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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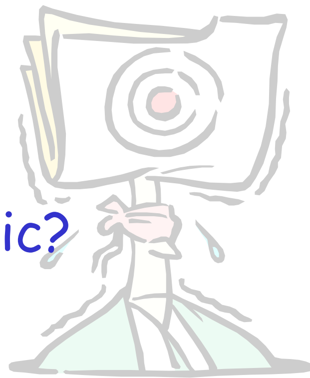
This speculative hypothesis is presented in an attempt to resolve the great question facing exploration geoscientists in their hunt for intrusion centred ore deposits: what are the relations between regional scale fault systems, magmas, host lithological assemblage oxidation state, and the intrusion 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.

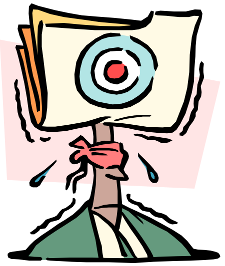
Why I Don't Like Magmas as "Direct" Metal Sources…..

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

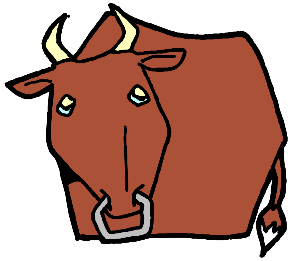


- Definitions
- Orthomagmatic vs Paramagmatic?
- The Evidence: A Tour
  - ❖ Iron Oxide Copper Gold
  - ❖ Intrusion Associated Copper (-Gold)
  - ❖ Intrusion Associated Gold

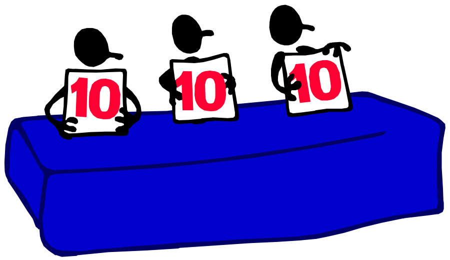
- The Evidence: A Tour
  - ❖ Host Lithological Assemblage Redox
  - ❖ Structural Associations
  - ❖ Isotopes – Briefest of Looks
  - ❖ A Tentative Model



- Orthomagmatic:



- Paramagmatic:

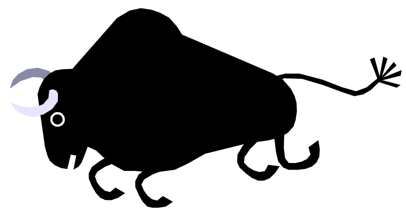


- Host Lithological Assemblage

  - ❖ 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, fO_2, ΣSO_4-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

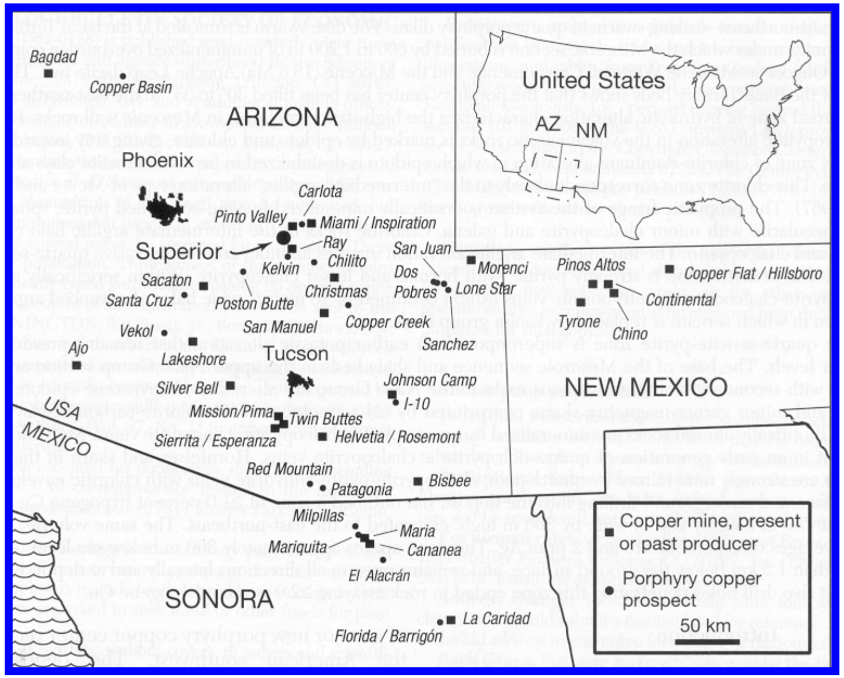
❖ Similar, BUT also greywacke, metagreywacke, metasiltstone.

❖ widespread reduced carbon in one or more lithological units >> 1000's metres thick

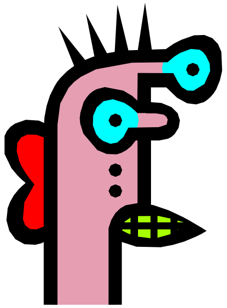
❖ non silicate iron minerals predominantly as sulphide forms ?

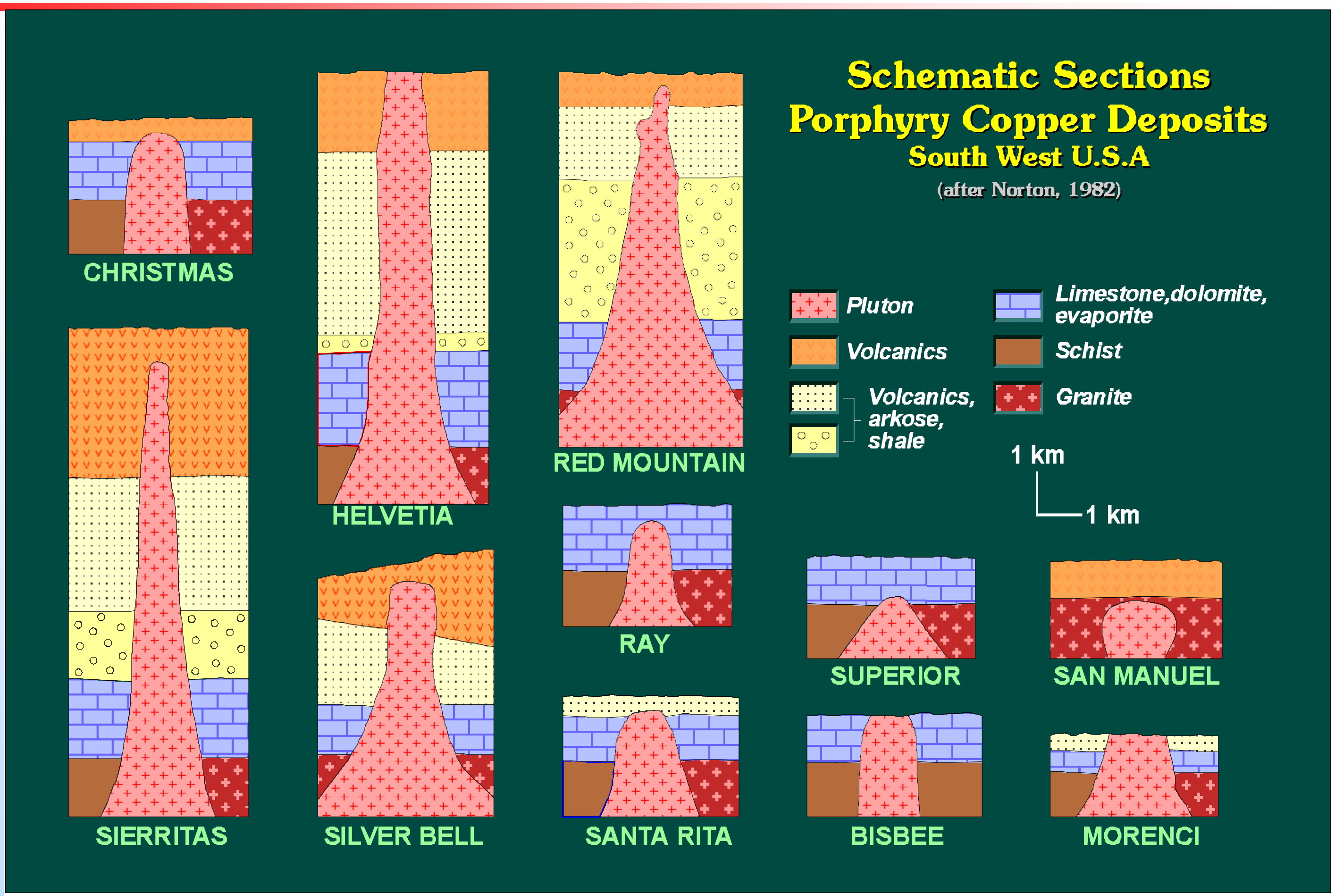
Remember, we are describing SHALLOW CRUST.. .. i. e. the top 5 to 8km or so

