Are Magmas Sources of Most or All Metals in Iron Oxide-Copper-Gold and Related Ore Types?

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Abstract – Magmas are unlikely to be an "ortho-magmatic" source of copper and gold in iron oxide-copper-gold deposits, although data are not sufficient to confirm this inference as yet. Current hypotheses positing ortho-magmatic sources deserve critical examination, because iron oxide-copper-gold deposits display: (1) no consistent local spatial relationships with coeval magmatic rocks; (2) no relationships between the size and grades of their metal inventories and the composition and configuration of regionally or locally associated bodies of coeval magmatic rocks; (3) no stable or radiogenic isotope signature unequivocally indicating an ortho-magmatic source of copper and gold; (4) suites of anomalous elements that do not uniquely characterise any specific magma type; (5) a unique association with geological provinces that contain sodic-calcic alteration; (6) a unique association with a host lithological assemblage which does not contain reduced carbon minerals; or which contains such minerals in minor amounts only, at the regional scale; and (7) complex fluid inclusion chemistries that indicate that two or more fluids have been involved in ore genesis. Where coeval magmatic rocks are closely associated, for example, Olympic Dam, they do not display textures indicative of magmatic volatile phase separation and loss.

Copper and gold in porphyry copper deposits likewise may not have an ortho-magmatic source. Porphyry copper deposits of the SW USA, the SW Pacific arcs, and Chile, display characteristics (2), (3), (4), and (6). Characteristic (6) is marked: the deposits only occur in host lithological assemblages that either do not contain, or which contain very minor, carbonaceous or graphitic rocks, for example, shale or schist, or carbonate, or greywacke, or quartzitic greywacke, at the regional scale.

A modified para-magmatic metal source hypothesis is proposed to account for the characteristics noted. The elements of the hypothesis are: (1) a magma stock is emplaced across a fault or fault sets that comprises part of, or is linked to, a major, seismically active system; (2) the fault is subject to repetitive high slip rates during the seismic activity; (3) strain damage within the crystallised shell of the stock is greatest near the fault; (4) fluid pressures in the fault periodically range from sub-hydrostatic to lithostatic during the seismic cycles; (5) at a lithostatic p_{fluid} at a depth of 8km or so, rocks in the stock adjacent to the fault are brittle at temperatures up to those of an intermediate magma on its liquidus during episodes of high strain rates or where stress regimes are favourable (e.g. Fournier, 1999, Fig 3; Sibson, 2000, Fig 4) (6) fluid is episodically pumped into the solidified part of the stock from a fluid reservoir within the fault, with fluid flow greatest in the zone of strain damage adjacent to the fault; (7) steep thermal gradients, and the thermal reservoir represented by the cooling stock contribute to the fluid pumping; (8) the injected packets of fluid ascend either under ductile conditions within the hot rocks near the interior of the magmatic body; or episodically under brittle conditions in the interior and in the sub-solidus shell of the magmatic body when strain rates are high; (9) the ascending packets of fluid reach their two phase region within or above the upper parts of the magmatic body (e.g. Hedenquist et al. (1998), Fournier (1999); Meinert et al (2003); (10) precipitation of ore minerals occurs in this region and at lower temperatures, (11) metals are sourced from rocks in the fluid flow paths, and from trapped tiny bubbles of "ortho-magmatic" fluid in flow paths of the fluids injected

into the stock; and (12) metals initially transported are controlled by initial fluid salinities and oxidation states.

The speculative hypothesis, clearly requiring further research, may help to account for (a) the association of porphyry copper deposits and iron oxide-copper-gold deposits with lithological assemblages predominantly free of reduced carbon at the regional scale; (b) an absence of evidence for magmatic volatile phase saturation and loss from the ore-associated magmatic rocks in the porphyry copper and iron oxide-copper-gold systems considered here; (c) vein orientations in porphyry copper deposits inconsistent with volatile-saturated magma depressurisation events (e.g. Burnham (1979); (d) faults and fault sets comprising parts of regional scale faults associated with ore-bearing or ore-proximal magmatic rocks; (e) porphyry copper deposits situated on the margins of the concealed parent stocks of the ore-associated intrusive bodies, rather than on their apices; (f) no correlation between metal grades and contents of the deposits and the size and configuration of an associated coeval body of magmatic rock; (g) "magmatic" oxygen and hydrogen isotope signatures of the "magmatic" volatile phase; (h) Sm/Nd systematics, and Pb and other isotope signatures which indicate a component within mineralisation and within the inferred source intrusion with crustal affinities; and (e) lack of robust *primary* geochemical, mineralogical, and textural indicators that differentiate mineralisation-associated magmatic rocks from barren magmatic rocks, even within mineralised districts.

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This speculative hypothesis is presented in an attempt to resolve the great question facing exploration geoscientists in their hunt for intrusion centred ore deposits: what are the relations between regional scale fault systems, magmas, host lithological assemblage oxidation state, and the intrusion centred ore deposits? The current ortho-magmatic hypothesis of ore genesis is currently too limited to resolve these questions, and it fails to satisfactorily account for the structural and lithological associations of iron oxide copper gold deposits and many porphyry copper deposits.

Burnham, C., 1979: in: Geochemistry of Hydrothermal Ore Deposits, 2nd. Ed., Barnes, H., ed., p. 71-136.
Fournier, R. O., 1999: Econ. Geol. 94, 1193-1212.
Hedenquist, J., Arribas, A., Reynolds, T., 1998: Econ. Geol. 93, 373-404
Meinert, L., Hedenquist, J., Satoh, H., and Matsuhisa, Y.: 2003: Econ. Geol. 98, 147-156.
Sibson, R., 2000: Econ. Geol. 95, 41-48.

Why I Don’t Like Magmas as “Direct” Metal Sources…..

A qualitative examination of empirical evidence and a tentative model: a reconnaissance look

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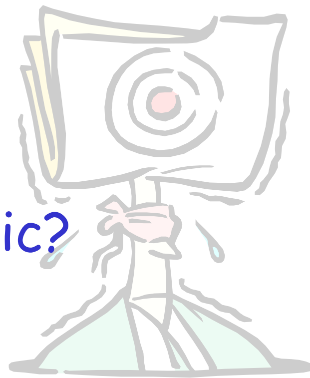
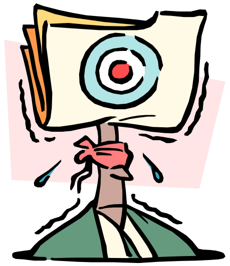
DHD

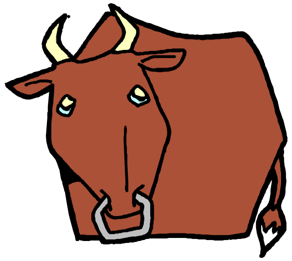
- Definitions
- Orthomagmatic vs Paramagmatic?
- The Evidence: A Tour
  - Iron Oxide Copper Gold
  - Intrusion Associated Copper (-Gold)
  - Intrusion Associated Gold



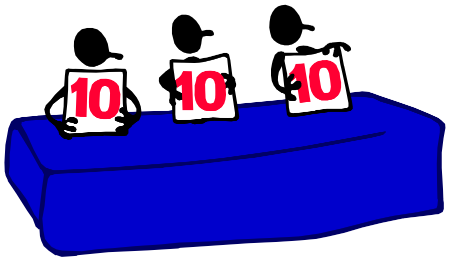
- The Evidence: A Tour
  - Host Lithological Assemblage Redox
  - Structural Associations
  - Isotopes – Briefest of Looks
  - A Tentative Model



- Orthomagmatic:

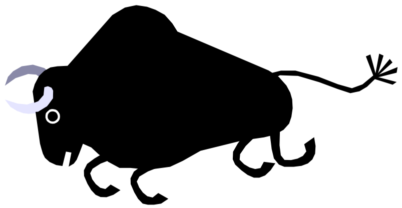


- Paramagmatic:



- Host Lithological Assemblage

  - ❖ Assemblage hosting the ore deposit AND its associated magmatic body
  - ❖ Greater than several km thick; extends 5 or more km beyond the ore deposit and associated magmatic body
  - ❖ Extensiveness enough to constrain pH, fO2, ΣSO4-HS.. .. in any hydrothermal fluid in adjacent large faults



- Deposits Discussed

  Iron Oxide Copper Gold (IOCG)

  Intrusion Associated Copper, Copper-Gold (IAC)

  Intrusion Associated Gold (IAG)

- Host Lithological Assemblage

- For IOCG, IAC:

  - felsic, intermediate volcanic or intrusive, felsic gneiss, quartzite, arenite, shale, limestone,.. ..
  - an absence or rarity of reduced carbon
  - non silicate iron minerals predominantly as non-sulphide forms ?

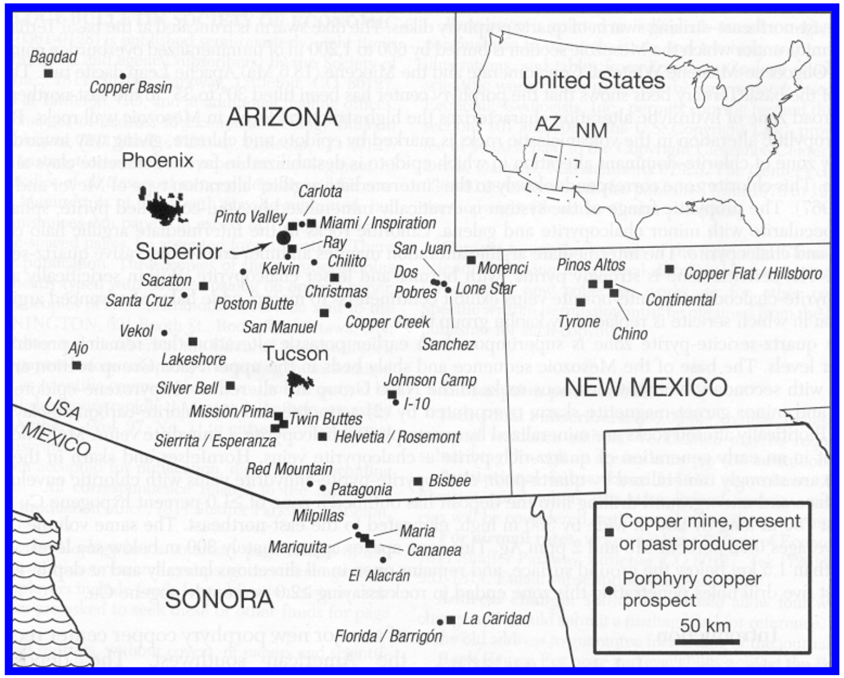
Remember, we are describing SHALLOW CRUST.. .. i. e. the top 5 to 8km or so

- Host Lithological Assemblage
  - For IAG

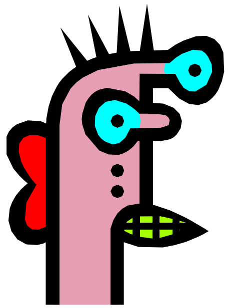
- Similar, BUT also greywacke, metagreywacke, metasiltstone.
- widespread reduced carbon in one or more lithological units >> 1000's metres thick
- non silicate iron minerals predominantly as sulphide forms ?

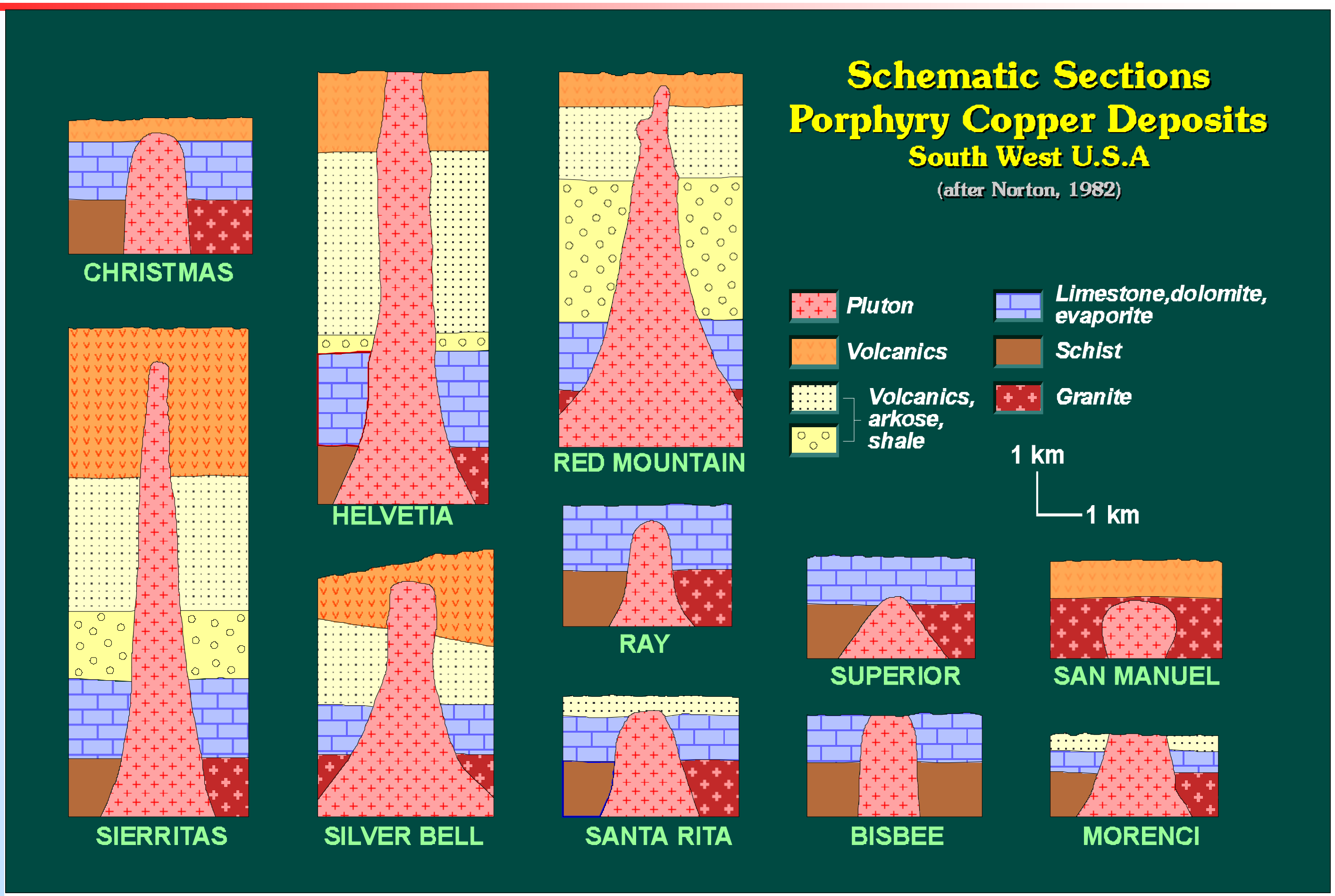
Remember, we are describing SHALLOW CRUST.. .. i. e. the top 5 to 8km or so

Arizona-New Mexico Porphyry Copper



From Manske and Paul, 2002





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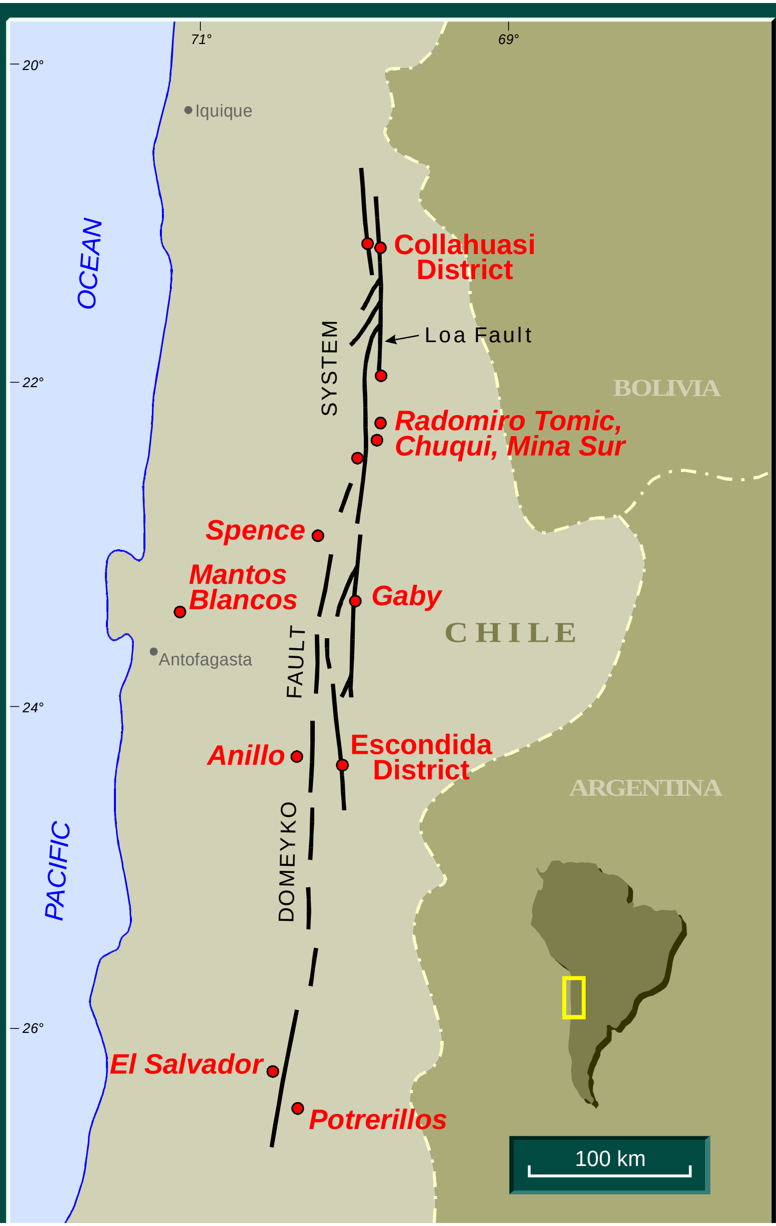
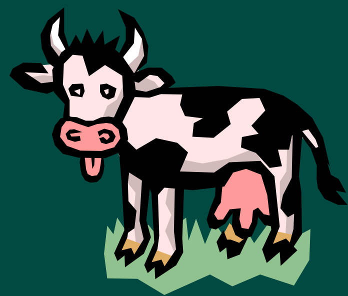
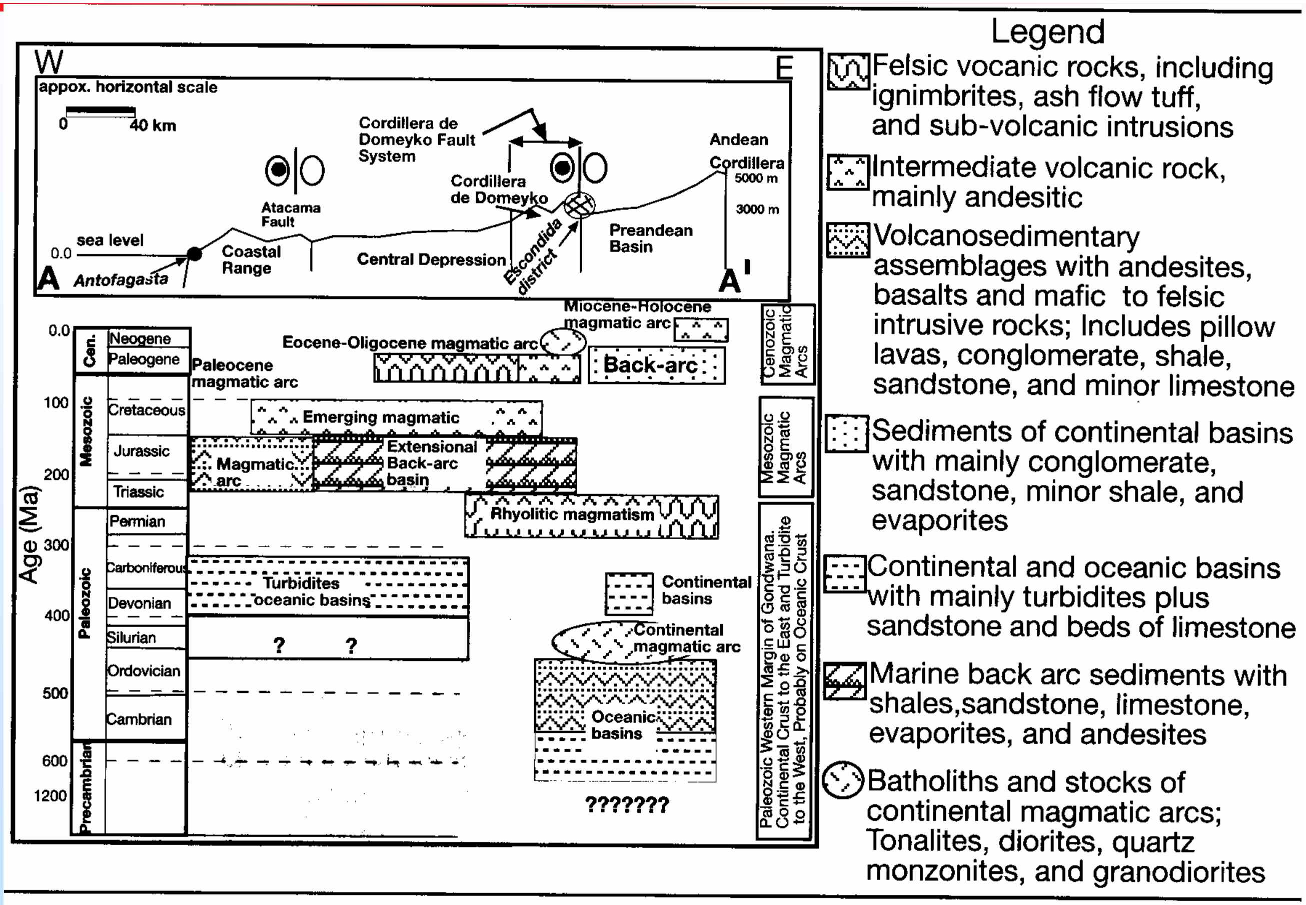


Copper and Iron-endowed Faults, Tertiary Arcs, Chile





Garza et al., 2001

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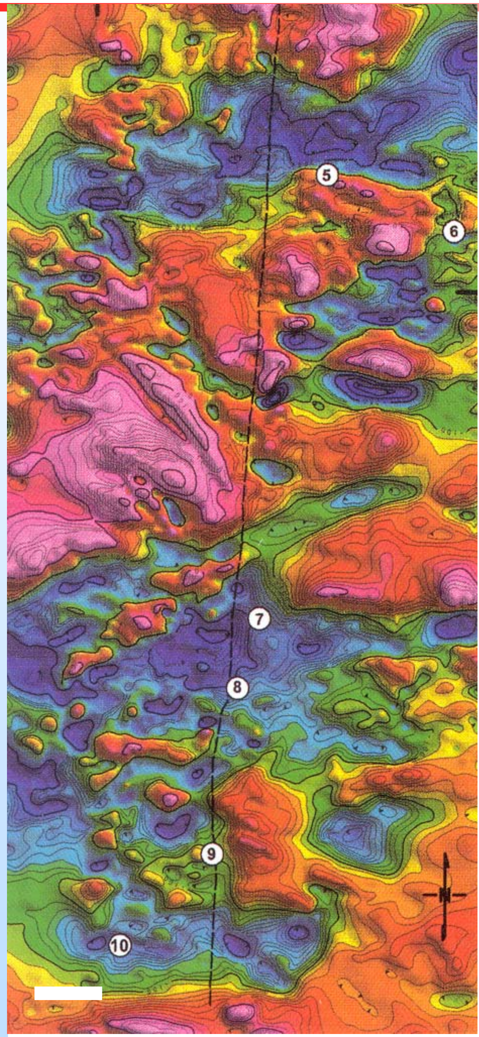

