THESIS SUMMARY AND COMPILATION

THE NATURE AND EVOLUTION OF SULPHIDE-CASSITERITE DEPOSITS WITHIN THE ZEEHAN HYDROTHERMAL SYSTEM, WESTERN TASMANIA

J A Anderson

June 1990

THESIS

THE NATURE AND EVOLUTION OF SULPHIDE-CASSITERITE DEPOSITS WITHIN THE ZEEHAN HYDROTHERMAL SYSTEM, WESTERN TASMANIA

PROGRESSIVE THEMES FOR CHAPTERS

RESEARCH RATIONALE

CHAPTER 1 - INTRODUCTION

1.1 *BRIEF DESCRIPTION-* location, resource, morphology, history (Figs. 1, 2, 3 & 4)

1.2 *ARGUMENTS-* (Figs.1 & 5)

a) classic example of hydrothermal zoning; debate of no. of sources and fluid vectors;

b) still insufficient for generally accepted classification and origin of sulphide-cassiterite deposits:- e.g. skarn vs replacement vs greisen; T vs P; boiling vs. carbonate neutralisation.

c) syngenetic vs epigenetic models.

1.3 *OBJECTIVES:*

a) nature of the deposits and likely fluid character

b) position in space and time within the hydrothermal system

c) role of syn-sedimentary C and S

1.4 *METHODS*

a) review regional and district data for setting

b) petrology for local stratigraphic and structural setting and for zoning and paragenetic interpretations

c) wholerock chemistry for hydrothermal overprint

d) carbonate and sulphide mineral chemistry and isotopes for sedimentary-hydrothermal relationships

e) fluid inclusions for interpretation of the mineralizing fluid

CHAPTER 2

EVIDENCE FOR A STRUCTURALLY-CONTROLLED CUPOLA LOCUS

2.1 *REGIONAL STRUCTURE*

(Fig. 6)

a) reactivating NNE faults = West Coast Range- Valentines Peak Di folds;

b) sinistral Zeehan-Queenstown zone;

c) Linda Zone;

d) Granitoids.

2.2 *DISTRICT GEOLOGY AND STRUCTURE*

(Figs. 7, 8 & 10)

a) Stratigraphy

b) Heemskirk granite

c) Folding and fault sequence

2.3 *INTERPRETATION OF STRUCTURAL MECHANICS*

(Fig. 9)

a) D1 --> sinistral S2 with ductile folding;

b) D2 --> " S3 " " " ;

c) D2L --> brittle S5 and S4 re-activation;

d) post-mineralization dextral re-activation.

2.4 *RE-INTERPRETATION OF LODE ZONING IN THE ZEEHAN FIELD-*

(Figs. 10, 11 & 12)

a) remove post-mineralization faulting;

b) relation of lode- & S2 and S3 fault-patterns;

c) contours of vertical siderite-pyrite transition;

d) paragenetic and structural control.

2.5 *EVIDENCE FOR A HIDDEN CUPOLA LOCUS*

(Figs. 12 & 13)

a) vertical lode- and tin-zoning;

b) magnetics and structure;

c) Rb anomaly;

d) dykes.

2.6 MORPHOLOGICAL MODEL FOR THE HEEMSKIRK-ZEEHAN GRANITE FIELD (Fig. 14)

a) structural control;

b) NE apex to Heemskirk granite;

c) Montana-Spray granitoid ridge;

d) Zeehan cupola and hydrothermal system.

CHAPTER 3

LOCAL STRATIGRAPHIC AND STRUCTURAL FRAMEWORK

3.1 INTRODUCTION

(Figs. 3 & 8)

a) previous Lutley model and adherents;

b) re-interpret stratigraphy and structural overprint to establish:-

i) stratigraphic position of mineralization;

ii) stratigraphic relation to syngenetic pyrite;

iii) spatial relation to feeder structures;

by DDH logging supported by regional, geochemical and isotopic correlations to characterise lithologies and faults.

3.2 HOSTING LITHOLOGIES

(Figs. 15, 16, 17, 18, 19 & 21)

a) deposit morphologies and containment;

i) psammopelites of Oonah Fm.

ii) Montana Volcanics (incl. Fig. 29- geochem)

iii) Queen Hill beds (incl. Figs. 35/36- geochem)

iv) Poverty Point beds (" " " ")

v) Crimson Creek Fm. (incl. Fig. 33- geochem)

3.3 STRUCTURAL OVERPRINT TO THE LITHOLOGIES

(Figs. 15, 16, 17, 18, 19, 20 & 21)

a) sedimentary facings and pre-fault folding;

b) fault and shear distribution;

c) timing and vectors of fault displacements;

d) spatial relation to mineralization.