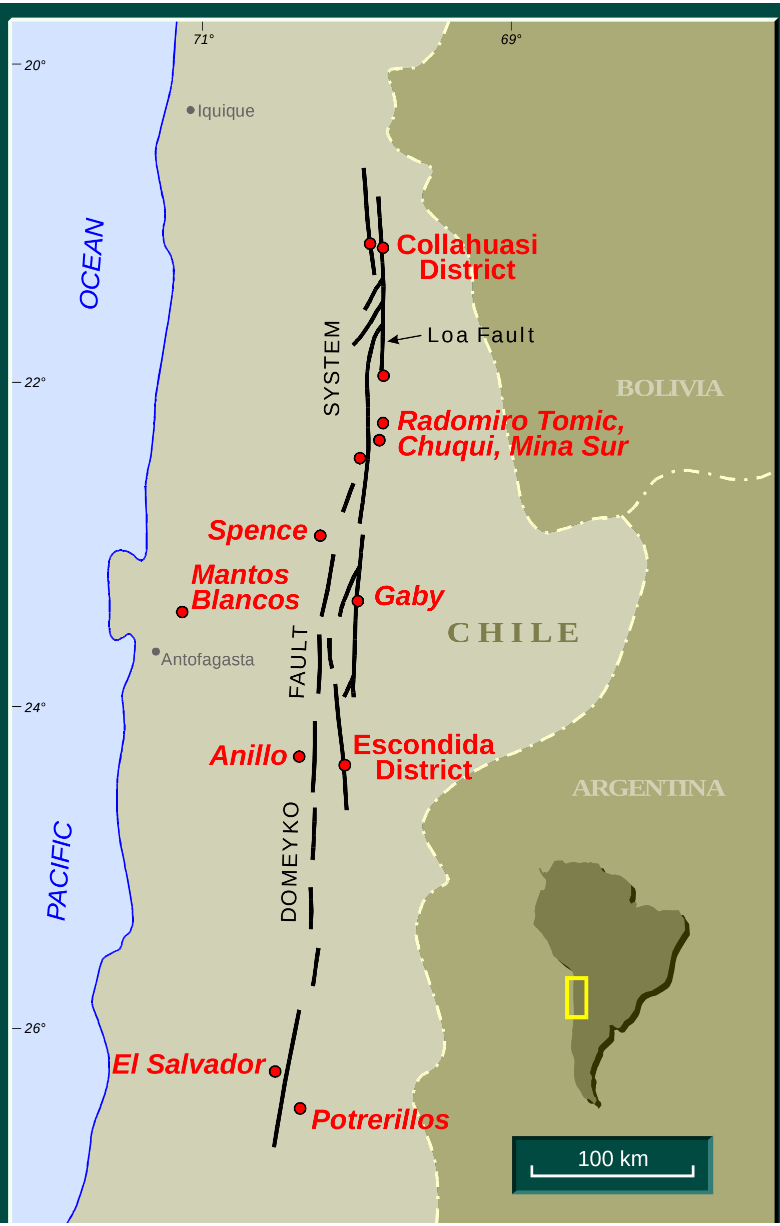
Arizona-New Mexico Porphyry Copper



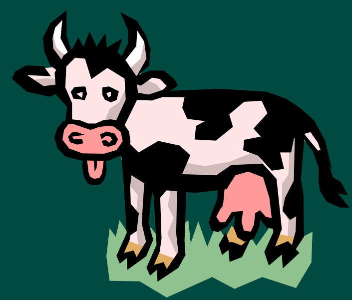
From Manske and Paul, 2002

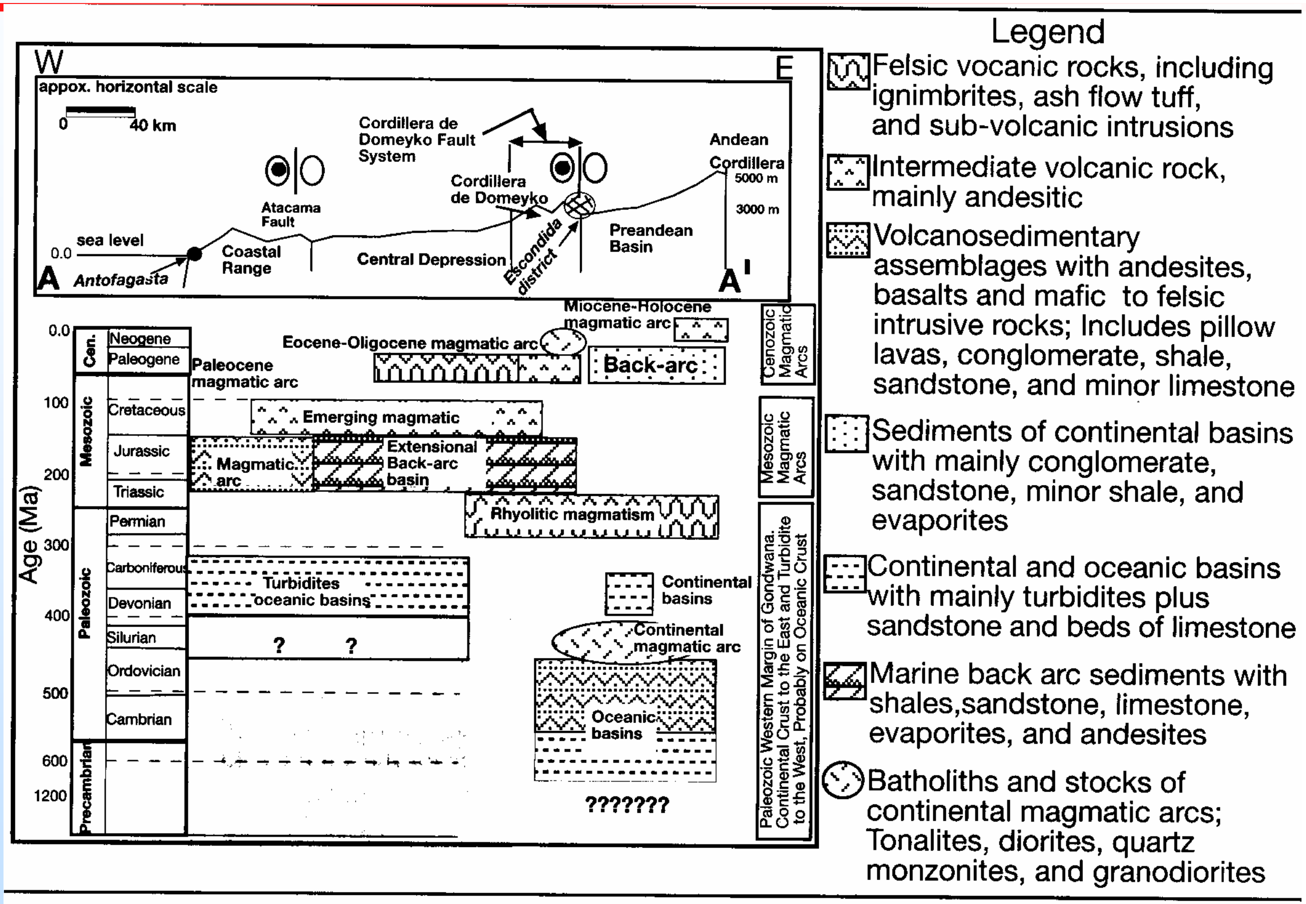



Schematic Sections
Porphyry Copper Deposits
South West U.S.A
(after Norton, 1982)
CHRISTMAS
HELVETIA
RED MOUNTAIN
SIERRITAS
SILVER BELL
RAY
SANTA RITA
SUPERIOR
SAN MANUEL
BISBEE
MORENCI
Pluton
Volcanics
Volcanics, arkose, shale
Limestone,dolomite, evaporite
Schist
Granite
1 km
1 km

