TAG:
Thermal Aureole (pluton-related) Gold

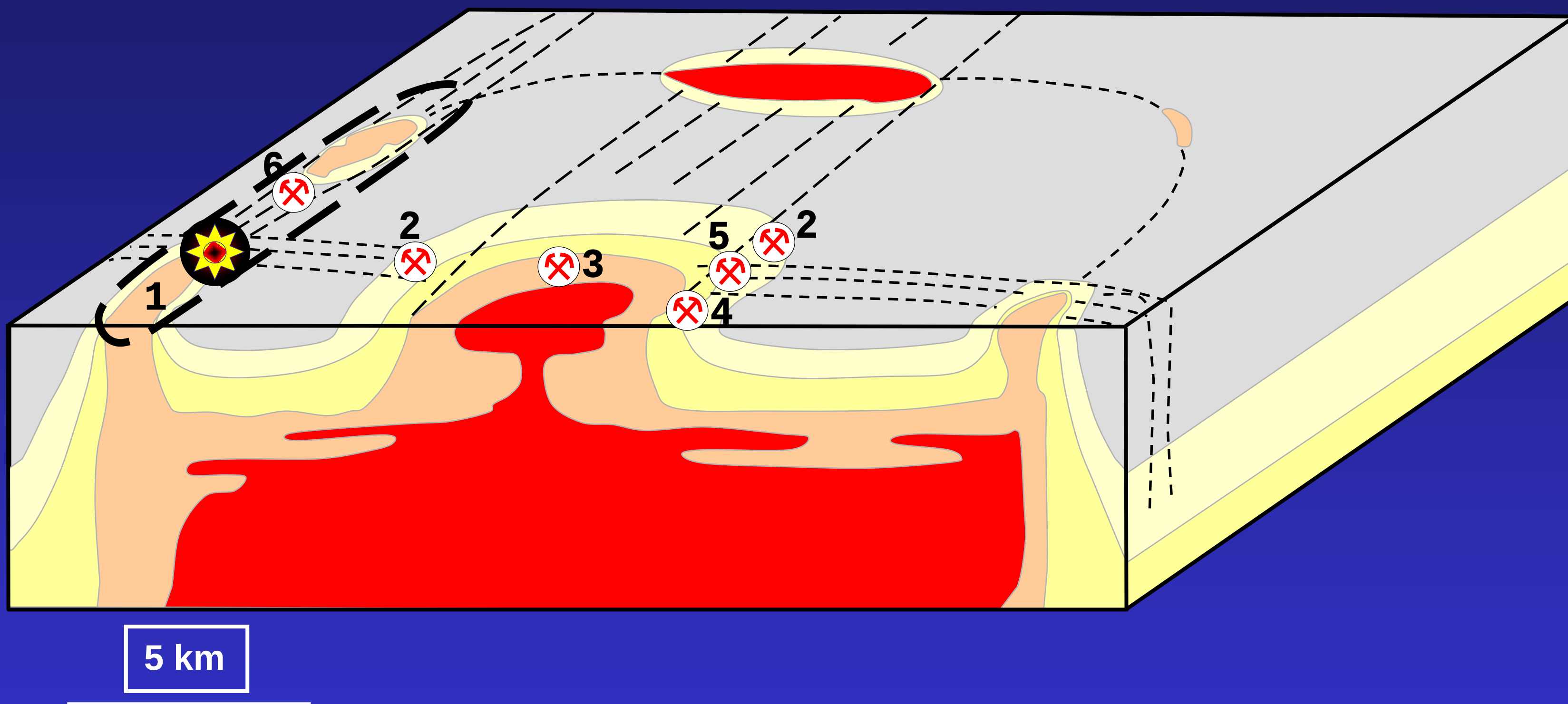
Vic Wall's Original Presentation
to CERCAMS Workshop
In Bishkek Kyrgzstan 2003
Presented to SMEDG on 24 June 2021

Greg Hall

TAG systems: nature & setting

- Pluton-related systems
  - spatially and temporally associated with emplacement and cooling of granitoid batholiths
    - mineralisation ages overlapping with those of nearby plutons
    - mineralisation overlaps emplacement of pluton-related, minor intrusions
- deposits hosted in
  - the thermal aureoles of and
  - tops of granitoid plutons

TAG (pluton-related) systems



- Granitoid pluton
- Thermal aureole
- Country rocks
- Key structural zones

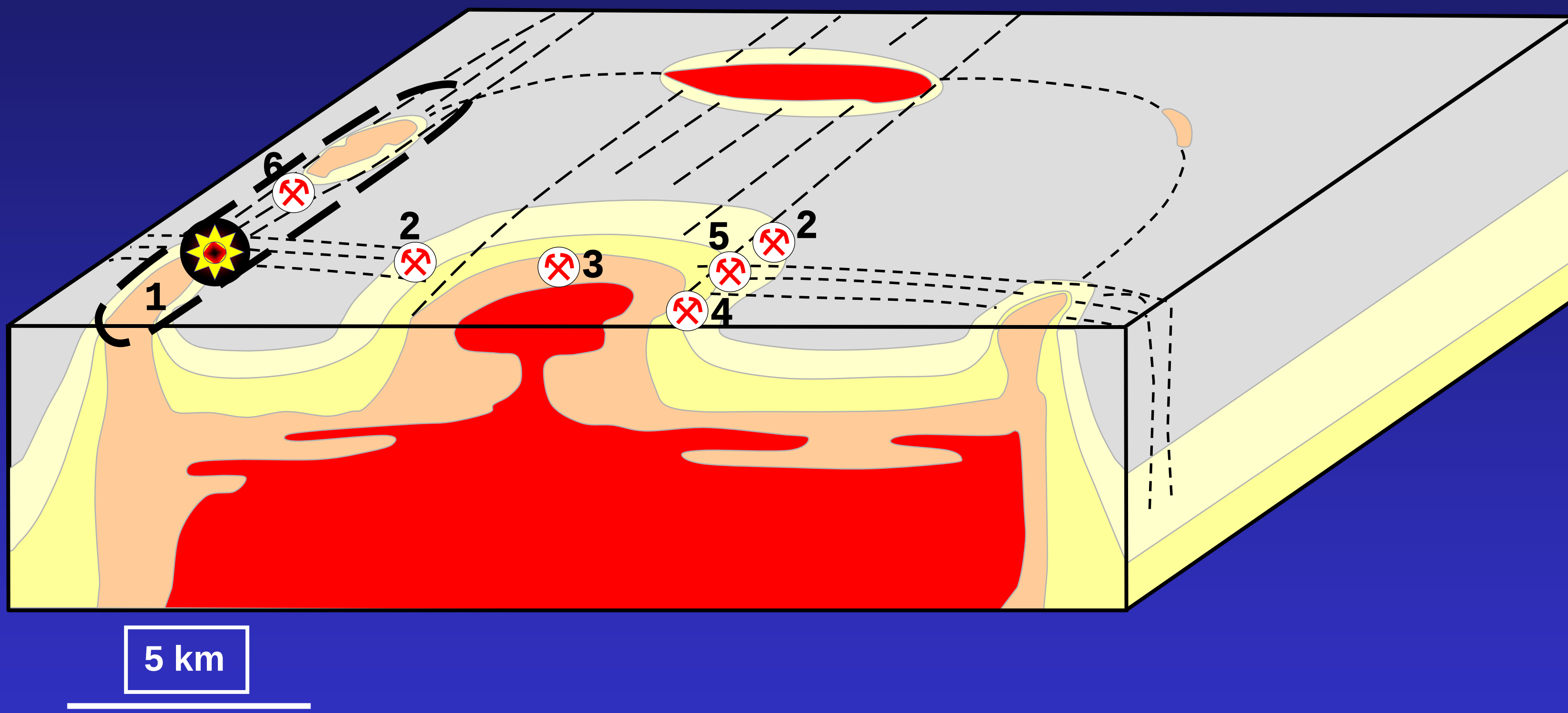
GOLD DEPOSIT SETTINGS

1 Fort Knox
2 Sukhoi Log, Kumtor
3 Pogo, Vasilkovskoye
4 Granites-Tanami
5 Muruntau
6 Obuasi, Telfer

TAG systems: nature & setting

- **deposits comprise vein networks and/or replacements in reactive rocks**
  - **associated with structures active during pluton emplacement & cooling**
- **range from high temperature (pluton proximal) to low temperature (pluton distal) parageneses**
  - **alteration and vein assemblages compatible with and formed contemporaneously with the pluton-related metamorphic grade of their hosts**

TAG (pluton-related) systems



Granitoid pluton

Thermal aureole

Country rocks

Key structural zones

GOLD DEPOSIT SETTINGS

1 Fort Knox
2 Sukhoi Log, Kumtor
3 Pogo, Vasilkovskoye
4 Granites-Tanami
5 Muruntau
6 Obuasi, Telfer

TAG systems: nature & setting

- distinct from other gold associations (eg. slate belt-, epithermal-, porphyry copper-gold, iron oxide Cu-Au,Carlin-, "orogenic", etc.)
  - geological setting
  - timing
  - but gradational to these associations
- many mesothermal "orogenic"gold deposits better referred to the TAG association
  - pluton-distal TAG deposits may be difficult to distinguish from and may overlap with "orogenic" gold deposits

The TAG association: Distribution

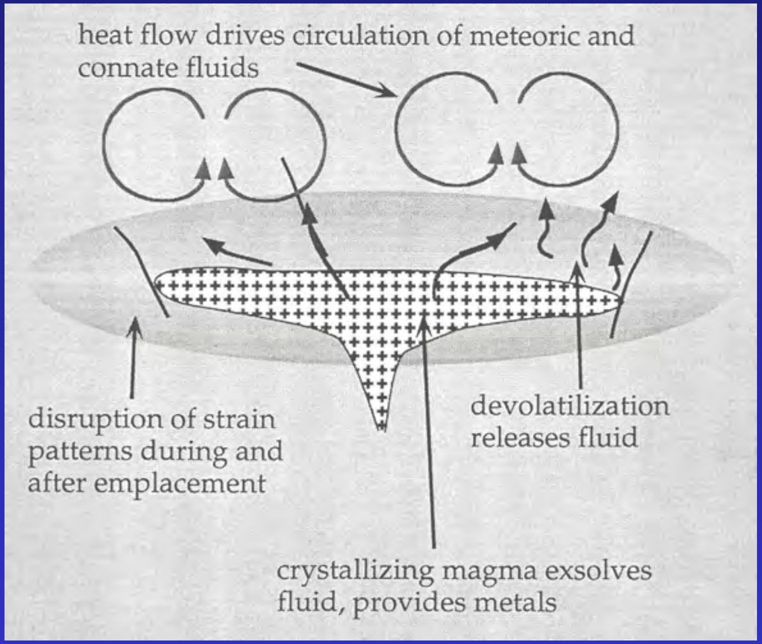
- Major, worldwide association
  - broadly distributed in time & space
    - Archaean to late Phanerozoic
    - Metasediment-dominated fold belts to granite-greenstone terrains
- Well represented in major goldbelts, e.g.
  - Australian & Canadian Archaean
  - South American Precambrian Shield
  - Birimian of West Africa
  - Australian Proterozoic belts
  - Central Asian & Russian Palaeozoic fold belts
  - Mesozoic belts in western North America, East Asia & Russia
- Comprises a significant proportion of world gold inventory and includes
  - several giant (>10Moz. Au), and numerous large deposits

TAG goldfields & deposits

Deposit	Location	Age	Host Rocks	Gold Content and Comments
Fort Knox	Alaska	Cretaceous	granitoids	>5.6Moz; pluton margin hosted
Pogo	Alaska	Cretaceous	gneisses	>5.7Moz @ 17.8g/t; pluton proximal
Muruntau	Uzbekistan	Permian	metasediments	>277Moz @ +3g/t medium-low T mineralization
Kumtor	Kyrgyzstan	Late Palaeozoic	metasediments	12.5Moz @ 3.6g/t; pluton distal
Vasilkovskoye	Kazakhstan	Early Palaeozoic	granitoids	13.3Moz @ 3g/t; pluton margin-hosted
Telfer	Australia	Late Proterozoic	metasediments	>31 Moz resource; pluton distal
Granites-Tanami	Australia	Early Proterozoic	metasediments	>12.9Moz,medium-high gold grades pluton proximal& distal
Obuasi	Ghana	Early Proterozoic	metasediments	>49Moz production + resources pluton distal
Morilla	Mali	Early Proterozoic	metasediments	> 7Moz., pluton proximal
Wallaby	Australia	Late Archaean	metasediments	>7.1Moz., pluton distal
Campbell-Red Lke	Canada	Late Archaean	mafics-ultramafics	>25Moz., pluton proximal

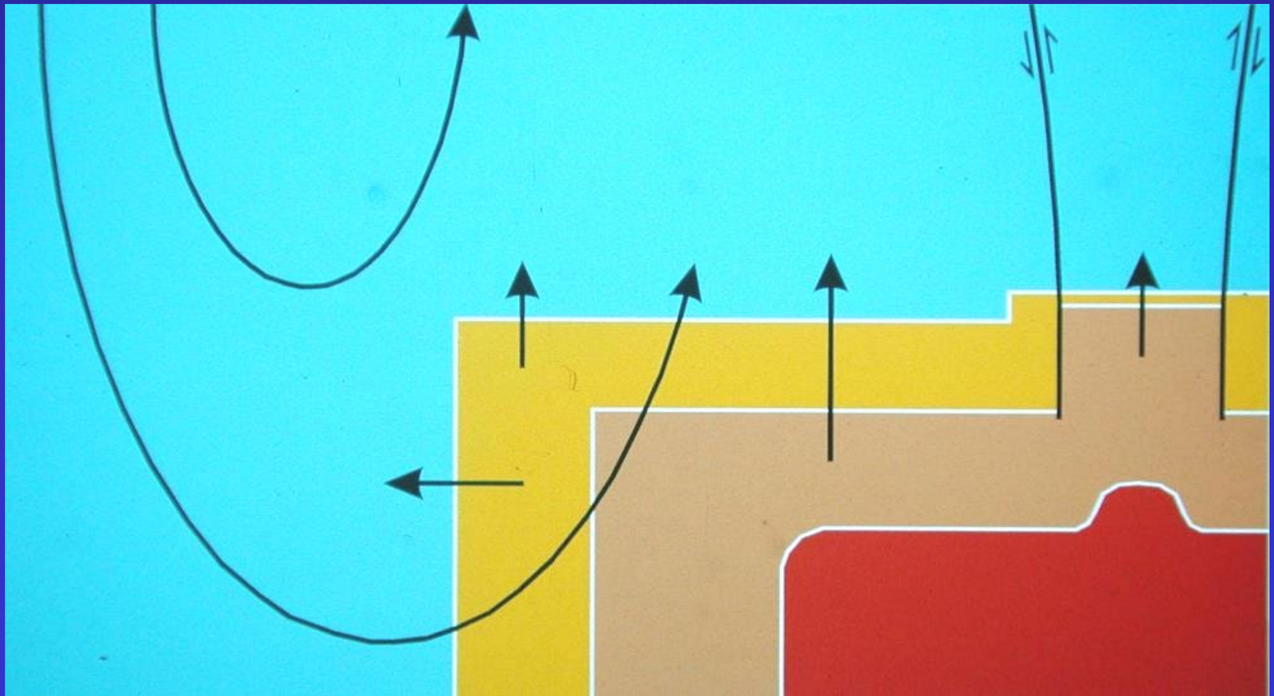
TAG: Why pluton environs?

- **Distinctive environment**
  - **rheological disruptions: pluton emplacement**
  - **heat engine: pluton**
  - **fluid sources & fluxes**
- **Plutons & thermal aureoles provide**
  - **metal & ligand sources**
    - **magmatic hydrothermal fluid, metamorphic devolatilisation, circulated meteoric fluids**
  - **driving forces for fluid migration**
    - **heat, fluid overpressuring, dilatancy**
  - **active structures to focus fluid flow**
    - **disruption of strain patterns, during & after pluton emplacement**
  - **a range of thermal, mechanical & chemical environs to effect ore deposition**



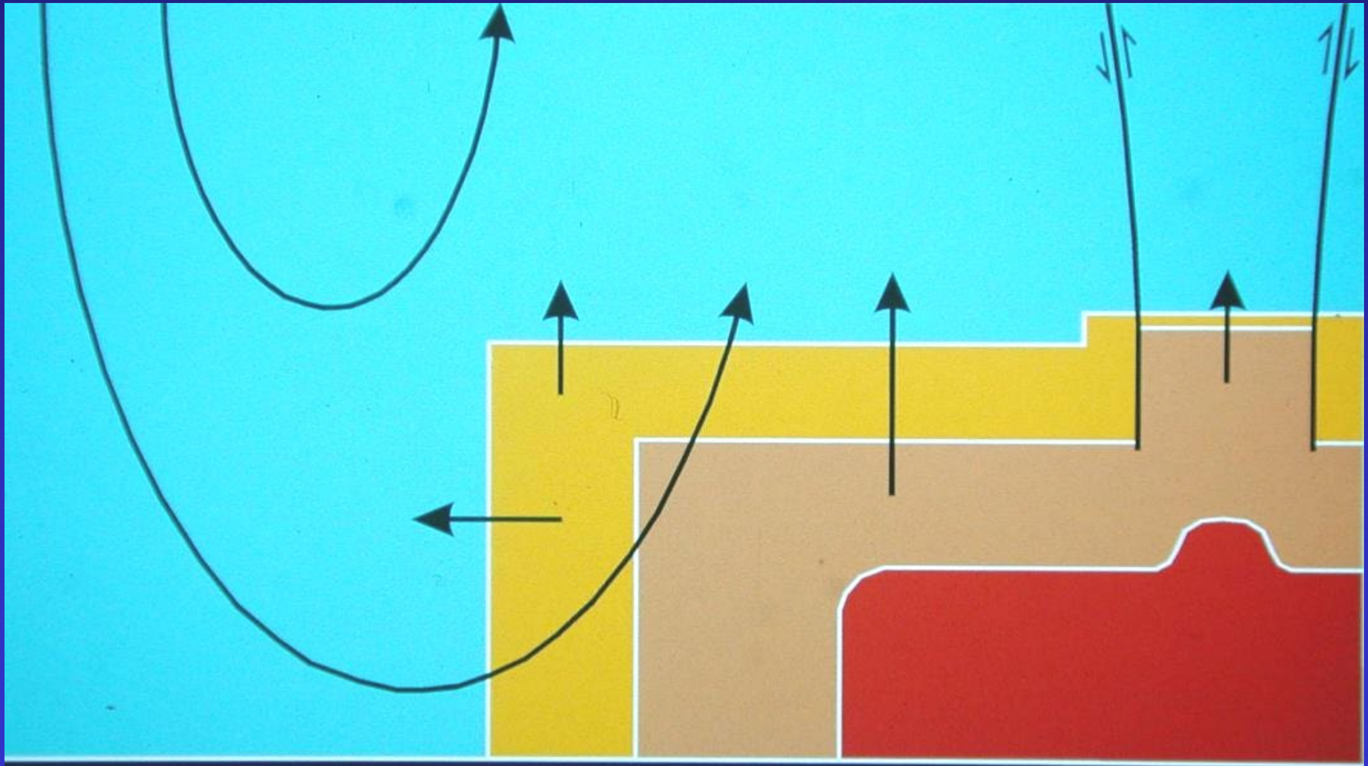
TAG: Why pluton environs?

- width and thermal history of thermal aureole
  - depends mainly on ambient (pre-emplacement) country rock temperatures
    - broad aureoles (>1Km): depths > 5kms.
- sill/laccolithic/lopolithic pluton shape
  - fluid loss mainly through roof zone
- pluton roof zones & pluton tops
  - host the most numerous & the biggest deposits
  - how do we recognise pluton roof zones?



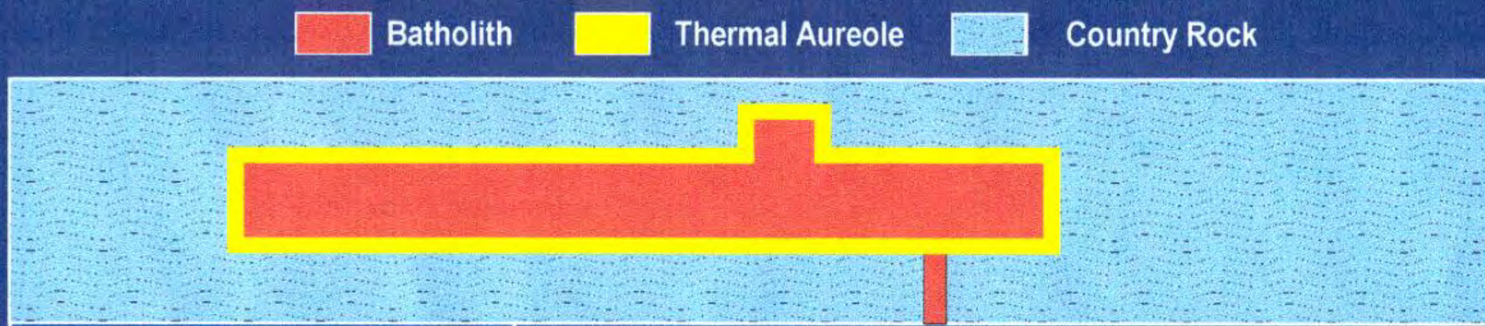
TAG: Pluton-related fluids

- **Hydrous granitoid magmas liberate high temperature (>700ºC) aqueous fluids during crystallisation**
  - **plutons cool & crystallise inwards**
    - **crystallised pluton tops & inner thermal aureoles, infiltrated by fluids >500ºC**



A range of possible fluid migration patterns established during granitoid emplacement and thermal metamorphism

Pluton roles



Tabular Batholith

50km long
20km wide
5km thick

Sill-like form

Roof-lifting emplacement

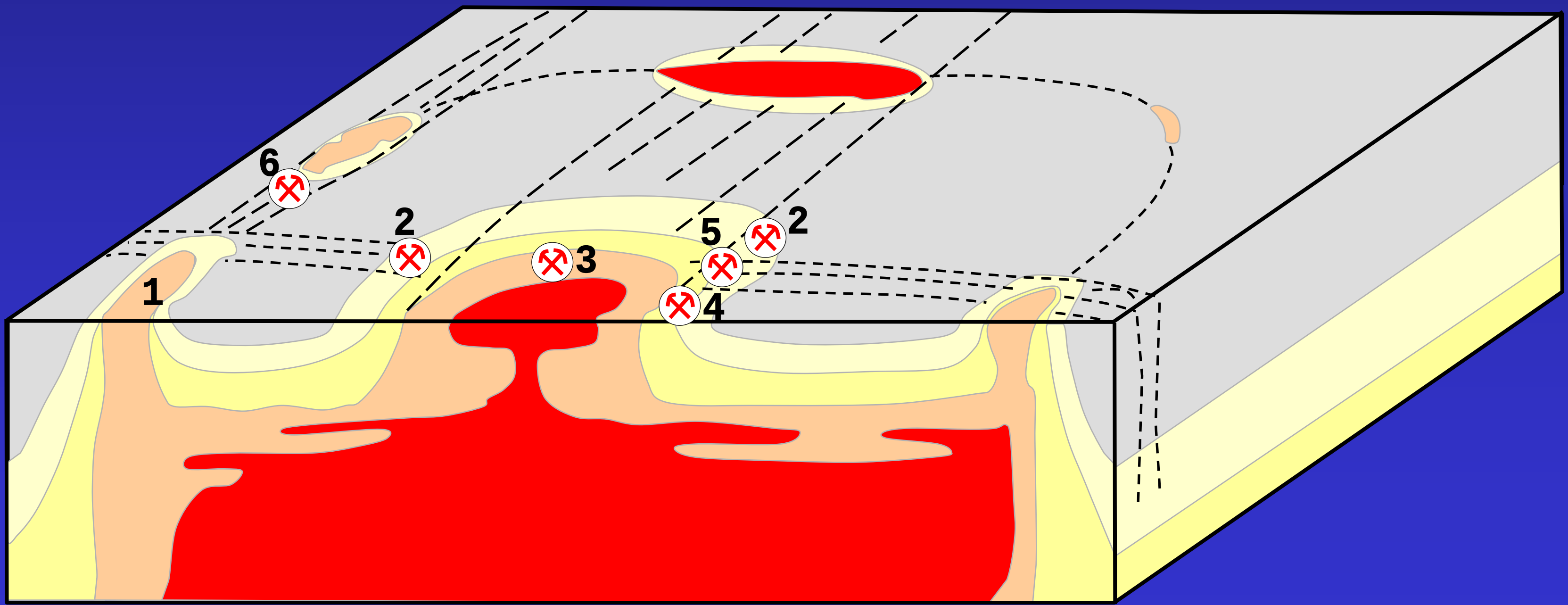
Pluton 20km diameter, 5km thick

Fluid	Volume (cu.km)	Gold mobilised (tonnes)
Devolatilisation	30 - 70	300 - 700
Hydrothermal-Magmatic	100 - 240	1000 - 10000
Free-convecting (meteoric)	Large (?)	?

Typical dimensions of a large, discordant batholith, based on both geological and geophysical data. Lower right box shows conservative estimates of the average volumes of fluid generated from within and around a 20km diameter, 5km thick pluton, and the mass of gold mobilised (10-50ppb in fluid).

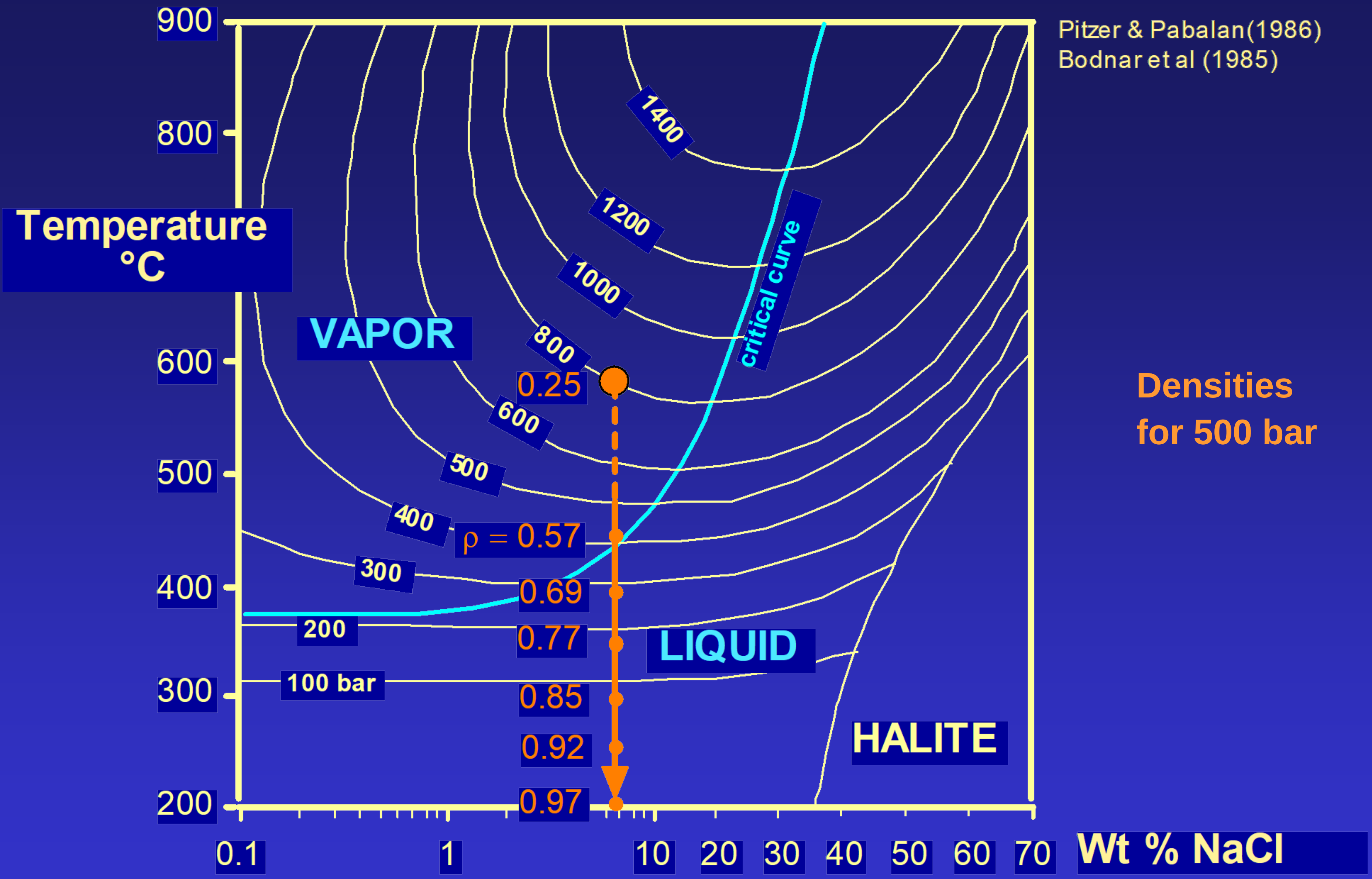
TAG: Why pluton environs?

- **Simple mass balance example:**
  - **single, typical granitoid pluton + thermal aureole**
    - **enough fluid & gold mobilised to make giant gold deposit**
    - **effective fluid focussing for big gold deposit**



TAG: Pluton-related fluids

- **For fluid exsolution at >5-6kms depth, magmatic hydrothermal fluids may be**
  - **supercritical,**
  - **weakly to moderately saline,**
  - **but contain high H_2S and/or SO_2 (and CO_2)**

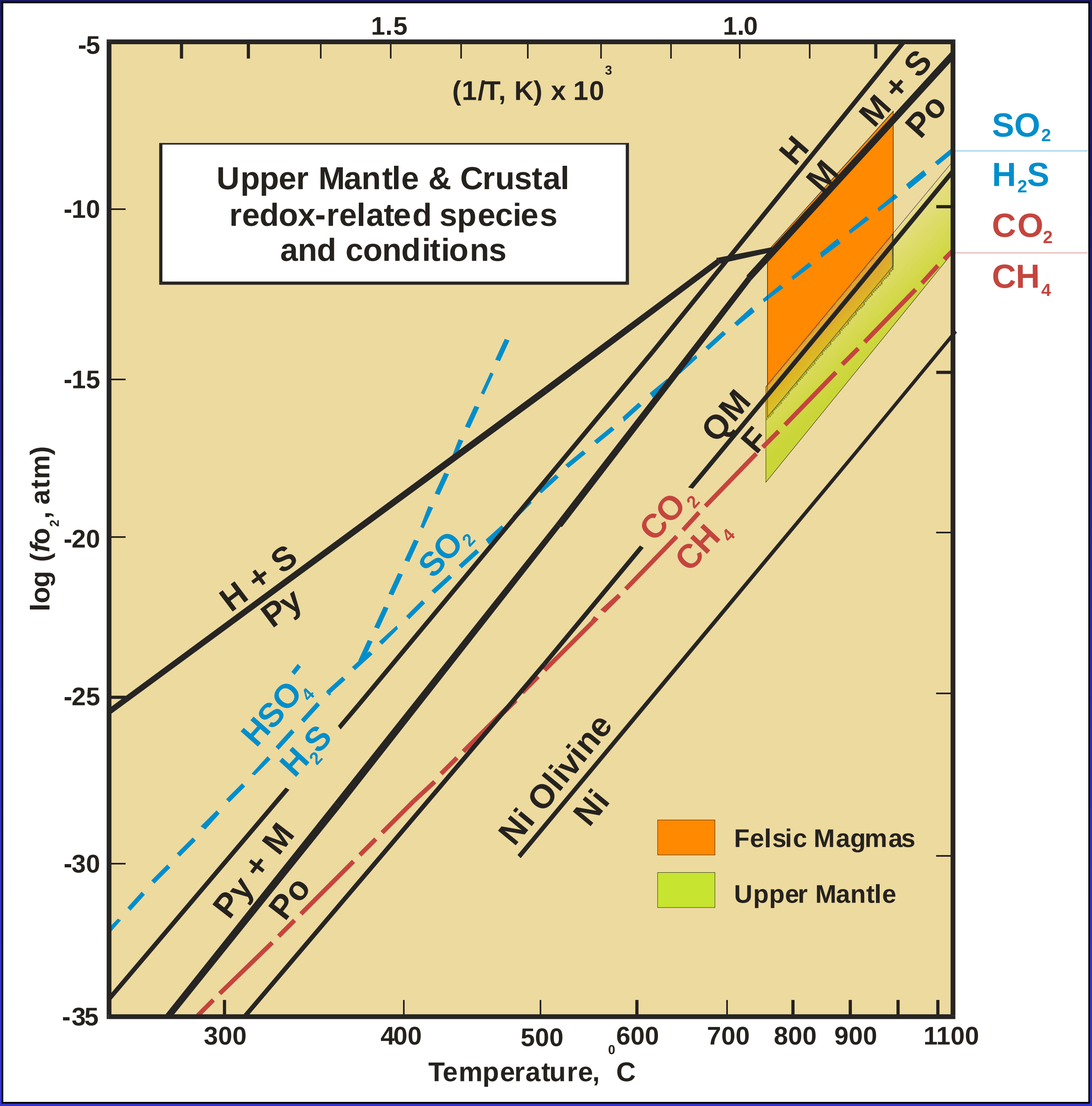


Vapor cools/condenses to aqueous fliud

C. Heinrich

C-O-H-S fluid sources & conditions

Wall, V.J. and Mason, D. "Black & gold: carbon, fluid mixing & auriferous hydrothermal systems." 2001 an Hydrothermal Odyssey. Townsvile



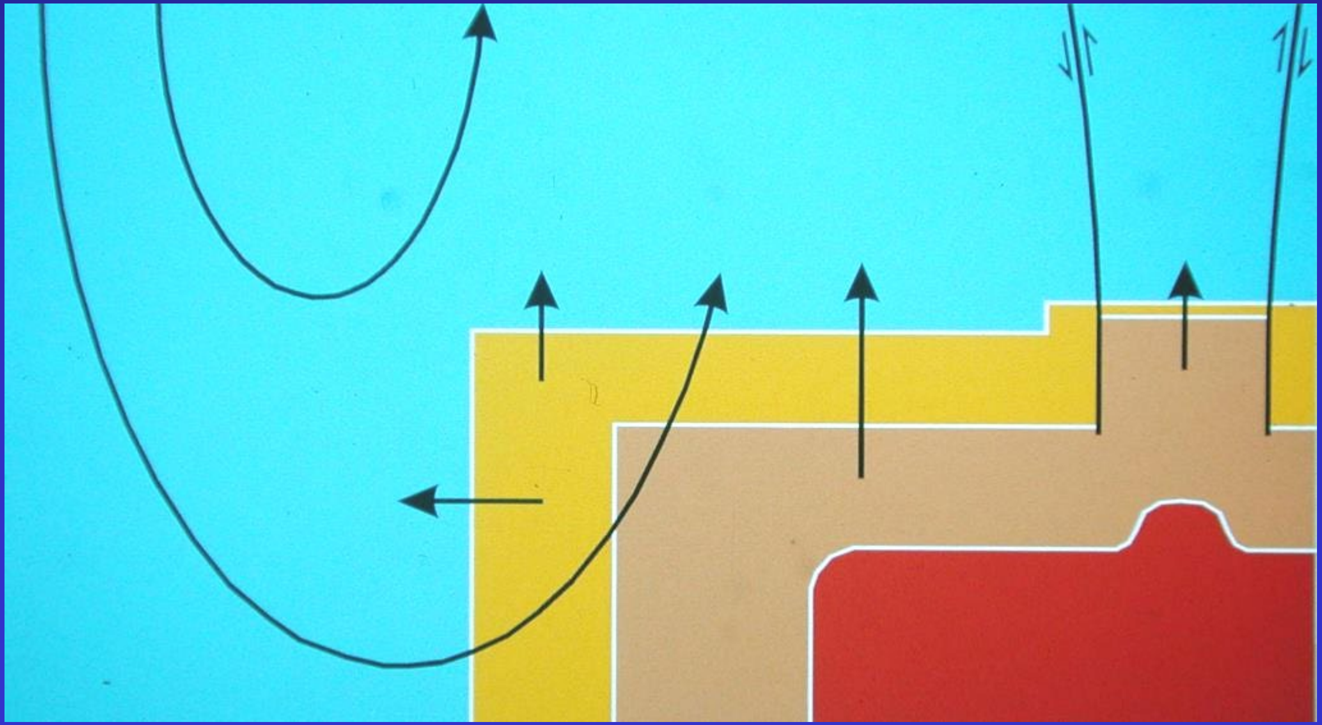
Taylor Wall & Associates
Mason Geoscience

TAG: Pluton-related fluids

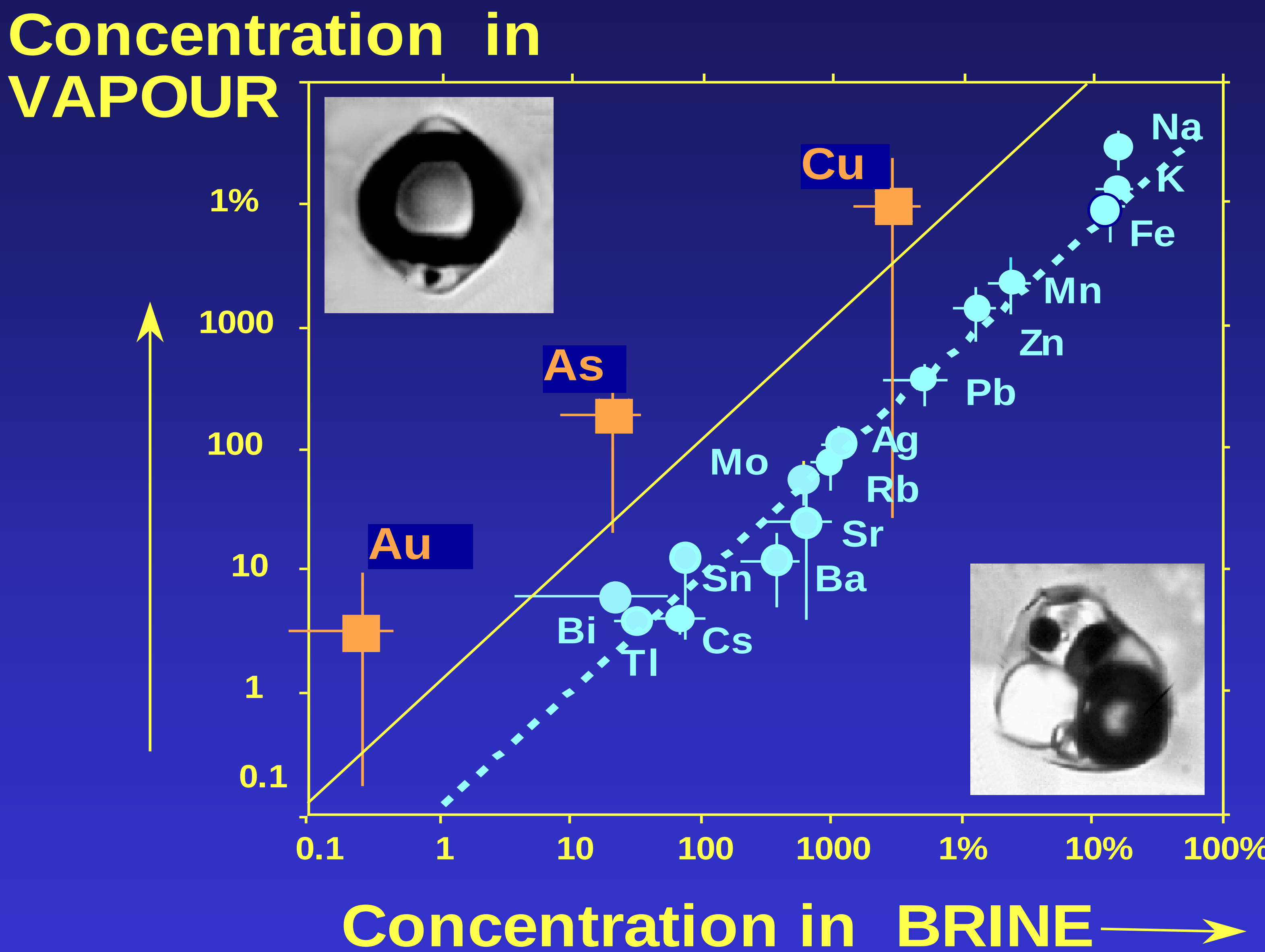
- Magmatic hydrothermal fluids may be
  - sulphur (H_2S and/or SO_2) rich, particularly from sulphide/sulphide melt saturated magmas
  - H_2S dominated to H_2S~SO_2 depending on
    - magmatic temperatures & redox conditions
- TAG systems typically associated with
  - relatively high temperature, late-orogenic granitoid plutonism
  - reduced I-type (ilmenite series) plutons
    - but also with magnetite series I-types,
      late magmatic arc and peraluminous plutons
    - cf porphyry- and iron oxide –copper-gold systems

TAG: Pluton-related fluids

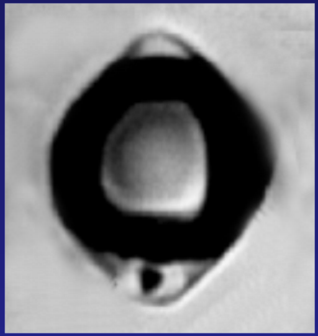
- Partitioning of gold between melt & hydrothermal fluid, poorly understood, but strongly favours aqueous fluid
  - a function of P,T of fluid separation; chlorinity & redox conditions, sulphur content of magma



Grasberg fluid inclusion chemistry



C. Heinrich ETH



- **Very Au (–As–Cu) rich vapor can coexist with porphyry brine:**

Grasberg	**2.9 % Na**	**1.3 % K**
	1.0 % Fe	**1.2 % Cu**
	200ppm As	**10 ppm Au**

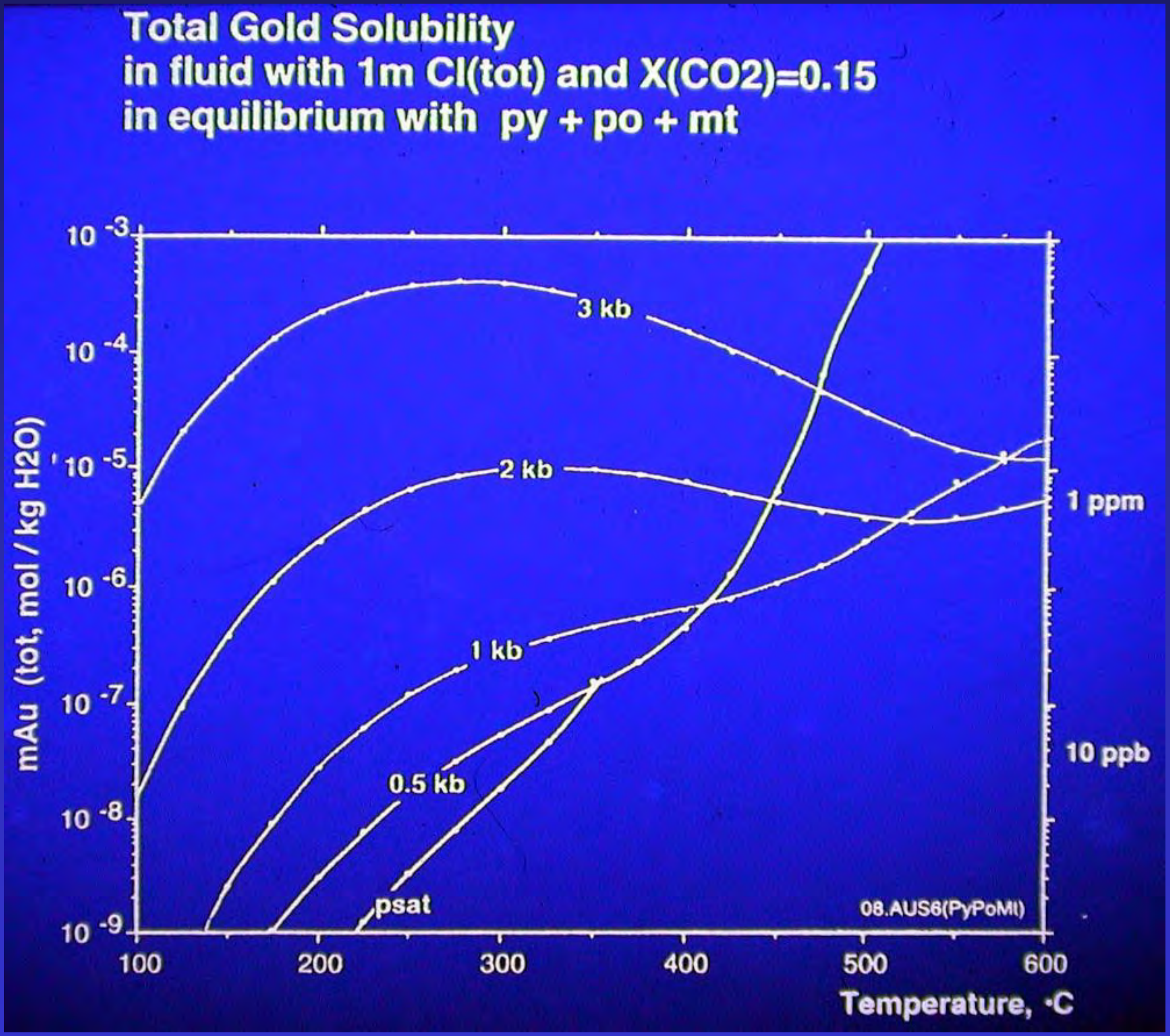
- **Oxidised (SO_2 ~ H_2S); S-rich; S_{tot} >metal**

- **A model for low-moderate salinity, supercritical aqueous magmatic hydrothermal fluids, separated from plutonic felsic magma chambers?**

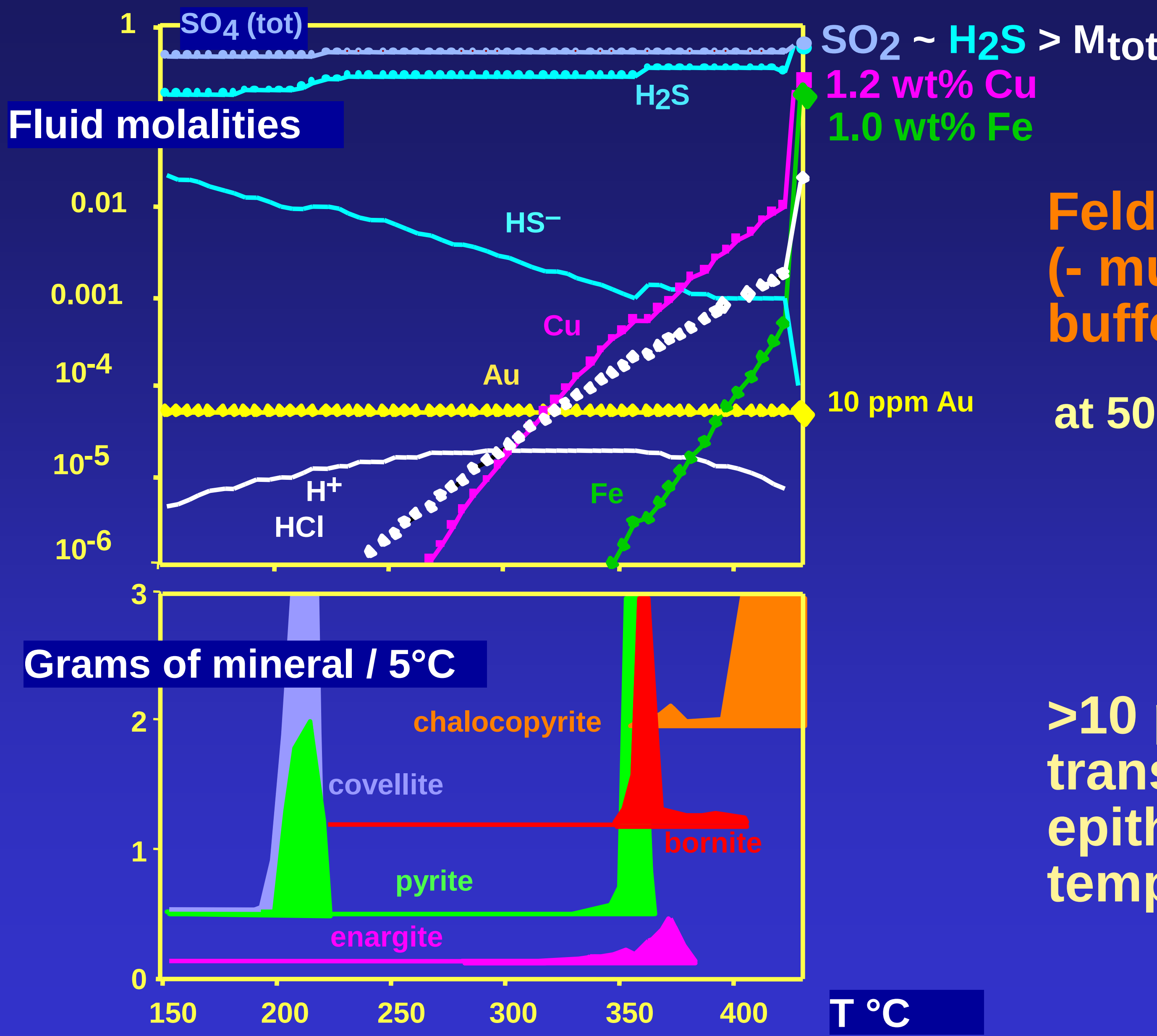
TAG: Pluton-related fluids

- **High temperature (particularly magmatic hydrothermal) fluids may be gold rich**
  - **capacity to form high-grade Au deposits**
- **Gold solubilities, as chloride- and/or thio- complexes, very high (ppm. range) at moderate to high temperatures and appropriate redox conditions**
  - **such fluids capable of transporting high gold concentrations to lower temperature, pluton distal environments**

Hydrothermal transport of gold



Thermodynamic modelling: evolution of a Grasberg vapor



Feldspar - (- muscovite) buffered cooling

at 500 bar

>10 ppm Gold transported to epithermal temperatures

C. Heinrich ETH

Gold precipitation: chemical mechanisms

GOLD-PRECIPITATION: CHEMICAL MECHANISMS

- depend on dominant ligand
- control site and grade of ore deposit

3 main groups of processes

1. Reduction of Au^+
   - Works for all complexing ligands
   - Reduced carbon (graphite, methane, oil....)

   Example Cosmo Howley: HT aureole
   Porgera high-grade Zone 7
   Carlin deposits ?