3.4 STRATIGRAPHIC INTERPRETATION

(Figs. 15, 16, 29, 33 and 43)

a) lithological comparison with regional interpretations;

b) wholerock geochem differentiation of Montana V. and Crimson Creek Fm.;

c) isotopic differentiation of carbonates in the Queen Hill beds, Poverty Point beds and Crimson Creek Fm.;

d) stratigraphic positions of mineralisation.

3.5 *CONCLUSIONS*

a) QH beds within MV = upper Oonah; PP beds= Redrock of SC Gp.;

b) multiple host horizons;

c) strong spatial relation to dilational jogs of S2/S3 intersections.

CHAPTER 4

PHYSICAL CHARACTERISTICS OF THE HYDROTHERMAL MINERALIZATION

4.1 *INTRODUCTION*

a) Method- fine grainsize required abundant and detailed microscopic examination

b) Objective

i) characterise the deposits mineralogically, texturally and zonally;

ii) interpret mineralization history especially wrt:-

- mineralization timing sequence (paragenesis)
- inherited sedimentary characteristics
- structural control

iii) basis of geochem, FI and isotope studies as additional investigations of the mineralizing processes.

4.2 *DEPOSIT MORPHOLOGIES AND SPATIAL RELATIONSHIPS TO FAULT STRUCTURES*

(Figs. 17, 18, 19, 20, 21 & 26)

a) 3 deposits; morphologies; sizes;

i) QH- stratoid; QH beds & MV; Clarkes S2/C North S3;

ii) Montana- stratabound; dolomite horizon; adjac. complex Severn S2/NQH S3/S4?/Montana S5 intersection;

iii) Severn- pseudo-stratabound; base of Severn fault zone; adjac. Severn S2/Astles S3(S4?)

4.3 *MACROSCOPIC TEXTURES*

a) Delicate replacements- QH volcanics(12D,E) & evaporites(5H)

b) Bedding slip replacements- Severn(14C,E)

c) Massive replacements- Montana(13C-F); some QH; core Severn?;

d) Vein stockwork- Severn(14D), upper Queen Hill dolomites (10C,D) & some evaporites(10E) & bedded pyrite(9B);

e) Lodes (fissure-filling large veins)- crustiform upper (18A-D), banded intermediate(9D-H), irregular splayed lower(9I,J).

4.4 *MINERAL ASSEMBLAGES*

(Figs. 22, 23 & 24)

a) principal minerals cf. cassiterite cf. each deposit-

  i) Dom.- sd Py; moderate- qz fl in all;

  ii) Initial composition--> k > in QH; tr cl > in Severn;

  iii) Zoning--> se & cs grainsize > Severn > Montana > QH; BM > QH & Montana; Po > Severn;

  iv) Variable minor tp, tc, ph

b) Cassiterite association

  se fl vs sd Po etc

c) Comparison with lodes

  i) mineralogy

  ii) cassiterite

4.5 *ZONING*

(Figs. 24-28)

a) Sulphide-cassiterite deposits

  i) early interpretation of cl--> pl--> tr--> tr + tp;

  ii) mineral distribution- tr tp fl cl Po BM St se pl

  iii) spatially distributed assemblages

    - tp tr fl se cs -->
    - pl cl Po sd cs -->
    - cl Py sd ± cs -->
    - sr ± Py sd

b) Lodes

  i) Vertical variation

    - qz Py cs (±Po) -->
    - Py (sd) ± St Sp-->
    - Py sd Sp (St Gn)-->
    - sd Gn Te

  ii) Structural variation

    - sd Gn = S3
    - Py sd = S2
    - Py cs qz = s3 at S2 intersection

4.6 *MICROSCOPIC TEXTURES AND INTERPRETED PARAGENETIC SEQUENCE (Fig. 23)*

a) Evidence of host rock replacements and veining

i) replacement

- evaporites(5H,9C, 10F,G,I,J, 11A-H)
- MV(12D-H)
- fram. Py(8F,G 9A,C,D,E)
- Severn bedding slip repl.?