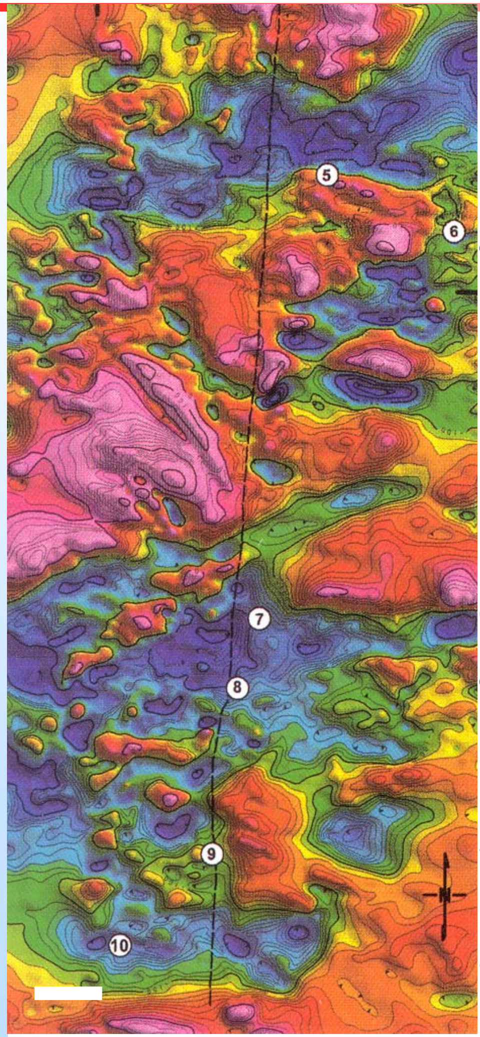


Copper and Iron-endowed Faults, Tertiary Arcs, Chile

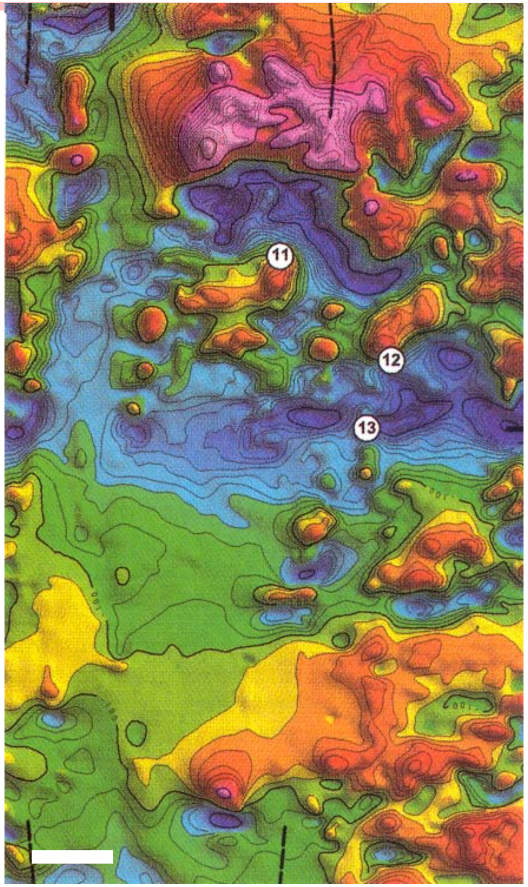




Garza et al., 2001

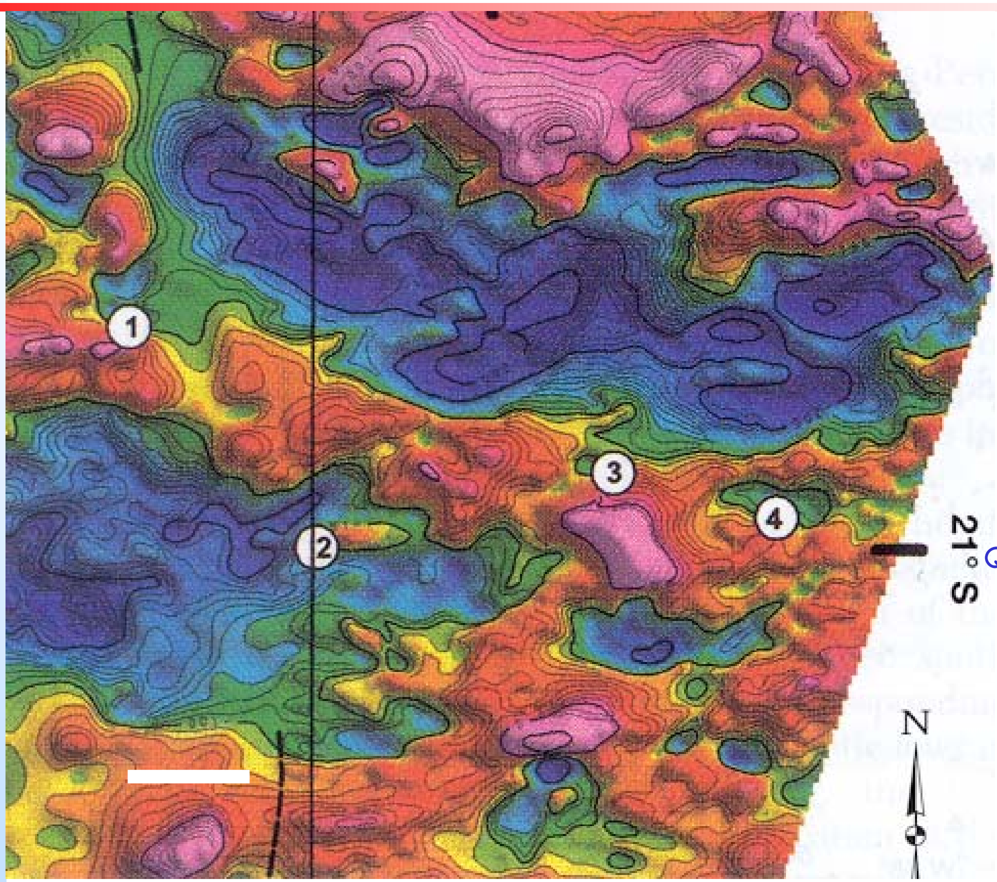


El Abra
Conchi
Radimiro T
Chuqui
Mansa Mina
Opache



Chimborazo
Zaldivar
Escondida

Behn et al., 2001



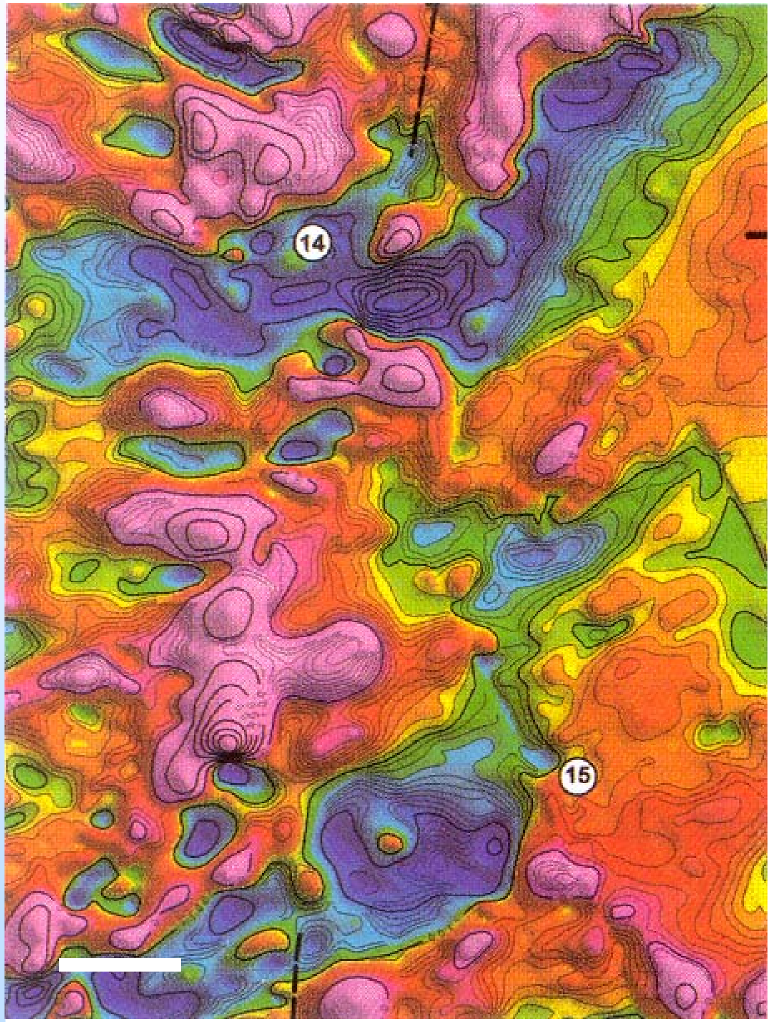
Copaguiri

Collahuasi

Ujina

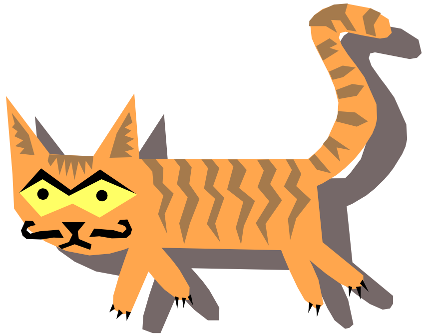
Quebrada Blanca

Behn et al., 2001