El Abra
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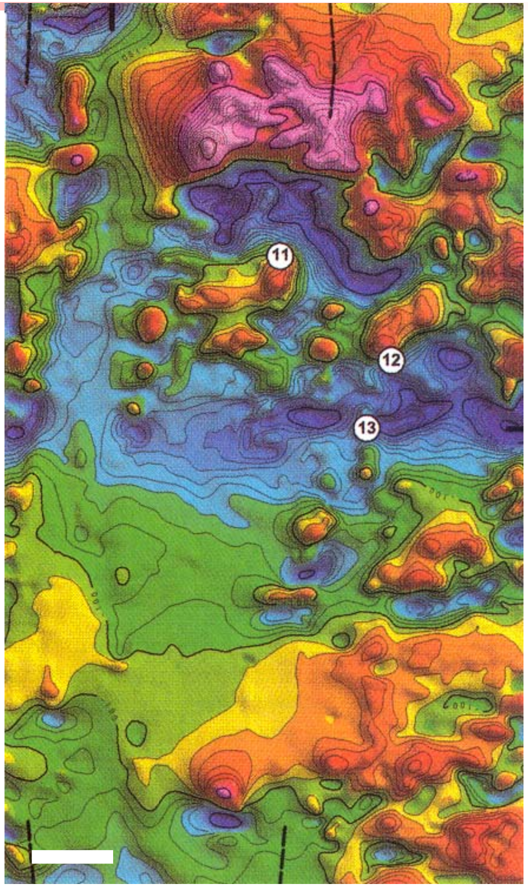
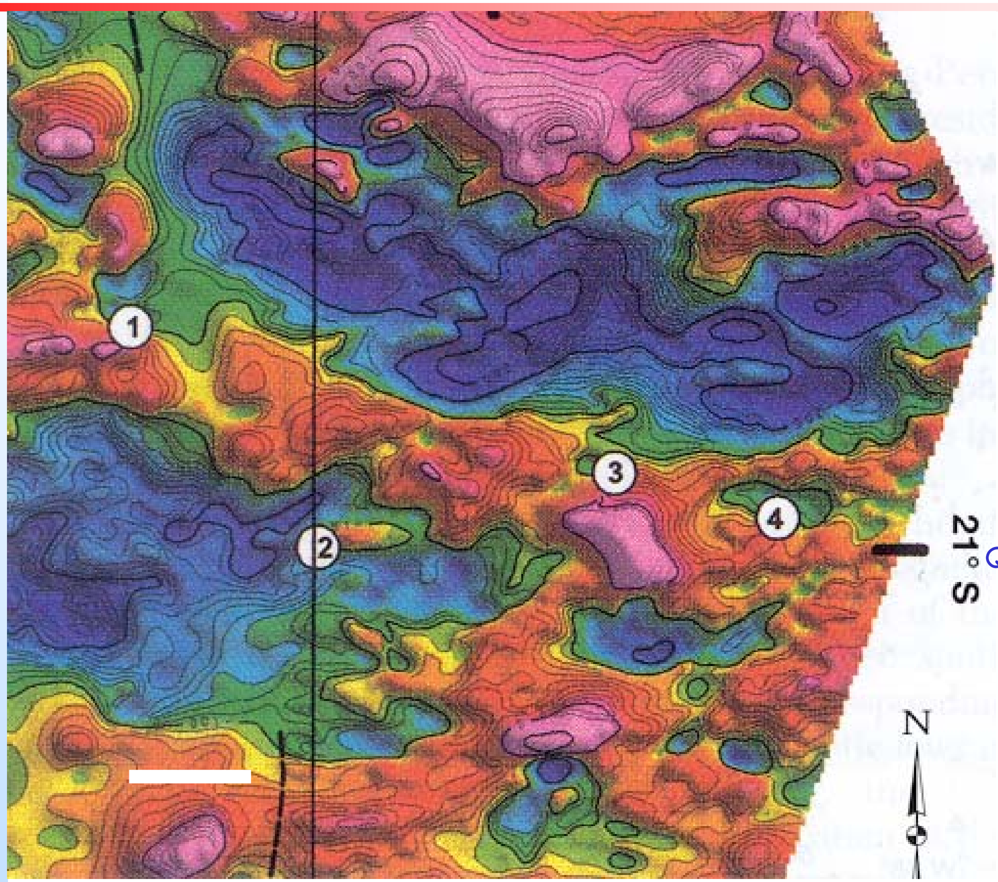
Radimiro T
Chuqui
Mansa Mina
Opache



Chimborazo
Zaldivar
Escondida

Behn et al., 2001



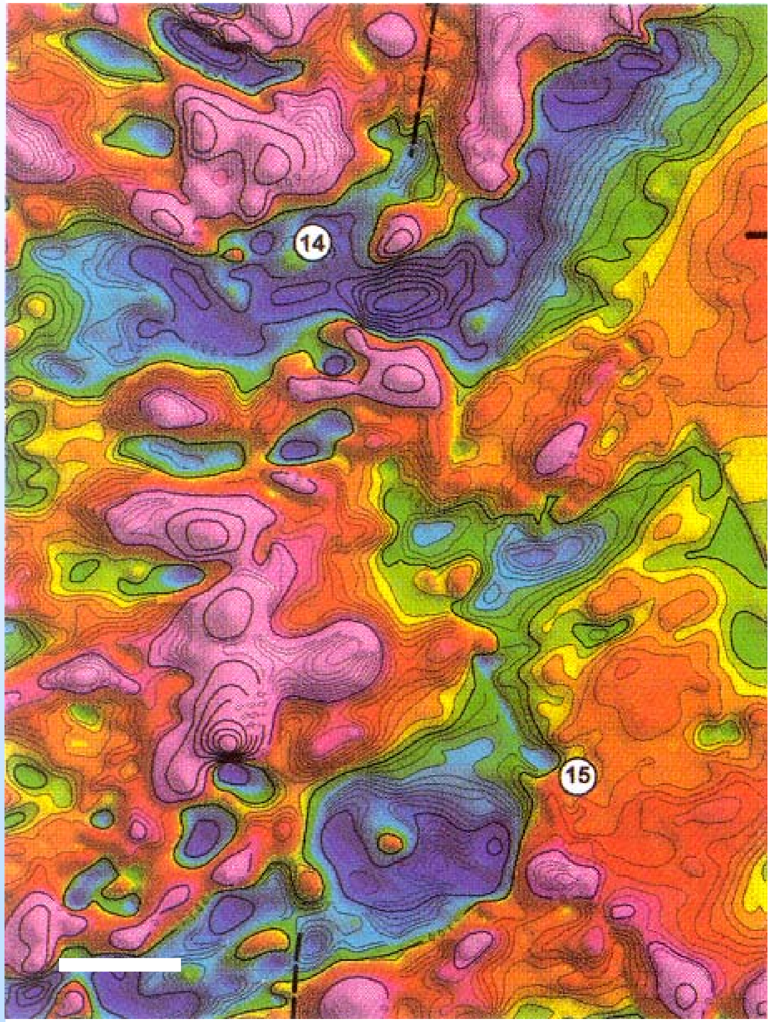
Copaguiri

Collahuasi

Ujina

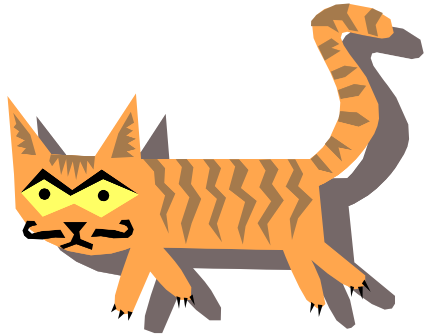
Quebrada Blanca

Behn et al., 2001



El Salvador

Potrerillos



Behn et al., 2001

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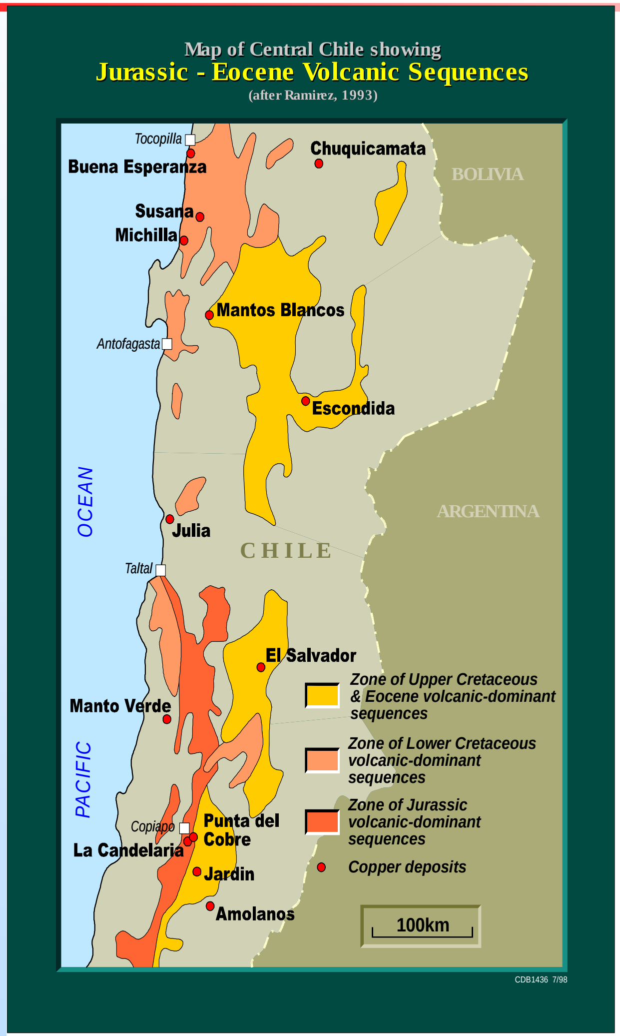
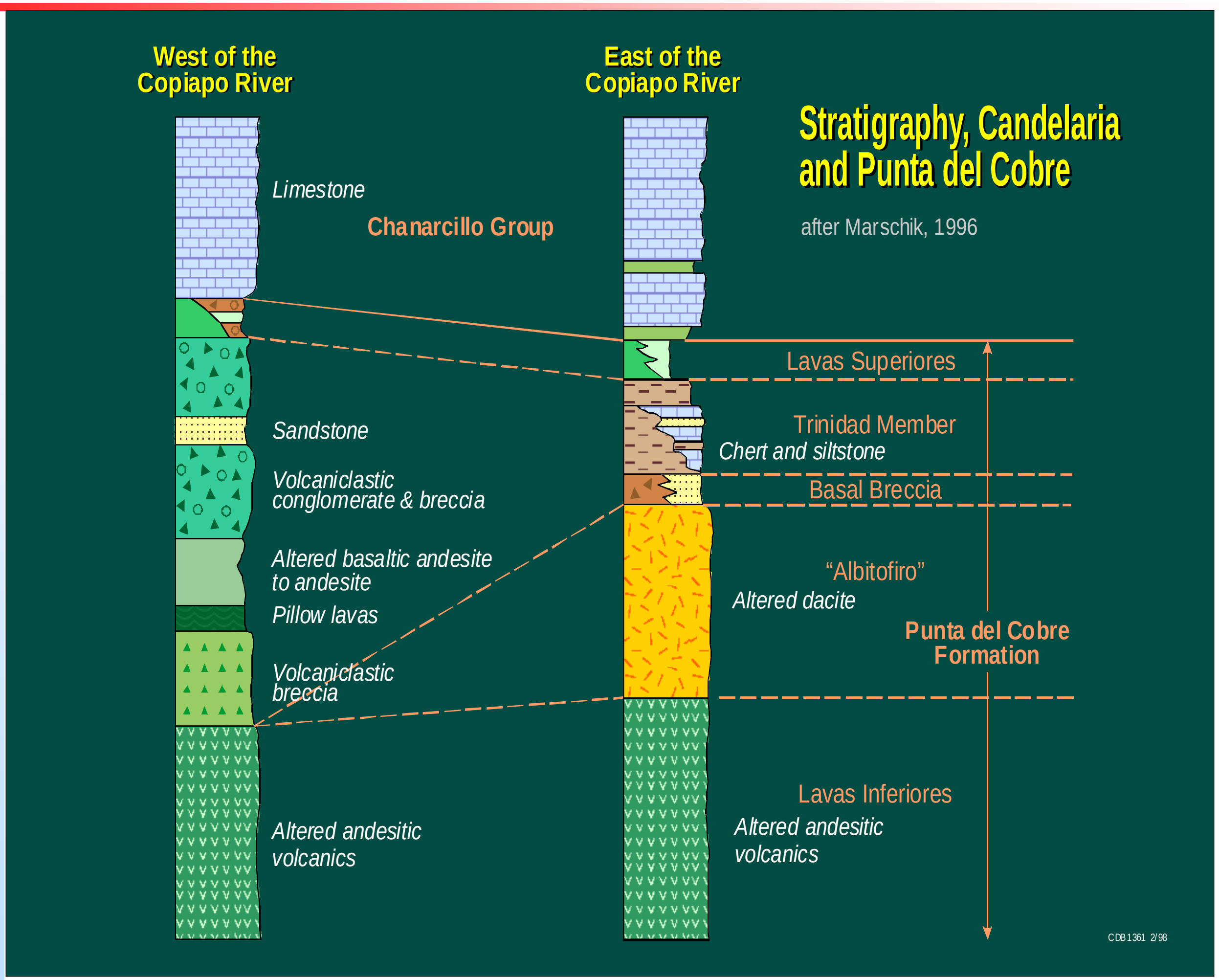


IOCG Deposits, Chile



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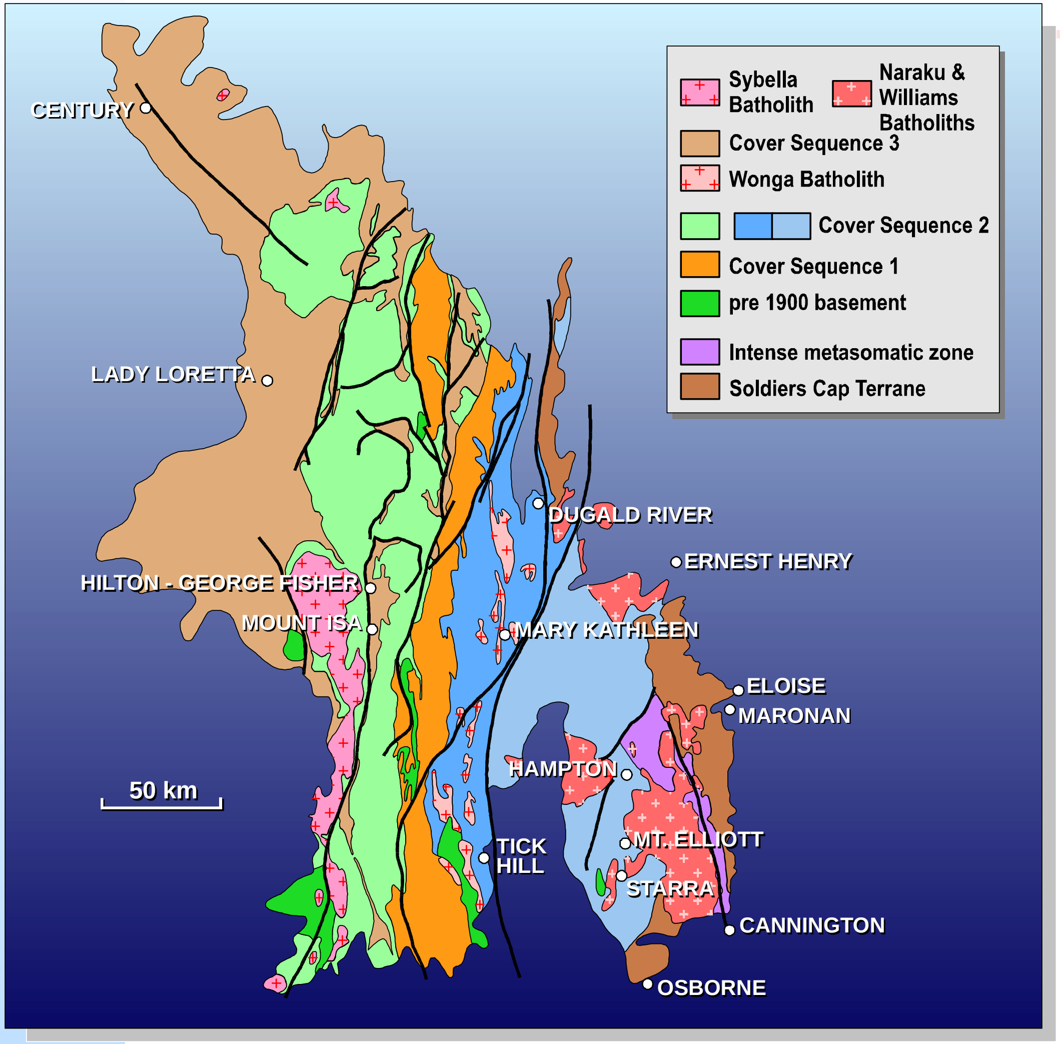
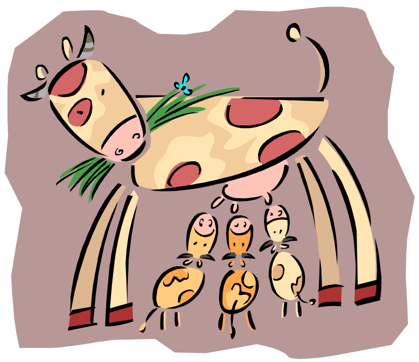
MOUNT ISA INLIER REGIONAL GEOLOGY





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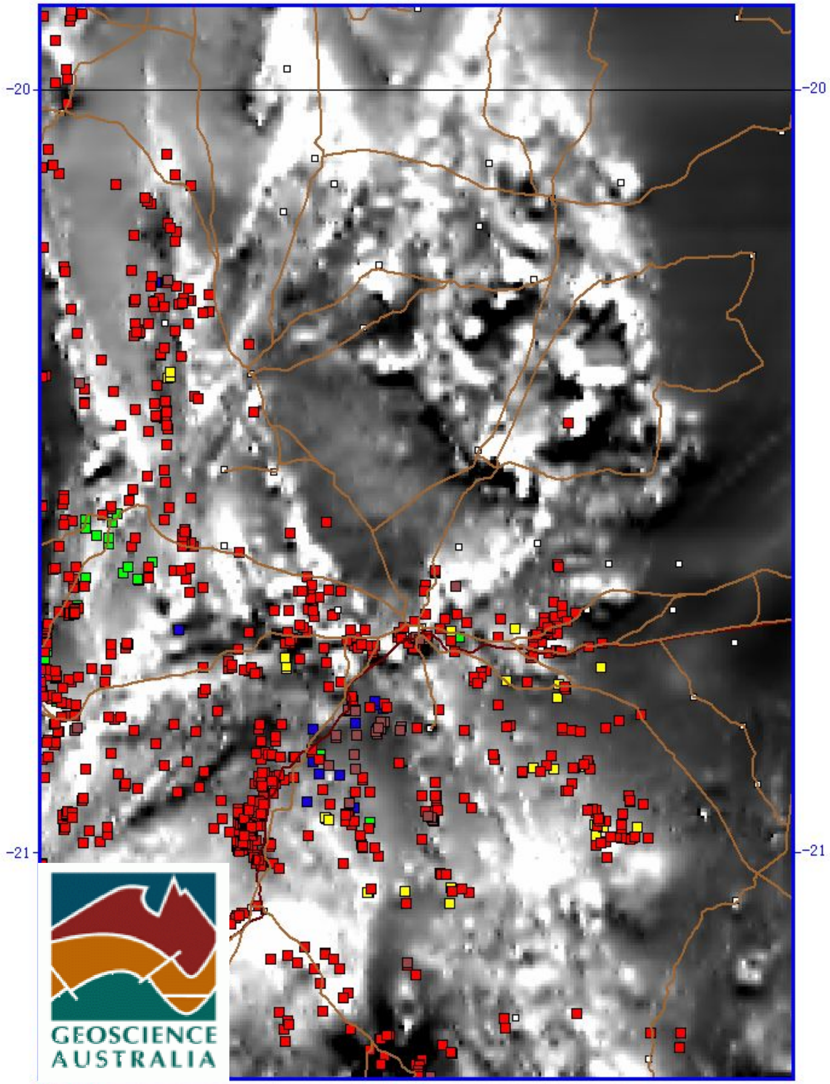
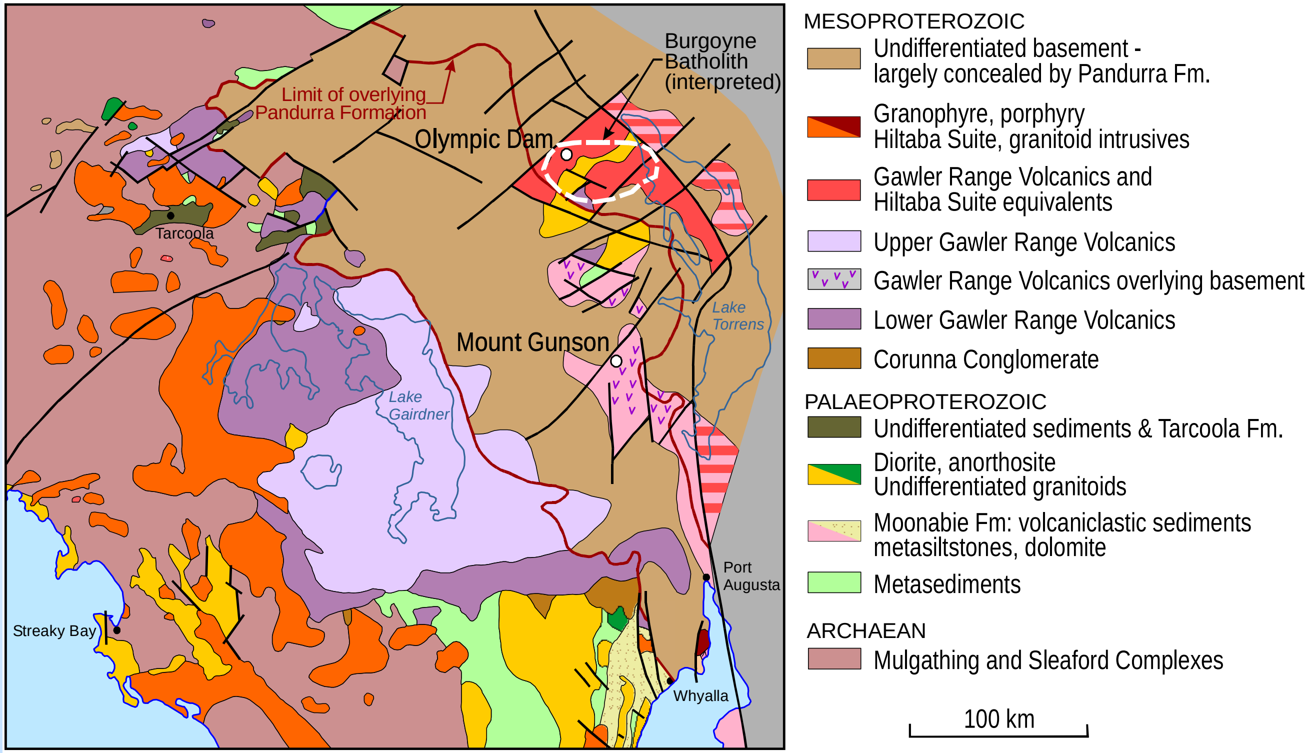
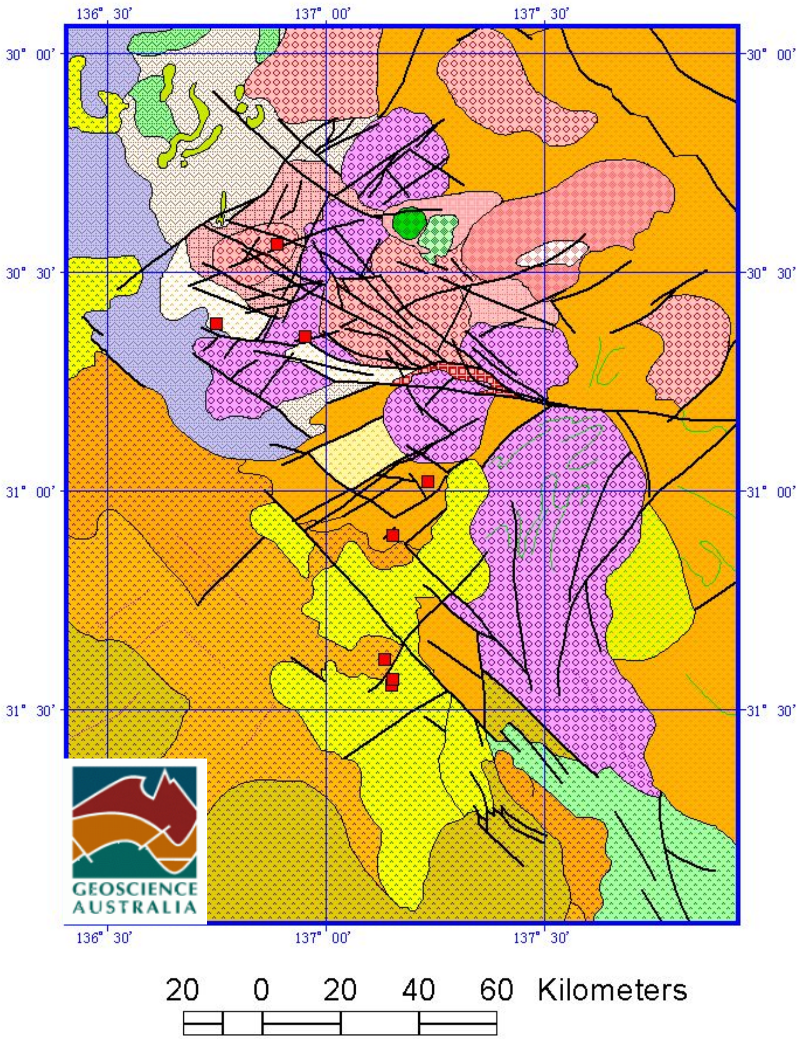


