

Lady Loretta Zn-Pb-Ag deposit and Lady Annie Cu deposit



LOCATION

Geological Domain

Western Fold Belt of the Mount Isa Inlier, Mount Oxide Structural Domain (Figs. 8.1 and 8.3).

Co-ordinates

Lady Loretta

Latitude: 19°46'07.85"S [-19.768992]
Longitude: 139°03'57.68"E [139.065961]
MGA Zone 54: 297,365 E; 7,812,917 N

Lady Annie

Latitude: 19°46'22.20"S [-19.773056]
Longitude: 139°02'43.84"E [139.04519]
MGA Zone 54: 295,193 E; 7,812,442 N

NATURE OF MINE

Mined Commodities

Lady Loretta: Pb, Zn, Ag
Lady Annie: Cu, Co, Au

Mining Method

The mining method at Lady Loretta is based on a mixture of transverse and longitudinal long hole open stoping with paste fill (Xstrata, 2012).
Ore from open pit mining at Lady Annie is subjected to heap leach processing (NetMind, 2017).

Depth of Mining

Underground mining at Lady Loretta has reached a depth of 480m (the base of the ore-body).
The Lady Annie open pit extends to approximately 80 m, restricted to the shallow supergene oxide copper mineralisation. The satellite pits for the Lady Annie project are also shallow open pit oxide copper mining operations.

PRODUCTION AND DIMENSIONS

Mineralised bodies

The mineralised body at Lady Loretta is stratabound within the Ore Horizon, and comprises relatively high grade Zn-Pb-Ag mineralisation. The Ore Horizon is located within the hinge and up the limbs of a tightly folded southwest-trending syncline (Fig. 8.2). The syncline is dissected by several faults, the most notable being the Carlton Fault Zone, which forms the northwestern margin to the deposit, and the steep north-trending Syncline Dividing Fault, which separates the "Big Syncline" to the south and the Small Syncline" to the north.
Economic grades are only present within the Ore Horizon in the Small Syncline, into which the main shaft has been developed. The highest grades occur in the hinge, with the ore widths and grades increasing down the limbs towards the keel of the syncline. The highest grade ore is concentrated at the bottom of the keel along the footwall contact where layering is overprinted by a degree of recrystallisation giving a slightly coarser texture (Hancock and Purvis, 1990).

The Lady Annie project incorporates mineral re-

sources from eight different deposits, which are located in three main clusters in the Western Succession. The Lady Annie and Lady Brenda deposits are in vicinity to the Lady Loretta deposit. The Mount Clarke, Flying Horse, McLeod Hill, Swagman and Lady Colleen deposits are in the Mount Kelly area, approximately 15km southeast of Lady Annie. The Anthill deposit is further south, approximately 45km south of Lady Annie.

Dimensions

The Lady Loretta U-shaped syncline-hosted orebody (Fig. 8.2) is approximately 30-50m thick, 300-600m wide from limb to limb including the thickest hinge zone, and approximately 600-800m long parallel to the Small Syncline.
The mineralised bodies in the Lady Annie and satellite pits have variable geometries and are typically not well constrained given drilling has been shallow and focused on copper oxide mineralisation. The best constrained Lady Annie orebody is approximately 500-700m length in the east-west direction, 250m N-S, and approximately 30-50m thick (Fig. 8.5)

Orientation of Mineralised bodies

The Lady Loretta Zn-Pb orebody comprises a U-shaped body (Fig. 8.2) with its thickest section in the southwest-trending hinge zone of the Small Syncline, thinning in a sub-vertical to steeply southeast-dipping orientation into the western limb of the Small Syncline.
The Lady Annie Copper oxide orebody is flat-lying to shallowly dipping, with the underlying sulfide mineralised system interpreted as a mod-

ed in Table 8.3, and summarised by tonnage in Figure 8.4.

REGIONAL MAPS

The following pages include a set of regional overview maps (Figs. 8.6 - 8.15) providing the geological mapping, the key regional geophysical datasets and the stream sediment geochemical coverage for the area covering the Lady Loretta deposit and the key projects of the Lady Annie project (with the exception of the Anthill deposit that is approximately 50km to the south of Lady Annie).

METAMORPHISM

Illite-crystallinity studies in the region (Gibson and Hitchman, 2005) have suggested peak metamorphic temperatures during D2 to have been in the range of 200 to 300 degrees celsius, and b cell parameter values of white micas suggest geothermal gradients at the time of between 25 and 30 degrees per km, suggesting burial depths between 7 and 10km.

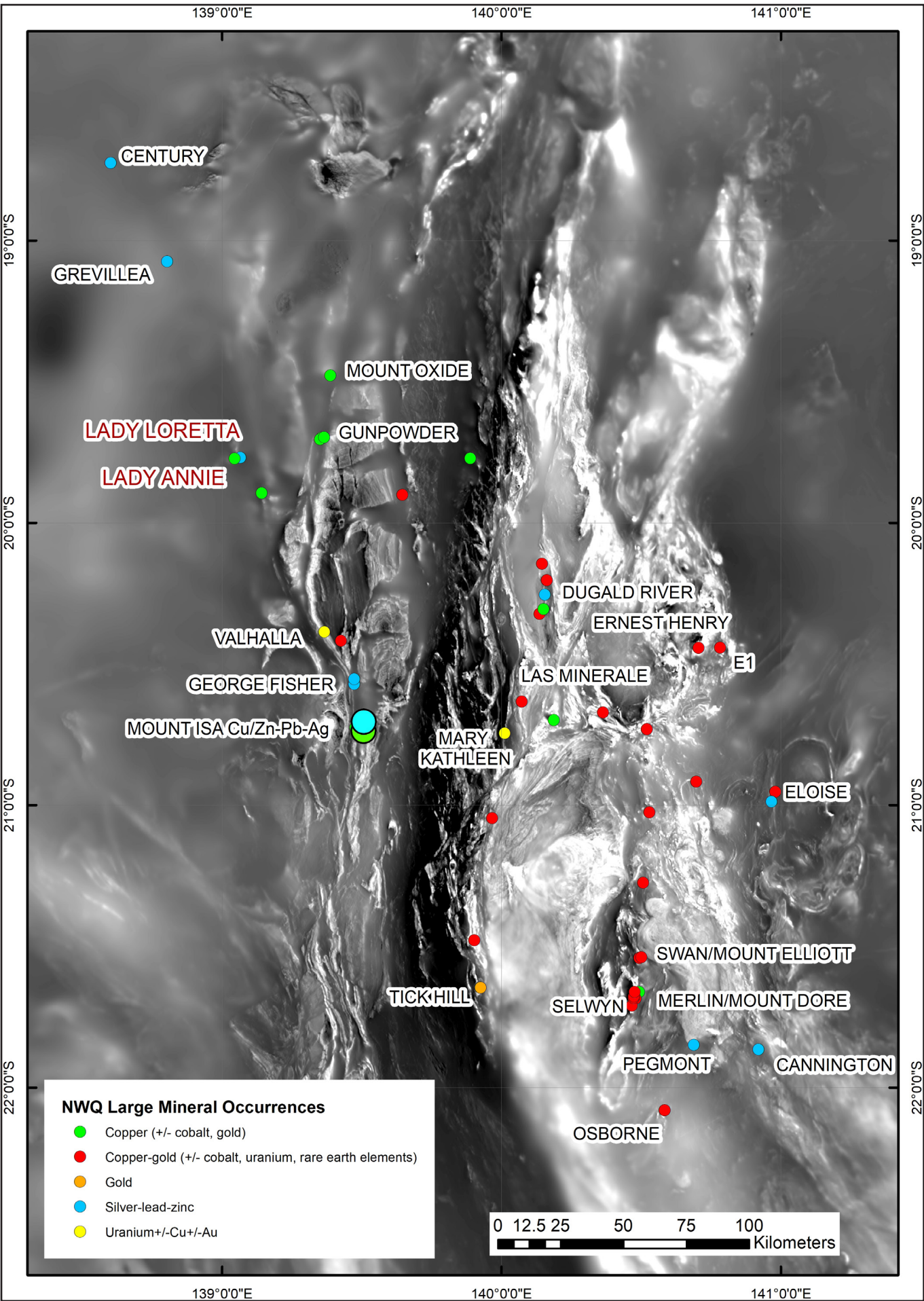


Figure 8.3. Regional location of Lady Loretta and Lady Annie overlain on an image of total magnetic intensity from the GADDS data for the region

Figure 8.4: Distribution of mineral resources by tonnage amongst the Lady Annie project main and satellite deposits.

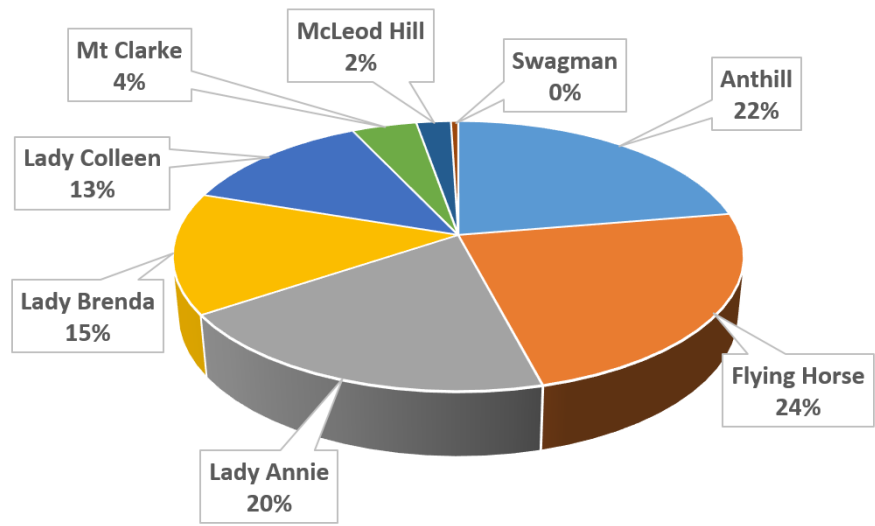


Table 8.2: Summary from Golder (2018) of the total mineral resources and ore reserves across the eight deposits of the Lady Annie Project.

Resources	Tonnage (Mt)	Cu (%)	Ca (%)
Measured	10.95	0.72	3.5
Indicated	36.35	0.72	4.8
Inferred	14.43	0.64	4.4
Total/average grade	61.7	0.70	4.5

Reserves	Tonnage (Mt)	Cu (%)	Ca (%)
Proved	1.44	0.74	3.0
Probable	0.54	0.83	3.5
Total/average grade	1.97	0.76	3.1

Deposit	Material Type	Total			
		Mt	Cu%	Ca%	Mg%
Anthill	Oxide	8.9	0.73	0.3	0.3
	Transition	2.4	0.74	5.6	3.2
	Sulphide	2.5	0.57	6.2	3.7
	Total**	13.8	0.7	2.3	1.4
Flying Horse	Oxide	1.45	0.48	0.6	0.6
	Transition	2.35	0.62	4.5	2.6
	Sulphide	10.71	0.85	5.5	3.2
	Total**	14.51	0.77	4.9	2.9
Lady Annie	Oxide	1.89	0.47	0.6	0.5
	Transition	5.39	0.77	8.1	4.8
	Sulphide	4.88	0.86	9.6	5.9
	Total	12.16	0.76	7.5	4.6
Lady Brenda	Oxide	4.02	0.44	1.2	0.8
	Transition	4.09	0.52	8.6	5.1
	Sulphide	0.84	0.51	8.7	5.2
	Total	8.95	0.48	5.3	3.2
Lady Colleen	Oxide	0.2	0.58	0.9	0.4
	Transition	2.1	0.75	3.8	2.1
	Sulphide	5.6	0.89	4.4	2.4
	Total	7.9	0.84	4.1	2.3
Mt Clarke	Oxide	0.52	0.44	0.3	0.5
	Transition	0.57	0.53	1.7	1.1
	Sulphide	1.55	0.57	1.9	1.2
	Total	2.64	0.54	1.6	1
McLeod Hill	Oxide	0.5	0.35		
	Transition	0.6	0.57		
	Sulphide	0.4	0.56		
	Total	1.4	0.49		
Swagman	Oxide	0.2	0.65		
	Transition	0.1	0.55		
	Sulphide	0	0.45		
	Total	0.3	0.6		
TOTAL	Oxide	17.65	0.59	0.5	0.4
	Transition	17.56	0.67	6.4	3.7
	Sulphide	26.52	0.8	5.9	3.5
	TOTAL	61.73	0.7	4.5	2.7

Table 8.3: Summary of the Golder (2018) mineral resource estimate for the Lady Annie project, which encompasses eight smaller deposits. The Measured, Indicated and Inferred categories have been summed, with the original breakdown available in Golder (2018).

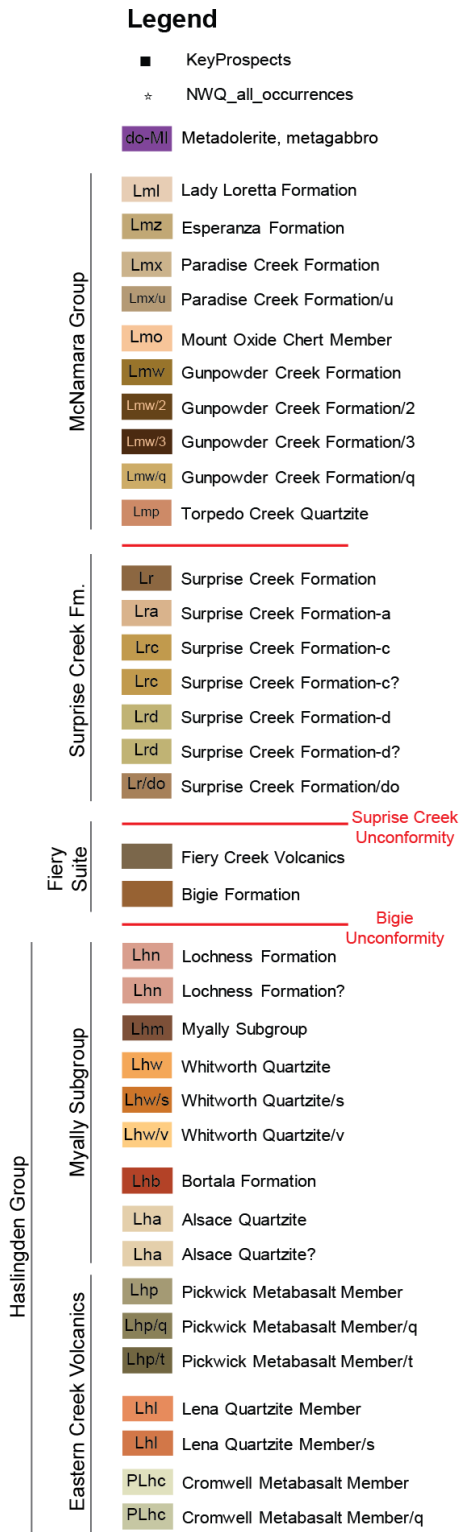
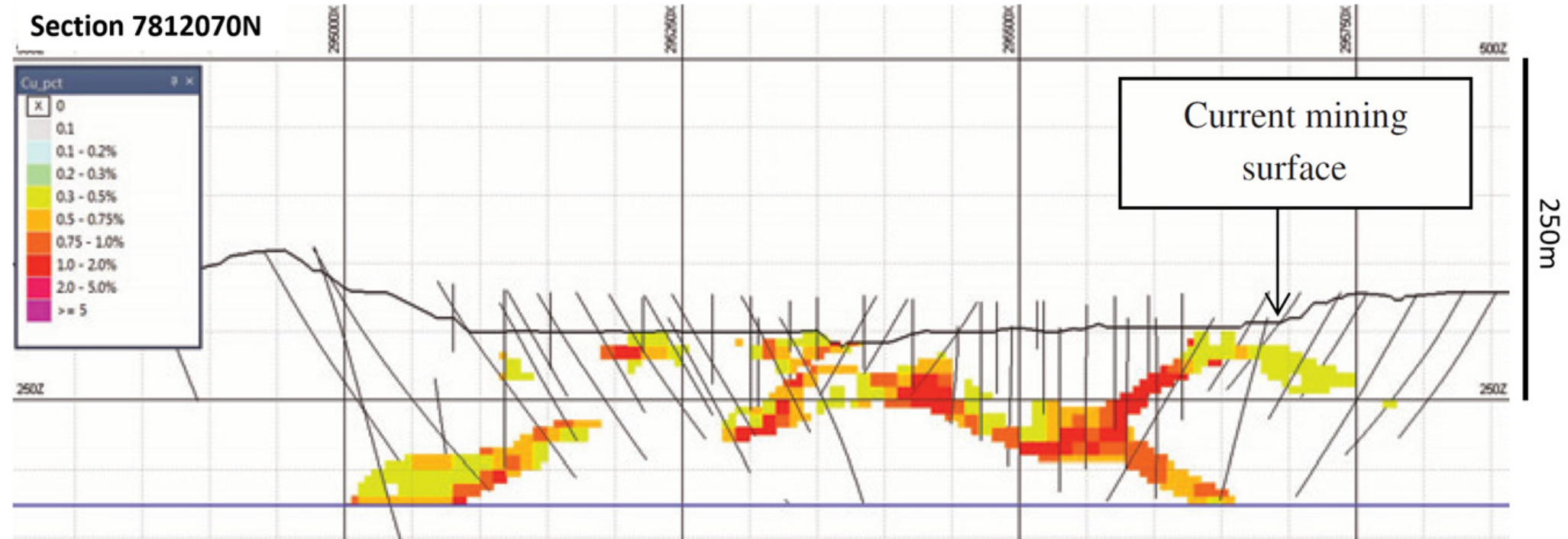


Fig 8.5: East-west cross section (7812070N) through the Lady Annie deposit as at 2012, The section highlights the shallowly dipping nature of the oxide copper zones, and the strong shallow drilling focus .