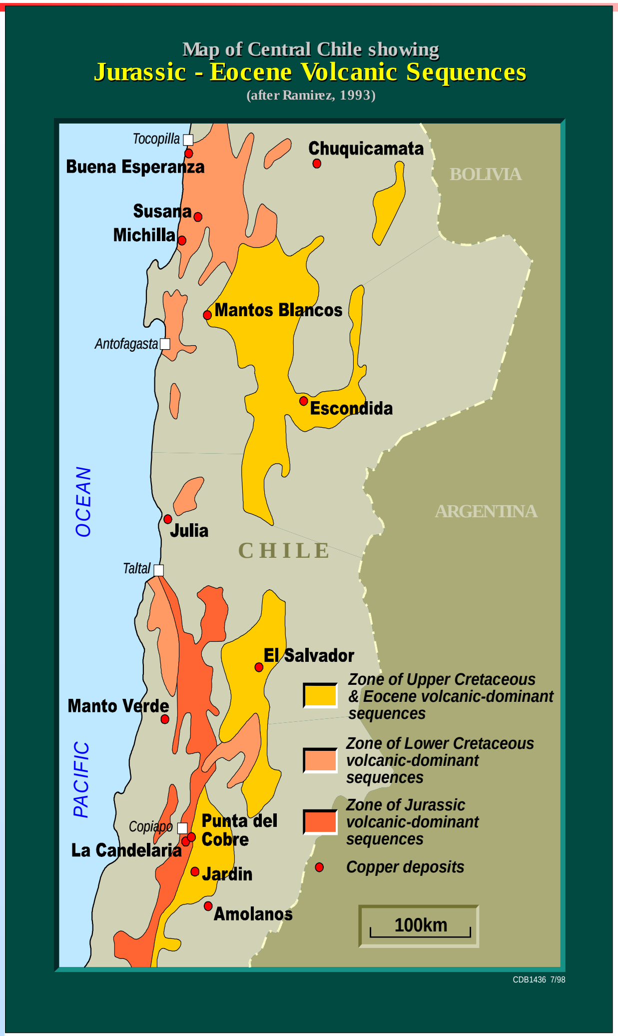


El Salvador

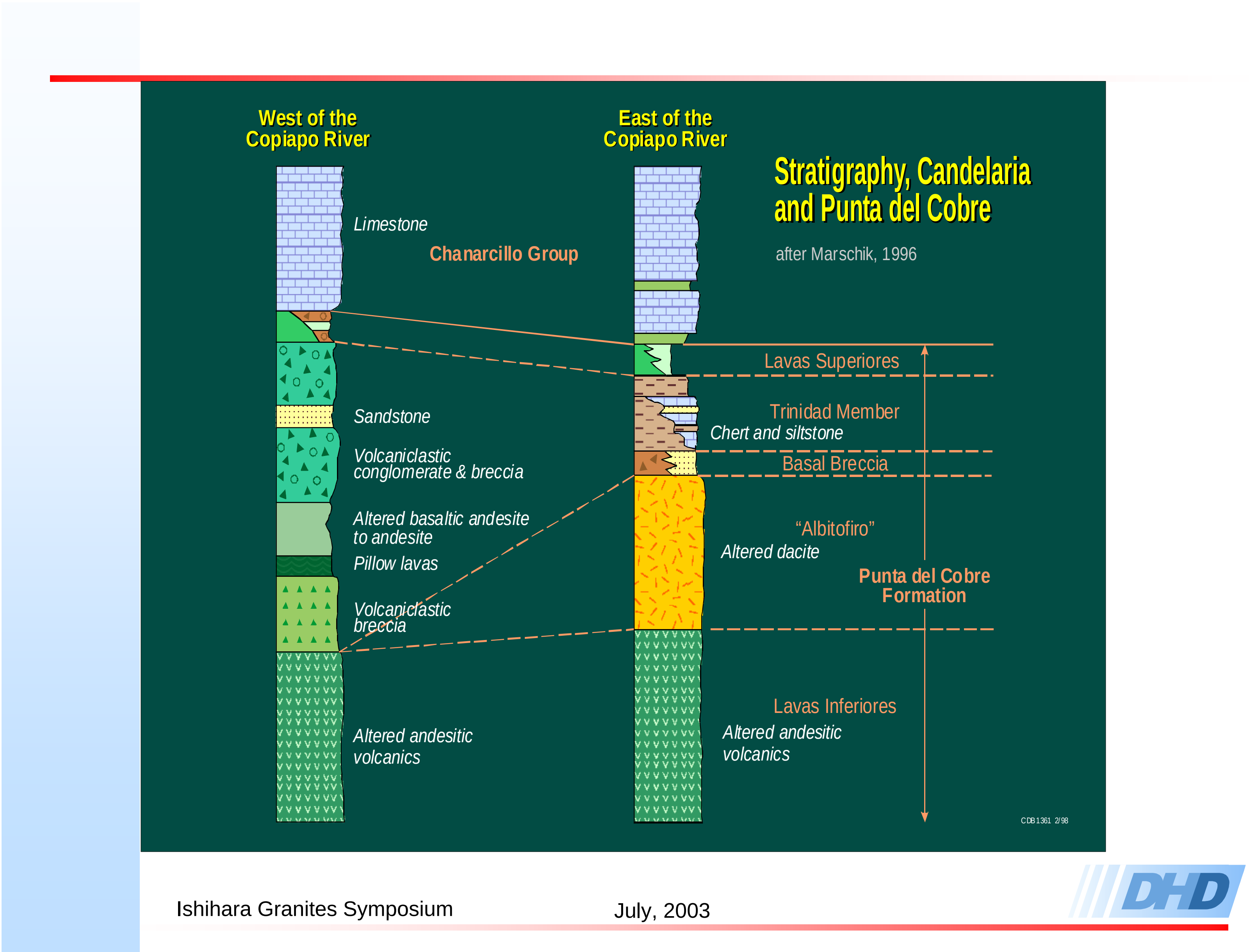
Potrerillos

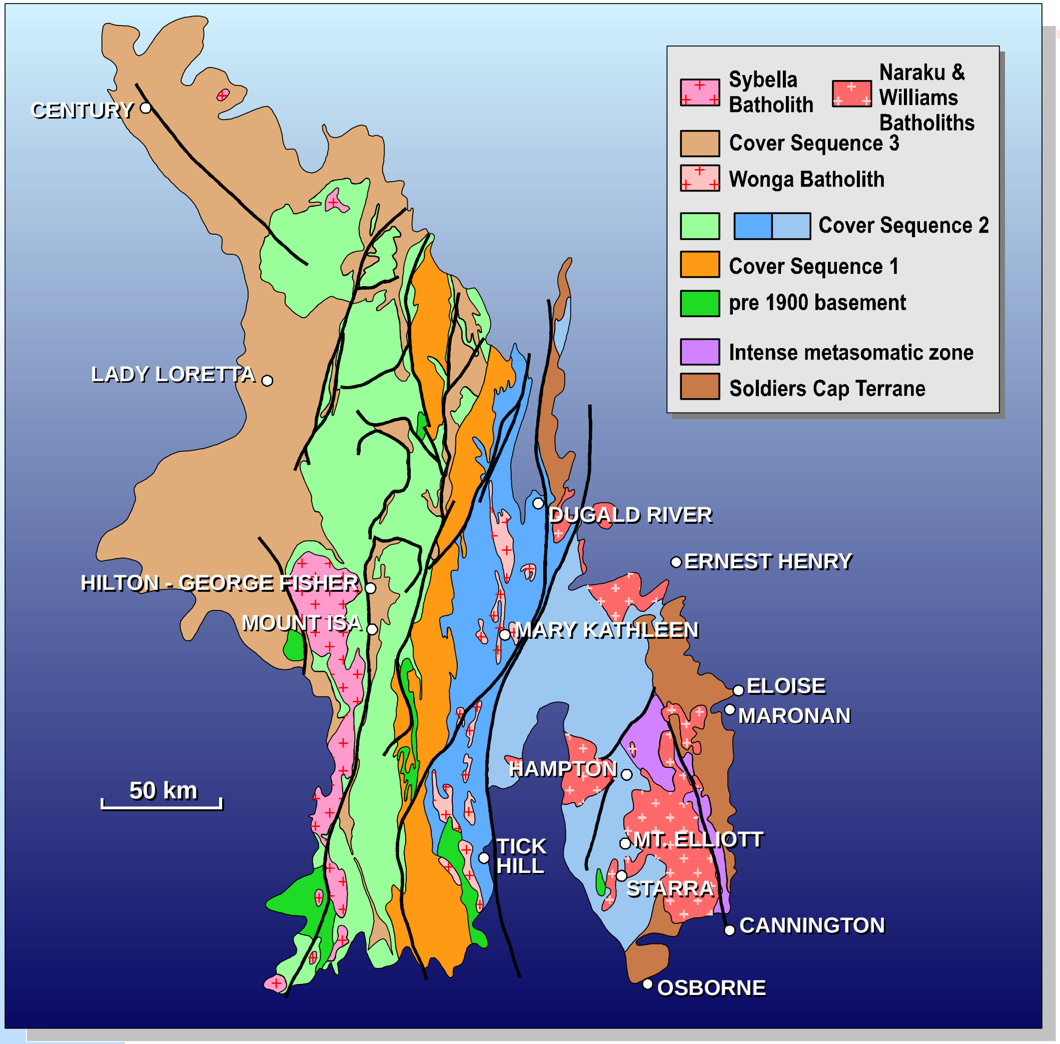


Behn et al., 2001

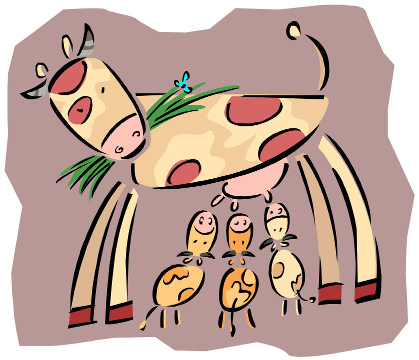


IOCG Deposits, Chile


West of the Copiapo River
East of the Copiapo River
Stratigraphy, Candelaria and Punta del Cobre
after Marschik, 1996
Limestone
Chanarcillo Group
Sandstone
Volcaniclastic conglomerate & breccia
Altered basaltic andesite to andesite