Ernest Henry
TMI Signature

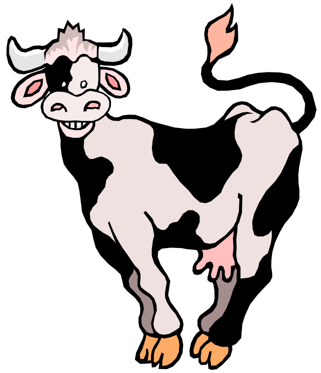
Olympic Dam



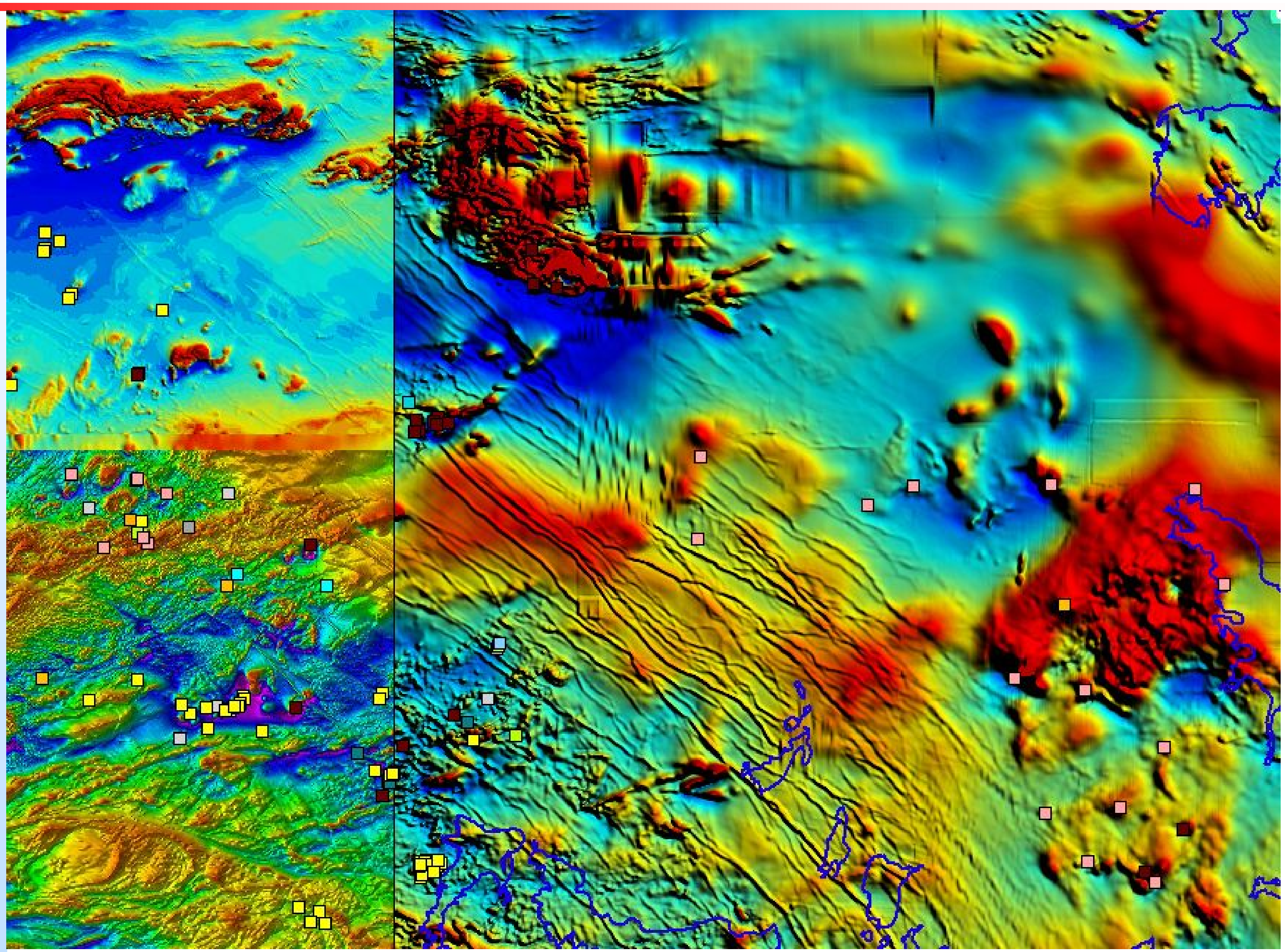
Adapted from Flint et al., 1993

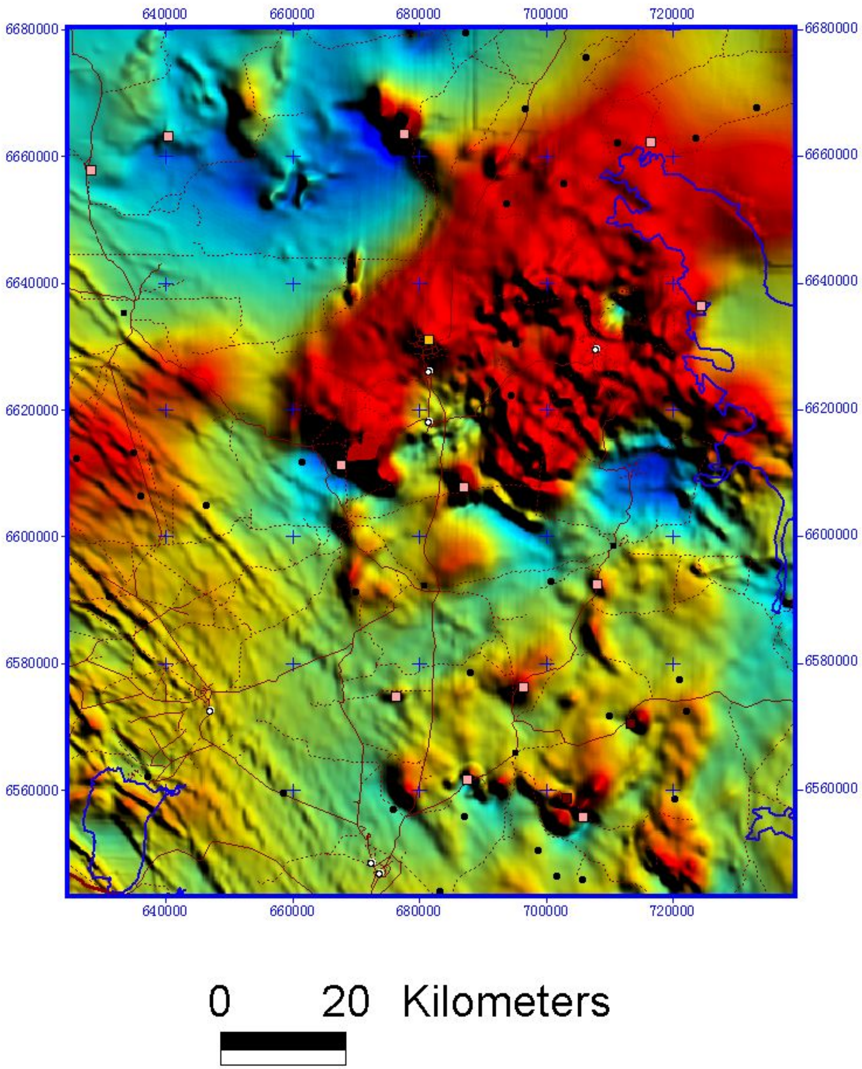


Olympic Dam Interpreted Geology



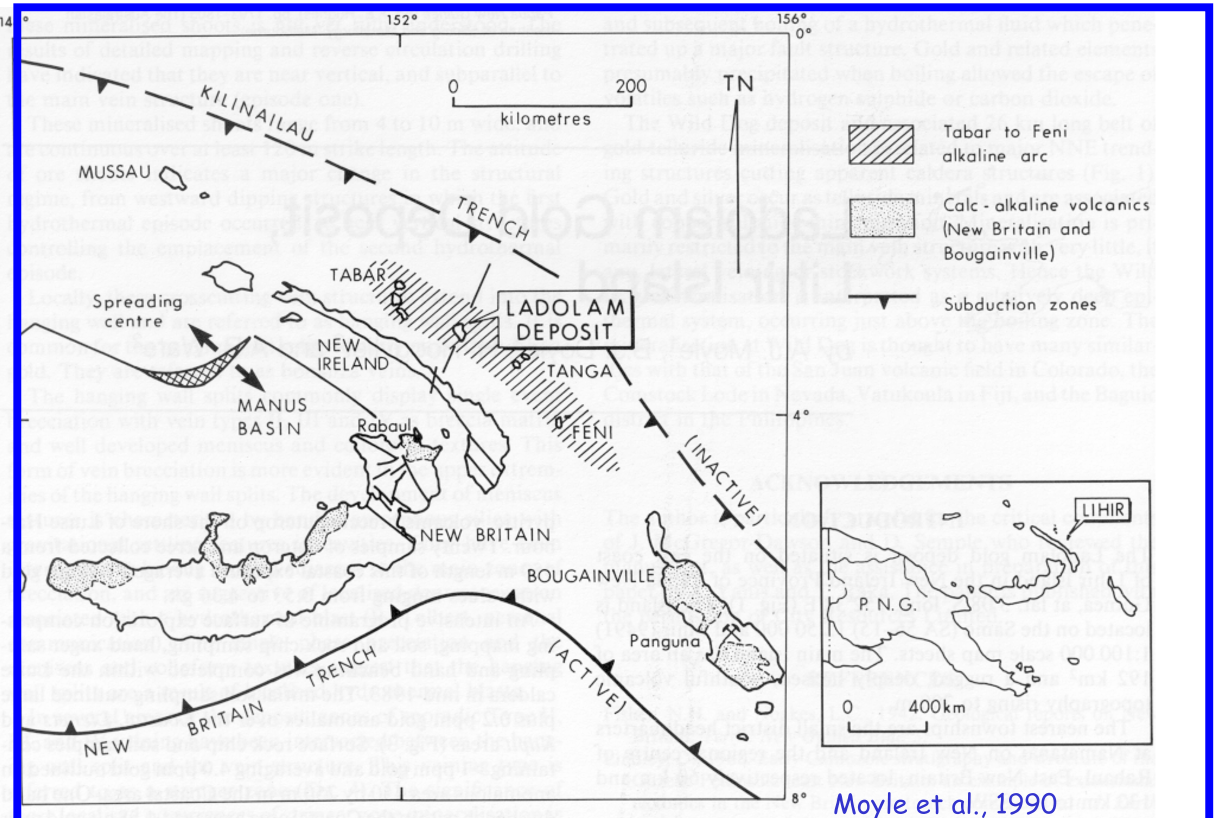
N& NE Gawler Craton: TMI Signature





Olympic Dam:
TMI Signature

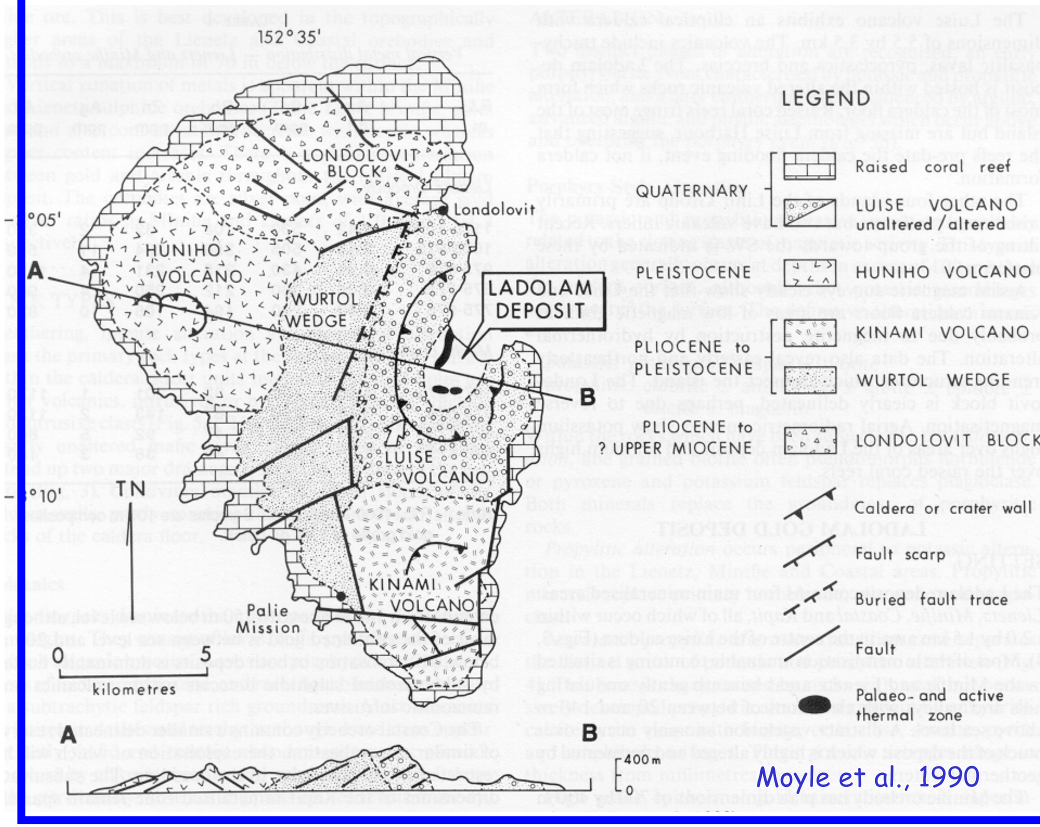
Ladolam, PNG



Moyle et al., 1990

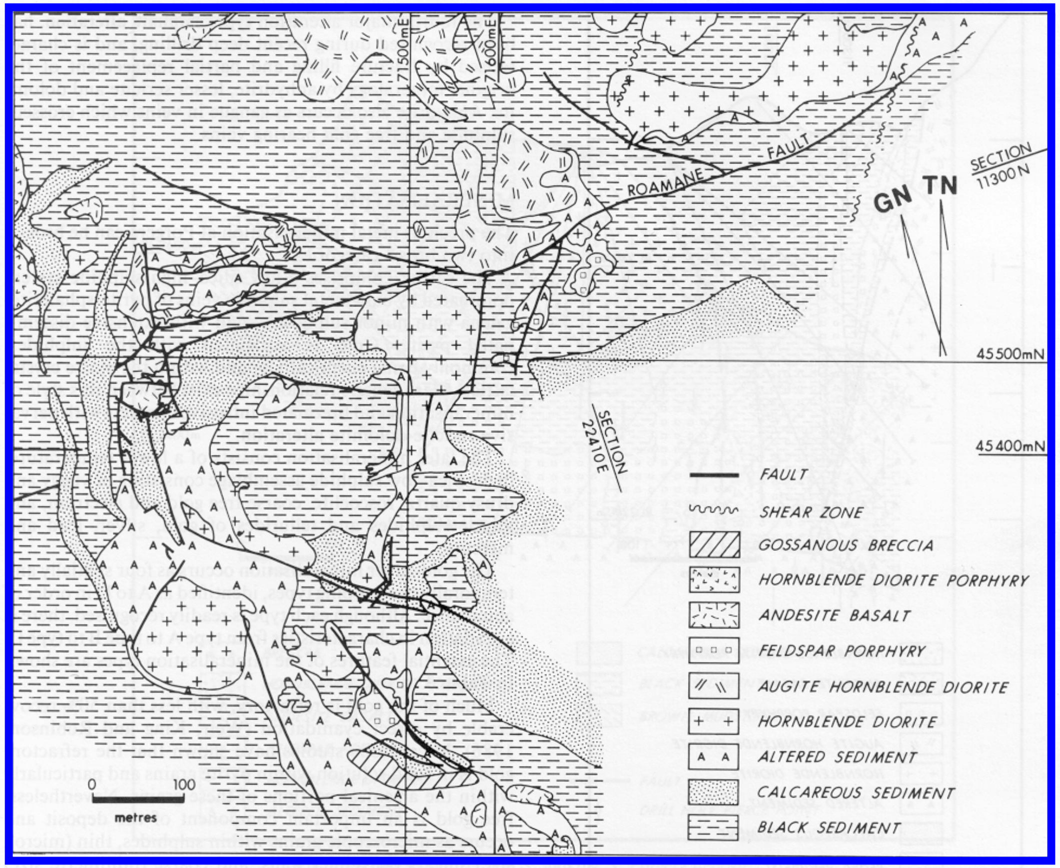
Fig. 1—Location and tectonic setting, Ladolam deposit.

Ladolam, PNG



Moyle et al., 1990

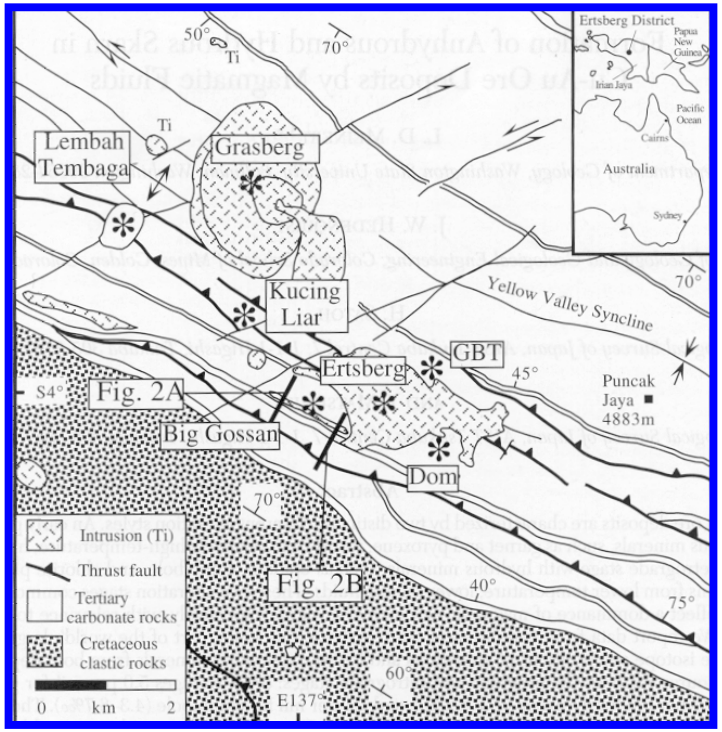
Porgera, PNG



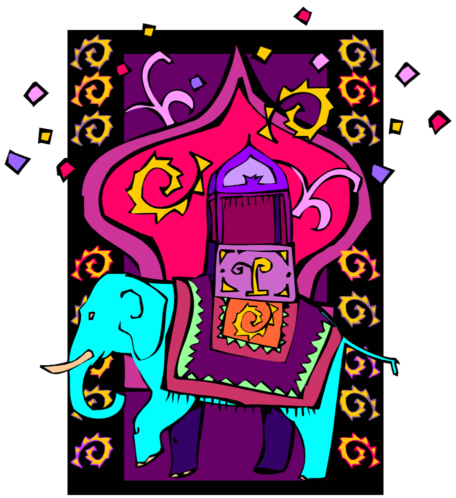
Handley and Henry, 1990

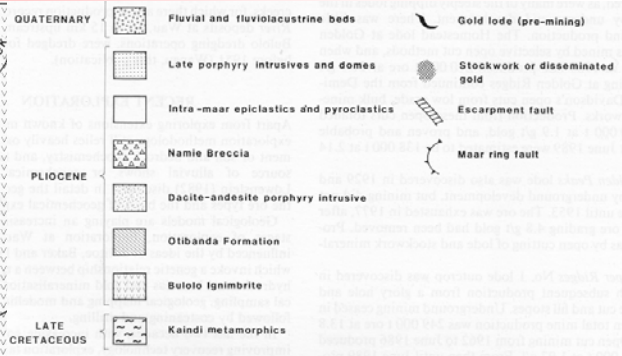
Fig. 2—Local geological map, Porgera deposit.