2. Removal of ligand
   - Oxidation of HS^- to SO_4

   Example VMS-deposits
   Acid sulfate epithermals

   . Sulphide precipitation

   - Sulfidation of Fe-rich wall rocks —> De-complexation of gold

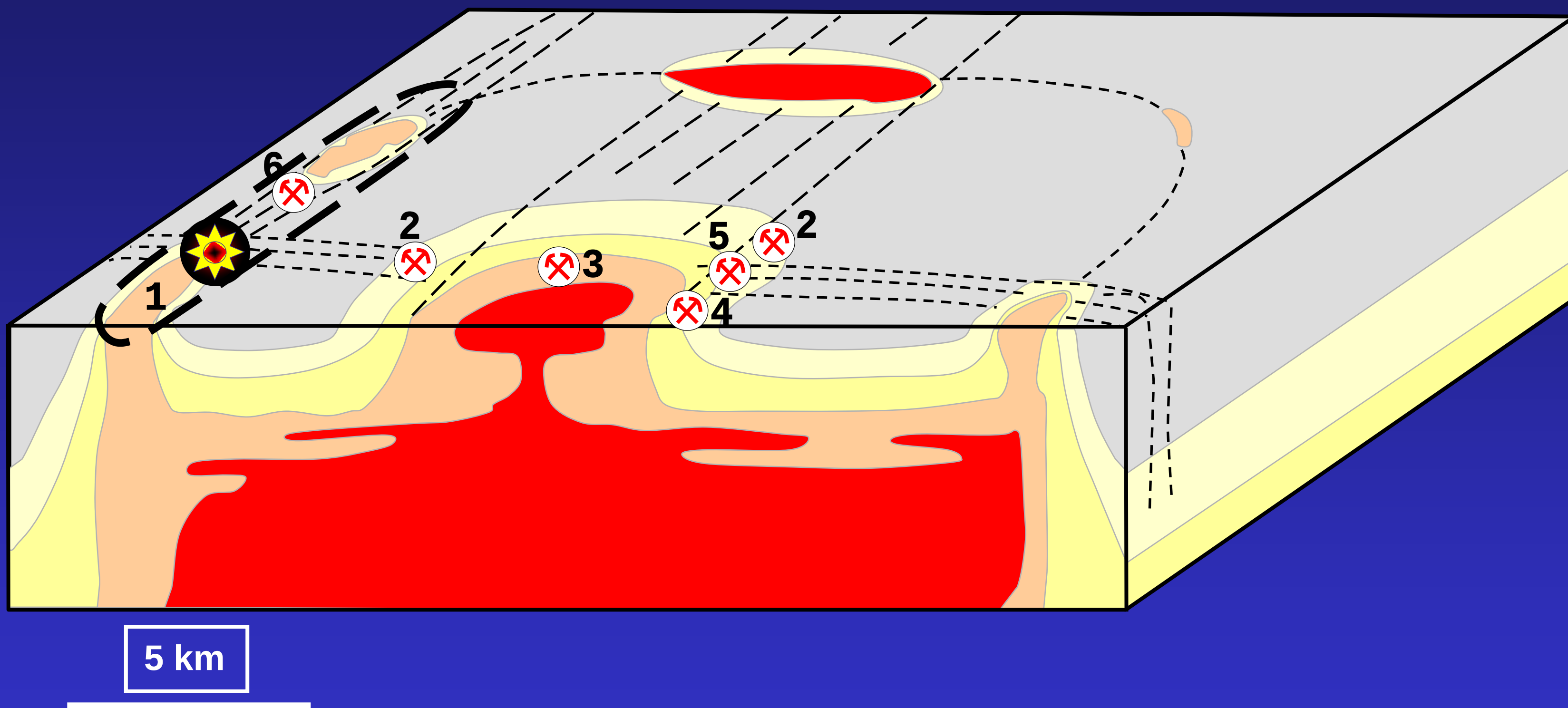
   Example Archaean Greenstone Belts
   Mt. Charlotte

   - Vapour separation at T < 400°C

   Example Adular-sericite epithermals,
   — really ??
   Topia Ag-veins, Mexico

3. Pressure-Temperature changes
   - Cooling in contact with rocks *does* drop gold solubility ...
   - ... but maybe doesn't make ore !

TAG (pluton-related) systems



Granitoid pluton

Thermal aureole

Country rocks

Key structural zones

GOLD DEPOSIT SETTINGS

1 Fort Knox

2 Sukhoi Log, Kumtor

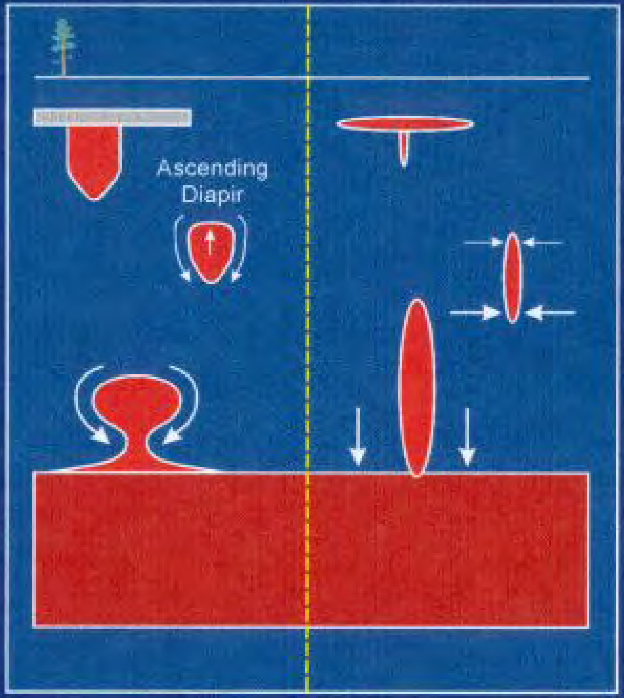
3 Pogo, Vasilkovskoye

4 Granites-Tanami

5 Muruntau

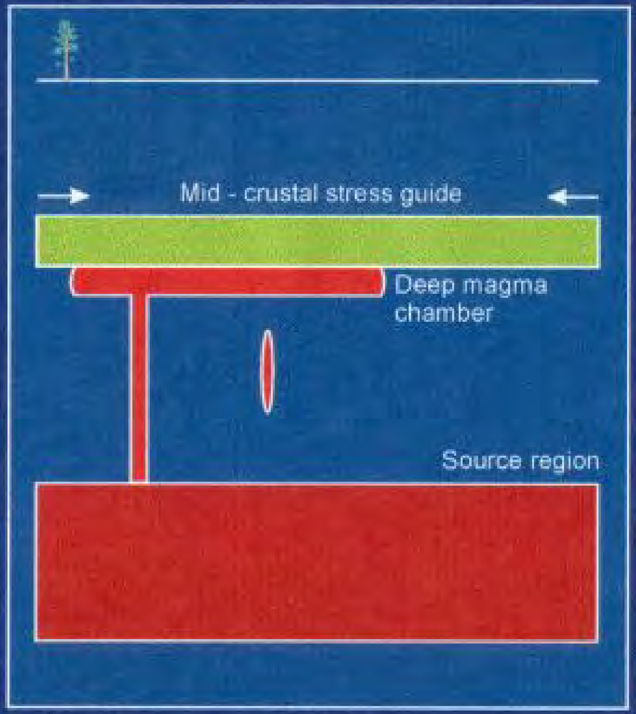
6 Obuasi, Telfer

Pluton roles: emplacement



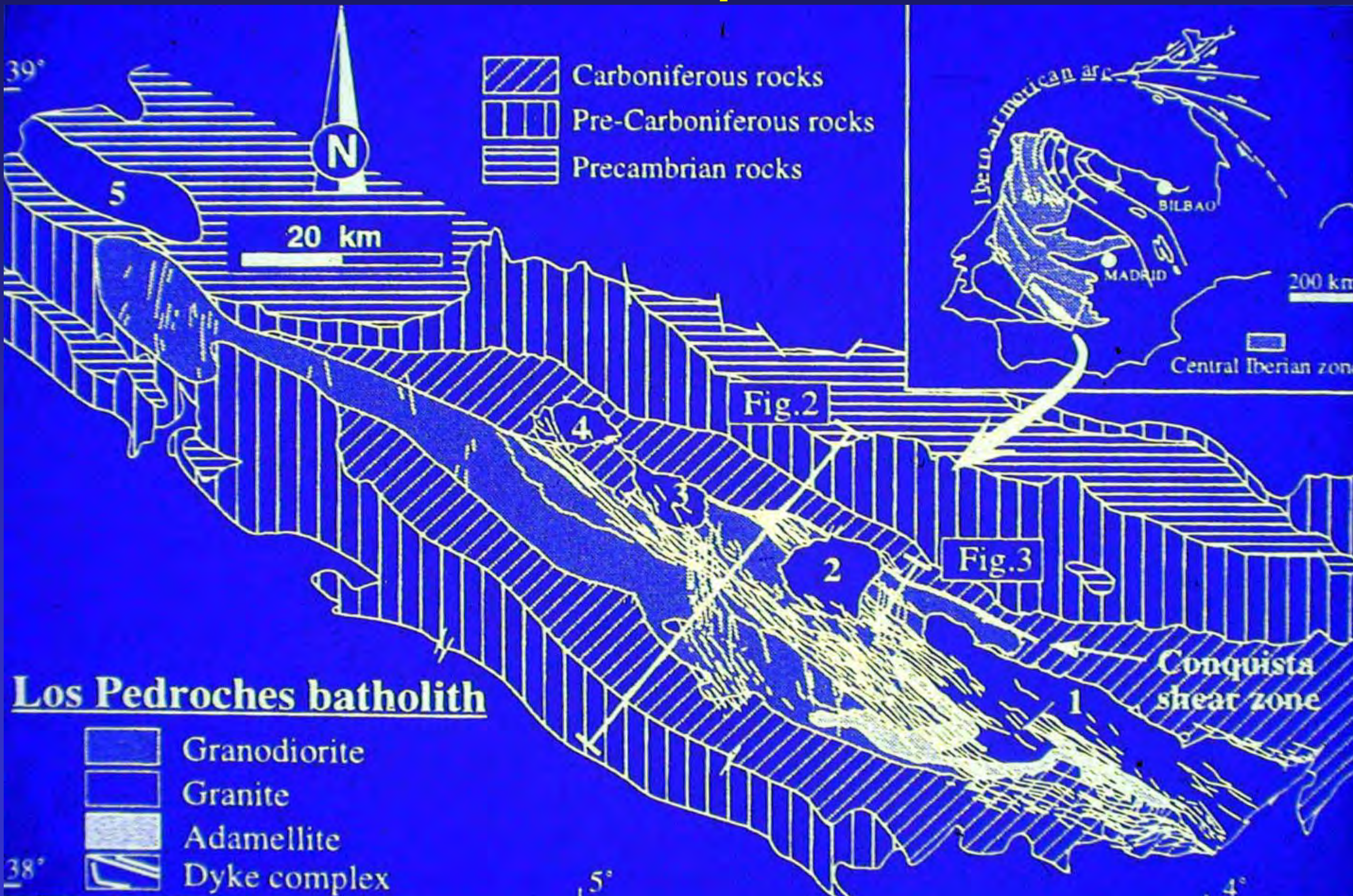
Cartoon contrasting the features of diapiric extraction and ascent of granite magmas with the model suggested in this paper. In the latter, efficient melt extraction processes operate in the magma's source region and magma subsequently migrates as Pollard (1973) -style bodies, driven by buoyancy. These intrusions may propagate by extension fracturing, brittle and ductile faulting.

Pluton roles: emplacement

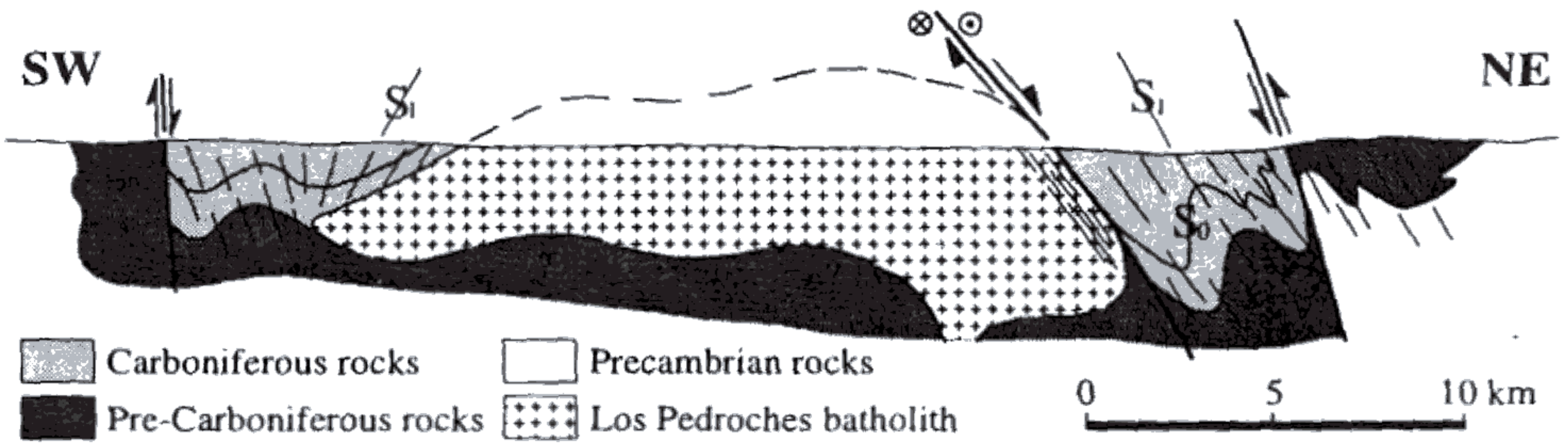


Cartoon showing a model for the formation of mid-crustal magma chambers. In this model the magma ascends as a Pollard (1973) -style intrusion until it encounters a regional stress-guide in the mid-crustal region. The region of higher stress prevents steeply-oriented extension fracturing and the intrusion forms a sill-like body, perpendicular to the steeply-oriented δ_3 minimum compressive stress. Subsequent stress relaxation may lead to the magmas ability to ascend to higher crustal levels.

Pluton roles: emplacement

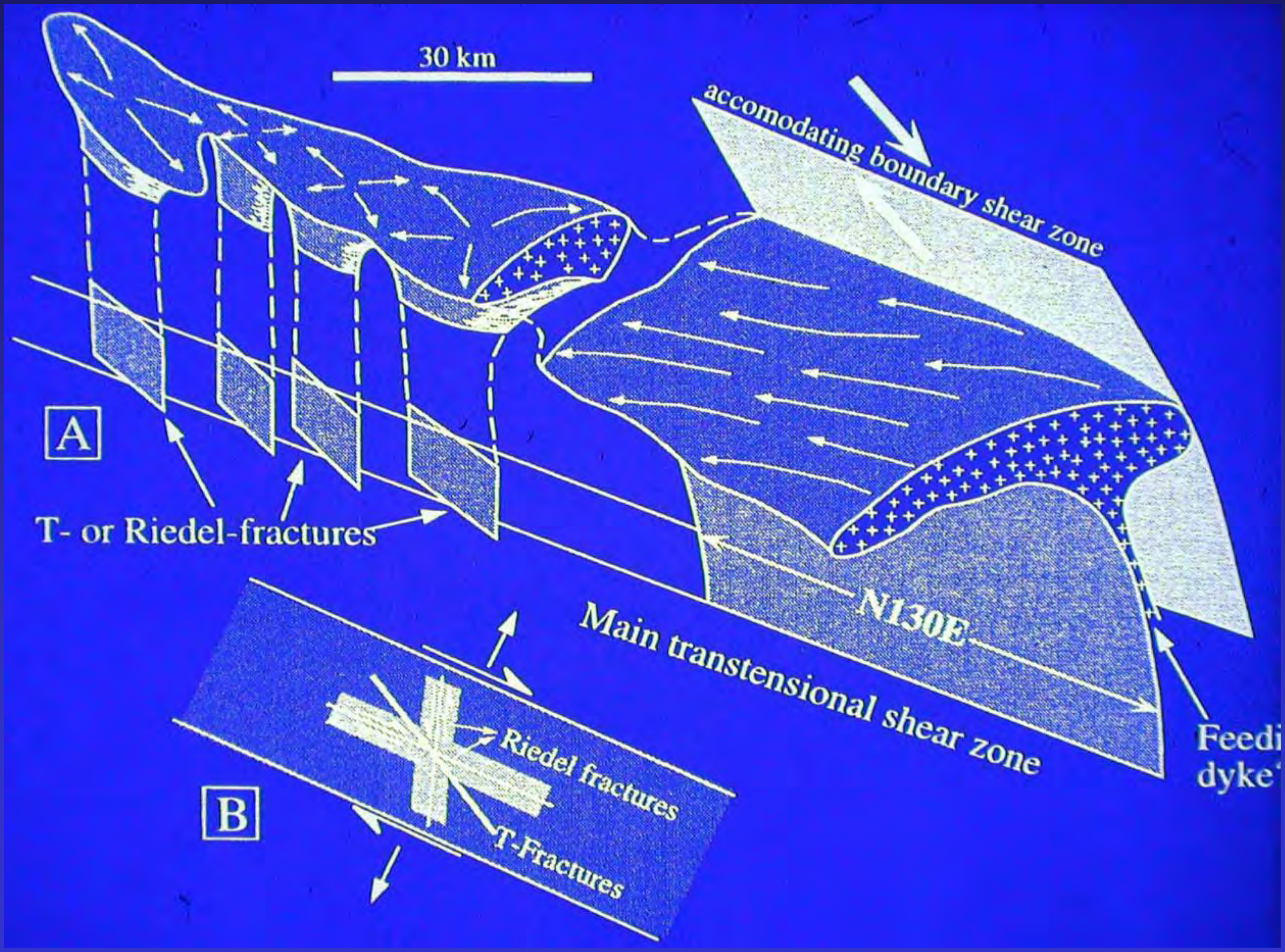


Pluton roles: emplacement

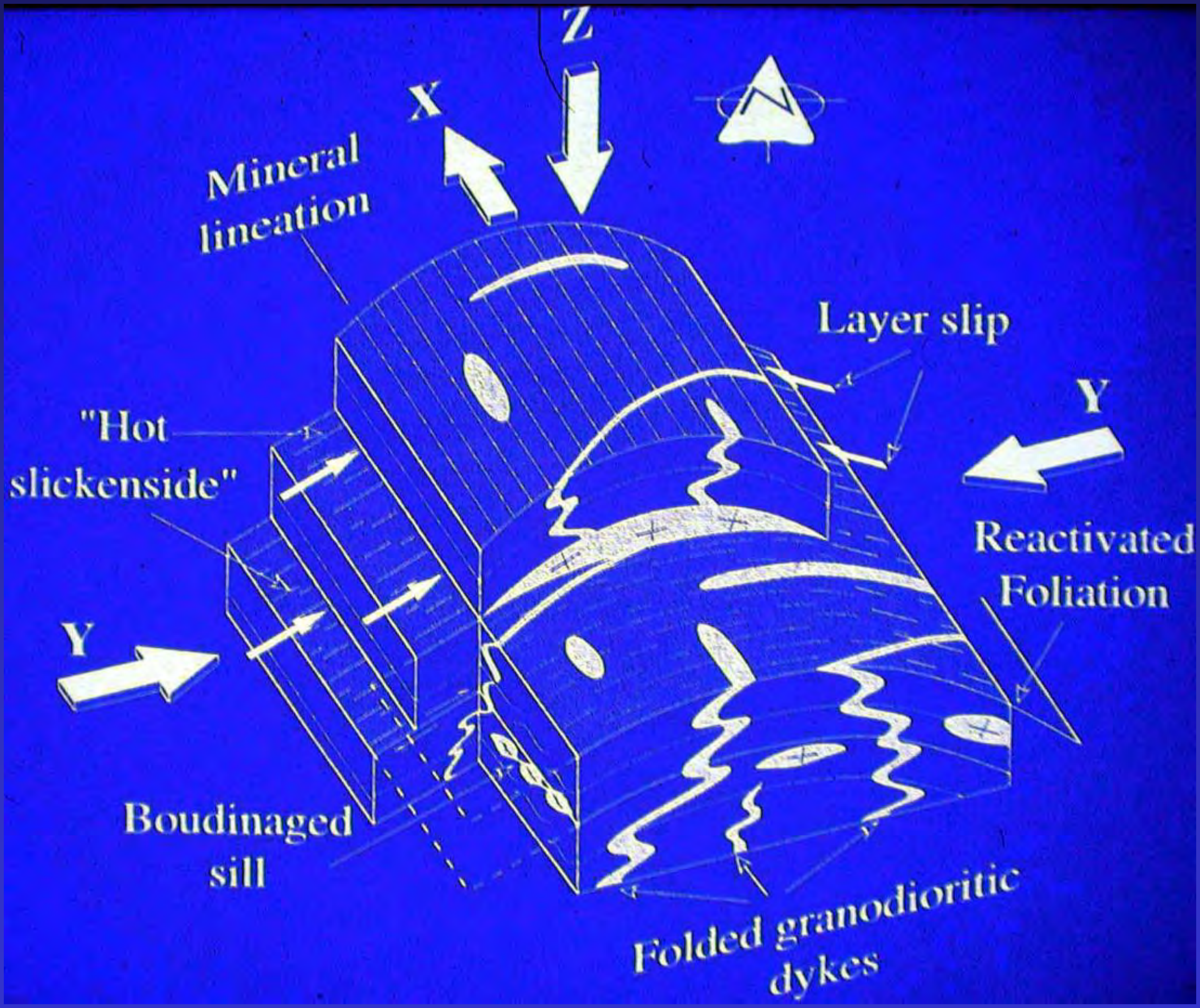


.- Schematic cross-section through the Los Pedroches batholith, showing the S_0-S_1 relationships in the country rocks. Note that the sSouthern contact is concordant with S_0 whereas the northern contact coincides with a north-dipping shear zone (see Fig. 1 for the location).

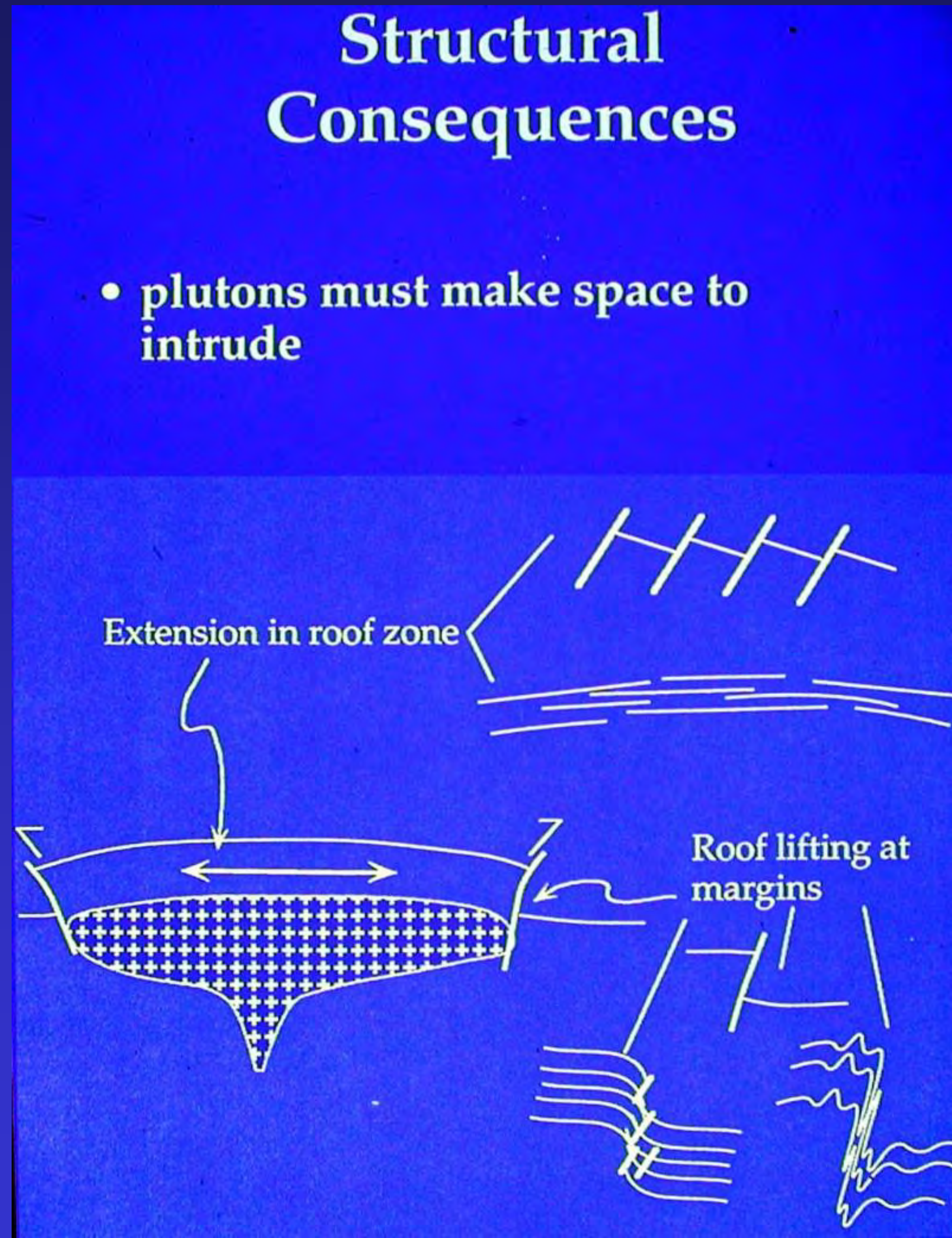
Pluton roles: emplacement



Pluton roles: emplacement

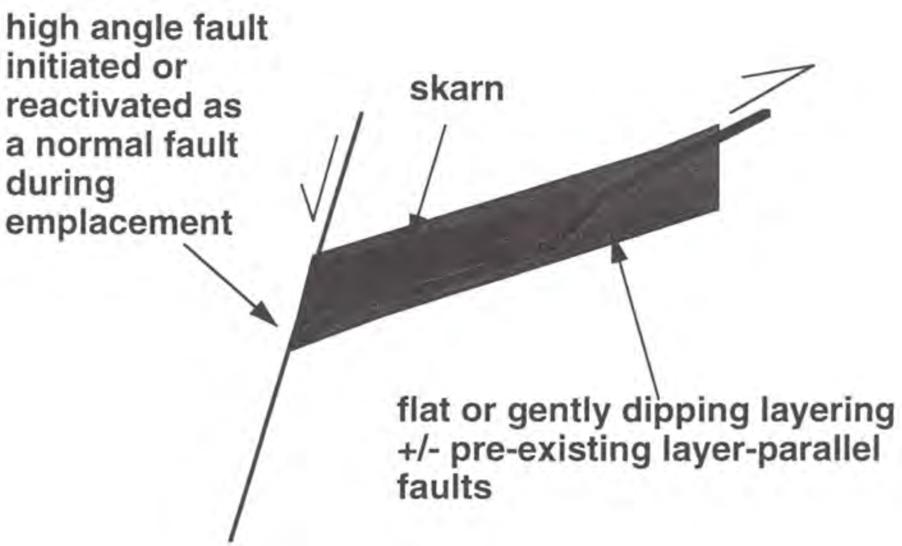


Pluton roles: emplacement & accommodation



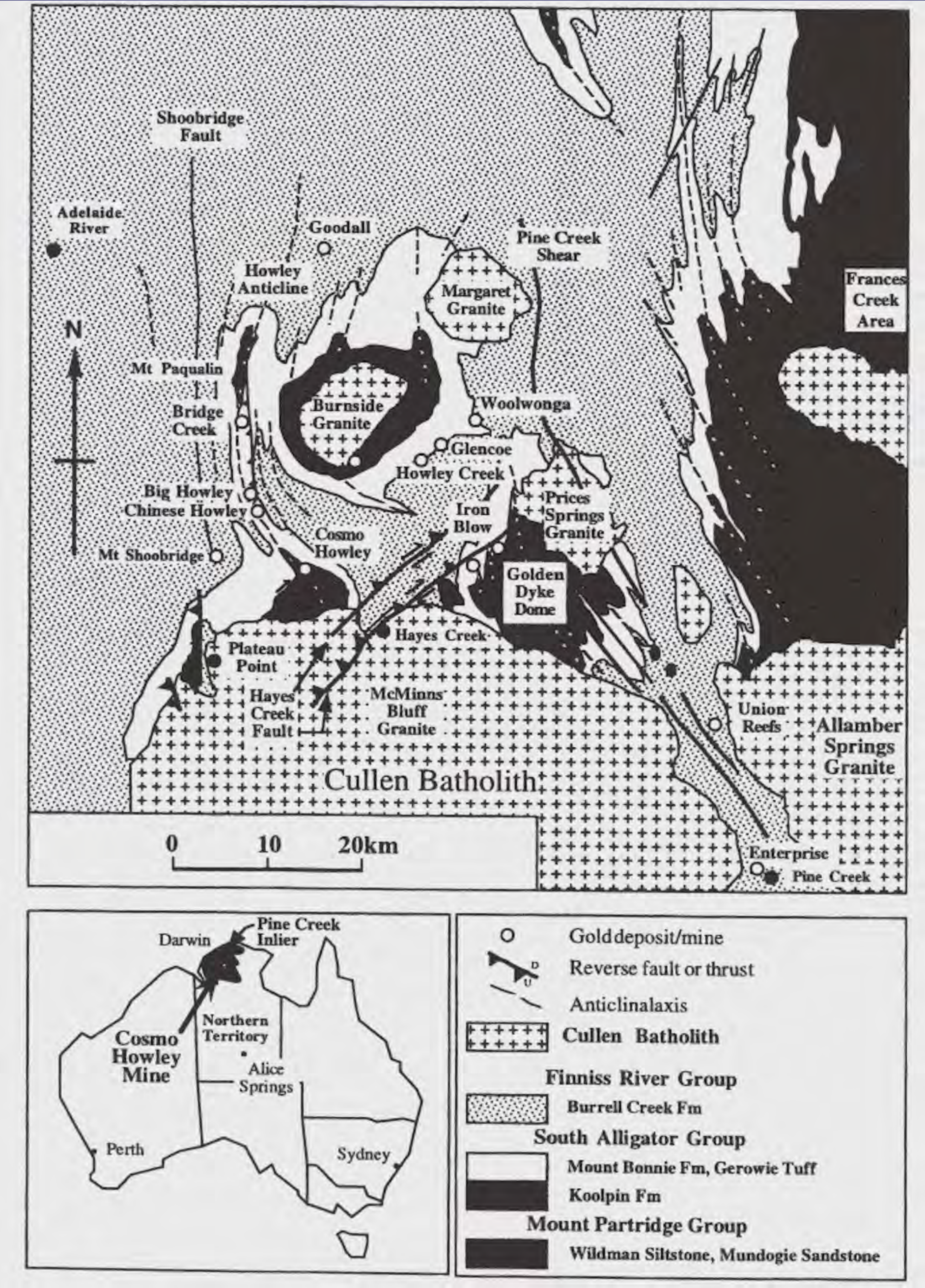
Pluton emplacement-related deformation

Pluton roof mineralization



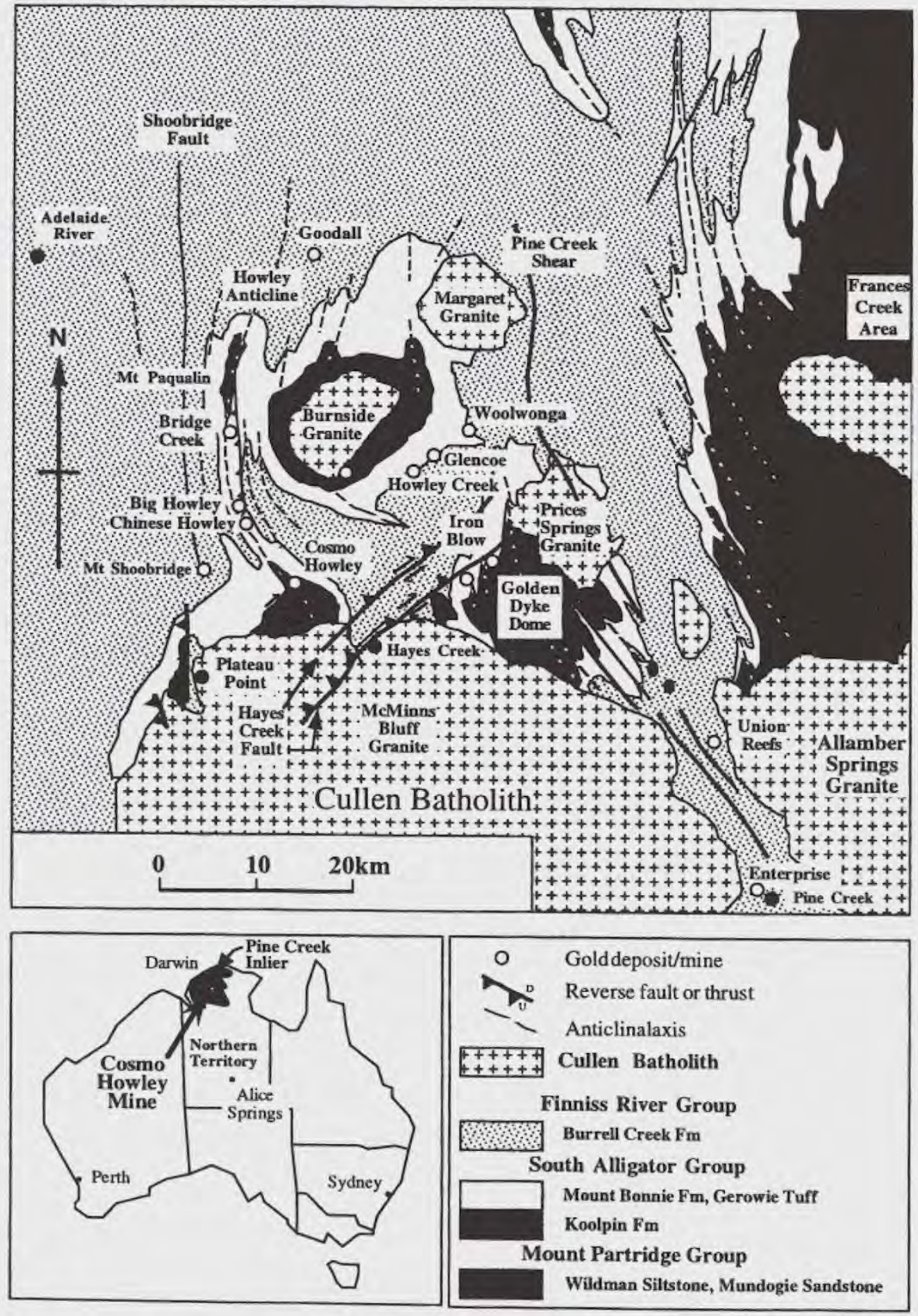
- Controls
  - host rocks (often calcareous)
  - high angle normal fault tapping magmatic fluids related to extension across laccolith
  - layer-parallel or layer-controlled permeability
  - fluids may also exploit this geometry after a return to regional boundary conditions

Pine Creek: geology



Pine Creek: plutons, structures & magnetics

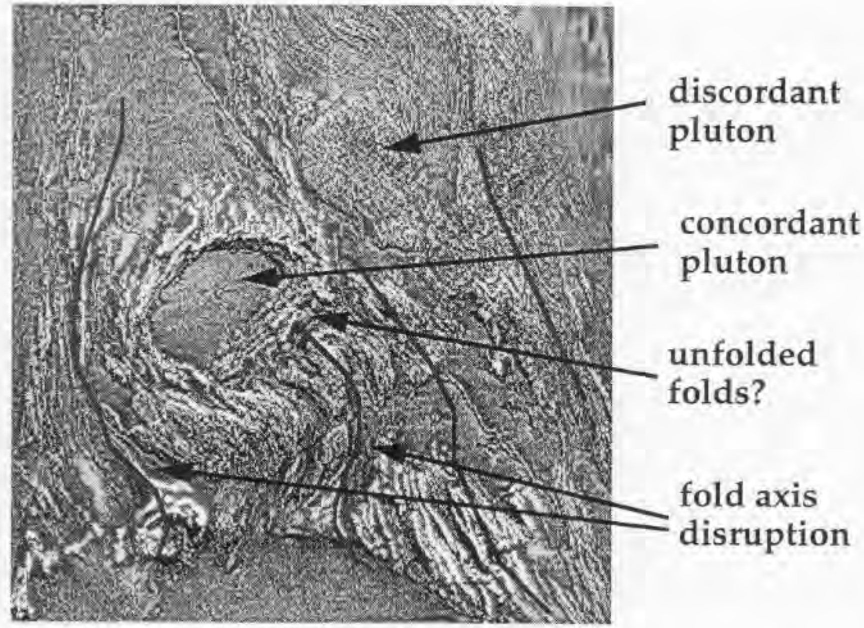
Pine Creek: geology



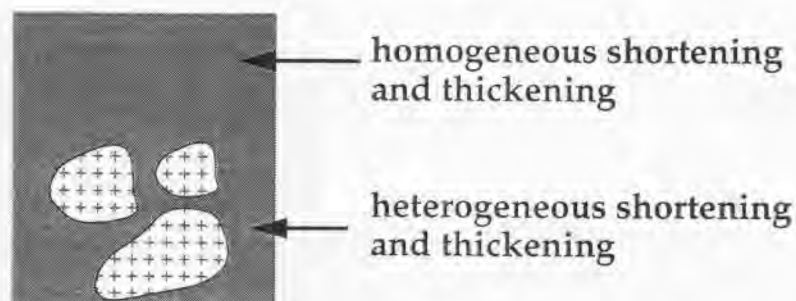
Post-pluton emplacement deformation:

-return to regional, far field stress
-rigid (though still partially molten pluton) modifies deformation response
-reactivated & new structures

Post-emplacement structural patterns



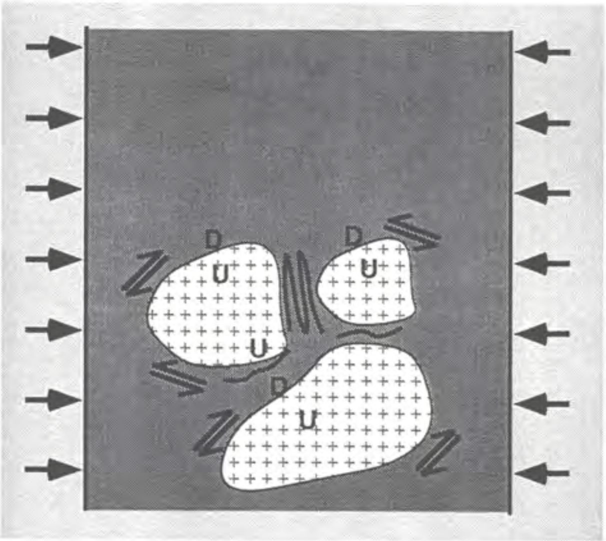
- in a folded sedimentary sequence undergoing deformation, plutons will act as rigid objects during subsequent deformation



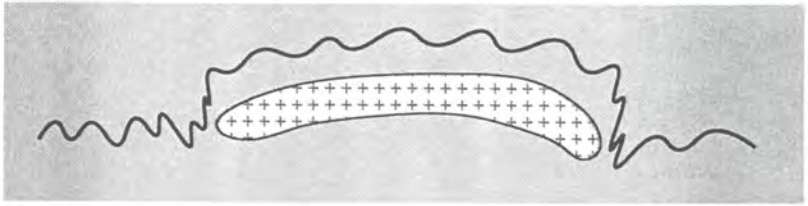
Post-pluton emplacement deformation

-reactivated & new structures focus fluid flow from and around cooling

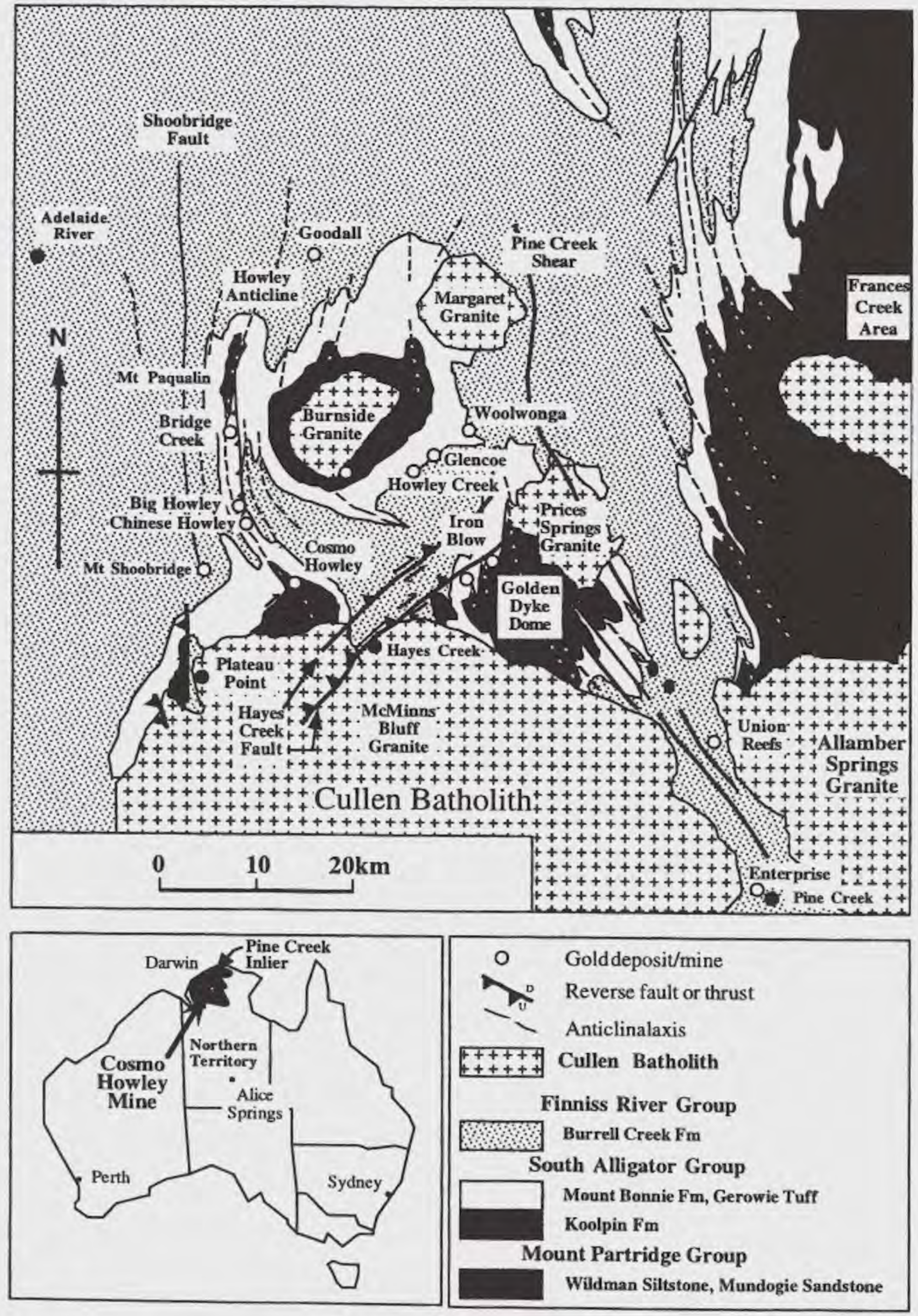
Structural Consequences



- material will flow around rigid plutons
- pluton contact orientations will produce low and high strain zones
- laccolithic plutons will fold at different wavelengths to surrounding rocks

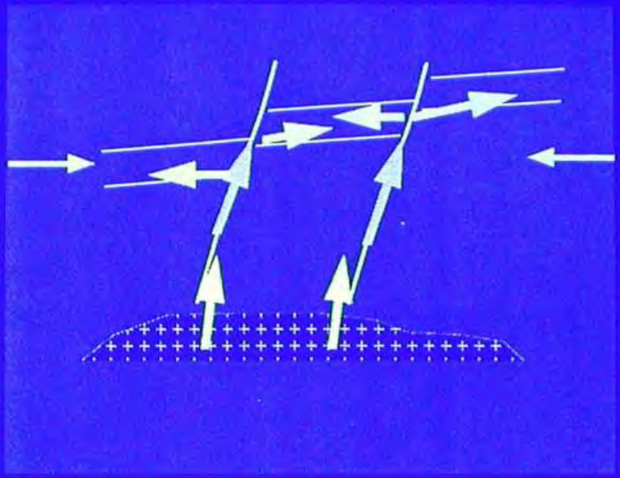


Pine Creek: geology



Post pluton emplacement deformation

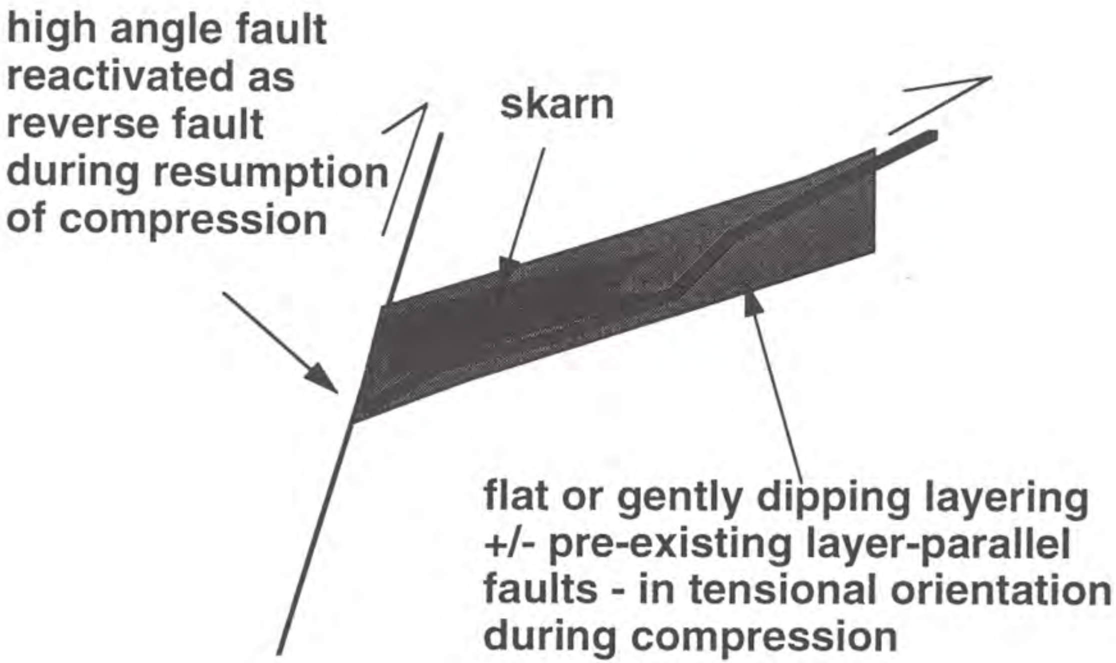
Reactivation



- granite exsolves a pulse of fluid under high pressure
- steep faults cannot reactivate unless fluid pressure is very high ("valves")
- if fluid pressure is high enough and faults reactivate - upward flow will dissipate pressure until reactivation is not possible
- fluid must then "break out" along layering or pre-existing flat structures

Post pluton emplacement deformation

Reactivation

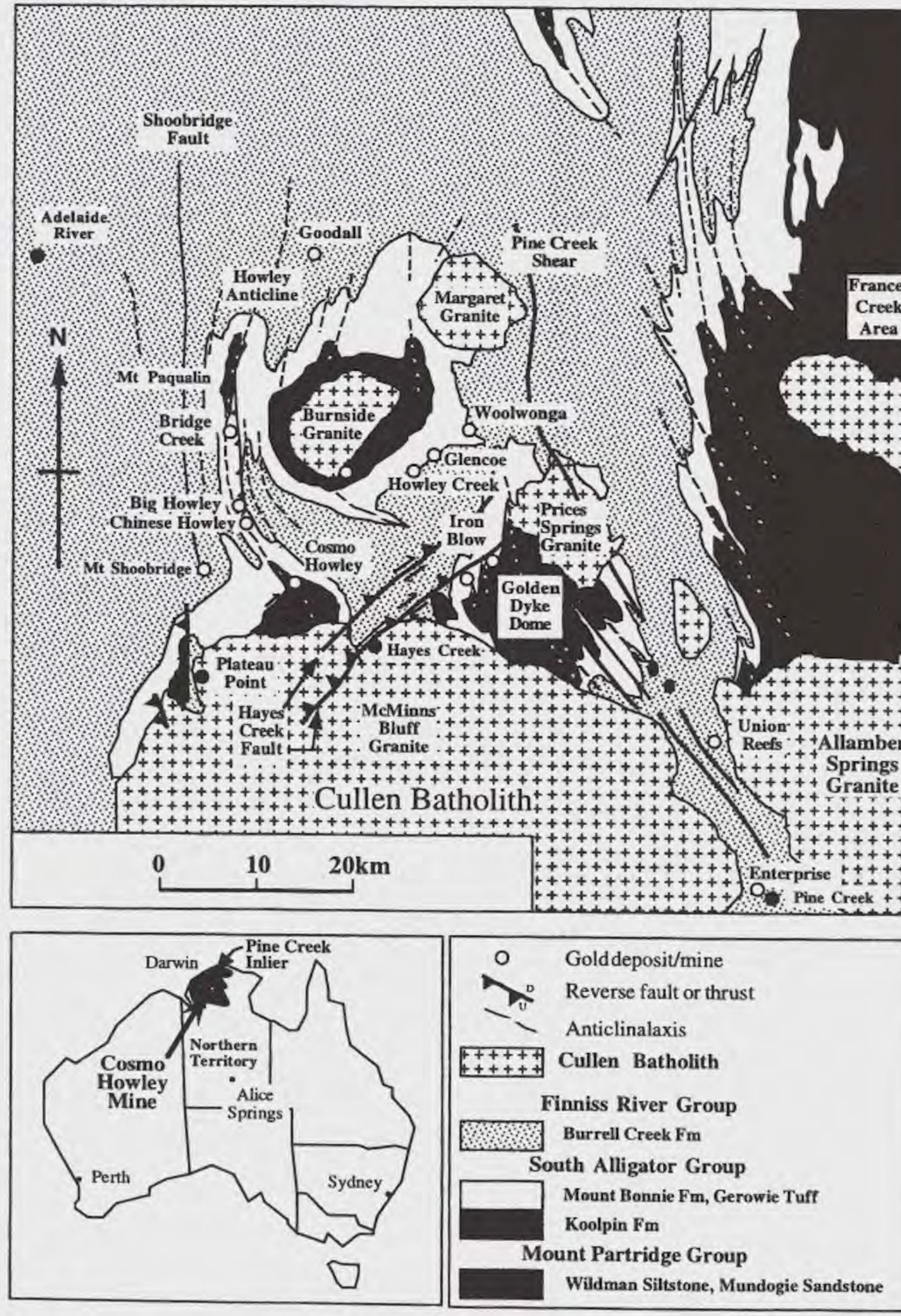


- eg - return to regional compression

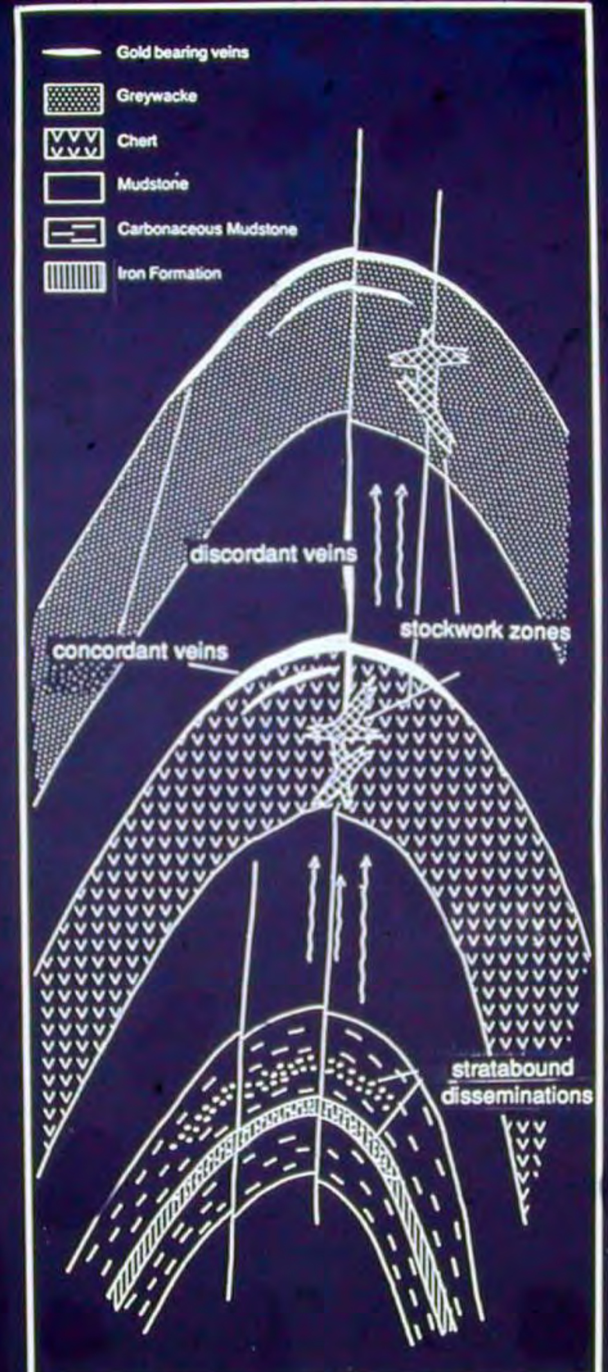
TAG: Northern Australia

- Pine Creek & Granites-Tanami regions
  - over 600t gold resources, 4 large deposits
  - Lower Prot. siliciclastics overlying carbonaceous, calcareous & silicate BIF units
    - greenschist facies folding & thrusting (1.86 Ga)
  - intruded by 1.8 Ga, ilmenite-series I-type granitoids
  - broad related thermal aureoles/pluton roof zones
  - deposits range from
    - sheeted vein systems (Mt. Todd, Enterprise, etc) to
    - vein-disseminations in carbonaceous & Fe-rich hornfelses (Cosmo Howley, The Granites, Callie, etc.)
    - pluton-proximal, high temperature to outer aureole types
      - formed under prograde to retrograde conditions
      - related systematic alteration mineralogy & geochemical character