Pillow lavas
Volcaniclastic breccia
Altered andesitic volcanics
Lavas Superiores
Trinidad Member
Chert and siltstone
Basal Breccia
"Albitofiro"
Altered dacite
Punta del Cobre Formation
Lavas Inferiores
Altered andesitic volcanics
CDB1361 2/98
Ishihara Granites Symposium
July, 2003
DHD



MOUNT ISA INLIER REGIONAL GEOLOGY



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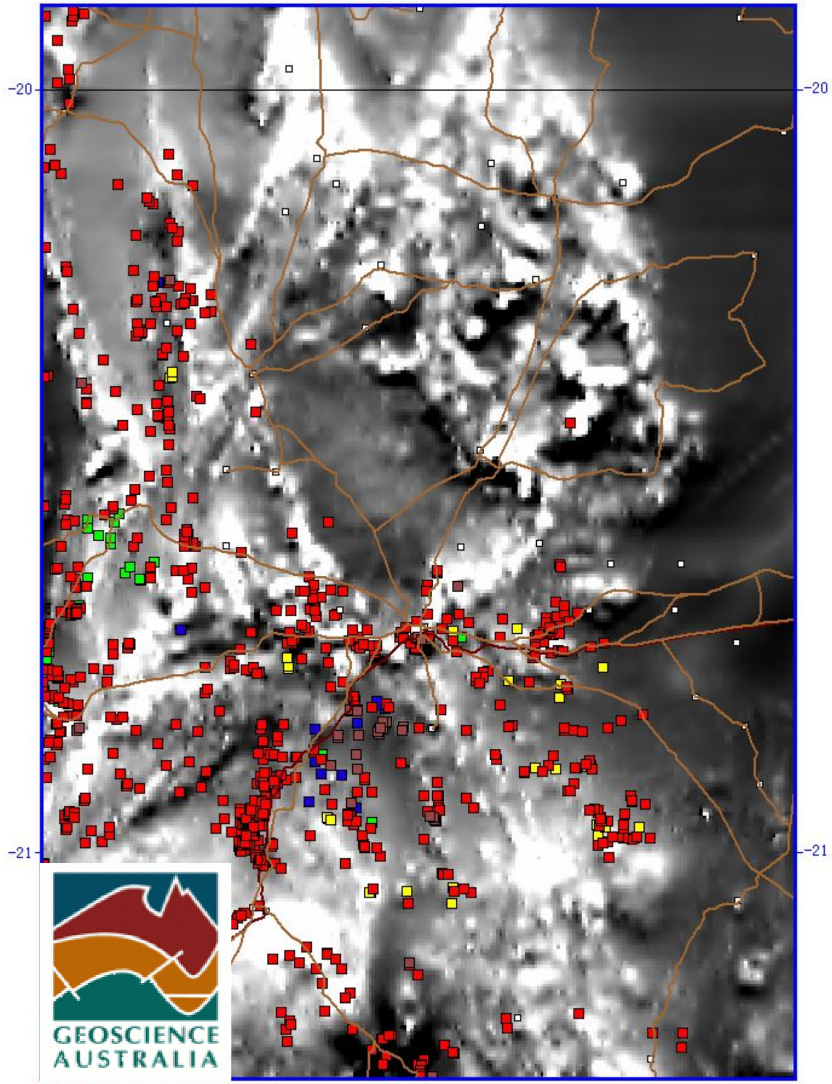
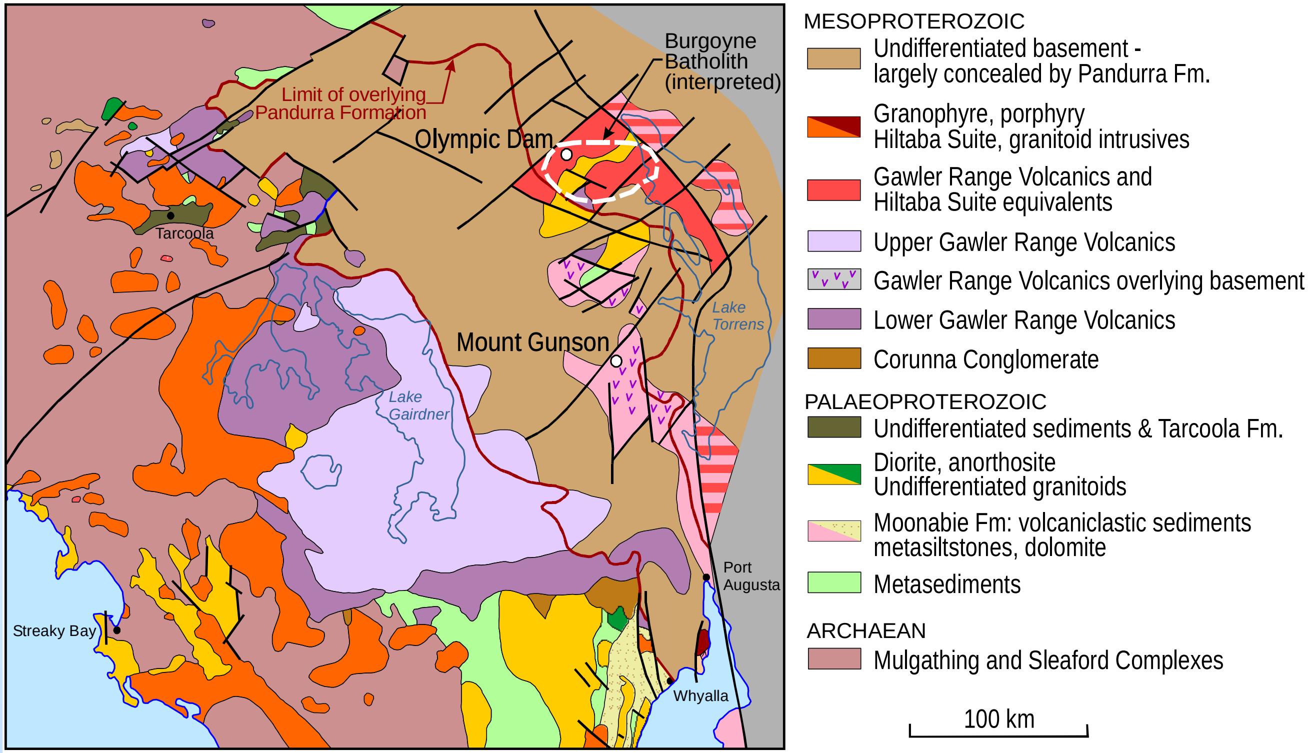
DHD