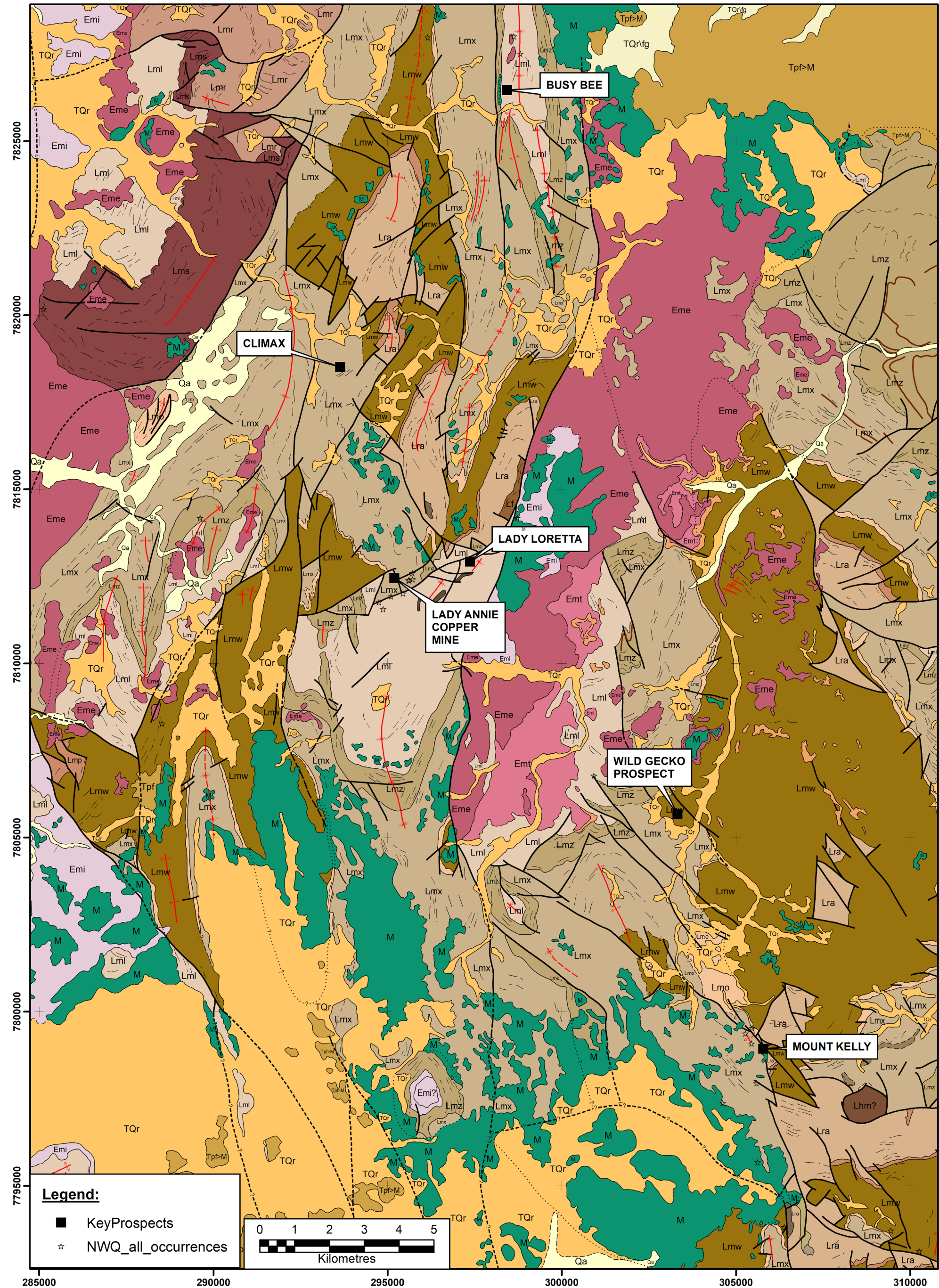


Figure 8.6. Regional geology of the Lady Loretta and Lady Annie region from the 1:100,000 scale Mammoth Mines sheet. See Legend on facing page.

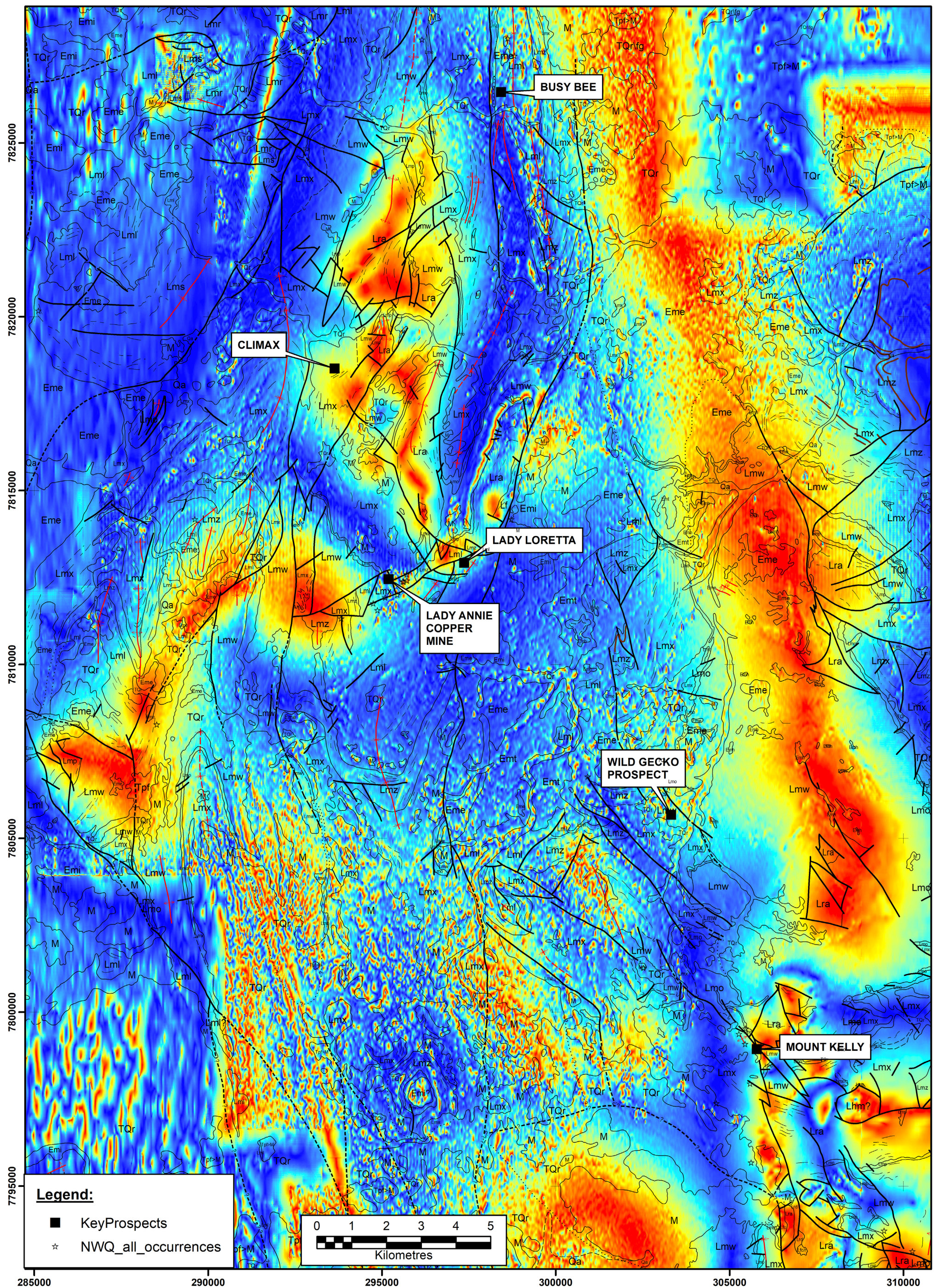


Figure 8.7: Pseudocolour image of a stitch of available detailed aeromagnetic datasets. Data has had a TILT filter applied.

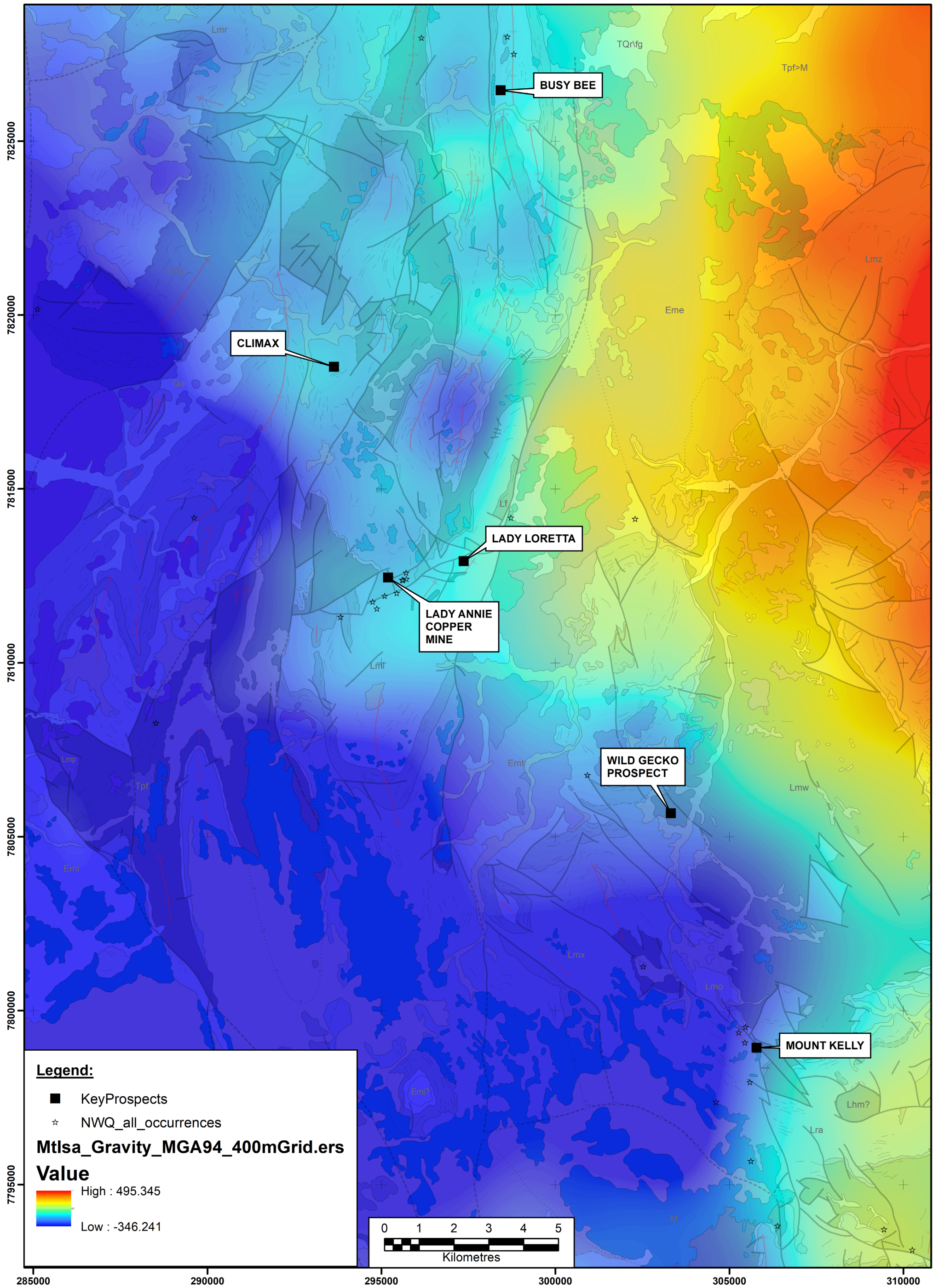
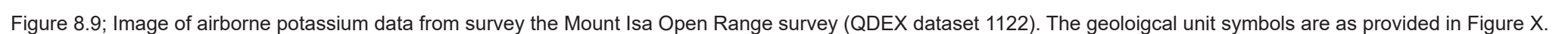
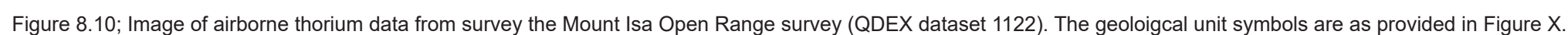


Figure 8.8: Image of the regional gravity dataset. The base dataset in this area is a 2km-spaced survey, although tighter station spacing is locally evident.





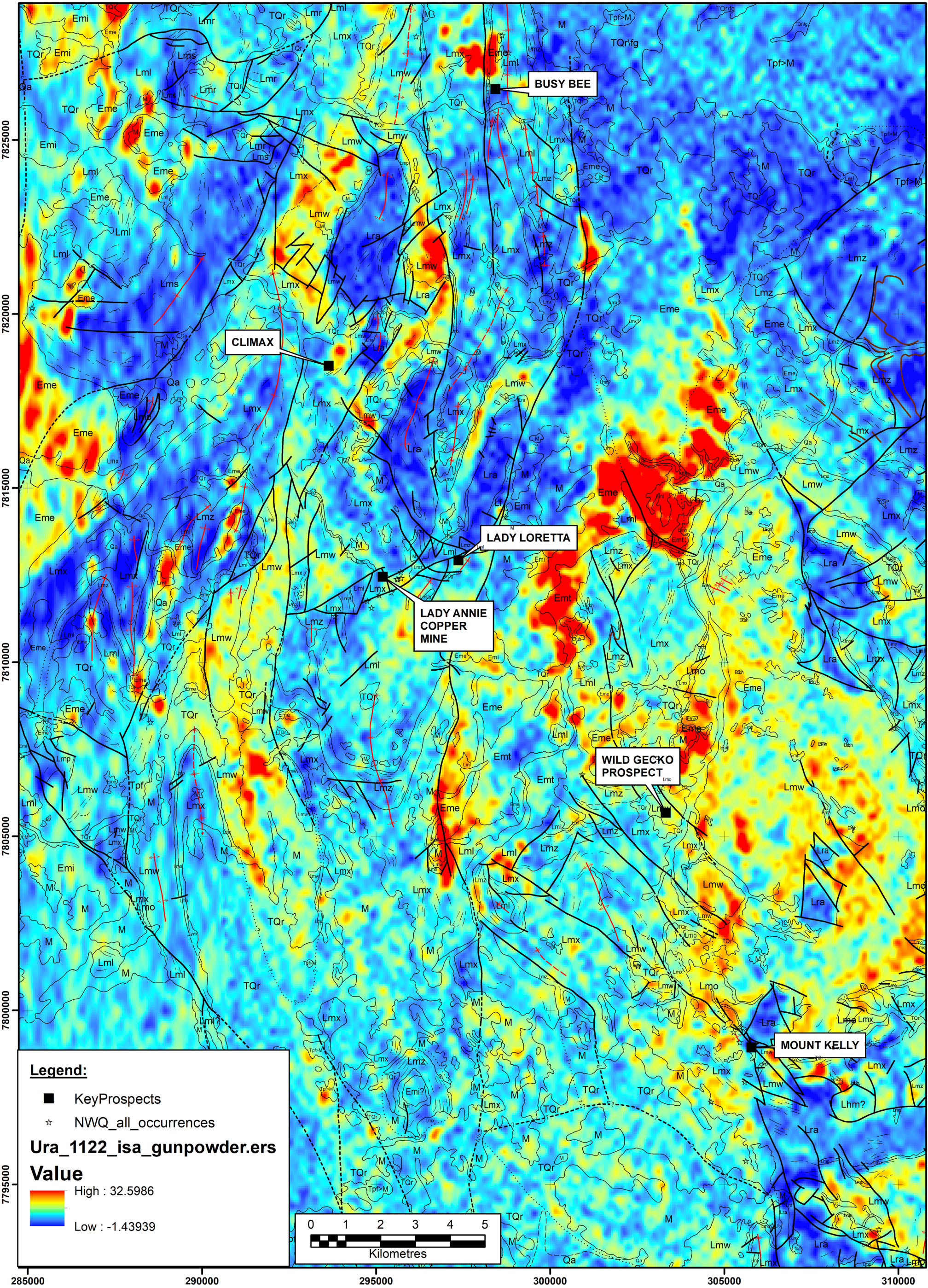


Figure 8.11; Image of airborne uranium data from survey the Mount Isa Open Range survey (QDEX dataset 1122). The geological unit symbols are as provided in Figure X.

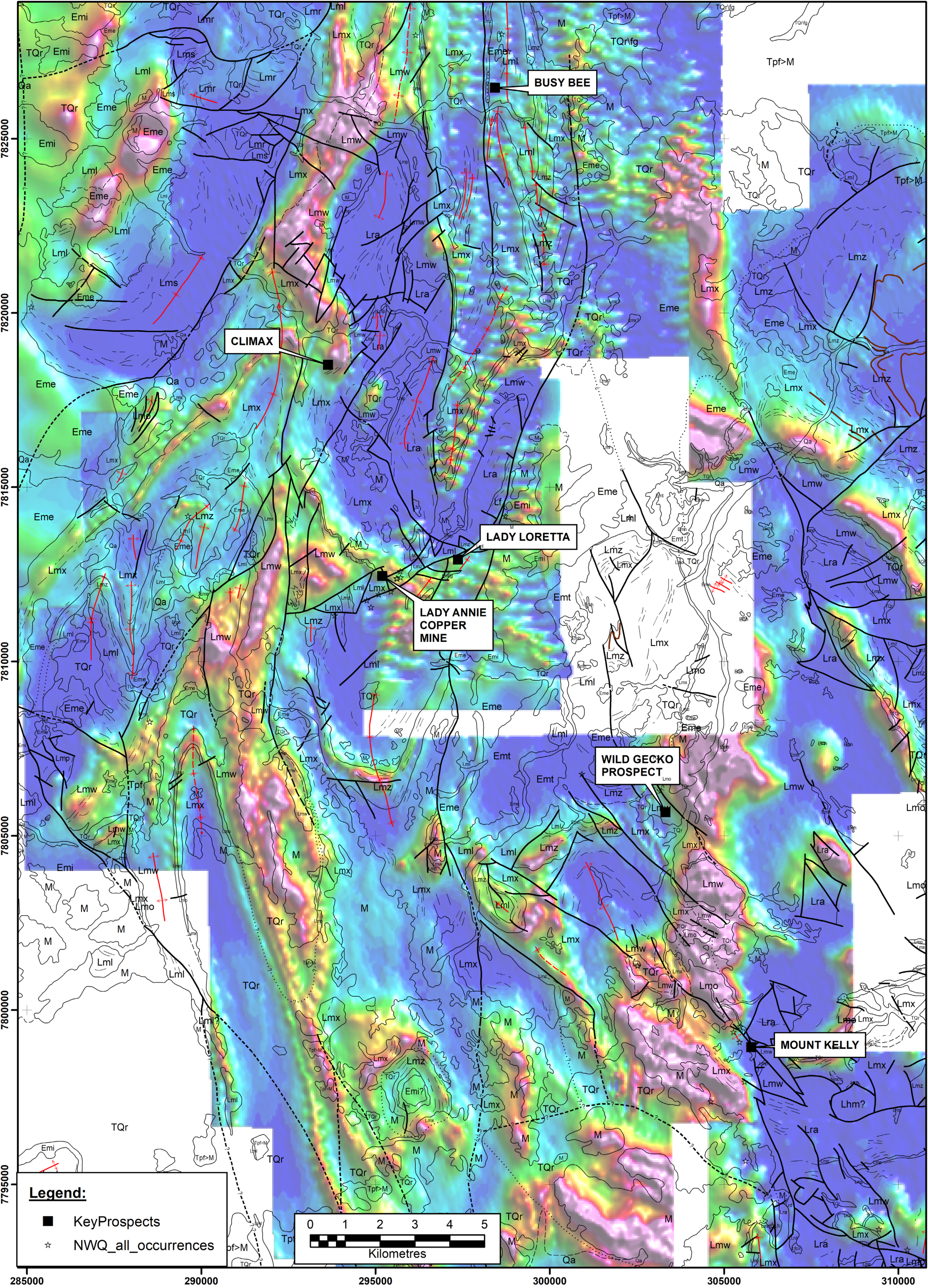


Figure 8.12; Image of airborne EM data compiled from various openfile surveys available from the QDEX Data service.