Pine Creek: geology



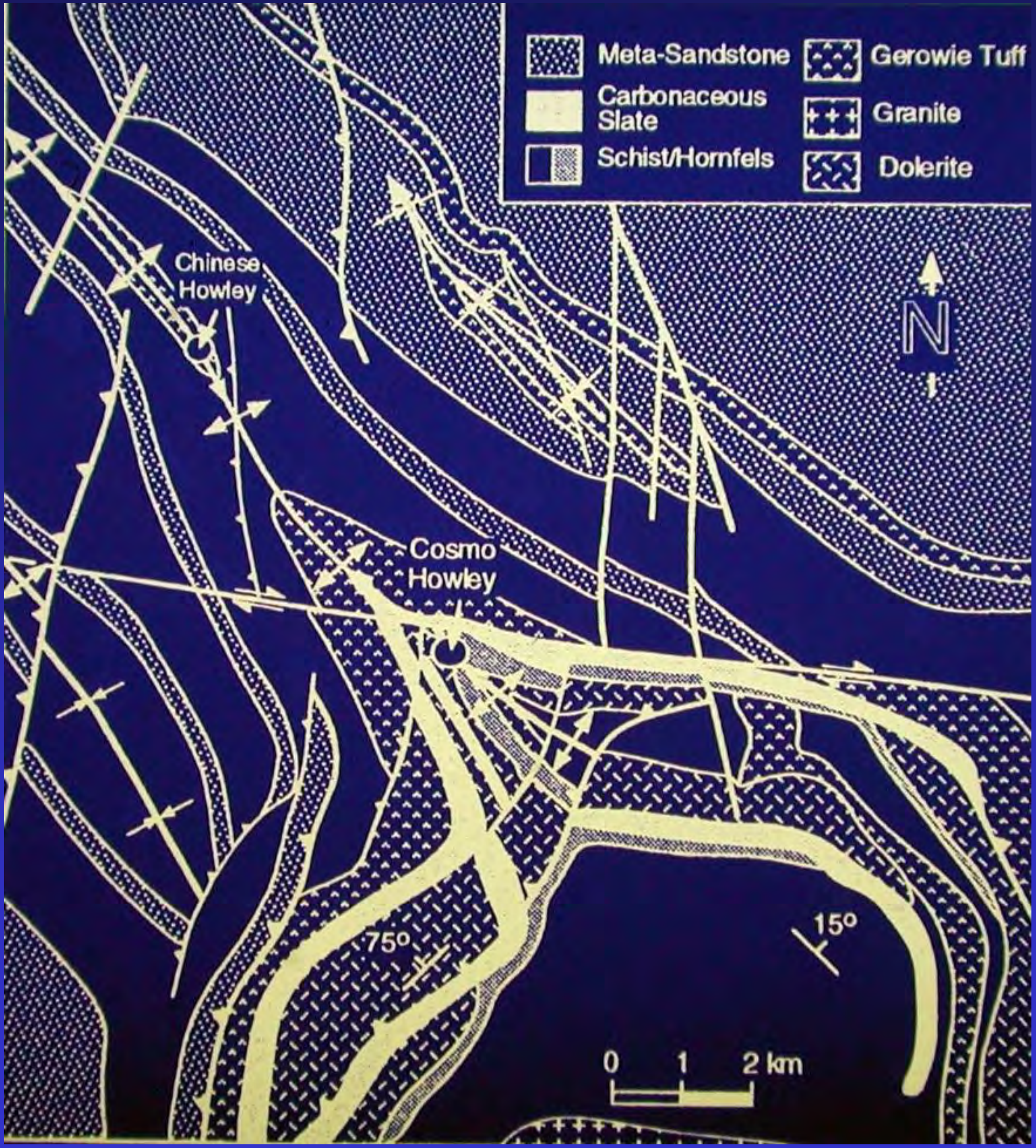
Pine Creek: gold deposits



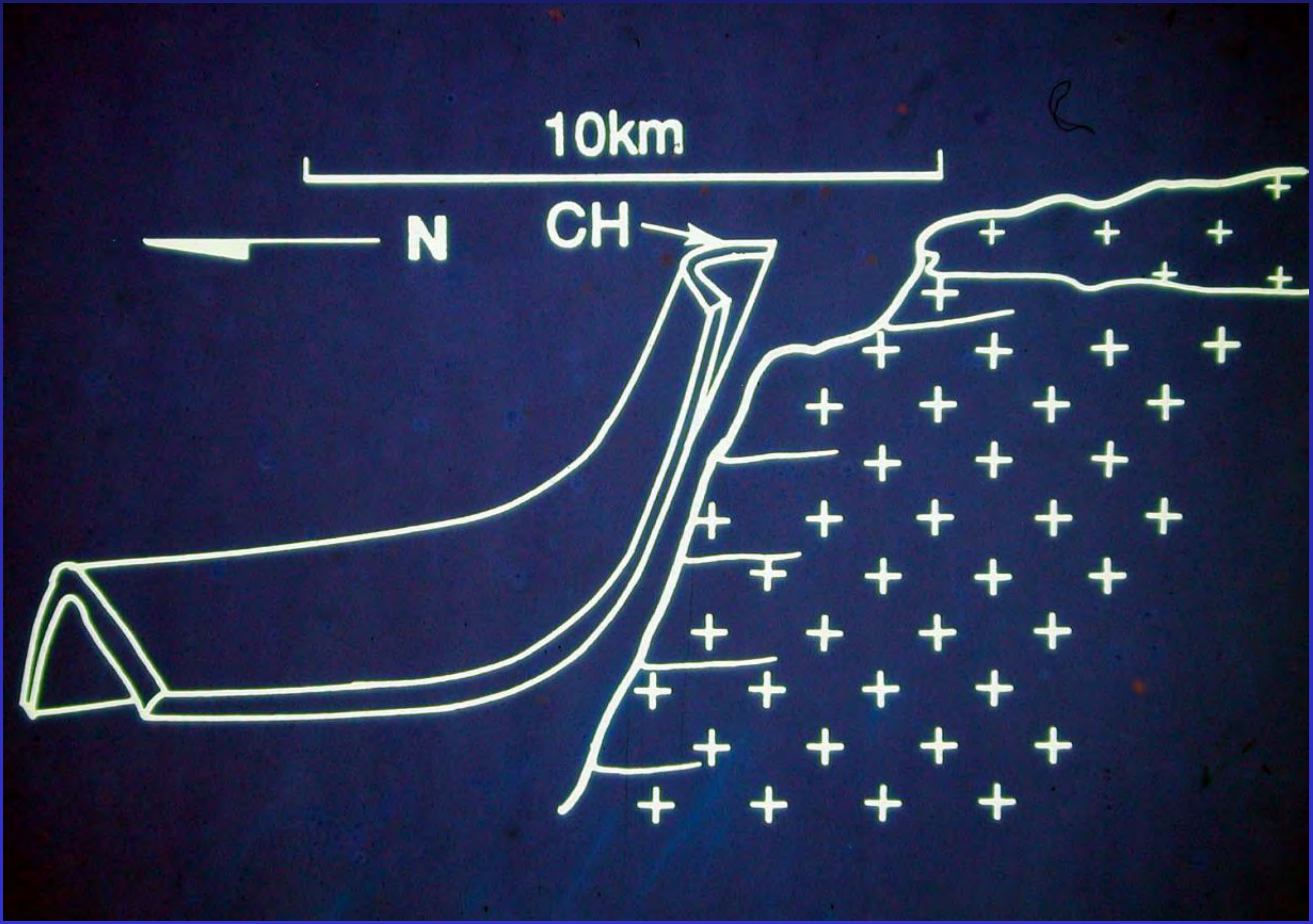
PINE CREEK - GEOMETRY OF THERMAL AUREOLE GOLD DEPOSITS

Pine Creek: plutons, structures & magnetics

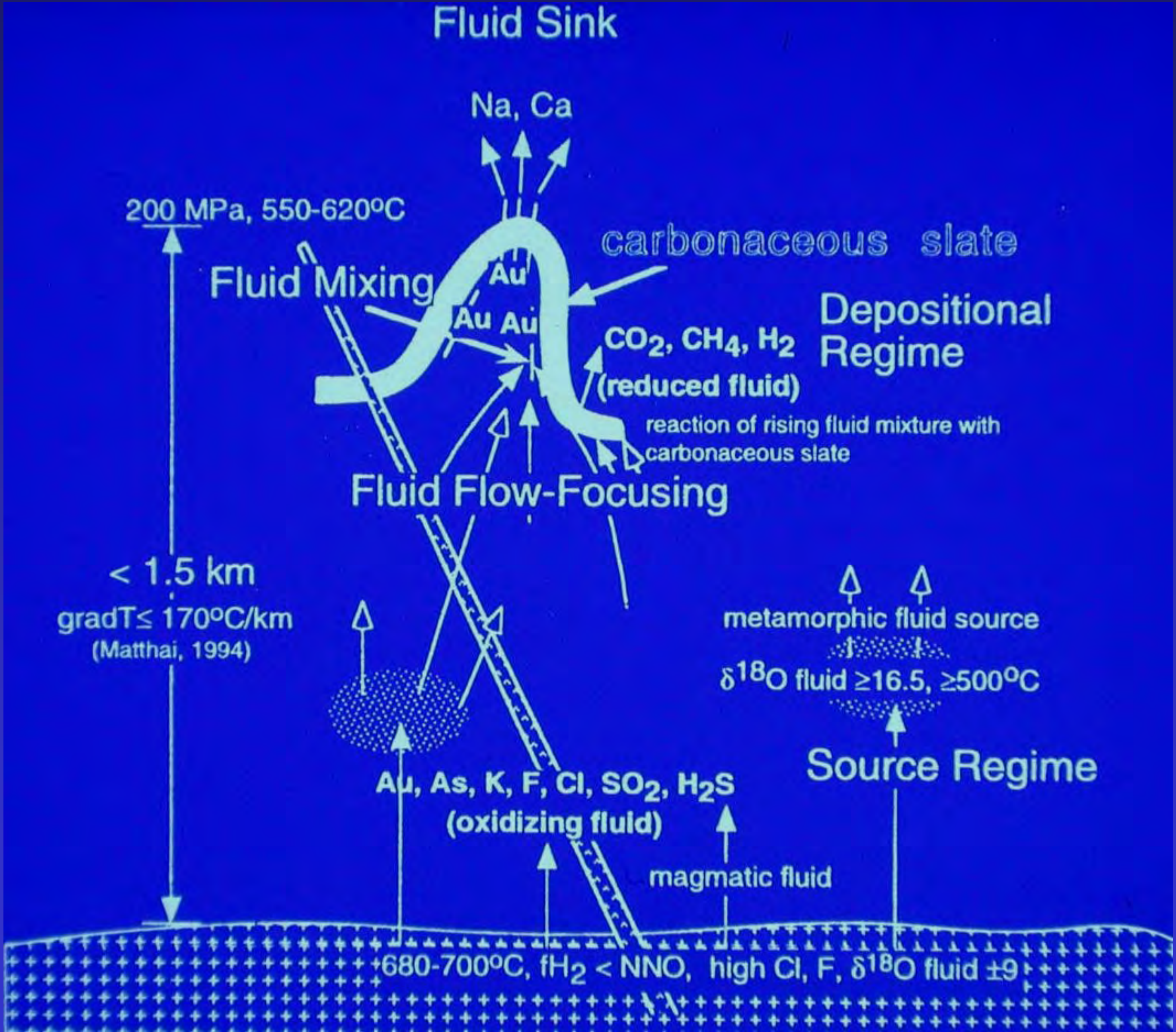
Cosmo Howley: structural setting



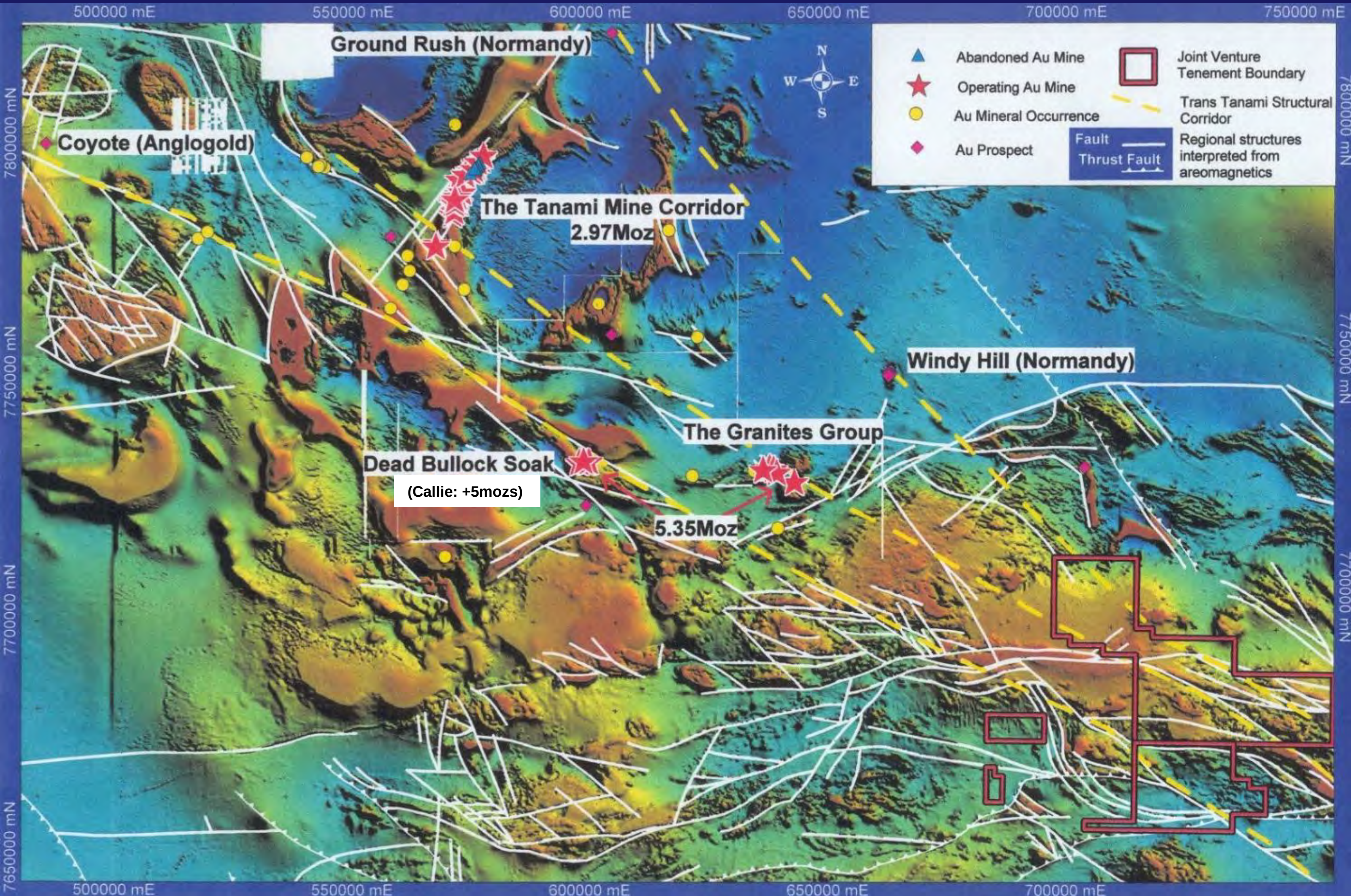
Cosmo Howley: structural setting



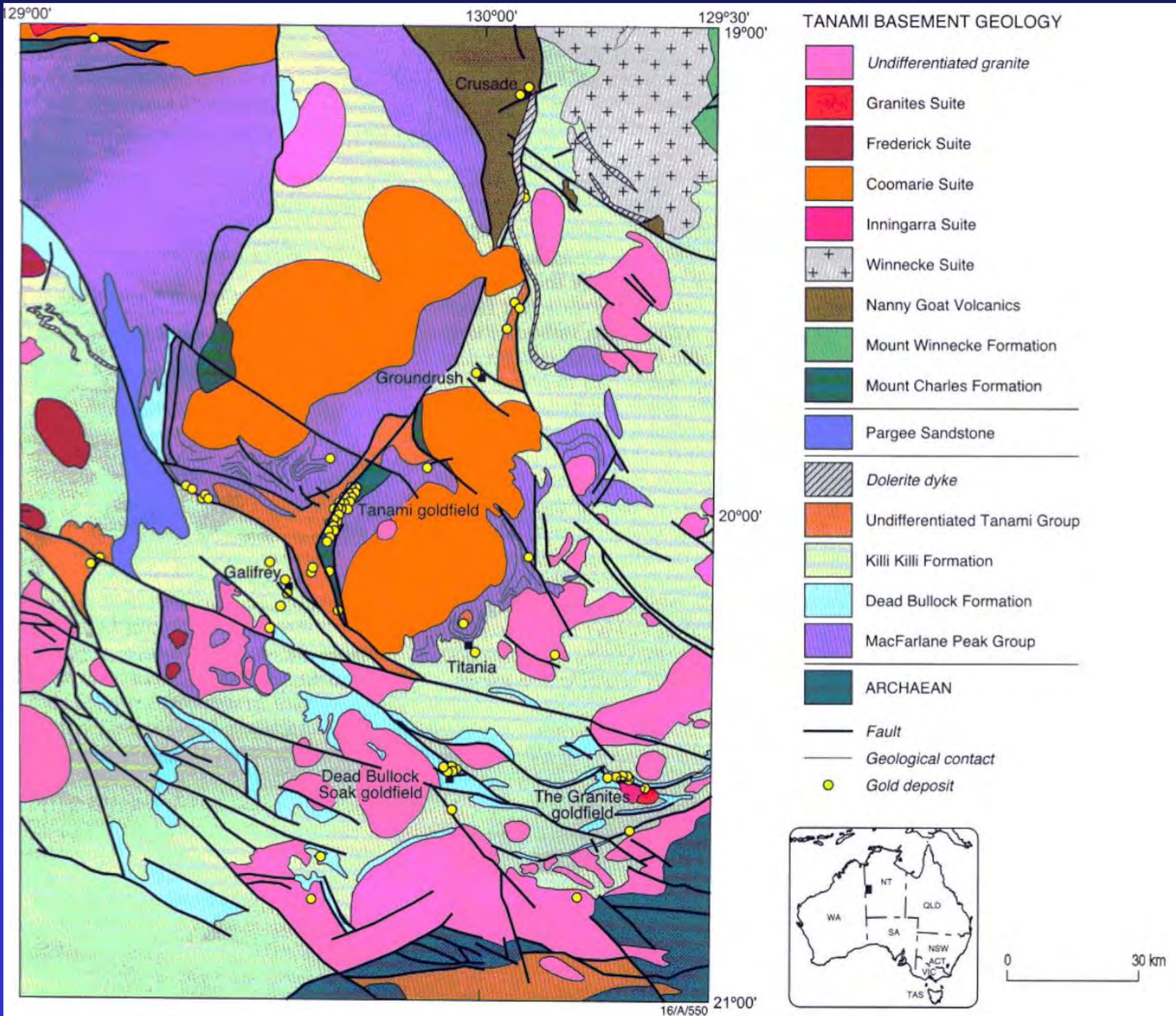
Cosmo Howley: conceptual system



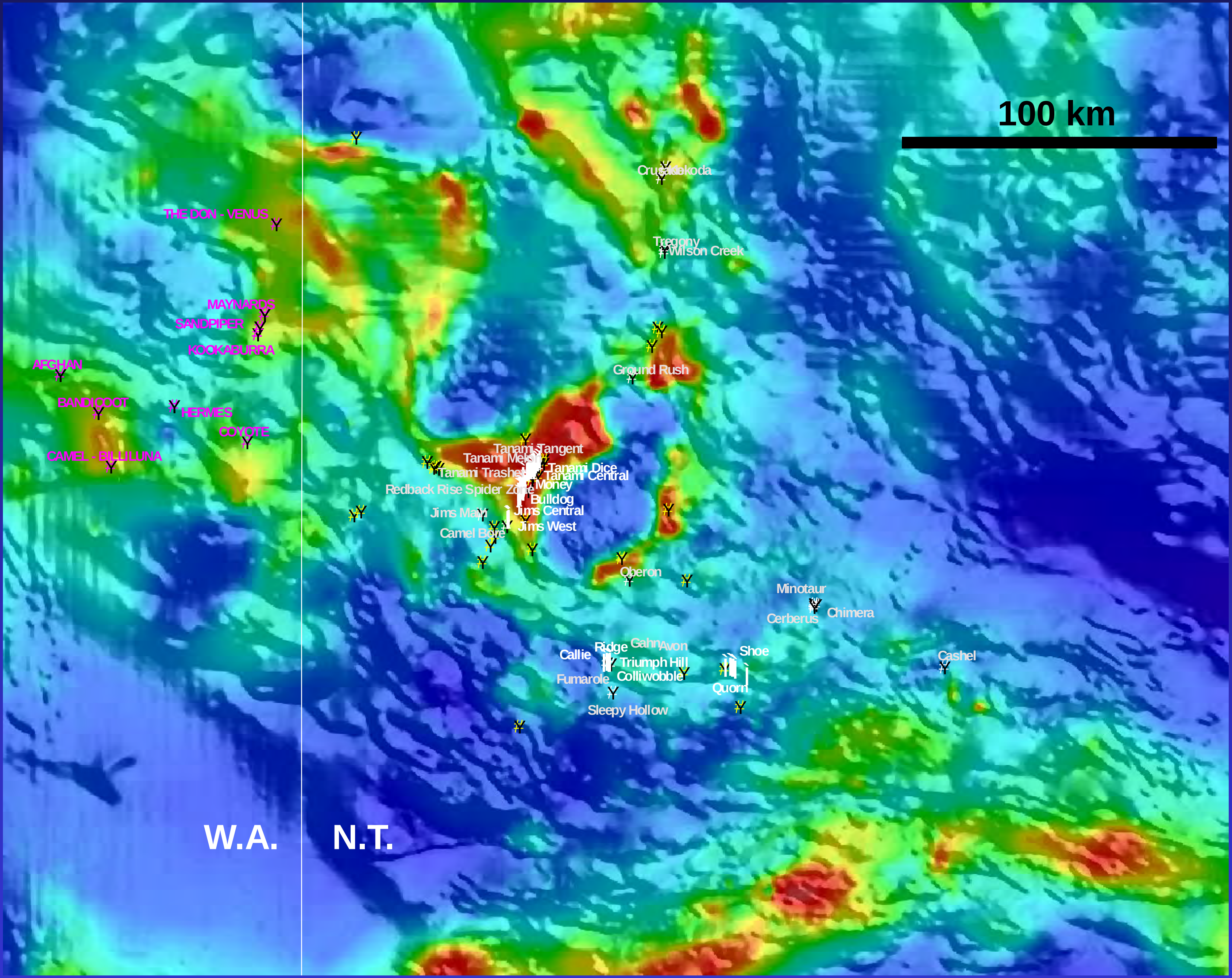
Granites-Tanami: deposits



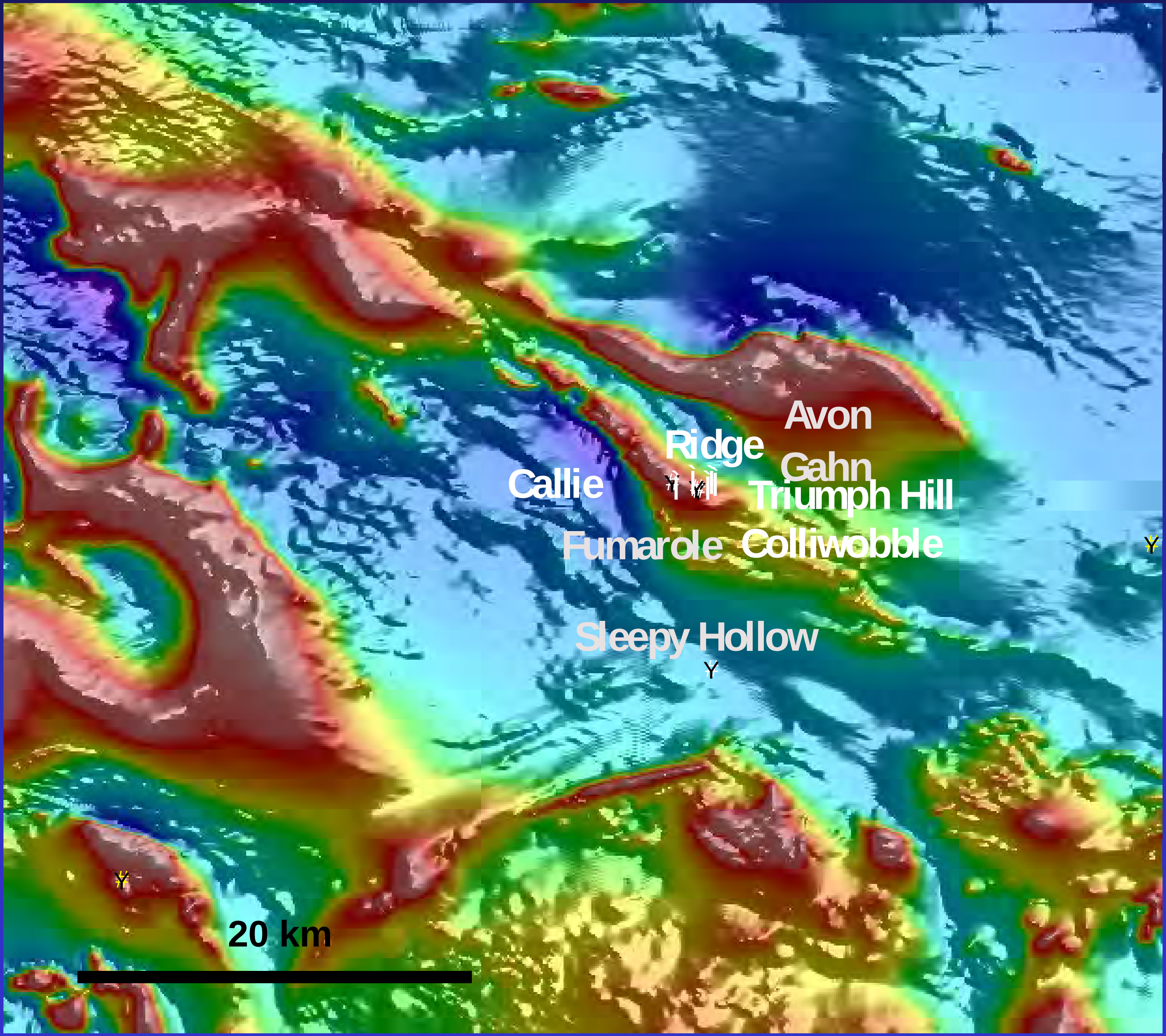
Granites-Tanami: regional geology



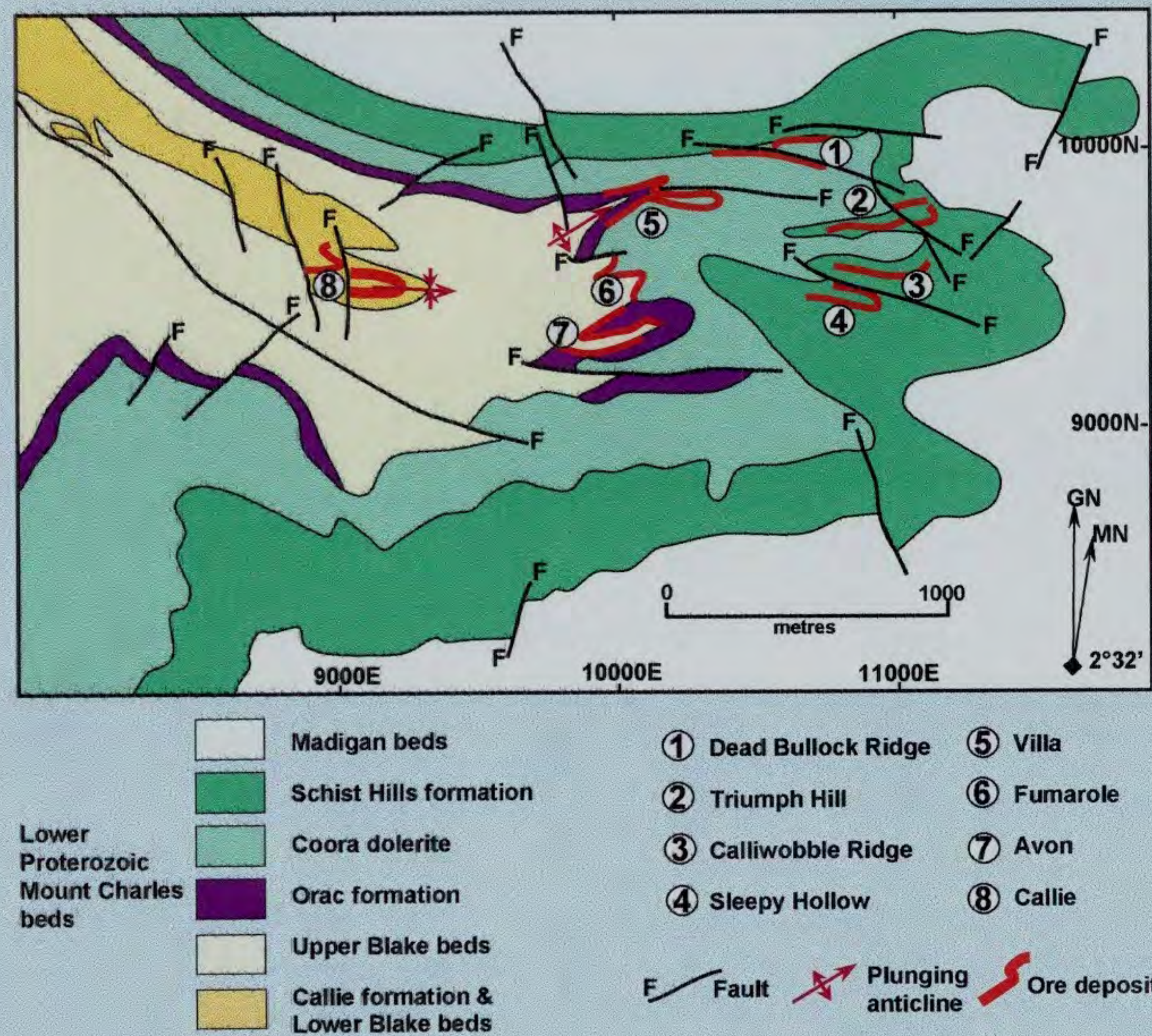
Granites-Tanami: bouger gravity/RTP



Callie area:
N-sun angle
RTP

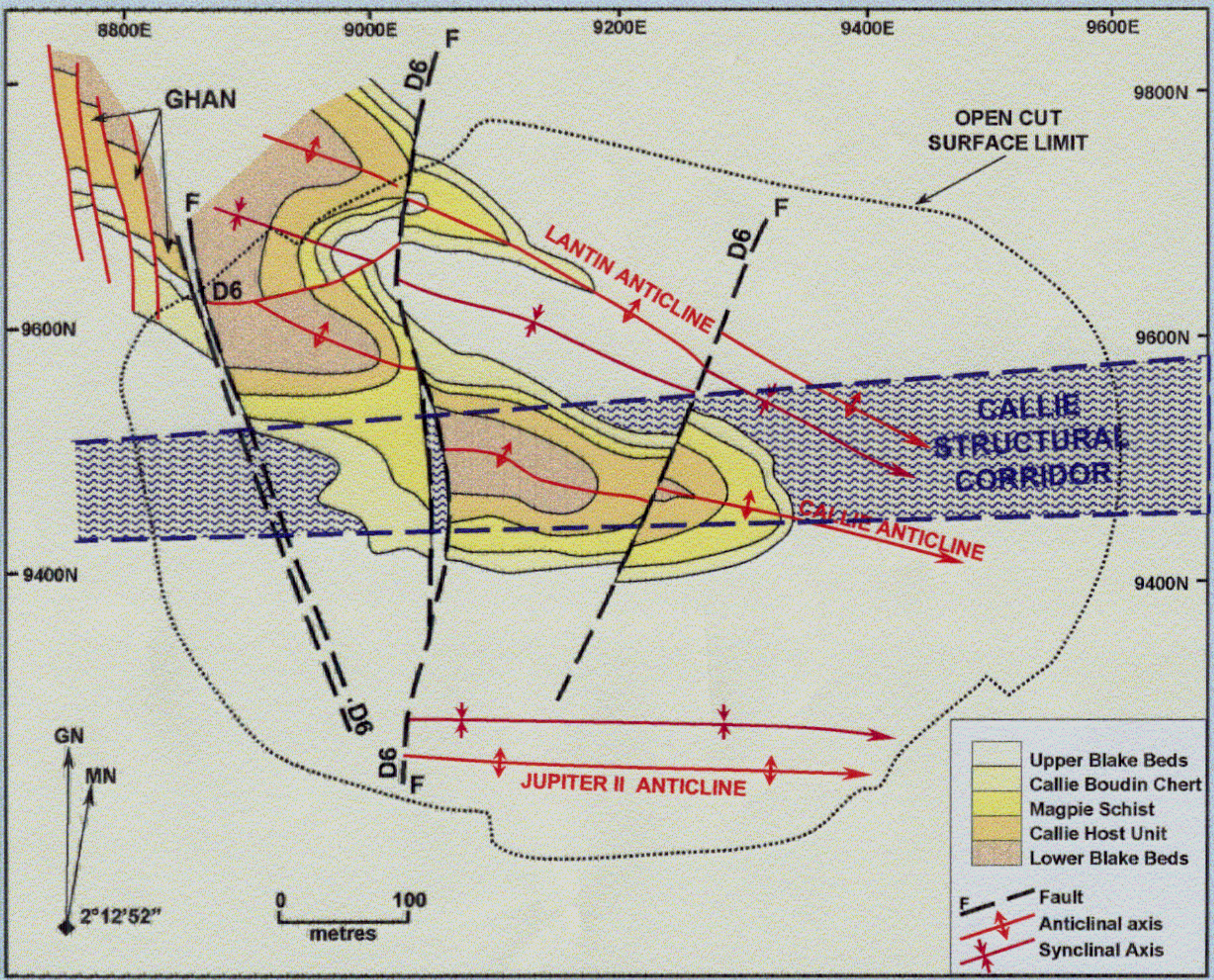


DBS geology



Solid Geology of the Dead Bullock Soak - Callie Area showing the Gold Deposits

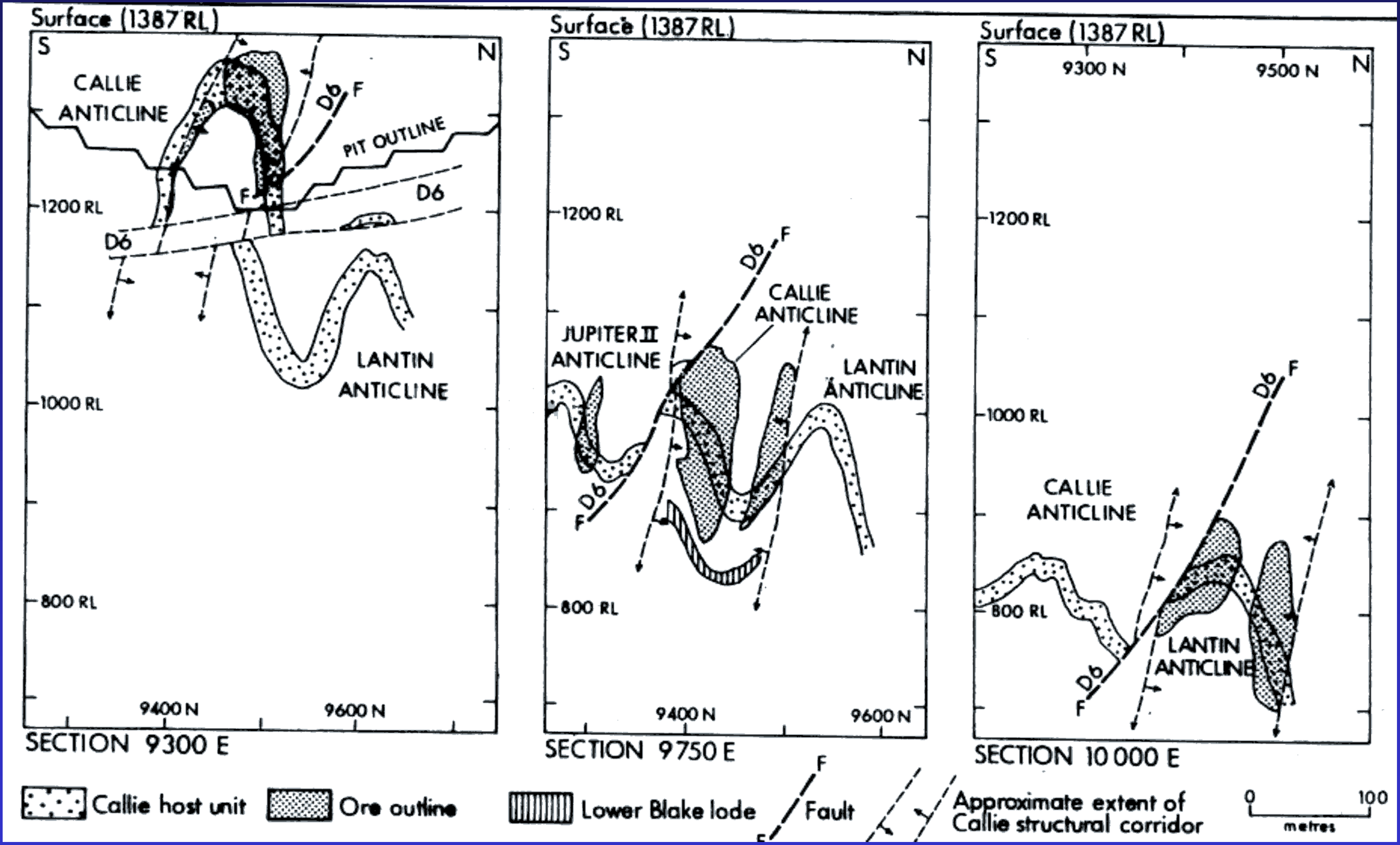
Callie geology



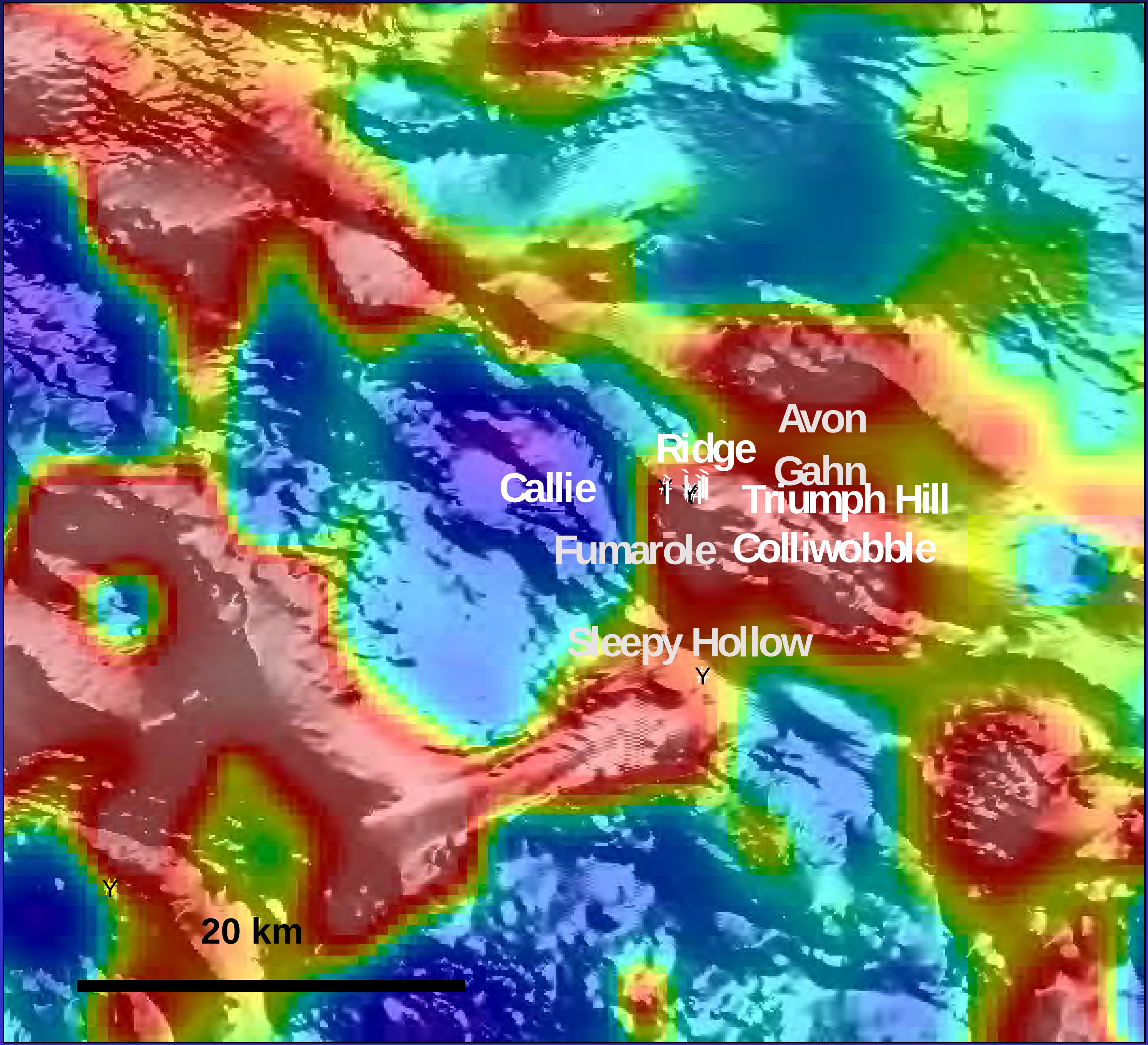
CALLIE DEPOSIT

Geological Plan 1380 RL (near surface)

Callie: Cross section

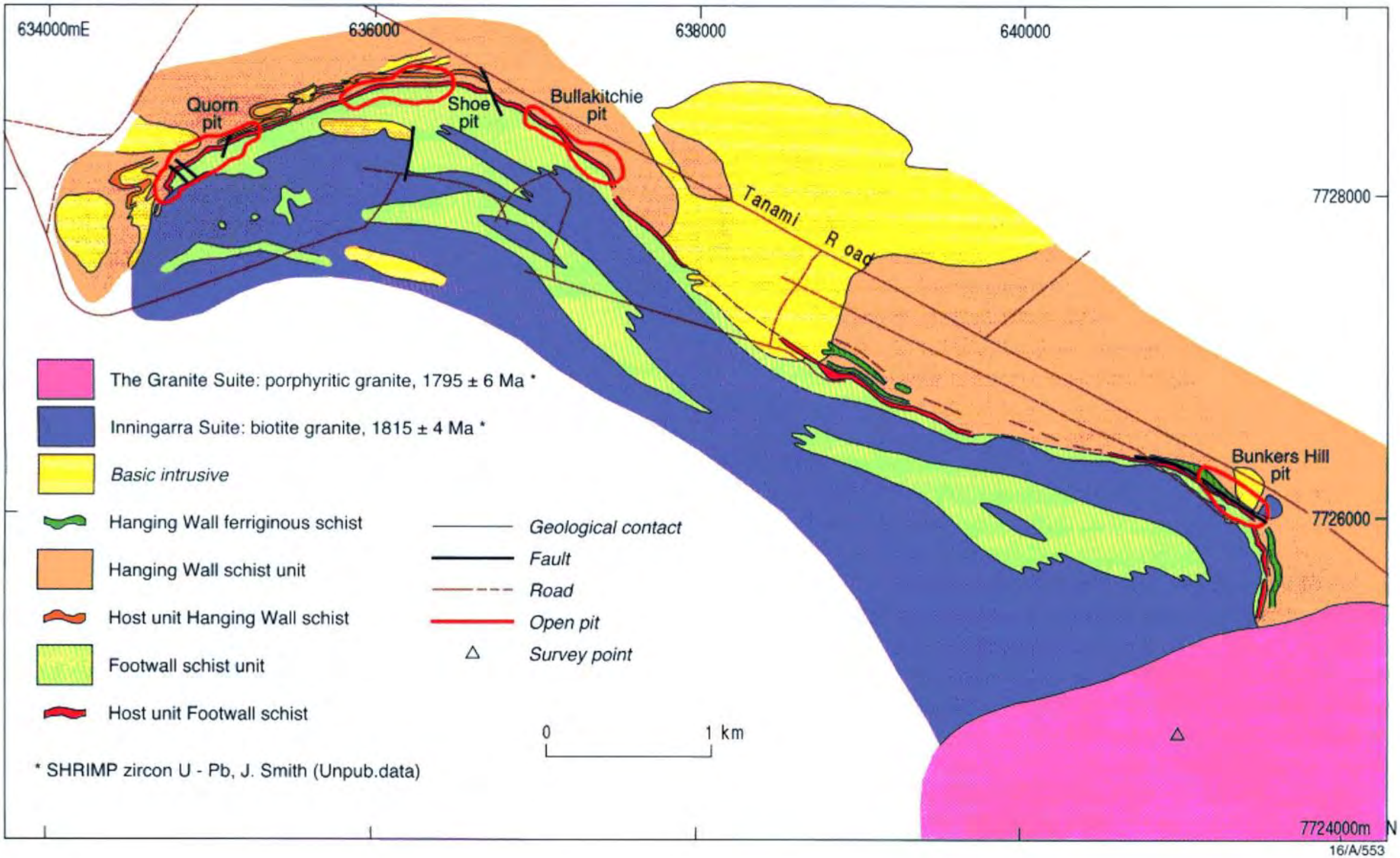


Callie area: layer gravity/ RTP

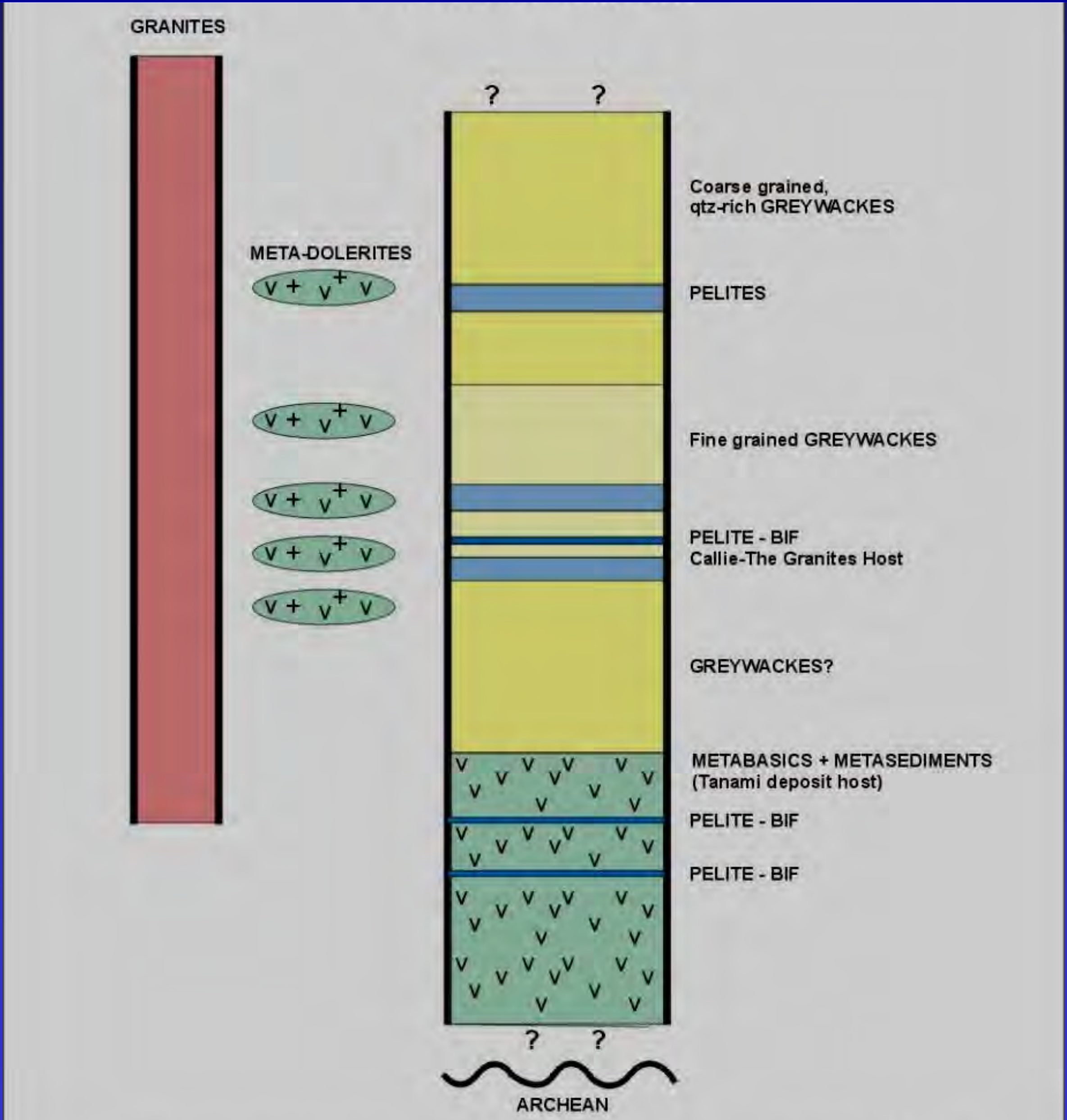


The Granites goldfield: geology

Figure 3. Geology of The Granites goldfield

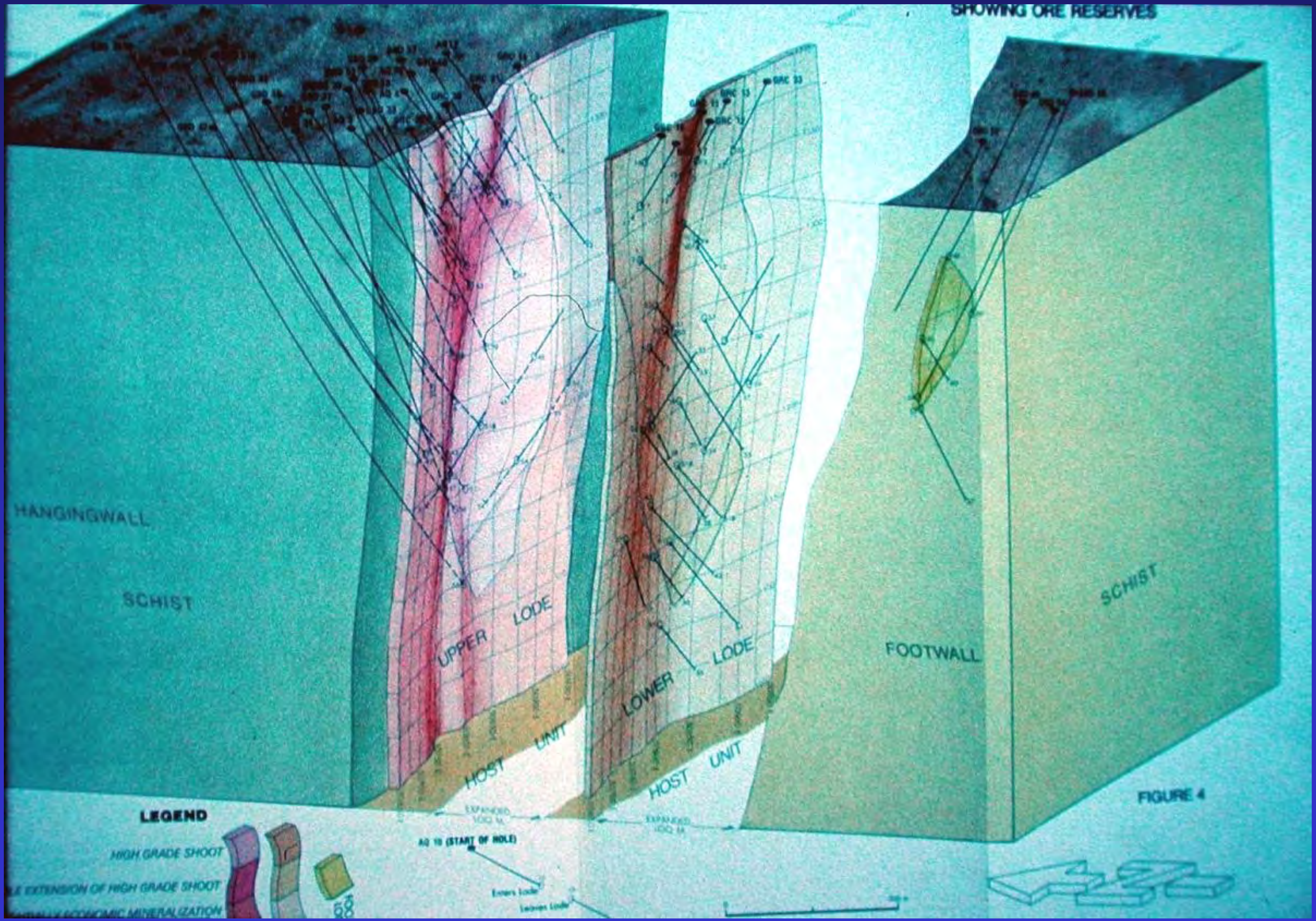


Granites-Tanami: regional lithostratigraphy

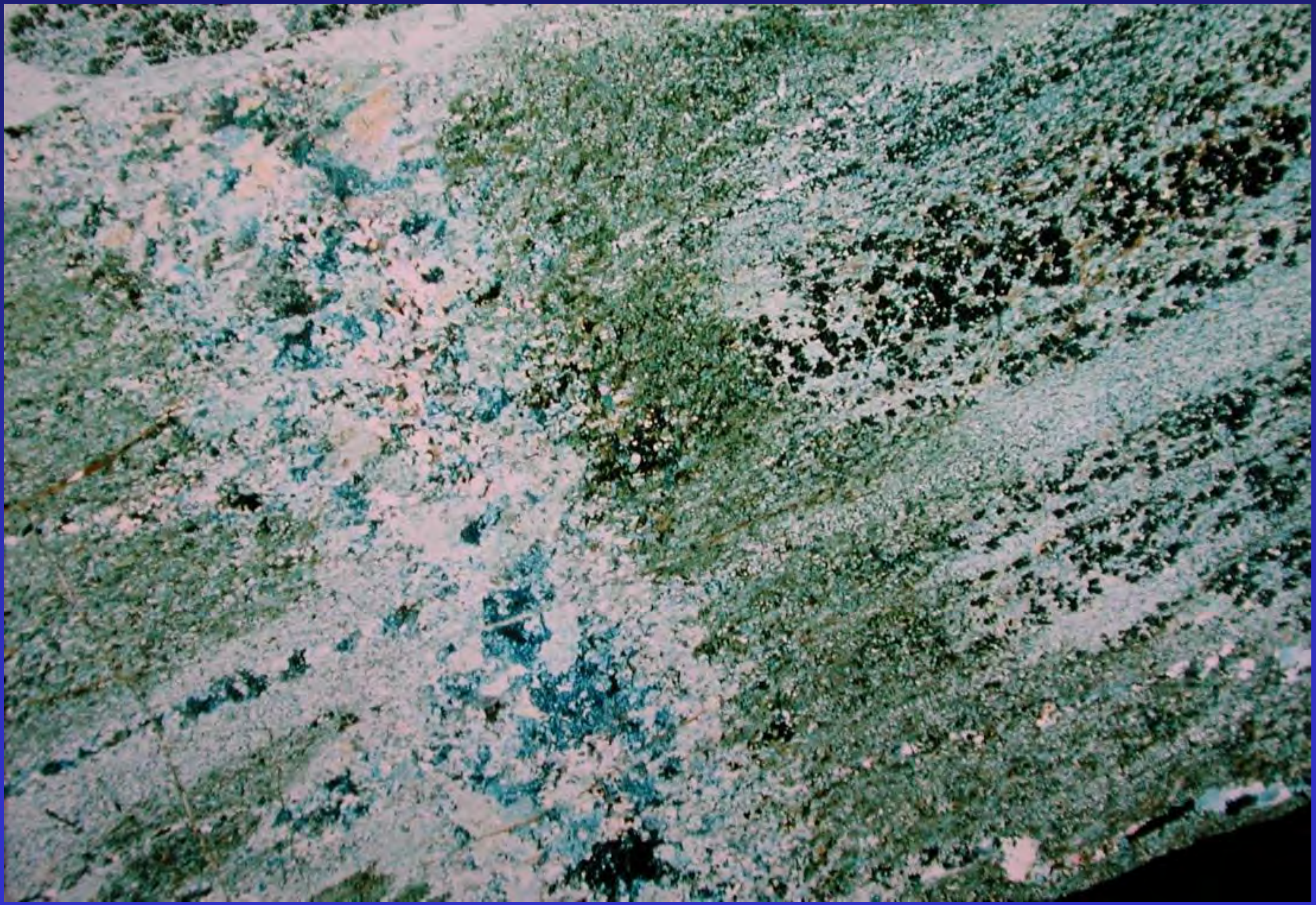


Proterozoic tectono-stratigraphy of the Granites-Tanami Inlier (Wall, V.J. 1989)