ii) veining

- evaporite(10E)
- fram. Py(9B,F)
- Severn vein?

b) Other common mineral textures-

- tp destruction(15A,B)
- tr(15C,D,E,F, 16E, 13G)
- cl(16B,C,D)
- qz(14F,G)
- se(15G,H, 16A,D,E, 13G,H,I)
- ph(11A, 12F, 15B,C,D, 16B)
- fl(9C, 11A,B,F,G,H, 13G,H,I, 16A, 20G)
- sd(9C,D, 10F,G, 11B,D,E,F,H, 13H,I, 16A, 17A,C,G, 19B,F)
- k after cs(16G, 17D); before Po(16H)
- Po & related sulphides(14F,G, 15A,B,C,D,E, 16A,B,C,D, E,F,H, 17C)
- Py etc after Po(17G,H)
- St(17C,D, 19A,B,C,D,E,G,H)
- BM(17A,B, 19B,E,F,H)

c) Paragenetic Interpretation

i) Basis for interpretation-

- veins
- corrosion(invasion trails, cuspates)
- association
- care with uncorroded euhedra

ii) Sequence gives stages

- tourmaline greisen
- fluoride greisen
- Fe sulphide
- BM sulphide

iii) Relation to lodes

4.7 *CONCLUSIONS*

a) Style of mineralization- stockwork/replacement

b) Single PA sequence shows one hydrothermal event & system

c) Classification- greisen, granitoid locus, structural control

CHAPTER 5
HYDROTHERMAL GEOCHEMISTRY

5.1 INTRODUCTION

a) Paucity of skarn geochem studies (quote Hosking, 1988)

b) Further investigate hydrothermal system and processes

5.2 WHOLEROCK CHEMISTRY OF THE MINERALIZATION PROCESS (Figs. 29 - 33)

a) Montana Volcanics

- mass increase (M_s/M_r- 1.35; M_t/M_s- 2.11)
- small-moderate volume gain
- Fe gain; Mg loss & some retention as sellaite & tourmaline

b) Evaporites

- constant SG; lose mass & volume
- weak mineralization--> lose S Mg CO_2 Ca
- strong " --> lose same; gain Ca F H_2O Si Al P Ti

c) Oonah Fm.

- constant volume; 10% mas increase
- Al--> tp tr
- Mg loss; slight Si Fe gain; large F Sn S gain

d) Poverty Point dolomites

- no constant elts; presume V/V= 1 --> M/M= 1.25
- possible high Si unmineralized samples
- + Fe Mn Al Sn S F; - Ti Ca K CO_2

e) Crimson Creek Fm.

i) hornfelsed= remote except +CO_2 Rb; - Ti Ca Na K Sr

ii) cl envelope

- + Fe Mg K Rb Sn S F; - Ca Na Sr
- constant Si Mn P CO_2
- constant volume, 28% mass increase

iii) tr core

- + Fe Mg K Rb Sn S F; - Ti Mn Ca Na
- C increase may be stratigraphic
- constant Si P

- slight volume increase; 30-40% mass increase
- S loss(0.63--> 0.03%) & C gain(o.81--> 5.87%?) in fault drag

f) Sn vs. F and S
- linear Sn vs F except for carbonates
- less linear Sn vs S

5.3 *MINERAL CHEMISTRY*

(Figs. 35 - 37)

a) carbonates- sedimentary--> hydrothermal shows local source

b) pyrite- Ni vs. As (+Co) --> some local contribution from syndiagenetic pyrite

c) sphalerite
- Cd vs. FeS --> district variations
- fluid?

d) arsenopyrite- fluid?

5.4 *GEOMETRY OF THE HYDROTHERMAL SYSTEM*

(Fig. 34)

a) Rb zoning = structure

5.5 *CONCLUSIONS*

a) Greisen hydrothermal system
- Sn F S Rb Fe K
- Sn = F; Sn approx. = S
- Rb = structural plume

b) Replacement processes
- insitu replacement of evaporite carbonate
- local early preservation of syndiagenetic sulphides--> minor contribution to hydrothermal S

c) Fluid conditions

CHAPTER 6

FLUID INCLUSION INVESTIGATION OF PALAEO-FLUID CHARACTER

6.1 *INTRODUCTION*

a) Past results and need for study

- e.g. Little, Lutley & Patterson results--> low homogenisation T for deposit type
- other deposit studies have inconsistent results eg boiling
- lack of good studies eg spatial T & salinity

b) Objectives

- further characterise mineralization by FI nature and T & salinity ranges
- thorough study using PA and zoning to establish changes with time and space
- place T scale on PA sequence