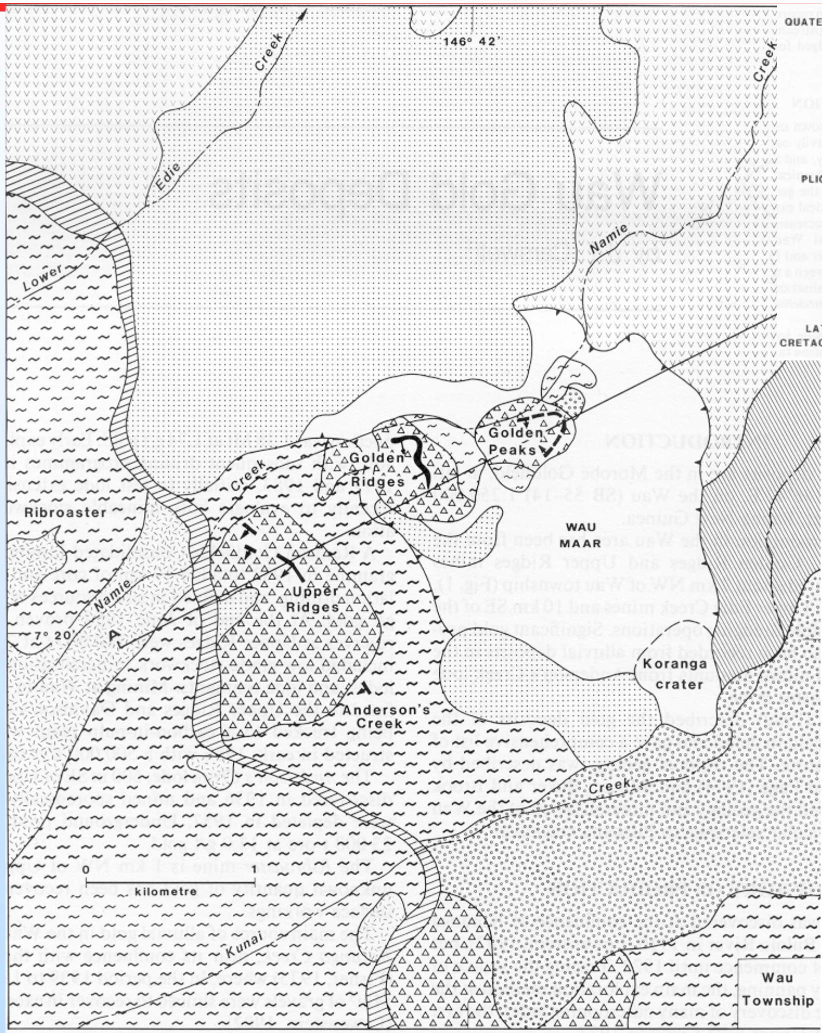
Grasberg, IJ



From Meinert et al., 2003







Carswell, 1990

Wau, PNG

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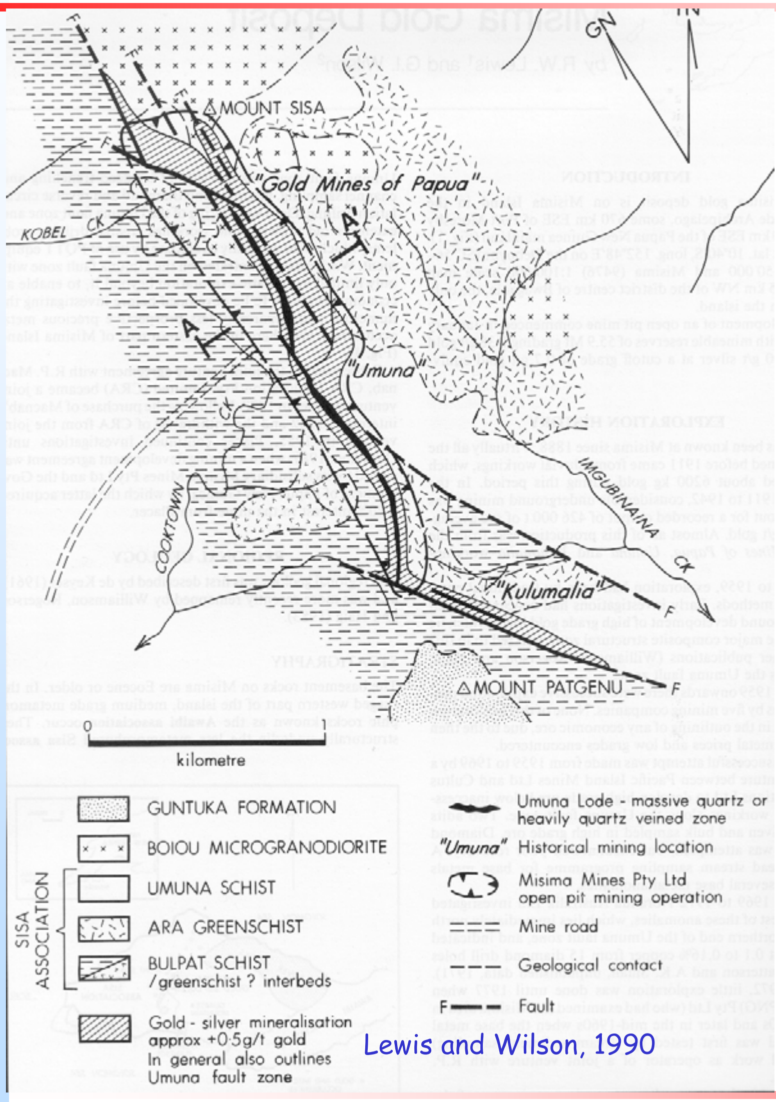
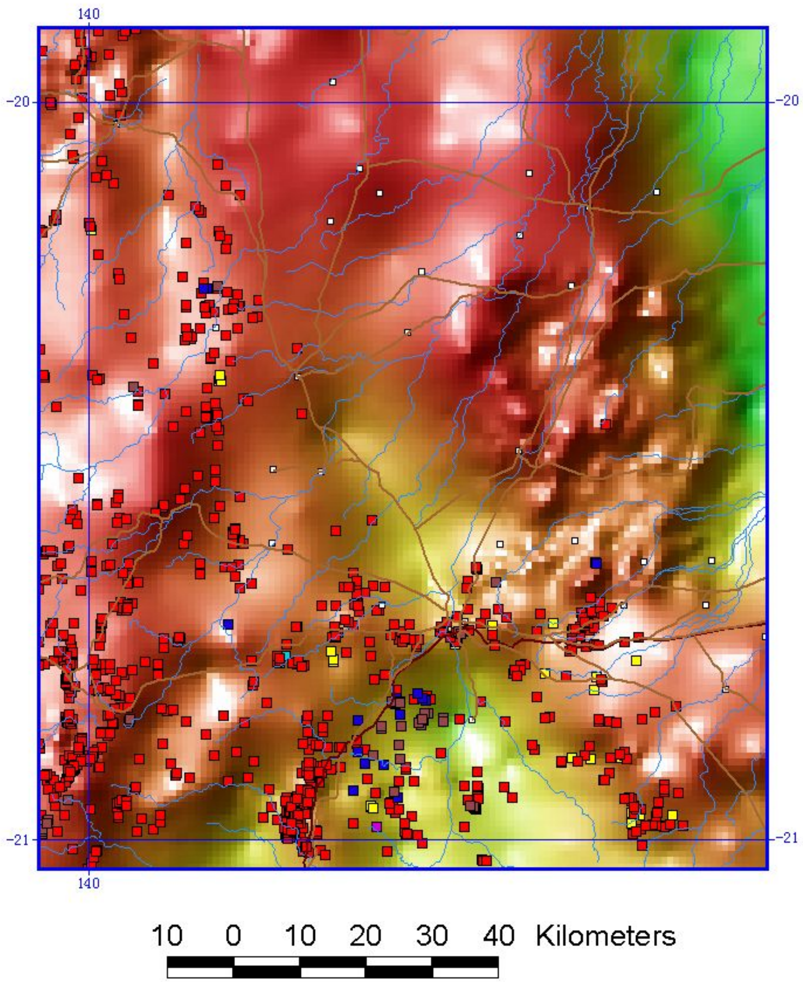


Lewis and Wilson, 1990

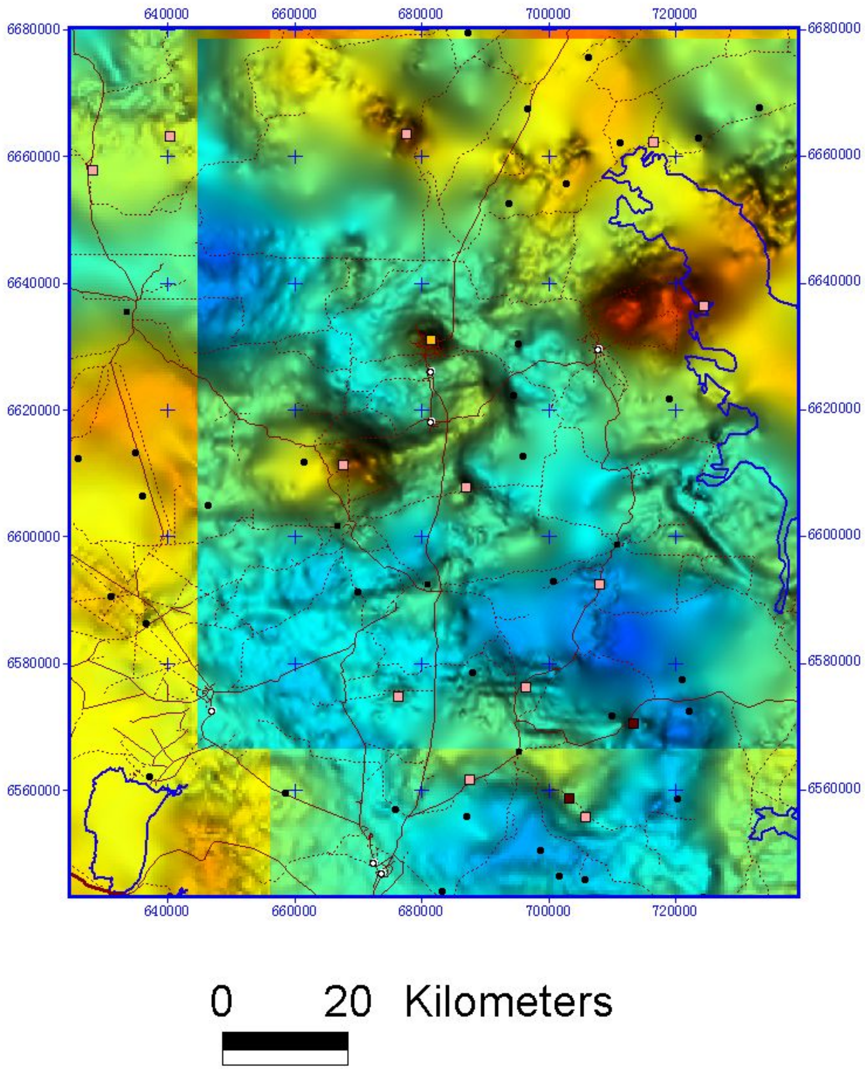
Misima, PNG

- Other IAG
  - SW Pacific Arcs,
  - Alaska Gold Belt,
  - Archaean Gold ....

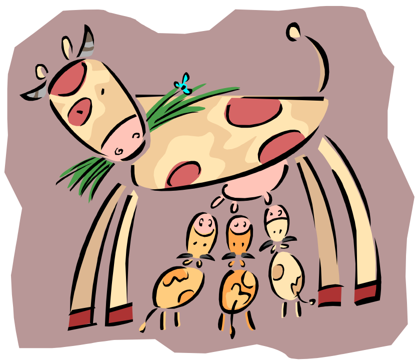
- Intrusives Association
  - For IOCG and IAC
    - IOCG: No consistent LOCAL relations
    - IOCG: Small and Lage, Felsic to Mafic
    - IOCG: No evidence in gravimetric data!
    - IAC: EDGES of subjacent plutons !!!!!

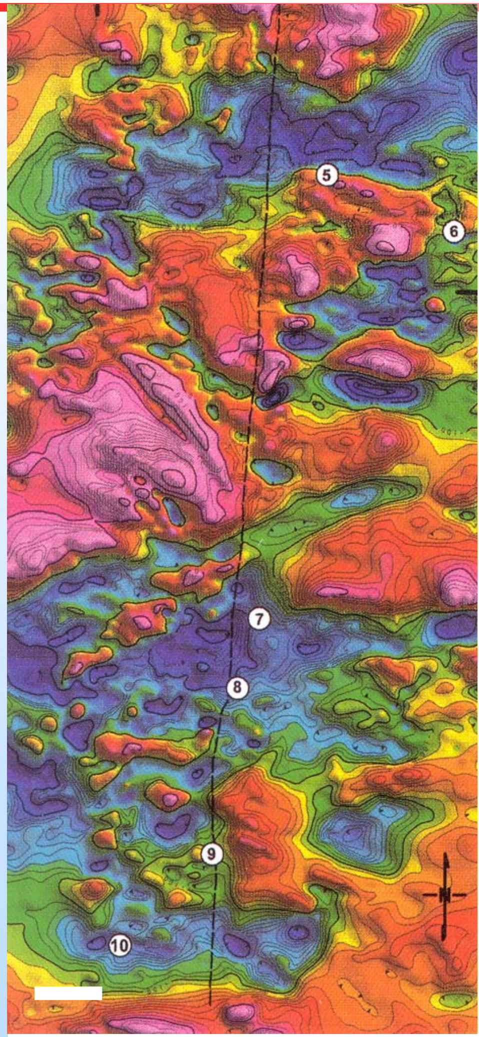


Ernest Henry
Bouguer Gravity
Signature



Olympic Dam Bouguer Gravity Signature





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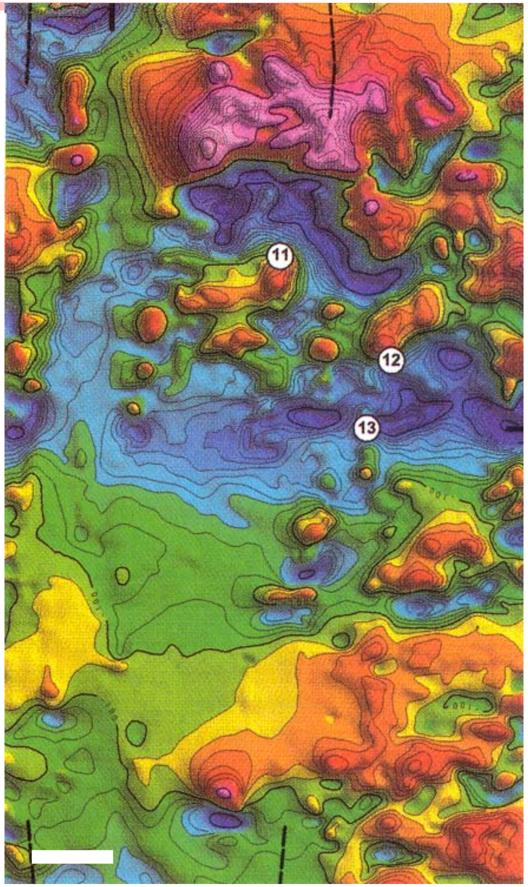

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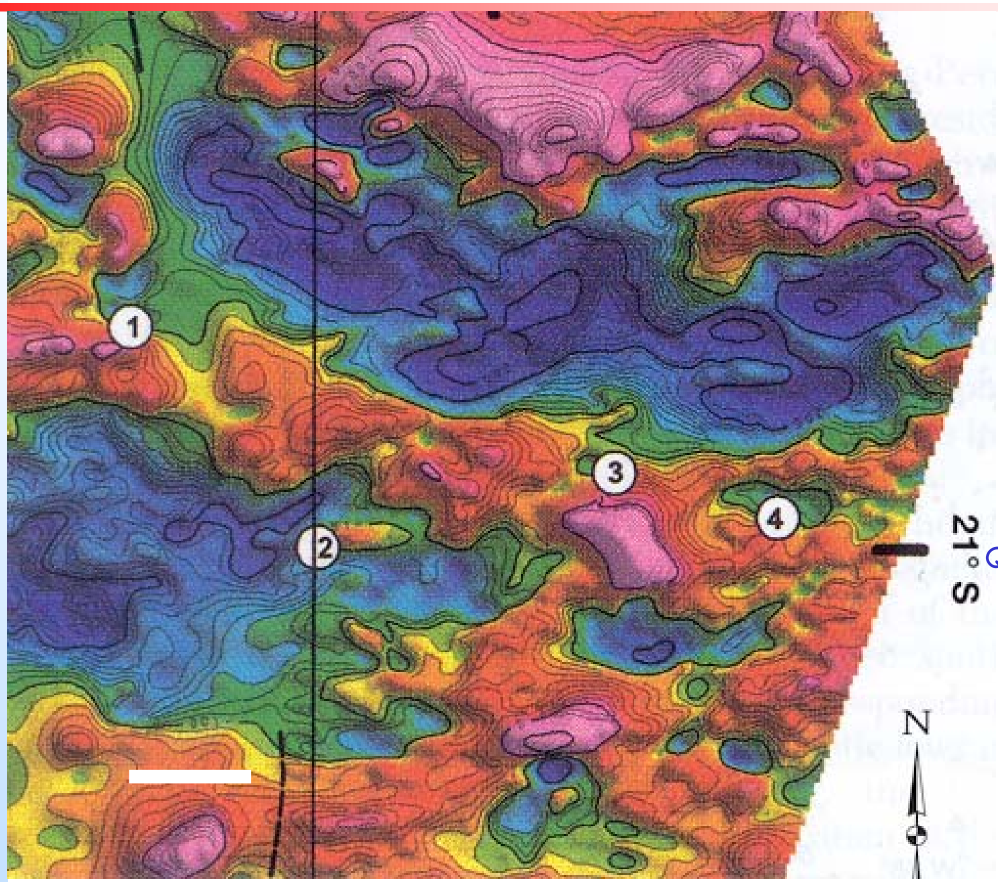

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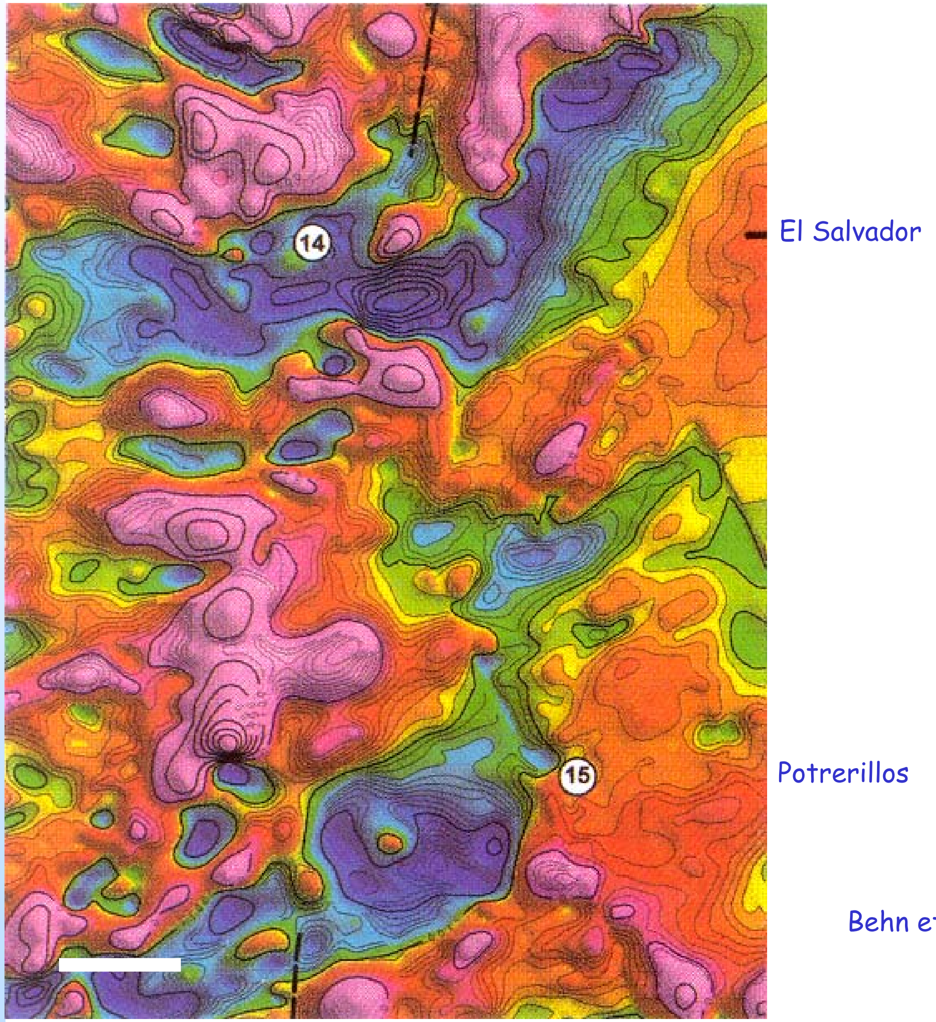
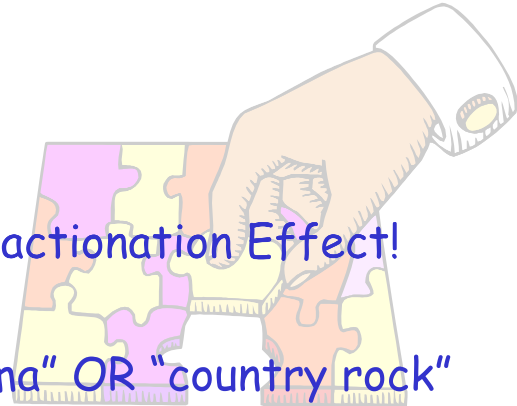


Behn et al., 2001

- Geochemistry and Isotope Signatures
  - For IOCG and IAC
    - IOCG: Geochemistry: Mixed Provenance
    - IOCG: Positive Eu
    - IAC: Re/Os: Grasberg: Cu, Au source is intrusive, and crustal sources. (Mathur et al., 2002)
    - ALL: S isotopes: sulphur sources are various rocks, incl "country rocks". O and H isotopes either magma or hot, sub-solidus "magma" under high R/W.

- Geochemistry and Isotope Signatures
  - For IOCG
    - Ag, As, Au, B, Ba, Bi, Ca, Co, Cu, Eu, F, Fe, Hg, K, LREE, Mn, Mo, O, P, Pb, S, Se, Si, Te, Th, U, W, Zn
    - No Zr, Nb. Low: Mg.

- Geochemistry and Isotope Signatures
  - For IOCG and IAC
    - Sulphur Isotopes:
      - Limited Reduced S Reservoir
      - $\Sigma M >> \Sigma S^{--}$
      - No or Little Fractionation Effect!
      - Reflects "magma" OR "country rock"



Reduced Sulphur Deficit

Redox: IOCG

$SO_4^{--} + 8H2O + 8Fe^{++} \rightarrow$

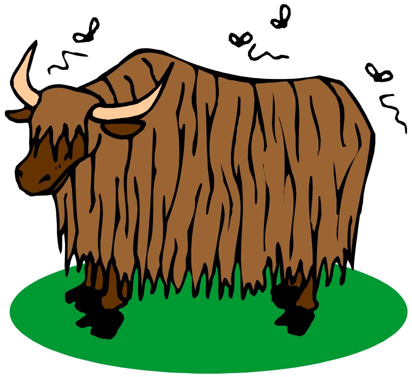
$4Fe2O3 + 14H^{+} + H2S$

Disproportionation: IAC

$4SO2 + 4H2O \rightarrow$

$H2S + 3H^{+} + 3HSO4-$

If $\Sigma M >> \Sigma S--$,
little fractionation in fluid flow path (~ 14 per mill at 300C in El Salvador)



