INTRUSION-RELATED GOLD DEPOSITS

SE Europe Geoscience Foundation Shortcourse

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OVERVIEW

- Part 1: Classification, nomenclature & deposit comparison
- Part 2: Examples: Tintina Gold Province
- Part 3: Other examples & exploration

INTRUSION RELATED GOLD DEPOSITS CHARACTERISTICS

- Sillitoe (1991)
  - Gold-rich porphyry deposits
  - Epithermal & skarn in porphyry Cu environments
  - Gold related to alkalic magmatism
  - Mostly associated oxidized intrusions
  - Intrusion related gold deposits in Sn-W terranes (Thompson et al., 1999)

EGRU

NOMENCLATURE

- Porphyry Au (Hollister, 1992)
- Fort Knox-style Au (Bakke, 1995)
- Intrinsic Au (Newberry et al., 1995)
- Plutonic Au (McCoy et al., 1997)
- Intrusion-related Au (Thompson et al., 1999)
- Granitoid Au (Goldfarb et al., 1999)
- Thermal aureole gold systems (Wall, 2005)

CHARACTERISTICS

- Intrusion related Au deposits in Sn-W terranes
- Metals
  - Au, Bi, Te, W, Mo, As (Sb, Sn, Pb, Cu)
- Magmas
  - Intermediate to felsic (wide range SiO2)
  - I-type (crustal input, transitional S-type)
  - Ilm>Mag
  - W-Sn-Mo association

(Thompson et al., 1999)

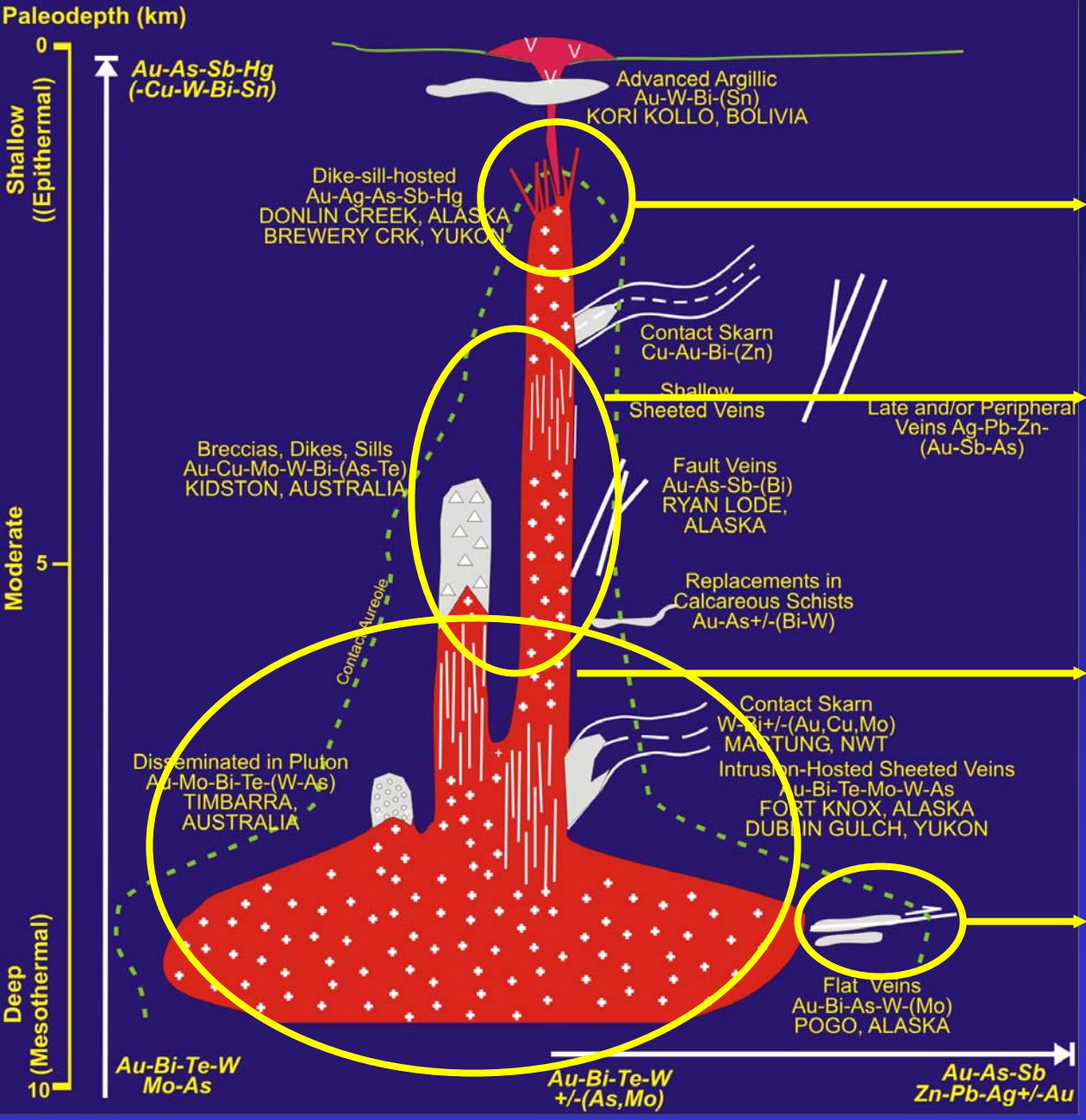
CHARACTERISTICS

- Tectonic environment
  - Continental setting, inboard, commonly late
- Age
  - Phanerozoic (Precambrian – Archean?)
  - Intrusions = mineralization
- Ore
  - Au, Bi, Te, W, Mo, As (Sb, Sn, Pb, Cu)
  - Reduced (no Mag-Hem), low sulfide (Po-Py-Apy)
- Style
  - Sheeted, breccia, stockwork, flat-vein, disseminated