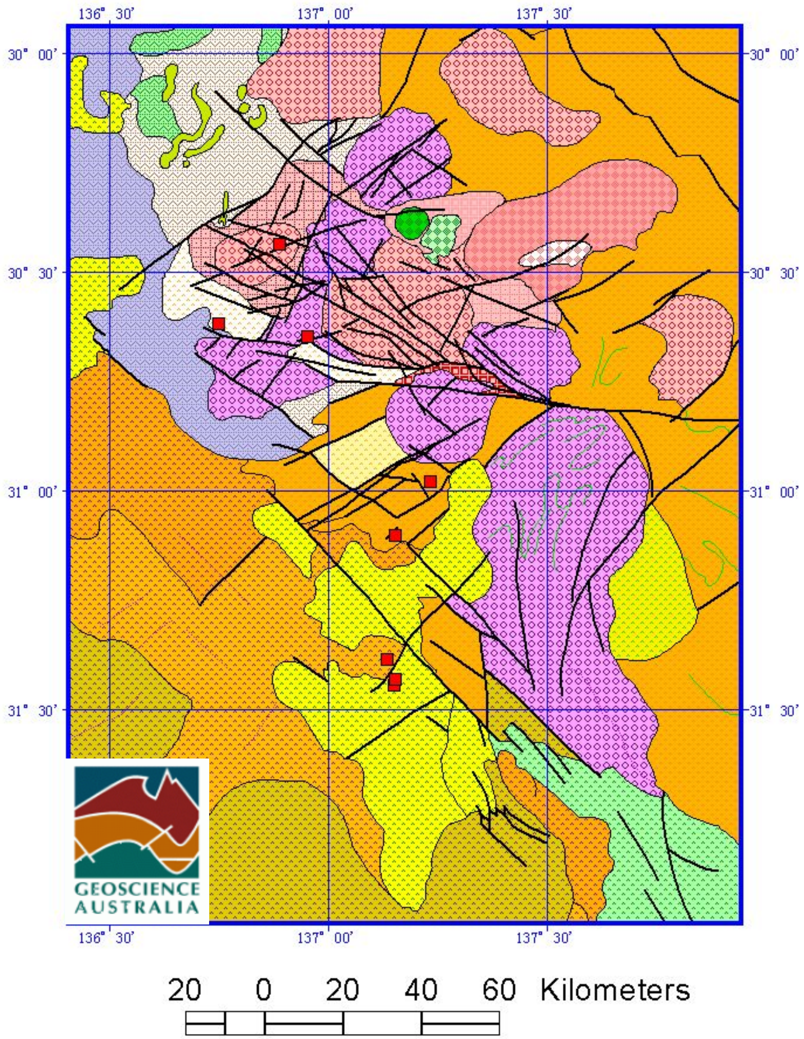


Ernest Henry
TMI Signature

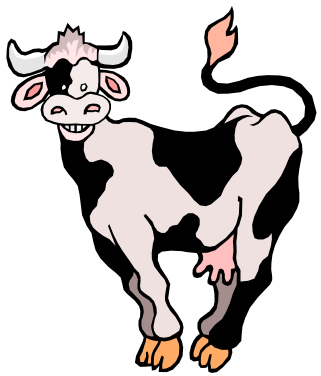
Olympic Dam



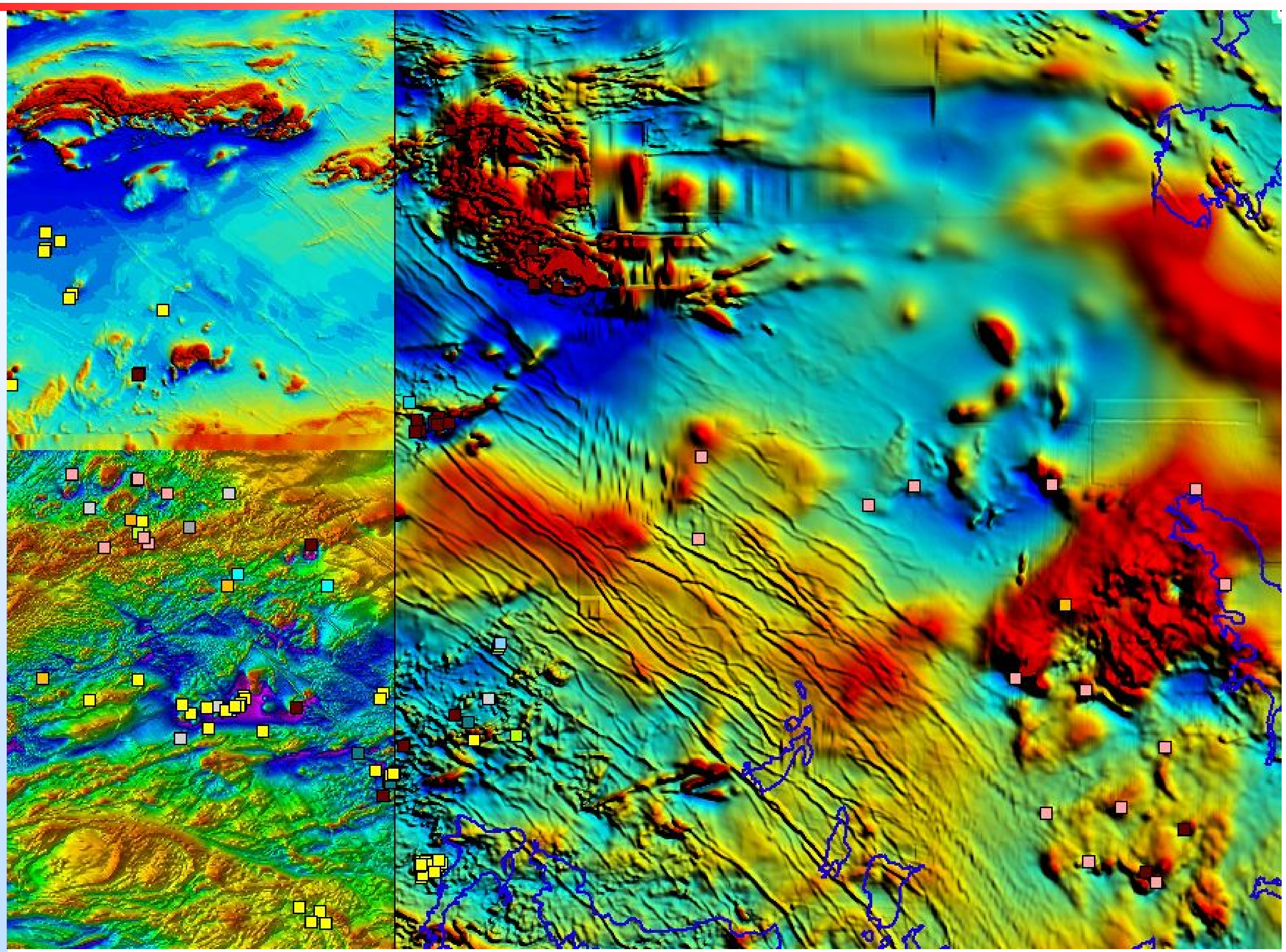
Adapted from Flint et al., 1993

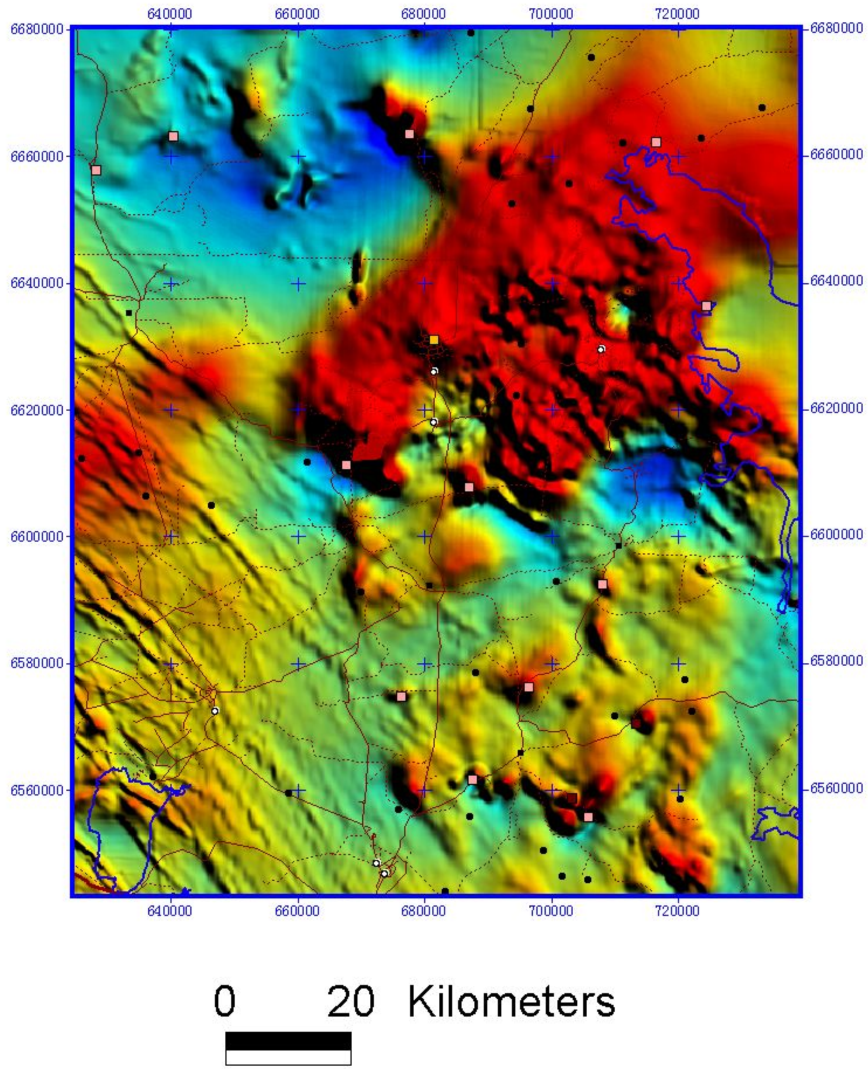