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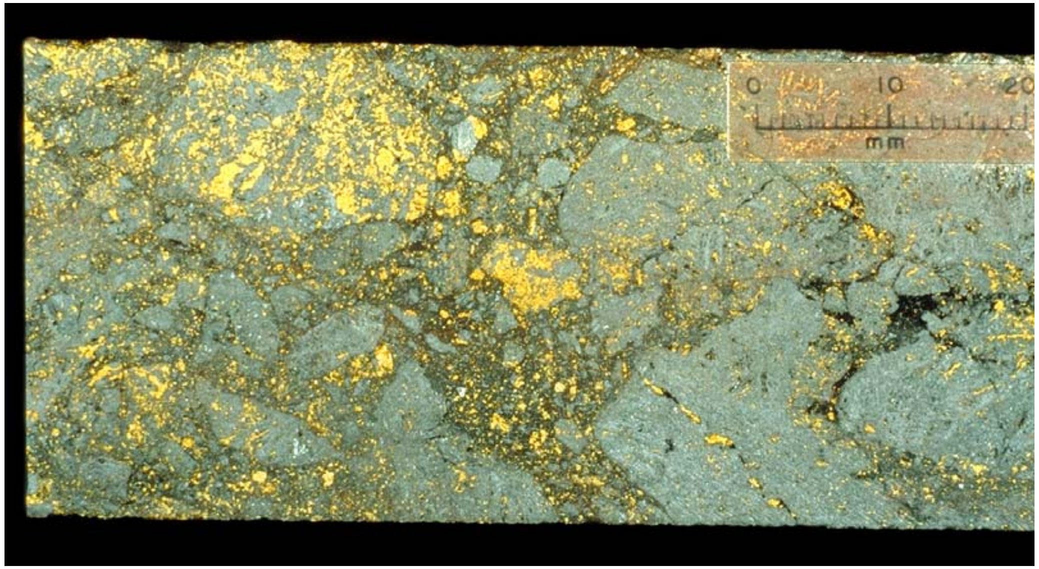
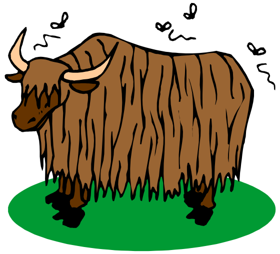
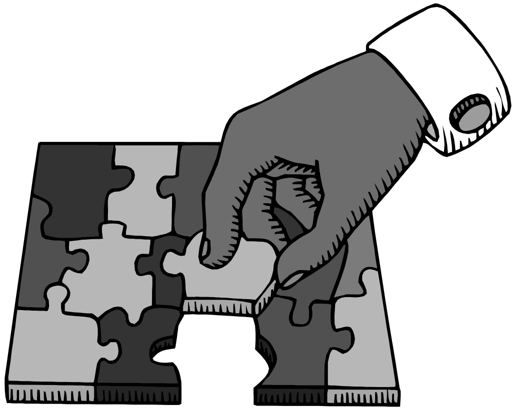
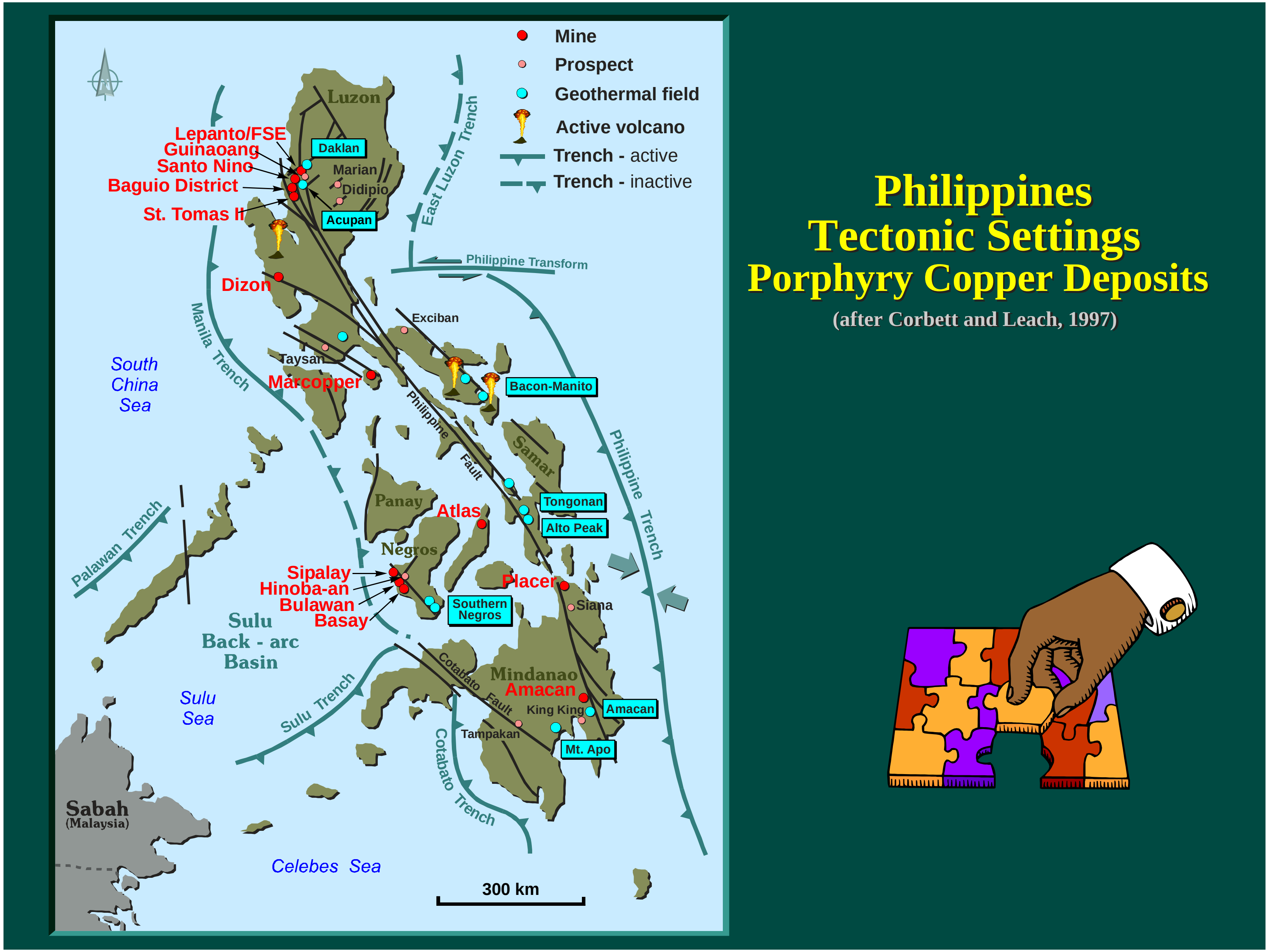
Reduced Sulphur Deficit

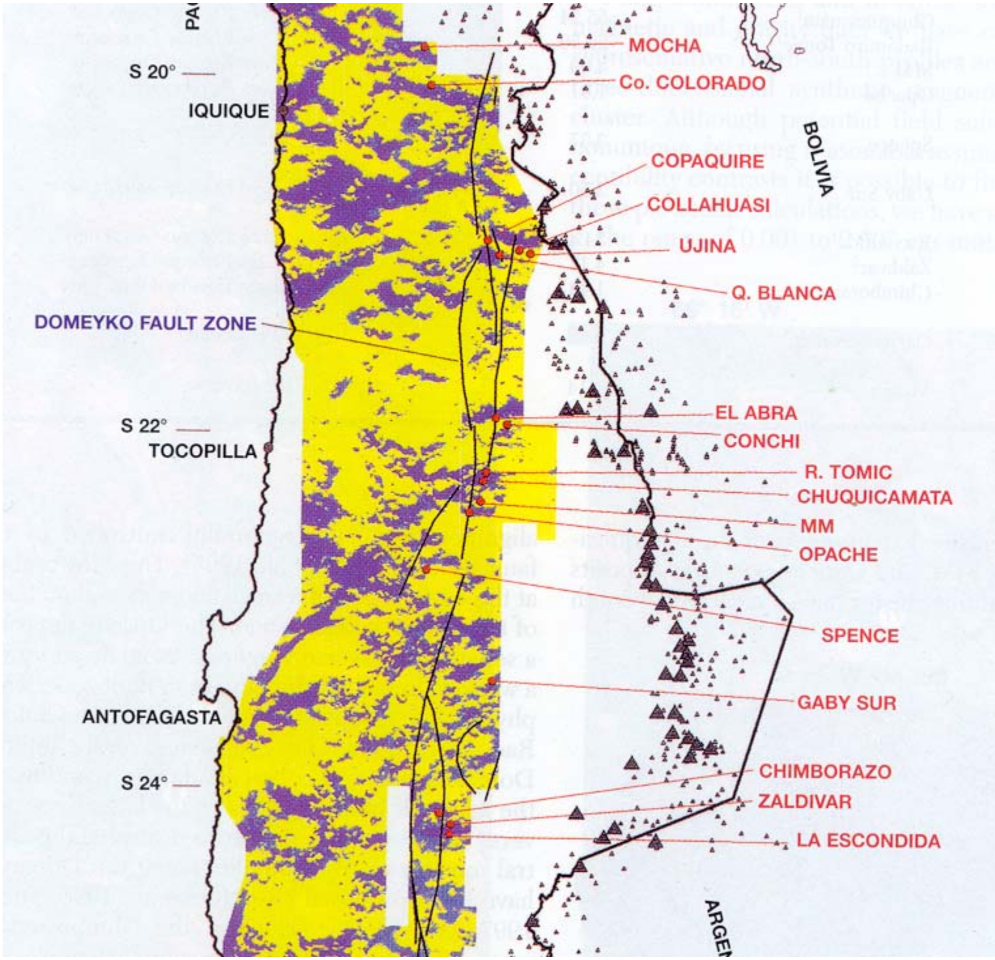




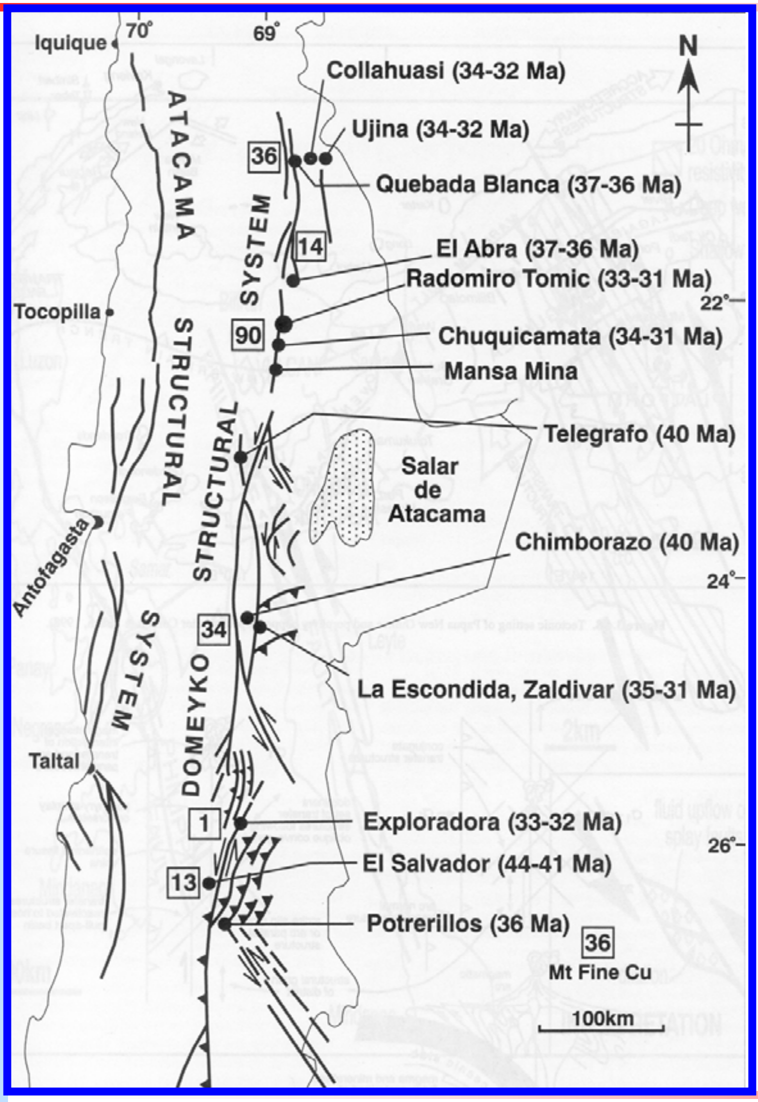
- Structural Association
  - For IOCG, IACG, and IAG
    - Regional Scale Faults and Associated fault sets
    - Demonstrated for IAC and IAG, less so for IOCG




Philippines
Tectonic Settings
Porphyry Copper Deposits
(after Corbett and Leach, 1997)
Mine
Prospect
Geothermal field
Active volcano
Trench - active
Trench - inactive
Luzon
Lepanto/FSE
Guinaoang
Santo Nino
Baguio District
St. Tomas II
Daklan
Marian
Didipio
Acupan
East Luzon Trench
Philippine Transform
Dizon
Manila Trench
Exciban
Taysan
Marcopper
Bacon-Manito
South China Sea
Philippine Fault
Samar
Philippine Trench
Panay
Atlas
Tongonan
Alto Peak
Negros
Palawan Trench
Sipalay
Hinoba-an
Bulawan
Basay
Southern Negros
Placer
Siana
Sulu Back - arc Basin
Mindanao
Amacan
Cotabato Fault
King King
Tampakan
Mt. Apo
Sulu Sea
Sulu Trench
Cotabato Trench
Sabah (Malaysia)
Celebes Sea
300 km

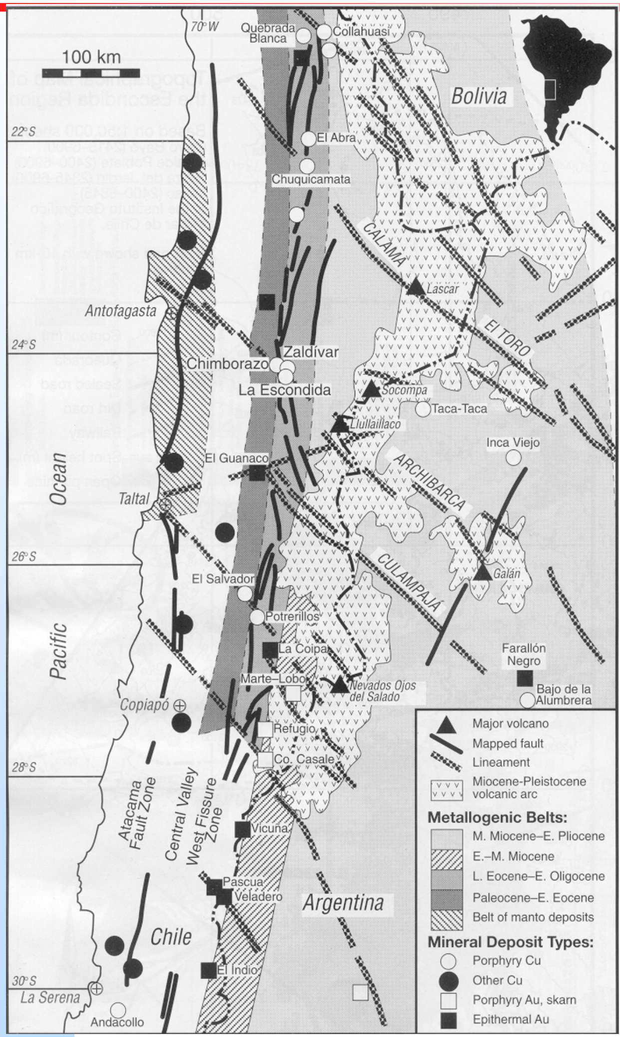


Behn et al., 2001

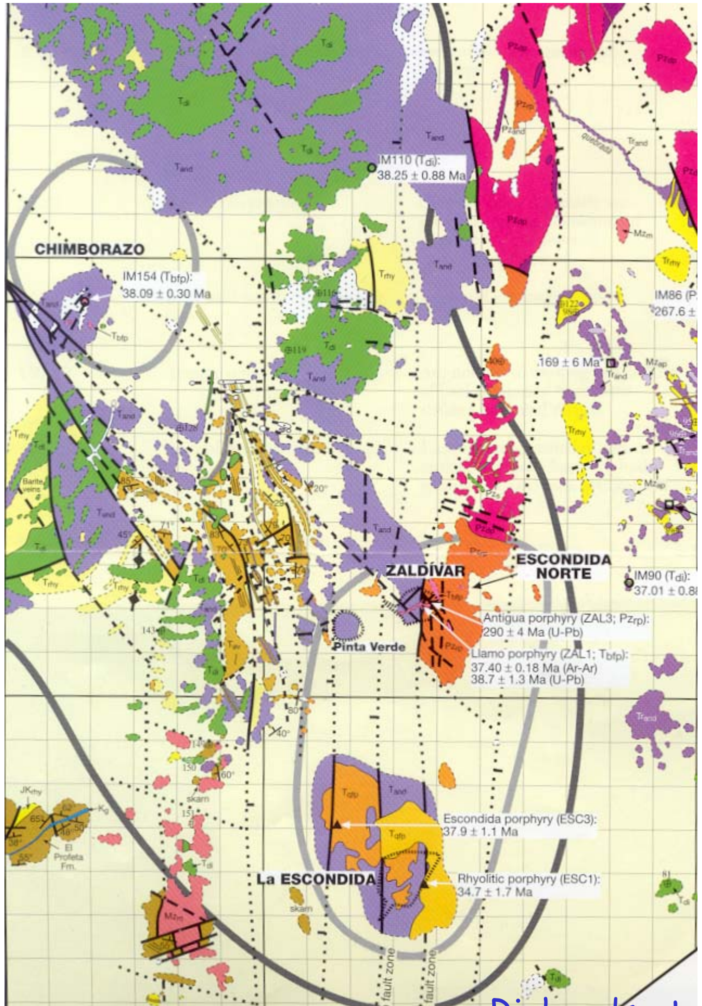


Domeyko Strike Slip Fault System, Chile (after Cornejo et al., 1997)

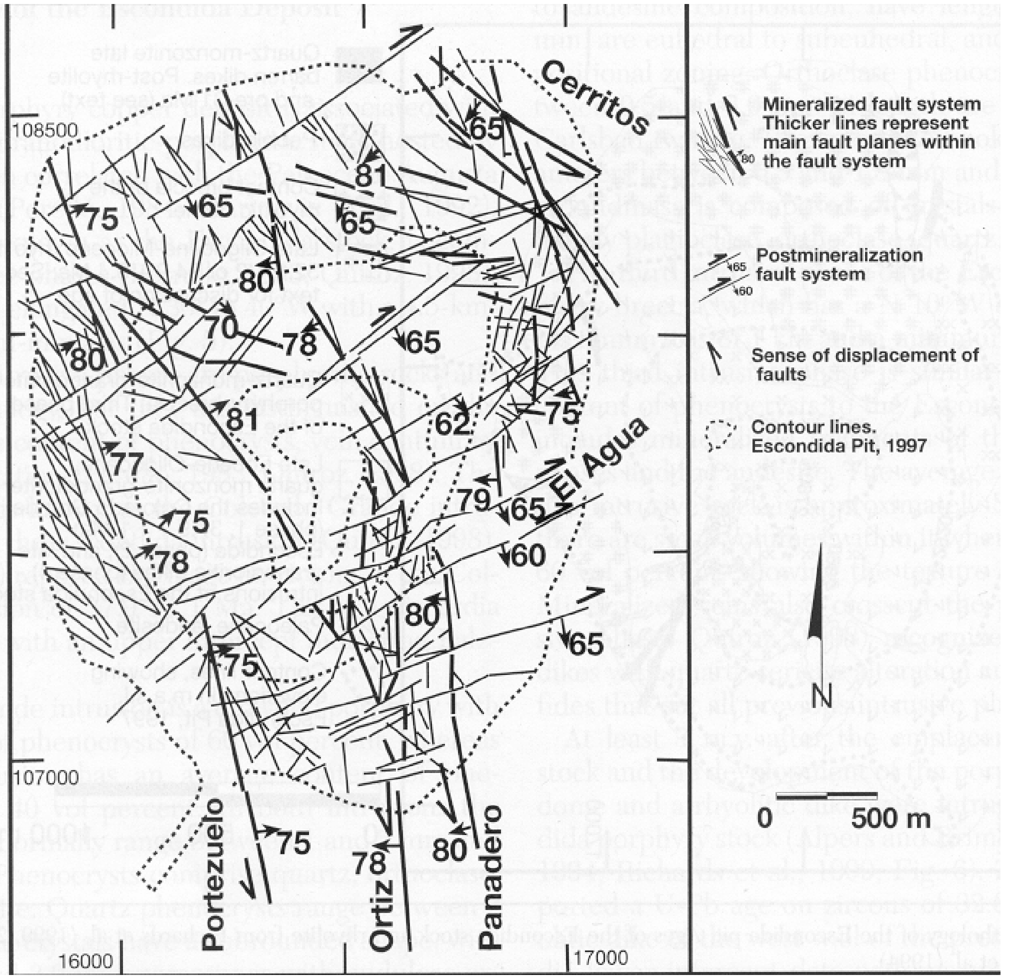
From K McClay, 2003, with permission



Richards et al., 2001



Richards et al., 2001



Padilla-Garza et al., 2001

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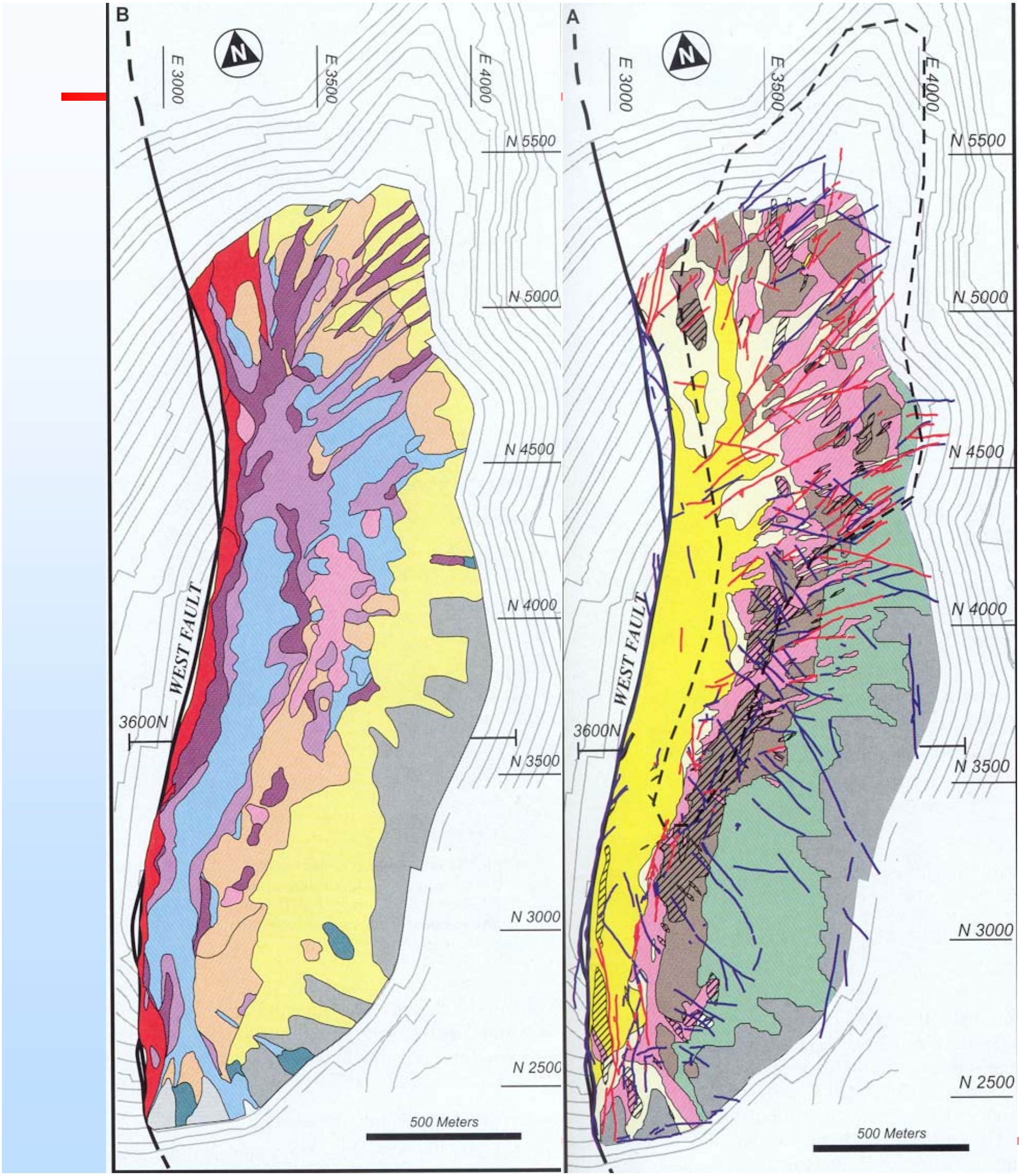
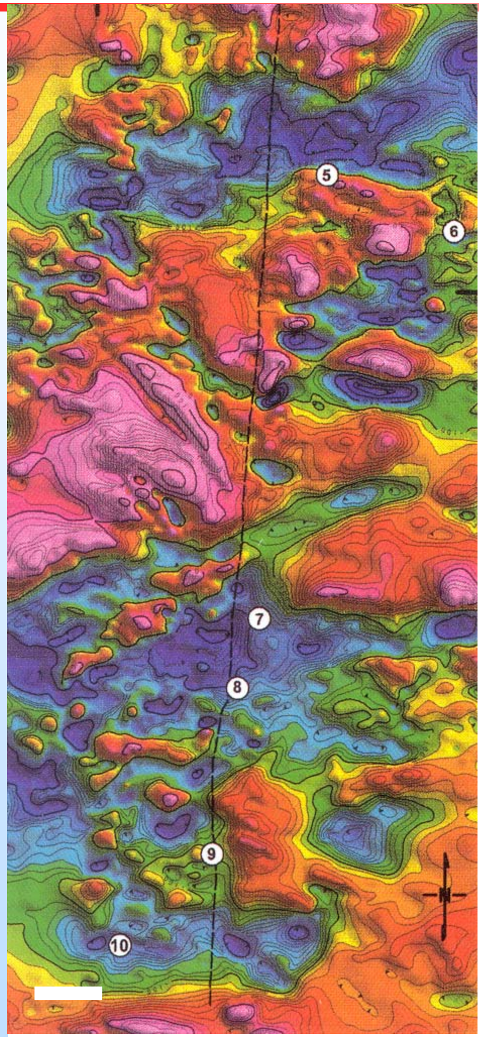