(Thompson et al., 1999)

LOCATION OF MAJOR GRANITE RELATED GOLD DEPOSITS

(Lang & Baker, 2001)



Shallow-level examples

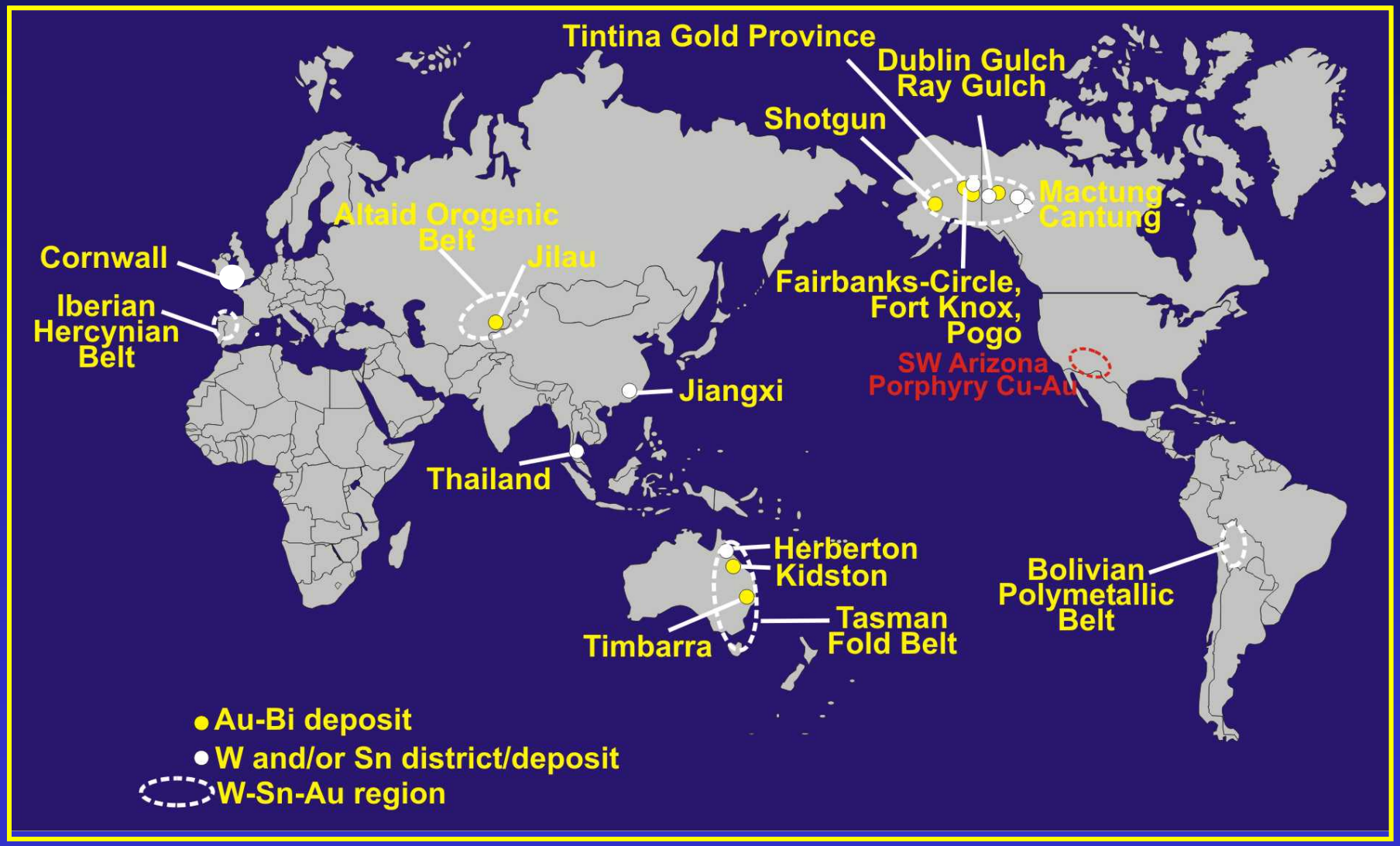
Porphyry-style examples

Type-examples

Pogo

GEOLOGICAL EXPLORATION MODEL

INTRUSION RELATED GOLD SYSTEMS IN Sn-W PROVINCES

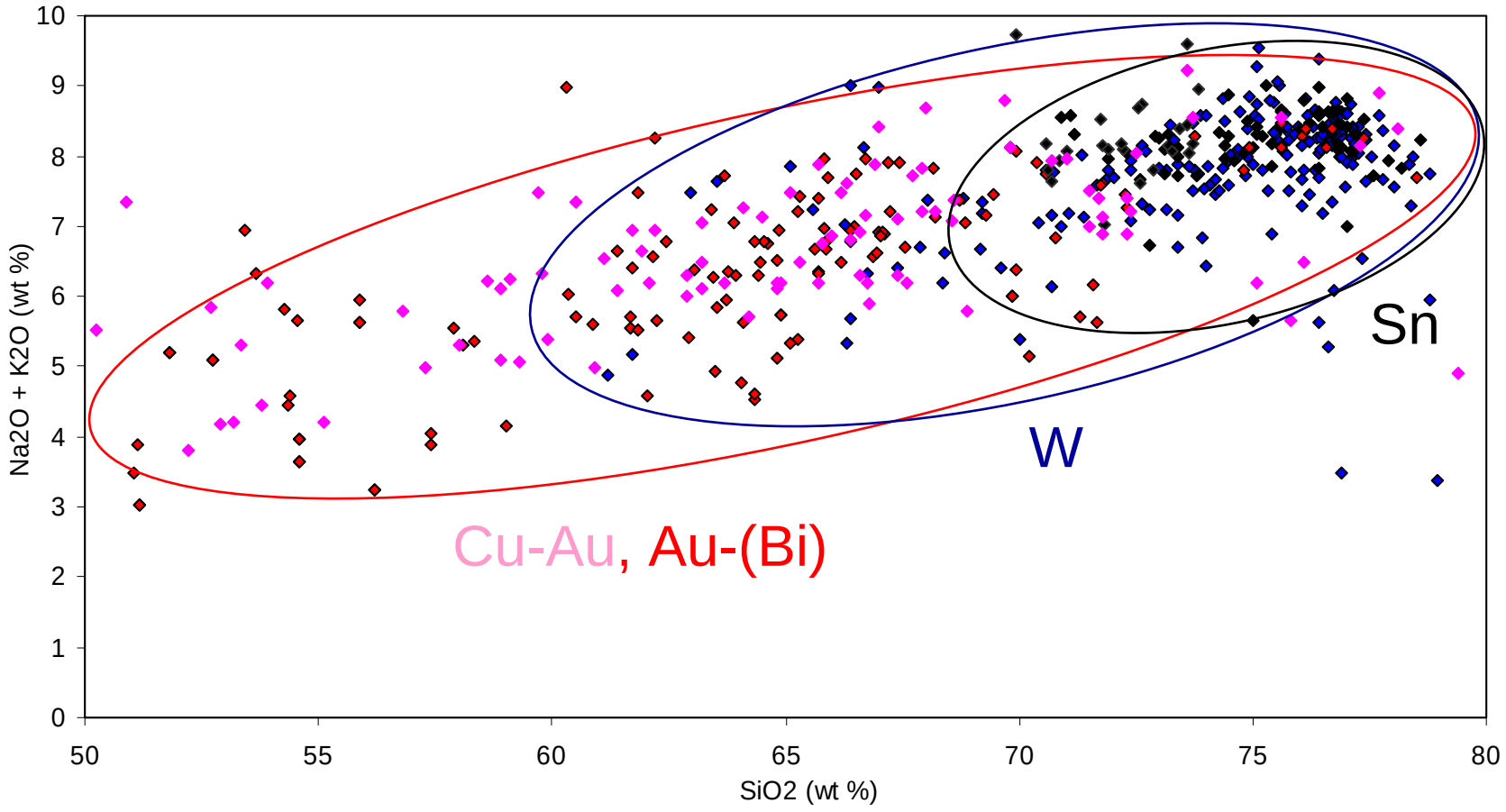


(Baker et al., 2005a)

Metallogenic Association	Region/ Deposit	Granite type	SiO2 wt %	Granitoid Series	Alumina saturation	Accessory minerals (in addition to zircon & apatite)
Sn-W-Bi	Cornwall	S	71-74	Ilmenite	peraluminous	ilmenite, monazite, andalusite, topaz, fluorite
Sn-W-Bi	Herberton	I	73-77	Ilmenite	peraluminous	ilmenite, monazite, topaz, fluorite
Sn-W-Bi	Fairbanks-Circle	I	71-77	Ilmenite	peraluminous	ilmenite, titanite, monazite, tourmaline, topaz
Sn-W	Western Thailand	I/S	70-74	Ilmenite	peraluminous	ilmenite, andalusite, pyrrhotite