6.2 *NATURE AND DISTRIBUTION OF INCLUSIONS (Plate 20)*

a) Small, 2 phase, L>V, homogenise to L, minor CO_2 --> minor clathrates (no evidence of boiling)

b) Common in

- qz (small, some growth zones, mostly secondary dusty overprint)
- sellaite (larger, often isolated, cleavage controlled)
- late fluorite (ribbons // vein walls, irregular size & shape)

c) Rare in cassiterite, early fluorite, early siderite, lode siderite/sphalerite

6.3 *HOMOGENISATION TEMPERATURE MEASUREMENTS AND SALINITY ESTIMATES (Figs. 38, 39 & 40)*

a) Investigative Method

- sample selection and preparation
- smallness & uniform P/S character --> large number (i.e. 37 of 62 plates --> 104 wafers

- microscope and stage
  - type
  - calibration
- Th and Tm(ice) measurements
  - heating rates
  - decrepitation & stretching --> Tm first and single field of view per wafer (i.e. 5 per wafer)
  - 565 Th & 159 Tm including 118 pairs

b) Results
- Th and salinity estimates for each sample vs. PA & deposit
  - replacement
  - style se, qz, sd fl, ap
  - lode qz, sd sp
  - late fl sd veins
  - diagenetic qz & mesitite
- paired Th/salinity plots
  - replacement-style phases $R_1 \rightarrow R_2$ & V
  - lode phases L_1 & L_2

6.4 *INTERPRETATION*

(Figs. 40, 41 & 42)

a) Estimates of trapping temperatures

i) pressure estimate (Table A)
- granitoid & mineralization age of 375-340Ma
- Lr. Permian unconformity at sea level at 300Ma
- erosion/uplift rates = Eastern Highlands i.e. max. uplift after mineralization to u/c is 600-1100m
- deposits formed 800-1700m beneath Devonian SL
- 400-2000m rock above SL
- total depth below surface = 1200-3700m or 30-100MPa

ii) T correction for pressure
- 80MPa --> 65-90°C (Potter, 1977)

iii) Tt for FI phases (Table B)
- R_{max} 460°C, R 320-390°C, Lodes 325-345°C, V 270°

b) Evolution of the mineralizing fluid (Table C)

i) silicate greisen- 460°C/7mass % NaCl

ii) fluoride greisen- 390°C/7% to 320°C/12%

iii) early- sulphide- 325°C/15%

iv) late-sulphide (second brecciation)- 270°C/5%

v) late brecciation- <230°C/5%

c) Spatial variations and structural interpretations

i) linear depth vs. Th relation (Figs. 38 & 41)
RL = 4.94Th - 589 for replacement-style samples

ii) requires vertical downwards P gradient of +20MPa/100m (i.e. 7.5x lithostatic- possible above cupola) if T gradient is +15°C/100m

iii) mismatch of only QH sample (R60,226) supports earlier proposition of E down post-mineralization tilting of 25° angle or less confining pressure in more open pipe configuration

iv) scant lode data suggests later event in different P regime

CHAPTER 7

ISOTOPIC INVESTIGATIONS OF THE HYDROTHERMAL MINERALIZATION

7.1 INTRODUCTION

a) Prior investigations

- i) Replacement-style deposits
  - Kwak (1987)--> greater information needed
    --> meteoric C, crustal S source
  - Walshe (vs. Chappel etc.) --> magmatic S
  - RB (Patterson, 1980)--> magmatic S, mixed H_2O
  - Changpo (Fu etc., 1984)--> ~~meteoric~~ S ? country rock
- ii) Zeehan
  - CSIRO Pb only on R-S deposits
  - Both et al.(1969) S on Zeehan field lodes
  - Hajitaheri (1986) Heemskirk Granite
    - highly -ve $\delta^{13}C$ & $\delta^{18}O$ --> fluid equilibrating with country rock
    - $\delta^{34}S$- Red Granite = +1.8
      - mineralization= +5 - +15 --> sed^{y}.
    - $\delta^{18}O$ & δD " --> contribution of meteoric water

b) Objectives

- i) Stratigraphic differentiation (already discussed)
- ii) Relative sedimentary/hydrothermal contributions of S, C & Pb
- iii) $\delta^{34}S$ zoning
- iv) Relate R-S deposits to Zeehan & Heemskirk systems