Ossandon et al., 2001



El Abra

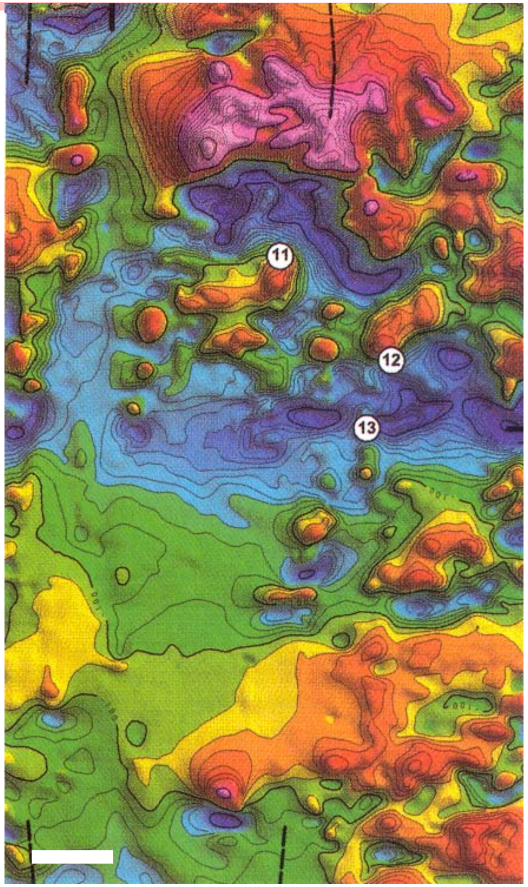
Conchi

Radimiro T

Chuqui

Mansa Mina

Opache

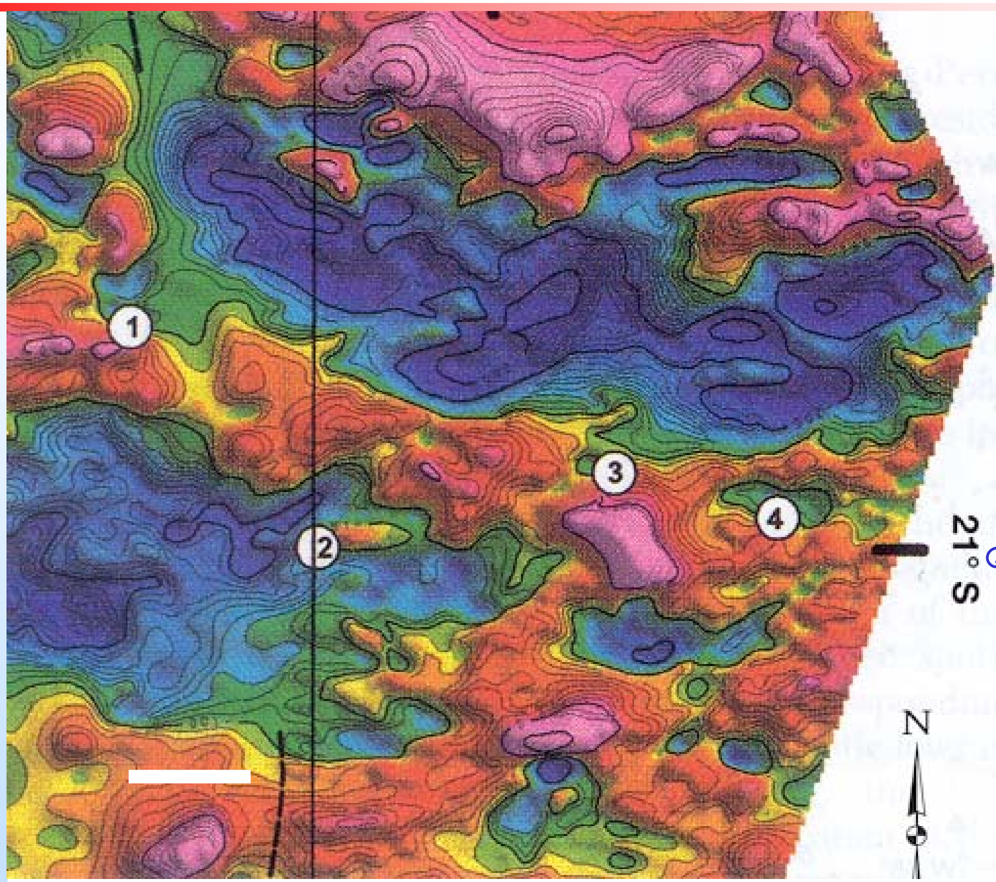


Chimborazo

Zaldivar

Escondida

Behn et al., 2001



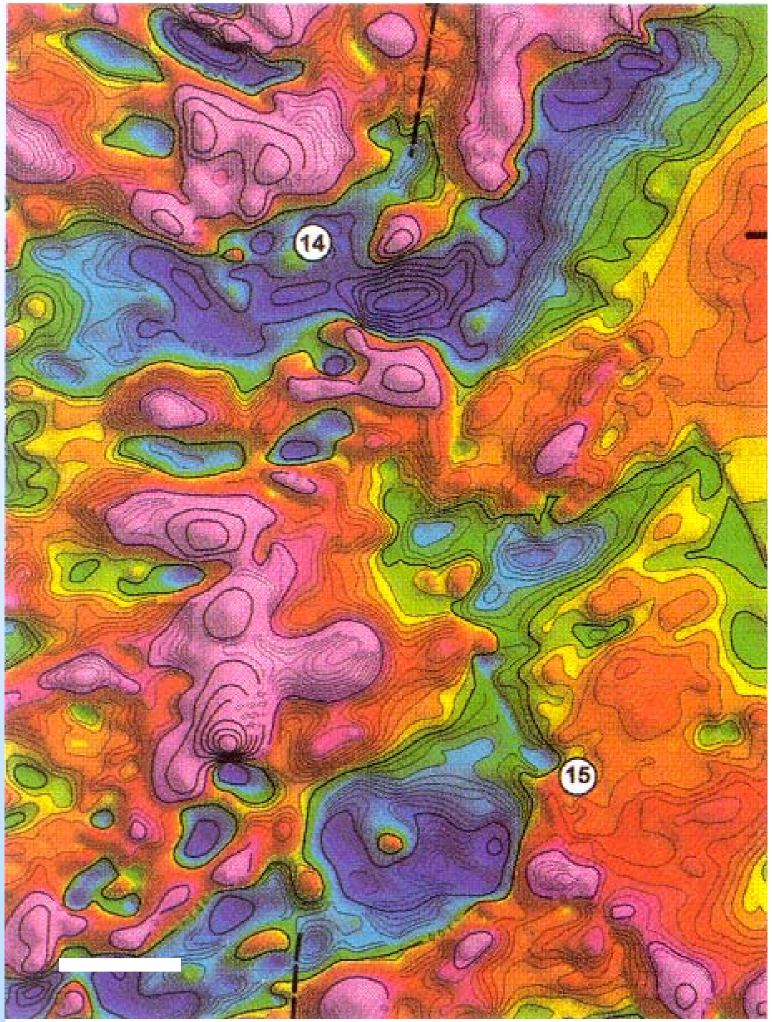
Copaguiri

Collahuasi

Ujina

Quebrada Blanca

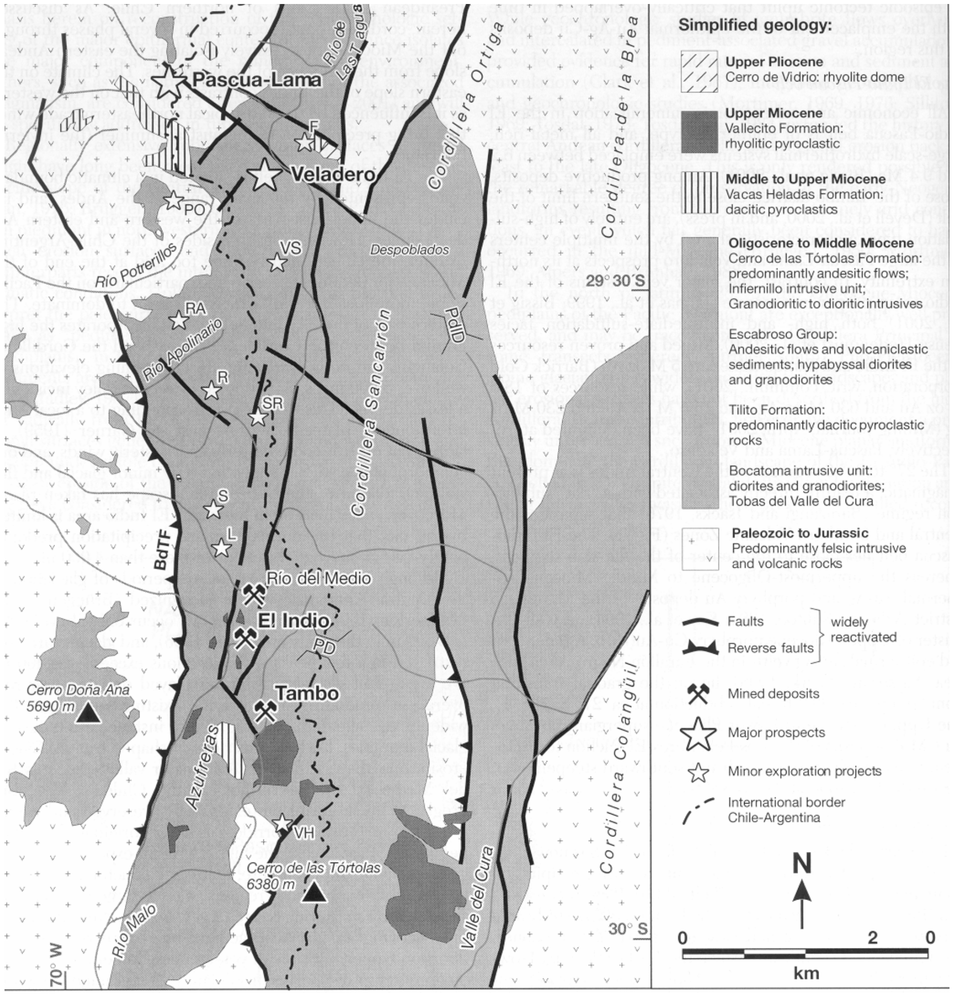
Behn et al., 2001



El Salvador

Potrerillos

Behn et al., 2001


Pascua-Lama
Veladero
Río de Las Taguas
F
PO
VS
Río Potrerillos
Despoblados
Cordillera Ortiga
Cordillera de la Brea
29° 30'S
RA
Río Apolinario
R
SR
PdD
Cordillera Sancarrón
S
L
BdTF
Río del Medio
El Indio
PD
Tambo
Cerro Doña Ana
5690 m
Azufreras
VH
Cerro de las Tórtolas
6380 m
Río Malo
Valle del Cura
Cordillera Colangüil
30° S
70° W
Simplified geology:
Upper Pliocene
Cerro de Vidrio: rhyolite dome
Upper Miocene
Vallecito Formation: rhyolitic pyroclastic
Middle to Upper Miocene
Vacas Heladas Formation: dacitic pyroclastics
Oligocene to Middle Miocene
Cerro de las Tórtolas Formation: predominantly andesitic flows; Infiernillo intrusive unit; Granodioritic to dioritic intrusives
Escabroso Group: Andesitic flows and volcaniclastic sediments; hypabyssal diorites and granodiorites
Tilito Formation: predominantly dacitic pyroclastic rocks
Bocatoma intrusive unit: diorites and granodiorites; Tobas del Valle del Cura
Paleozoic to Jurassic
Predominantly felsic intrusive and volcanic rocks
Faults
Reverse faults
widely reactivated
Mined deposits
Major prospects
Minor exploration projects
International border Chile-Argentina
N
0
20
km

Porgera, PNG

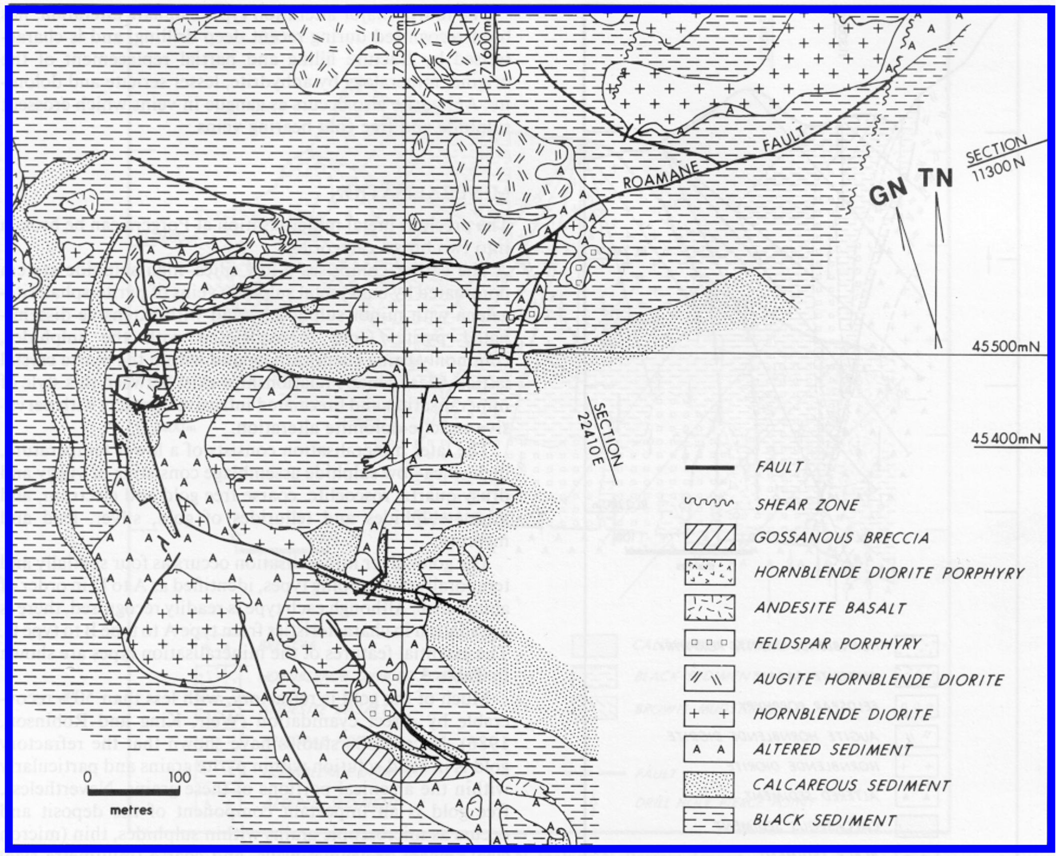
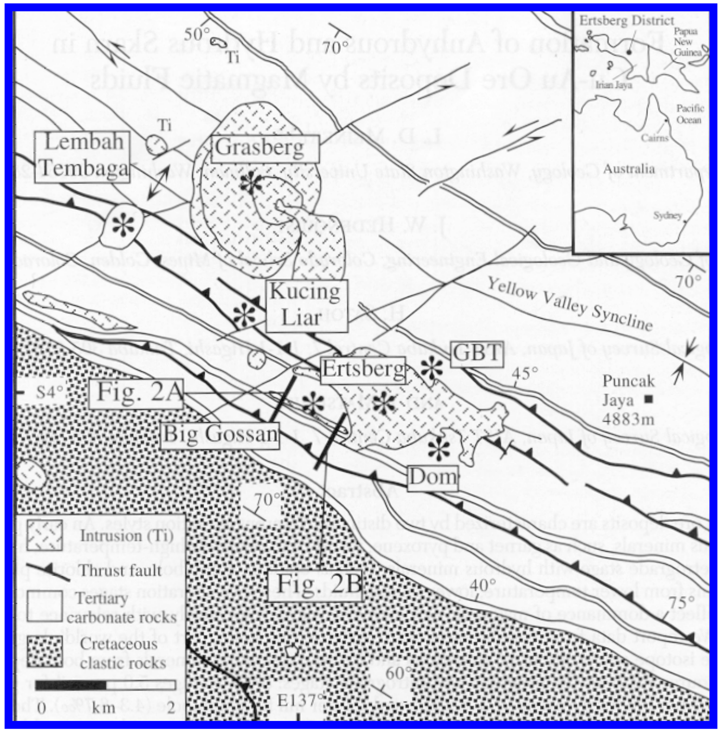
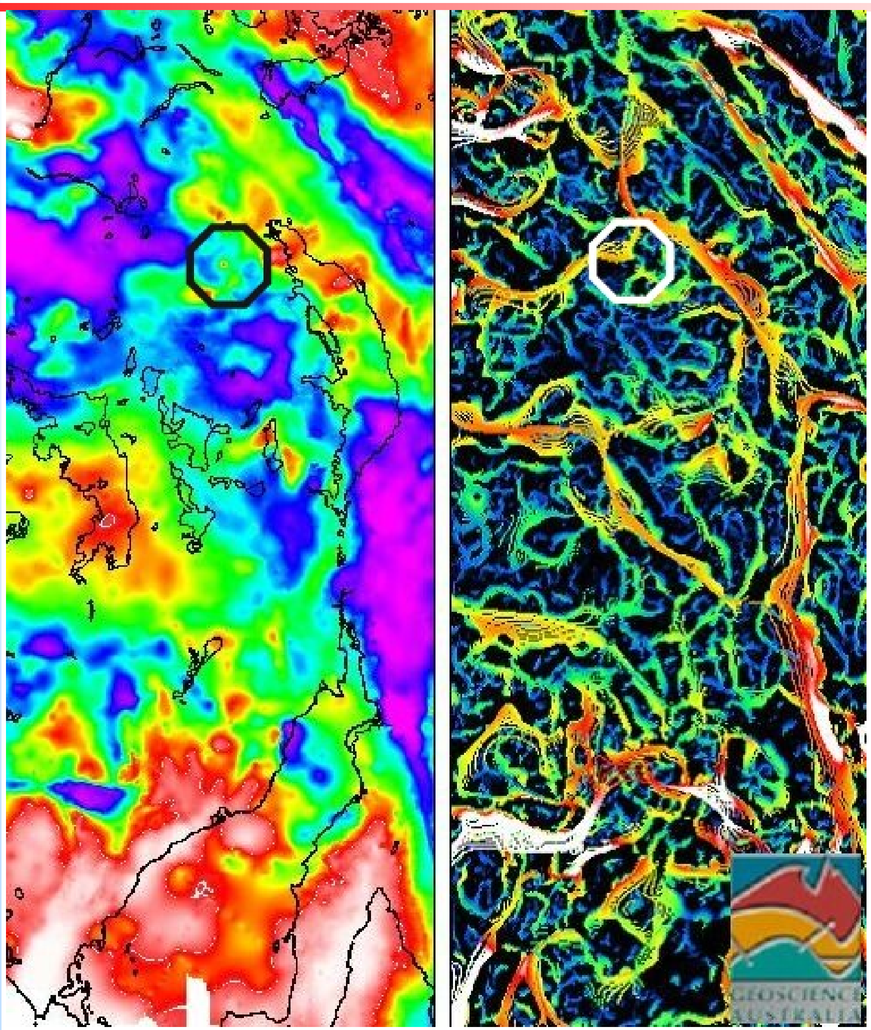


Fig. 2—Local geological map, Porgera deposit.