W-Sn-Mo	Jiangxi	S	66-76	Magnetite	peraluminous	magnetite, ilmenite, garnet, monazite, tourmaline, fluorite
W-Cu-Mo	E Yukon	I	67-77	Ilmenite	metaluminous to peraluminous	ilmenite, monazite, garnet, andalusite, allanite, tourmaline
W-Mo-Sn-Bi	Altaid orogenic belt	I	63-77	Magnetite	metaluminous to peraluminous	magnetite, titanite, monazite, allanite, ilmenite
W-Mo-Bi-Sn	Herberton	I	56-72	Magnetite	metaluminous to peraluminous	allanite, fluorite, ilmenite
W-Sn-Au	Iberia	I/S	62-76	Ilmenite	metaluminous to peraluminous	cordierite, garnet, titanite, andalusite, sillimanite, tourmaline, topaz
Au-Bi-W	Tintina Gold Province	I	50-74	Ilmenite	metaluminous to peraluminous	ilmenite, titanite, allanite
Au-Bi-Mo	Tasman Fold Belt	I	49-78	Both	metaluminous to peraluminous	magnetite, ilmenite, titanite, fluorite
Cu-Au-Mo	SW Arizona	I	48-79	Magnetite	metaluminous to peraluminous	magnetite, titanite