Olympic Dam Interpreted Geology



N& NE Gawler Craton: TMI Signature





Olympic Dam:
TMI Signature

Ladolam, PNG

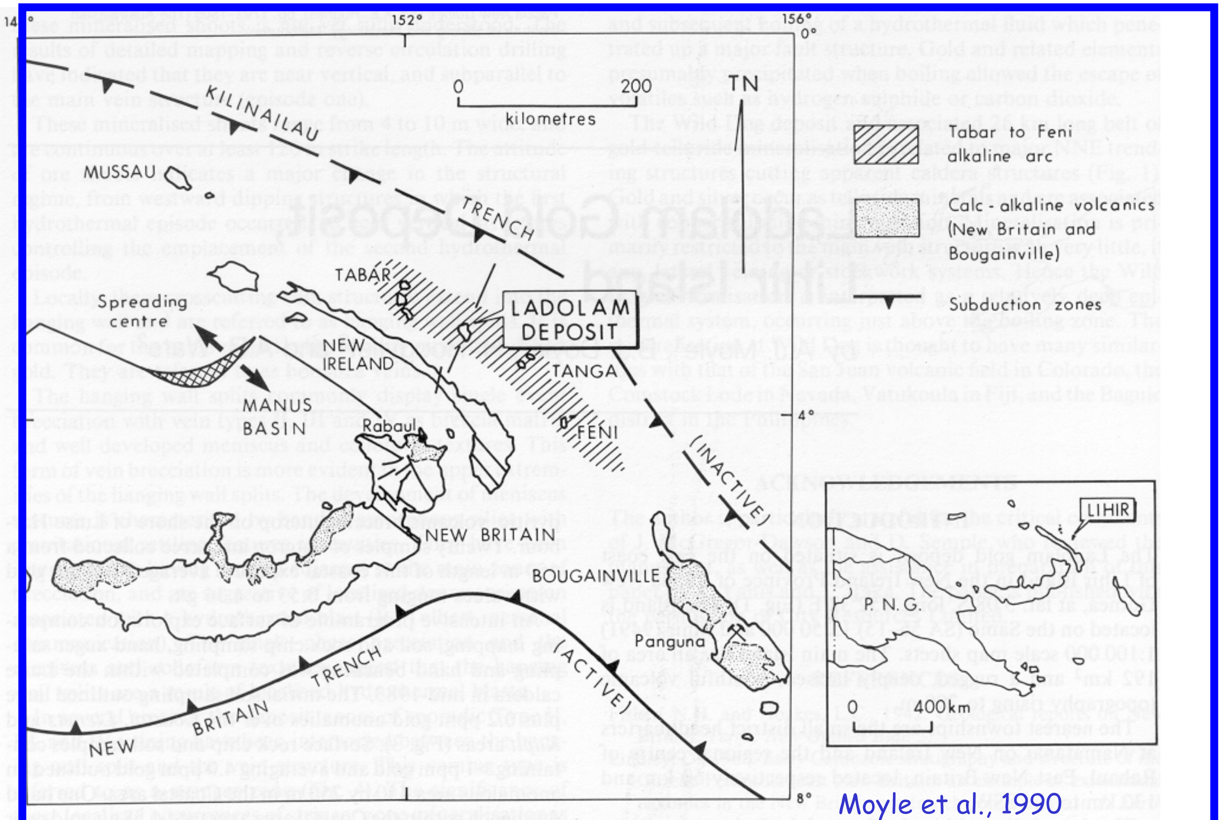
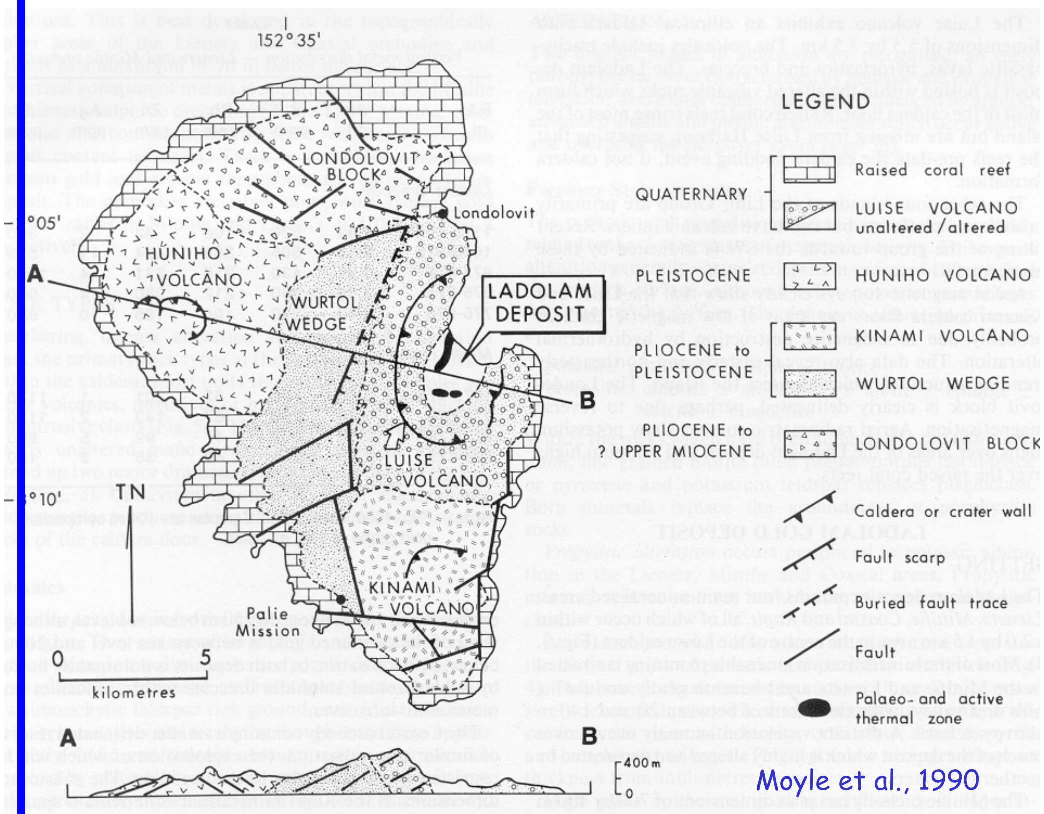


Fig. 1—Location and tectonic setting, Ladolam deposit.