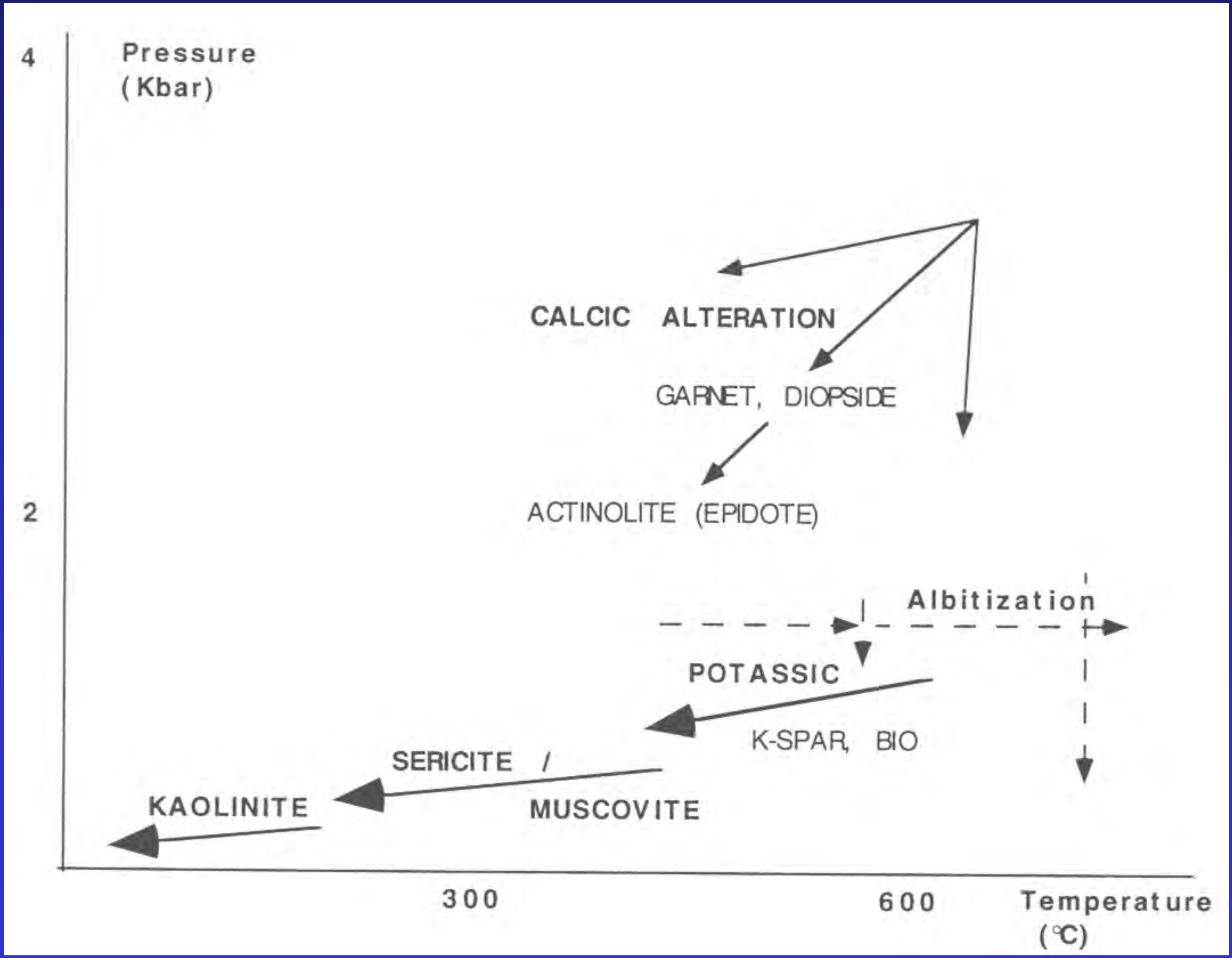
Bullakitchie ore zones



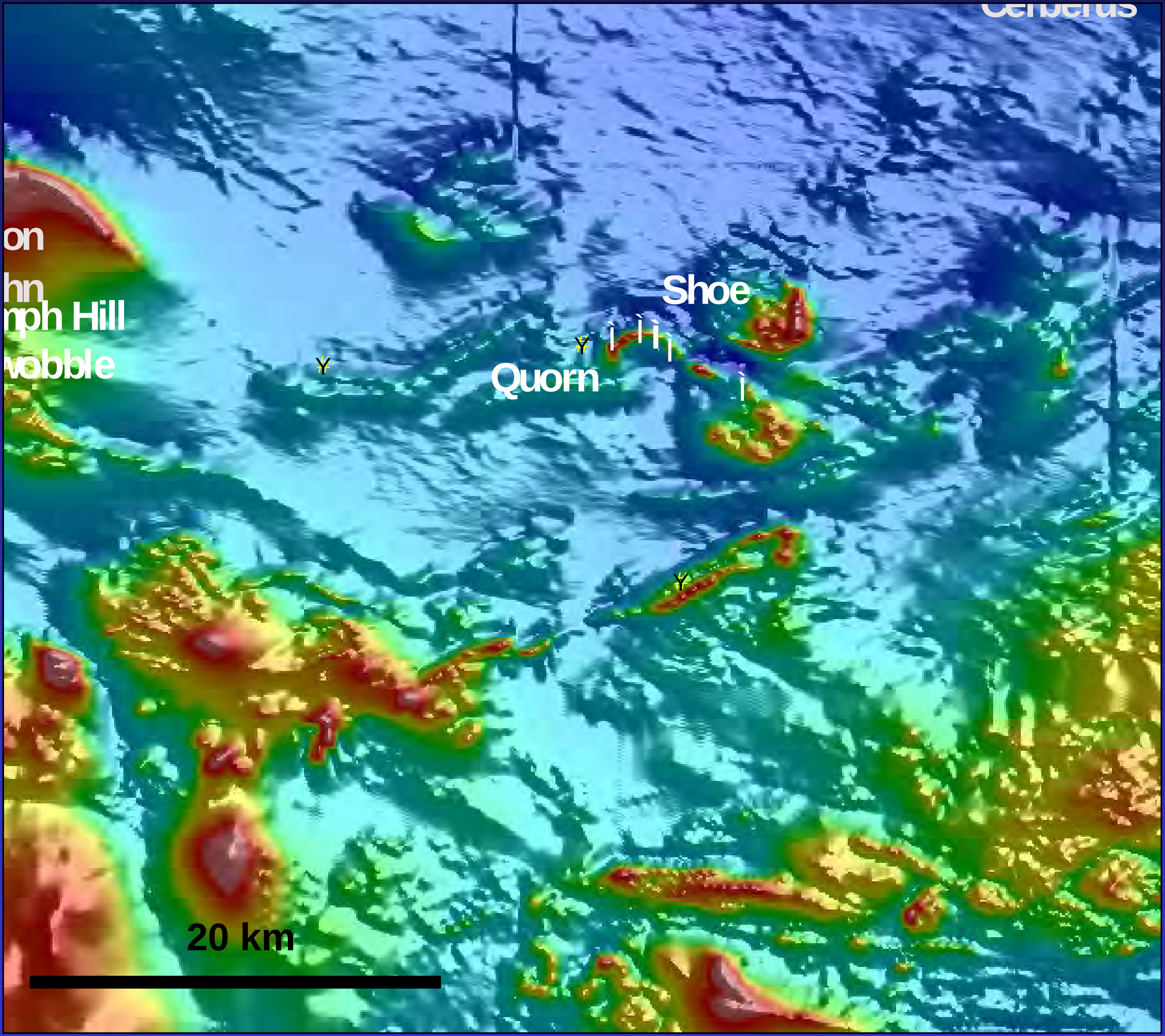
High temperature Ca-Fe metasomatism & sulphidation of BIF



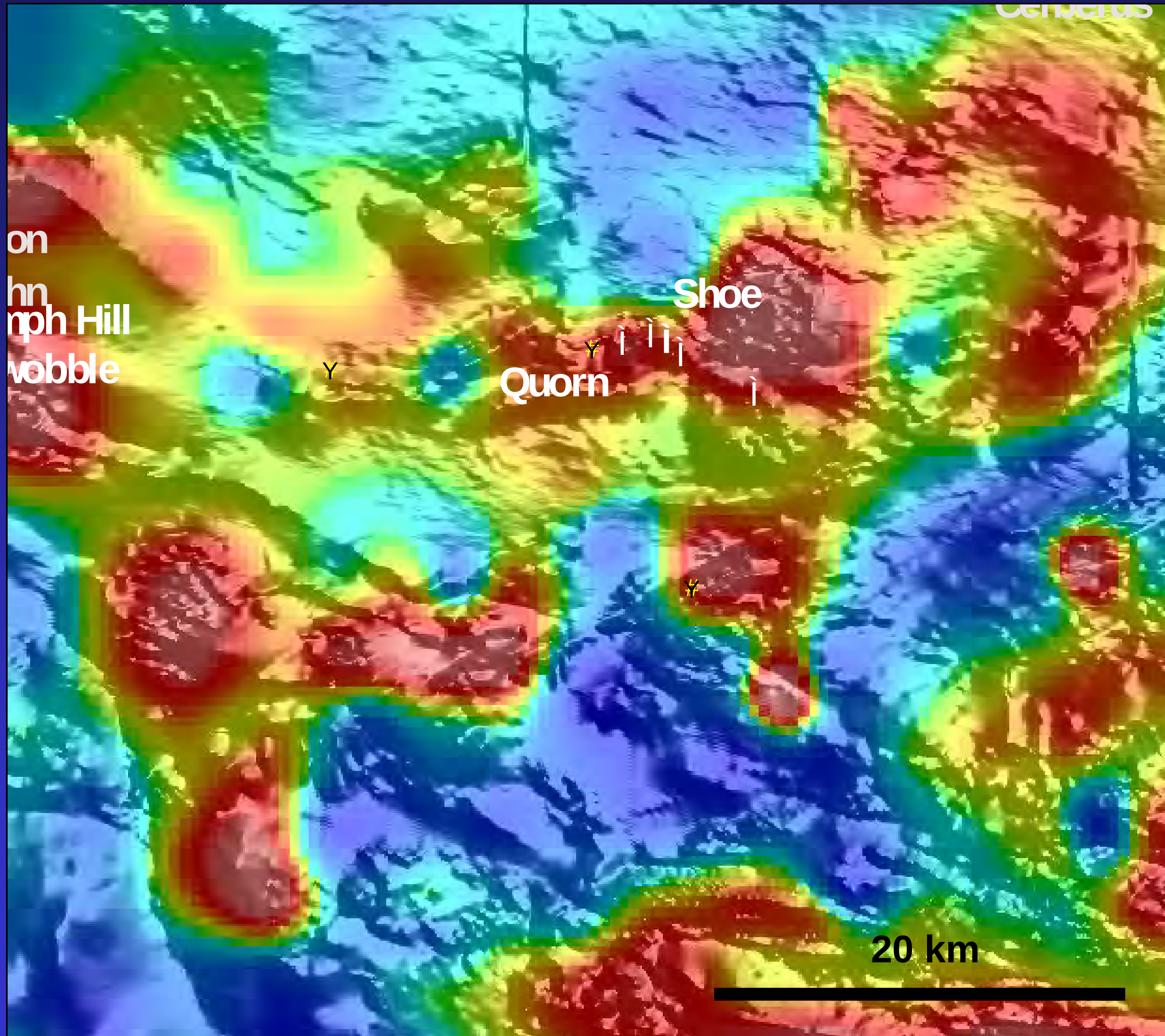
Hydrothermal metasomatic & vein assemblages



**The Granites area:
N-sun angle
RTP**



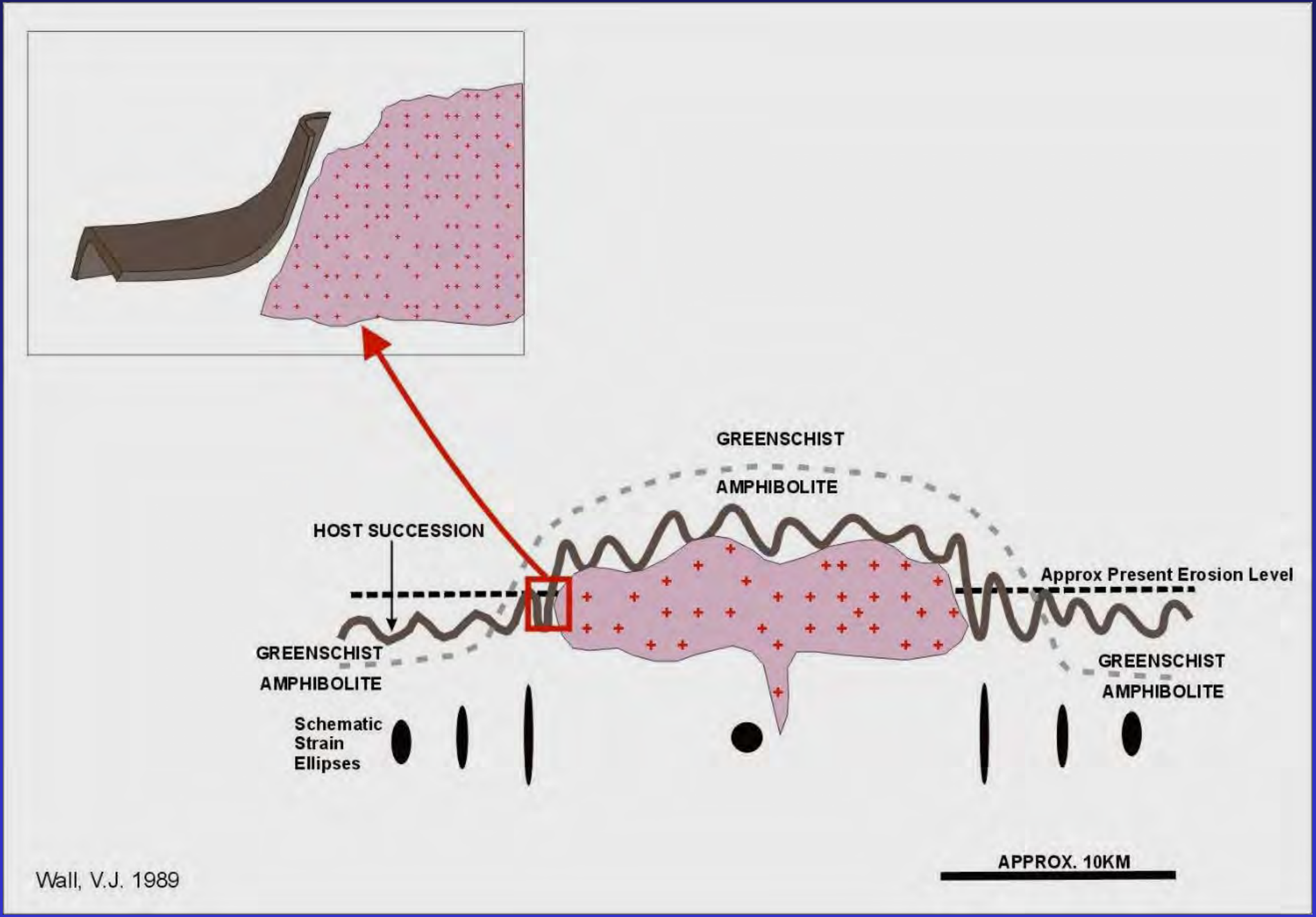
The Granites area: layer gravity/ RTP



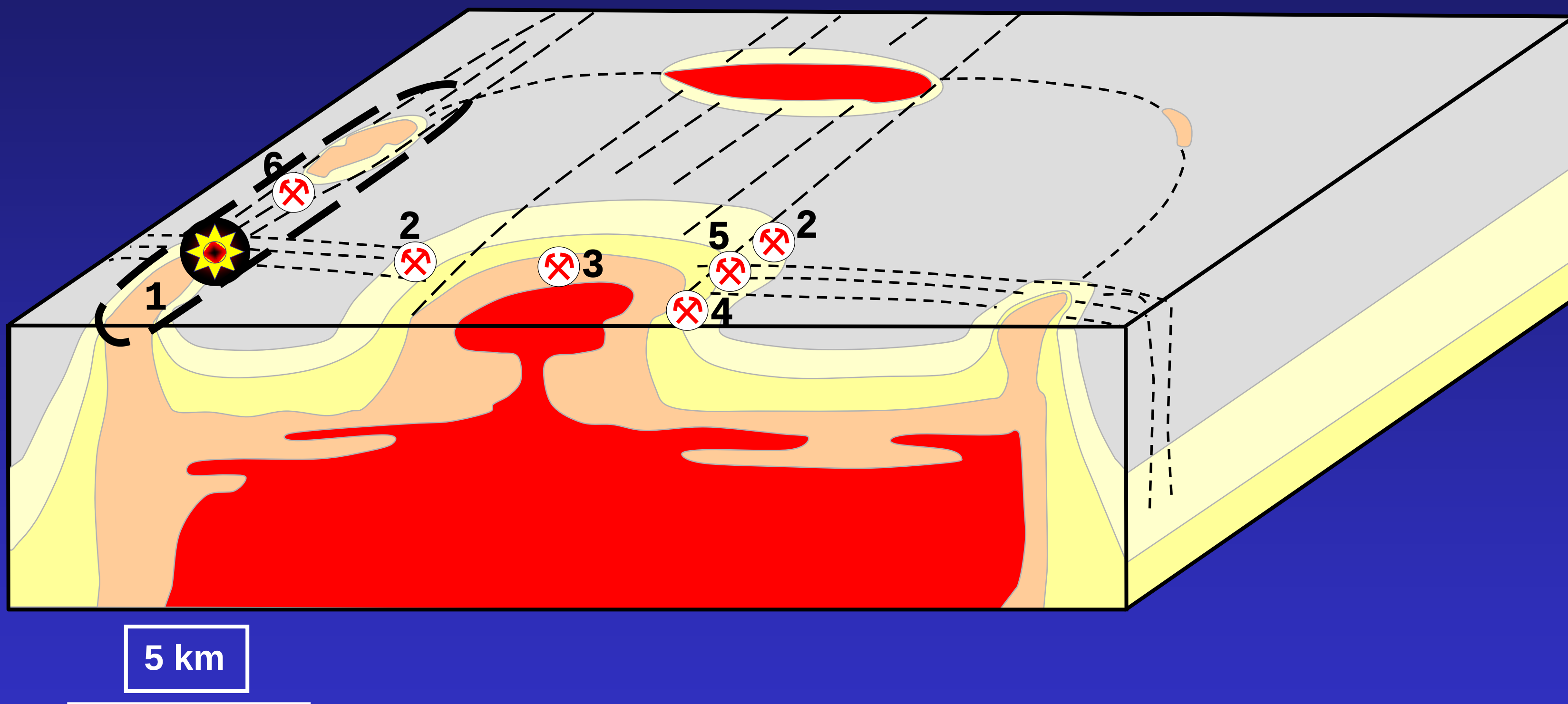
TAG: Northern Australia

- **Key factors in deposit localization:**
  - **large areas pluton roof zone preserved**
  - **reactivation of pre-pluton emplacement structures**
    - **anticlinorial (& blind thrust) zones**
      - **layer parallel veining (Cosmo Howley, Callie, The Granites etc,)**
    - **syn-pluton deformation**
      - **accommodation (roof lifting) deformation**
        - eg. intrusion marginal ductile shears
    - **stratigraphically-related mechanical contrasts**
      - **eg. thick bedded metagraywackes vs. metalutites**
    - **reductants: carbonaceous & Fe-rich metasediments (Callie, The Granites, etc)**
    - **high temperature (?gold rich) fluids**

Granites-Tanami: geology model



TAG (pluton-related) systems



Granitoid pluton

Thermal aureole

Country rocks

Key structural zones

GOLD DEPOSIT SETTINGS

1 Fort Knox

2 Sukhoi Log, Kumtor

3 Pogo, Vasilkovskoye

4 Granites-Tanami

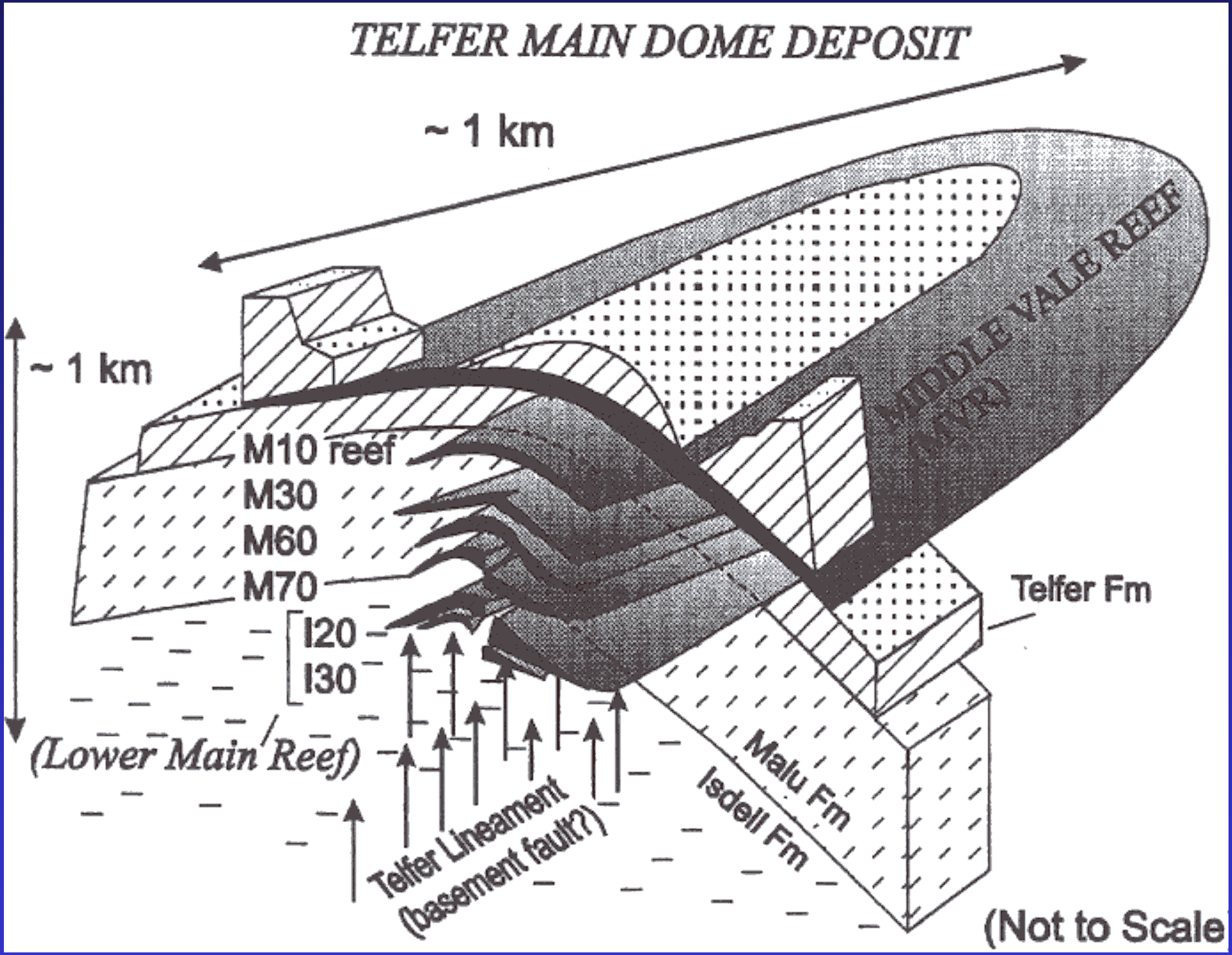
5 Muruntau

6 Obuasi, Telfer

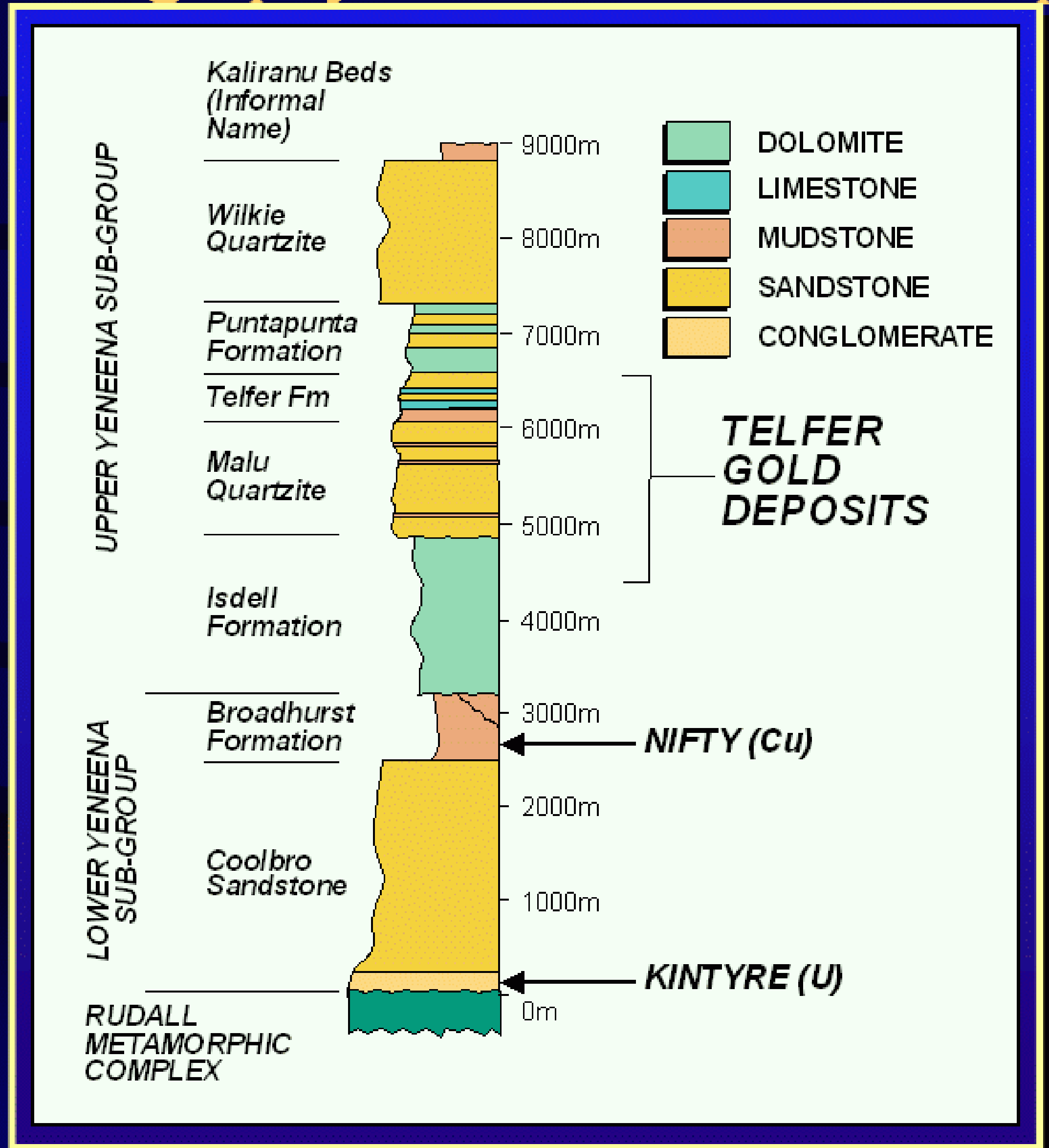
TAG: north Western Australia

- Telfer, >30 Moz. Au (-Cu) deposit
    - bedding parallel veins; discordant stockworks, breccias
    - high grade quartz-carbonate-pyrite-chalcopyrite veins
  - – hosted by ?mid Proterozoic siliciclastic succession with some carbonates & evaporites
  - – fold-thrust compressional deformation & greenschist metamorphism;
    - reactivation of basement structures
  - – felsic pluton/batholith emplacement
    - post main regional deformations
    - ~620Ma., similar isotopic age to Au mineralization
    - fractionated I-type suites

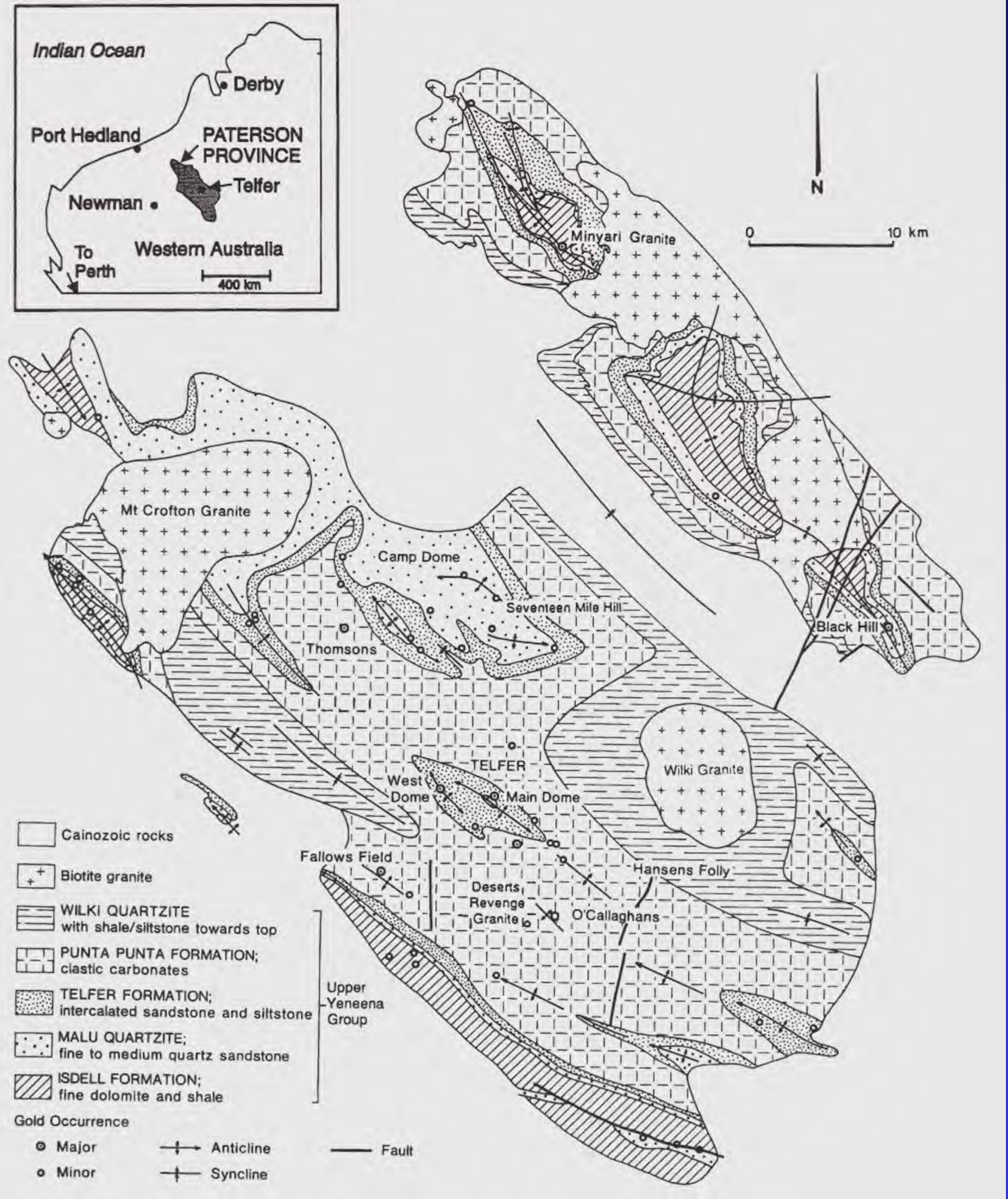
Telfer Au-Cu deposit



Stratigraphy of the Yeneena Group



Telfer: district geology

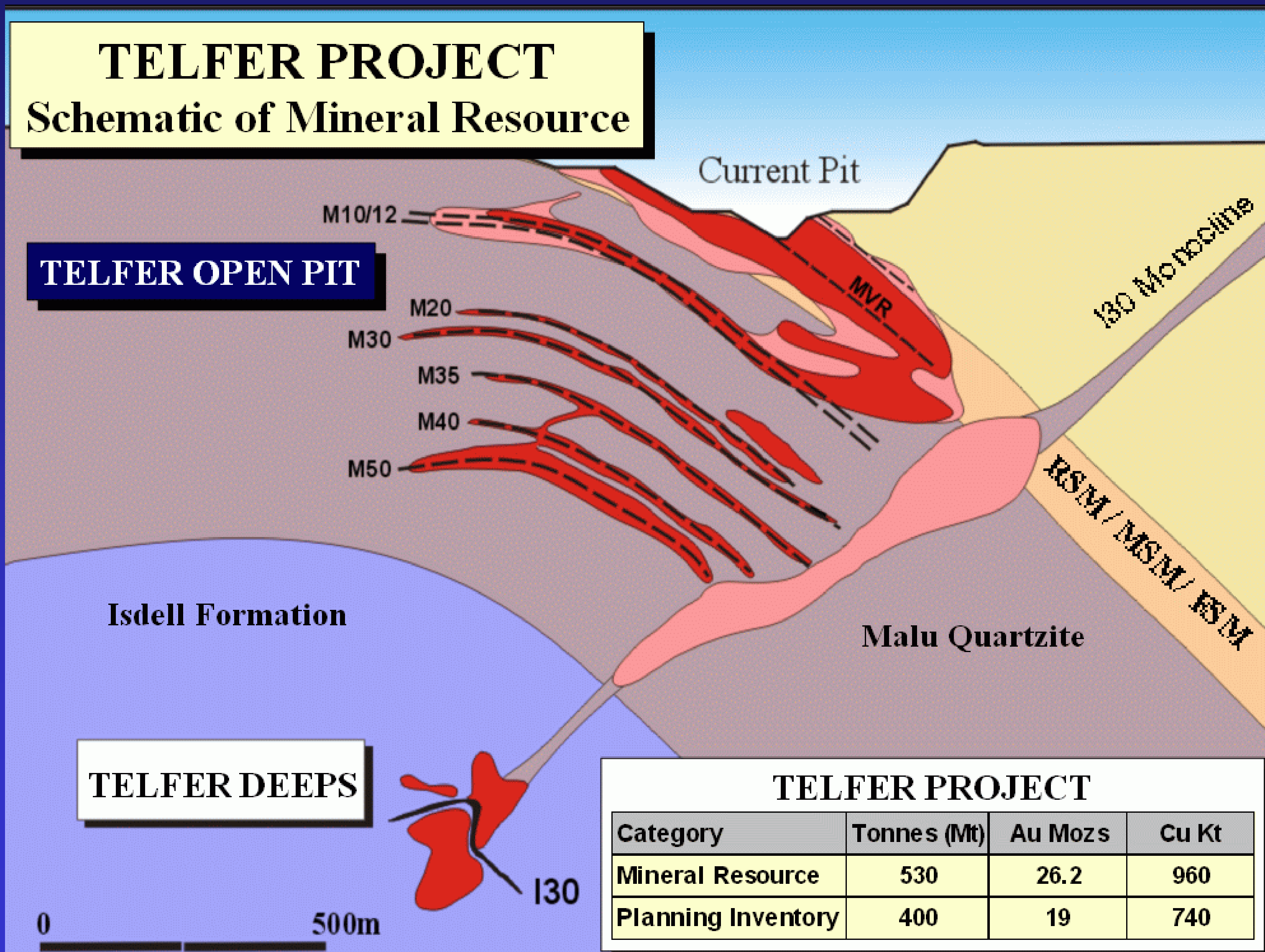


TAG: north Western Australia

- Telfer deposit localised in
  - pluton roof zone (above pluton edge?)
    - regional gravity signature
    - note map pattern, nearby skarns & other pluton proximal deposits
      - outer aureole setting
  - multiply plunging, asymmetric, anticlinorial ‘domal’ structures
    - reactivated fold-(blind) thrust system
      - dilation along bedding controlled by stratigraphy, small thrusts
      - dilation in discordant zones, related to small scale fault-fold systems
  - favourably thin-bedded stratigraphy, in over more than 1km. thickness
    - higher temperature alteration & higher Cu with increasing depth; highly saline fluids

Telfer 'dome'

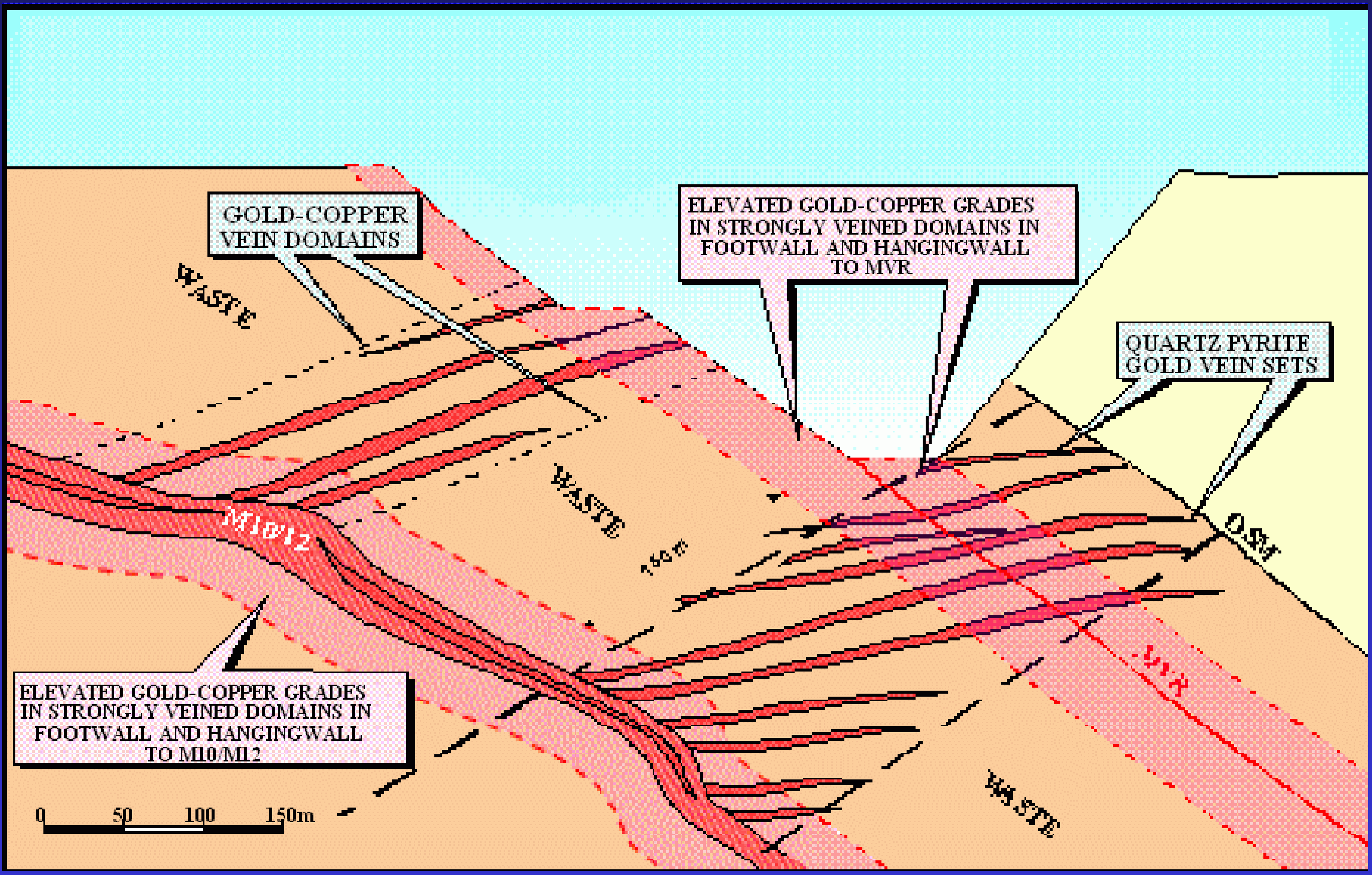
Telfer cross section



TELFER PROJECT

Category	Tonnes (Mt)	Au Mozs	Cu Kt
Mineral Resource	530	26.2	960
Planning Inventory	400	19	740

Telfer: ore zones

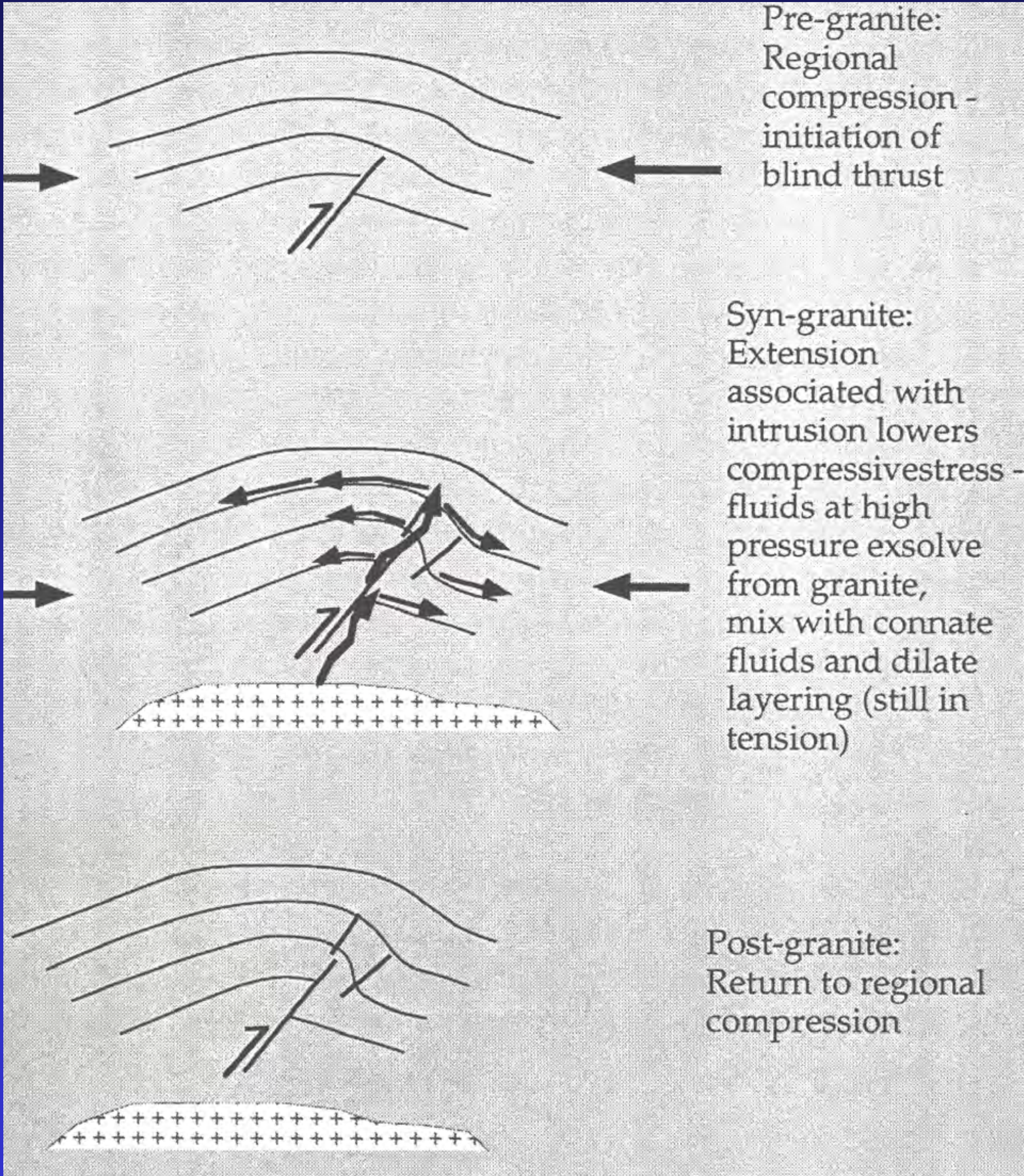


Reef Mineralisation Style

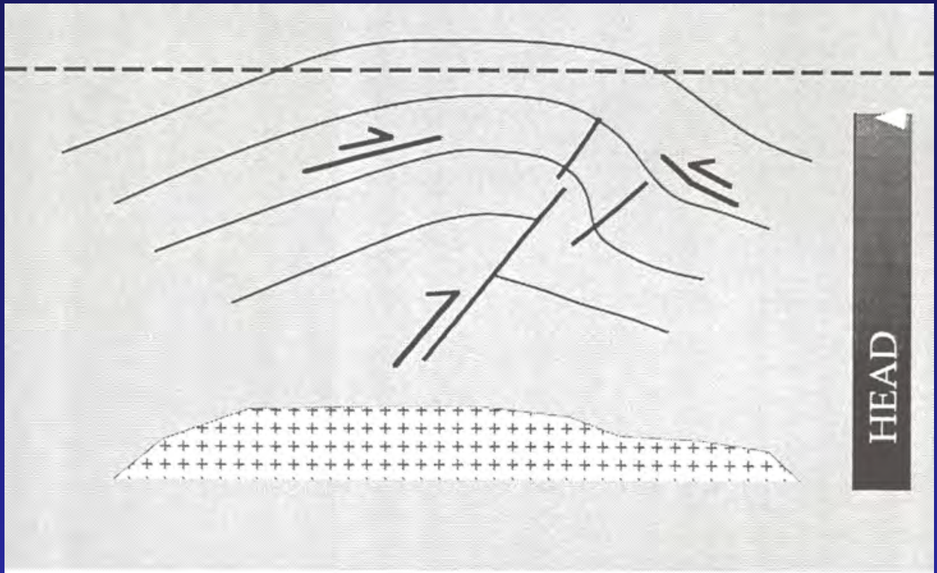
620E Bulk Sample Drive - Cut ID 1530 - 13.1g/t Au, 0.9% Cu