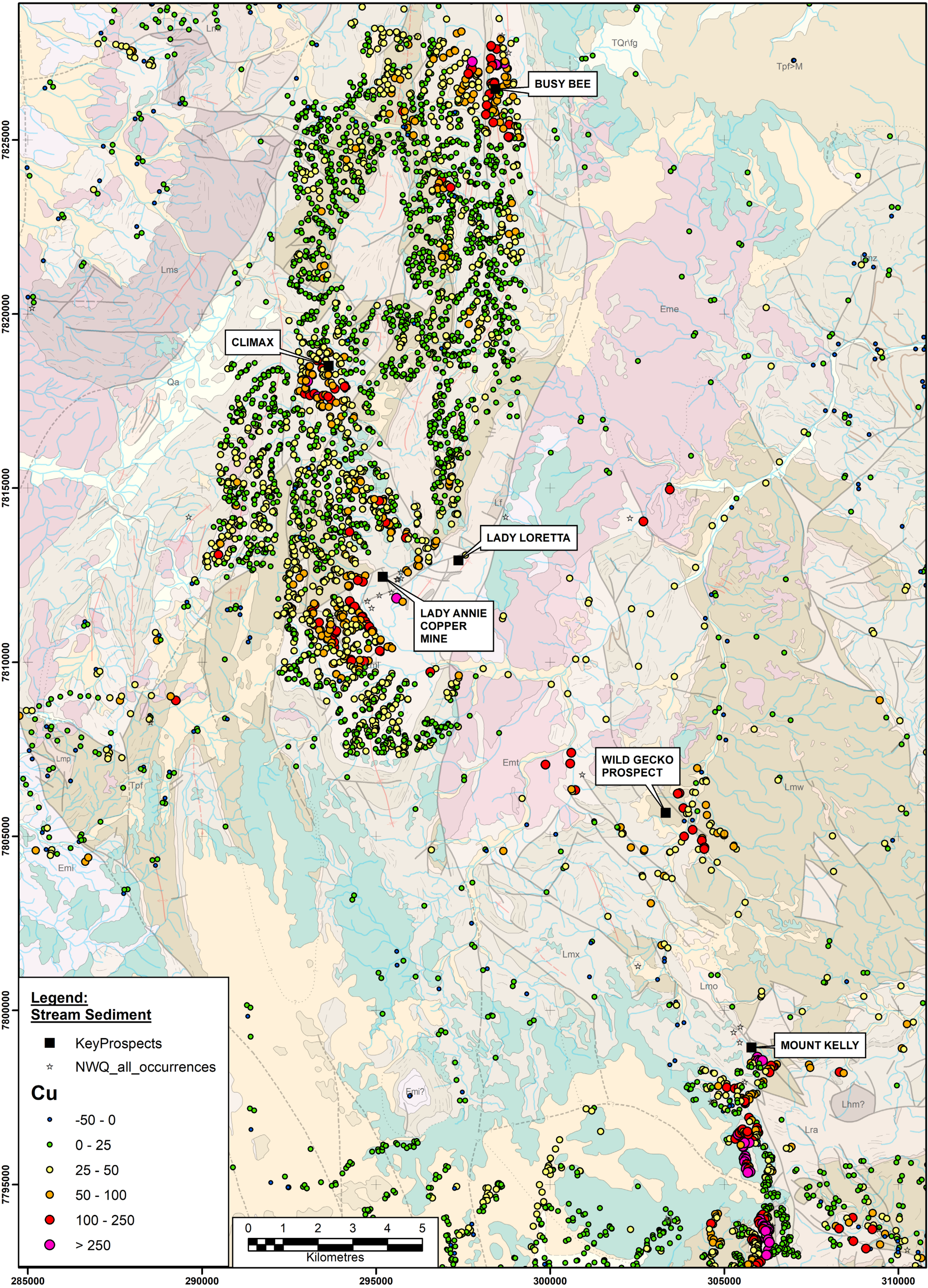


Figure 8.13; Plot of copper values from the open file stream sediment geochemistry dataset (Isa West).

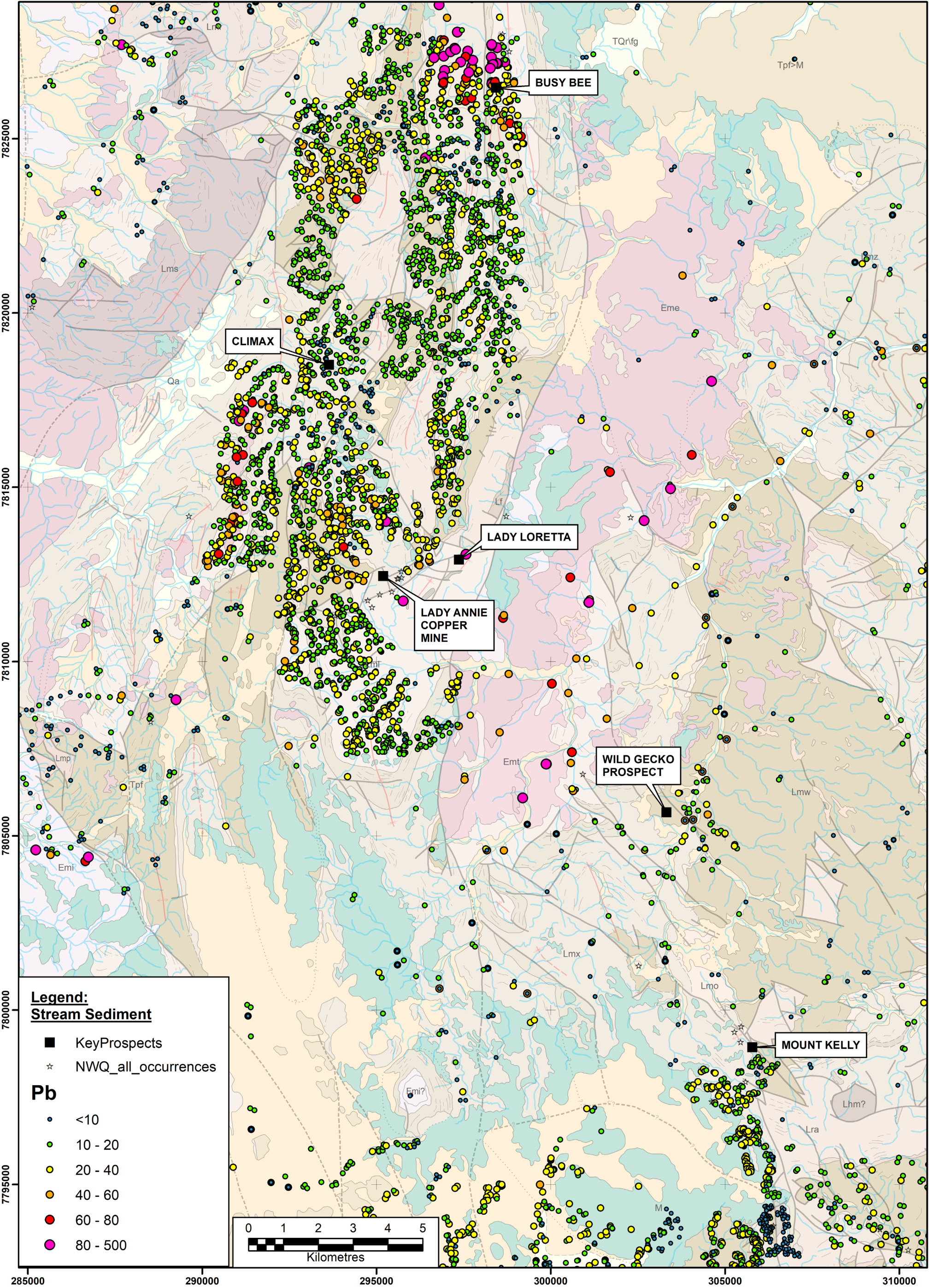


Figure 8.14; Plot of lead values from the open file stream sediment geochemistry dataset (Isa West).

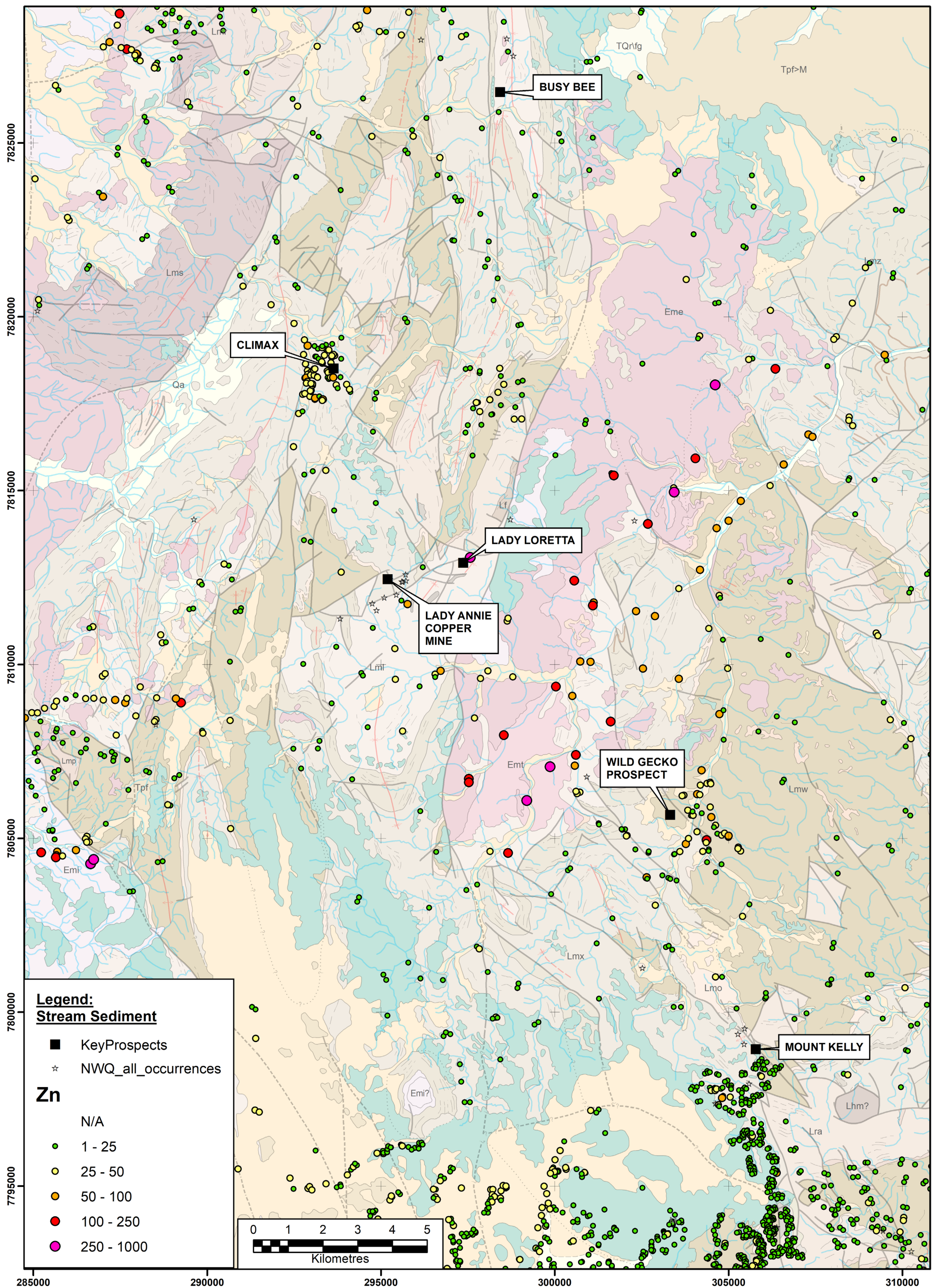


Figure 8.15; Plot of zinc values from the open file stream sediment geochemistry dataset (Isa West). Note many of the early surveys in this area only assayed for Cu and Pb, and not for Zn.

STRUCTURAL CHARACTERISTICS - LADY LORETTA

Structural Setting

The Lady Loretta Deposit is hosted in the keel of the Small Syncline, a tight northeast trending fold truncated by steep to moderately north-west dipping NE to ENE faults (the Koff and Max's Faults - Fig. 8.17), and with the major Carlton Fault Zone truncating the syncline to the northwest (Fig. 8.16). The northeast trending syncline is interpreted as an F2 structure by Lee (1972).

The syncline is truncated to the northwest by the Carlton Fault Zone, which is a steeply southeast dipping fault with a normal sense of movement, having the younger Lady Loretta Formation rocks in the hanging wall against the underlying older Esperanza Formation. The Carlton Fault is associated with extensive zones (up to 200m wide) of shearing and brecciation (Hancock and Purvis, 1990). Whilst the Carlton Fault truncates the ore horizon, it is considered as having an extended history of movement and probably pre-dating mineralisation. It is postulated as a feeder zone for metal-rich fluids (Hancock and Purvis, 1990).

Structural Control on Mineralisation

The Carlton Fault Zone is considered to have an extended movement history and has been postulated as a possible feeder zone for metal-rich fluids. However, sedimentological work (by Dunster and McConachie and reported by Bull, 1996) within the Lady Loretta Formation suggests a lack of sedimentary evidence for a localised sub-basin (the "Paradise Creek Graben") at Lady Loretta times that would have been associated with the Carlton Fault Zone acting as a growth fault.

Instead, Bull (1996) suggests that while there is no evidence for syn-sedimentary faulting in the Lady Loretta Formation, the mineralisation sits adjacent to an older growth fault in the sub-surface which is a northwestern continuation of the Redie Creek Fault trend (which was

a NNE-dipping growth fault during early Mc-Namara Group times). This area is structurally complex and is interpreted to host several closely spaced transfer structures, with the inference that areas may be prospective even if well above the stratigraphic levels at which the growth faults were active.

HOST ROCKS - LADY LORETTA

Mine Stratigraphy

The Lady Loretta Zn-Pb-Ag deposit is hosted within the Paleoproterozoic Lady Loretta Formation, which forms the uppermost outcropping unit of the McNamara Group in the deposit area (Fig 8.16). The lower half of the McNamara Group is correlated with the Mount Isa Group. The Lady Loretta Formation is bracketed by an age from the Paradise Creek Formation approximately 30km NNE of the Lady Loretta deposit of 1653±7Ma (Page and Sweet, 1998) and tuffaceous sediments from near the top of the McNamara Group dated at about 1620 Ma (Lawn Hill Formation, from McGoldrick, 1993a quoting Page, pers. comm., 1993).

The Lady Loretta Formation has been interpreted by McGoldrick (1993a) as deposited in a variety of dominantly shallow water depositional environments. Within the Lady Loretta Syncline the section is over 1800m thick, and comprises pyritic, carbonaceous, and dolomitic shales and siltstones, and minor sandstone, quartzite, dolarenite, chert, barite, tuffaceous sediments, and stratiform Zn-Pb-Ag mineralisation (McGoldrick, 1993a). The sequence in the Lady Loretta Syncline was thought to represent an isolated sedimentary (sub-) basin bounded to the north by the Carlton Fault (Hutton and Wilson, 1985).

phide lens up to 50 metres thick (in the 'keel' of the Small Syncline). The ore is commonly banded (pyrite and base metal sulphides – Fig 8.18E), but a variety of minor ore types and textures are present (Fig. 8.18A). Highest grades (> 30 wt% Zn equivalent) are in massive ore immediately overlying the 'Pyritic Unit'. Lower grade parts of the 'Ore Horizon' contain more sediment interbeds. These include siltstone, chert (sometimes with cryptalgal textures - Fig. 8.18D), sedimentary breccias, and at least one potassic, tuffaceous marker bed near the top of the 'Ore Horizon'. The 'Ore Horizon' is barite (±sphalerite) -rich, and galena-poor in upper parts of the west limb of the fold, and in the northern part of the east limb (McGoldrick, 1993a).

The beds are commonly contorted by slumping, folding and faulting, but cross cutting remobilisation and veining are rare. Sulphides commonly constitute 75% or more of the rock and are dominantly sphalerite, pyrite and galena. The mineralisation is fine-grained (10 to 50µm). A distinctive barite-chert-sulphide (sphalerite rich and galena poor) facies occurs on the east limb of the more northerly sections and in the upper parts of the west limb. The lowest section of the ore horizon is massive sphalerite-galena forming an irregular discontinuous high grade layer above the massive pyrite of the Pyritic unit (Hancock and Purvis, 1990).

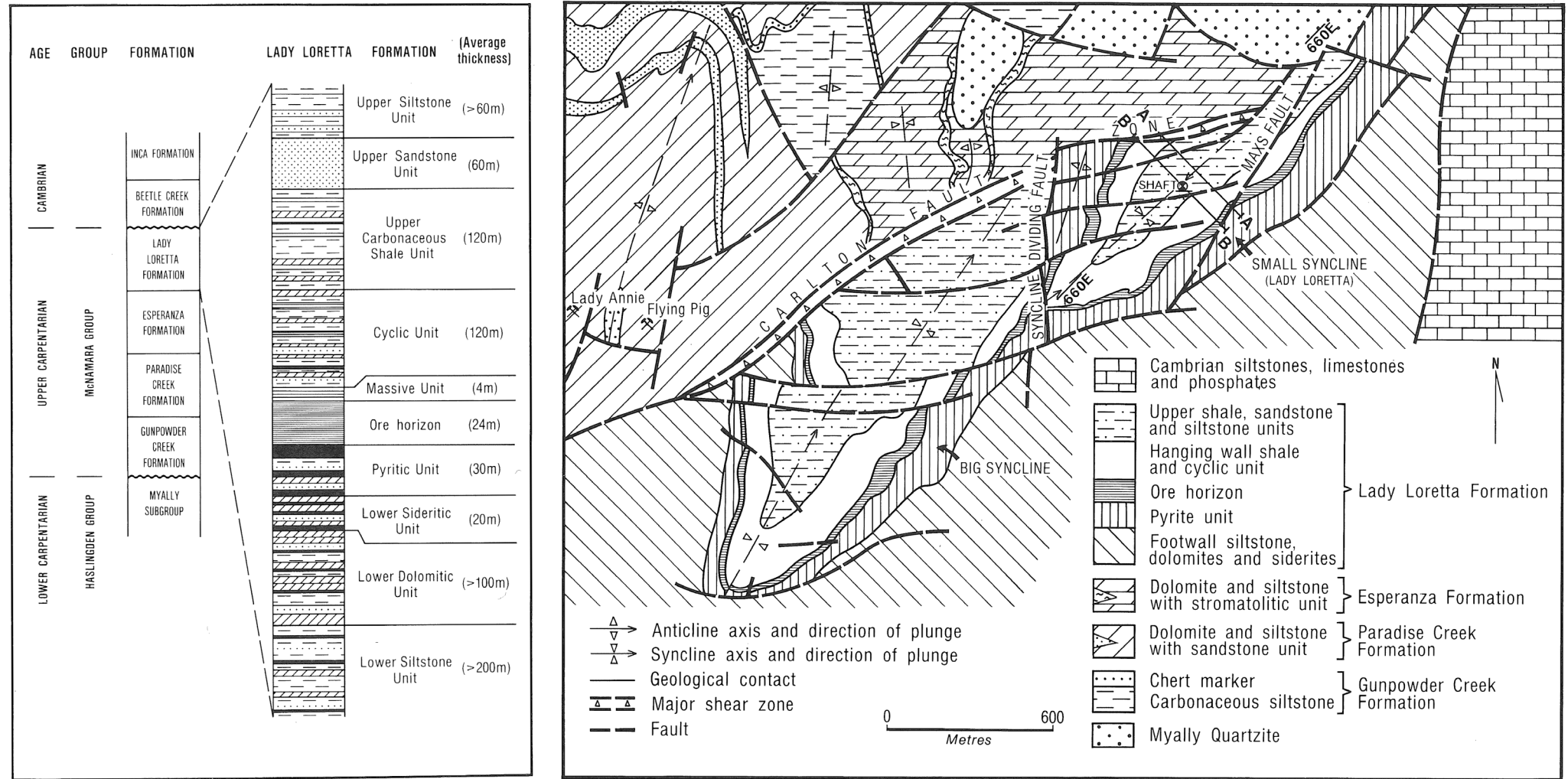
Intercalations of finely bedded siltstone, cherty silica lenses and brecciated sediments exhibiting graded bedding occur within the ore horizon, particularly in the northern part of the deposit. These 'ore sediments' are often irregular in thickness, discontinuous and devoid of sulphides. One potassic tuffaceous marker bed occurs at the top of the ore horizon, and other pyritic, chloritic and sideritic marker beds have been used for local stratigraphic correlation (Hancock and Purvis, 1990).