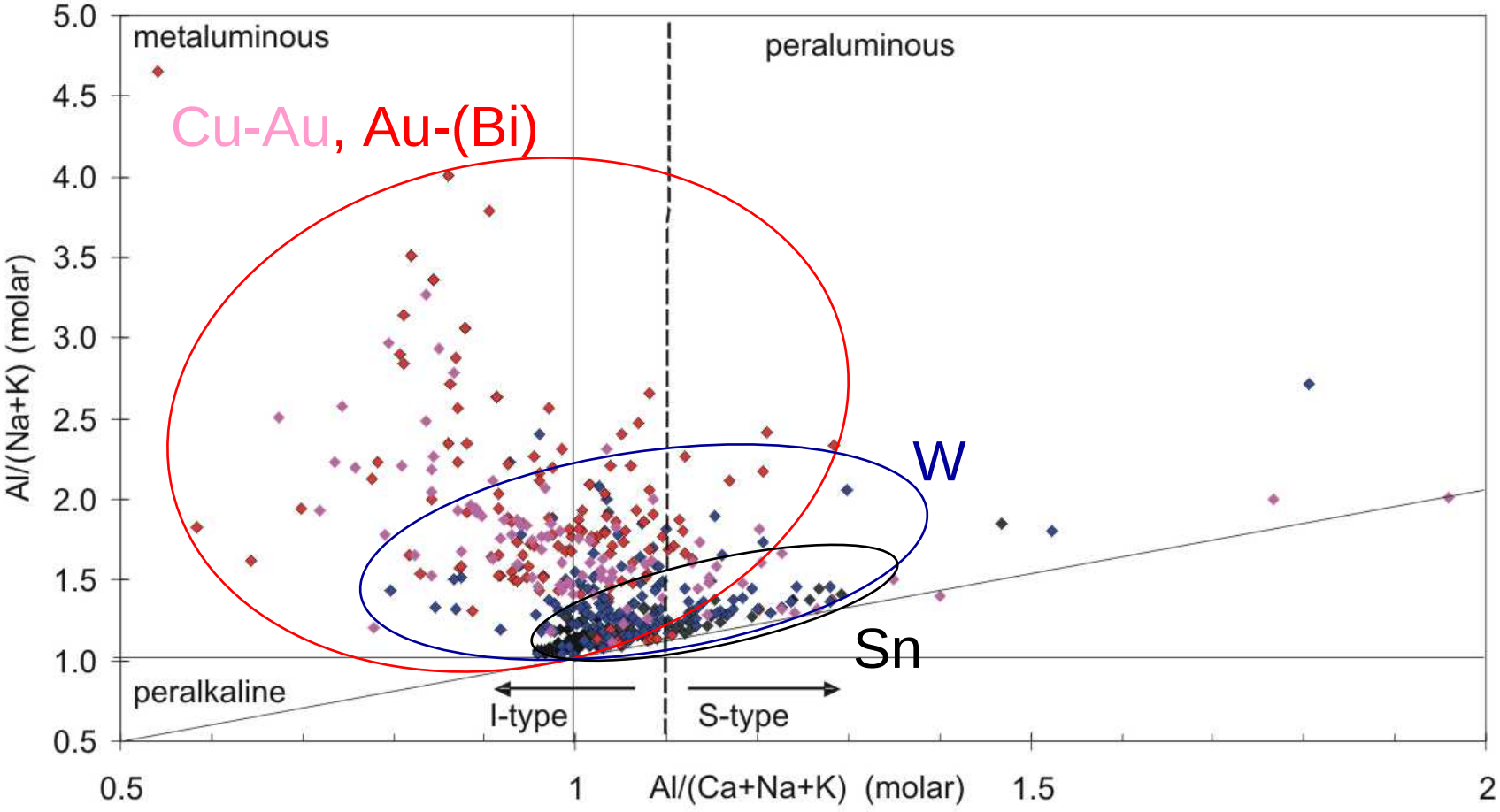
(Baker et al., 2005a)

MAGMAS & METALS



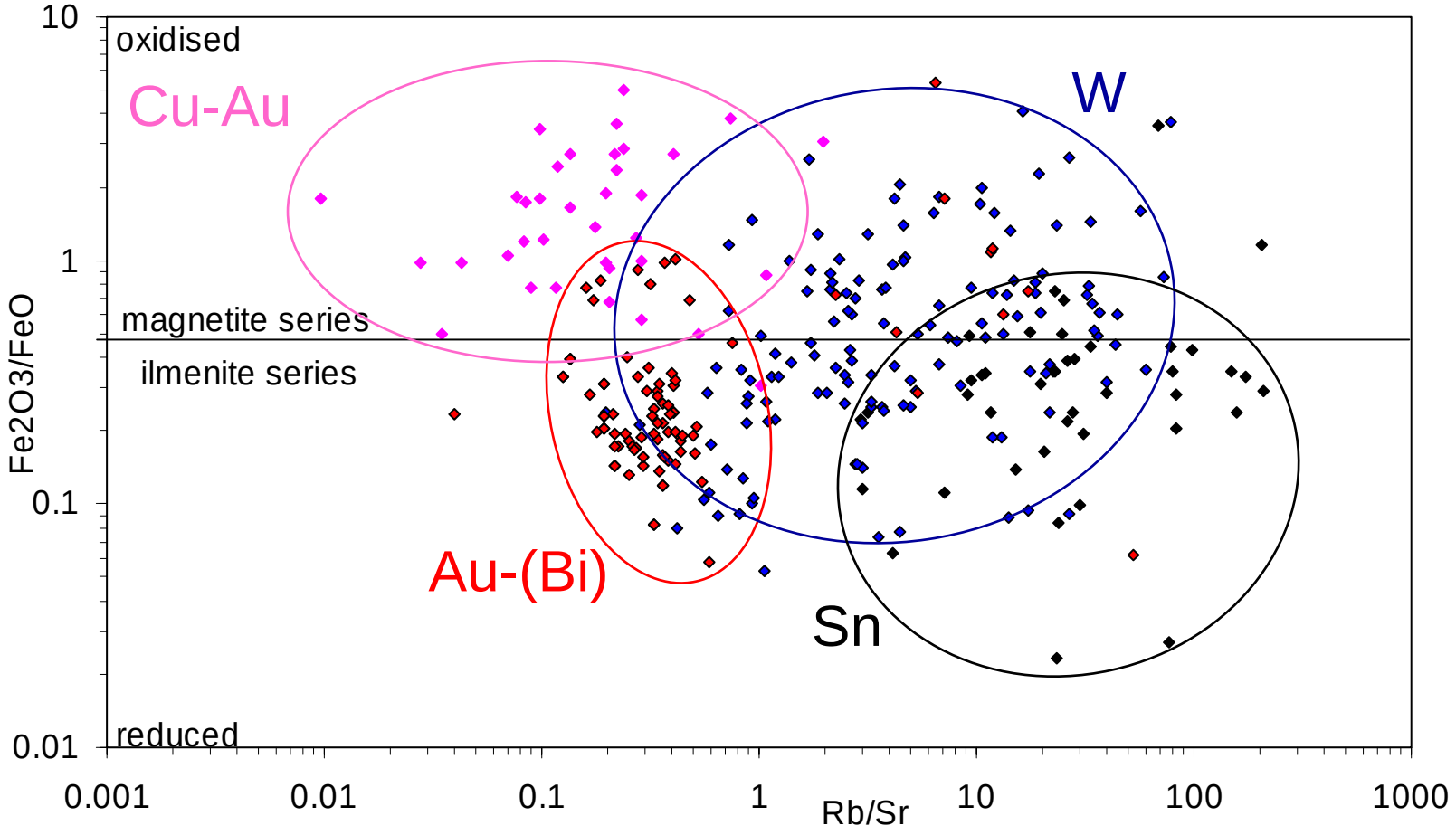
(Baker et al., 2005a)