Grasberg, IJ



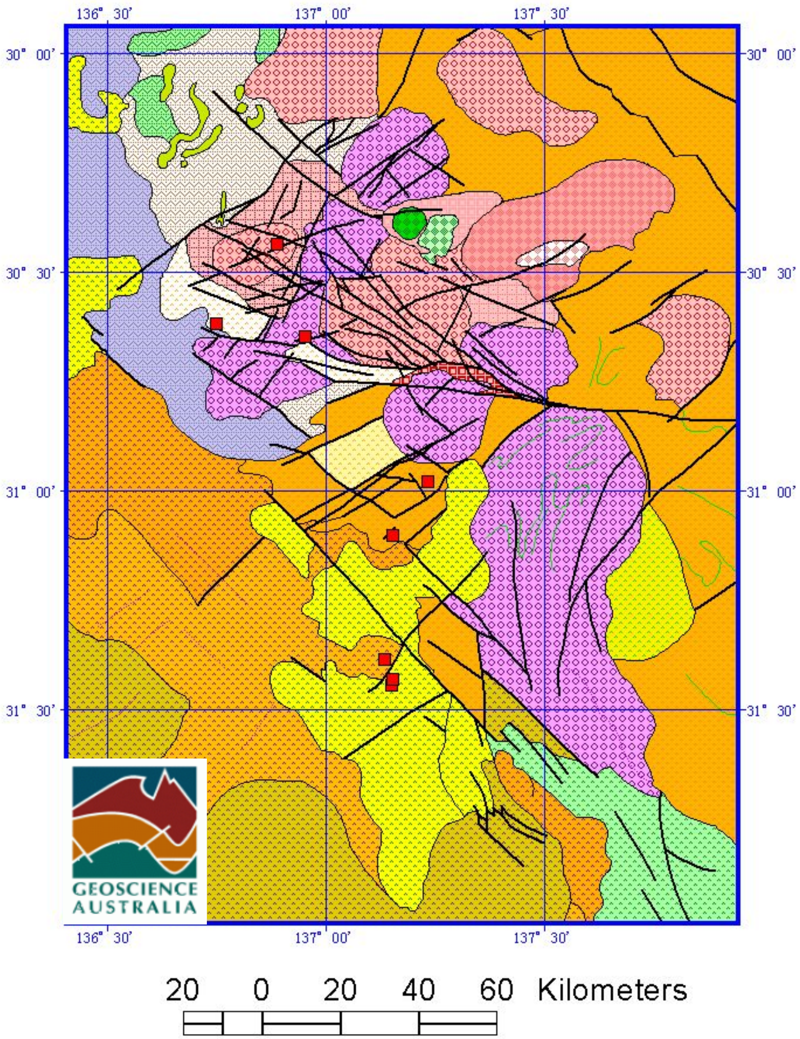
From Meinert et al., 2003



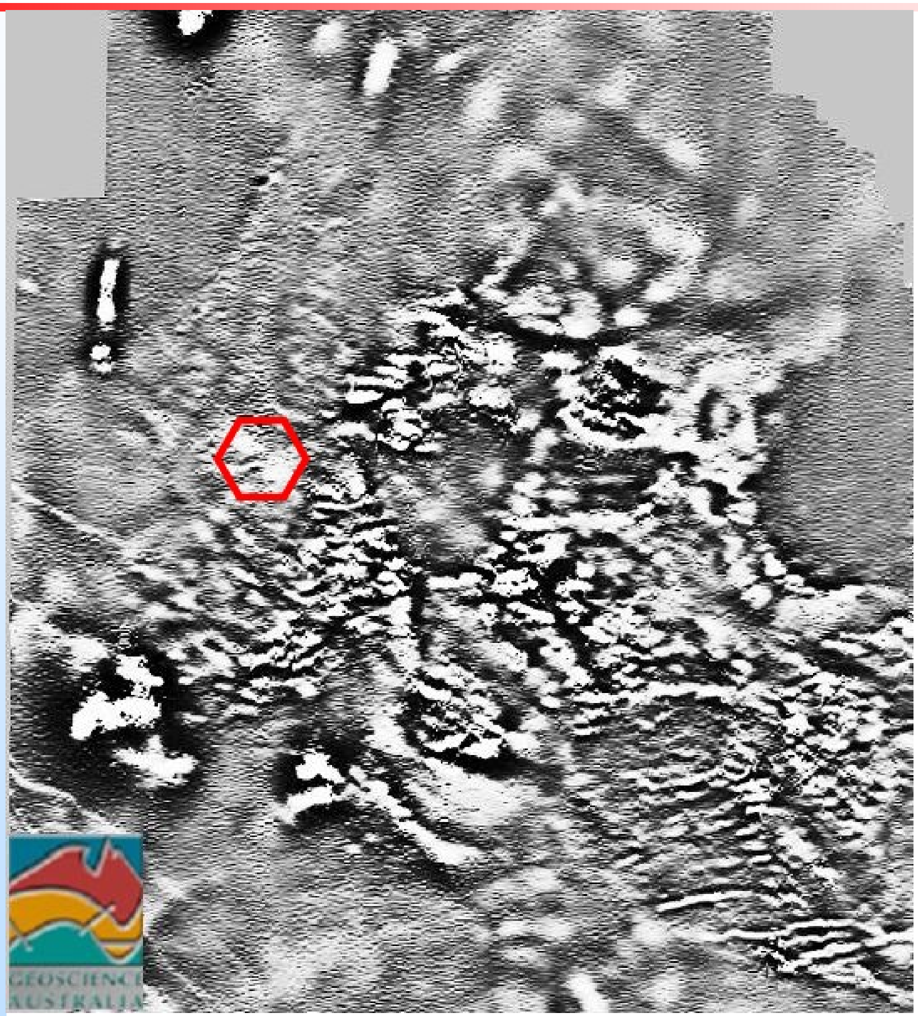
Olympic Dam
Regional Major
Faults

Courtesy:
R Skirrow
N Direen

Ishihara Granites Symposium July, 2003



Olympic Dam
Interpreted
Major Faults



Olympic Dam
Detailed 1VD
Magnetic
Signature

Courtesy:
R Skirrow
N Direen

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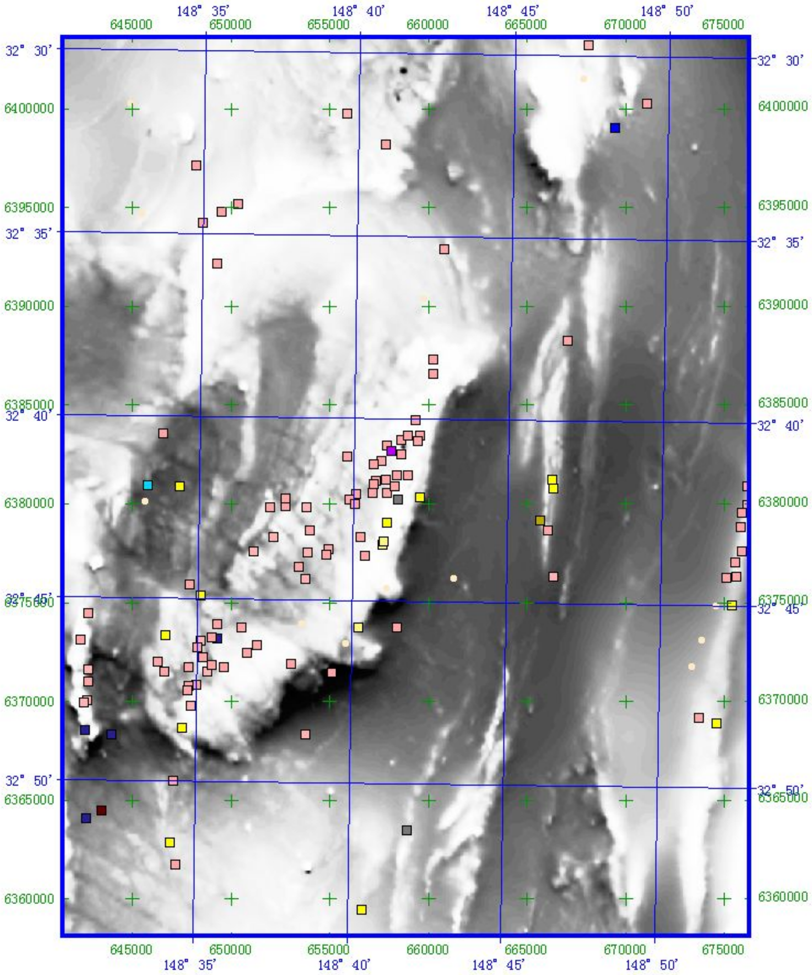
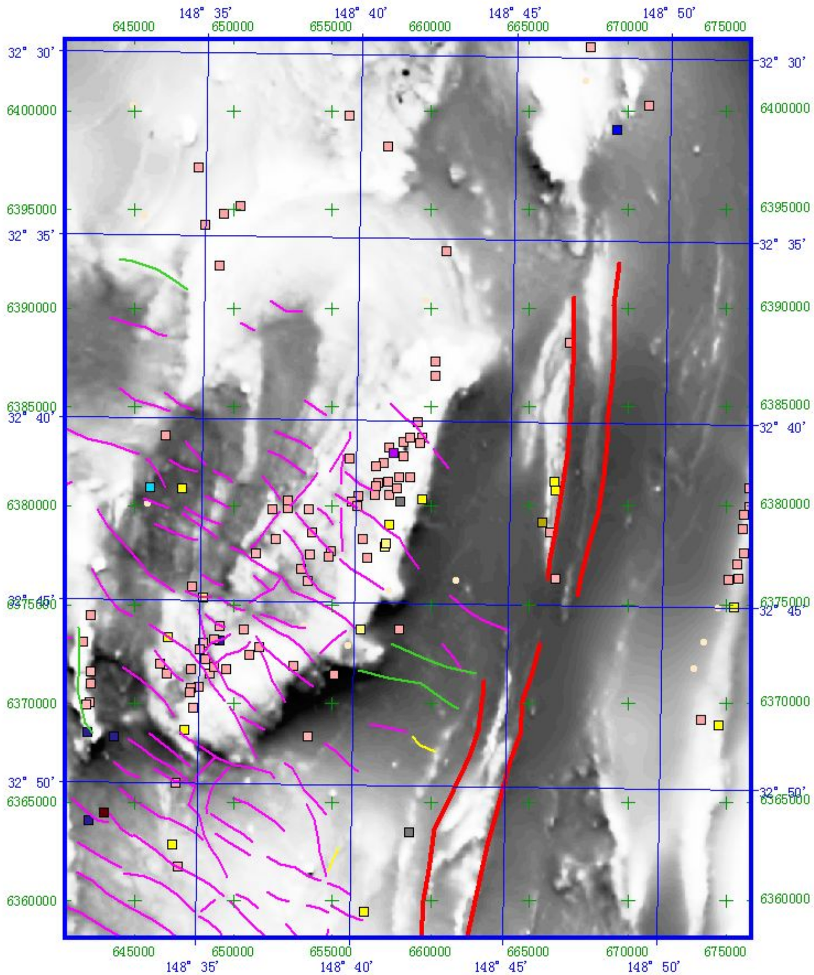


Yoeval Area, N Lachlan Fold Belt: TMI Signature

Courtesy: NSW Geological Survey



Yoeval Area, N Lachlan Fold Belt: Magnetite-depleted Faults

Courtesy: NSW Geological Survey

- Structural Association
  - For IOCG, IAC, and IAG
    - Regional Scale Faults and Associated fault sets
    - Demonstrated for IAC and AIG, less so for IOCG
    - " Barren" intrusives with identical primary mineralogy and texures mostly remote from large faults?

- Structural Association
  - For IOCG, IACG, and IAG

❖ Close association with major faults with several episodes of activity

❖ Vein arrays of several generations

❖ Vein arrays relatable to major faults and far-field stress regimes.

❖ No relation of vein arrays to "Burnham-type" MVP fracturing events

- Textures and Fabrics of Associated Intrusive
  - For IOCG, IACG, and IAG

❖ Phaneritic, porphyritic, seriate-to hiatal textured

❖ No aplitic rocks: not observed for IOCG and not for most IAG or IAC

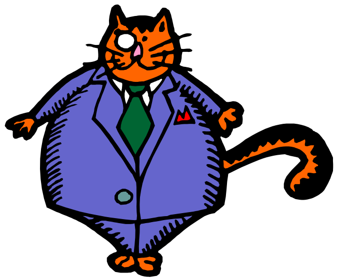
❖ Dykes are simple, phaneritic uniform to porphyritic to seriate texture

- Textures and Fabrics of Associated Intrusive
  - For IACG, and IAG
  - "Macro" marialitic cavities NOT present
  - Two domain textures (cf Mole Granite (Candela)) NEVER observed in Chile & SW USA IAC(G)
  - "Primary" mineralogy and textures identical: mineralised & barren !

A Tentative Model

- "Magmatists" Need to Explain:
- Host lithological assemblage oxidation state control!
- Structural association!
- Re/Os, Pb, δS34, Sm/Nd indicating mixed magmatic rock & shallow crustal rocks!
- Identical 'primary' mineralogy, texture, and geochemistry of "barren" and "mineralised"
- "Magmatic textured" systems, e.g. Timbarra, Lightning Creek tiny, or extremely low grade, or barren of Cu, Au!

A Tentative Model



- Magma emplaced across or next to major contractional or strike slip fault
- Depth 5 to 10 km or so!
- Fluid filled compartments in fault
- Cycling from sub-hydrostatic to supra-lithostatic P (say lithostatic P + 20 MPa)
- Fluid P increase (expansion) also driven by heating from adjacent intrusive

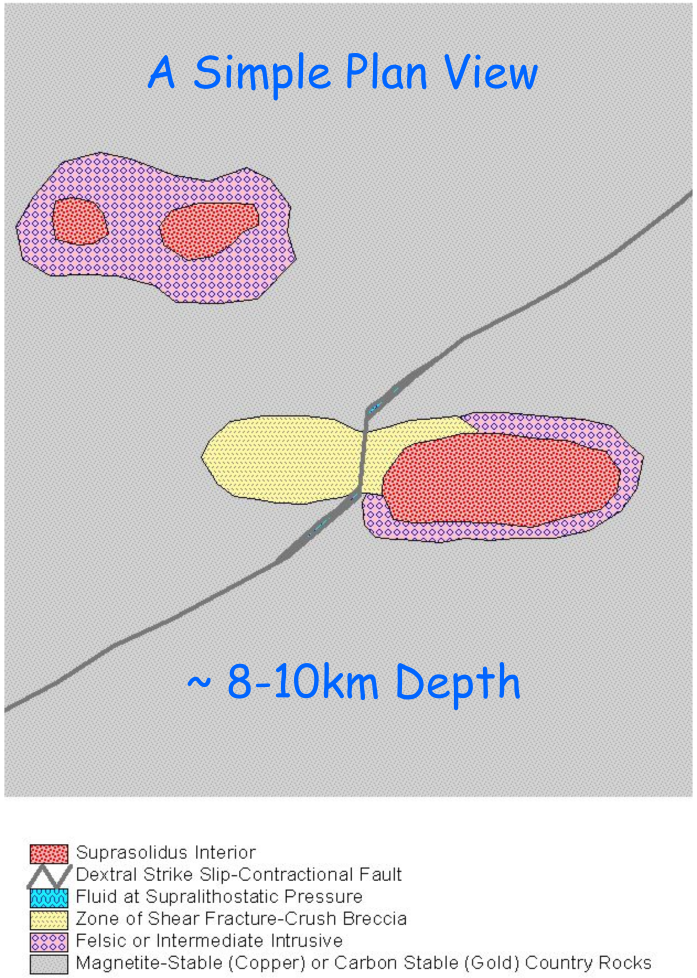
A Tentative Model

- In slip events, high strain rate/damage in adjacent shell of magma driven to brittle behaviour, at T~ 600-700 C (see Fournier, 1999 Fig 3; Sibson 2000 Fig 4)
- Fluid at supra-lithostatic P in extension fractures & fault promotes brittle behaviour in "magma" shell
- Fluid at supra-lithostatic P driven into "magma" shell and adjacent viscous interior which is at lithostatic P.

A Tentative Model

- Fluid migrates upwards in solid shell of the “magma” during episodically brittle conditions & under ductile conditions in adjacent viscous interior

- Strong thermal/density gradients in fluid path drives migration into the “magma” during the fault slip events



A Tentative 'Model'

1: Cooling magma next to contractional fault

2: Extension veins in strain damage zone

3: Fluid P supralithostatic in fault & veins

4: Fluid driven into magma (where Pfluid is lithostatic)

5: Magma then acts as a fluid pump .. ..

A Tentative Model

- Fluid ascends to ~ 3 to 5 km depth in shell of "magma" and adjacent viscous interior.. .. ..
- Fluid intersects two phase fluid region at T ~ 550C, generates "magmatic" appearing fluids, one gas rich, other very saline.. .. ..
- Fluid collects metals & gases from the tiny trapped bubbles of MVP & primary mineral phases on its way "up"
- Initial fO2, ΣSO4, ΣCl in inflow determines size of metal reservoir in "magma" as it migrates through "magma"

A Tentative Model

- Possible local magma remelting & generation of "remelt" textures on flank of "magma", e.g. Lightning Creek

- Salinity of fluid increasing through loss of water to wall rocks in "magma"

- Initial fO2 in fluids controlled by magma, either above or below solidus, but subsequently by inflow fluid as R/W decreases in fluid flow paths

A Tentative Model

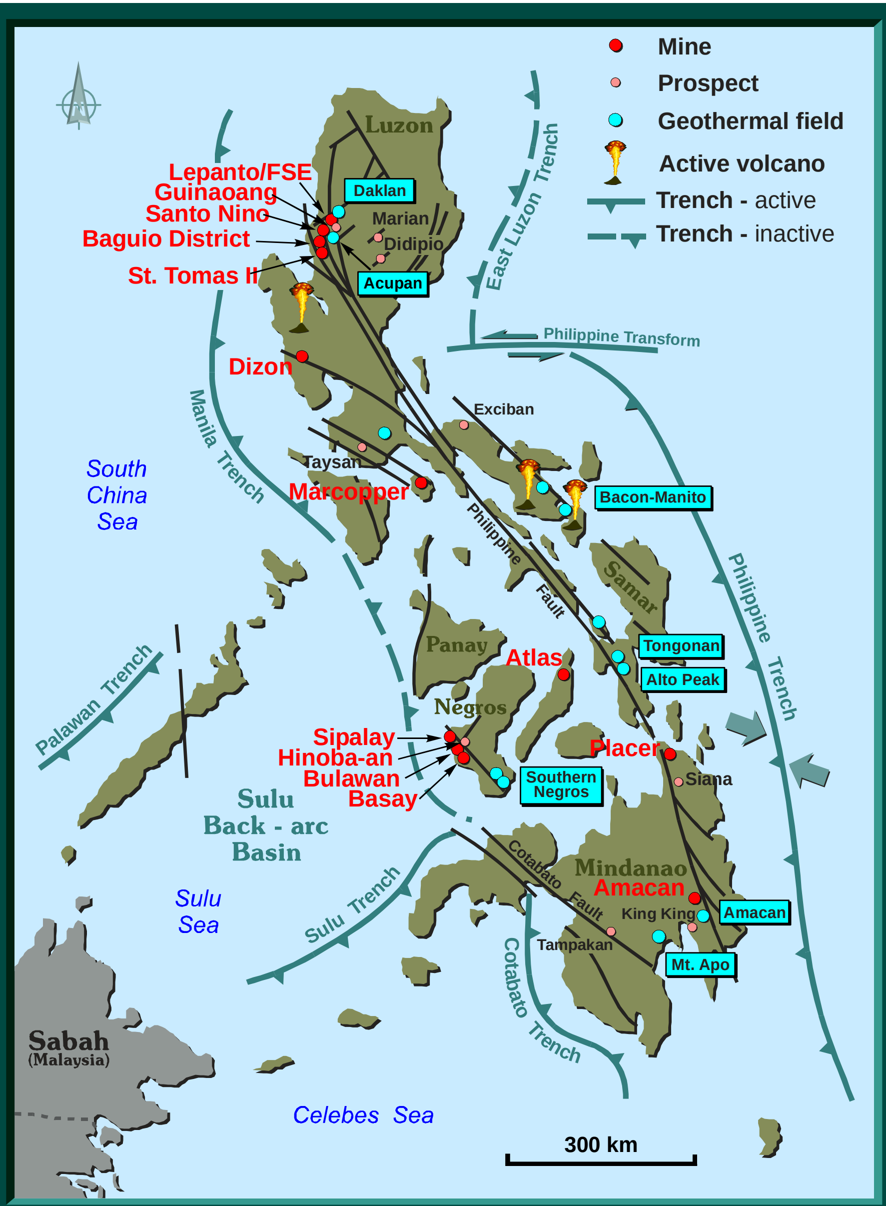
- Bisulphide predominant external fluid, and magnetite-stable magma: weak early Cu; major Au: Porgera, Lihir, ...
- Bisulphide predominant external fluid, and magma “below” QFM: major Au
- Sulphate predominant external fluid, and magnetite-stable magma: major Cu, Au
- Et cetera.. .. ..

A Tentative Model

- Potentially fertile magmas distributed randomly above the zone of mantle-lower crust partial melting in the tectonic unit of interest

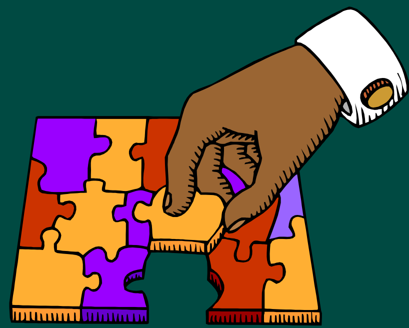
- The ones that make it, though, are those which hit the "wet spots" near and at the surface

- The wet spots are where faults/joint arrays/lithological contacts are capable as acting as fluid reservoirs with fluid P > lithostatic at episodic intervals



Philippines Tectonic Settings Porphyry Copper Deposits

(after Corbett and Leach, 1997)

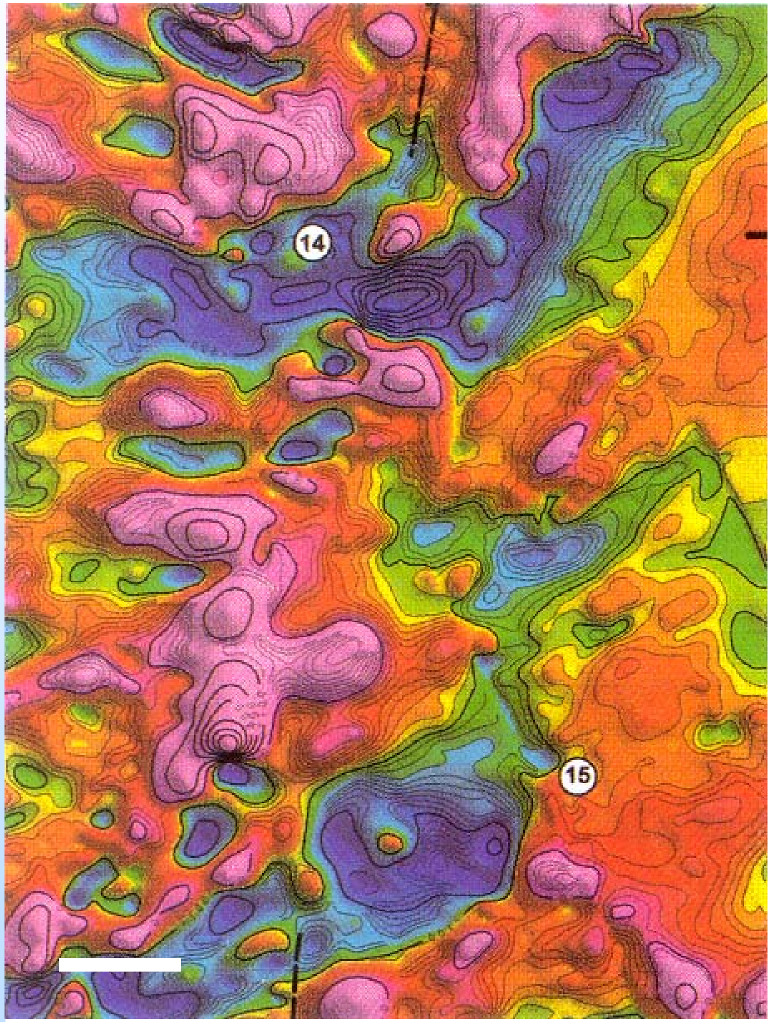


A Tentative Model

- Albite in prograde, deep flow paths (deep veins at El Salvador & deep alteration at Yerington)

- K-spar in retrograde flow paths (at and near top of intrusive body)

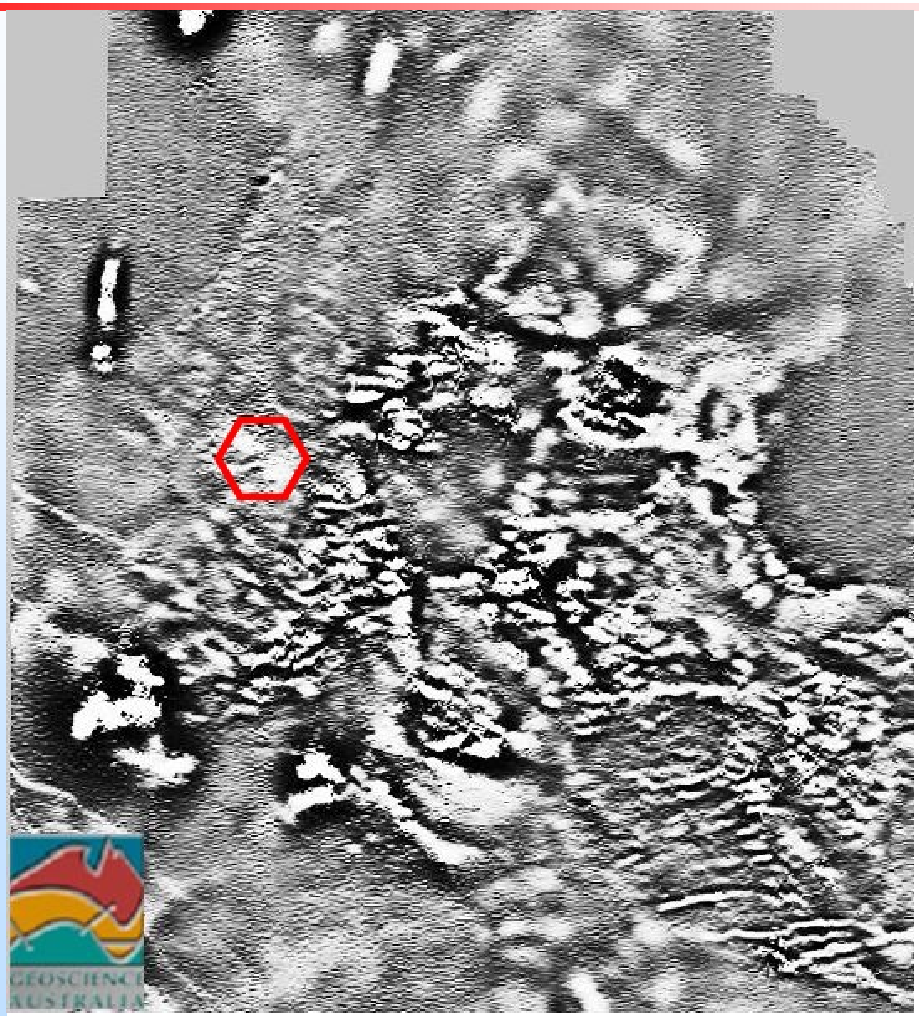
- Fluid recharge zones evident in detailed aeromagnetic data ?