Major Host Rock

Ore Horizon

The Lady Loretta orebody comprises a sul-

Figure 8.16 (below). Stratigraphic column for the Lady Loretta region and plan view geological map of the Lady Loretta deposit (Hancock and Purvis, 1990).



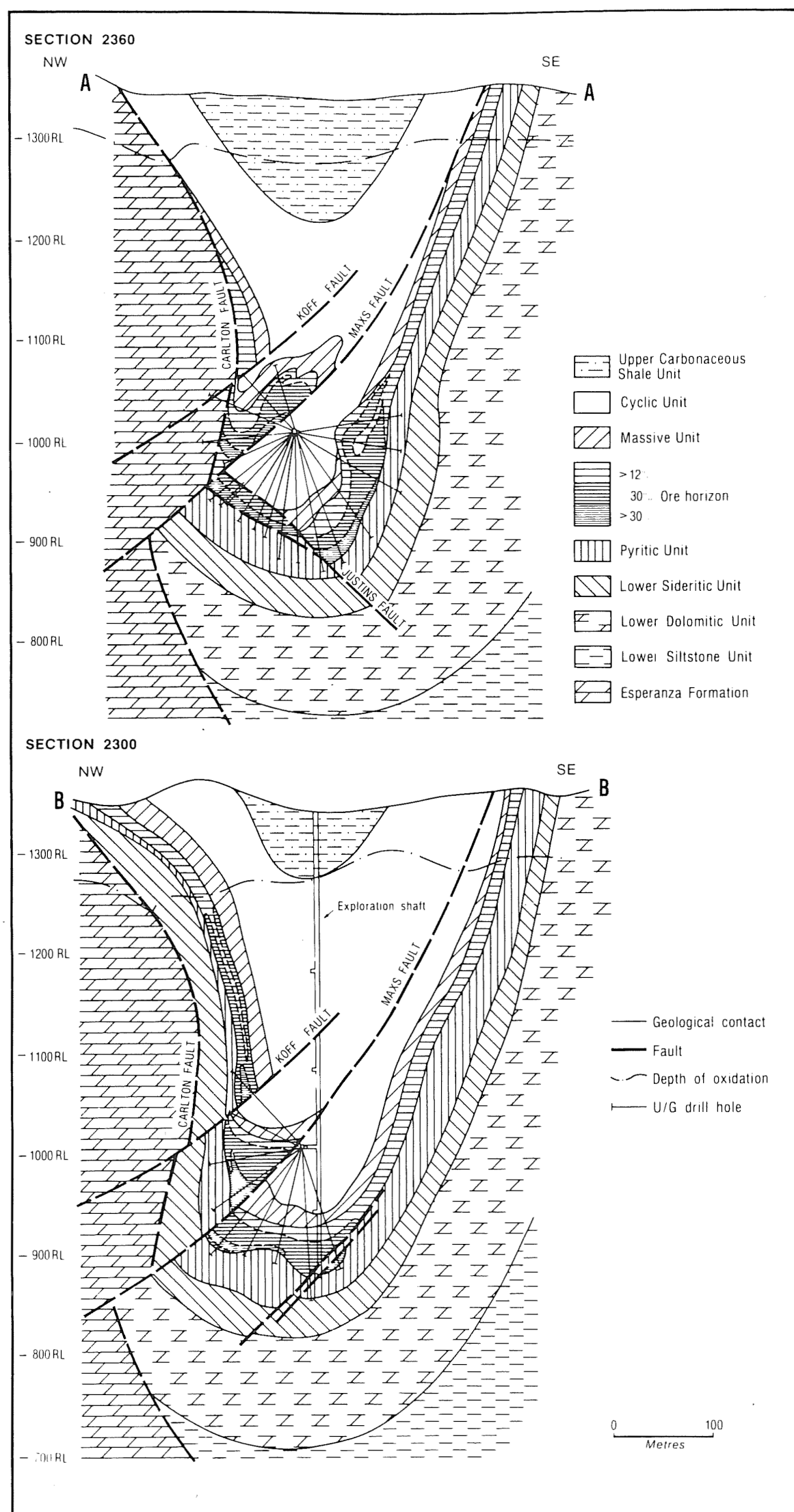


Figure 8.17 Lady Loretta cross sections A-A' and B-B' from Fig. 8.16 (Hancock and Purvis, 1990).

Microscopically the base metal sulphide ores comprise fine grained anhedral to subhedral galena and sphalerite aggregates that are interlayered with and surround fine grained euhedral to subhedral laminated pyrite. Detrital and chalcedonic quartz and siderite are the most abundant gangue minerals in high grade sulphide ore (Carr, 1981).

On the surface in the Big Syncline the 'Ore Horizon' is marked by a resistant ferruginous, baritic chert and ferruginous sediments. Mud cracks decorated with gypsum(?) moulds are also present. In the Big Syncline the 'Ore Horizon' comprises strongly pyritic and hematitic sediments and barite. Ore grade mineralization

is known from only one drill hole (P68) (McGoldrick, 1993a).

Hancock and Purvis (1990) describe three principal ore types from the deposit, as follows:

1. Stratiform ore: laminated pyrite-sphalerite-galena mineralisation, which contributes the bulk of the reserves
2. High grade ore: banded, recrystallised, very high grade zinc-lead sulphides with minor pyrite and kaolin, commonly with 45-60% combined Pb+Zn, located near the footwall contact and averaging 2-4m in thickness.

3. Barite-chert-sulphide mineralisation: low iron sphalerite dominant mineralisation occurring with pyrite in recrystallised bands, with galena generally minor. Barite constitutes up to 60% by weight. Occurs in the limbs in the Ore Horizon, principally in the eastern limb, but also in the upper western limb.

Minor Host Rock

Minor Host Rocks

The non-Ore Horizon units are described below, from base to top, with text from Hancock and Purvis (1990).

Lower Siltstone Unit

The Lower Siltstone unit is the lowest stratigraphic unit intersected by drilling. It comprises silt, shale and intercalated dolomite with occasional pyrite lenses. This unit is intersected in only a few holes and is more than 150 m beneath the principal mineralised zone.

Lower Dolomitic Unit

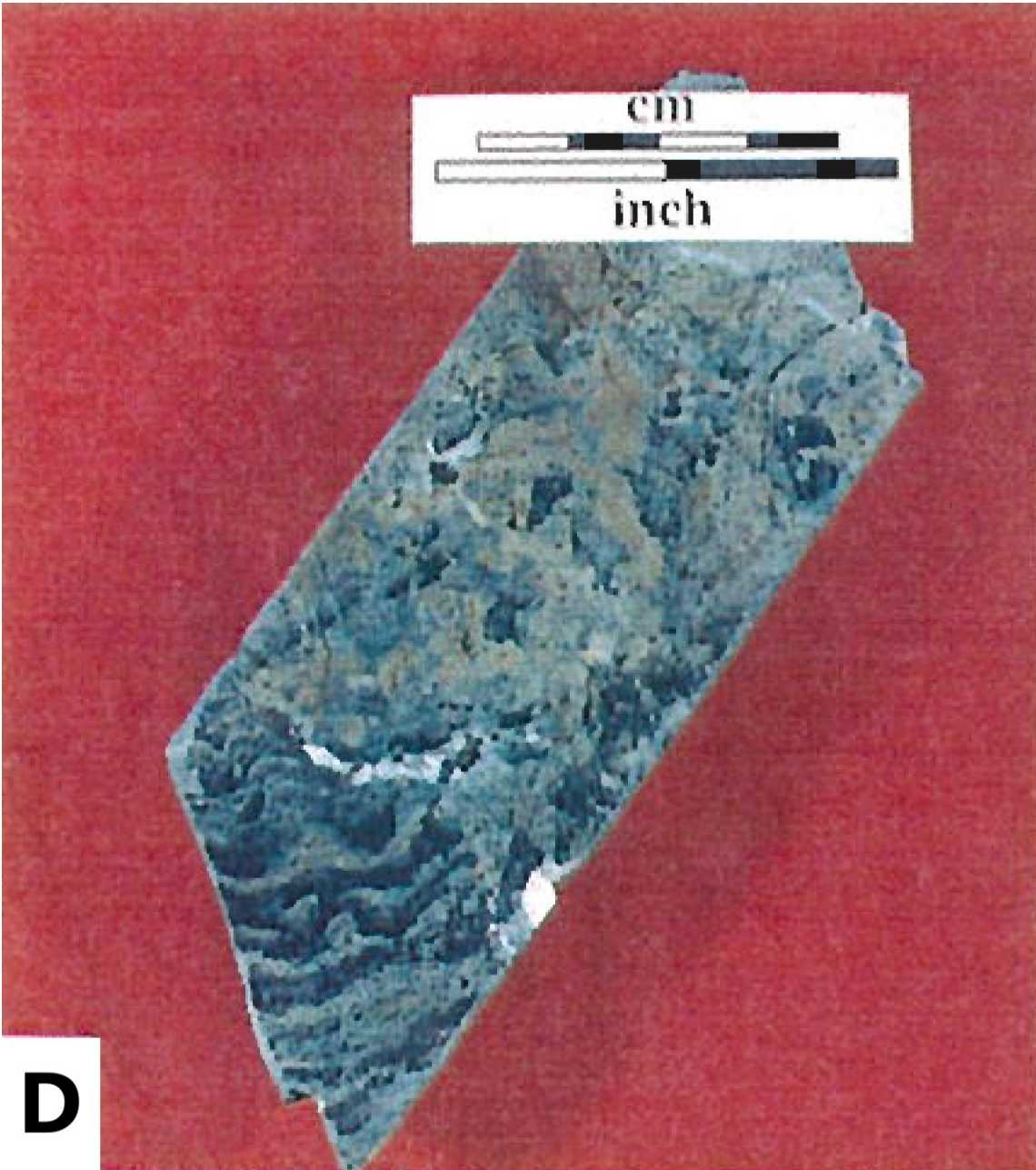
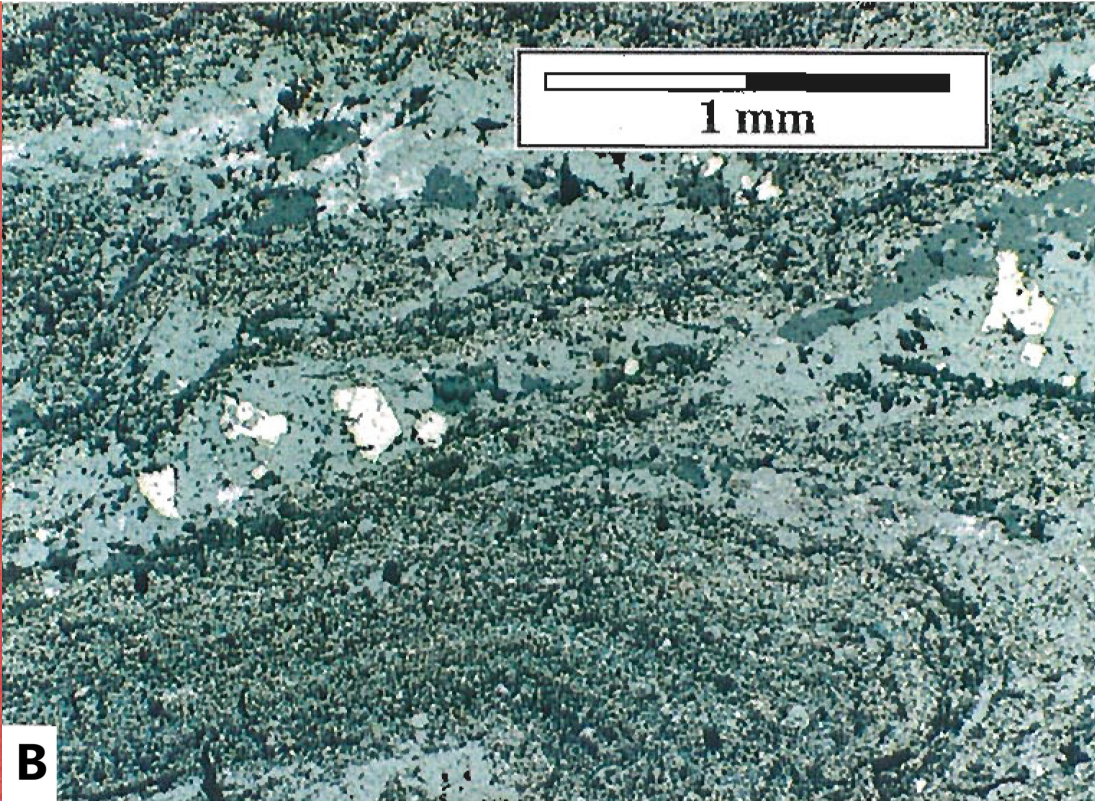
The Lower Siltstone becomes progressively more carbonatised and passes into the Lower Dolomitic unit, a sequence of more than 120 m of finely bedded grey siltstone and fine grained sandstone with minor interbeds of laminated fine grained pyrite. The coarser beds are commonly more carbonate rich, and are dolomitic in composition.

Lower Sideritic Unit

Overlying the dolomitic sediments is a similar sequence of silts and sands from 15 to 50 m

Fig. 8.18 (facing page) Hand specimen and thin section samples from the Ore Horizon (A-E from McGoldrick, 1993a; F-I from AMIRA P384 Report dated December 1998, p.89)

- A. A selection of sulphide-rich samples from the Ore Horizon at Lady Loretta. Finely banded pyrite dominates the left hand sample, in contrast, the most base metal rich material lacks obvious fine banding and has an almost massive appearance (e.g., third sample from the left).
- B. Photomicrograph of base metal sulphide mineralization from the Lady Loretta Ore Horizon. A folded layer of fine grain pyrite is present in the lower half of the field of view, and the upper part of the field of view is mainly sphalerite with some coarse euhedral pyrite and minor fine grain pyrite.
- C. Left hand sample is a graded polymictic breccia unit from within the Ore Horizon at Lady Loretta (Small Syncline). McGoldrick (1993a) suggests reverse grading near base indicates this unit was deposited from a high density mass flow; lighter clasts are mainly carbonate, while pyrite dominates the upper part of the unit. No unequivocal clasts of base metal sulphide are present in this unit. The right hand sample is high grade mineralization from Lady Loretta with layered base metal sulphides and an upwards widening discordant vein or pipe. The pipe contains fragments of pyrite and base metal sulphides in a fine sulphide matrix. This feature is interpreted by McGoldrick (1993a) as a fluid escape structure suggesting high fluid pressures and cross-stratal fluid flow syn- or post the formation of the ores.
- D. Chert with wavy cryptalgal laminations from the Ore Horizon, Small Syncline, Lady Loretta.
- E. Polished slab of high grade Zn-Pb mineralization from Lady Loretta. Fine scale layering and folding is well developed in pyrite-rich parts of the specimen; the base metal sulphides are not as obviously layered and appear to infill around, and be coarser than the pyrite bands.



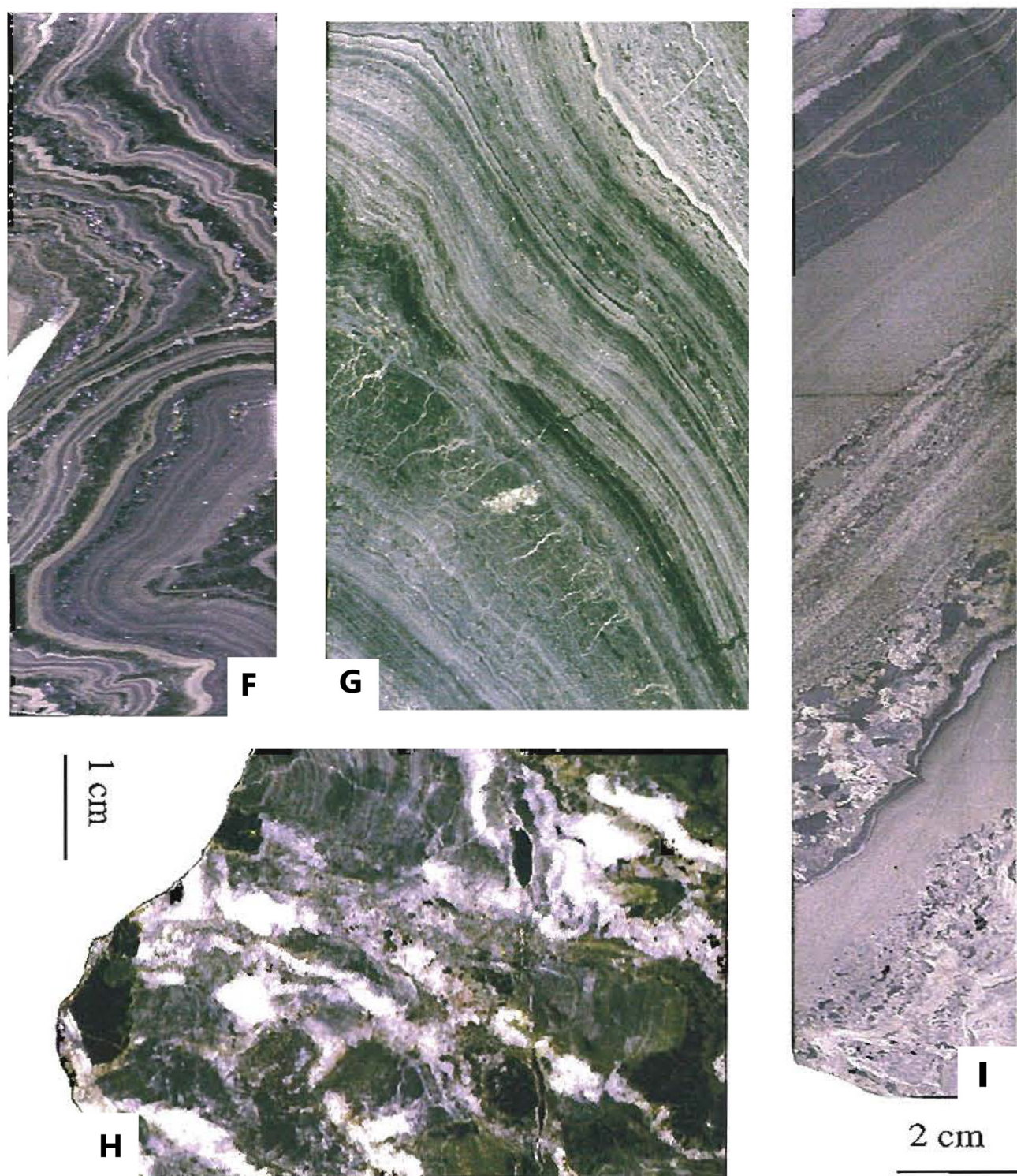


Fig. 8.18 (continued) Hand specimen and thin section samples from the Ore Horizon (A-E from McGoldrick, 1993a; F-I from AMIRA P384 Report dated December 1998, p.89)

- F. Tightly folded, high-grade Zn-Pb-Ag ore; grey bands are base metal sulfide-rich, light brown bands are fine grained pyrite, dark bands are coarsely recrystallised base metal sulfides and carbonate and quartz gangue.
- G. Delicately laminated high-grade Zn-Pb-Ag ore; stratigraphic top is at top right; note shrinkage (?dissolution) cracks in lower middle of the specimen.
- H. Barite-sphalerite ore (barite is white, sphalerite is black and light brown); grey areas with convex-up banding (e.g. lower left) are silicified stromatolites.
- I. High grade massive Zn-Pb-Ag sulfide ore with elastic (fragmental) textures; note the very coarse bases of two lower beds and normal grading to sulfidic mud in the upper parts of the two beds.

thick with siderite rather than dolomite as the dominant carbonate. Gypsum is common at the dolomite-siderite boundary. Interbeds of dolomite and siderite occur within each domain, but on a microscopic scale they are mutually exclusive. Fine grained bedded pyrite content increases up sequence and is associated with minor sphalerite.