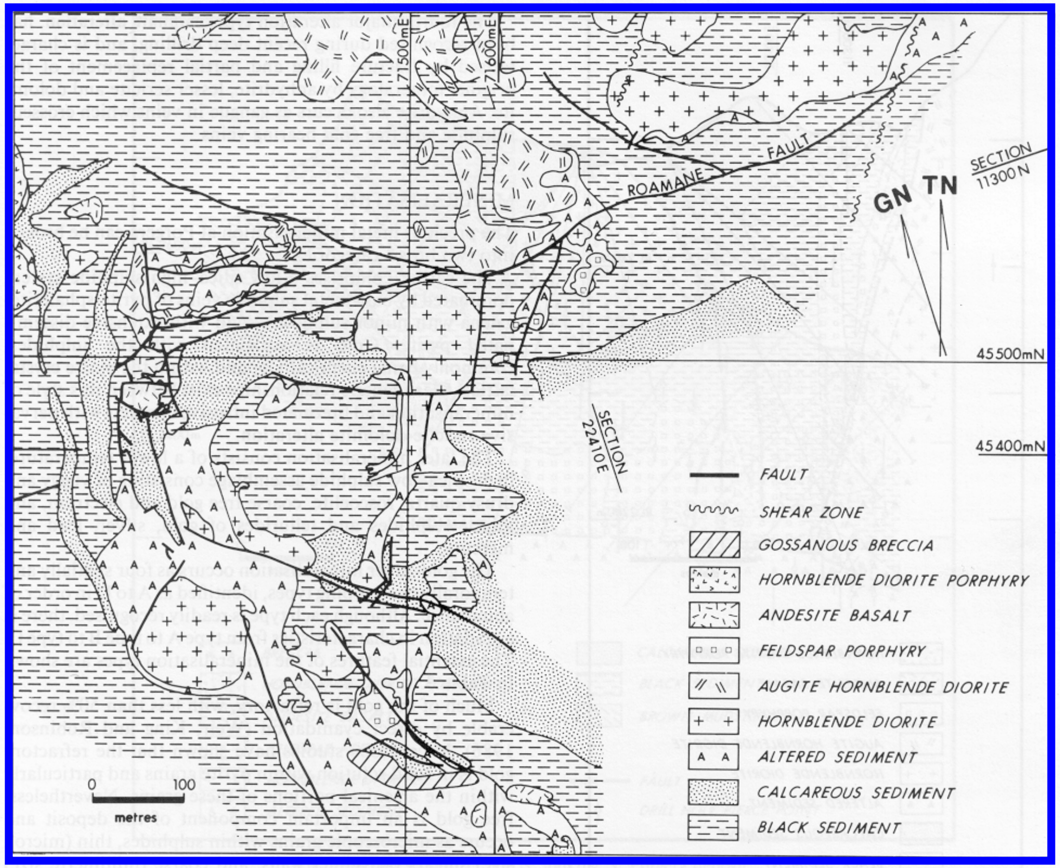
Moyle et al., 1990

Ladolam, PNG



Moyle et al., 1990

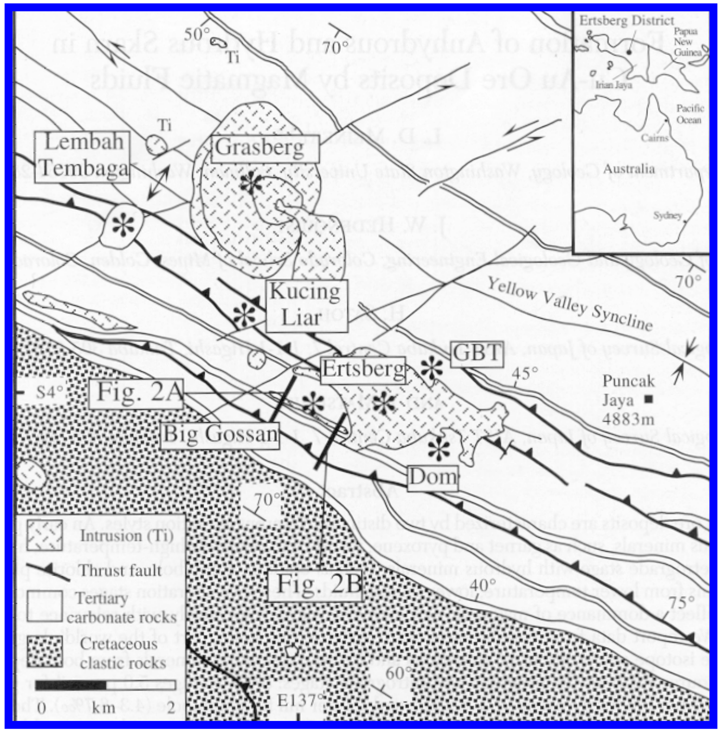
Porgera, PNG



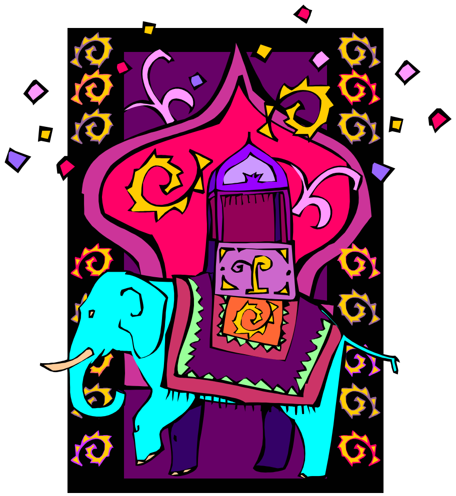
Handley and Henry, 1990

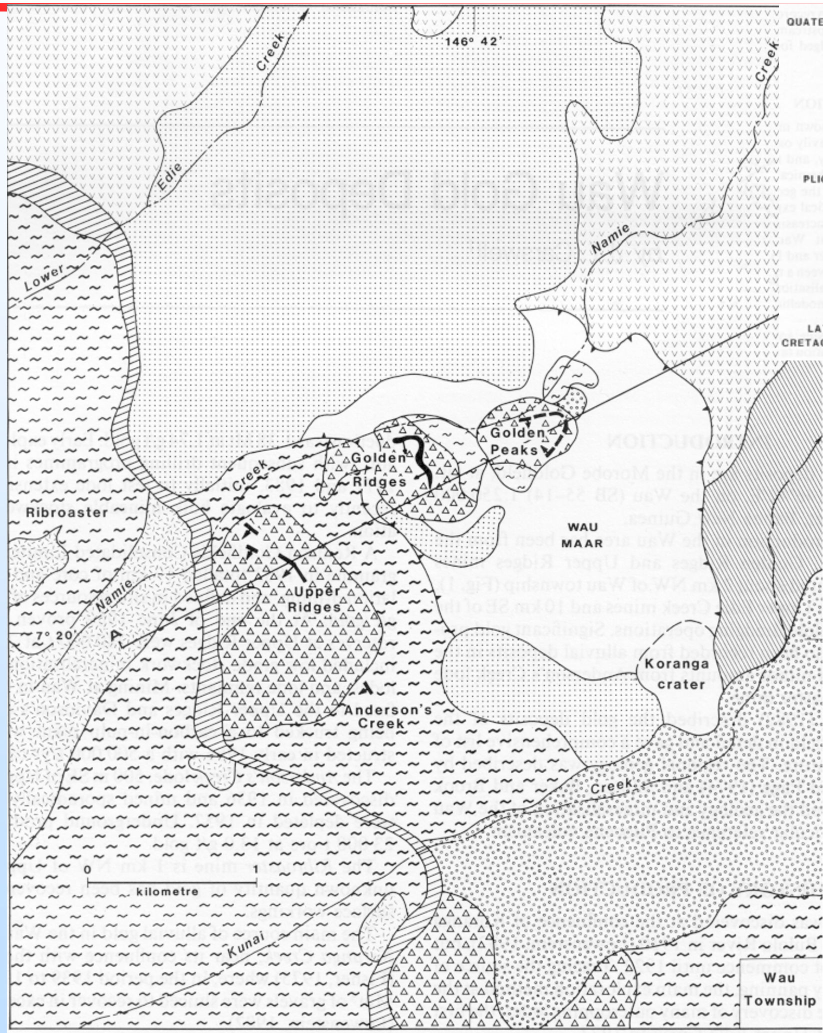
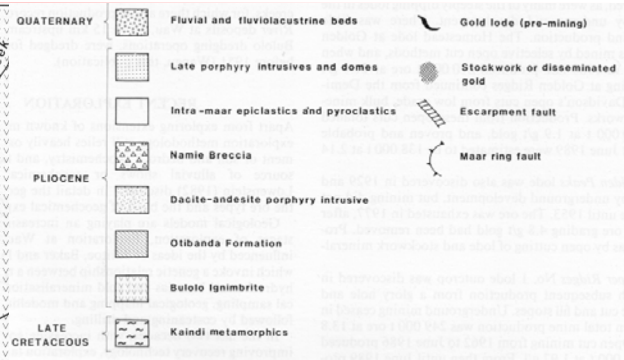
Fig. 2—Local geological map, Porgera deposit.

Grasberg, IJ



From Meinert et al., 2003



Carswell, 1990

Wau, PNG

Ishihara Granites Symposium July, 2003