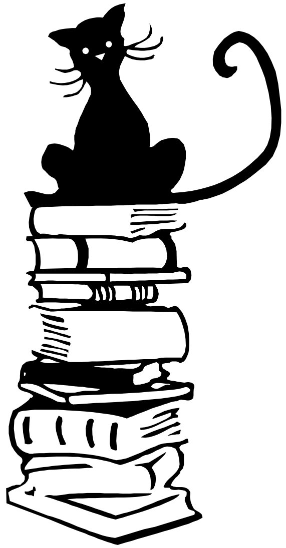
El Salvador

Potrerillos

Behn et al., 2001



Courtesy:
R Skirrow
N Direen



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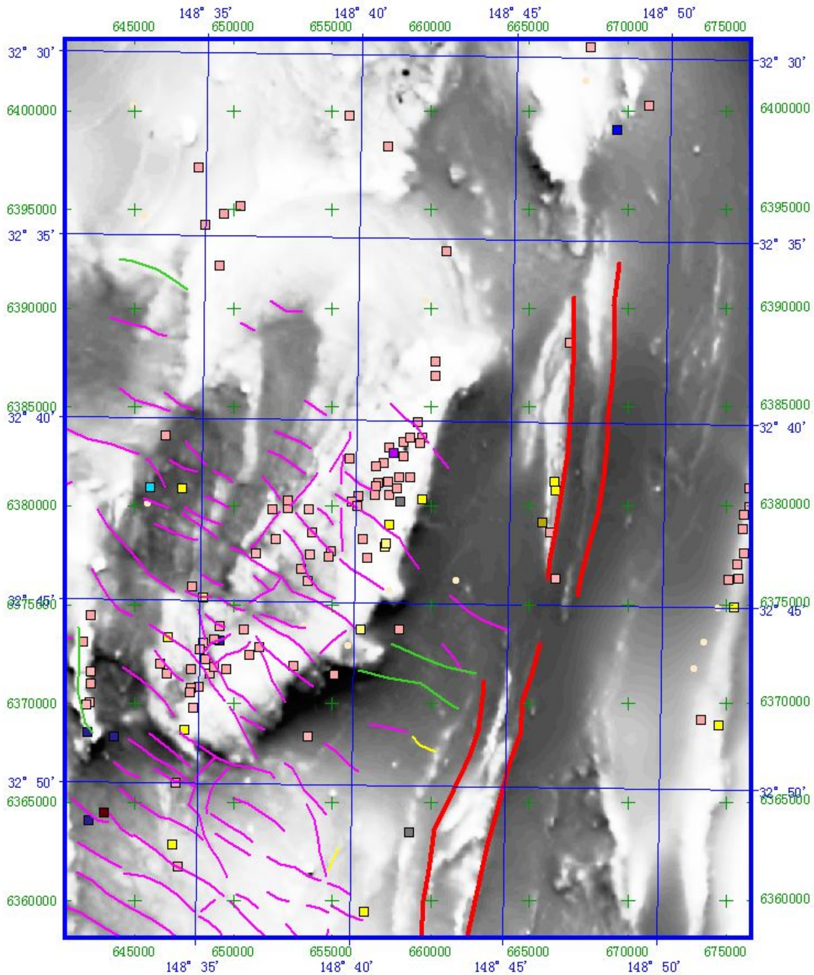
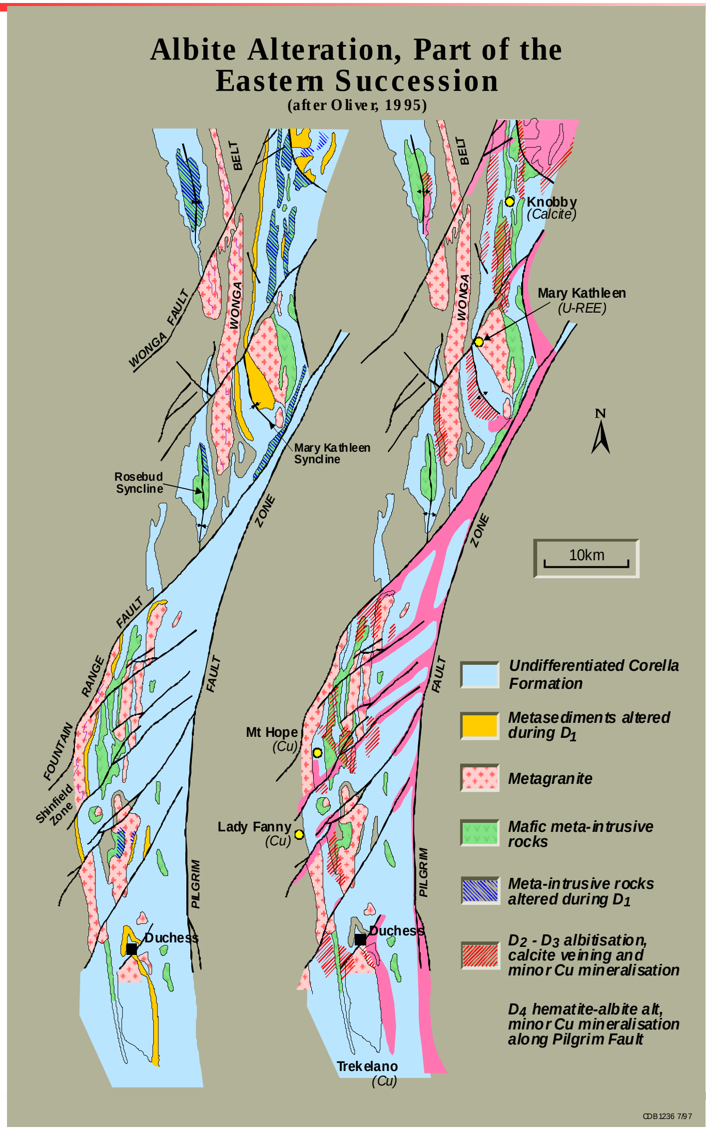
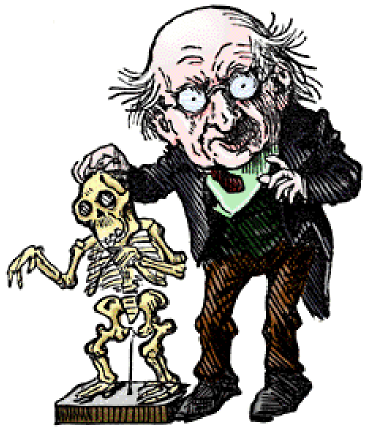
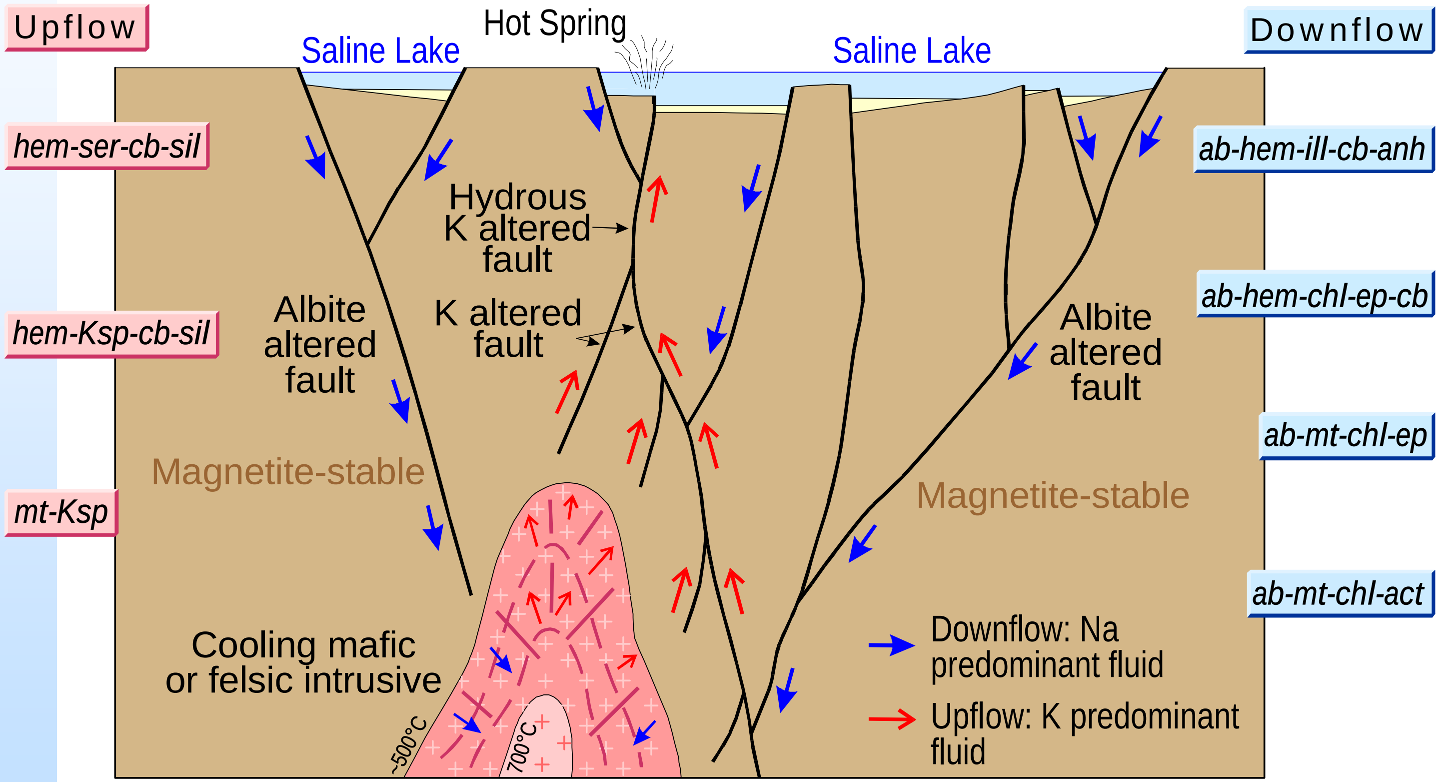


Yoeval Area, N Lachlan Fold Belt: Magnetite-depleted Faults

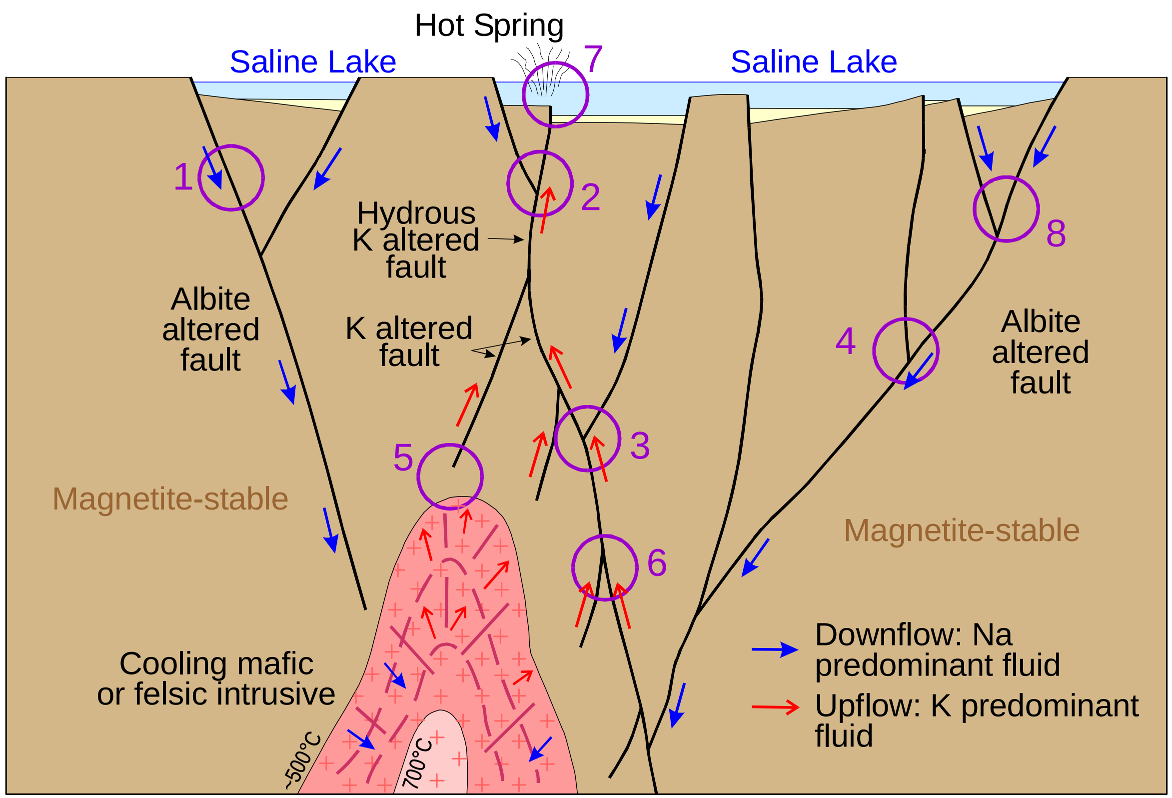
Courtesy: NSW Geological Survey


Albite Alteration, Part of the Eastern Succession
(after Oliver, 1995)
BELT
WONGA
WONGA FAULT
Rosebud Syncline
Mary Kathleen Syncline
ZONE
FAULT
RANGE
FOUNTAIN
Shinfield Zone
PILGRIM
Duchess
Knobby
(Calcite)
Mary Kathleen
(U-REE)
N
10km
Mt Hope
(Cu)
Lady Fanny
(Cu)
Trekelano
(Cu)
Undifferentiated Corella Formation
Metasediments altered during D1
Metagranite
Mafic meta-intrusive rocks
Meta-intrusive rocks altered during D1
D2 - D3 albitisation, calcite veining and minor Cu mineralisation
D4 hematite-albite alt, minor Cu mineralisation along Pilgrim Fault

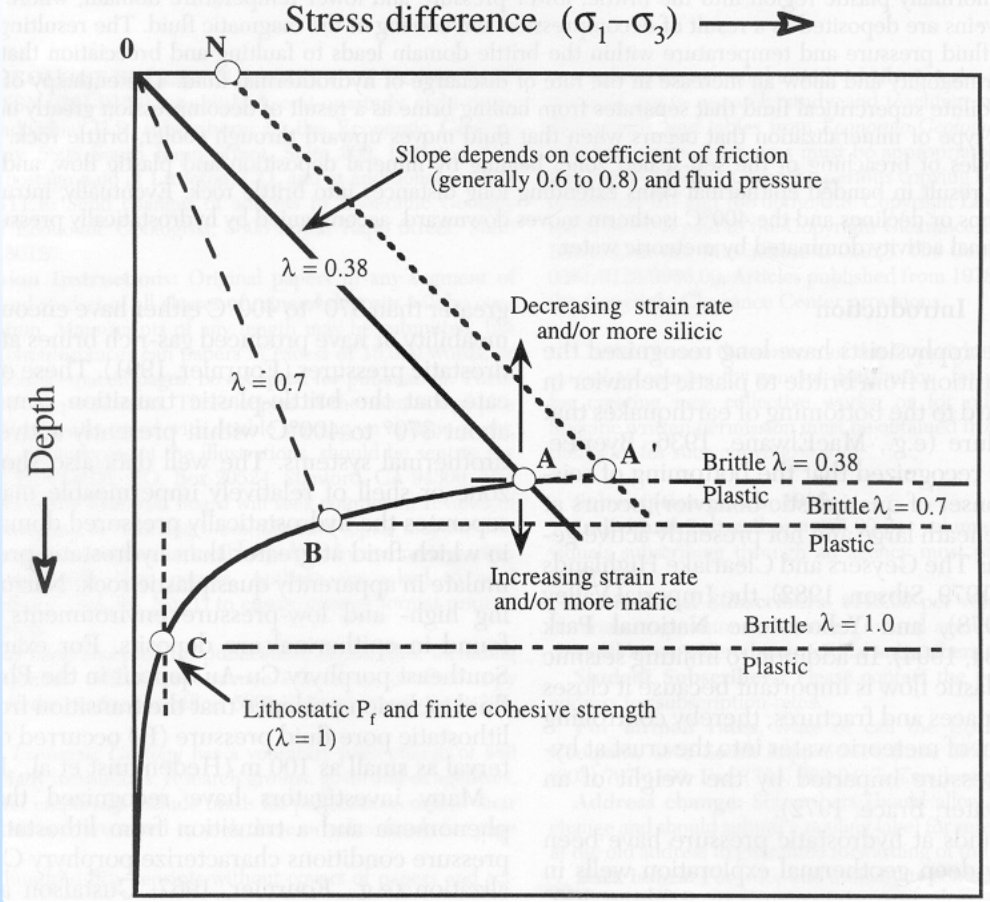




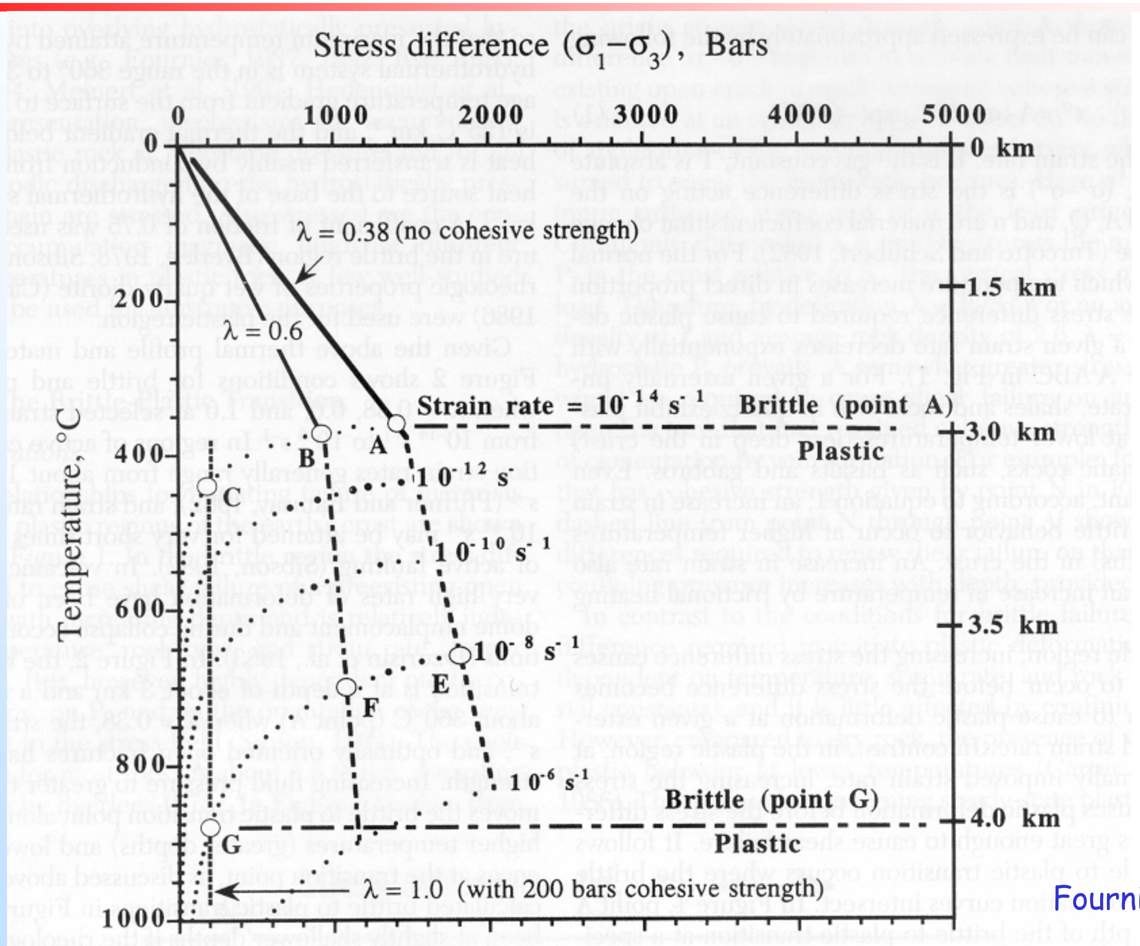
Intracratonic Transtensional Setting



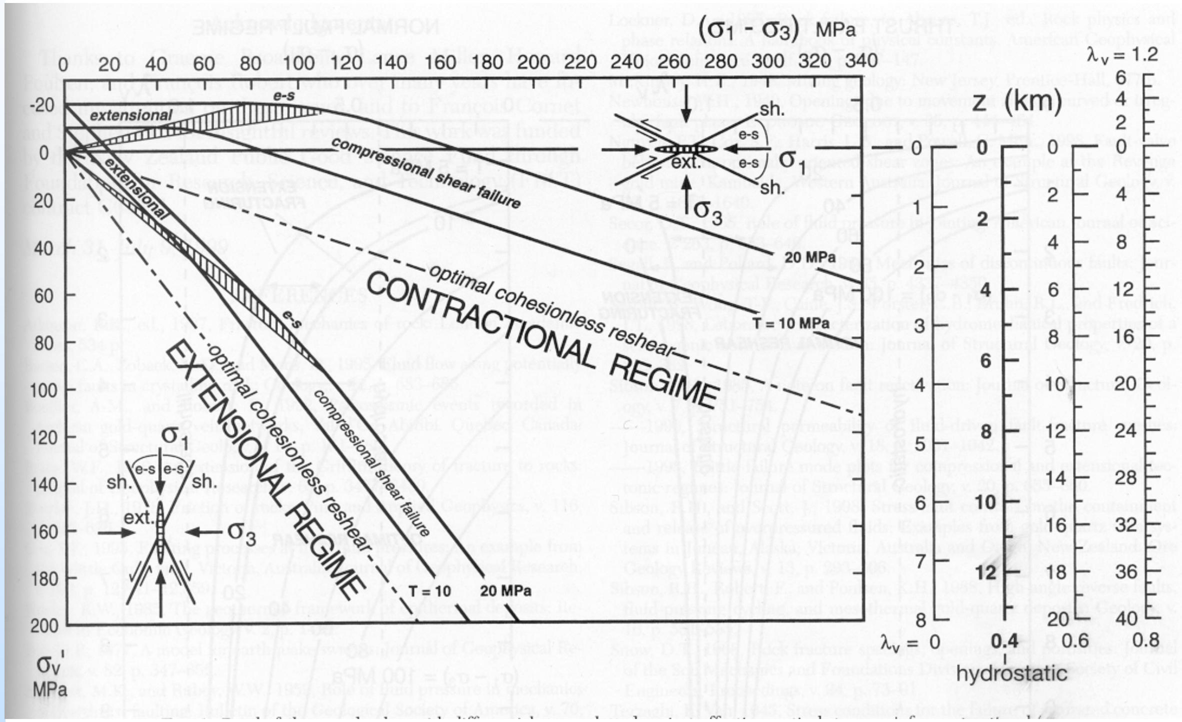
1,8 Mantos Blancos
2 Hem-ser rich "cooler" Ernest Henry
3 Ernest Henry, La Candelaria, Salobo
4 Starra
5,6 Barren mt-act - Ksp
7 Mnox-hem-cl-sil -"exhalite"



Fournier, 1999



Fournier, 1999



(σ1 - σ3) MPa
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340
extensional
e-s
compressional shear failure
extensional
optimal cohesionless reshear
CONTRACTIONAL REGIME
EXTENSIONAL REGIME
optimal cohesionless reshear
compressional shear failure
20 MPa
T = 10 MPa
T = 10
20 MPa
sh.
ext.
σ1
σ3
z (km)
hydrostatic
σv' MPa

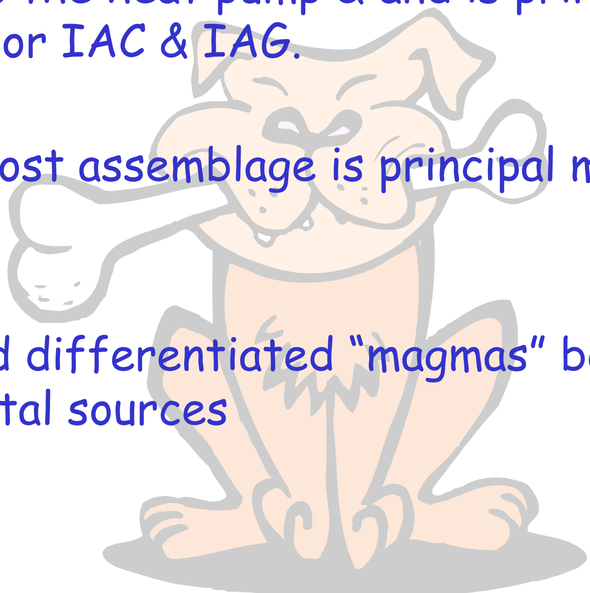
Sibson, 2000

Conclusion

- "Magma" is the heat pump & and is principal metal source for IAC & IAG.

- "Magma" host assemblage is principal metal source for IOCG

- Hotter and differentiated "magmas" better heat pumps and better metal sources



Conclusion

- Regional scale contractional faults provide much if not most of the "water".
- Host assemblage of magma largely constrains fO_2, ΣSO_4^{--}, and hence metal ratios in resulting ore deposit
- "Magma" initially constrains fO_2, pH, ΣSO_4, .. then injected water "takes over" with increase in W/R
- Ore deposit where magma intersects a contractional fault in a stress regime that causes injection of "water" from the fault zone at ~ 5 to 10km depth

Notes Added: Post Symposium

- Regional scale contractional faults must also inject "water"into magma in the suprasolidus state as well.. ..
- This "water" either adds methane/reduced sulphur or oxidised sulphur, as sulphate, to the magma or hot rock.. ..
- Magmas are not fertile if they are not "juiced up" by the fluid reservoir in the contractional fault.. ..
- Metallogeny of magma dependent on $fO_2/\Sigma SO_4/\ \Sigma HS$ in the fluid injected into the melt… & hence redox of host lithological succession
- Largely suprasolidus mineralisation if fluids injected suprasolidus, mineralisation largely subsolidus if fluids injected subsolidus. Latter scenario generates bigger & better deposits