Pyritic Unit

The Pyritic unit overlies the sideritic sediments and immediately underlies the base metal sulphide ore horizon. This unit is 15 to 40 m thick and comprises an interbedded sequence of fine grained laminated to massive pyrite, dark graphitic shale, and light grey sideritic fine grained sandstone. The contact with the high grade zinc-lead sulphides above is usually abrupt and conformable with local bedding trends, but it is commonly also a zone of shattering and decomposition.

Up to three phases of pyrite can be distinguished in polished sections forming overgrowths and framboidal masses. The Pyritic unit together with the ore horizon crops out at surface as a gossanous ridge of limonite, hematite, chert, shale and barite.

Massive Unit

The Massive Unit is stratigraphically above the Ore Horizon and is a 2 to 15m thick grey silt-shale unit with massive to graded bedding and

minor or no sulphide mineralisation.

Cyclic Unit

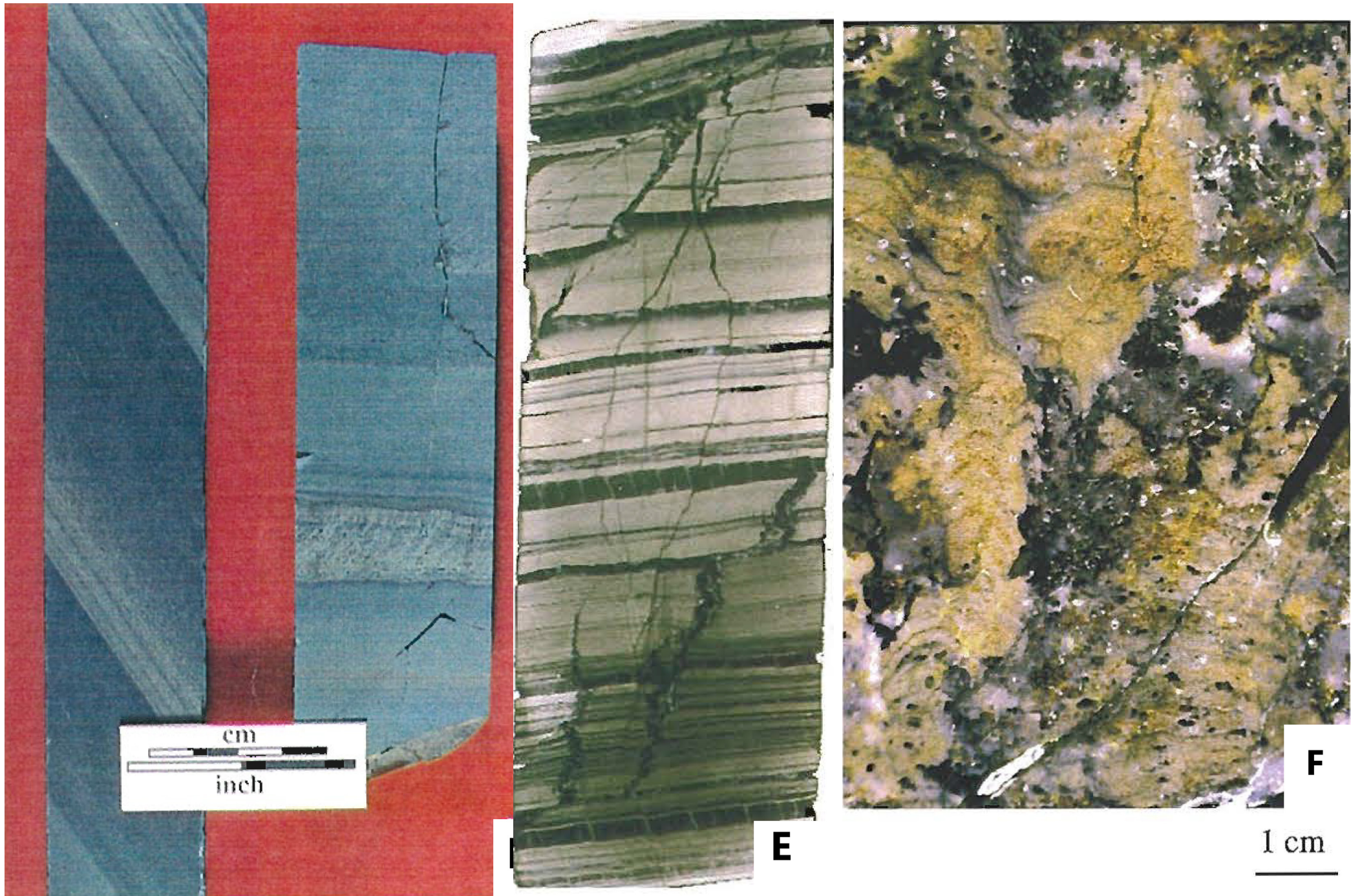
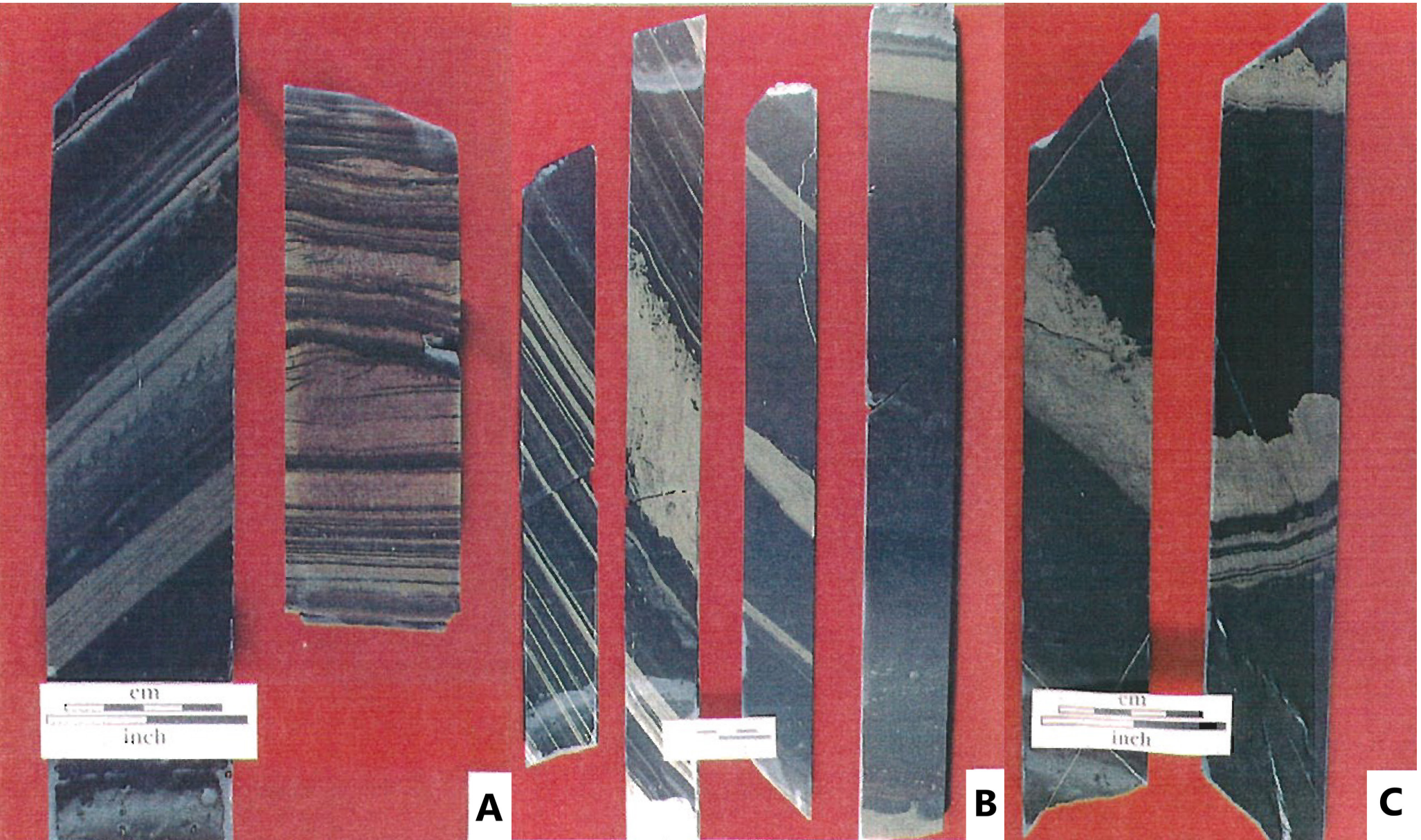
Overlying the low sulphide massive siltstone is a sequence of more than 220 m of rhythmically layered pyritic siltstone, carbonate rich fine grained sandstone and minor carbonaceous shale. Siltstone, sandstone or pyrite can dominate locally. Weak base metal sulphide mineralisation occurs some 50 to 70 m above the ore horizon forming a recognisable marker horizon. Fine conformable interbeds of pyrite commonly constitute 8 to 15% of the sequence.

Upper Units

Overlying the Cyclic unit, but intersected only in the Big Syncline, is the Upper Carbonaceous Shale unit with up to 120 m of carbonaceous shale and thin beds of dolomitic siltstone and pyrite. This is overlain by 60 m of fine micaceous sandstone (Upper Sandstone unit), and a similar thickness of interbedded siltstone and shale with sandy lenses (Upper Siltstone unit).

Fig. 8.19 (facing page) Lady Loretta Minor Host Rock Units

- A. Hangingwall sediment samples from the Small Syncline, Lady Loretta. The left hand sample has a band of laminated pyrite just above the scale, and well developed flame structures in silty lithologies. Right hand sample is a coarse silt containing minor cross bedded units; the sample is quite sideritic with well developed brown discolouration.
- B. Samples from the hangingwall (Cyclic Unit), Small Syncline, Lady Loretta. Pyrite bands are present in all the samples (both 'laminated' and 'fluffy' varieties). The third sample from the left has several pyrite bands separating individual siltstone/mudstone cycles. The fourth sample from the left has pyrite top and bottom with three siltstone/shale cycles in between; layering in the siltstone bases has been disturbed by compaction/dewatering effects.
- C. Detail of 'fluffy' pyrite bands from the hangingwall (Cyclic Unit), Small Syncline, Lady Loretta. Note the planar bases and irregular jagged tops to the pyrite bands. Internal (microbial?) laminations are well preserved in the left hand sample, but a sub-vertical layering (cleavage?) is more prominent in the pyrite band in the right hand sample.
- D. Sediment samples from the hangingwall (Cyclic Unit), Small Syncline, Lady Loretta. The left hand sample has a laminated pyrite band (just above the scale) and the overlying siltstone/shale cycle contains pyrite flecks in the base of the siltstone.
- E. Massive bedded pyrite (brassy colour) with (dark) sphalerite bands and pygmatic veins; layer parallel veins replace the bases of some of the pyrite units; sphalerite veins may have been early infill of open fractures
- F. 'Honeycomb' microbially laminated chert with microdigitate stromatolites; honeycomb moulds may be after siderite, gypsum or pyrite.



WALLROCK ALTERATION - LADY LORETTA

General Characteristics

The Lady Loretta deposit is marked by the presence of abundant sulphide, being base metal sulphides + pyrite in the ore horizon, or pyrite with minor base metal sulphides in the stratigraphy immediately above and below the ore horizon.

Lateral to the orebody, in what are now the limbs of the Little Syncline, is a notable barite-chert-sulphide facies.

Inner (ore) Zone

- The inner ore zone is comprised of:
- banded, recrystallised, very high grade zinc-lead sulphides with minor pyrite and kaolin, commonly with 45-60% combined Pb+Zn, located near the footwall contact and averaging 2-4m in thickness.
 - Stratiform ore: laminated pyrite-sphalerite-galena mineralisation, which contributes the bulk of the reserves

Outer Zone

Large and McGoldrick (1998) document the presence of an inner sideritic halo, an outer ankerite / ferroan dolomite halo, and a marginally elevated manganese dolomite that merges with low iron dolomitic sediments representative of the regional background composition.

- The dimensions of the halo are (Fig. 8.21):
1. The inner siderite halo has a dimension of approximately 50-100m across strike and 800m along strike.
 2. The ankerite halo has a dimension of approximately 250m across strike and 1400m along strike.
 3. The elevated manganese dolomite halo is not tightly constrained by Large and McGoldrick (1998) note that the MnO content of dolomite increases from 0.2 to 1 wt% over 300m approaching the orebody.

This halo model suggests a carbonate composition model to vector towards ore of dolomite->ankerite->siderite.

Lithogeochemistry

- Large and McGoldrick (1998) note:
- The Zn content of sediments increases erratically from 100ppm to 1 wt% over 100m in the footwall and hangingwall.
 - The TI content of sediments increases erratically from <4 ppm to 100ppm over a distance of 200m approaching the ore position across strike.
 - The Mn content of dolomite increases from 0.2 to 1 wt% MnO over 300m approaching the orebody
 - The SEDEX alteration index, defined by $SEDEX\ AI = (FeO + 10MnO) \cdot 100 / (FeO + 10MnO + MgO)$ increases from 30 to <90 over at least 300m approaching the ore across strike.

Deposit	Host Unit	Lithology
Lady Annie	Paradise Creek and upper Gunpowder Creek Formations	dolomitic, carbonaceous and argillaceous sandstones and siltstones
Lady Brenda	Paradise Creek and upper Gunpowder Creek Formations	dolomitic, carbonaceous and argillaceous sandstones and siltstones
Mount Kelly	McNamara Group (Paradise Creek Formation?)	siltstones and dolomitic siltstones
Swagman	McNamara Group (Paradise Creek Formation?)	siltstones and dolomitic siltstones
McLeod Hill	McNamara Group (Paradise Creek Formation?)	siltstones and dolomitic siltstones
Anthill	Esperanza Formation	dolomitic siltstones

Table 8.4: Summary of the host rock and stratigraphic unit for the various Lady Annie Project deposits.

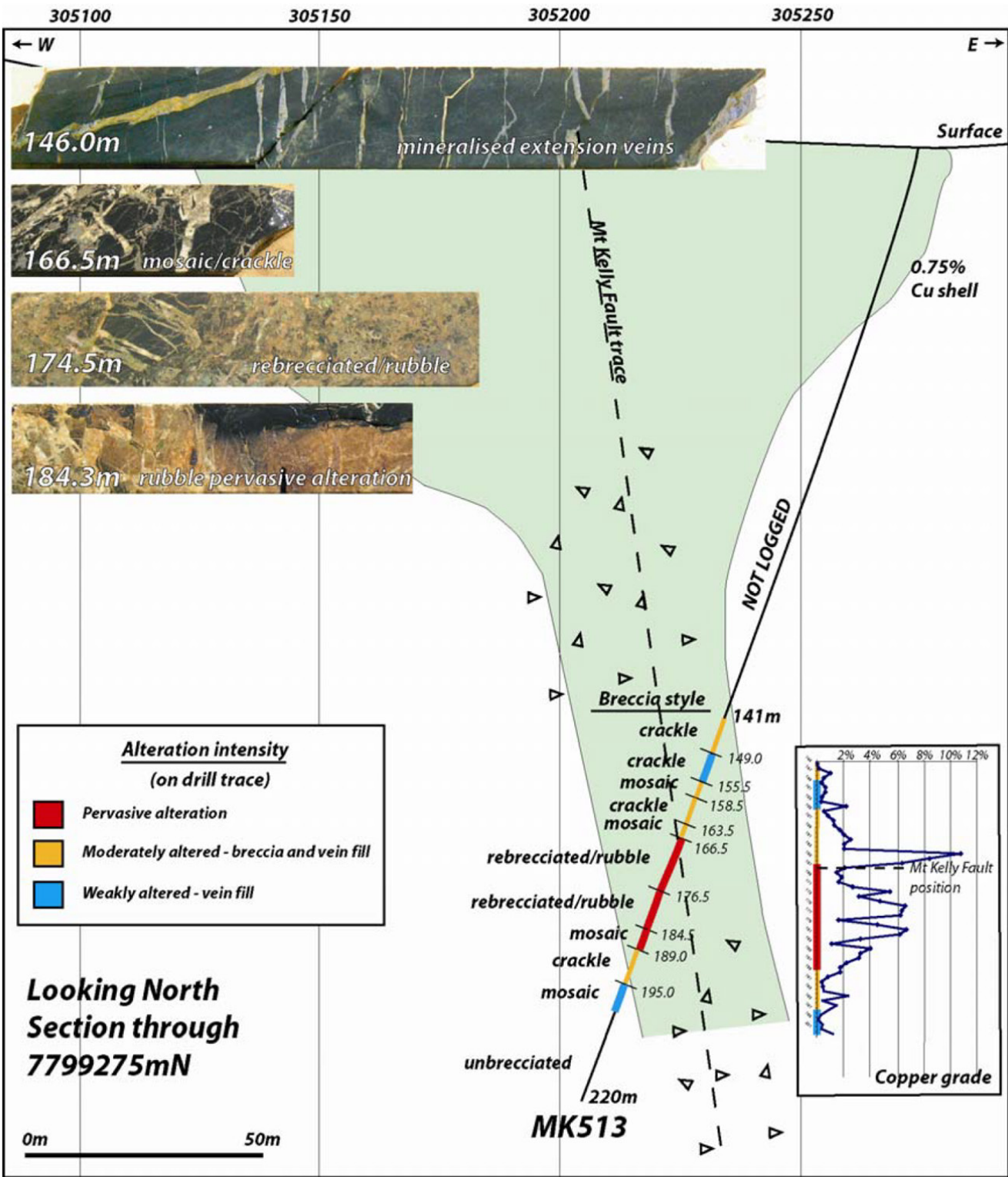


Figure 8.20: North-looking cross-section through the Mount Kelly Fault zone documenting the high-grade copper intersection associated with the fault in drill hole MK513 (from Keys, 2008). The upper drill core specimen shows the host dolomitic (+carbonaceous) shale/siltstone with only minor carbonate veining and disseminated pyrite, which proceeds to more intense brecciation and carbonate alteration within the fault zone.