CERCAMS TAG Workshop 2003

Telfer: structural interpretation

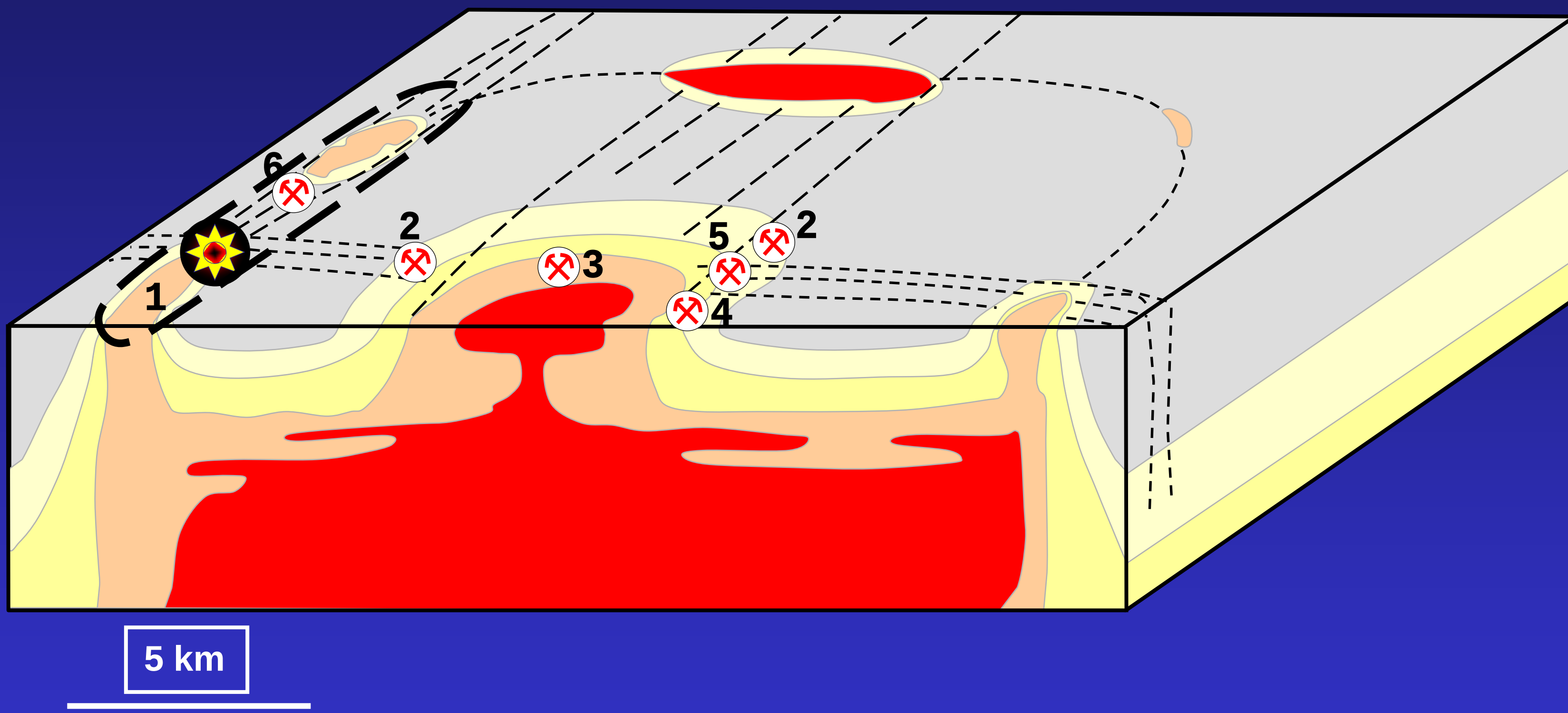


Telfer: structural interpretation



- granite acts as fluid source and heat engine
- large head gradients due to magmatic fluid and devolatilization
- fluids focussed by faults in fault-fold system, as well as by multiply reactivated layer-parallel shears
- continued compression favours layer-parallel mineralization

TAG (pluton-related) systems



Granitoid pluton

Thermal aureole

Country rocks

Key structural zones

GOLD DEPOSIT SETTINGS

1 Fort Knox

2 Sukhoi Log, Kumtor

3 Pogo, Vasilkovskoye

4 Granites-Tanami

5 Muruntau

6 Obuasi, Telfer

PLACER DOME INC

Tintina gold belt

	Ounces Gold
Pogo *Teck Corp. / Sumitomo Metal Mining Co.*	5,210,000
Fort Knox *Kinross Gold*	4,100,000
True North *La Teko Resources / Newmont Exploration*	1,310,000
Dublin Gulch Deposit *New Millennium Mining*	1,150,000
Brewery Creek Deposit *Viceroy Resources Corp.*	925,000
Ryan Lode Deposit *La Teko Resources Ltd.*	820,000
Ester Dome *(past placer production)* *Silverado Mines Ltd. / Placer Dome*	3,000,000
Golden Summit *Intl. Freegold Min. Devel. / Barrick Gold*	1,232,624
Donlin Creek *(indicated/inferred)* *Placer Dome Inc.*	6,700,000
Total	**24,447,624**

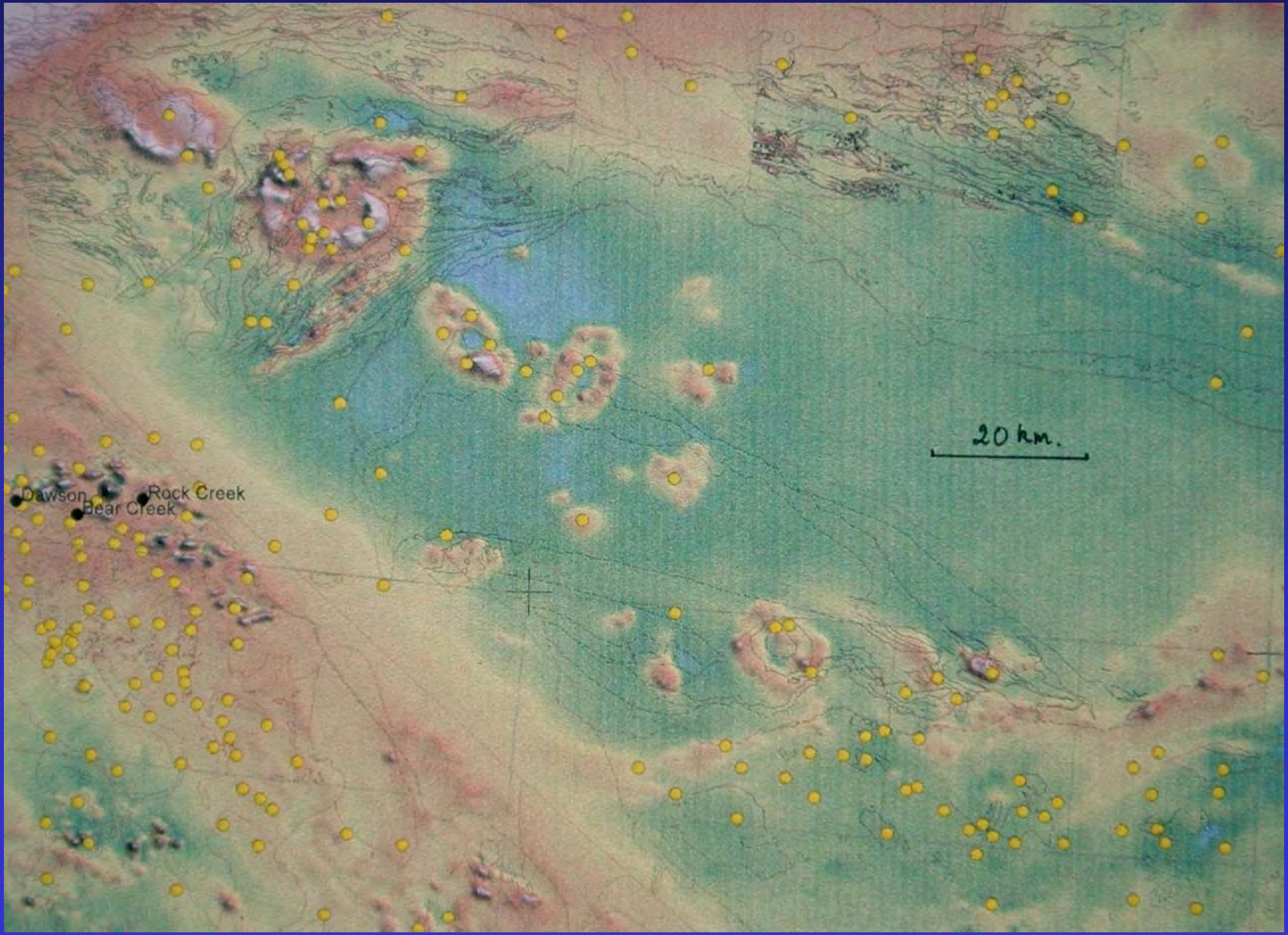
TAG: Alaska-Yukon

- Tintina gold belt
  - hosts numerous large & small hardrock & placer deposits, >80Moz. Au (production + resources)
    - eg. Fort Knox, Pogo, Donlin Creek, Ester Dome, etc.
  - hardrock deposits range from pluton-hosted through inner aureole to outer aureole types
  - comprises gneissic (?Lower Palaeozoic?/Precambrian) basement, deformed Palaeozoic shelf successions
    - fold thrust deformations & regional metamorphism
    - belt parallel & transverse structures
      - mainly pre-pluton?

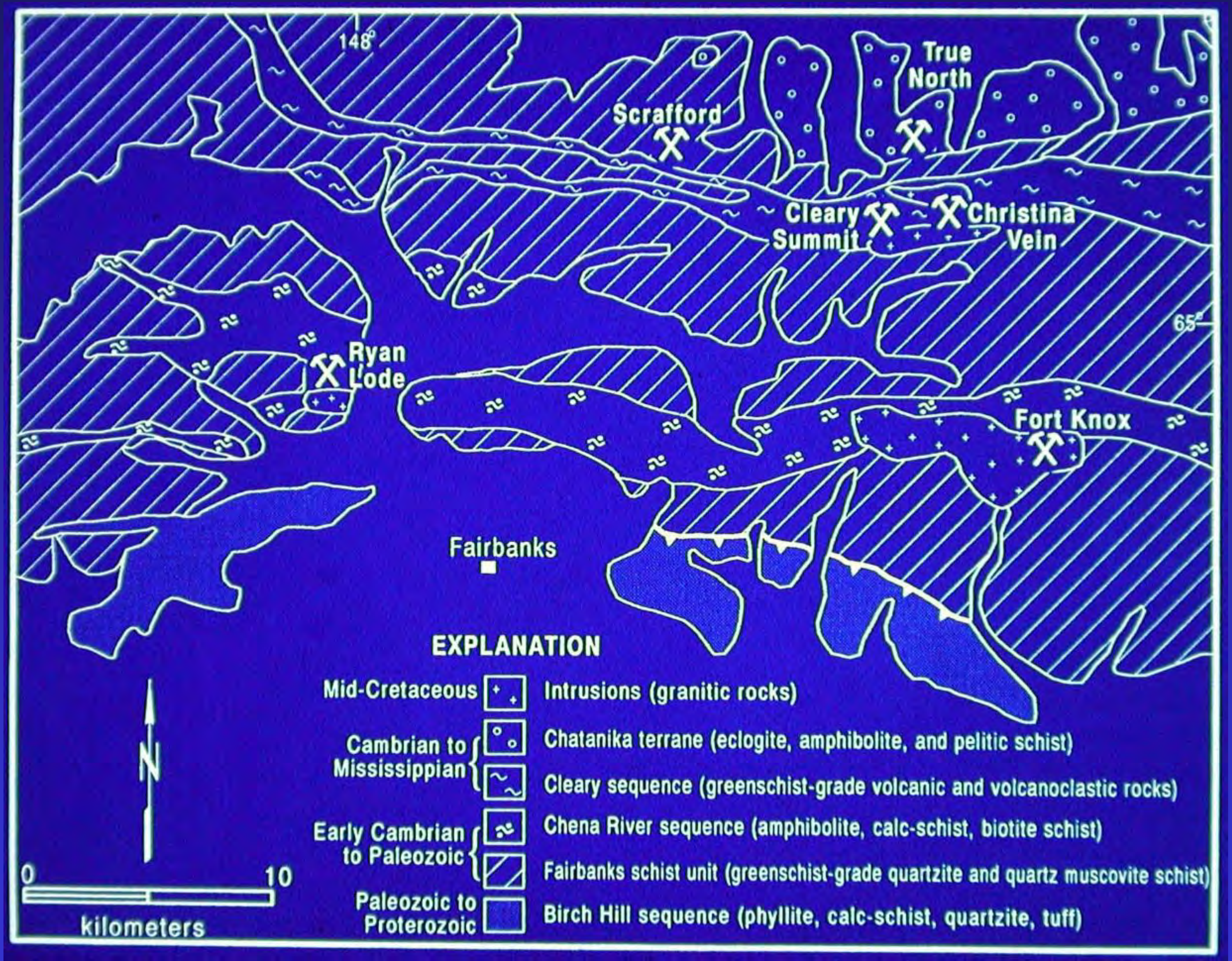
TAG: Alaska-Yukon

- intruded by extensive Cretaceous, intermediate to felsic plutonic suites
  - postdate major regional deformation(s)
  - high temperature, fractionated, ilmenite series (I-type) magmatism most abundant
    - peraluminous felsic intrusions also occur
- gold mineralization spatially & temporally associated with Cretaceous intrusive suites
  - intrusion-hosted & intrusion margin eg.
    - Fort Knox: pluton top; Au-Bi
  - inner aureole (medium-high temperature) eg.
    - Pogo & others: Bi, As, W anomalous
  - outer aureole (metasediments & small intrusions)
    - Dublin Gulch: As, Sb
    - Ag-Pb-Zn deposits (eg. Keno Hill), more distal

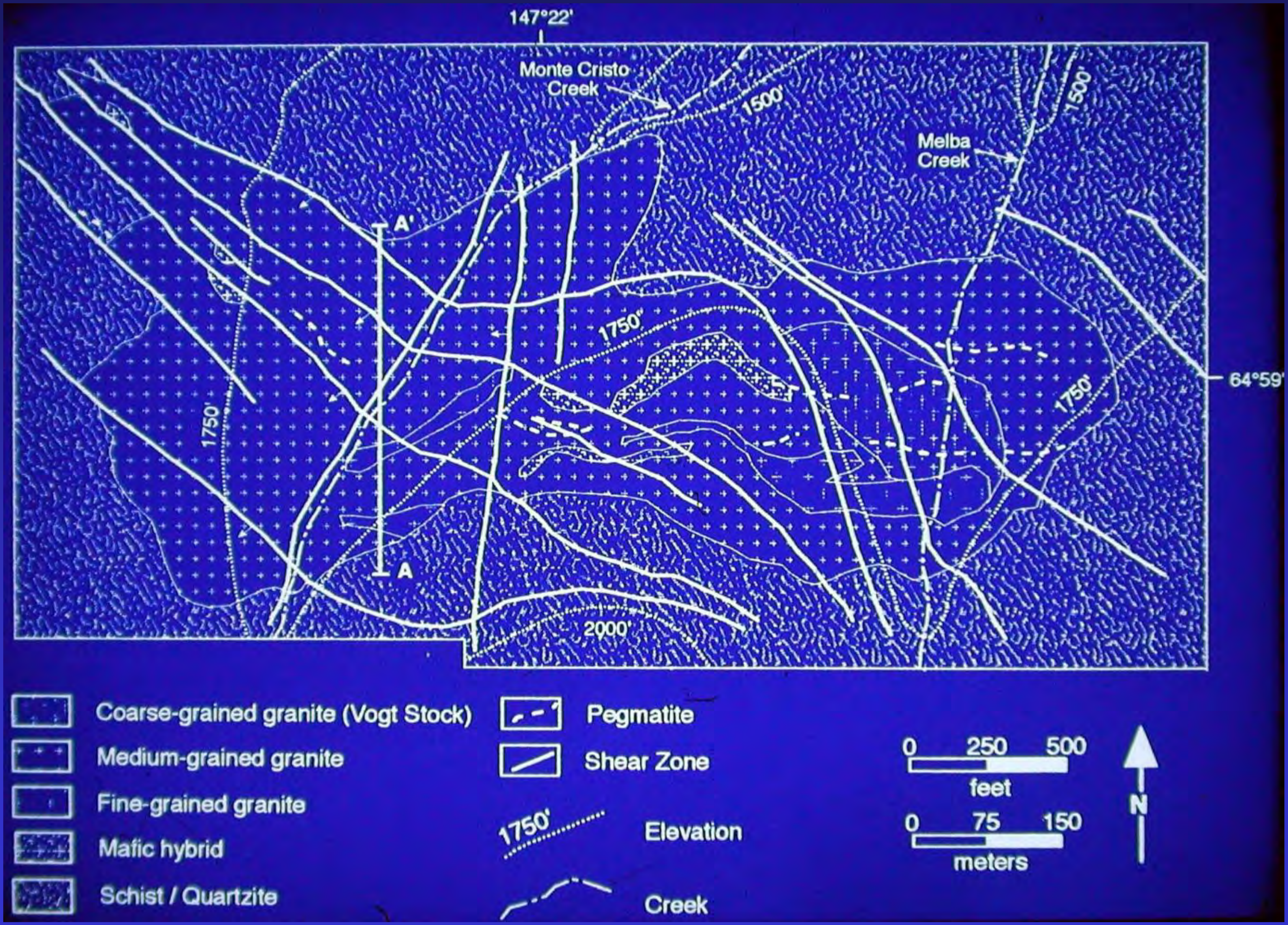
Tintina belt: pluton roof zones & magnetics



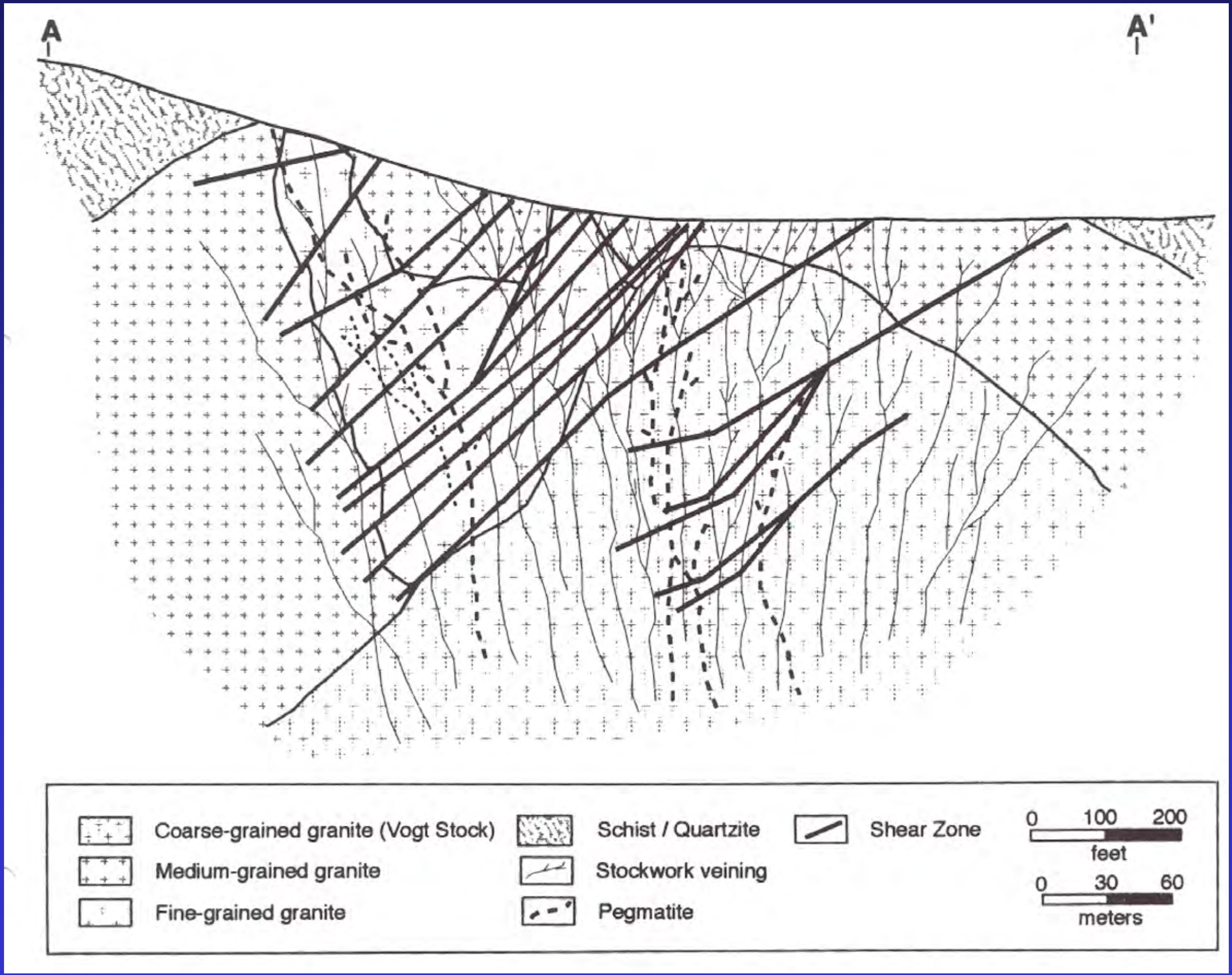
Fort Knox district



Fort Knox surface



Fort Knox: cross section



Fort Knox: gold distribution

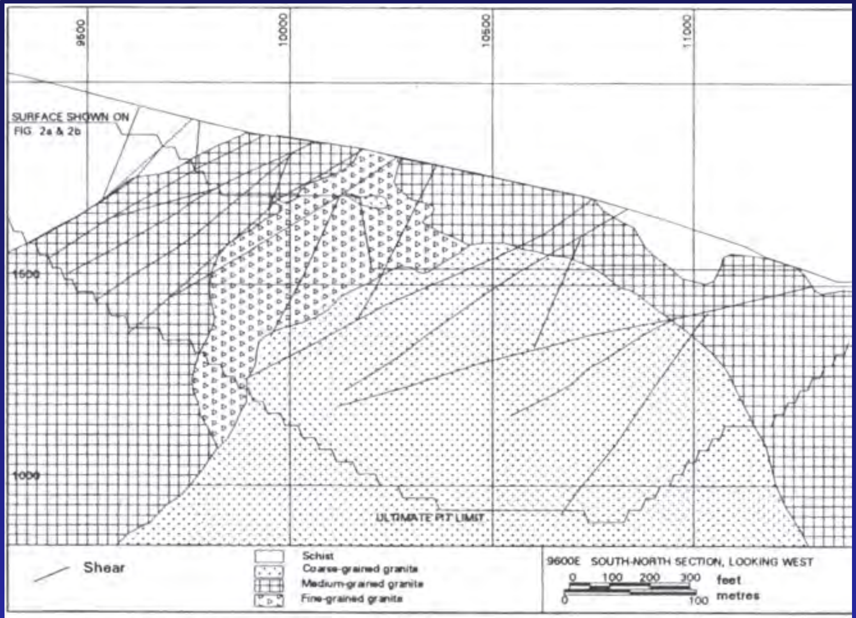


Fig 78 a Geologic cross- section -- 9600E South-North, looking West.

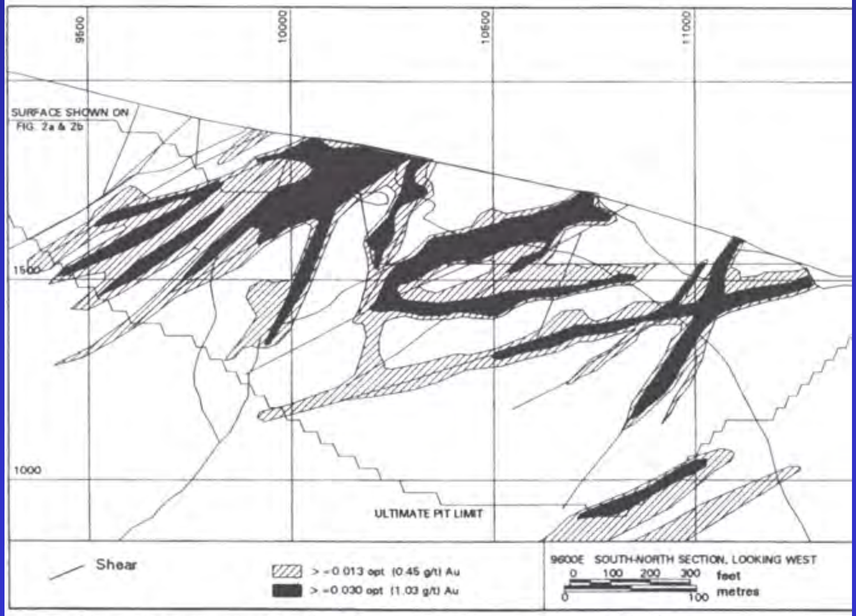
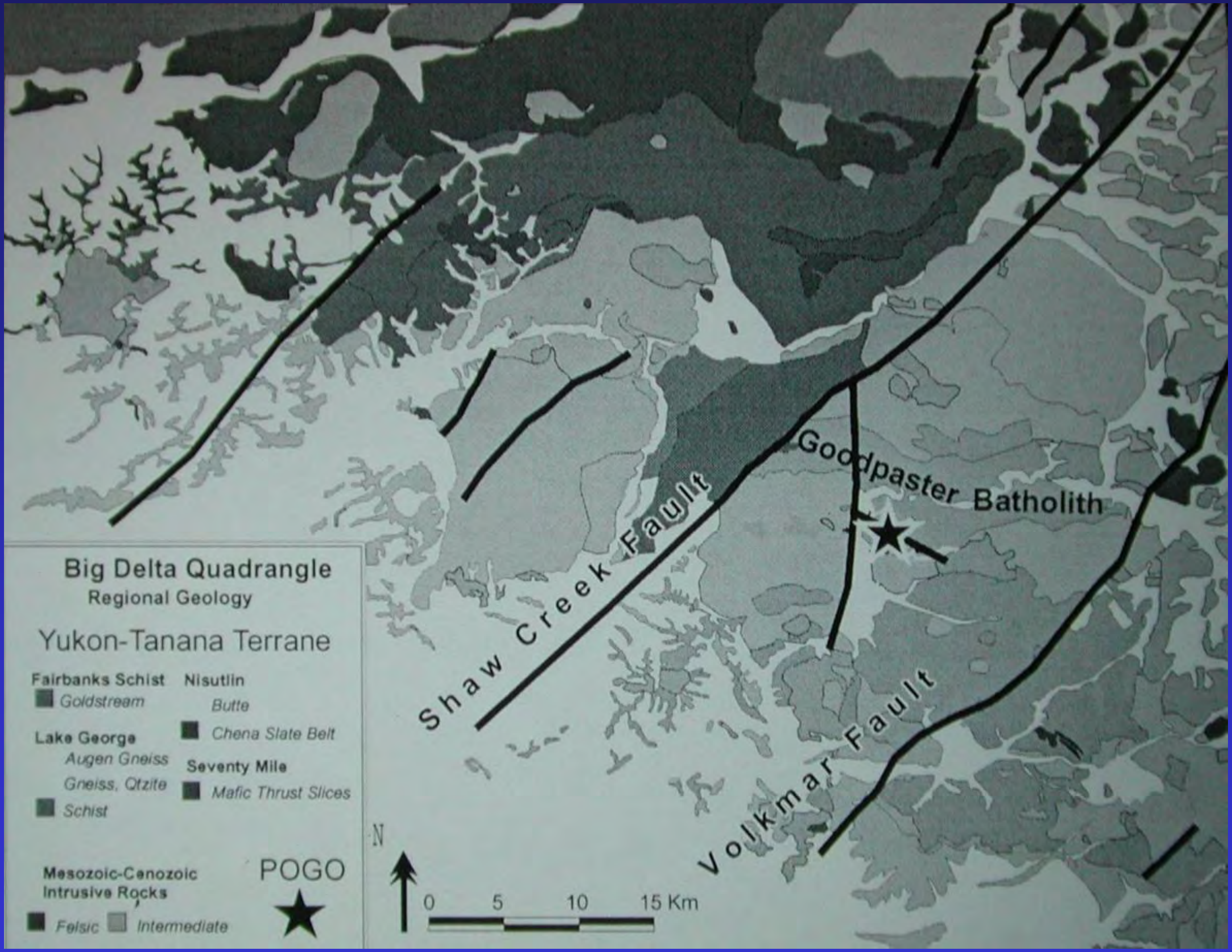
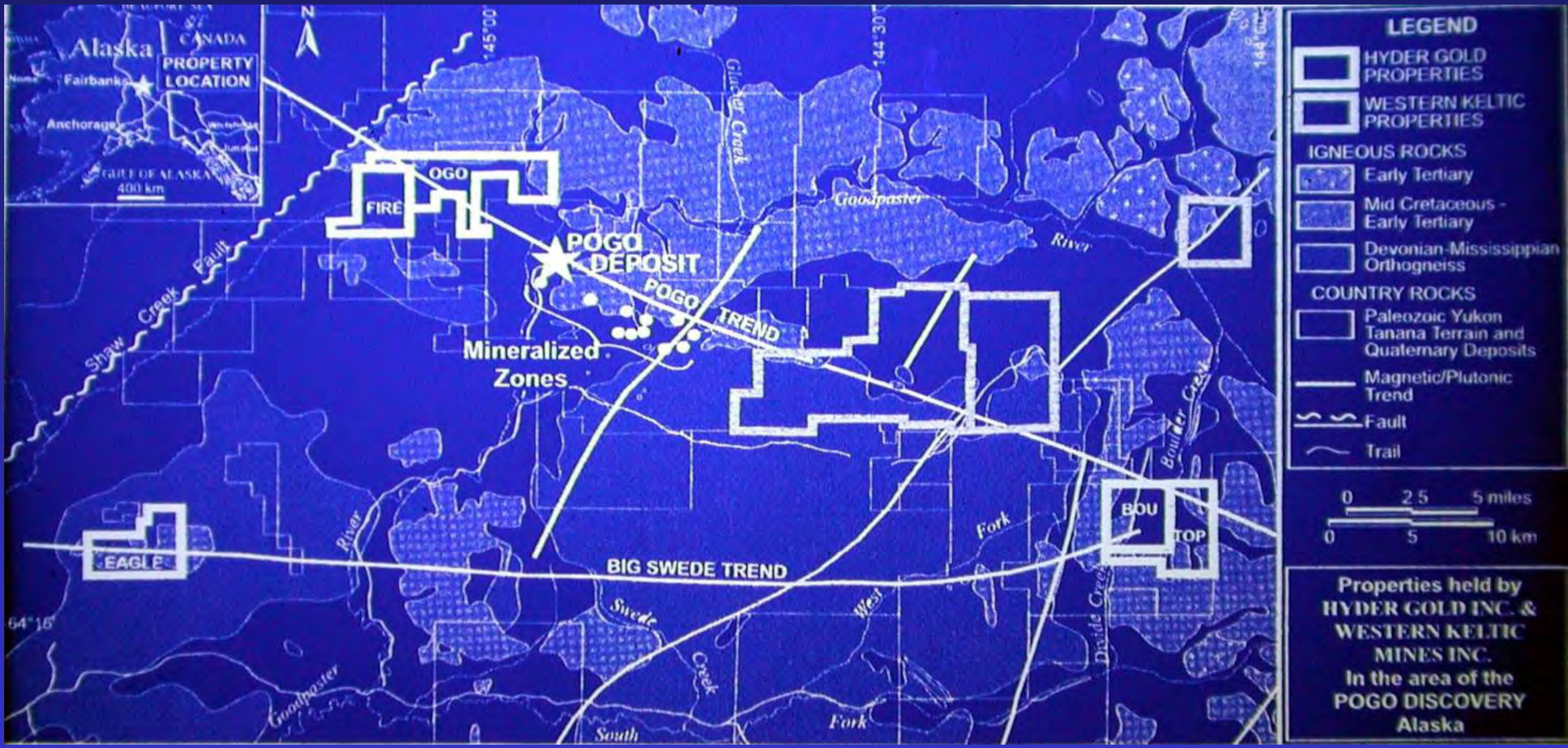


Fig 78 b . Contoured gold values from blastholes and 30 foot drillhole composites. 9600E South-North cross-section, looking west.

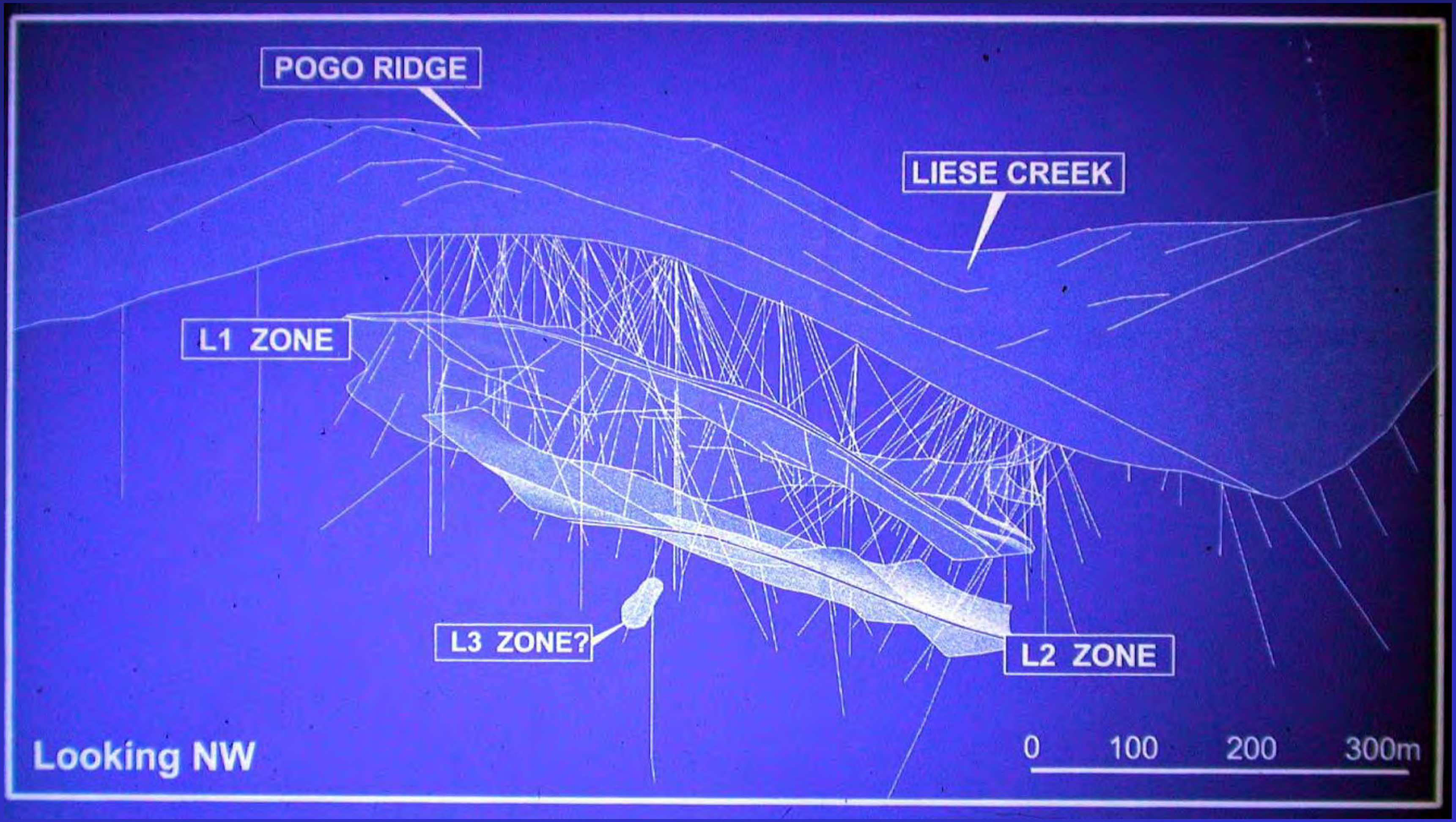
Pogo: regional geology



Pogo district geology



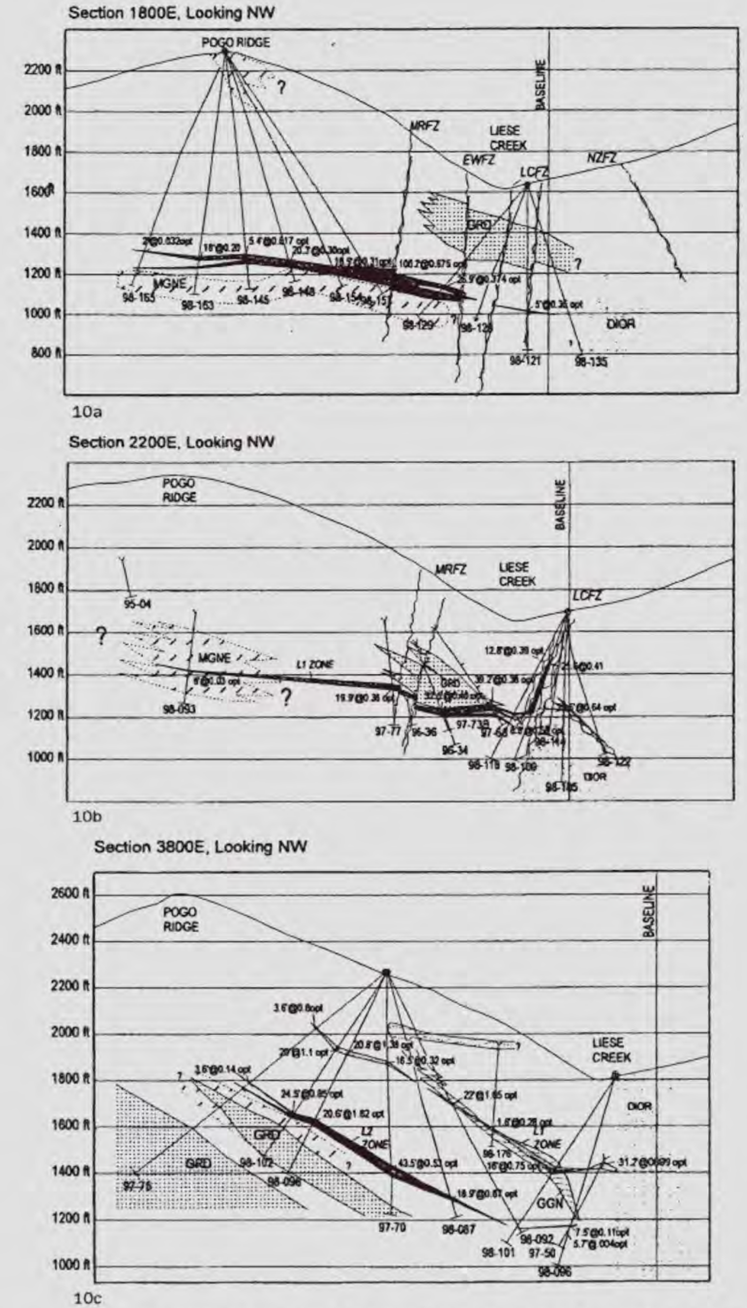
Pogo: ore zones



CERCAMS TAG Workshop 2003

PLACER DOME INC

Pogo: drill sections



Representative cross sections through the Liese zone. See Figure for locations of section lines. DIOR = post-mineral diorite, MGNE = mafic gneiss, GRD = granite dike, GGN = Granite gneiss, MRFZ = Mid-Ridge fault zone, LCFZ = Liese Creek fault zone, EWFZ = East-West fault zone, NZFZ = North Zone fault zone.

Pogo:
Bi, As, Ag

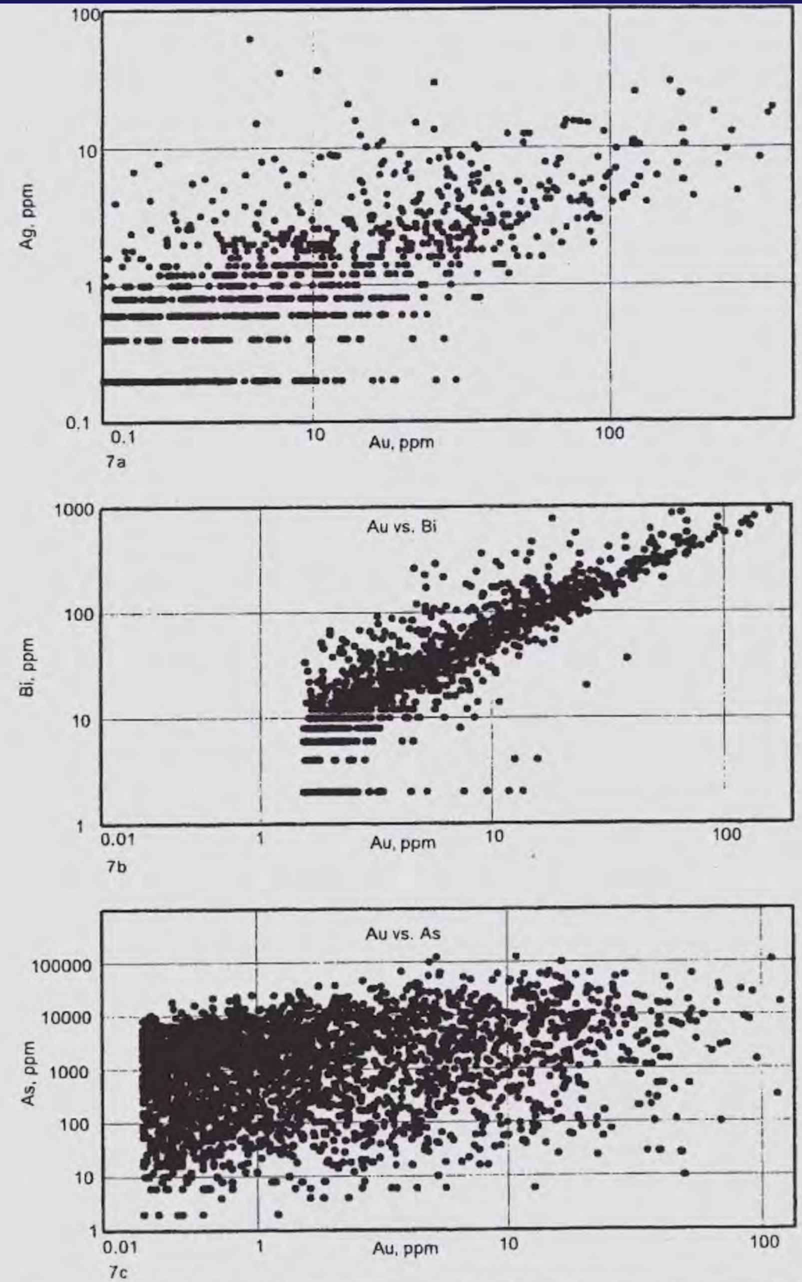
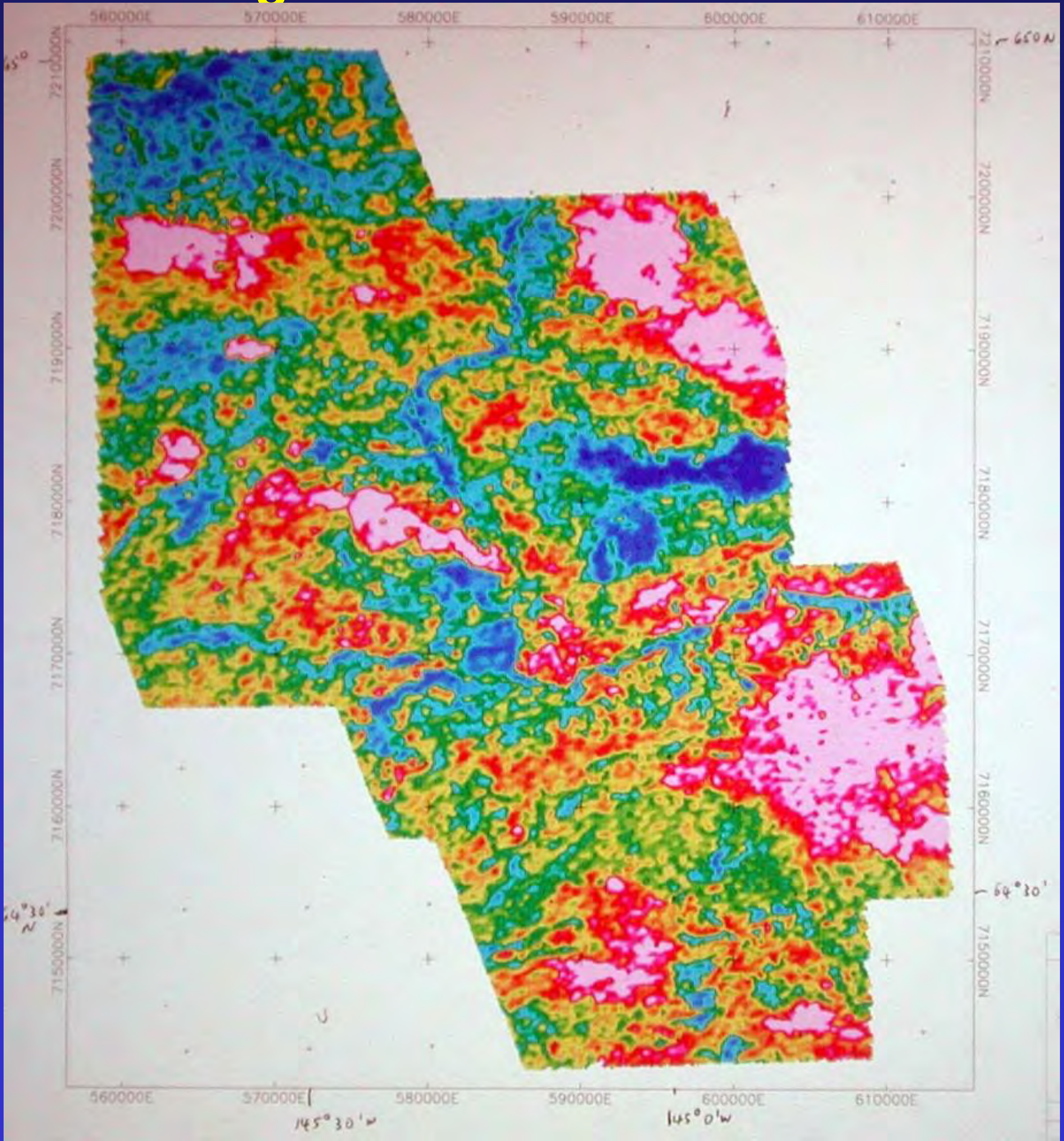


Figure 7. Correlation of Au with Ag, Bi and As. **a.** Au vs. Ag; 1,014 samples

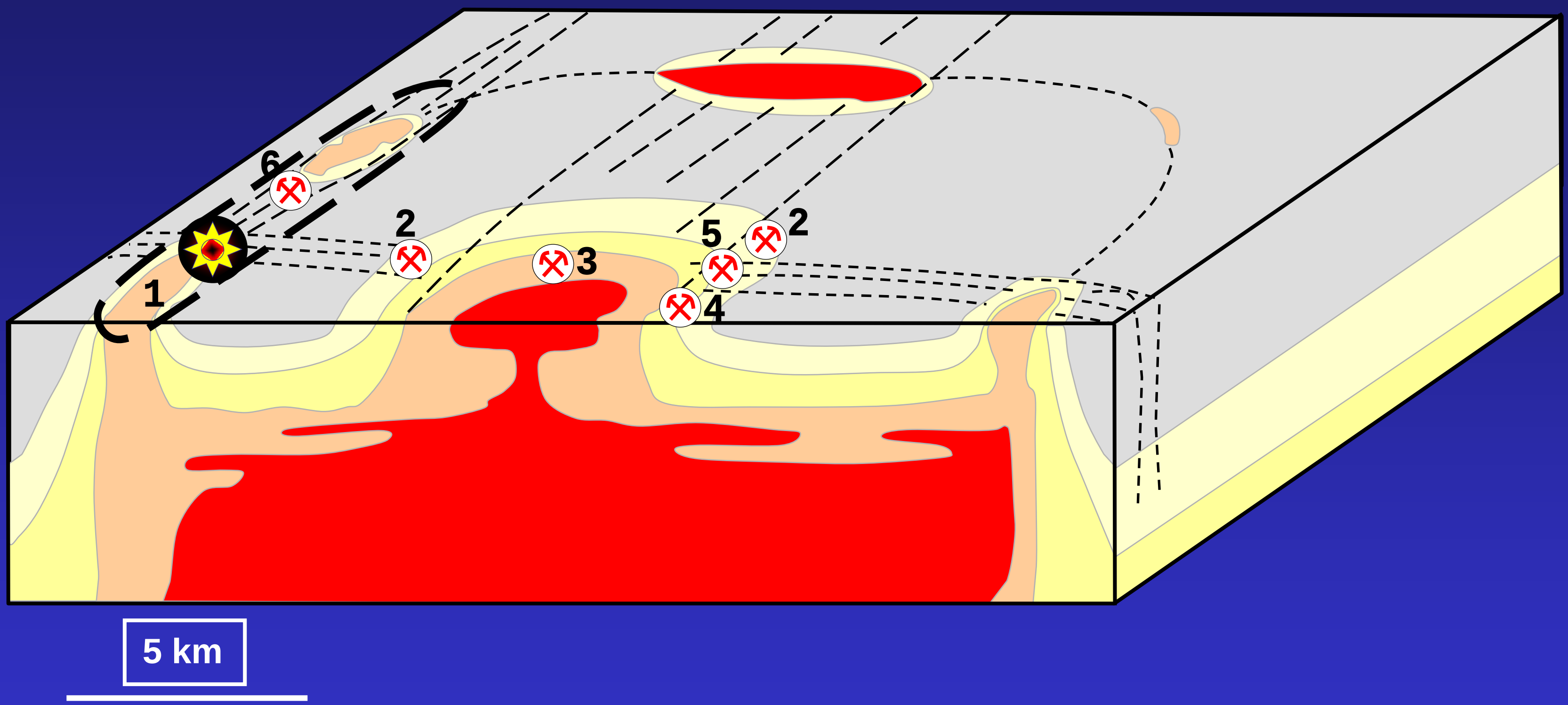
Pogo: K/Th radiometrics

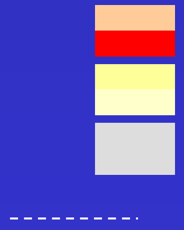


TAG: Alaska-Yukon

- commonly shallow-dipping & plunging mineralized zones (Pogo, Fort Knox)
  - characteristic of pluton tops & overlying roof zones; massive vs. schistose rocks
  - apophyses/cupolas above main bodies of plutons?
  - exploration potential
- extensive Cretaceous pluton roof zones preserved
  - unusually wide thermal aureoles (eg Dublin Gulch)
  - map patterns of small felsic intrusions
  - ?gravity & magnetic signatures
- significance of regional structures?
- note subtle alteration & lack of veining in some pluton-hosted/proximal deposits
  (eg.Timbarra & Golden Mountain, Eastern Australia)