7.2 LEAD ISOTOPES (Fig. 49)

a) Objectives

- i) Compliment 1980 CSIRO sampling (13 x Clarke/Taylors lodes & miscellaneous veins, 4 x syngenetic Py, only 1 x QH analysis, no Severn/Montana analyses)
- ii) Investigate contribution of syndiagenetic sulphides by Pb signatures

b) Procedure

- i) Sample selection
  - new samples- 3 x QH syngenetic Py (450ug/g to 1.7%

Pb); 1 x QH hydr., 1 x Montana, 2 x Severn whole-rock (50 - 250ug/g Pb); 1 x Montana Gn

- drill and acid dissolution extraction

iii) Machine- CSIRO

c) Results

i) Homogeneous population; same as earlier CSIRO results i.e. Devonian, except 1 strongly radiogenic sample of Py fl se cs mineralization from QH.

ii) Lodes slightly less radiogenic but same spread

iii) No discrimination of syngenetic vs. hydrothermal samples except 1 CSIRO sample from between QH & Clarkes lode with lower radiogenic (older?) ratio despite having a strong hydrothermal overprint

c) Interpretation

i) No advance; confirmed homogeneous radiogenic ratios

ii) Close to 2-stage linear model of Gulson & Porritt(1987)

iii) Renison Bell slightly more radiogenic; within field of Murchison deposits

iv) Low Pb content of syngenetic sulphides and isotopic homogenisation by cupola related thermal cell --> swamping by Devonian signature, so very low local Pb and hence S contribution

7.3 CARBON ISOTOPES (Fig. 43)

a) Procedure

i) Machine

ii) Sample selection and preparation

- 44 samples by drilling
  - 3 x QH dolomites, 3 x QH mesitites, 5 x min. QH mesitite replacement, 2 x PP dol, 5 x Montana repl., 2 x CCFm dol/lst, 5 x QH repl/veins, 8 Severn repl./veins, 7 x local lodes

b) Results (Fig. 43)

i) hydrothermal cluster at $\delta^{13}C= -5$, $\delta^{18}O= +17$ --> magmatic signature

ii) replacement & vein plots adjacent respective sedimentary carbonate e.g. light C for QH evaporites

& mineralization, heavy C for CCFm limestones & Severn mineralization, heavy O for SC dolomites & Montana min.

iii) some (25%?) local contribution; least in Montana, most in Severn --> source vector.

7.3 SULPHUR ISOTOPES (Figs. 44 - 47)

a) Procedure

i) Machine

ii) Sample selection and preparation

- 46 samples by drilling & acid dissolution (including 6 recent Py samples from recommended 1989 drilling
  - 5 x framboidal Py (2 x bedded, 3 x evaporite interstitia; QH only as CCFm syngenetic Py too scarce for extraction)
  - 25 x R-S (6x Po, 12 x Py, 4 x Sp)
  - 16 x lodes (6 x Py, 7 x Sp)

b) Results (Fig. 44)

i) replacement-style mineralization

- cluster at 2 - 4°/oo, range -1.5 to +8°/oo
- S in Sp slightly(0.5-2°/oo) lighter than in Py & Po
- little difference between R-S deposits

ii) lode mineralization

- +2 to +3.5°/oo cluster, but more skewed within +2 to +8.2°/oo range

iii) diagenetic Py

- limited data--> range -14.3 to +8.5°/oo

c) Incorporation of earlier data (Fig. 45)

i) constant intra-sample variation for sulphide species

- similar $\delta^{34}S$ in Po, Py & Sp
- Gn values consistently less (ave. -2.85°/oo)
- concept of normalised $\delta^{34}S' = \delta^{34}S_{Py,Po,Sp} = \delta^{34}S_{Gn} + 2.85$

ii) geographic variation of $\delta^{34}S'$ (Figs. 45, 46 & 47)

- review Both et al. (1969) interpretation of SW to NE decrease away from source
- NW to SE increase (-0.5 to +12.0°/oo) within mineralogical zones more correct