HOST ROCKS- LADY ANNIE PROJECT

Mine Stratigraphy and Host Rocks

The eight deposits comprising the Lady Annie Project are hosted by a variety of rock packages as follows (summarised from Golder, 2018):

- The Lady Annie mining area is contained within the north trending Lady Loretta High Strain Zone. The Lady Annie deposit is hosted by fault bounded blocks of gently folded Paradise Creek and Upper Gun-

powder Creek Formations.

- The Lady Brenda deposit is located approximately 300m to the south-west of the Lady Annie deposit. Copper mineralisation at Lady Annie and Lady Brenda 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. The primary copper sulphide

- mineralisation appears to be structurally controlled, being commonly associated with well-defined fault-related silicification.
- The Mount Kelly mining area (Mount Clarke) is dominated by early to mid-Proterozoic siltstones and dolomitic siltstones of the McNamara Group. Copper mineralisation occurs within units of the McNamara Group and is reportedly related to the north-west-trending Mount Kelly and Spinifex Faults, which intersect and cut the McNamara Fault. The known mineralisation is associated with multiple phases of brecciation and veining along the fault zones. The copper oxide mineralisation appears to be shear and fault controlled (Figure 8.20).
 - The Swagman and McLeod Hill deposits occur within a few kilometres of the Mt Kelly mining area and have similar rock types and mineralisation styles. The mineralisation at both deposits is controlled by structural features such as shear zones and faults.
 - The Anthill deposit is hosted predominantly within the Esperanza Formation. The host lithology of the orebody is inferred to be dolomitic siltstones; however the strong weathering and oxidation process has resulted in the near complete loss of dolomite from the rock in the upper oxide zone. The mineralisation appears to be controlled by a combination of steep structural elements and broad dome features. The Anthill mineralisation is commonly hosted in structurally controlled silicified zones as well as in silicified sedimentary breccia in dolomite, which appears to have been a preferred permeability horizon for mineralising fluids.

WALLROCK ALTERATION - LADY ANNIE PROJECT

General Characteristics

Detailed geological information regarding the Lady Annie and associated satellite deposits is sparse, however several company reports and the thesis of Keys (2008) document parts of the different deposits.

Inner (ore) Zone

Keys (2008) reports details from the Mount Kelly deposit. The primary copper mineralisation consists dominantly of chalcopyrite and pyrite, concentrated in a matrix of breccias zones and in quartz-carbonate stockwork veins. Copper oxide mineralisation is present as malachite, with minor azurite, chrysocolla, cuprite and tenorite. Both the sulphide and the copper oxide mineralisation appear to be shear and fault controlled. Interestingly, the Mount Kelly deposits also hosts localised high-grade gold mineralisation (drill hole MK475A) (Keys, 2008).

Outer Zone

Keys (2008) documented a strong correlation between the degree of brecciation, the copper grade and the Mount Kelly Fault trace (Fig. 8.20)

GEOPHYSICAL EXPLORATION

Petrophysics

Comprehensive petrophysical data is available from the entire sequence present at the Lady Loretta Mine, collected as part of a PhD thesis (Duffett, 2000). Significant points from the data

- (Fig. 8.22) are:
- the Ore Horizon has the strongest contrast with the immediately surrounding units in density (3.76 t/m3 mean and 3.88 t/m3 median values) and chargeability (17 IP% mean and 13.4 IP% median values).
 - The Pyritic Unit has the highest magnetic susceptibility, albeit still relatively low (mean of 0.52 x 10-3 SI) relative to non-sedimentary rock types such as the basaltic units of the Eastern Creek Volcanics (50-80 x 10-3 SI units).
 - The Lower Carbonate Unit has the greatest velocity (5525 m/s).
 - The Massive Unit has the lowest resistivity (472 ohm-m median value), with the Pyritic Unit second least resistive (5110 ohm-m). It is unclear why the Massive Unit, which is a 2-15m thick grey silt-shale unit with massive to graded bedding and minor or no sulphide mineralisation, is most conductive.

Duffett (1998) reported on the magnetic susceptibility and density of the key units from the Lady Loretta and broader area. Whilst there are minor contrasts among the sedimentary rocks, the key contrast in both density (2.65 vs 2.90 t/m³, respectively) and magnetic susceptibility (0.3 vs 65 SI x 10-3, respectively) are between the sedimentary units and the Eastern Creek Volcanics (Table 8.5).

Note the Fiery Creek Volcanic units do not have a strong contrast with the sedimentary units.

Regional Geophysical Datasets

Images of the regional geophysical datasets

LADY LORETTA HALO MODEL

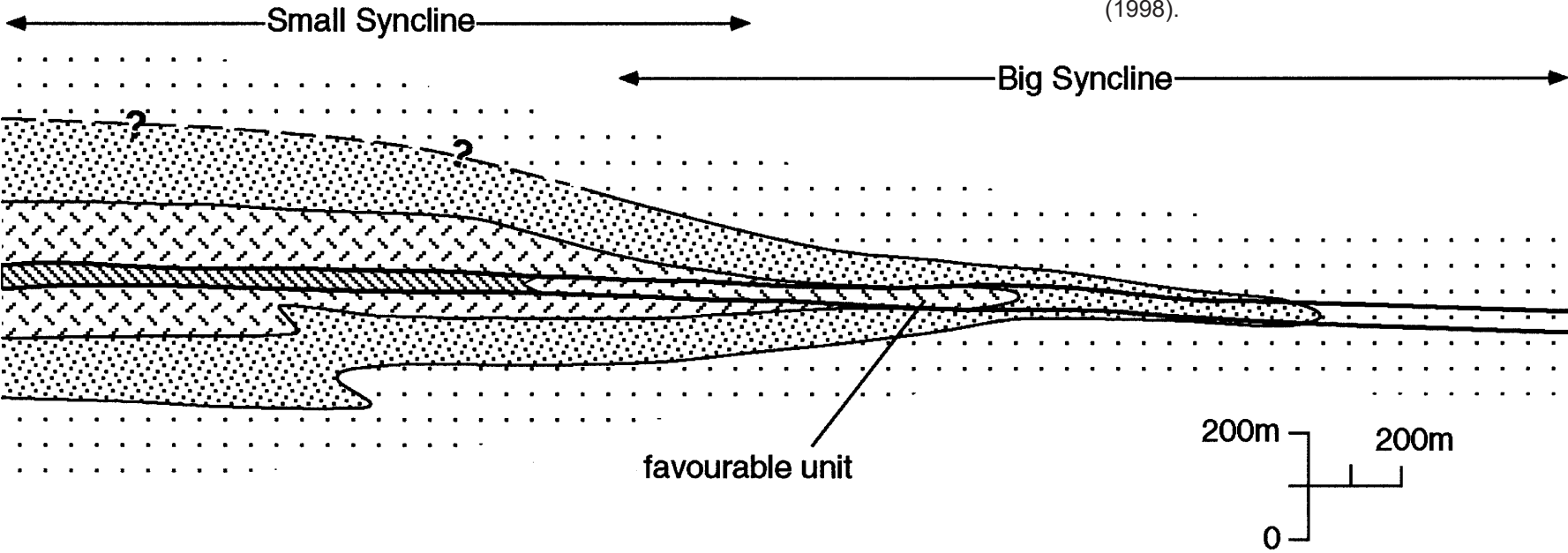


Figure 8.21: Summary diagram of the (pre-folding) Lady Loretta halo model of Large and McGoldrick (1998).

	Zn	Pb	dominant	Tl	MnO	CaO	SEDEX AI	MnO _d /s	Metal
		ppm	Carbonate	ppm	%	%		%	Index
Zn-Pb ore	>5%	>1000	siderite	>50	0.1-0.4	0-1	80-100	1-10	>8x10 ⁴
Siderite halo	100ppm to 5%	10-1000	siderite	2-50	0.01-1	0-1	60-100	1-10	2x10 ³ -3x10 ⁴
Ankerite halo	20-200ppm	<70	ankerite	2-50	0.01-0.04	1-2	38-60	0.4-0.7	2-7x10 ³
Dolomite halo	<30ppm	<20	dolomite	<2	<0.01	5-10	10-40	<0.3	<3x10 ³

are provided earlier in the chapter. These images show that the Lady Loretta deposit does not have a notable signature in the regional datasets, consistent with the petrophysical data and the relatively restricted deposit size.

The Lady Annie and satellite deposits also do not produce notable geophysical signatures in the regional datasets.

Deposit-scale Geophysical Signatures

As indicated by the petrophysical data from Lady Loretta, the strongest petrophysical contrast of the Lady Loretta Ore Horizon is its density. Duffett (1997) reports that the deposit has a 1mGal positive anomaly spatially associated with the keel of the Small Syncline. Duffett (1997) interprets this anomaly is associated with:

- 1. The Pb-Zn ore which has a high density of 4.0 ± 0.5 t/m3
- 2. Massive pyrite above and below the ore sequence, and
- 3. Barite within the ore sequence
- 4. The sideritic halo

Fig. 8.23 illustrates the tight correlation between the subtle gravity anomalies (of 0.6 to 0.8mGal) over the Lady Loretta deposit and the keel of both the Little and Big Synclines.

Cox and Curtis (1977) report that in 1968 an induced polarization (IP) survey centred on the Lady Annie Mine covered the Big Syncline and established IP anomalies along the eastern limb and part of the western limb of the Big Syncline. Two diamond drill holes were sited to test these anomalies and intersected thinly bedded dolomitic and carbonaceous shales and beds of fine-grained pyrite establishing a further analogy between Mount Isa and the Lady Annie-Lady Loretta area.

No specific deposit-scale geophysical information is available for the Lady Annie deposit, although the gravity data shown in Fig 8.23, and the regional magnetic datasets suggest there is no significant potential field anomalism associated with the deposit.

EXPLORATION GEOCHEMISTRY

Surface Geochemistry – Gossan Sampling

The zinc-lead pyritic shales of the Lady Loretta deposit form the most resistant feature of the stratigraphic sequence, outcropping as a lateritized plateau surface 60m above the surrounding plain (Cox and Curtis,1977). However, due to the weathering regime and extreme leaching, the surface ironstone gossans do not exhibit strong base metal anomalism (Table 8.6). Whilst the bedded porous gossan has anomalous Pb (2960ppm), the massive ironstone gossan has no notable Cu-Zn anomalism, and only weakly anomalous Pb (241 ppm).

Surface Geochemistry – Soil Sampling

Combined results of soil sediment surveys are shown in Figure 8.24 for Pb, Ag, Zn and Cu from Cox and Curtis (1977) showing the absence of Pb-Ag-Zn anomalies in the Lady Annie region. The distribution of Pb and Ag are closely related to the position of the Lady Loretta Ore Horizon and the distribution of limonitic sediments (after pyrite) around topographic highs with lim-

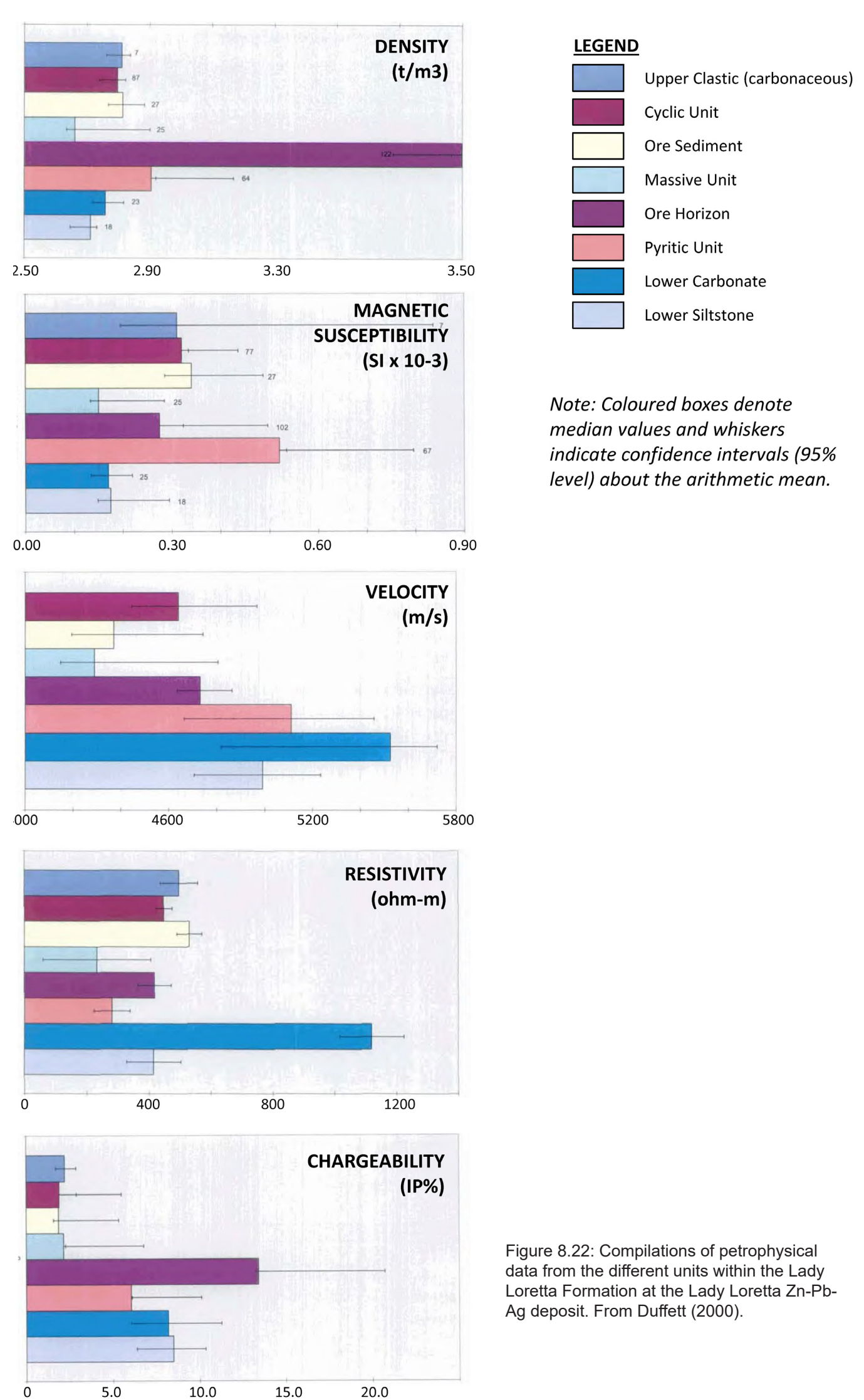


Figure 8.22: Compilations of petrophysical data from the different units within the Lady Loretta Formation at the Lady Loretta Zn-Pb-Ag deposit. From Duffett (2000).

Table 8.5: Density and magnetic susceptibility ranges for units of the Western Succession, compiled from various studies. From Duffett (1998).

Unit	Density (t/m3)	Susceptibility (SI x 10-3)
Cambrian sediments	2.52 - 2.66	0.05
Lady Loretta Formation	2.75 - 2.78	0.45
Esperanza Formation	2.65 - 2.69	0.10
Paradise Creek Formation	2.70 - 2.76	0.10
Gunpowder Creek Formation	2.67 - 2.74	0.30
Torpedo Creek Quartzite	2.64 - 2.66	0.05
Surprise Creek Formation	2.60 - 2.65	0.10
Fiery Creek Volcanics	2.62 - 2.72	0.50
Bigie Fornation	2.57 - 2.62	0.12
Myally Subgroup	2.61 - 2.65	0.10
Eastern Creek Volcanics	2.85 - 2.91	50 - 80

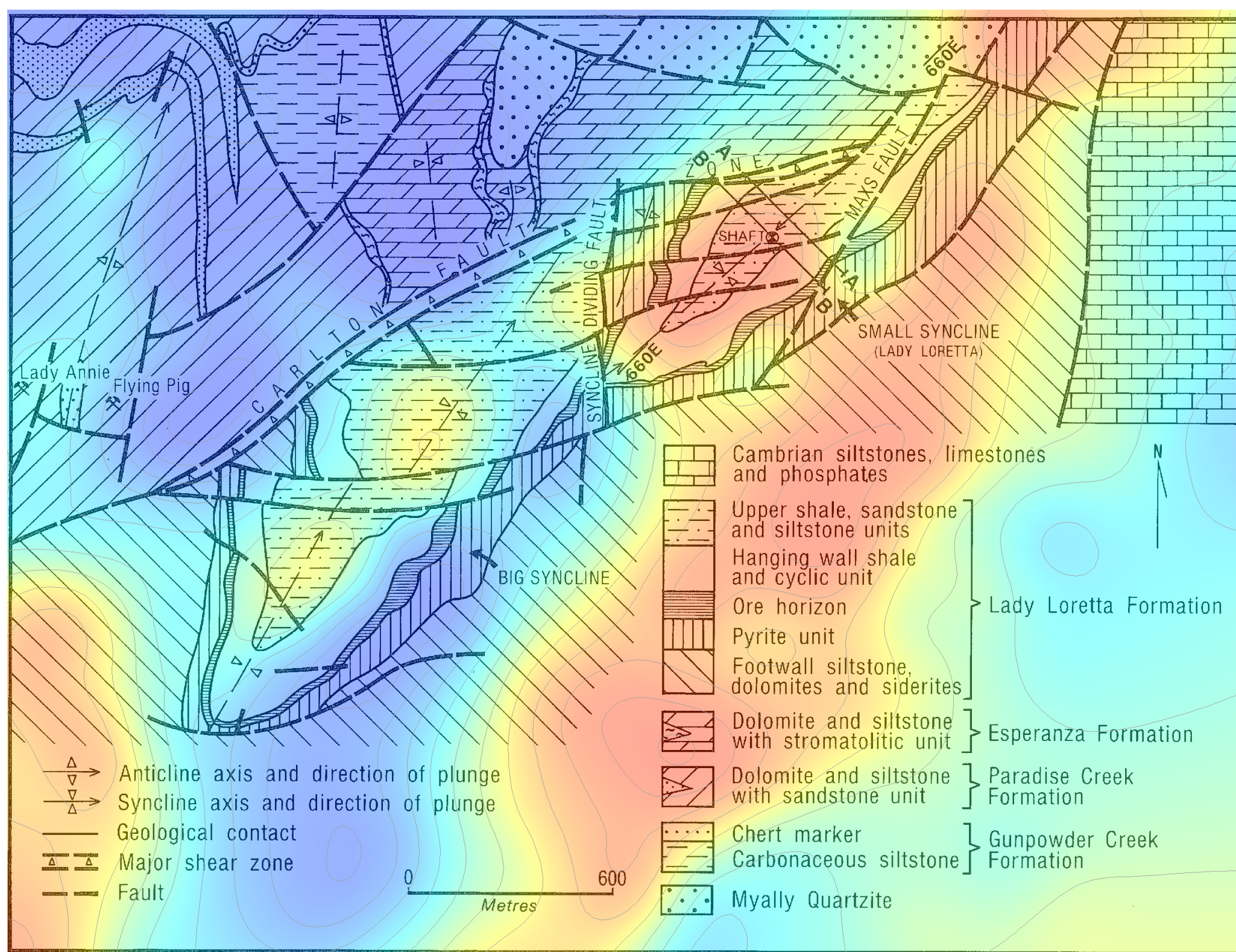


Figure 8.23 Image of residual gravity anomaly (with $2\mu\text{m/s}^2 = 0.2\text{mGal}$ contours) and the geology of the Lady Loretta deposit (from Hancock and Purvis, 1990). The residual anomaly was estimated by subtraction of the "regional" field interpolated from the 2km-spaced survey data from the interpolation of all data (data from the GSQ database).

