Drive to main road and head west towards the abandoned Mary Kathleen township, and drive north towards the Mary Kathleen open cut. Stop for lunch 12noon under a shady tree at rough turnoff into the open pit area. Allow half hour or so — depart for open pit 12.30pm

**Stop 7/4 — Drive up rough track to Mary Kathleen open cut – arrive 12.45pm**
**WARNING: take care in walking through boulder field to open pit; on open pit bench, stay away from overhangs, loose rock faces and edges of benches.**

Boulder and cobble conglomerate, amphibolite and other calcareous sediments can be traced north to south into a massive andradite skarn stockwork; the latter replaces all of the above units, with skarn formation occurring firstly in calcareous units, along fractures and in the matrix material of massive cgm. At the western end of the bench is a monzonite dyke striking almost E-W subparallel to the bench. It displays massive crackle fracturing with extensive andradite-diopside garnet alteration, producing a massive skarn breccia. This skarn breccia should not be confused with the skarn-altered boulder conglomerate, which has a north-strike trend. Ghosts of both cgm clasts and brecciated dyke fragments can be seen in the massive garnet-pyroxene skarn further east along the bench, and some late fractures and joints display a retrograde alteration to black allanite within the skarn. This black allanite is host to uraninite, the main U ore mineral, which occurs as fine-grained inclusions within the allanite. Two ages of skarn are indicated — one is related to the 1740Ma Burstall Granite event, with which the skarn system appears spatially and possibly genetically related; the other skarn event is dated at about 1500Ma i.e. D3 age, and is related to semi-regional resetting and late metamorphism. No 1500ma granites have been found near Mary Kathleen at this stage. The ?diorite or monzonite dyke is undated, but does cut across the upright D2 fold trends.

Note the Mary Kathleen shear to the west of the open pit - movement sense is west block up - a late D2 to D3 structure.

**Extracts from Oliver et al., 1999**, *Mary Kathleen metamorphic-hydrothermal uranium-REE deposit: ore genesis and numerical model of coupled deformation and fluid flow. Austr. J. Earth. Sci., 46, 467-484.)*

- The ore is allanite (the REE-bearing epidote-family, black), uraninite, andraditic garnet, and some scapolite, clinopyroxene, and a host of rare REE-minerals.
- The orebody originally contained 10,000 tonnes of $U_30_8$ at a grade of 1.2 kg 1 tonne, and large tonnages of REE (up to 7.6%). It opened in 1956 and closed in 1982 after an intermittent mining history.
- Isotopic modification of primary skams occurred during regional metamorphism, with a 1580 $\pm$ 50 Ma Sm-Nd age on altered skarn in the orebody (Maas et al. 1988), and 1550-1500 Ma U-Pb dates for the uraninite-bearing ore (Page 1983). On structural and petrological grounds, the timing of the ore was late-D2, possibly extending to D3. The model envisaged for ore genesis is leaching of a uraniferous host during regional metamorphism, concentration in the regional metamorphic fluid, and focussing of the fluid towards chemically- and structurally favourable sites, particularly in veins and dilatant zones. Finite difference modelling of skarn, marble, the Mary Kathleen Shear Zone, and ore shoots explains the geometry of the ore veins by tensile failure in strong skarn rocks mechanically coupled to the large ductile Mary Kathleen Shear Zone. The major remaining point of contention concerning ore genesis is the nature and scale of

the U-bearing source region (cf. Maas et al. 1988; Oliver et al., 1999).

- The ore shoots form an anastomosing array that crosscuts the earlier monzonite and metaconglomerate breccia (Pearson 1982), giving strange double-breccias in some places. A tentative theory for a chemical mechanism for ore deposition is redox-related:

Reduced cpx-rich (Mg-Fe2+) skarn + oxidised U-REE bearing saline fluids
===> oxidised (Al-Fe3+) garnet-rich skam + U-REE ore + reduced fluid

- As you will appreciate from the irregularly brecciated and metasomatic appearance of the ore, it has proven very difficult to do quantitative mass balances on the ore-forming process because of the heterogeneity of the ore and the hosts. We prefer a distant origin for the U-REE, although Maas et al. (1988) prefer a "protore" model in which the U-R-EE is derived from preexisting local ore.
- The greatest rheological heterogeneity that influenced fluid flow during the regional metamorphism in the MKFB was the contrast between the strongest rocks (skarns, dolerites) and the weakest rocks (marbles). The most extreme example of this in the MKFB is across the Mary Kathleen Shear Zone.

Depart open pit area by 2pm for Mount Isa

Arrive Mount Isa 4pm at latest to meet with departing flight at 6.50pm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