- centred on principal S_3 axis
- constant gradient contours with abrupt increase across principal S_2 near intersection with principal S_3

d) Interpretation

i) Magmatic fluid source for field near 0°/oo at 2km depth beneath Montana Silver Lead

ii) Fluid flow SE along principal S_3 then SW along various S_2 faults especially principal Severn F.

iii) Gradual mixing with meteoric water with country rock S of >12°/oo

iv) vertical contours show hydrothermal plumes up S_3 intersects of S_2 Severn & QH S_2 faults. These correlate with mineralization peaks & proposed new targets

v) Heemskirk values (Hajitaheri, 1986) fall within same regime. Fluid flow along Barnetts S_2 from same deep source may be possible

CHAPTER 8

CONCLUSIONS

8.1 *GEOMETRY OF THE HYDROTHERMAL SYSTEM*

a) Granite morphology

i) Heemskirk-Renison ridge

- gravity/magnetic/deposit delineation
- S-isotope pattern --> medial ridge & increasing depth to NE

ii) Montana S.L.- Spray ridge

- Rb, deposit zoning, S-isotopes, magnetics

iii) Zeehan cusp

- Rb, magnetics
- dyke proximity

b) Fault control

i) granites

ii) site preparation

- sinistral, dilational jogs

iii) fluid flow vectors

- S-isotopes

iv) post-mineralization

- dextral
- tilting --> asymmetric zoning

8.2 *NATURE OF THE HYDROTHERMAL FLUID*

a) T, salinity, P (via trapped fluid inclusions)

i) T & salinity --> mixed & cooled

ii) P gradient --> cupola underneath

b) Mineralogy

i) B, F, Al, Mg minerals

ii) Zoning- tp tr greisen--> cl tr se fl cs greisen--> Po Py sd St Sp--> fl sd Gn Te sulphides

iii) pH, fO_2, fH_2S etc.

c) Geochemistry

i) Rb, F, S, Mg, Al, Fe, K (Si, Ca, H_2O) addition

ii) Na, Ca, Sr loss

d) Isotopes

i) Pb --> Devonian, magmatic

ii) S --> magmatic, mixing with formation water --> initial mantle source (refer to Walshe,p.c.)

iii) C, O --> some local assimilation, mostly homogenized by magmatic overprint

8.3 CONTROLS ON MINERALIZATION

a) Stratigraphic

- i) carbonate replacement
- ii) volcanic replacement
- iii) biogenic pyrite
- iv) multiple hosts

b) Structural preparation

- i) lode-filled fluid channels
- ii) Severn carbonate-smeared bedding slips
- iii) network fracturing

c) Fluid evolution and mineral stabilities

- i) T:- se = cs at 320-390°C; St = lodes at 325-345°C
- ii) pH, aF^-, aK^+ --> tp/sr relation
- iii) fluid inclusions --> no boiling at cs stage
- iv) fH_2S, fO_2 --> FeS/FeS_2 relation, SnO_2
- v) paragenesis:- tp destruction + se production --> SnO_2
  i.e. prior greisen, not skarn although tp greisen not essential

<u>equations</u>

greisen destruction 1) $Al_2(SiO_4)(OH,F)_2 + 2H^+ = SiO_2 + 2Al(OH)^+_{aq} + HF + \frac{1}{2}O_2$

2) $2Al_2(SiO_4)(OH,F)_2 + 3(Mg,Fe)Cl_2 + NaAl_2Si_2O_8 + 2SiO_2 + 3BO_3^{2-} =$
$Na(Mg,Fe)_3Al_6((OH)_4(BO_3)_3Si_6O_{18} + 6Cl^-$

3) $6Al_2SiO_4(OH,F)_2 + 2KMg_3AlSi_3O_{10}(OH,F)_2 + 6H_2O + 8H^+ = 2KAl_2(AlSi_3O_{10})(OH)_2 + Mg_6Si_4O_{10}(OH)_8 + 2SiO_2 + 8HF + 8Al(OH)^+ + 3O_2$

se pptn. 4) $2MgCaCO_3 + 2HF + FeCl_2 = MgF_2 + H_2O + FeMgCO_3 + CO_2 + Ca^+$

sd pptn. 5) $FeCl_2 + Ca^{2+} + CO_3 + \frac{1}{2}O_2 = CaCl_{2(aq)} + FeCO_3$

cs pptn. 6) $SnCl_2 + O_2 + Ca^{2+} = SnO_2 + CaCl_{2(aq)}$

fl pptn. 7) $MgCaCO_3 + FeCl_2 + 2HF = MgFeCO_3 + CaF_2 + 2HCl$

advanced repl. 8) $MgFeCO_3 + FeCl_2 + 2HF + \frac{1}{2}O_2 = FeCO_3 + MgF_2 + H_2O$