The keels of both the Small and Large Synclines produce subtle positive gravity anomalies, the Small Syncline more so. The pale grey contours are 0.2 mGal.

ited lateral dispersion (Cox and Curtis, 1977). Zn displays a higher mobility than Pb and Ag and is interpreted to have been dispersed downslope of the outcropping Ore Horizon. The distribution of Zn is therefore not considered to be as robust an indicator of bedrock Pb-Zn-Ag mineralisation (Cox and Curtis, 1977).

Soil fraction sizing analysis using 12-mesh (1.7 mm), 22-mesh (approx. 0.85 mm), 44-mesh (approx. 0.355 mm) and 80-mesh (0.18 mm) indicated that 40 to 80 % of the mass of each sample was coarser than 12-mesh (1.7 mm). This coarser fraction was dominantly composed of rock and gossan fragments and had higher assay grades than the fines leading to routine sieving of the soil samples not being carried out (Arthur, 1972). The samples were crushed to minus 200-mesh (-0.075 mm or -75 µm) and dissolved in perchloric acid 165°C for 8 hours prior to atomic absorption spectroscopy (AAS) for Pb, Zn, and Cu (Cox and Curtis, 1977). Ag analysis was by AAS following nitric acid (+ Hg)

digestion (Cox and Curtis, 1977).

Cox and Curtis (1977) reported the following (Table 8.7) threshold and anomalous values for Pb, Zn and Ag for the combined soil sediment surveys in Lady Loretta region.

Surface Geochemistry – Stream Sediment Sampling

Figures 8.13 - 8.15 provide maps of the stream sediment analysis base metal data from the broader Lady Annie – Lady Loretta district. Stream sediment data is not available in close proximity to the two deposits, and it is not possible to differentiate the signatures from the two deposits. However, the data does show elevated base metal anomalism (+100ppm Cu, +40ppm Pb, insufficient Zn analyses) associated with the Lady Annie – Lady Loretta area.

Regolith Sampling

Following a study over several of the copper deposits in this district (Lady Annie, Mount Kelly and Anthill) Salama et al (2016) reported that thick kaolinitic saprolite and silcrete are formed over sulfide mineralization, particularly along faults (Fig. 8.25, 8.26). Ferruginous duricrusts marginal to fault-controlled sulfide mineralization are anomalous in Cu, Zn, Cd, Sb and Be, and thus can be used as useful medium in geochemical exploration. Gold, Ag, Pb and As are residually concentrated in pedolith and kaolinitic saprolite over the primary sulfide

mineralization. Thus, these elements can be used effectively as pathfinder elements, particularly in truncated landscape, where pedolith is eroded and the exposed kaolinitic saprolite is depleted in Cu. Ferruginous soil (850–300, 300–80 and < 80 µm size fractions), lag (> 1.6 and > 7.6 mm) and termite mounds have been applied successfully as sampling media for Cu oxide exploration in Anthill.

Soil and lag over sulfide mineralization are rich in Fe, As, Pb, Ag, Bi, In, V, U and Mo. The best response over sulfide mineralization is recorded in the > 7.6 mm ferruginous lag. However, broadest signature of well-defined Au, Bi and In anomalies are better detected using termite mounds than soil and lag. Successful use of soil in exploration for Cu oxide deposits in Mount Isa requires a genetic discrimination between residual and transported origin

Airborne Hyperspectral Mineral Mapping – HyMap

Hyperspectral mineral maps acquired by HyVista Corporation for the Mount Isa Inlier in 2006 and have been made publicly available through the Next Generation Mineral Mapping collaborative project between the Geological Survey of Queensland (GSQ) and CSIRO. Raw HyMap data images were corrected to apparent ground reflectance using HyCORR and CSIRO's C-HyperMap software was used to extract mineralogical information (Cudahy

Element	Unit	Lady Loretta: Bedded Porous Gossan	Lady Loretta: Massive Ironstone Gossan
Zn	ppm	59	10
Pb	ppm	2960	241
Ag	ppm	11.9	7.2
Cu	ppm	30	18
Fe	wt%	11.66	55.85
As	ppm	319	93
As	ppm	366	116
Sb	ppm	55.5	79.3
Tl	ppm	0.4	0.3
Mn	ppm	31	40
Ba	ppm	400	400
S	ppm	1040	180
Ni	ppm	<1	3
Mo	ppm	6.4	39.1
V	ppm	11	11
Ti	ppm	3117	360
Cr	ppm	47	33
Rb	ppm	1.5	1.1
Sr	ppm	237	22
Sc	ppm	8	1.1

Table 8.6: Composition of two gossans from the Lady Loretta deposit. The data is from McGoldrick et al. (1997), but the precise location of the samples are not known.

et al., 2008). Processed hyperspectral images were downloaded from the QDEX portal (<http://qdexdata.dnrm.qld.gov.au/flamingo/>) for the Lady Loretta area in dataset ‘Lady Loretta_Dugald River Block C’ (Cudahy et al. 2008).

Processed HyMap images are shown in Fig. 8.27 overlain on the regional 1:100,000 geological map. Hyperspectral maps include true (RGB) and false colour (stretched RGB reflectance bands). Ferric (Fe3+) iron oxide content reflects the presence of hematite, goethite, limonite, ferrihydrite and jarosite as well as Fe3+ bearing phases including pyroxene, amphibole and carbonate (Laukamp et al. 2011). Ferrous oxide maps Fe2+ bearing silicate and carbonate minerals including carbonate, amphibole, pyroxene and chlorite. White mica composition shows the position of the 2200 nm feature in muscovite mineral with blue indicating shorter wavelength (2180 nm) Al-rich micas (muscovite, illite, paragonite) and red indicating longer wavelength positions (2215 nm) for Al-poor muscovite (phengite; Laukamp et al., 2011). White mica crystallinity shows low crystallinity mica as a ratio between the 2200 nm feature depth and the 1900 nm feature depth

with blue indicating low crystallinity (ratio: 0.004) and red indicating high crystallinity (0.13; Laukamp et al. 2011). Kaolin content maps the abundance of kaolin group minerals (kaolinite, dickite, nacrite and halloysite) with blue indicating low abundance, red indicating high abundance (Laukamp et al. 2011). The smectite abundance map shows the relative abundance of montmorillonite, nontronite and hectorite.

TIMING OF MINERALIZATION

Relative Timing

The genetic models proposed for the Lady Loretta deposit include a sedimentary exhalative model and a diagenetic model, such that either genetic model would require a mineralisation age similar to that of the host sediments (the Lady Loretta Formation).

The timing of mineralisation at Lady Annie or any of the satellite deposits is not well constrained. Typically, the mineralisation is thought to be of a similar age to the Mount Gorgon and Mount Isa Copper deposits (Keys, 2008), potentially placing it in the broad period

Table 8.7: Threshold and anomalous values for Pb-Zn-Ag in soils, as determined by Cox and Curtis (1977).

Element	Threshold Value (ppm)	Anomalous Value (ppm)
Pb	60	+ 380
Zn	35	+ 180
Ag	0.24	+ 0.9

1530Ma to 1370Ma.

Absolute age

Zircons from a tuff bed of the Paradise Creek Formation, which is in the Lower McNamara Group, provide a U-Pb zircon age of 1653±7Ma (Page and Sweet, 1998). The sampled tuff was approximately 30km NNE of Lady Loretta, and provides a maximum age for the Lady Loretta Formation.

The minimum age is constrained by tuffaceous sediments from near the top of the McNamara Group dated at about 1620 Ma (Lawn Hill Formation, from McGoldrick, 1993a quoting Page, pers. comm., 1993).

Zircons from a tuff bed of the Paradise Creek Formation, which is in the Lower McNamara Group, located approximately 30km NNE of Lady Annie, provide a U-Pb zircon age of 1653±7Ma (Page and Sweet, 1998). The sample provides a likely maximum age for the Lady Annie mineralisation, assuming was broadly synchronous with the Mount Kelly mineralisation, which is hosted by the Paradise Creek Formation.

GENETIC MODEL

- Lady Loretta has been interpreted as:
- a syngenetic exhalative deposit (e.g., Carr, 1981; Hancock and Purvis, 1990), or
 - a deposit formed in a shallow lagoonal setting with a syn-diagenetic timing for the formation of base metal sulfides (McGoldrick et al., 1996).

The Lady Annie and other satellite deposits described here have typically been interpreted as structurally controlled, epigenetic shear, fault or breccia-hosted deposits, of a broadly similar style to the Isa Copper deposit.

POST-FORMATION MODIFICATION

The Lady Loretta deposit has been folded and faulted (see above) post-formation. In addition, the deposit has been subject to weathering and oxidised to a depth of approximately 100m (Hancock and Purvis, 1990).

The Lady Annie and satellite deposits have been subject to weathering (Salama et al., 2016) such that near-surface oxide copper has been the dominant historic mining product from this set of deposits.

DISCOVERY METHOD

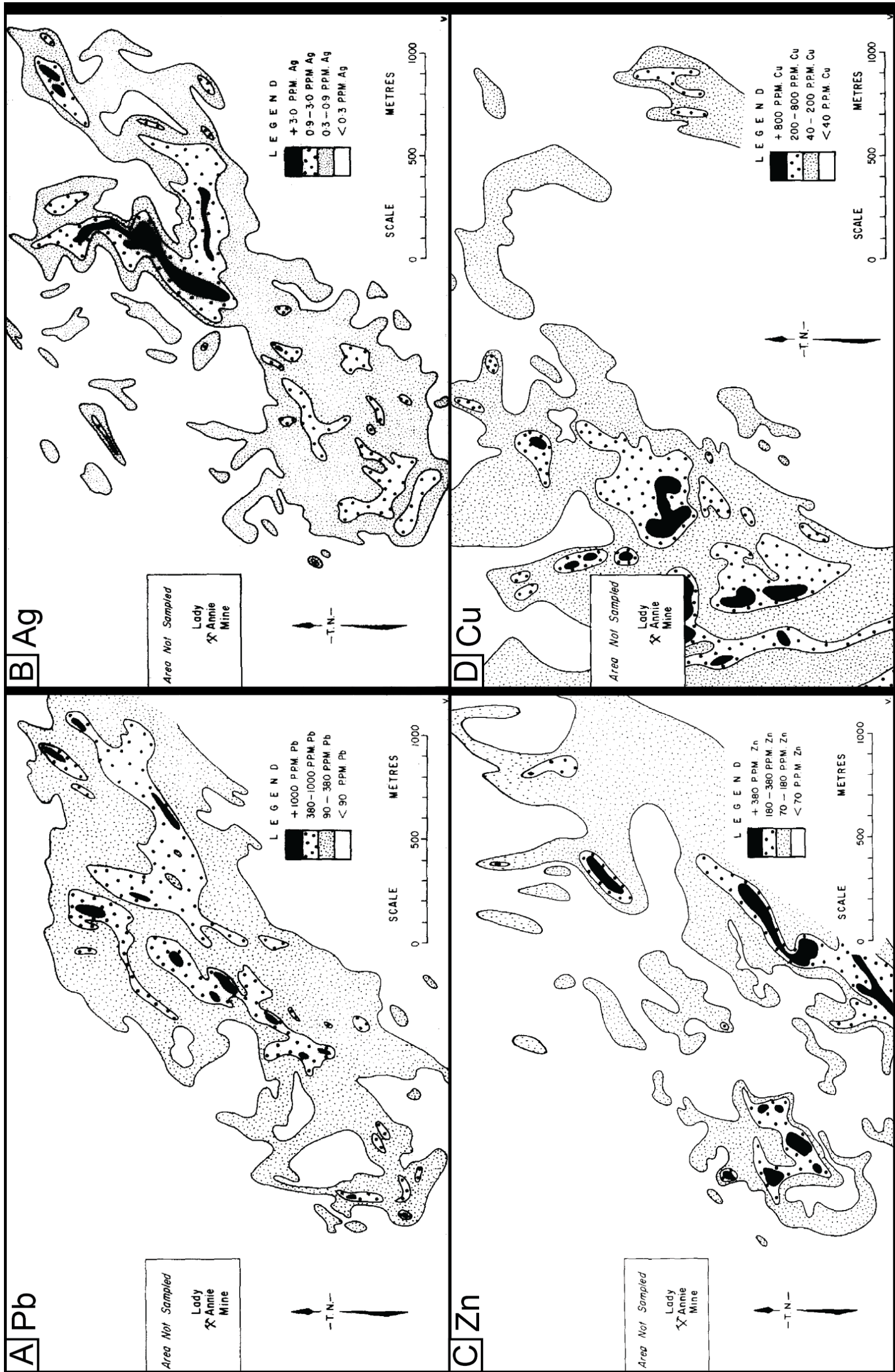
Lady Annie and most of the copper deposits in the Lady Annie project have been known since the early-mid 1900’s based on the presence of oxide copper at surface.

The Lady Annie deposit itself was discovered in 1919 and worked intermittently on a small scale over the ensuing 40 years (Hancock and Purvis (1990).

Typically, as is the case at Lady Annie, the mineralisation was further outlined by rock and soil sampling, and shallow drilling.

Lady Loretta was discovered in 1969 during regional reconnaissance exploration surveys east of the Lady Annie Cu deposit (Cox and Curtis,

Figure 8.24: Contours of detailed (15m x 60m) soil survey data over the Lady Loretta deposit, from Cox and Curtis (1997).



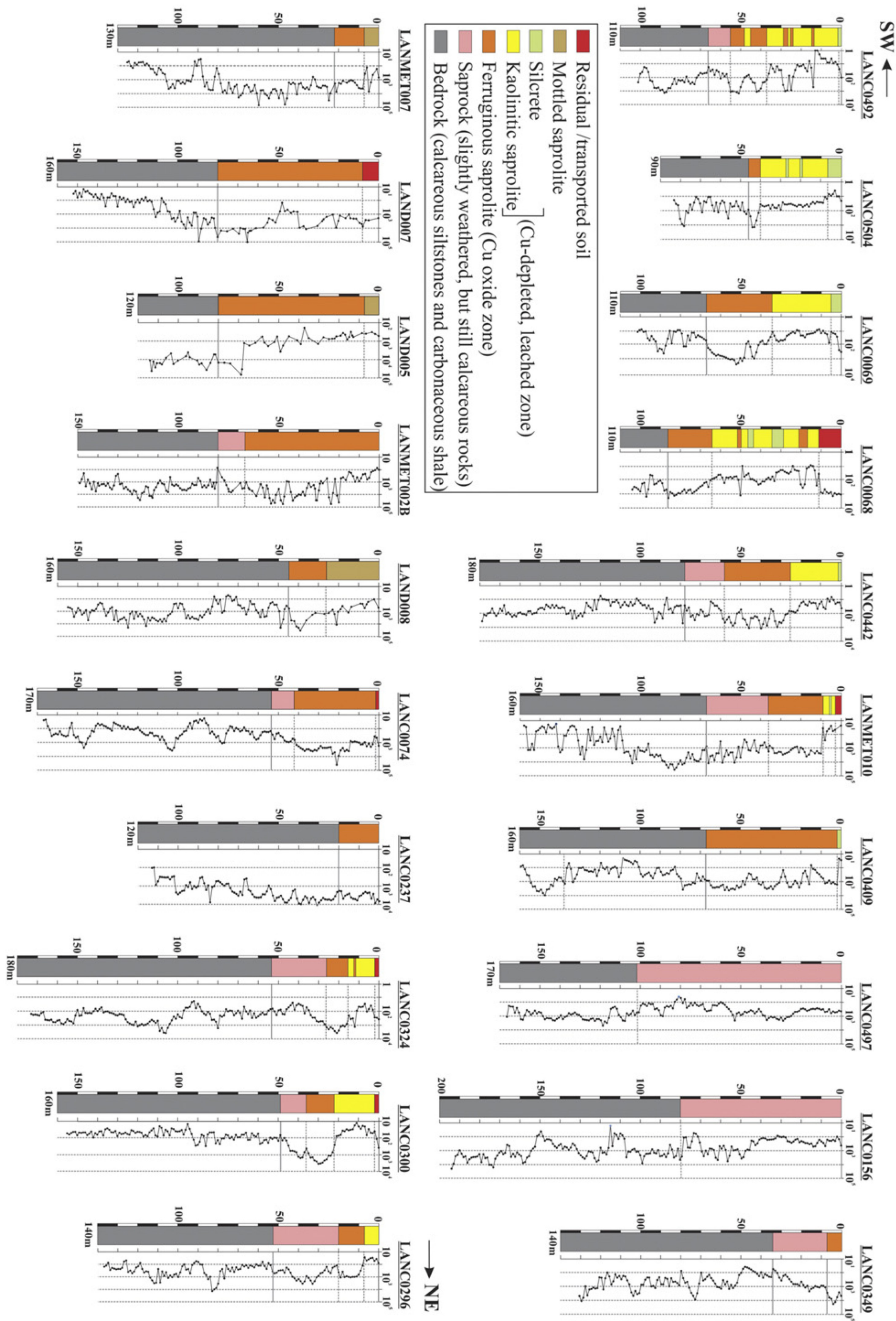


Fig 8.25: Stratigraphic logs vs copper plots from 20 reverse circulation and diamond drill holes from a SW-NE cross-section at the Lady Annie deposit. The plot shows the different stratigraphic/regolith units and the vertical distribution of copper (from Salama et al. (2016). The schematic geology along the section is shown i the next figure.