MAGMAS & METALS



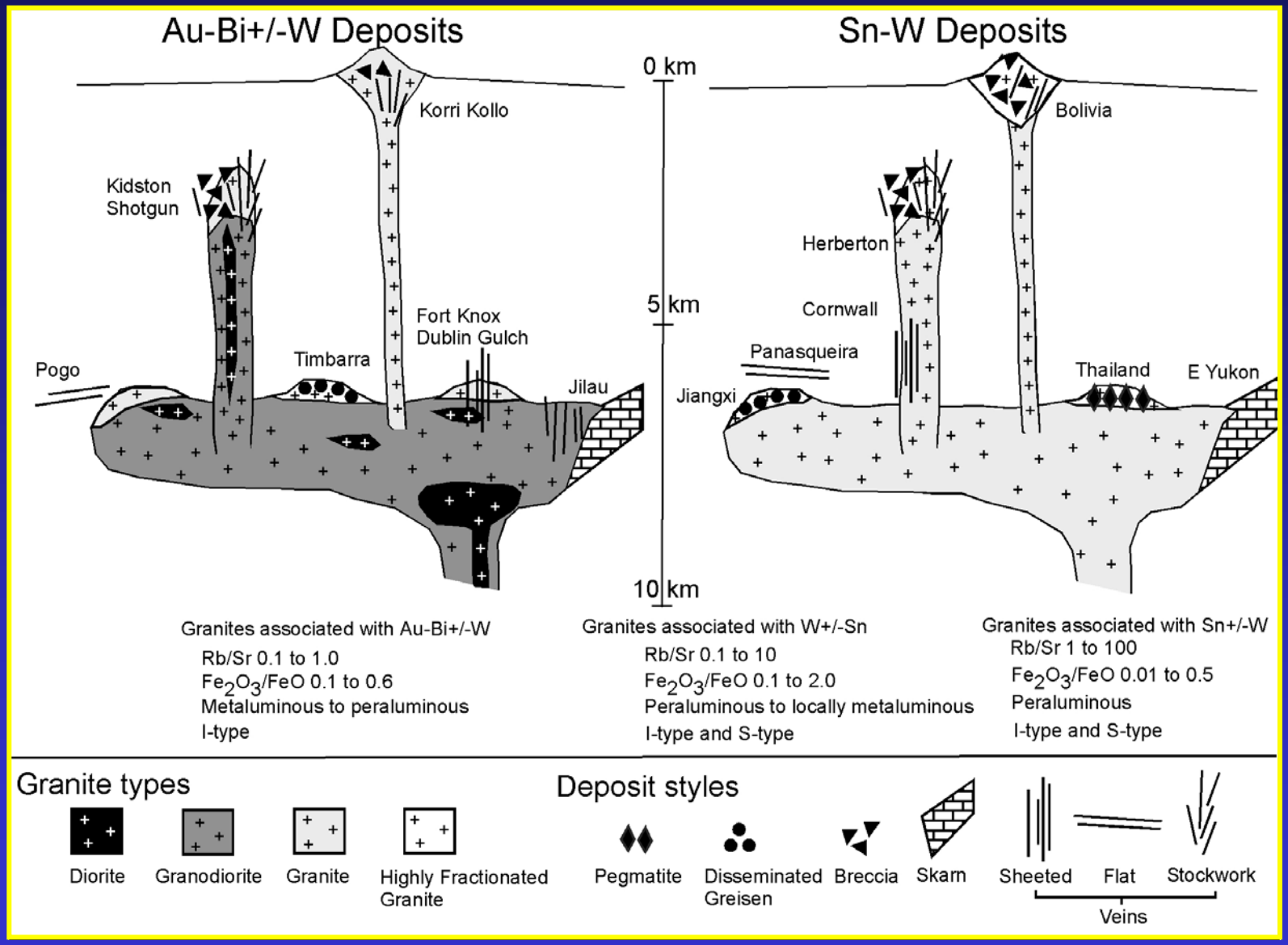
(Baker et al., 2005a)