TAG (pluton-related) systems

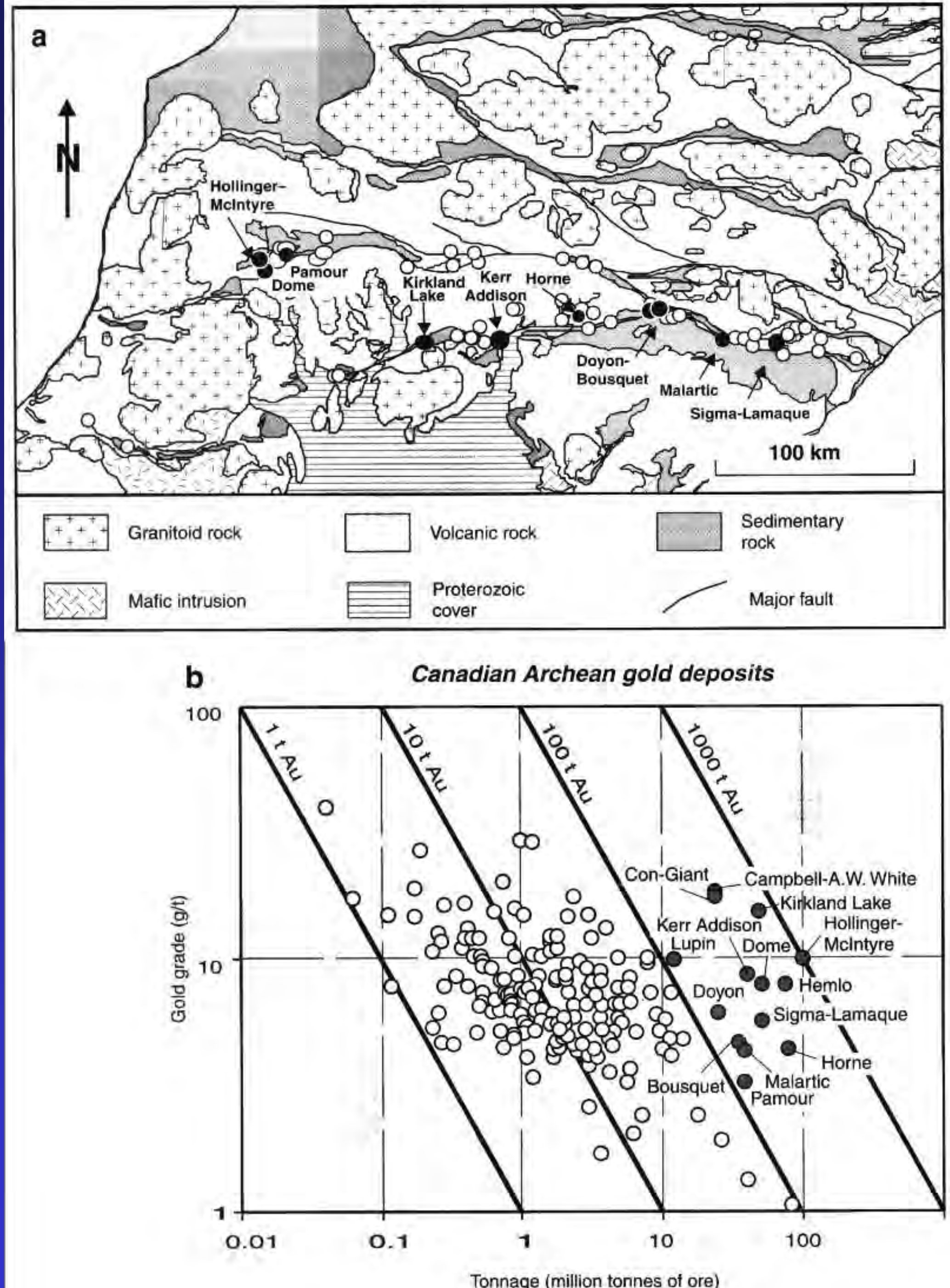




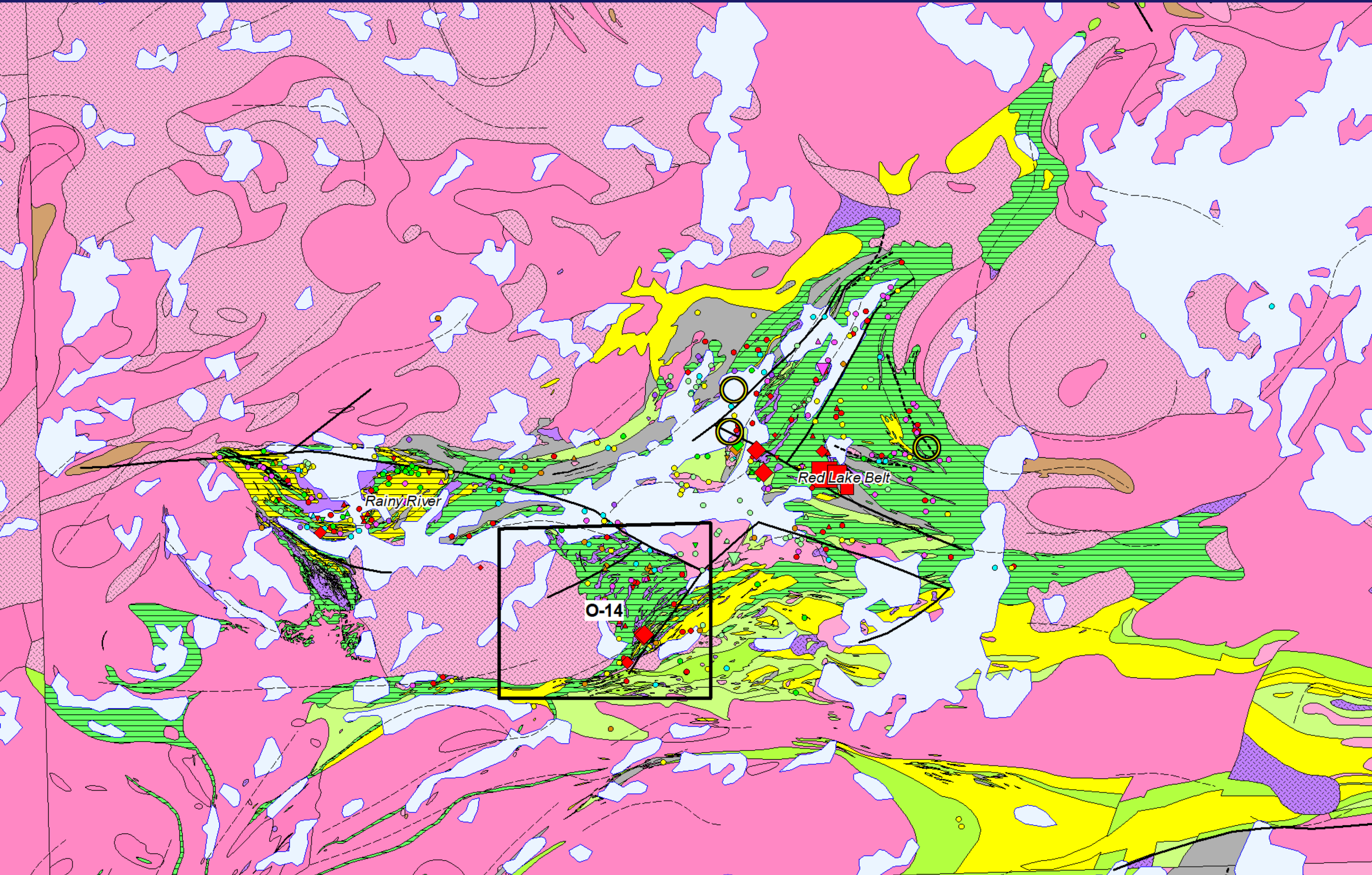
GOLD DEPOSIT SETTINGS

1 Fort Knox
2 Sukhoi Log, Kumtor
3 Pogo, Vasilkovskoye
4 Granites-Tanami
5 Muruntau
6 Obuasi, Telfer

Major Canadian Archaean gold deposits



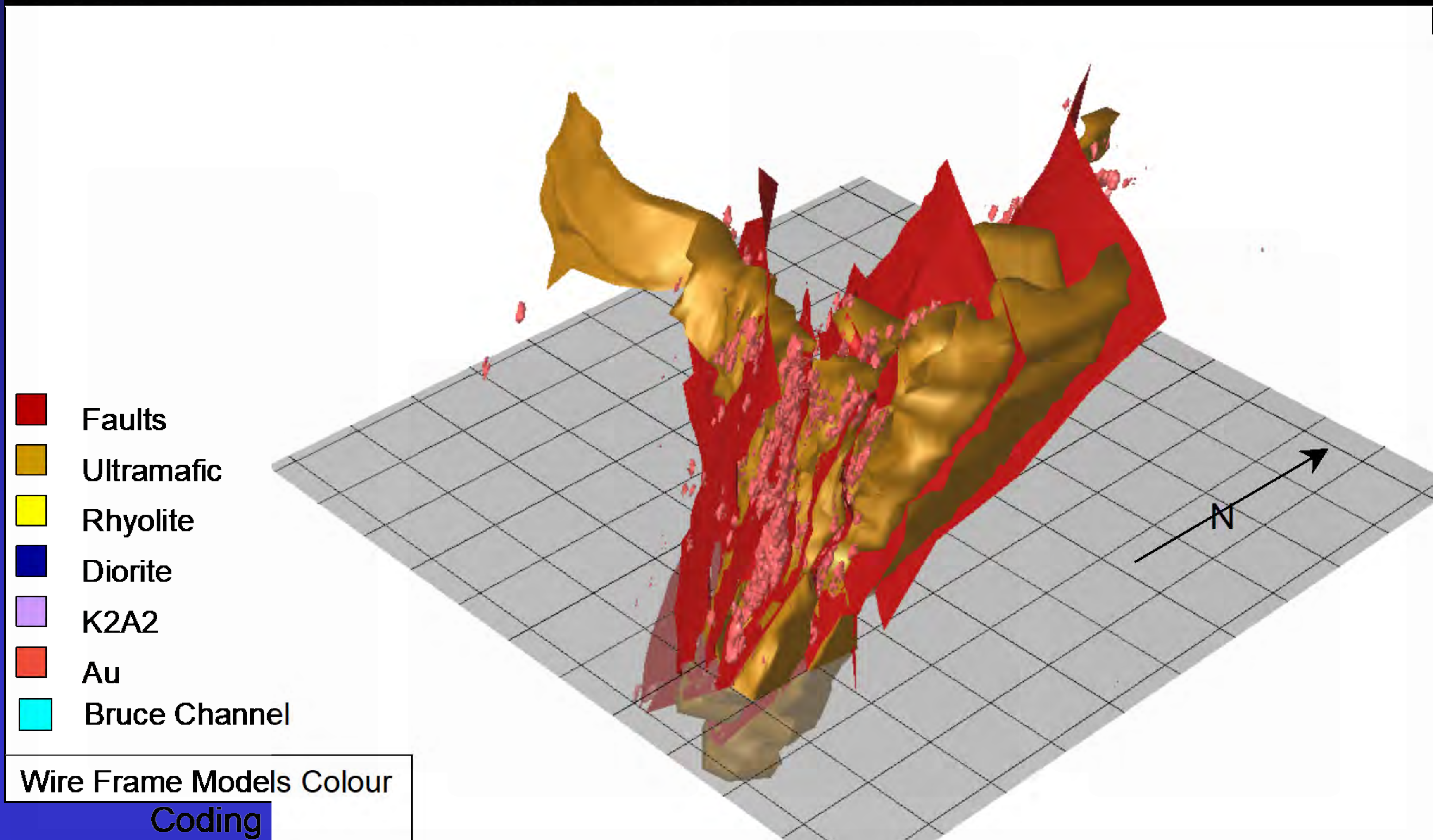
Red Lake: geology & gold occurrences




Goldcorp
RED LAKE RICHES
Re-Submission for the Finals
Tayor Wall
& Associates
FRACTAL GRAPHICS
LEVEL 34
The Challenge
6 MILLION MORE OUNCES

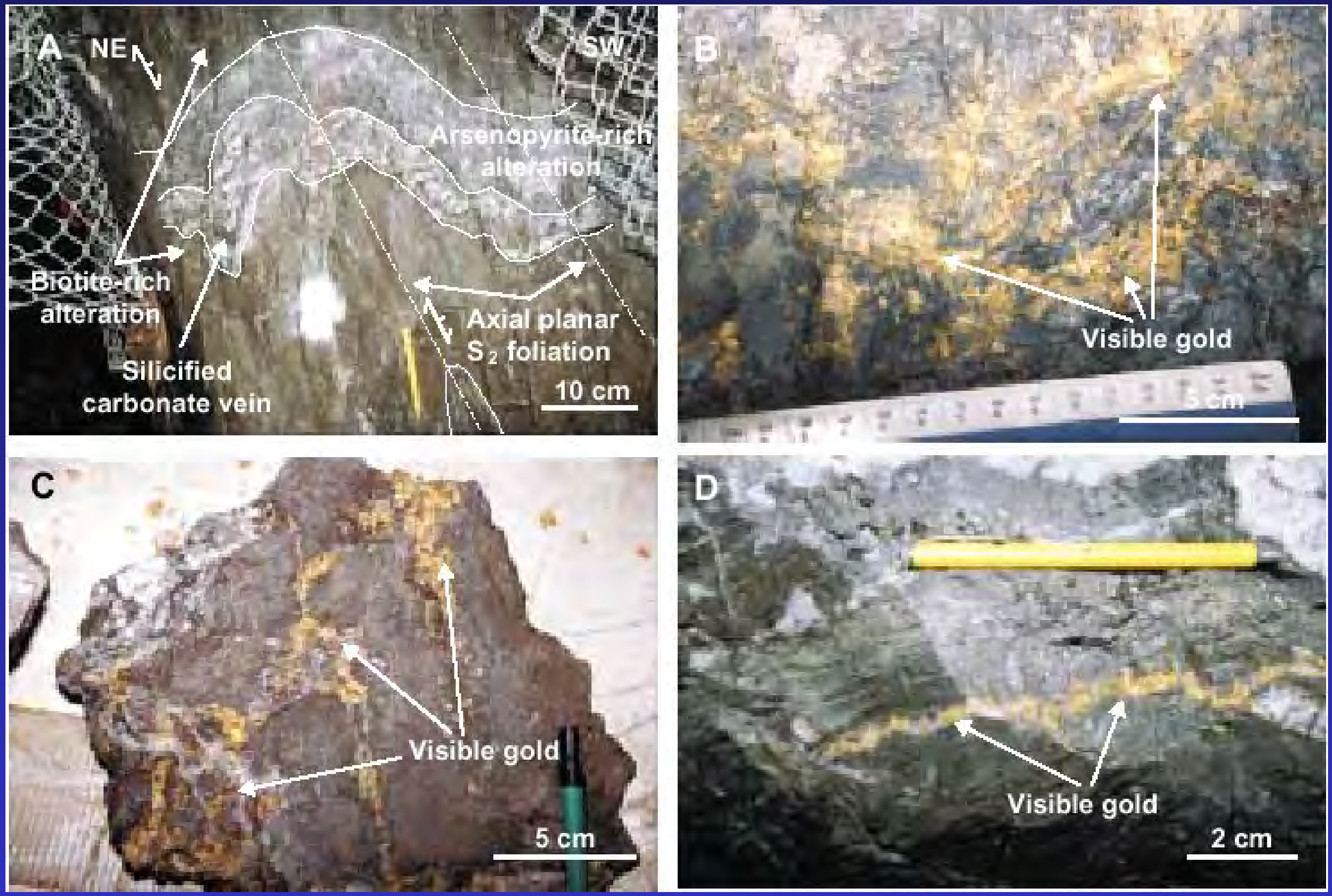
Campbell mine: geology

re_4_2_1_C 3D view showing 0.1 oz gold isosurface, faults and ultramafics



Natural Resources Canada

Campbell-Red Lake: geology



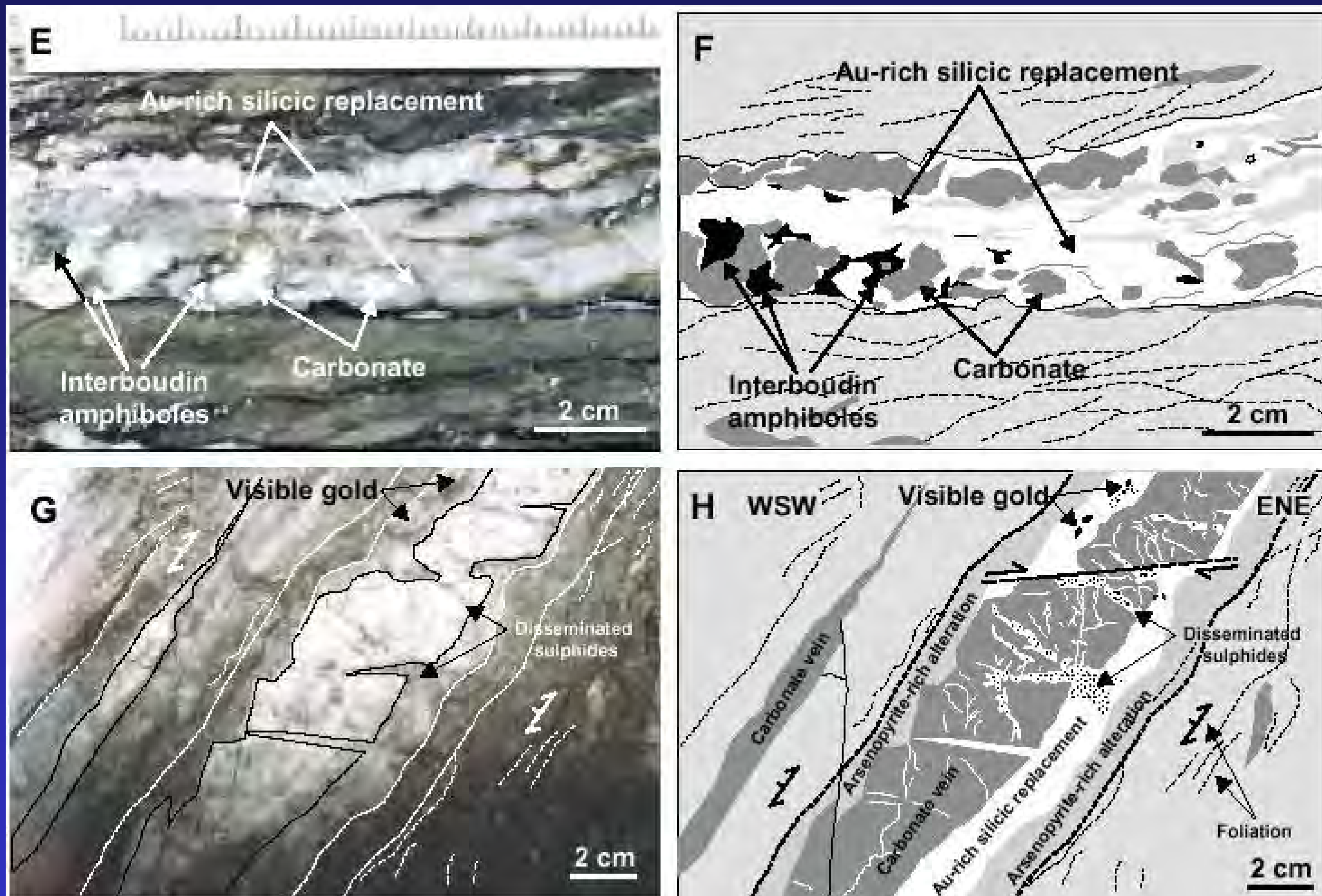
A) Shallow-dipping high-grade arsenopyrite-rich silicified carbonate vein and selvages folded by F_2, section view

B) Visible gold coating late, shallow-dipping fracture

C) Gold veinlets stockwork

D) Extensional carbonate veinlet replaced by quartz containing abundant visible gold and cutting replacement-breccia style ore

Natural Resources Canada



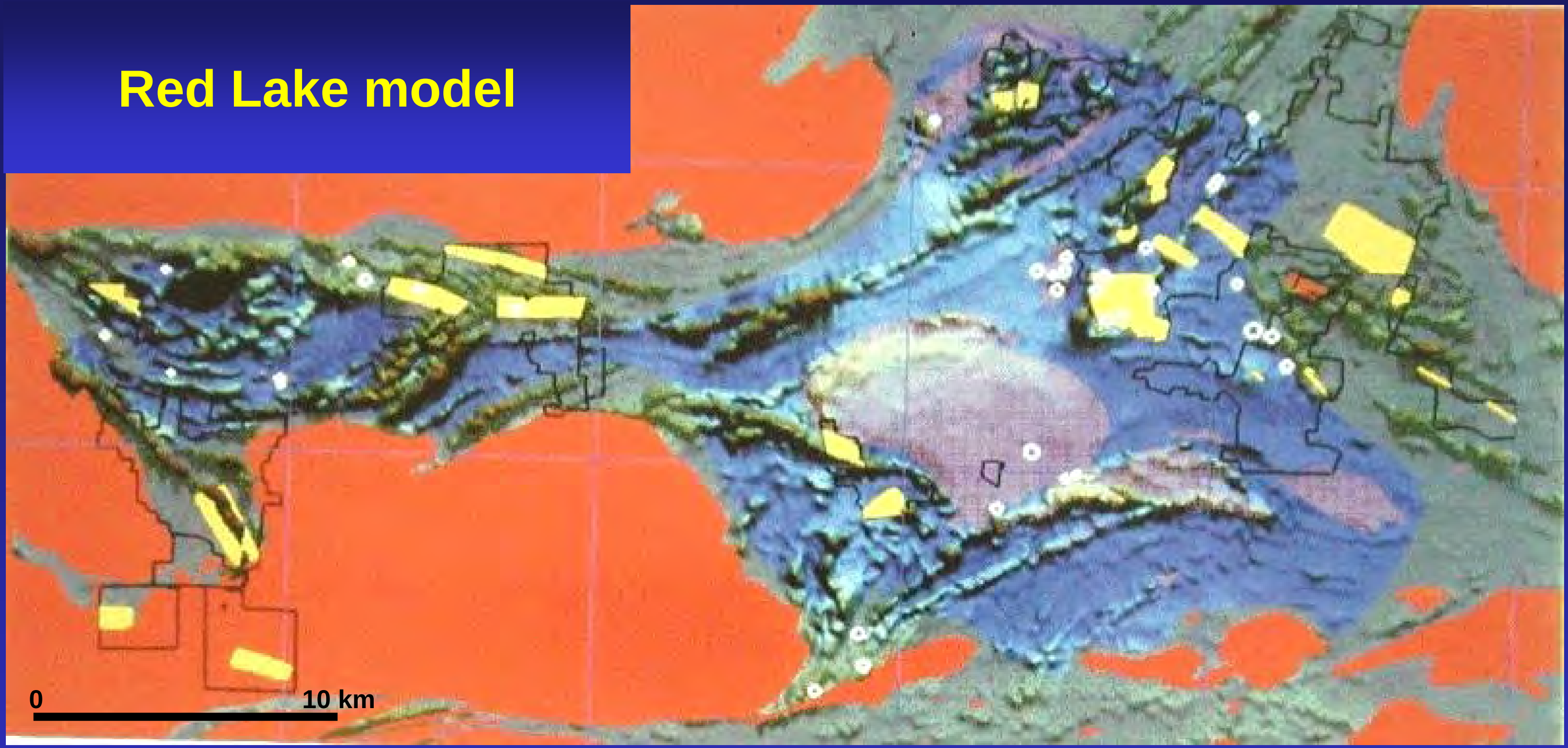
E) **Gold-rich quartz replacing already boudinaged carbonate vein as well as the amphibole in pull-aparts**

F) Figure 5F is a drawing of Figure 5E

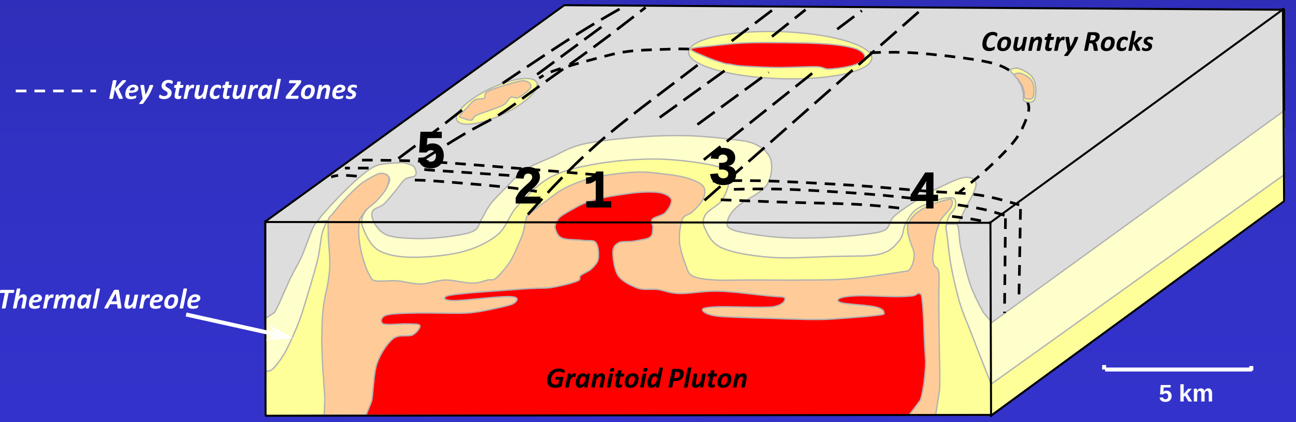
G) **Boudinaged steeply dipping carbonate vein partly replaced by Au-rich silica with quartz filling pull-aparts and both carbonate and quartz being locally cut by subhorizontal shear plane, hanging-wall-side-up, section view**

H) Figure 5H is a drawing of Figure 5G

Red Lake model



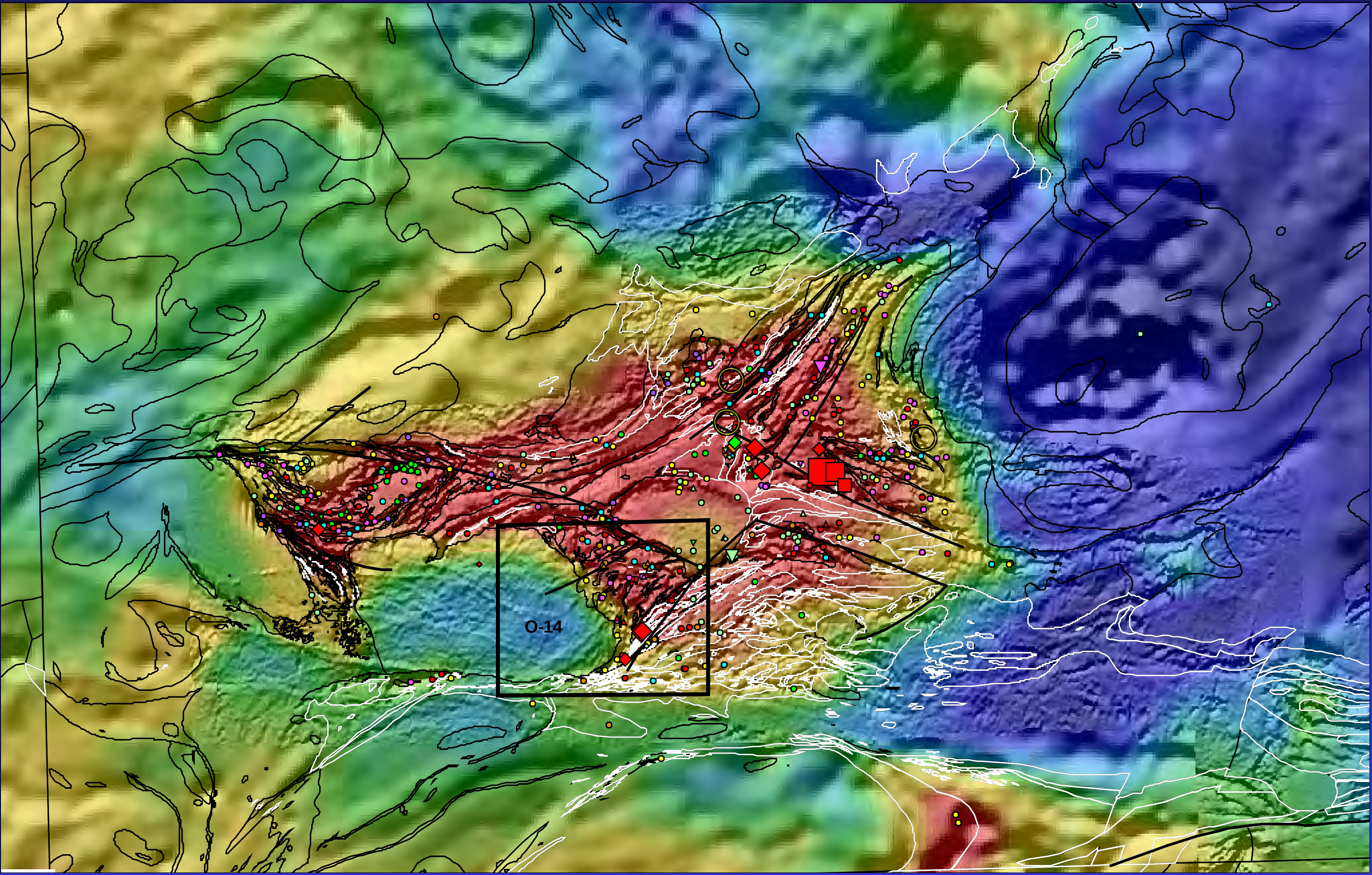
NW illuminated Total Magnetic Intensity background to 2700Ma Plutons and Amphibolite facies
Gold exploration targets & Gold deposits (white circles)



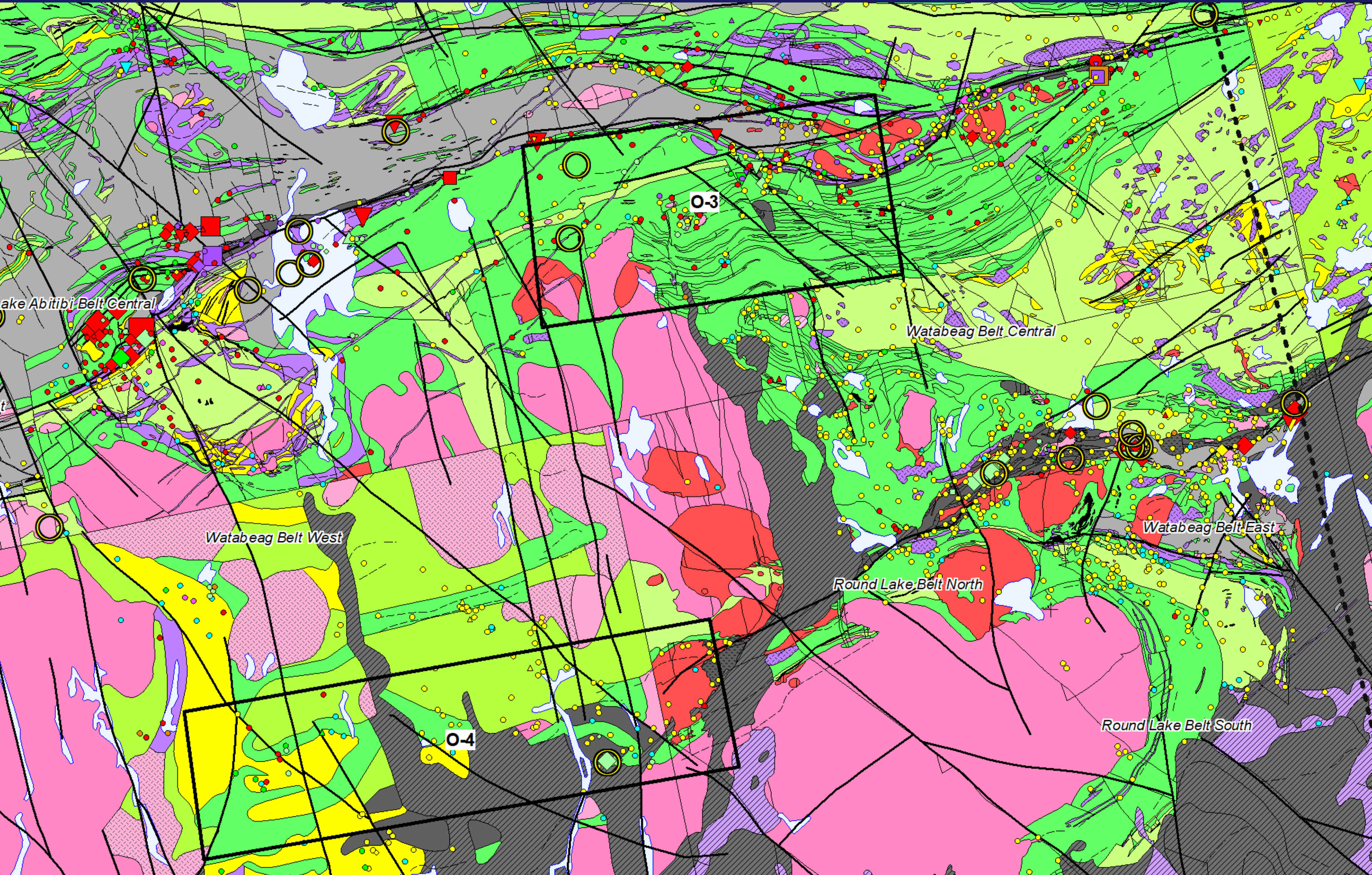
Pluton Roof Zone Gold Deposits

1 Vasilovskoye
2 Pogo
3 Madsen
4 Red Lake
5 Telfer

Red Lake: gravity on TMI, geology outline, gold occurrences



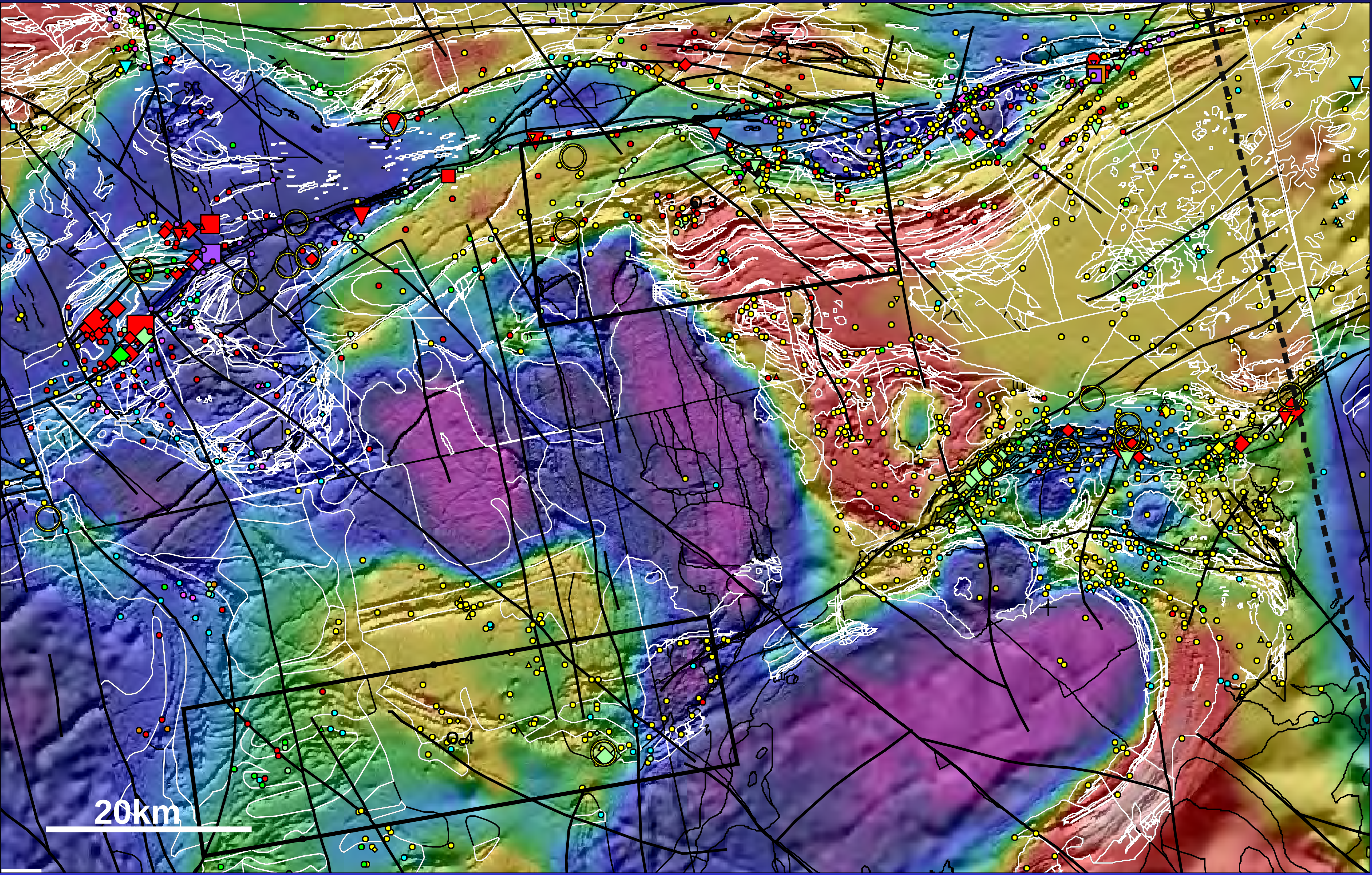
Timmins : geology & gold occurrences



CERCAMS TAG Workshop 2003

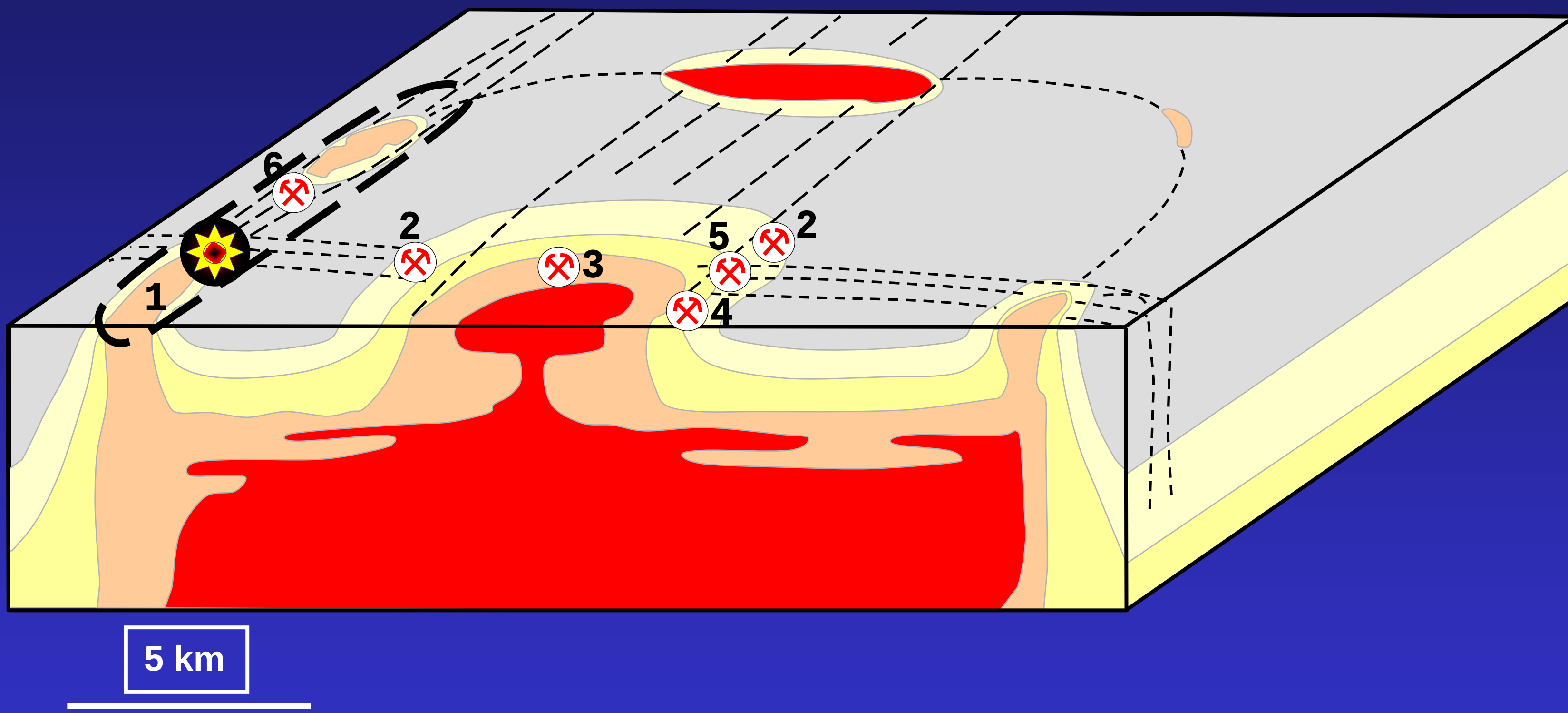
PLACER DOME INC

Timmins: gravity on TMI, geology outline, gold occurrences




WALLABY
(the 'tale' continues...)

TAG (pluton-related) systems



Granitoid pluton

Thermal aureole

Country rocks

Key structural zones

GOLD DEPOSIT SETTINGS

1 Fort Knox

2 Sukhoi Log, Kumtor

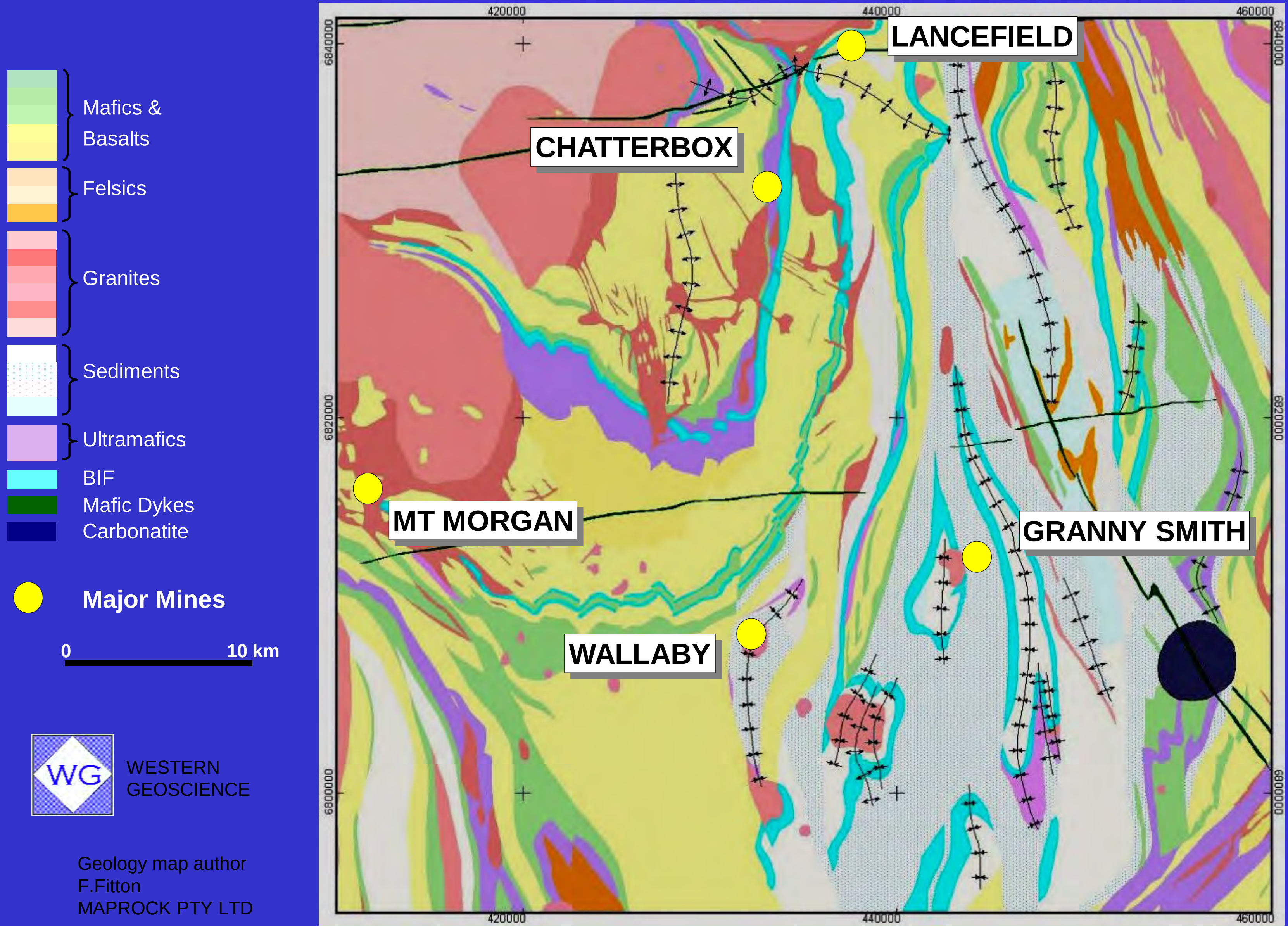
3 Pogo, Vasilkovskoye

4 Granites-Tanami

5 Muruntau

6 Obuasi, Telfer

LAVERTON Geology

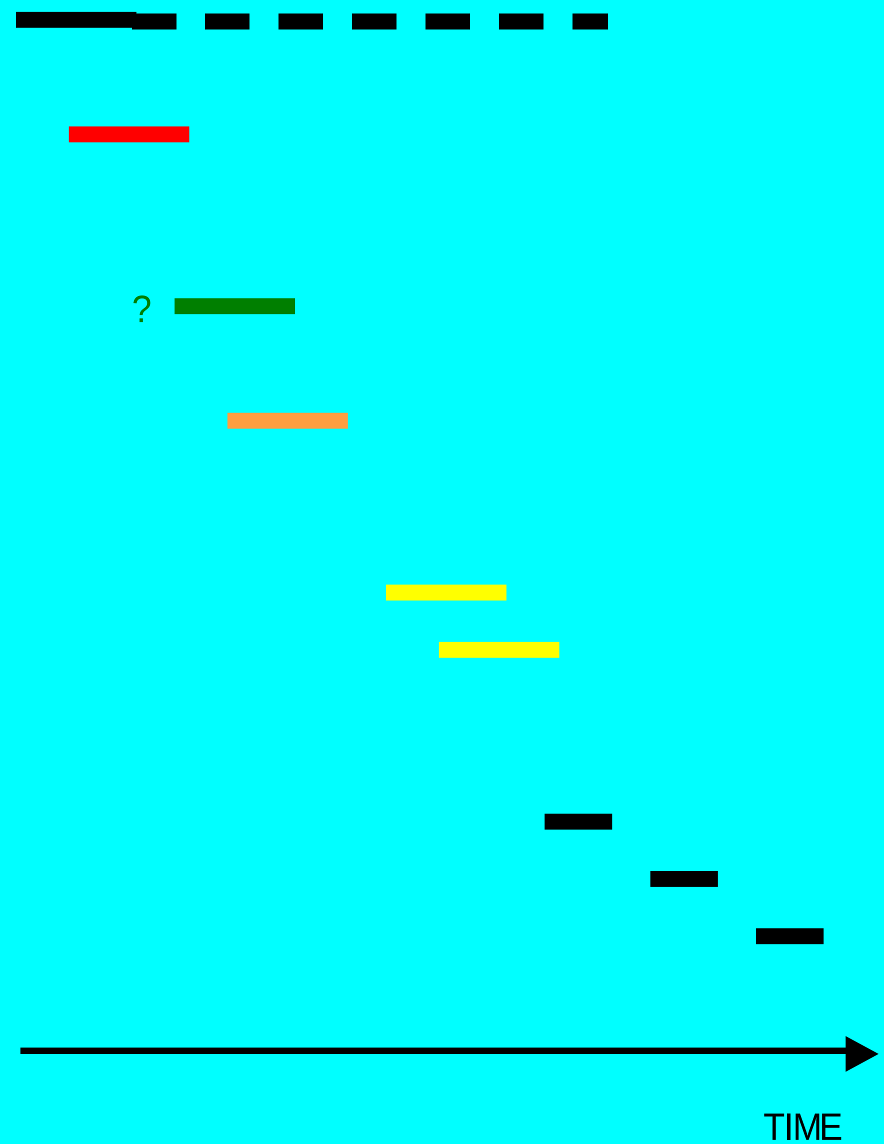


Geology map author
F.Fitton
MAPROCK PTY LTD

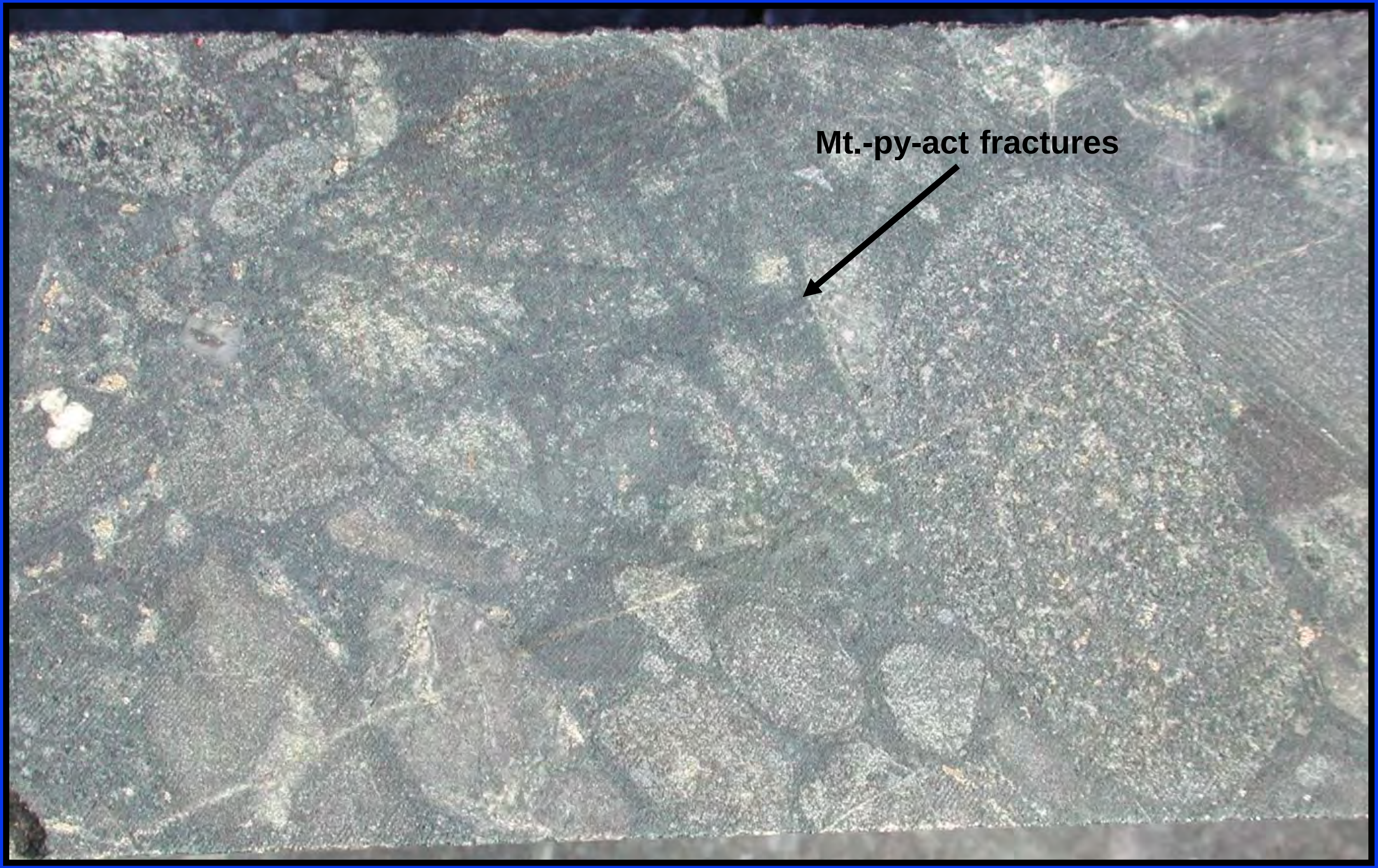
Wallaby : Event paragenesis

EVENT	CONDITIONS
1 Regional metamorphism	Lower greenschist T~300-350°C, P~2kb
2 Intrusives	High-T (~1000°C) Alkaline suite, lamprophyres
3 Act-mt event	
3a Act-mt alteration	T~450°C, oxidised S-bearing fluid
3b Carb. veins (calc-sil., cal-bio-sulps.)	T~?550-400°C, oxidised S-bearing fluid
4 Gold ore event	T~350°C, oxidised Au-S-bearing fluid
4a Biotite alteration	
4b Carb-gold alteration	
5 Deformation	Ductile-brittle, lower greenschist, T~300-350°C
6 Lamprophyres	High-T
7 Faulting	Brittle, low-T, varied clasts