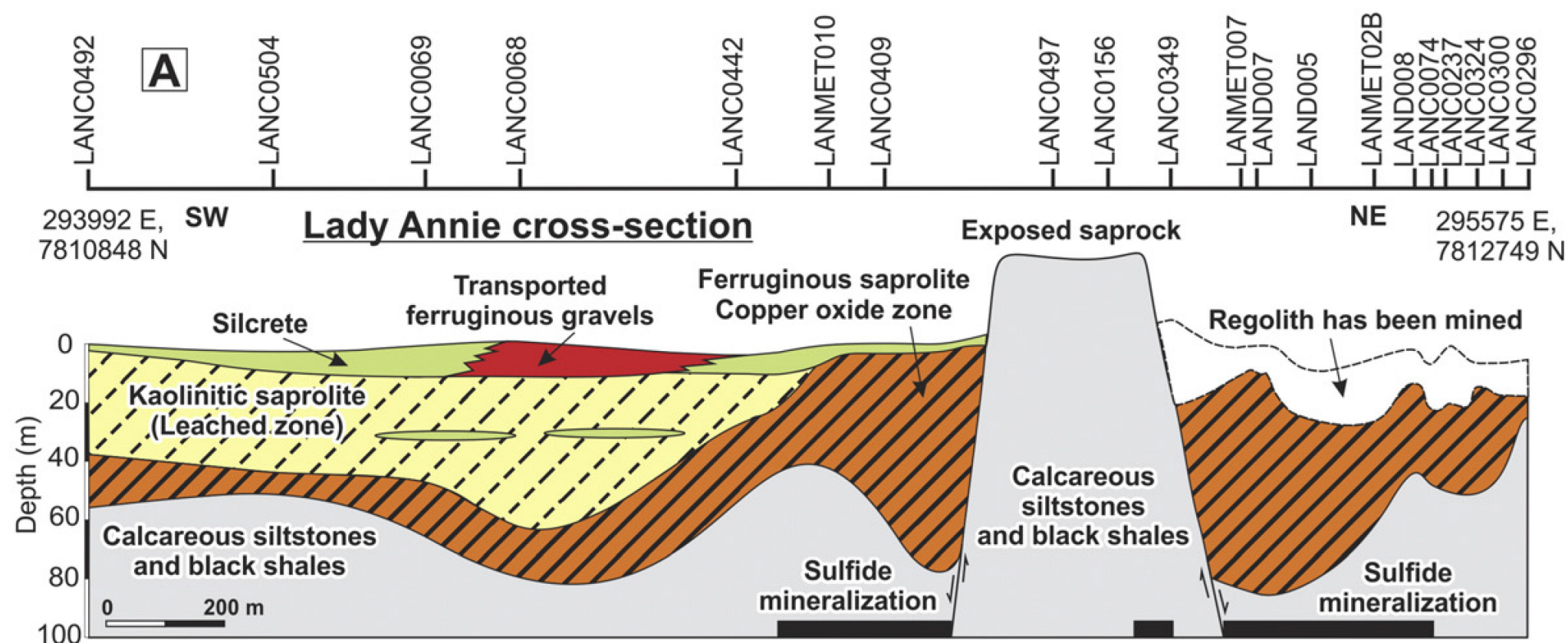


Fig 8.26: A simplified cross-section across Lady Annie deposit showing the lateral distribution of the different regolith units, the location of the primary sulfide mineralisation. It also shows that the ferruginous saprolite (Cu oxide zone) is thicker above the primary sulfides and pinch out laterally, where the thickness of the kaolinitic saprolite increases. From Salama et al., 2016. The detail of the drillhole geology and copper geochemistry is shown in the preceding figure.

1977). The surveys were conducted by Placer Prospecting (Australia) Pty. Ltd. in an attempt to assess the potential for additional Cu ore reserves at Lady Annie.

An initial soil sediment survey was carried out in 1968 on a 122 x 30.5 m (400 x 100 ft) spacing centred on the Lady Annie mine and an adjacent secondary Cu anomaly known as the Flying Pig (Cox and Curtis, 1977). Only Cu was assayed in these initial samples due to the target mineralisation-style being an extension of the Lady Annie Cu system. However, as part of the exploration program, available drill core from Lady Annie was re-logged and it was noted that dolomitic and carbonaceous shales intersected in the unweathered zone resembled the host units of the Mount Isa Pb-Zn orebodies (Cox and Curtis, 1977). In response, every tenth soil sample was also analysed for Pb, Zn and Ag. This sampling campaign delineated three Pb anomalies (Fig. 8.28) with coincident elevated Ag and Zn. The Lady Loretta area is noted by a depletion in Cu relative to the Lady Annie area. The Pb anomalies shown in Fig. 8.28 delineate the outcrop of the Lady Loretta Ore Horizon (Cox and Curtis, 1977). In December 1969, a diamond drill hole (P36) centred on the Pb anomaly marked B in Fig. 8.28 intersected 7.6 m @ 21.2 % Pb as cerussite (PbCO_3) and anglesite (PbSO_4) within the weathered zone. Previous drilling of an induced polarisation survey which terminated west of the Pb soil anomaly shown intersected thinly bedded dolomitic and carbonaceous shales and beds of fine grained pyrite which were interpreted to represent stratigraphic analogues to the Mount Isa Succession (Cox and Curtis, 1977). In December 1970, further drilling intersected massive sulphide Zn-Ag-Pb mineralisation in drill hole P63A located in the Small Syncline area, with grades of 13.6 % Zn, 8.9 % Pb and 100 g/t Ag over 45 m (Cox and Curtis, 1977).

By 1973, 69 holes totaling 24,000m had been completed and a Prefeasibility Study was completed in 1974.

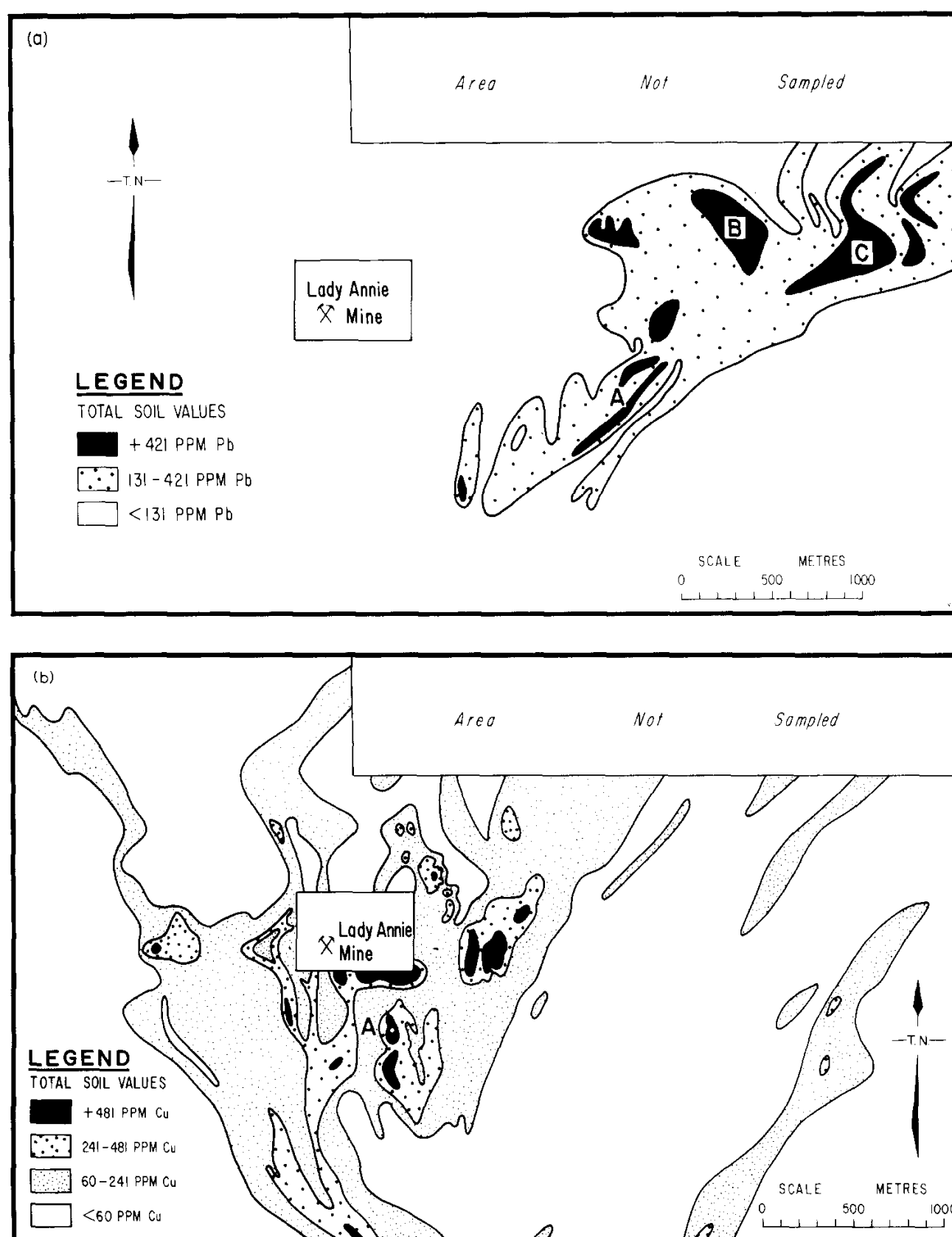


Fig. 8.28: Plot of soil Pb and Cu contours from the original soil survey that resulted in discovery of the Lady Loretta Zn-Pb-Ag deposit. From Cox and Curtis (1977).

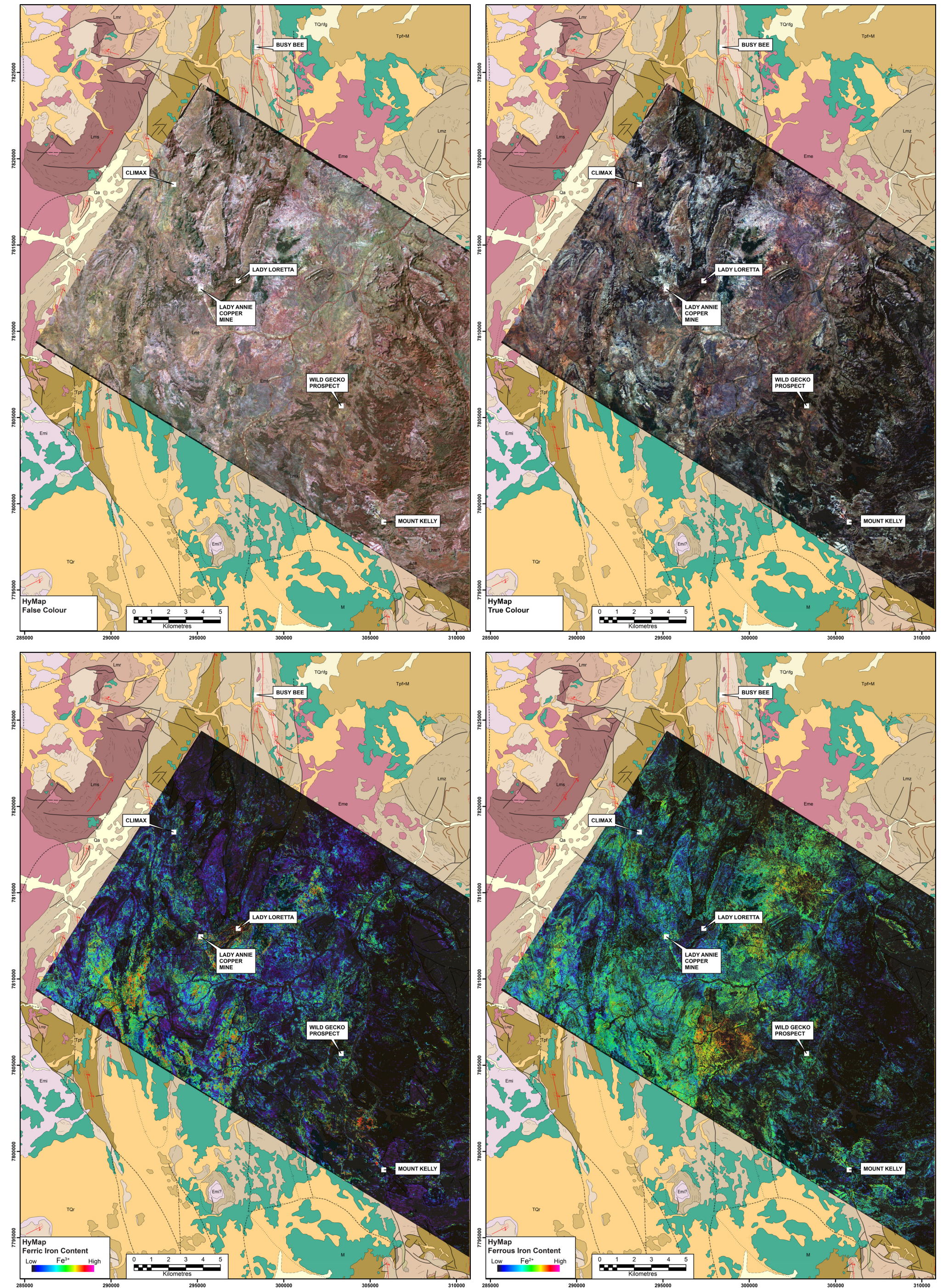
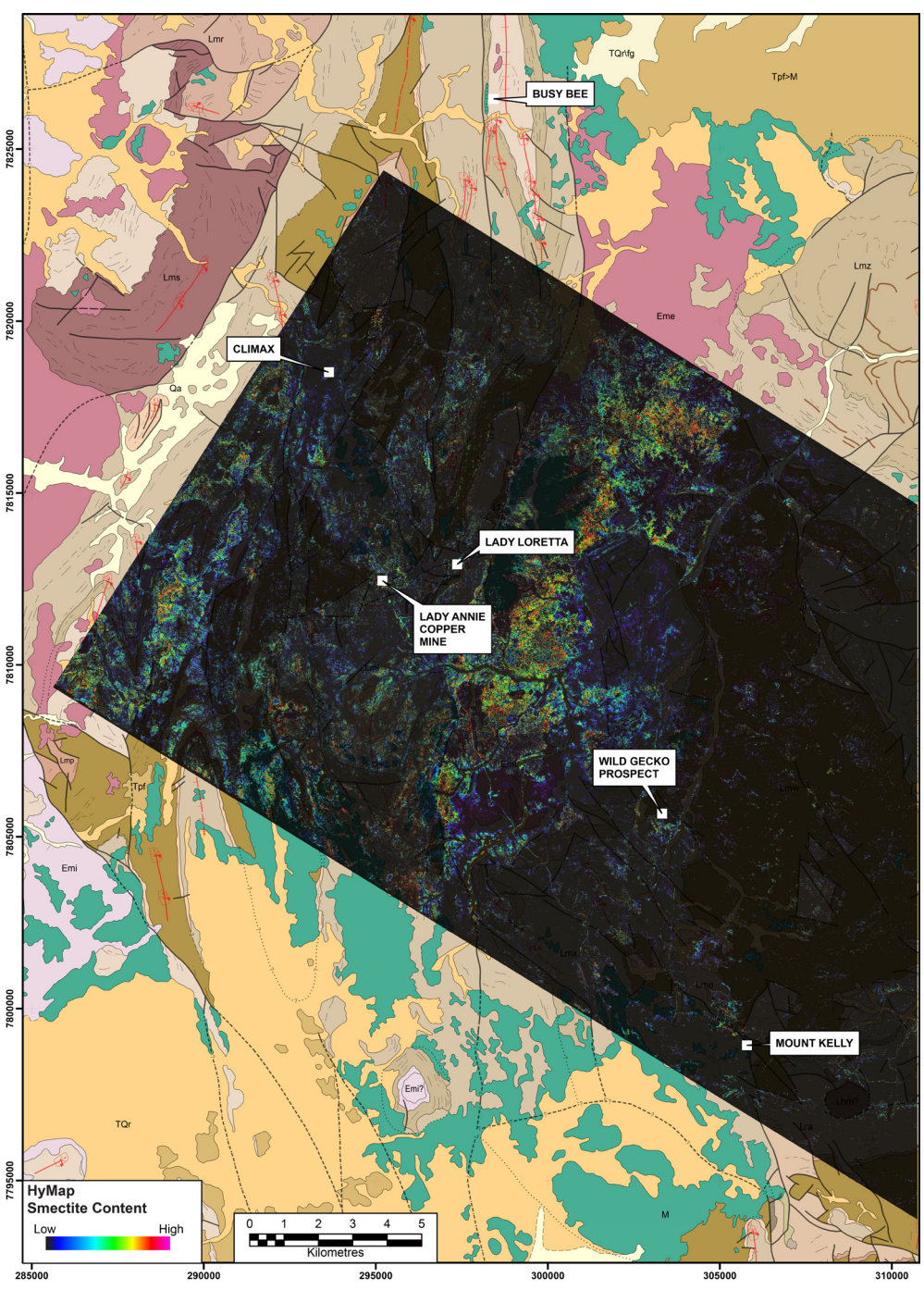
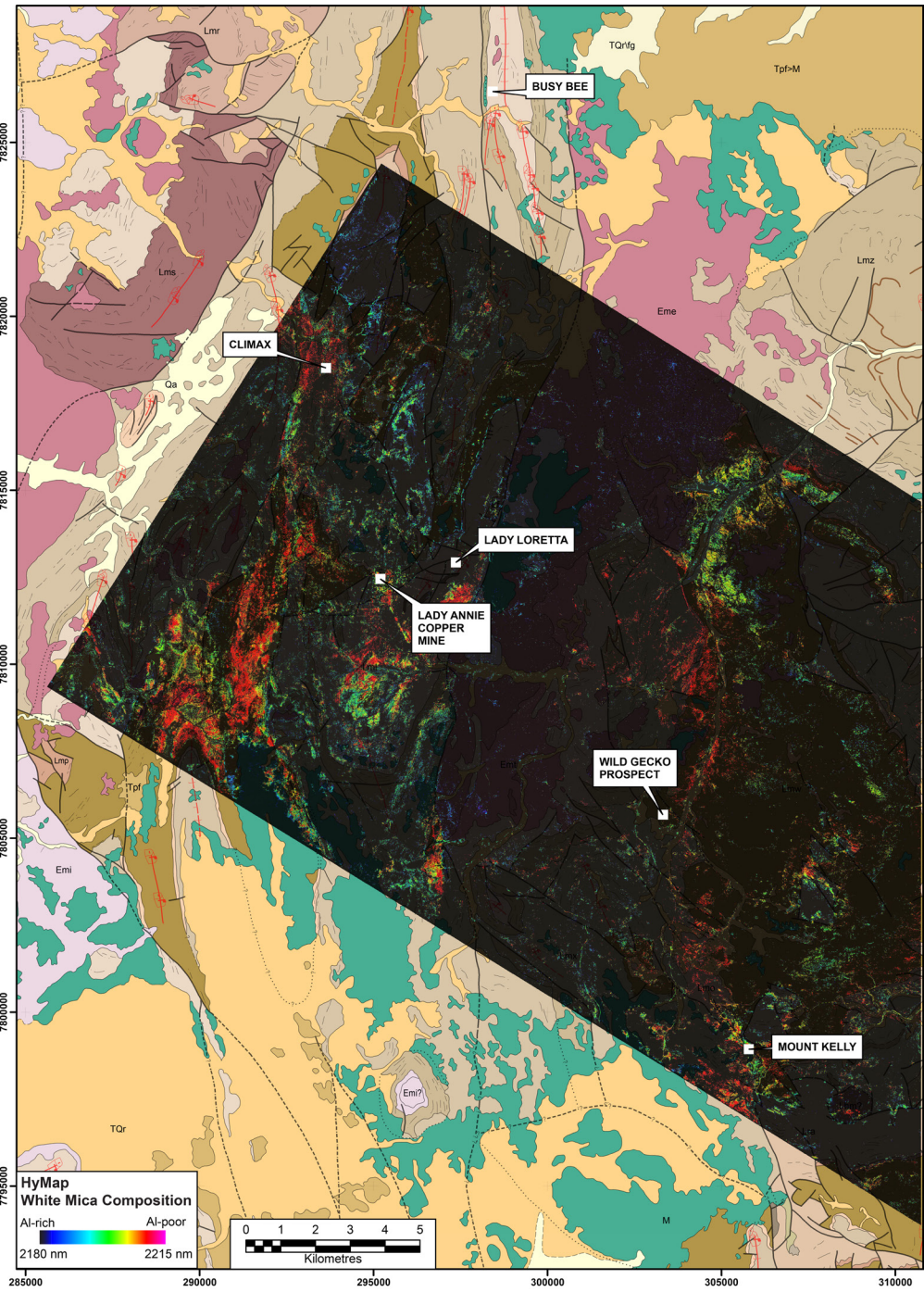


Figure 8.27. Processed HyMap hyperspectral images from Cudahy et al. (2008) overlain on the 1:100k geological map sheet. See text for descriptions.



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