MAGMAS & METALS

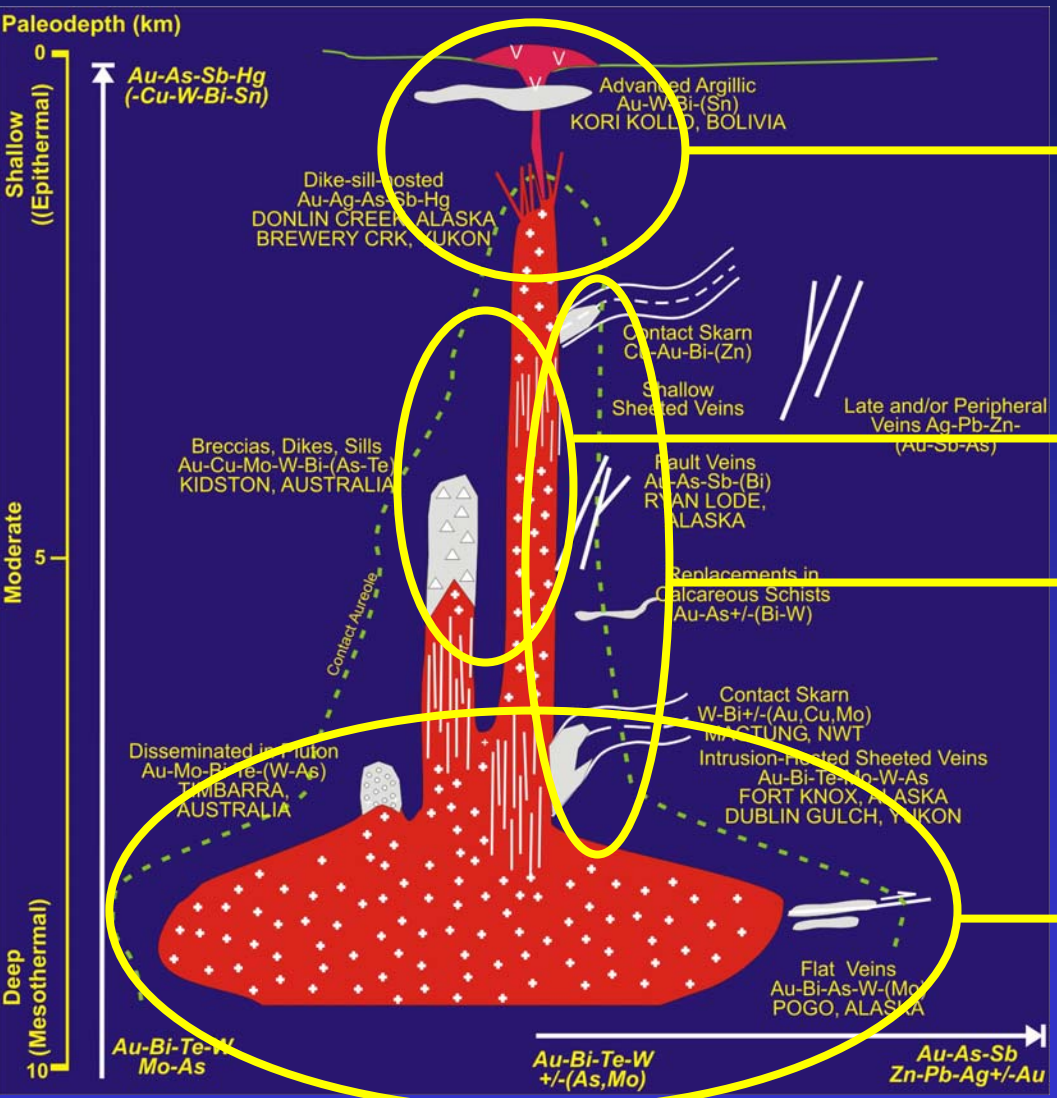


(Baker et al., 2005a)

GRANITE Au-Bi & Sn-W COMPARISON



COMPARISON WITH OTHER ORE SYSTEMS



Epithermal/epizonal gold

Porphyry Cu-Au (PCD's)

Skarn & sed-hosted Au (Carlin-like)

Mesothermal/orogenic gold

COMPARISON WITH OROGENIC GOLD

- Differences
  - Metals: Au-As-Sb-(W-Bi-Te)
  - Magma: Lacks spatial/temporal relationship
  - Structure: Regional scale faults
  - Ore: Py abundant
  - Alteration: Varies: host rock/metamorphic grade
- Similarities
  - Metals: Intrusion-hosted may have W-Bi-Te
  - Magma: Lacks spatial/temporal relationship
  - Structure: Deeper IRG have regional stress influence
  - Ore: Low-mod sulfide, reduced Po-Asp
  - Alteration: Albite, carbonate, quartz
  - Fluids: Low salinity, H_2O-CO_2-(CH_4)

EGRU

EPITHERMAL/EPIZONAL GOLD

- Shallow-level IRG
  - Donlin Creek, Brewery Creek, Korri Kollo
- Similarities: depth; As-Sb-Hg association
- Differences:
  - General geological & tectonic environment
  - LS – lack textures & wide structurally-controlled veins
  - HS – lack acidic fluids & related-alteration features; low Cu
  - Shallow IRG - High CO_2 content to fluids
- Epizonal orogenic gold
  - Less well defined
  - Shallow IRG – spatial & temporal association with intrusions