Po pptn. 9) $FeCl_2 + H_2S = FeS + 2HCl$

Po destrn. 10) $FeS + H_2S + CO_3 + O_2 + FeCl_2 = FeS_2 + FeCO_3 + H_2O + Cl_2$

8.4 *MODEL*

a) Physical parameters

i) morphological

- stratabound/stratafault
- fault-abutting
- cupola-locus

ii) mineralogical

- tp Fe-tr pl greisen stage overprinted by
- cl Fe+Mg-tr se fl cs greisen overprinted by
- Po Py sd Sp St stage overprinted by
- late fl sd Gn Te stage

iii) chemical

- B, F, Cl, Si, Mg, Al, S greisen

b) Interpretive Genetic Parameters

i) mineralization controls

- structural preparation
- acid neutralization
- T fall

ii) regional mixing of initial magmatic fluid (isotopes) with formation waters (FI)

- only small local biogenic S contribution
- moderate magmatic C overprint

c) Comparison with other sulphide-cassiterite deposits

i) dyke proximity distal vs.

- Mt Bischoff/Cleveland proximal
- Renison Bell distal

ii) greisen system (no skarn minerals) cf.

- greisenised skarn at Mt Bischoff and Cleveland
- massive sulphide replacement at Renison & Changpo

iii) low-moderate Po overprint & subsequent Pyr^{n}. cf.

- massive Py at Changpo & Cleveland
- massive Po at Renison & Mt Bischoff

iii) cs precipitation due to acid neutralization cf.

- boiling (Halley) vs neutralization (Wright) at Mt Bischoff
- acid neutralization at Cleveland
- RB- boiling in F-B fault, not in carb.-repl.

iv) temperature 320-390°C cf.

- Cleveland- proximal skarn 480°C to greisen skarn 280°C
- Changpo- cs-sde 250-400°C
- Renison Bell 325°C
- Mt Bischoff- greisen 340-480; cs 340-380°C

v) S-isotopes +2.5 - +3.5‰ cf.

- Dachang- Lamo skarn -2 to +3
  - R-S deposits affected by host S
    e.g. <-5 with bedded Py in Changpo,
    +2 to +11 in sulphate-rich Bali
- Renison Bell +3.7 to +7.4
- Cleveland +2.3
- Mt Bischoff +0.2 to +2.4

d) General R-S deposit model *(Fig. 50)*

$\delta^{34}S$ is a measure of distance from initial point of mixing of magmatic fluid with formation water i.e. effective source, which by corollary approximates granitoid proximity i.e. size & configuration of genetically- related granitoid body determines heat gradients & fluid flow & therefore rate of mixing away from effective source. If body is small (e.g. Mt Bischoff), precipitation T reached quickly before much mixing --> small fields, whereas if body is large (e.g. Renison, Dachang), larger volumes of higher T magmatic fluids take longer to cool and therefore have more opportunity to mix while cooling to precipitation T. The result is volumetrically bigger and more diverse fields (e.g. Zeehan). Large deposits may form in small fields (e.g. Mt Bischoff) if smaller fluid flux is concentrated into a large local receptive host.

e) Classification

* tourmaline-chlorite-sellaite-siderite-fluorite-cassiterite magnesian greisen
* with a light pyrrhotite-dominated sulphide overprint
* as replacement/stockwork after structural preparation
* of either topaz tourmaline phlogopite greisen or variety of sedimentary carbonates (mesititized evaporites, dolomicrites, dololutites) or sideritized sericitized basalts;
* derived from moderate- to far-distal (700-1500m) magmatic fluid diluted to 390 - 320°C, <15% salinity & 2-6‰ $\delta^{34}S$;
* conduited through prior Tabberabberan dilational jogs, subsequently infilled by lode mineralization with zoning of qz-Py-cs --> qz-Py>sd-Sp-St --> sd>Py-Sp --> sd Gn Te up and out from the R-S deposits