RELATIVE TIMING

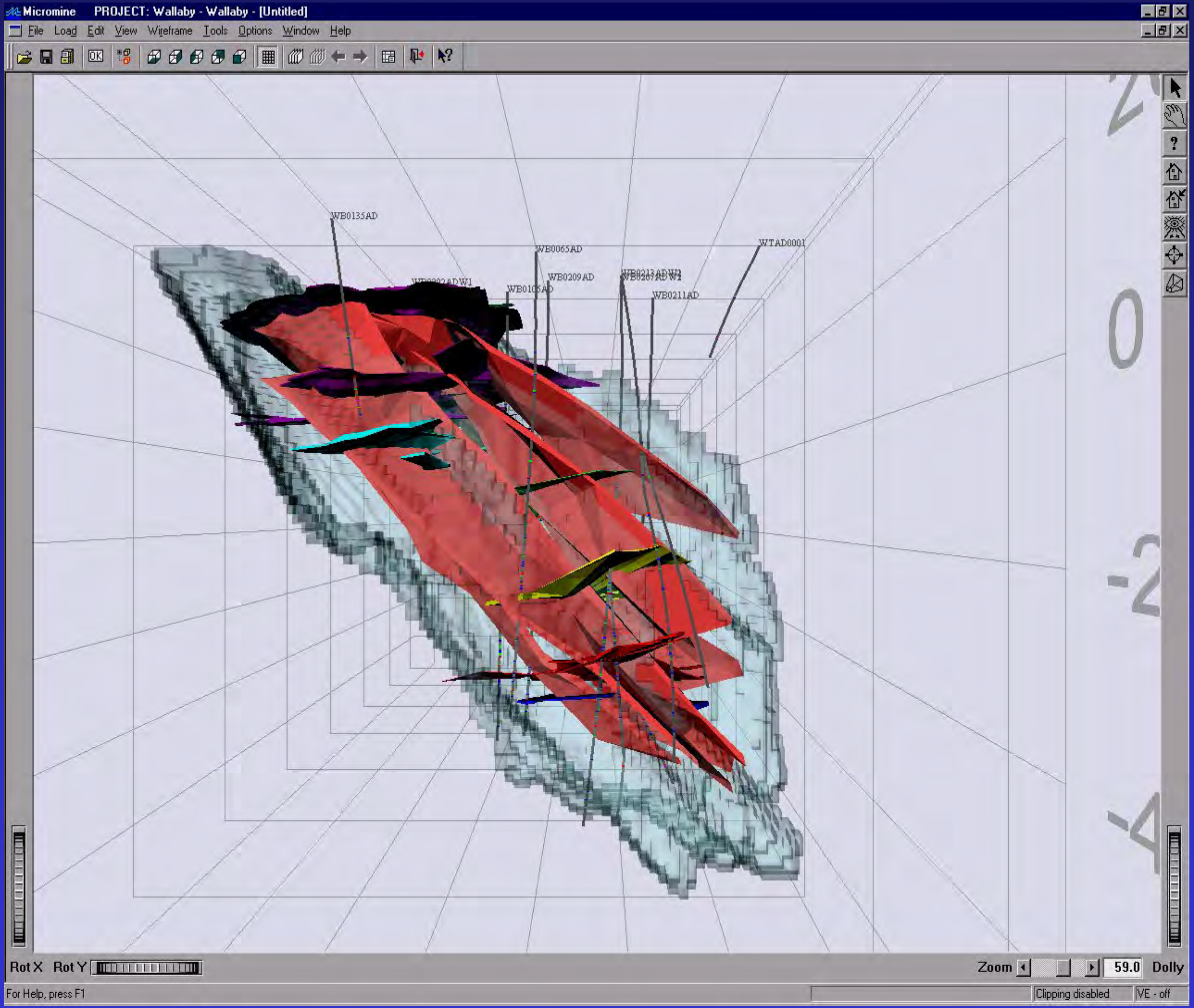


Wallaby: Mt.-py-act. alteration

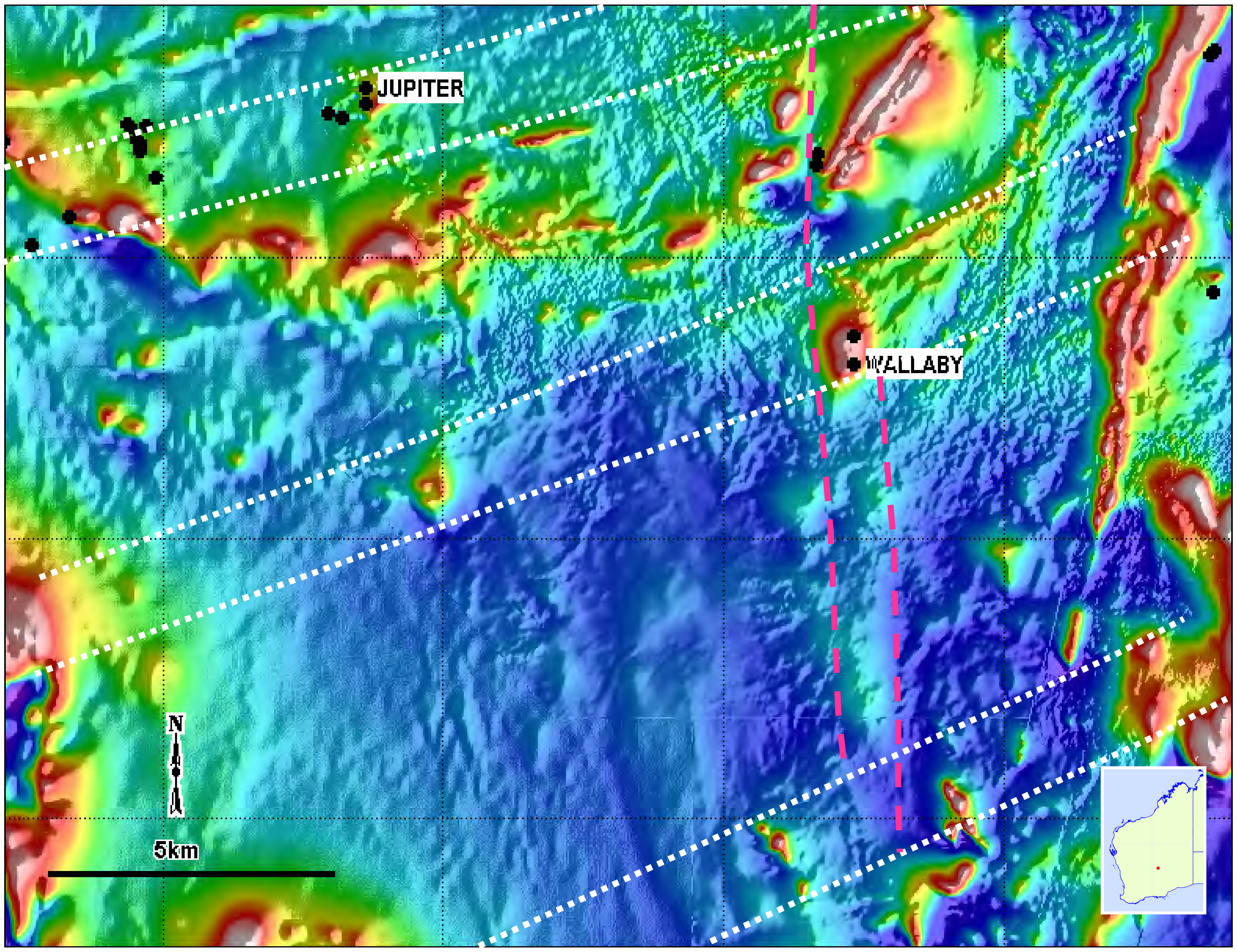


WB0207ADW1 879m

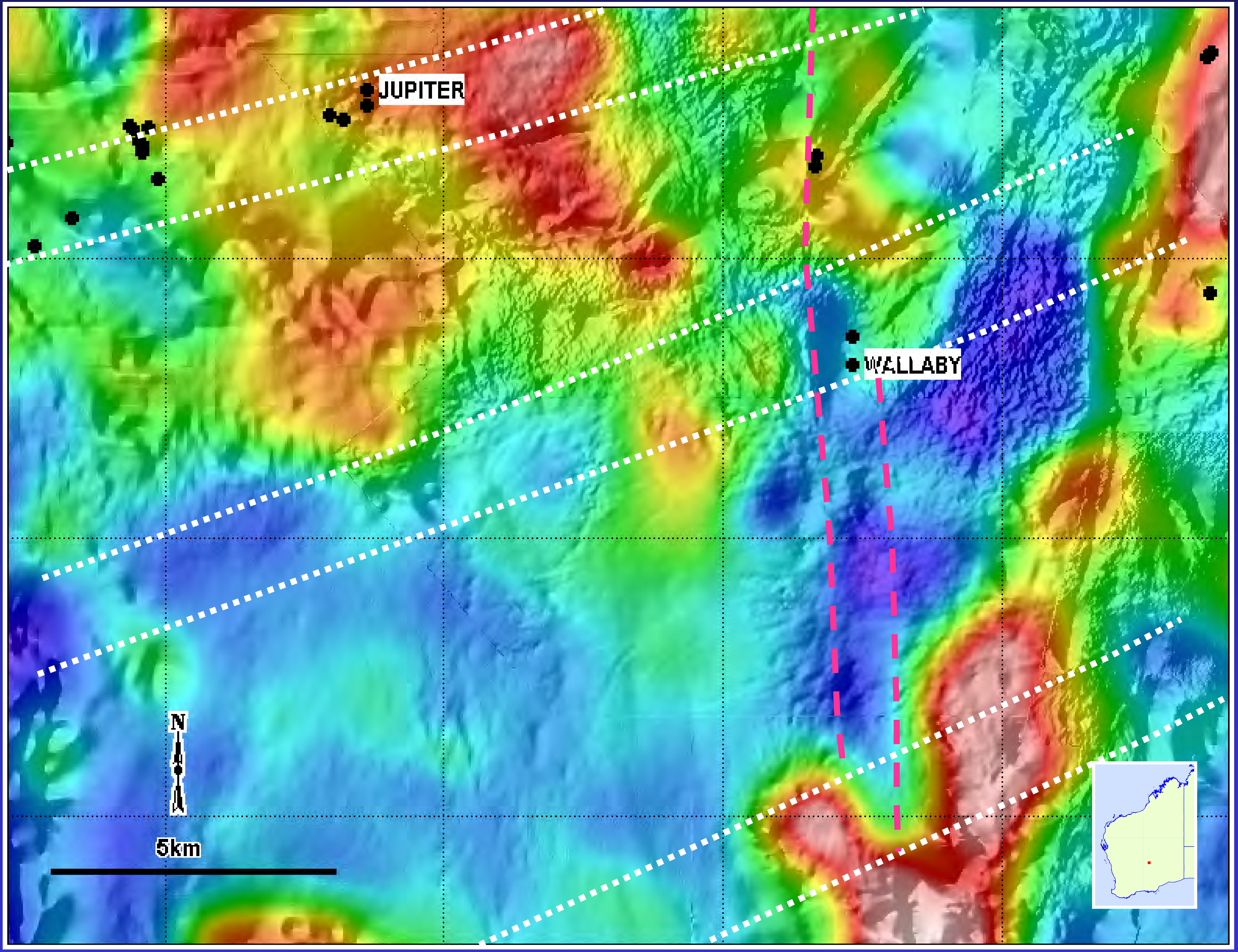
Wallaby: Intrusions & ore zones



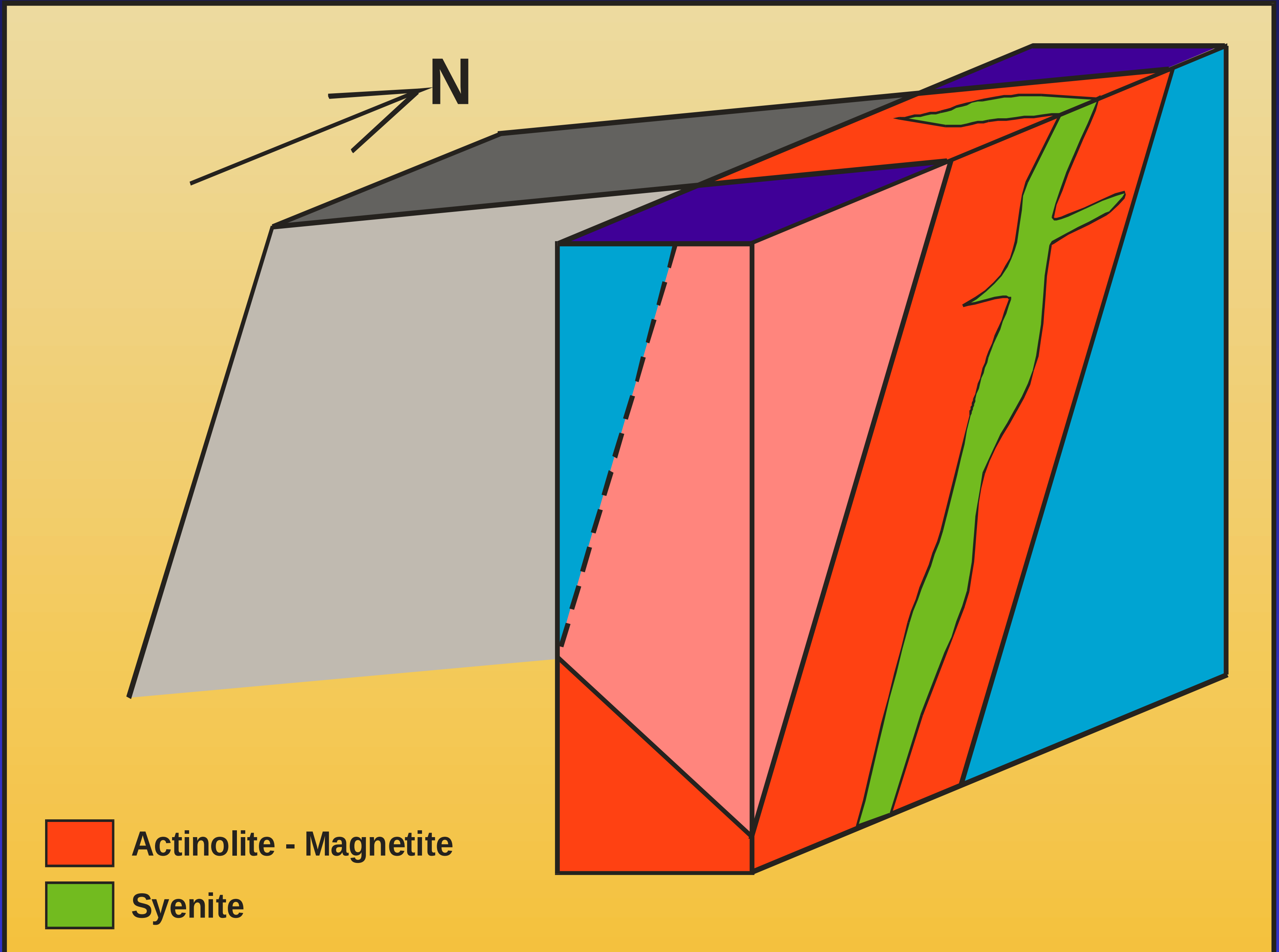
Wallaby Area – Magnetics



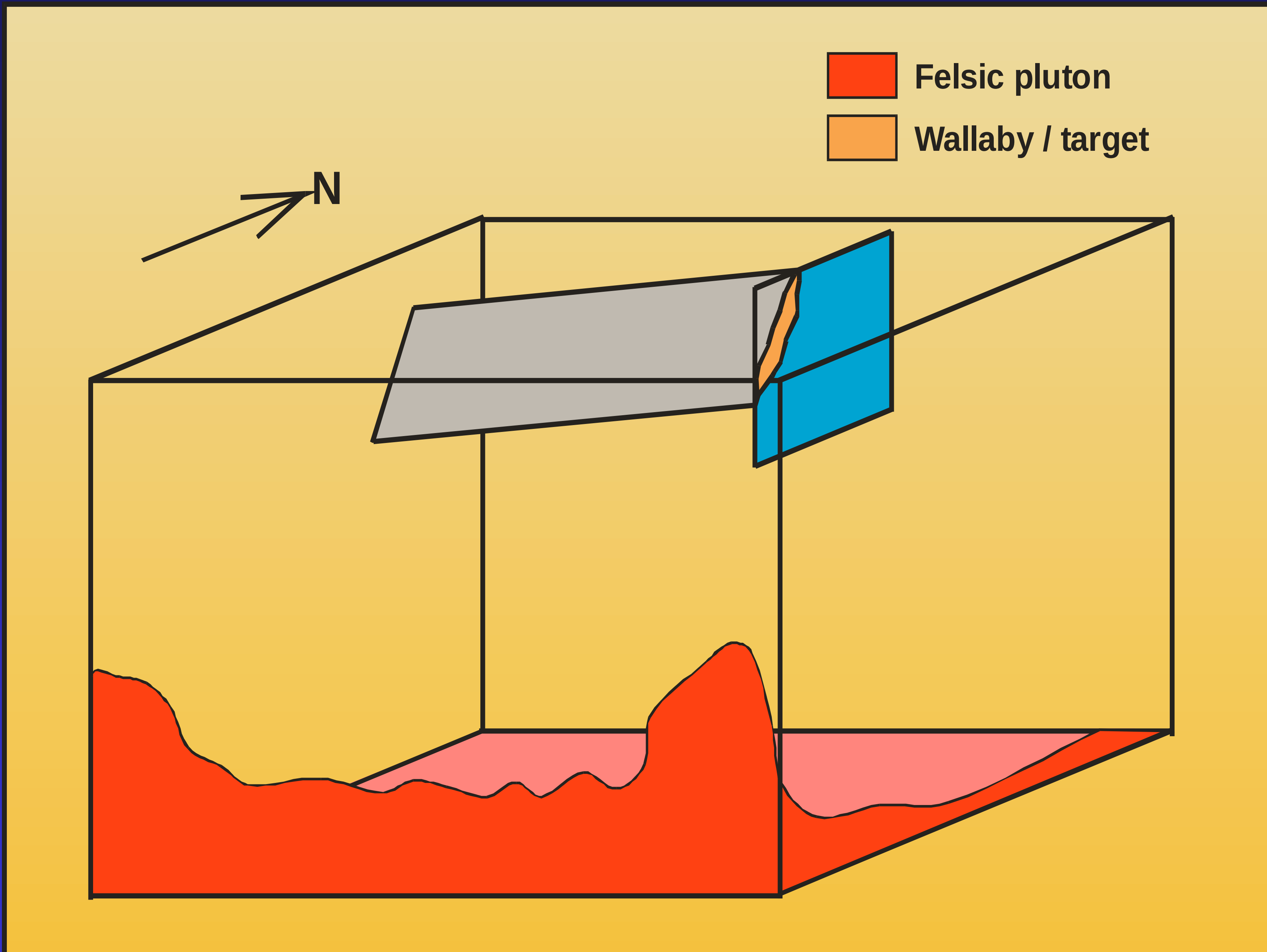
Wallaby Area – Layer Gravity on Magnetics



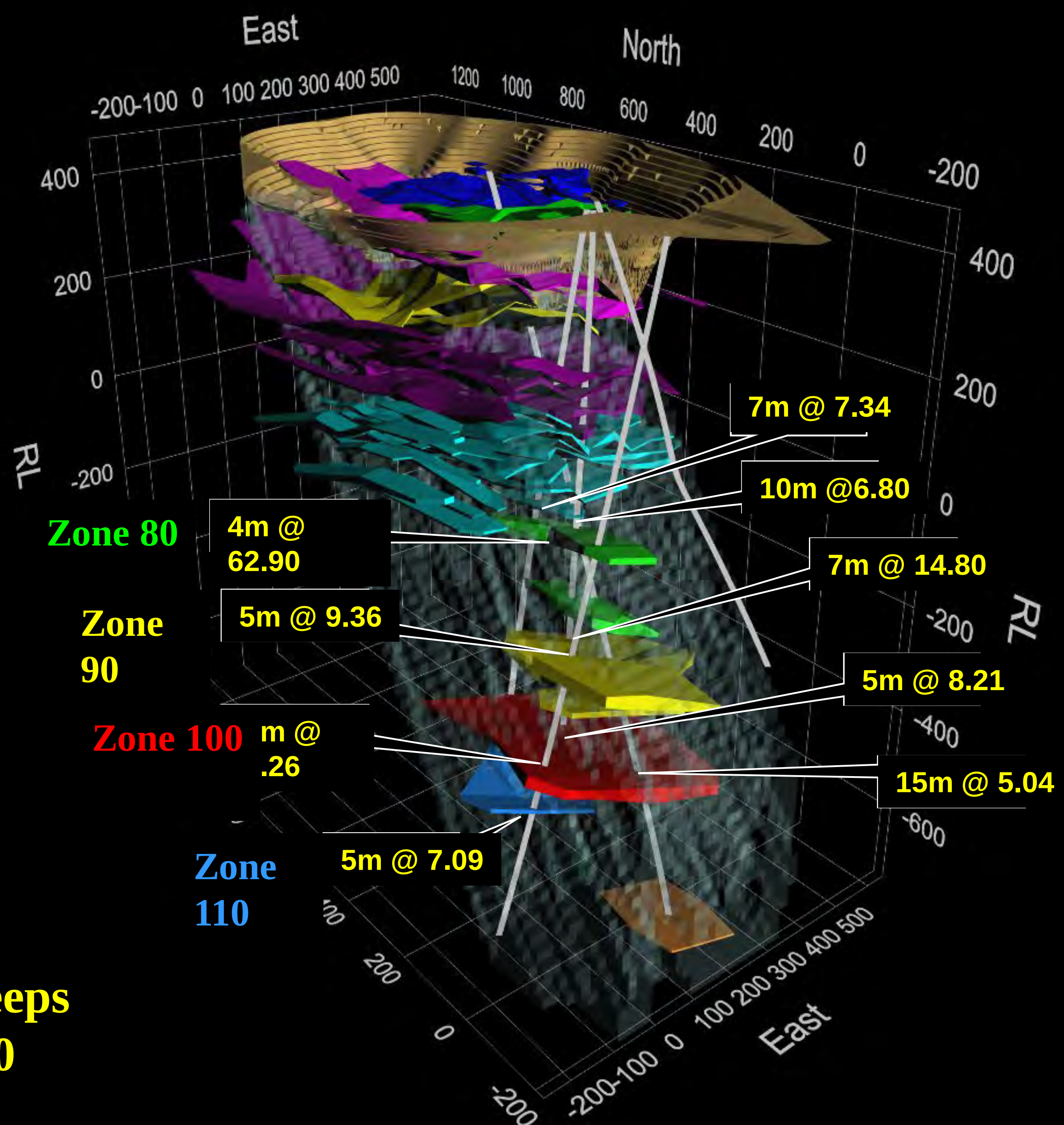
Wallaby: Stage I geometries



Wallaby: pluton edge & regional fractures



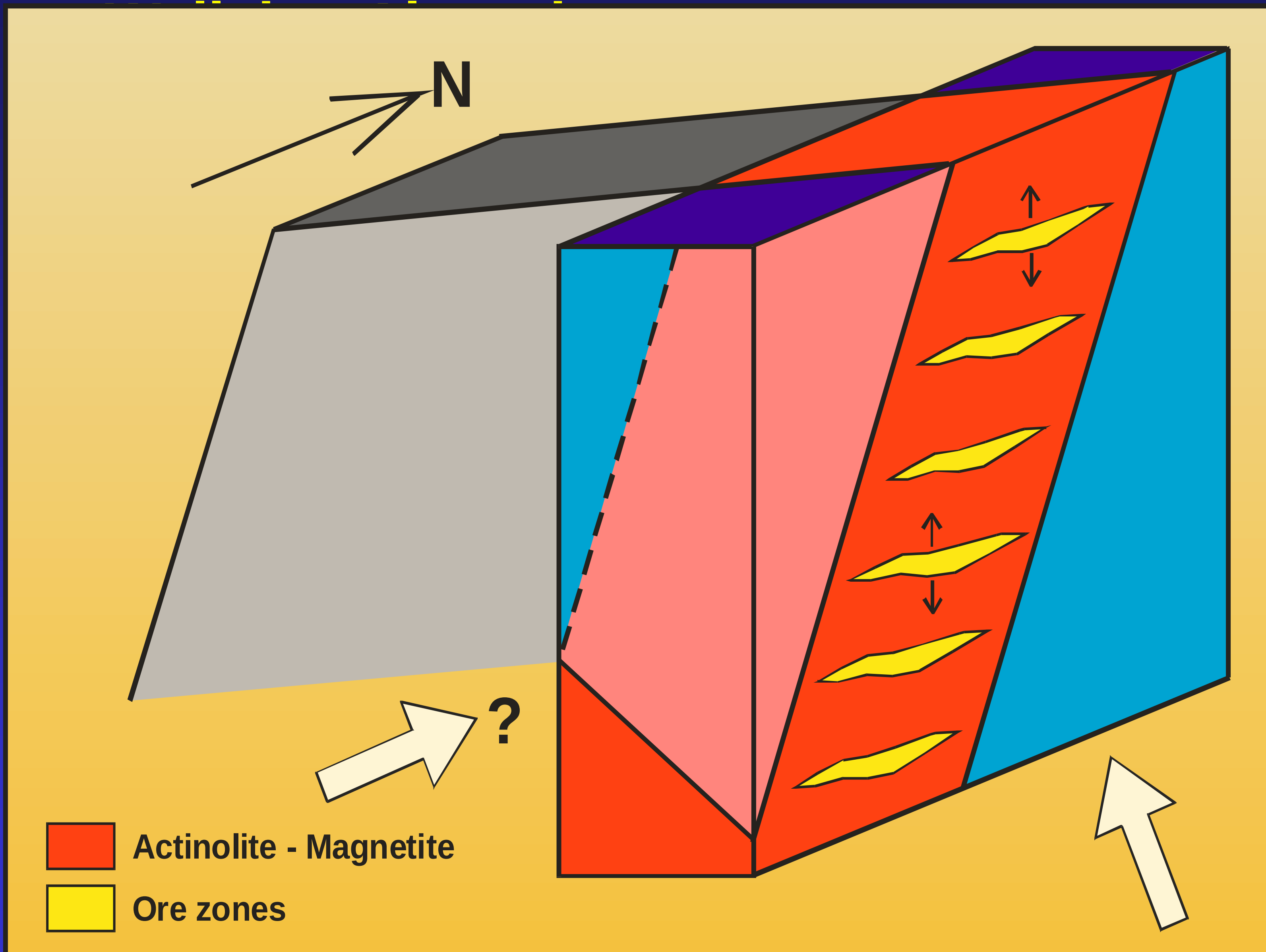
PLACER DOME INC



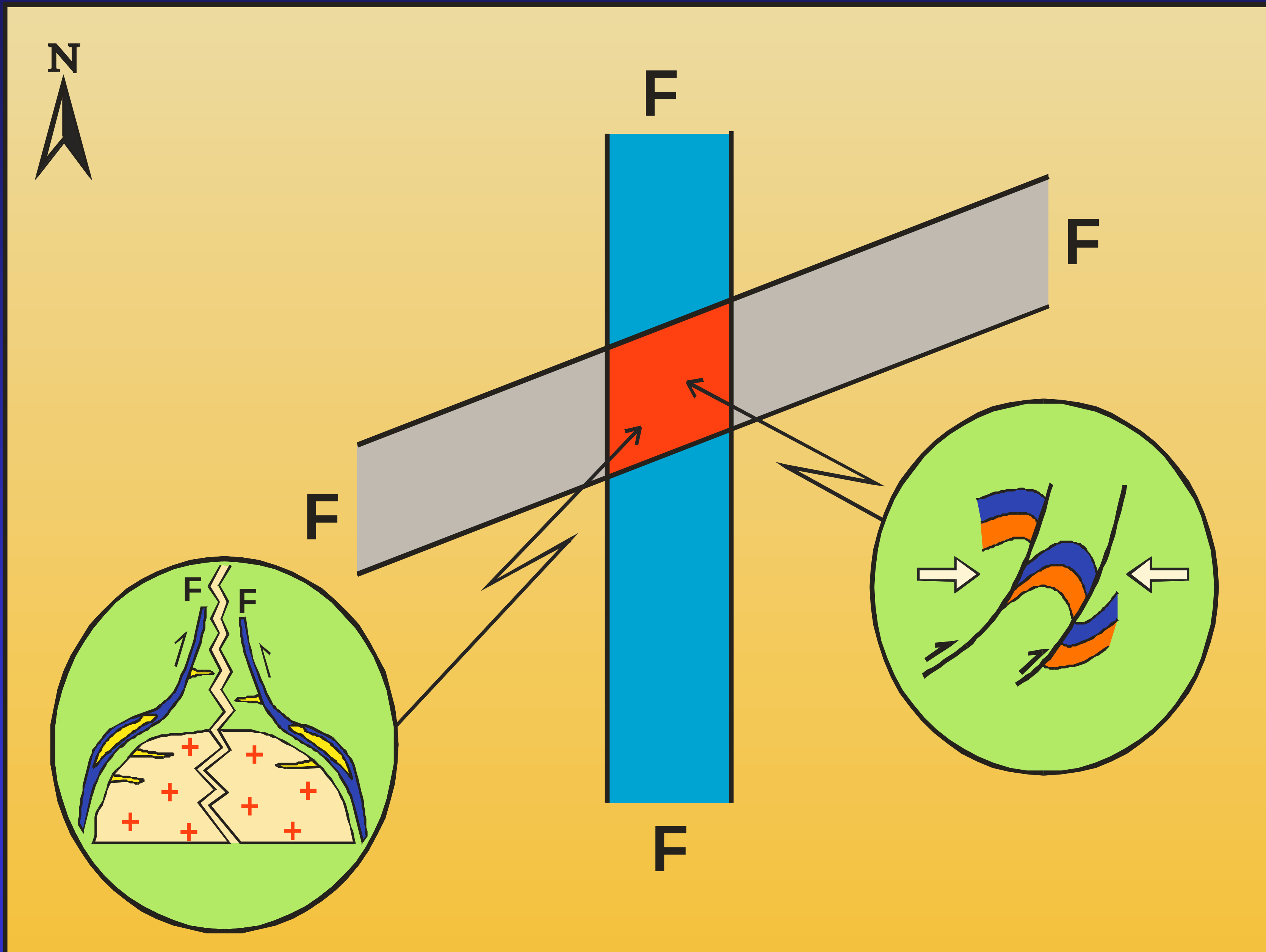
Wallaby Deeps
July 2000

Wallaby: Alteration II/III

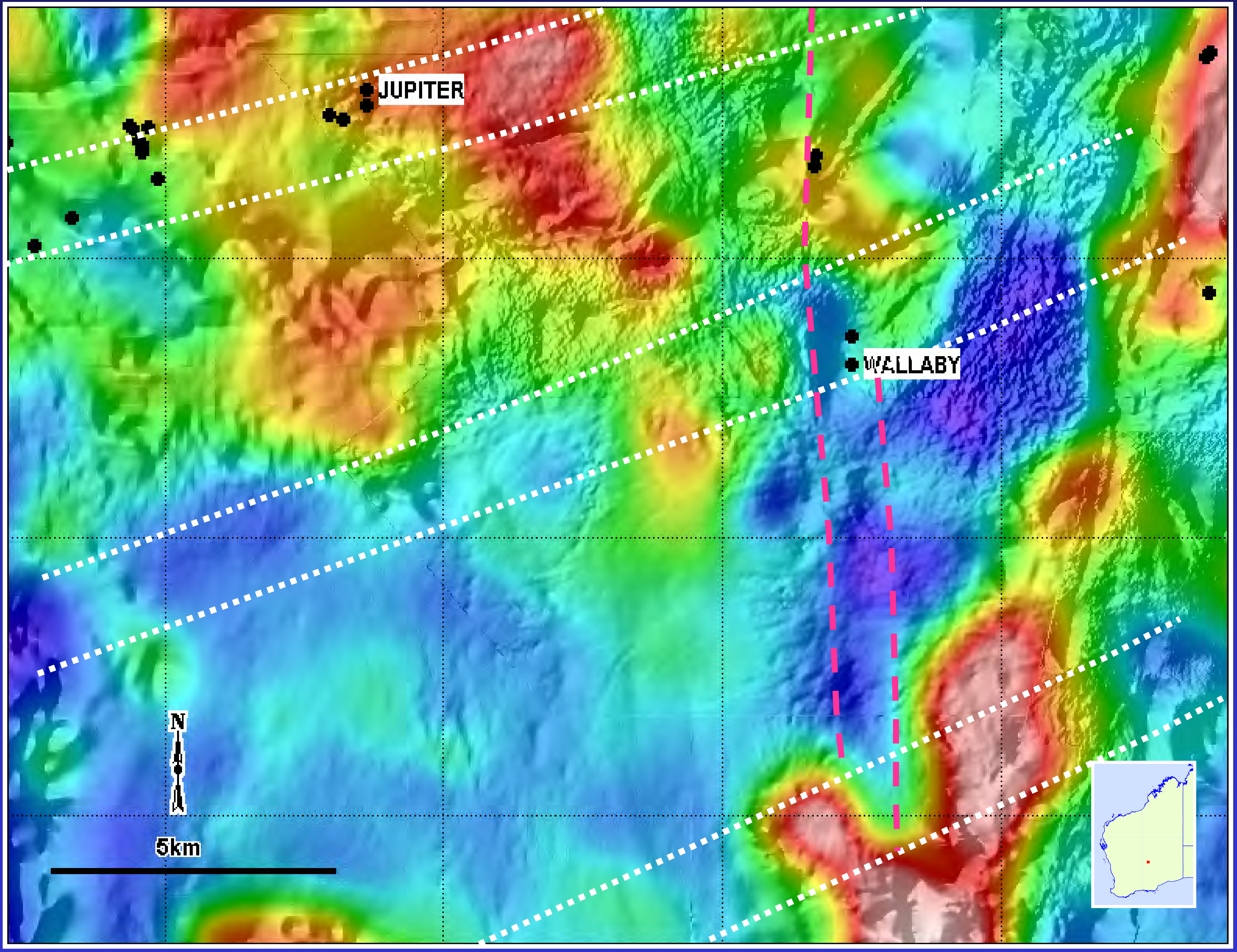
WB0202AD 1091.5


N
?
Actinolite - Magnetite
Ore zones

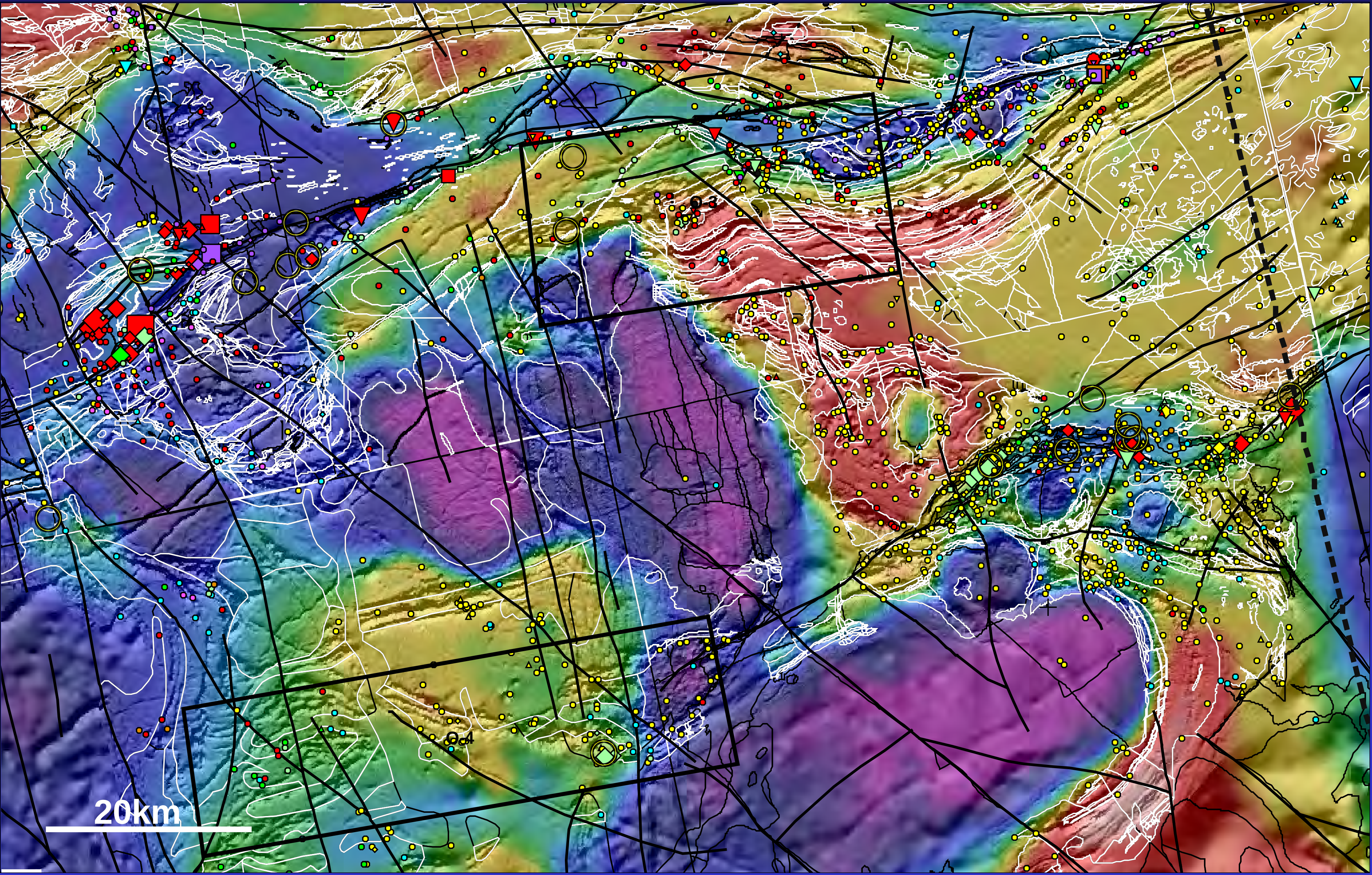
Laverton district target models

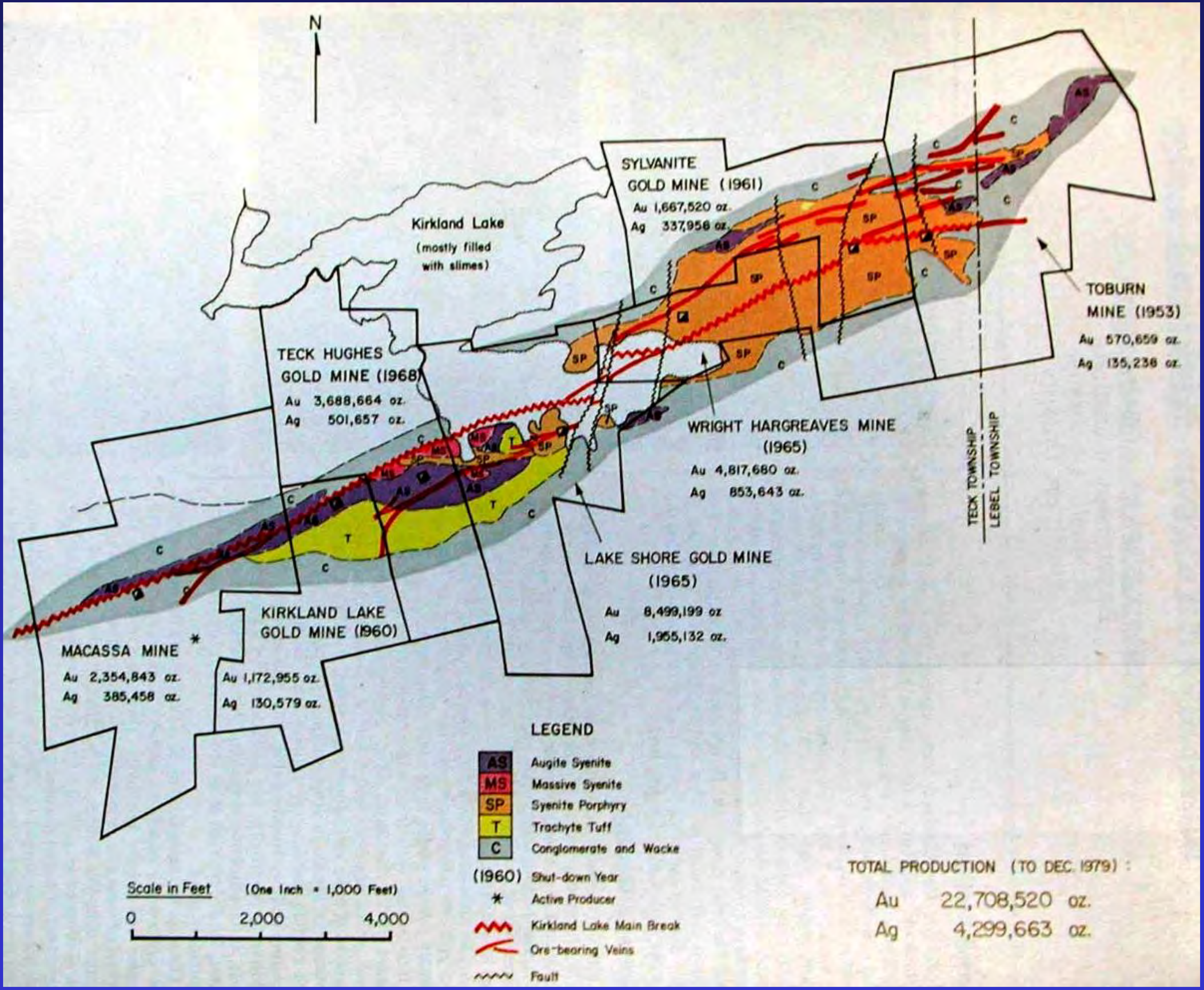


Wallaby Area – Layer Gravity on Magnetics



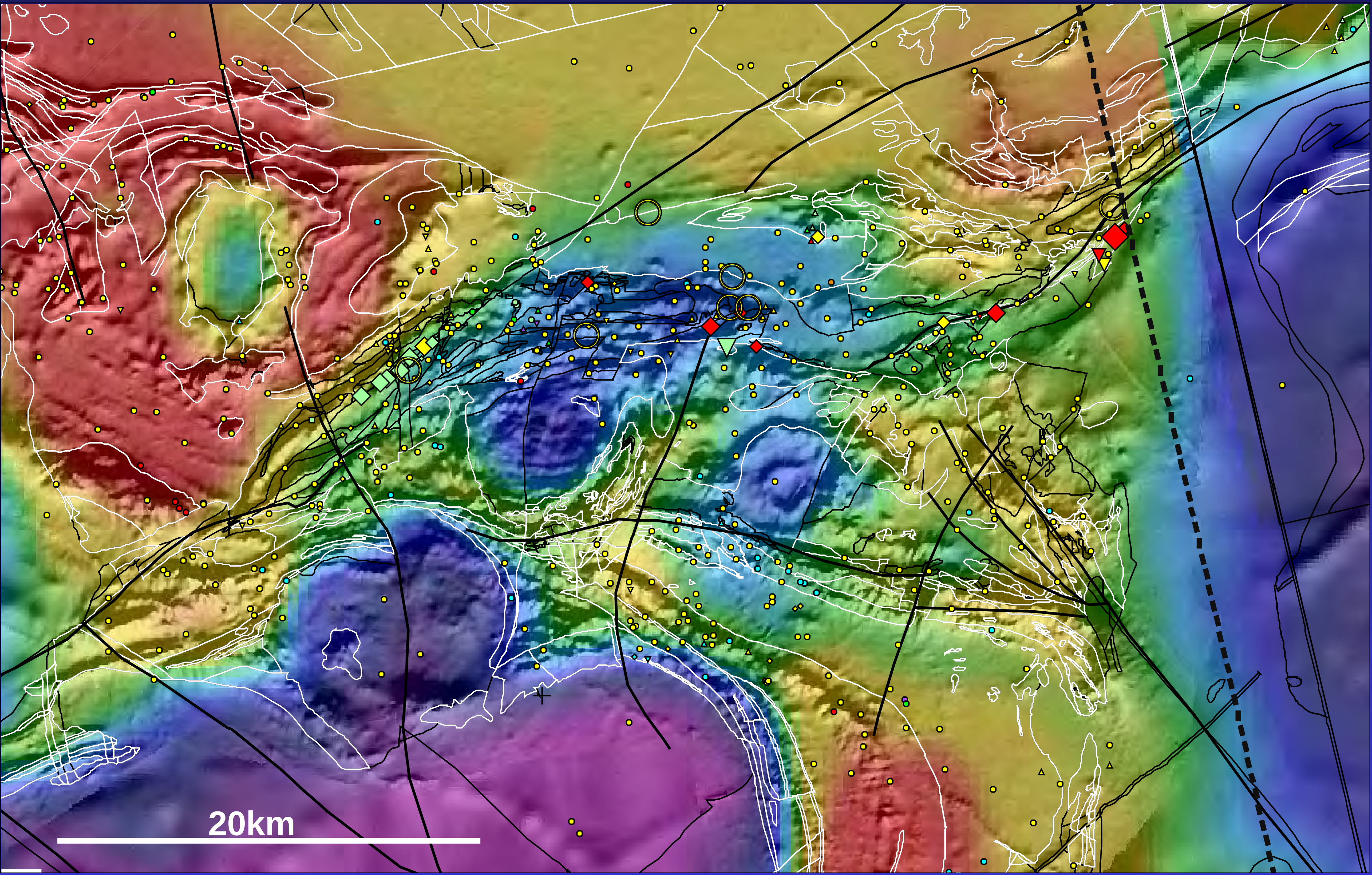
Kirkland Lake: gravity on TMI, geology outline, gold occurrences