SKARN & SED-HOSTED GOLD

- Parallels with reduced Au skarns (Meinert,2000)
  - Part of total hydrothermal system
  - Calcareous host rocks
  - Associated with ilmenite series diorite to granodiorite
  - Reduced sulfide mineralogy; Au-Bi common
- Non-carbonate sequences may have links to Carlin systems (Poulson et al, 1997)

EGRU

COMPARISON WITH PCD's

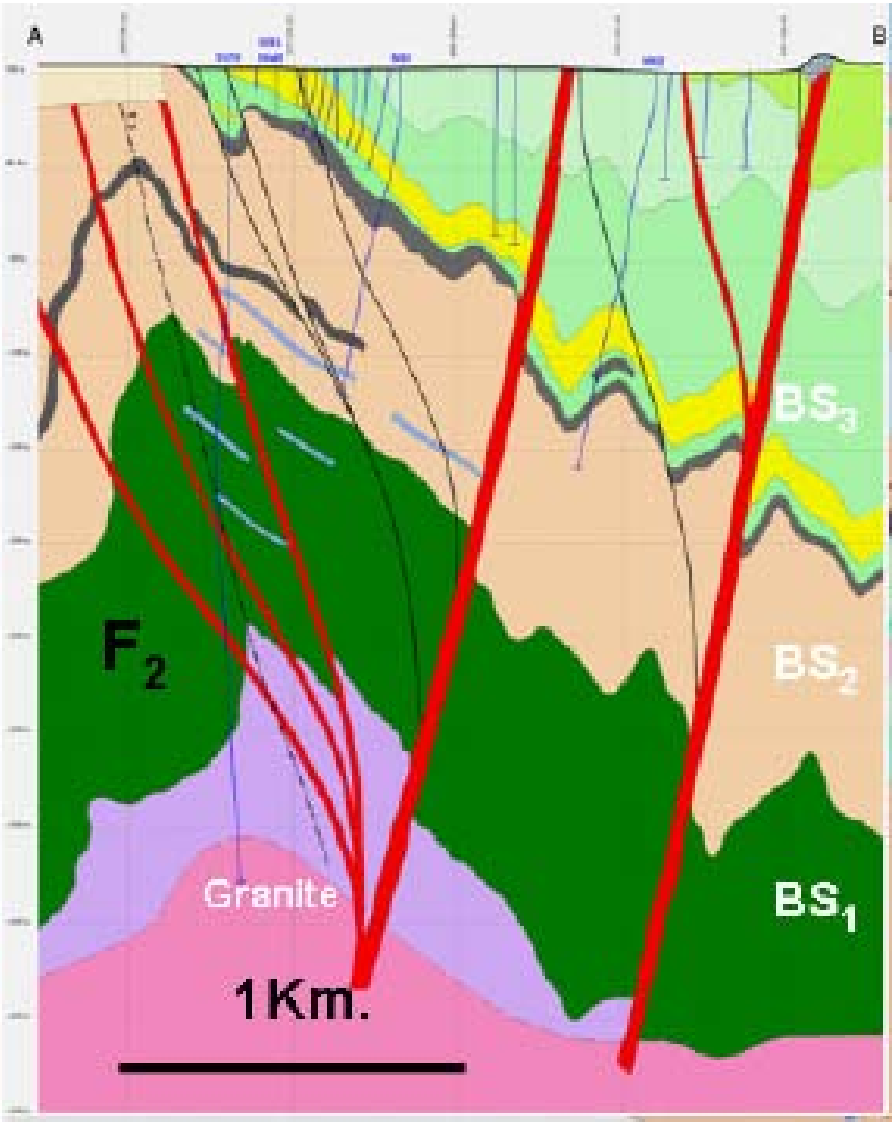
- Metals: Cu-Au-Fe-Pb-Zn-Ag-Mo
- Magmas: Oxidized I-type, higher Fe content
- Style: Multiple intrusions, stockwork & breccia
- Ore: High sulfide content, oxidized
- Alteration: Extensive, variety of types
- Fluids: High salinity, aqueous; carbonic rare

REDUCED PCD's (Rowins, 2000)

- Most examples NOT Cu deposits
- Some overlap with shallow porphyry-hosted environment (e.g. Shotgun but again no Cu)
- Also distinct from alkalic Au & Cu-Au systems
- More parallels with W-Sn-Mo systems

EGRU

THERMAL AUREOLE GOLD SYSTEMS



Deposit	Location	Age	Host Rocks	Gold Resource 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	meta-sediments	>100Moz @ 2-3g/t; medium temperature mineralisation
Kumtor	Kyrgyzstan	Permian	meta-sediments	9.3Moz @ 3.6g/t; pluton distal
Vasilko-vskoye	Kazakhstan	Early Palaeozoic	granitoids	13.3Moz @ 3g/t; pluton margin hosted
Telfer	Australia	Late Proterozoic	mainly meta-sediments	>31Moz; pluton distal Granites
Tanami	Australia	Early Proterozoic	meta-sediments	>13Moz; medium-high gold grades pluton proximal to distal
Obuasi	Ghana	Early Proterozoic	meta-sediments	>49Moz production + resources; pluton distal
Morila	Mali	Early Proterozoic	meta-sediments	>7.0Moz; pluton proximal
Wallaby	Australia	Late Archaean	meta-sediments	7Moz; pluton distal
Campbell-Red Lake	Canada	Late Archaean	mafics-ultramafics	>25Moz @ >15g/t; pluton proximal

Table 1: Some examples of TAG deposits

(Wall, 2005)