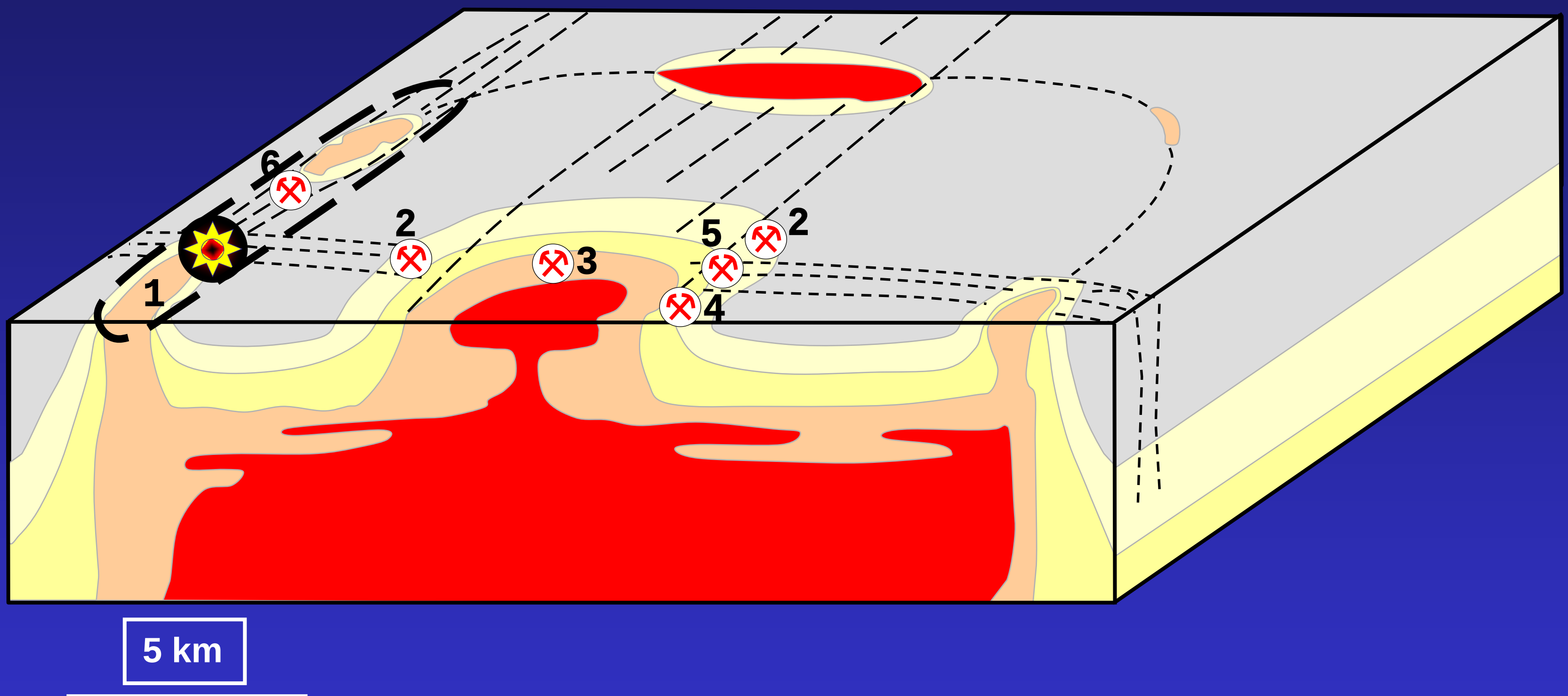


Kirkland Lake

Kirkland Lake: gravity on TMI, geology outline, gold occurrences



TAG (pluton-related) systems

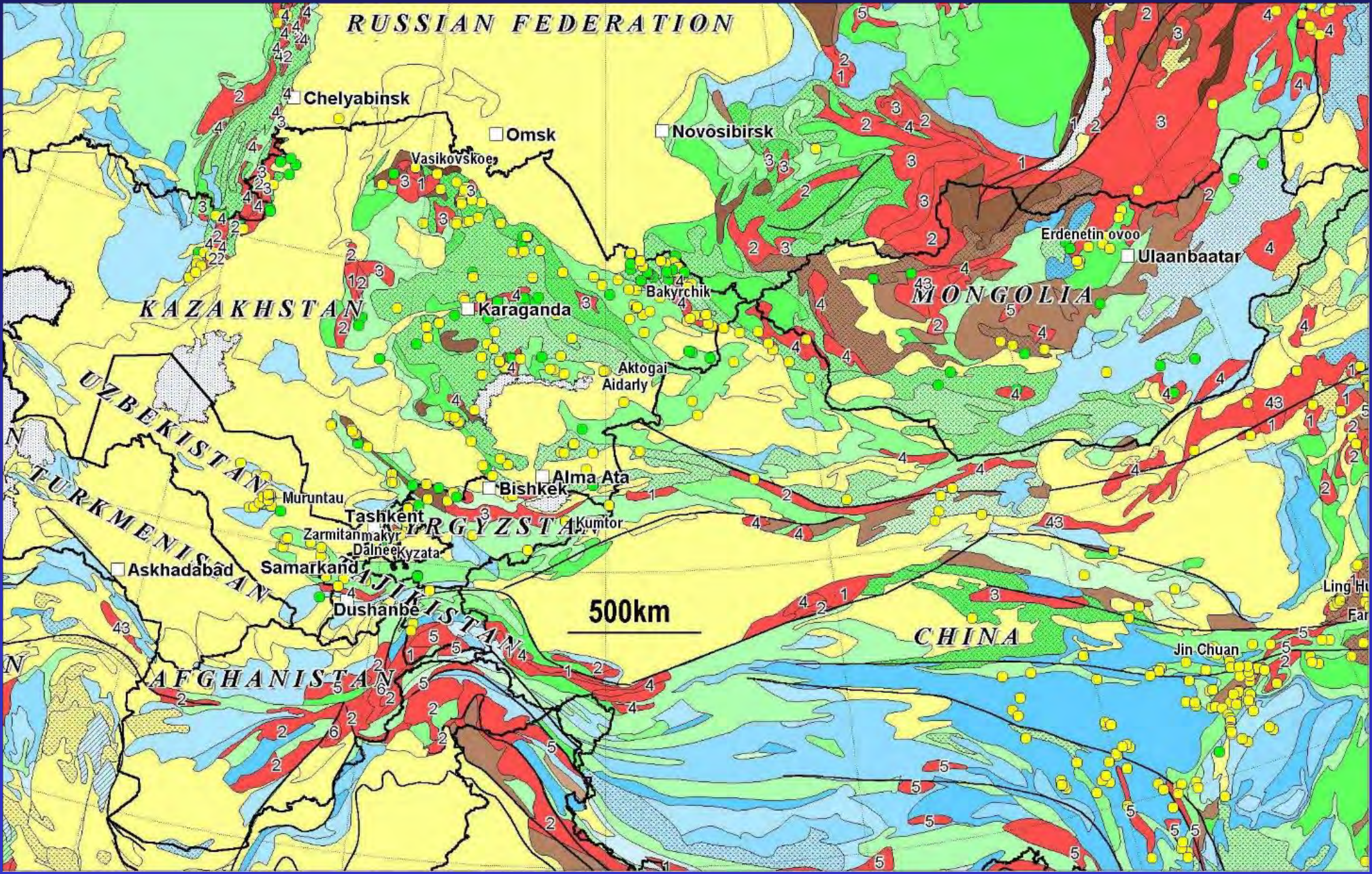


- Granitoid pluton
- Thermal aureole
- Country rocks
- Key structural zones

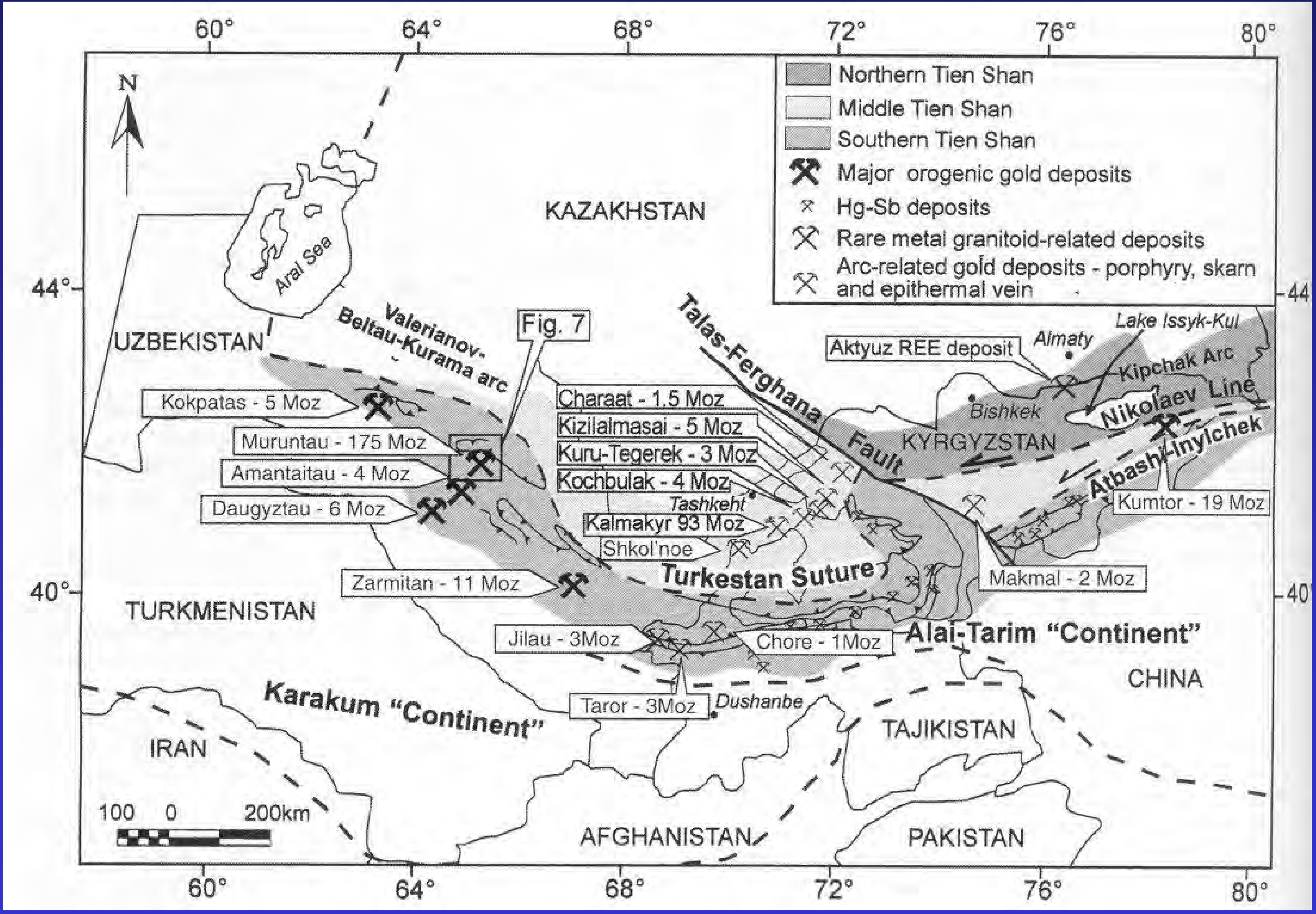
GOLD DEPOSIT SETTINGS

1 Fort Knox
2 Sukhoi Log, Kumtor
3 Pogo, Vasilkovskoye
4 Granites-Tanami
5 Muruntau
6 Obuasi, Telfer

Central Asia: major gold deposits



Tien Shan: major gold deposits

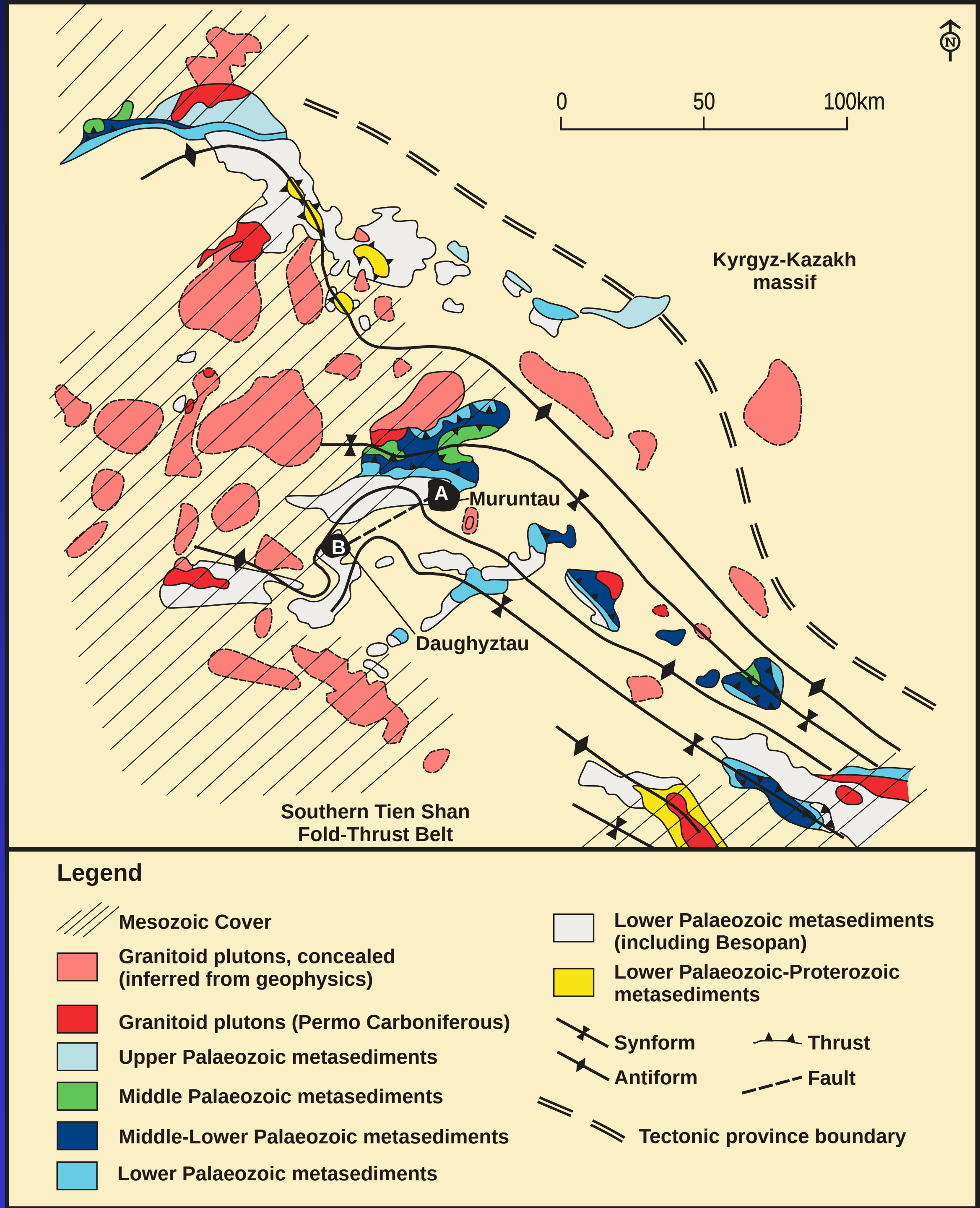


TAG: Tien Shan

- **Muruntau**
  - **in Hercynian (Permo-Carboniferous) compressional orogenic belt (Tien Shan)**
    - **fold-thrust deformation**
      - **extensive zones of shallow dipping foliation & bedding**
      - **overprinted by weak later deformations**
        - shallow, multiply plunging interference folds
        - localised in belt transverse (eg. NE - trending) zones
        - reactivation of basement & later structures
      - **regional greenschist facies metamorphism**

CERCAMS TAG Workshop 2003

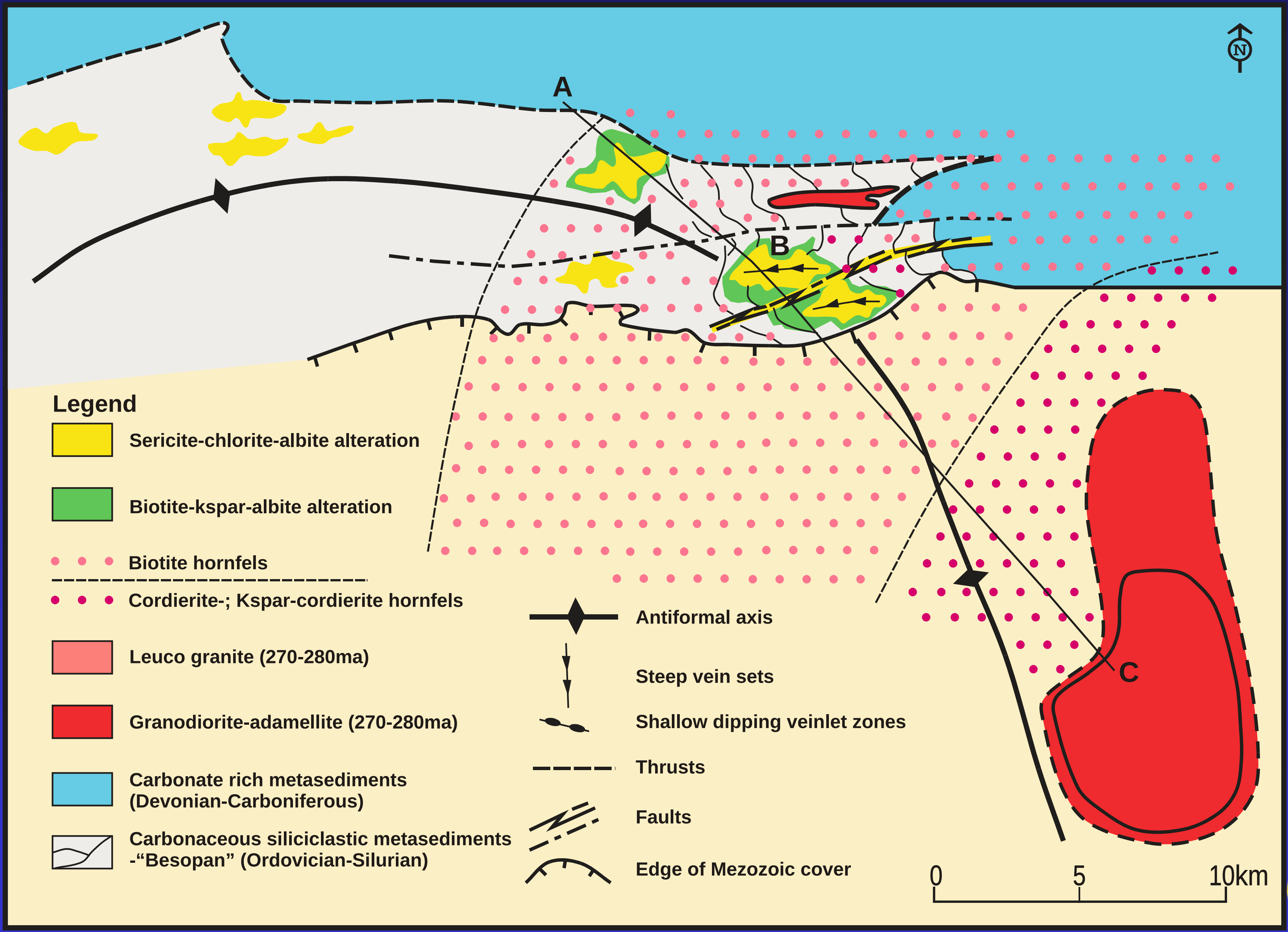
Muruntau: regional geology



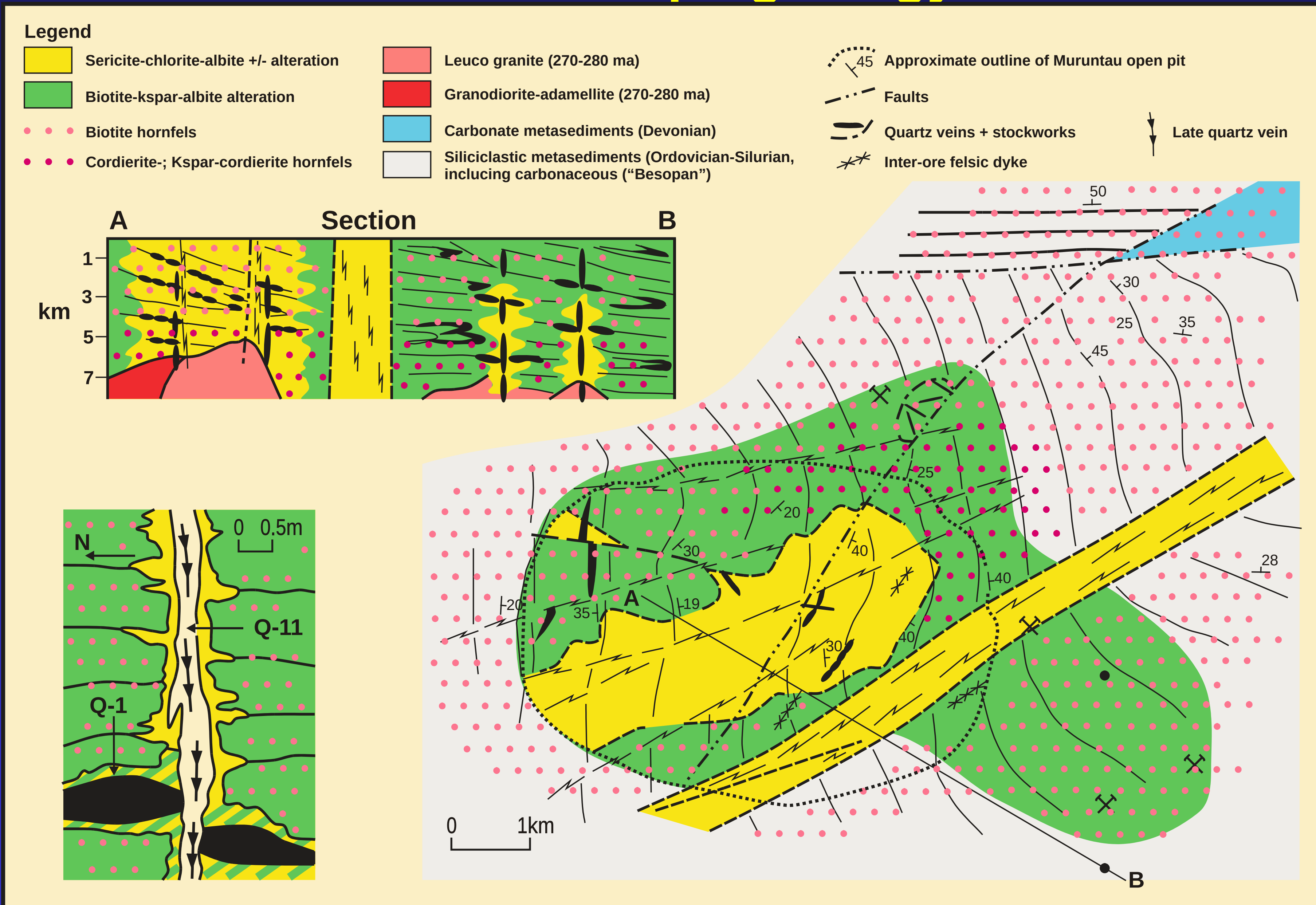
TAG: Muruntau district

- Hercynian fold belt extensively intruded by
  - I-type felsic batholiths which
    - post major fold-thrust deformation, ie. late- to post tectonic felsic magmatism
    - overlap with later weak deformation
    - are enveloped by wide thermal aureoles
    - were relatively deeply emplaced
      - > 5-10kms: andalusite-sillimanite etc. hornfels assemblages
- Regional gravity & magnetic data indicate
  - widespread unroofed/concealed plutons
    - ie. extensive pluton roof zones

Muruntau: local geology



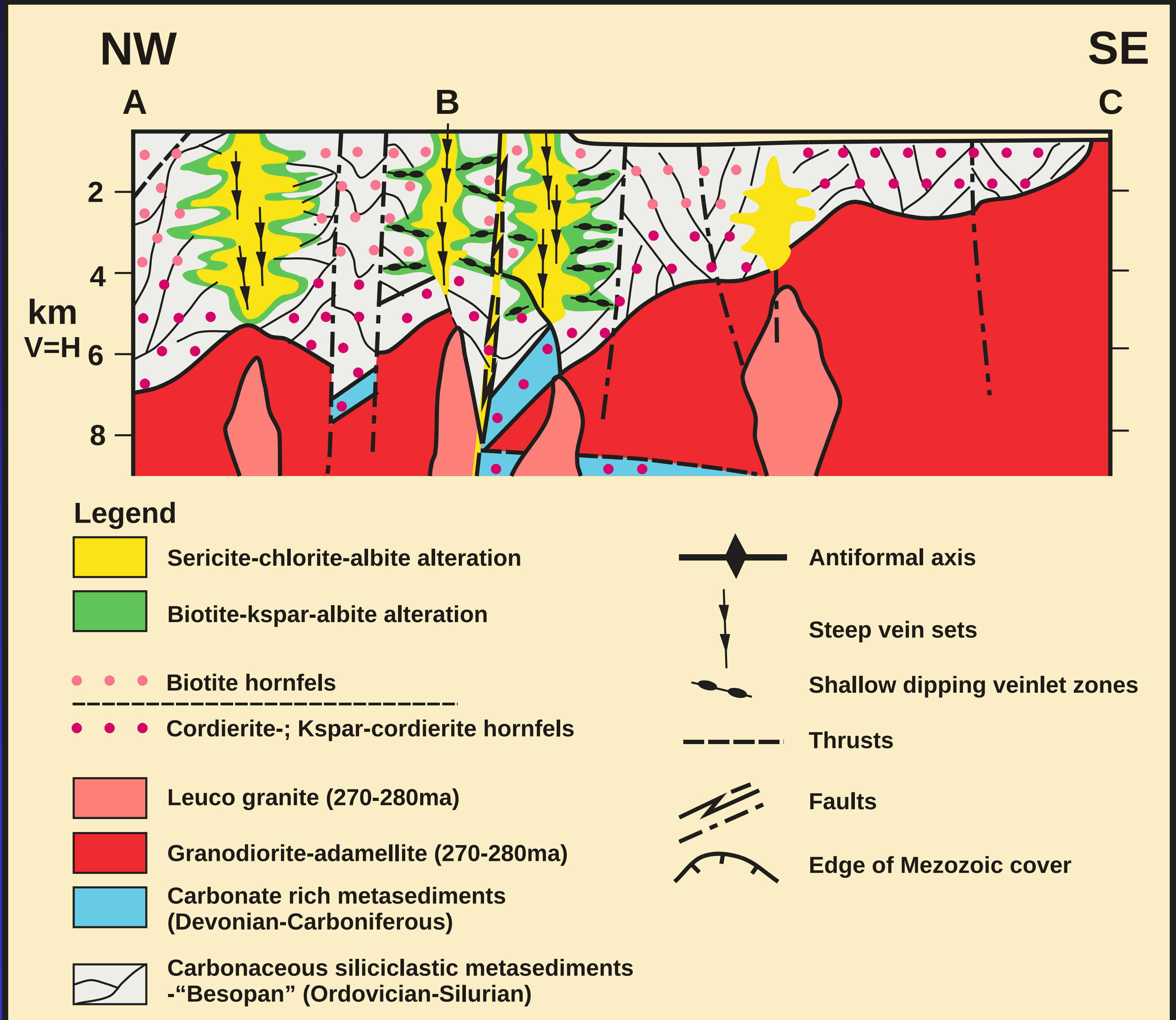
Muruntau: pit geology



TAG: Former C.I.S

- **Muruntau deposit hosted by**
  - broad (km. scale) zone of medium (biotite) grade hornfelsing
    - plutons exposed 10kms to SE.
    - metamorphic grade increases to sillimanite assemblages at depth
    - felsic intrusions in deep drilling
  - ie. the roof zone of a concealed pluton
- **Muruntau gold mineralisation (2400t Au @ 3.5g/t) ranges from medium to low temperature:**
  - early auriferous vein alteration selvedges contain biotite-feldspar & some calcsilicate,
  - but overprint high temperature(eg. calcsilicate) assemblages
  - later, steep discordant veins exhibit sericite-chlorite carbonate-albite fringes

Muruntau: schematic cross section

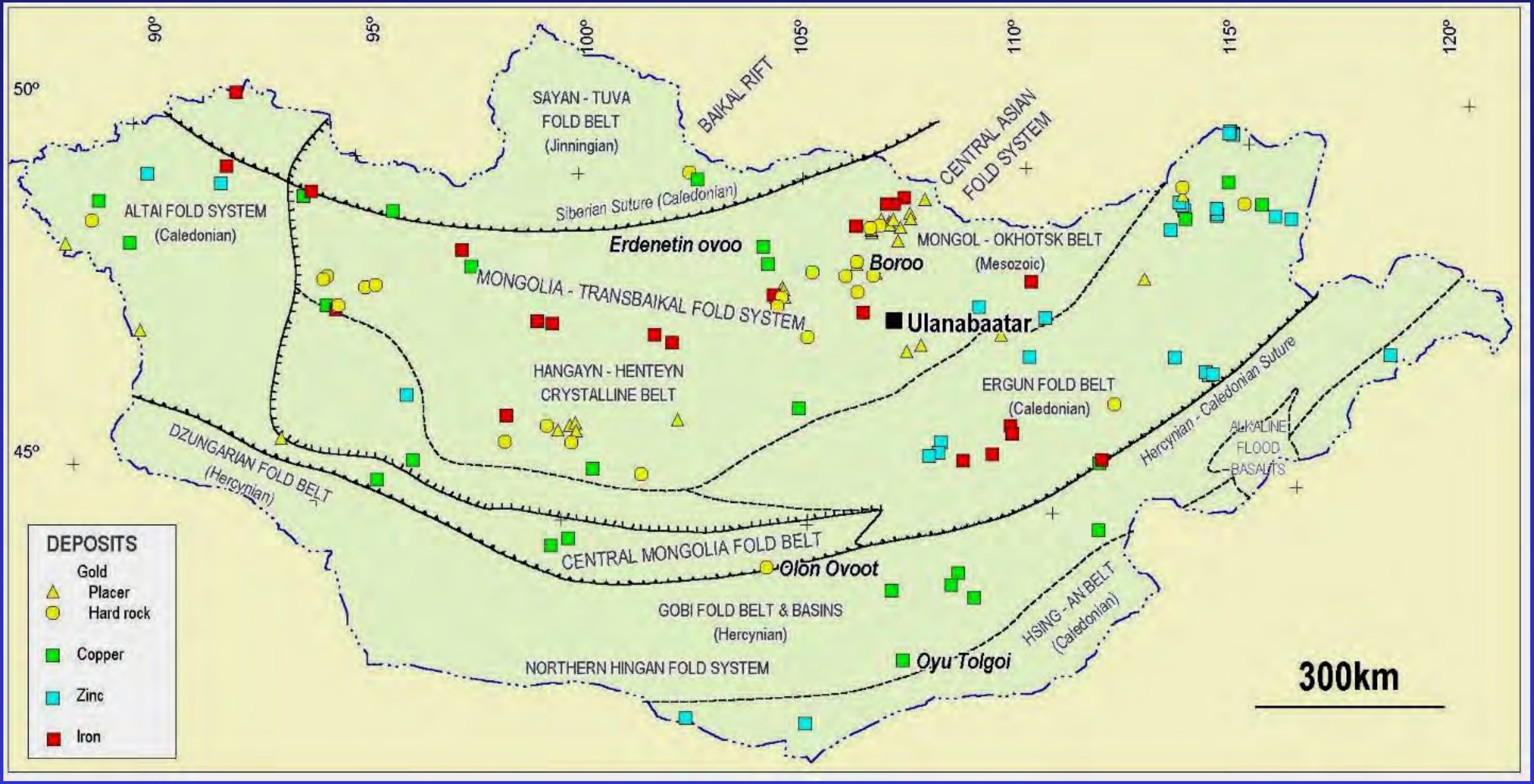


TAG: Former C.I.S

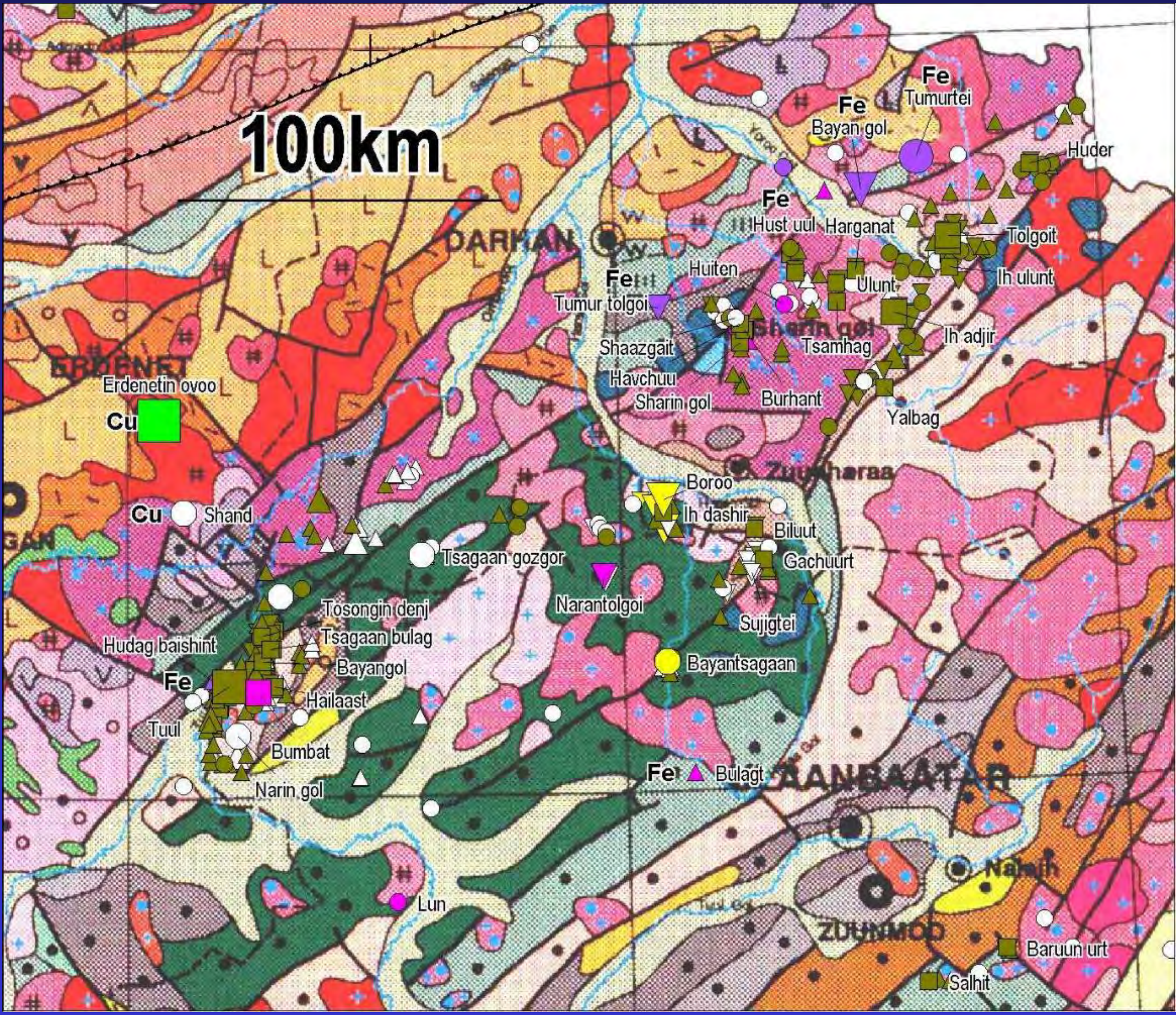
- ie. mineralization partly during retrograde contact metamorphism.
  - overlaps with minor felsic intrusions
- gold mineralization is associated mainly with
  - early, layer-foliation subparallel veinlets
    - shallow-dipping layering-foliation anisotropy
  - discordant, steep vein sets
    - high gold grades
    - lower temperature assemblages
    - localised in late fault-fold systems

- **What are key factors in localization of Muruntau & why is it so large?**
  - structural geometries & kinematics
  - mechanically & chemically favourable hosts
  - ?pluton geometry & effective focusing of (magmatic) hydrothermal fluids(through cupola/'apical zone'?)

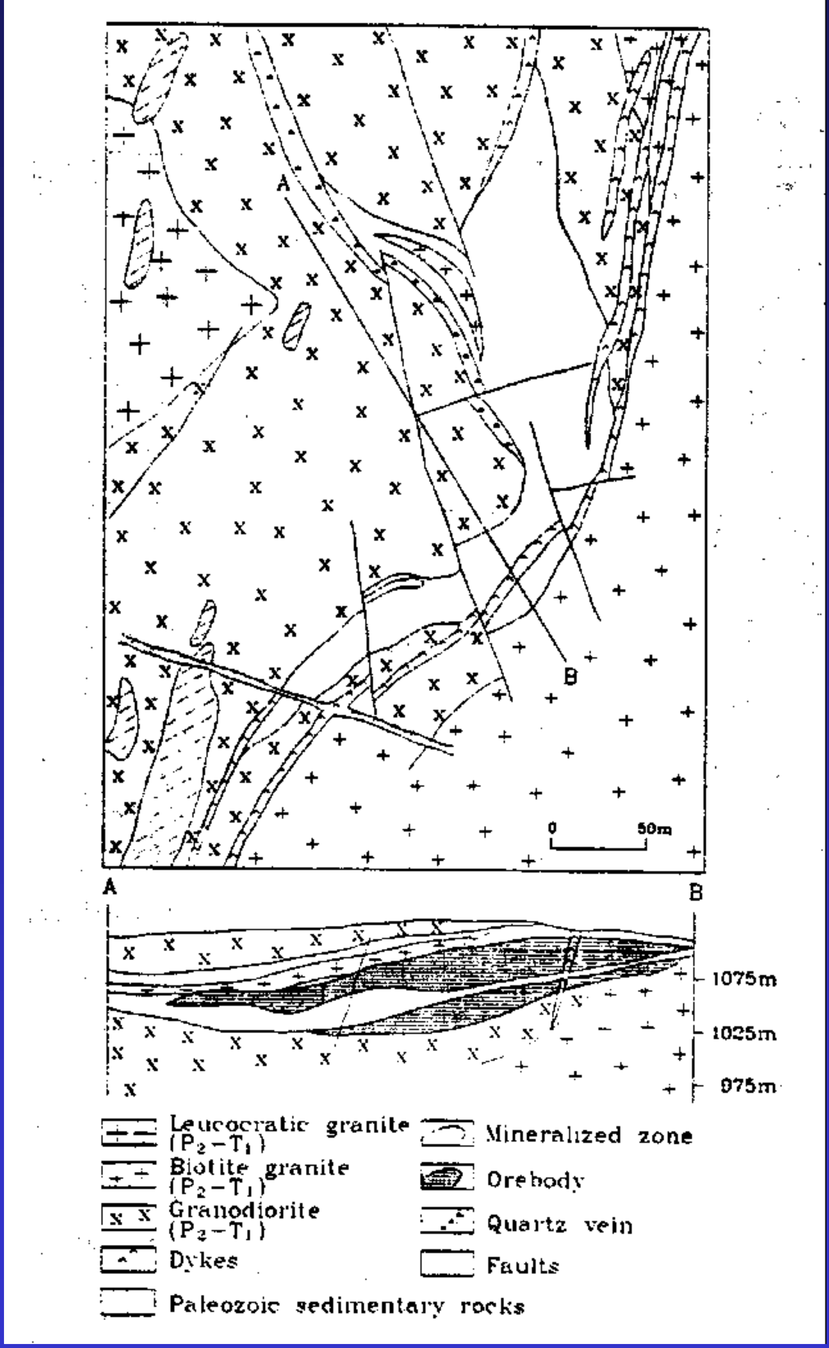
Mongolia: mineral deposits



Mongolia: Boroo district



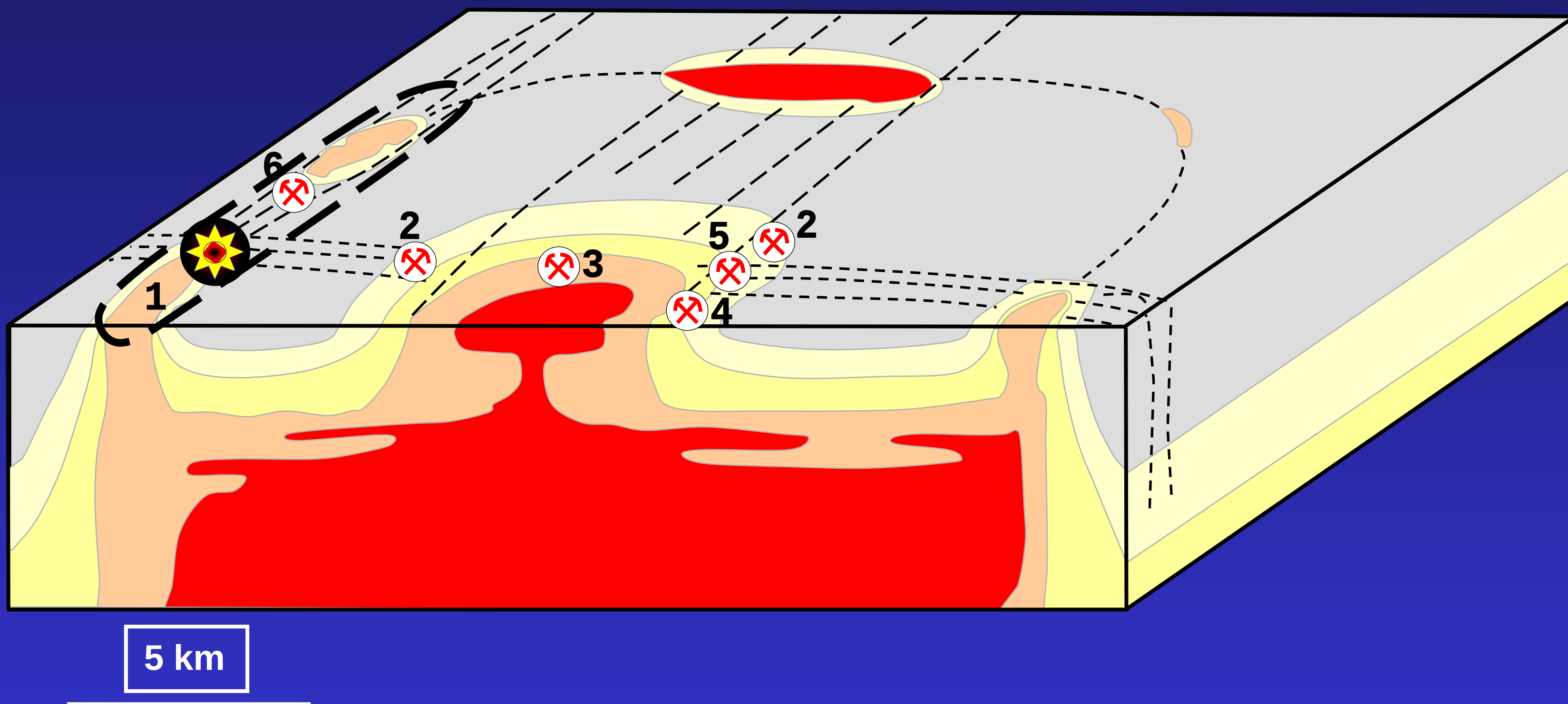
Boroo: local geology



TAG: Exploration

- Major, under-recognised association, hosts significant proportion of world gold inventory
- underutilized, but useful exploration models
- highly prospective in
  - Central & east Asian Palaeozoic & Mesozoic felsic plutonic belts
    - China-Mongolia, Eastern Russia, the ‘Stans’, Iran
  - Alaska & Yukon: Mesozoic plutonic belt
  - West Africa: Birimian-Proterozoic granitoid belts
  - Australia
  - parts of Central & South America

TAG (pluton-related) systems



Granitoid pluton

Thermal aureole

Country rocks

Key structural zones

GOLD DEPOSIT SETTINGS

1 Fort Knox

2 Sukhoi Log, Kumtor

3 Pogo, Vasilkovskoye

4 Granites-Tanami

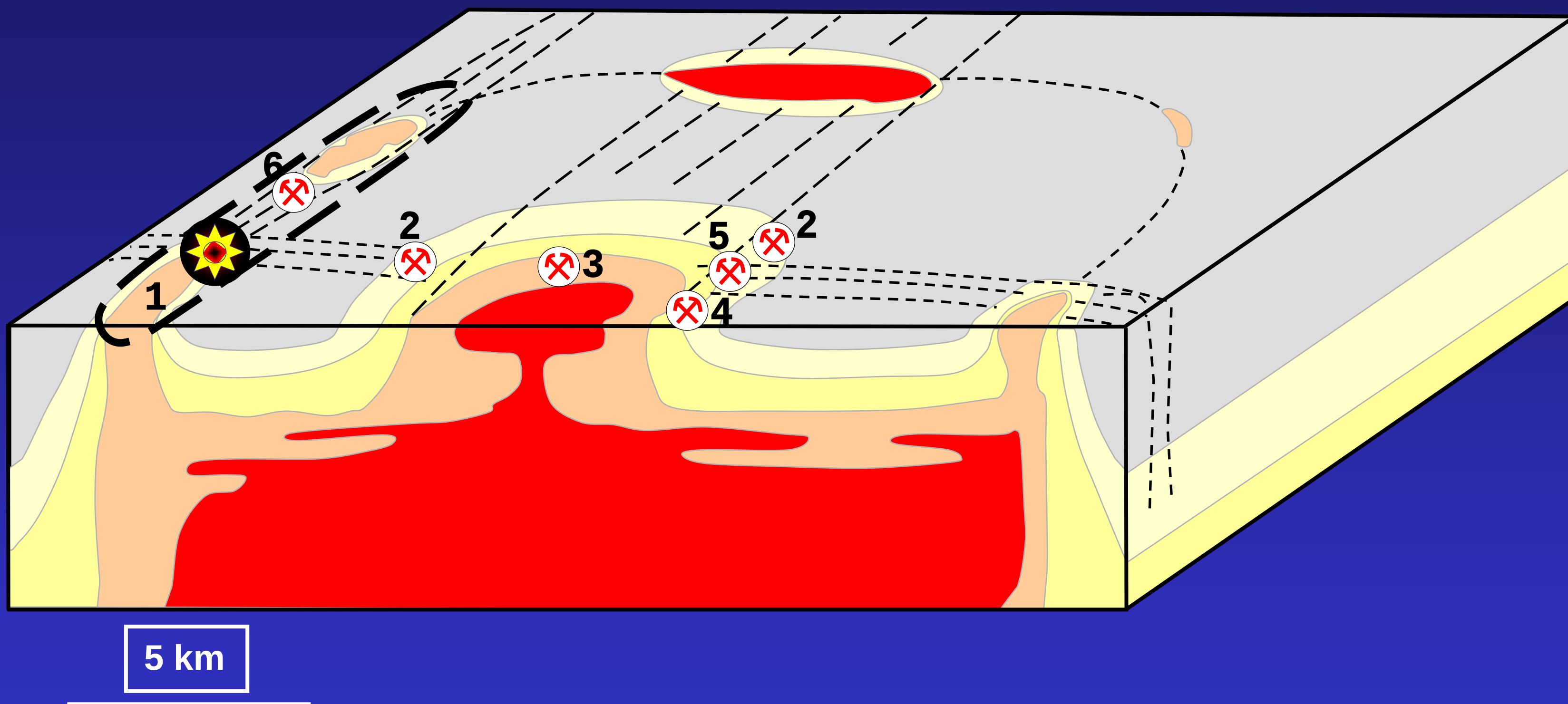
5 Muruntau

6 Obuasi, Telfer

TAG: better predictivity

- Empirical model is adequate for
  - belt, regional & district selection & evaluation
- Improve by application & testing
  - selection of key fertile belts, eg:
    - Eastern Russia, the ‘Stans’, China, West Africa
  - evaluation and compilation of
    - regional architecture & geodynamic evolution
    - localisation of mineralized systems
      - intrusive styles & ages, country rock lithologies & structures, district structural evolution, potential field geophysical signature (eg pluton roof zones)
      - auriferous placer source areas

TAG (pluton-related) systems



Granitoid pluton

Thermal aureole

Country rocks

Key structural zones

GOLD DEPOSIT SETTINGS

1 Fort Knox

2 Sukhoi Log, Kumtor

3 Pogo, Vasilkovskoye

4 Granites-Tanami

5 Muruntau

6 Obuasi, Telfer

TAG: Regional indicators

- Fold/thrust belts,
  - metasediment dominated
    - thick siliciclastics, turbidites &/or marine shelf assemblages
      - commonly reduced and calcareous packages
  - major shortening/compressional orogenic zone
  - typically low regional metamorphic grade (greenschist facies)
- Main shortening deformation prior to batholith emplacement

TAG: Regional indicators

- Felsic plutonism
  - late orogenic, multiple pluton, batholith scale intrusions
  - related, broad (km. scale), thermal aureoles
  - accompanied by (localised) deformation
  - mostly reduced (ilmenite series) I-types
    - but magnetite series & peraluminous types also represented
    - fractionated-, high temperature granitoid suites

TAG: Regional/district indicators

- Host metasedimentary package typically
  - siliciclastic-dominated, well-bedded
  - contains prominent reduced (carbonaceous) units
  - commonly also calcareous units
  - silicate BIF's uncommon, but a bonus
- Host metasediments in broad thermal aureoles
  - pluton roof zones
  - elliptical gravity lows (20-50km diam.-underlying plutons)
  - small felsic intrusions penecontemporaneous with and utilising same structures as mineralization

TAG: Regional/district indicators

- **Structures: timing**
  - **deformation accompanying pluton emplacement and thermal metamorphism**
    - **commonly fault(shear)-fold zones**
    - **reactivation of pre-pluton structures**
      - **pre-existing regional fault/shear zones important**

TAG: Regional/district indicators

- **Structures: geometry**
  - **favourable geometries**
    - **bedding/foliation concordant veining (+ discordant veining)**
    - **shallow dipping bedding & foliation**
    - **multiply plunging, antiformal settings (eg. domes) are best**
    - **commonly relate to the intersection/interference of long-lived, regionally throughgoing structures**

TAG: Regional/district indicators

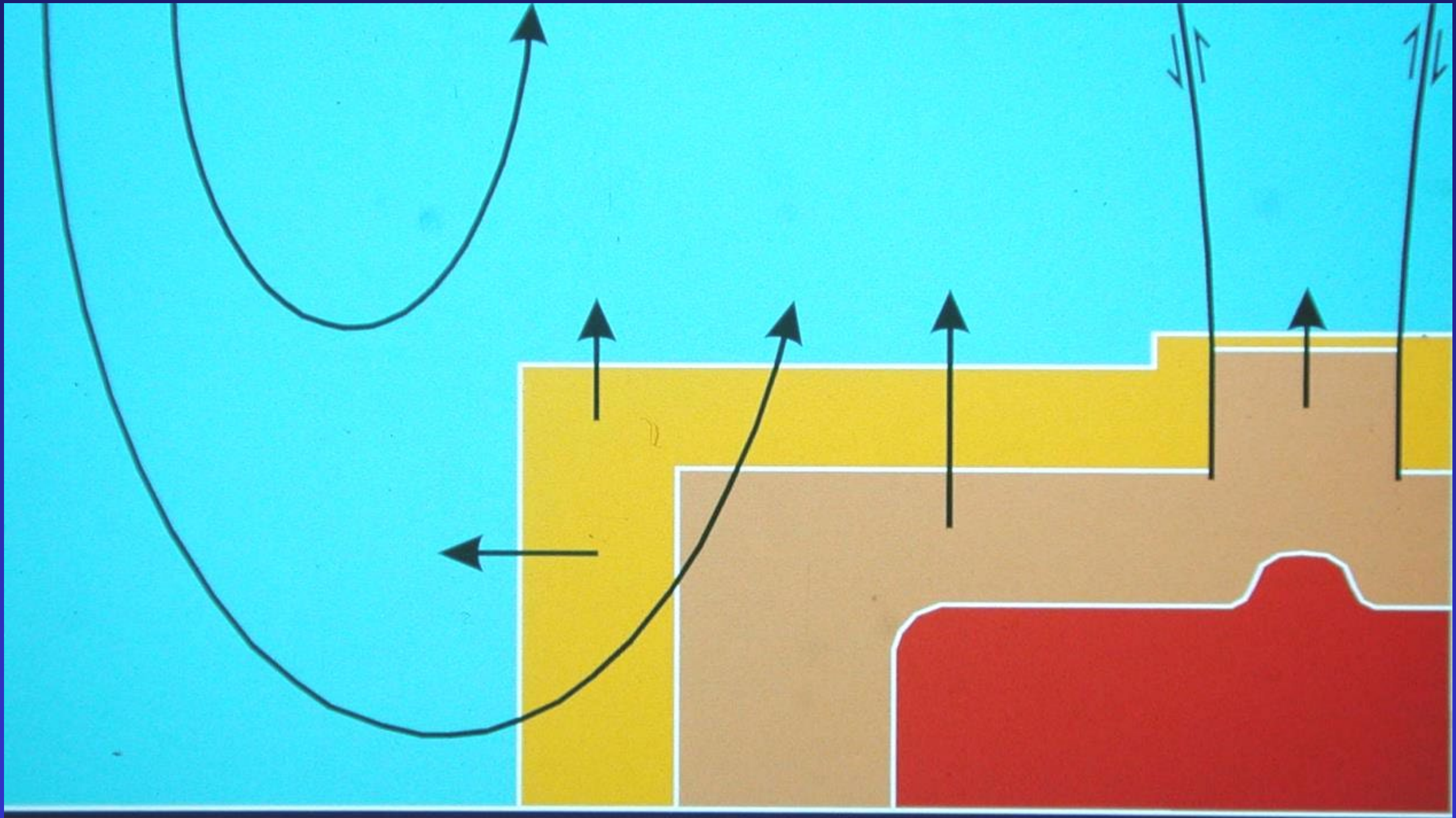
- **Structures: kinematics**
  - **pluton roof-lifting & expansion**
    - **steep marginal shear zones**
    - **reactivation of earlier structures**
  - **post pluton emplacement, syn-cooling deformation**
    - **typically reflects continued regional shortening**
    - **reactivation of earlier fault-fold systems**

TAG: Regional/district indicators

- District scale geochemical/mineralogical zonation
  - antimony-gold: low temperature, distal deposits
  - arsenic- gold : medium to high temperature deposits
  - high grade gold (+ pyrrhotite+/-arsenic, Bi, +/-W,Sn): commonly pluton proximal, and/or in carbonaceous, Fe-rich and/or calcareous hosts
- Syn-mineralization hydrothermal alteration

  reflects thermal setting & host rock chemistry
  - biotite and/or calcsilicates: high temperatures
  - sericite+/chlorite, carbonate: low temperature

Fluid paths & plutons



A range of possible fluid migration patterns established during granitoid emplacement and thermal metamorphism