OVERVIEW

- Part 1: Classification, nomenclature & deposit comparison

- Part 2: Examples: Tintina Gold Province

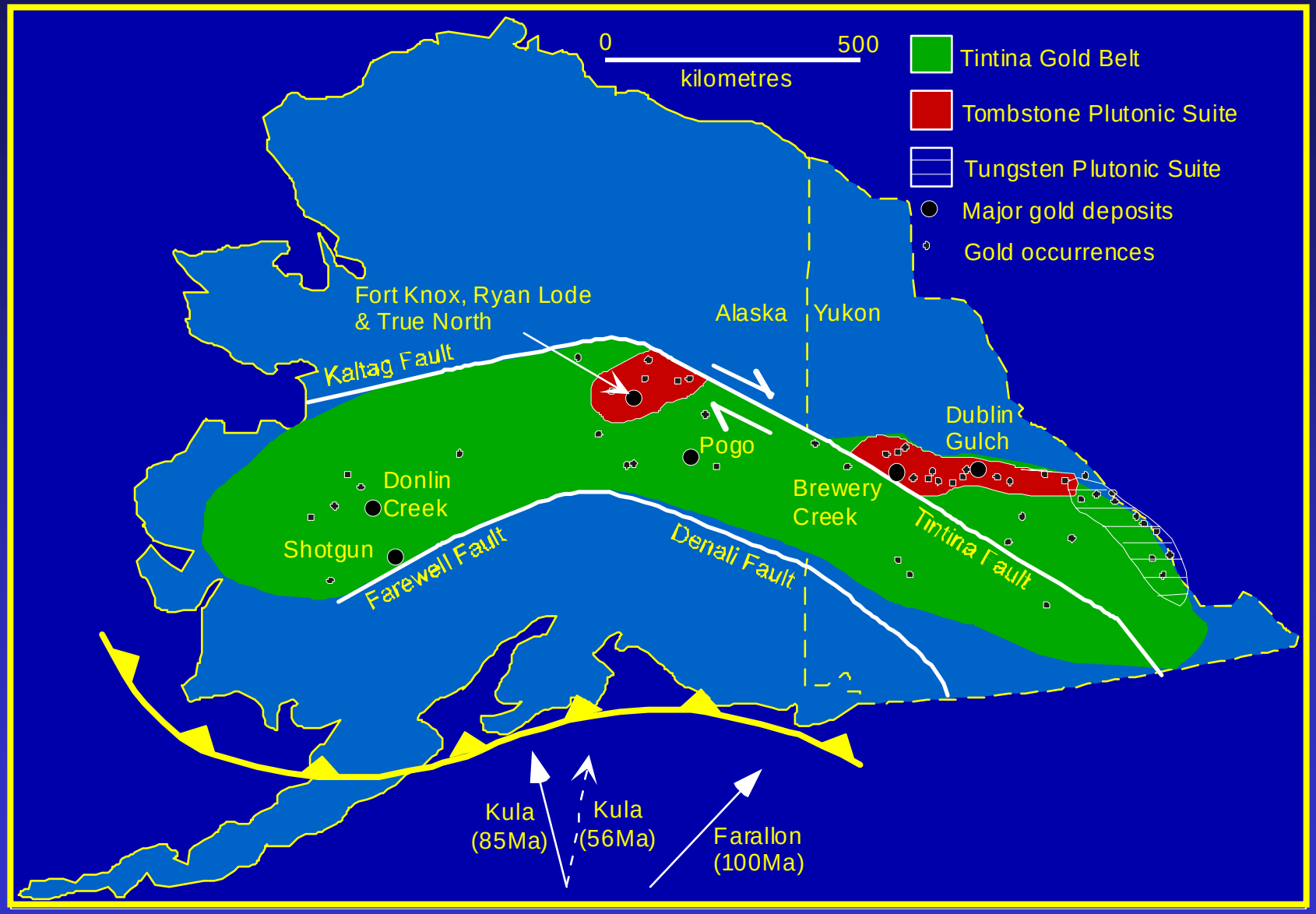
- Part 3: Other examples & exploration

TGB EXAMPLES

Deposit	Size (Mt)	Grade (g/t)	Country rocks	Intrusion composition	Deposit type	Age (Ma)	Metal suite
Tintina Gold Belt							
Fort Knox, Alaska	> 5 M.oz.		Mica-quartz schist	Porphyritic granite	Sheeted veins	92	Bi, Te, Mo, As, Sb, W
Pogo, Alaska	> 5 M.oz.		Gneiss	Granite, aplite	Flat lenses	107-92?	Bi, Te, As, Ag, Cu, Pb
Ryan Lode, Alaska	4.1	3.1	Quartz-mica schist	Granodiorite	Veins, breccia	90	As, Sb
True North, Alaska	16.5	2.5	Schist & eclogite	Granite	Disseminated, breccia	90	As, Sb, (Hg)
Dublin Gulch, Alaska	50.3		Qtz-bt & calcareous schist	Granodiorite	Sheeted veins	92	Bi, Te, Mo, As, Sb, W, Pb
Brewery Creek, Yukon	~ 2 M.oz. 13.3	1.4	Calcareous schist	Monzonite, syenite	Disseminated, veinlets	91.4	As, Sb, (Hg)
Shotgun, Alaska	~1M.oz.		Quartz-biotite schist	Granite	Stockwork	70	Ag, Bi, Mo, Te, Cu
Donlin Creek, Alaska	> 25 M.oz.		Greywacke & shale	Rhyodacite	Veins, veinlets	70	Ag, As, Sb, Hg

(Thompson et al., 1999)

TINTINA GOLD BELT



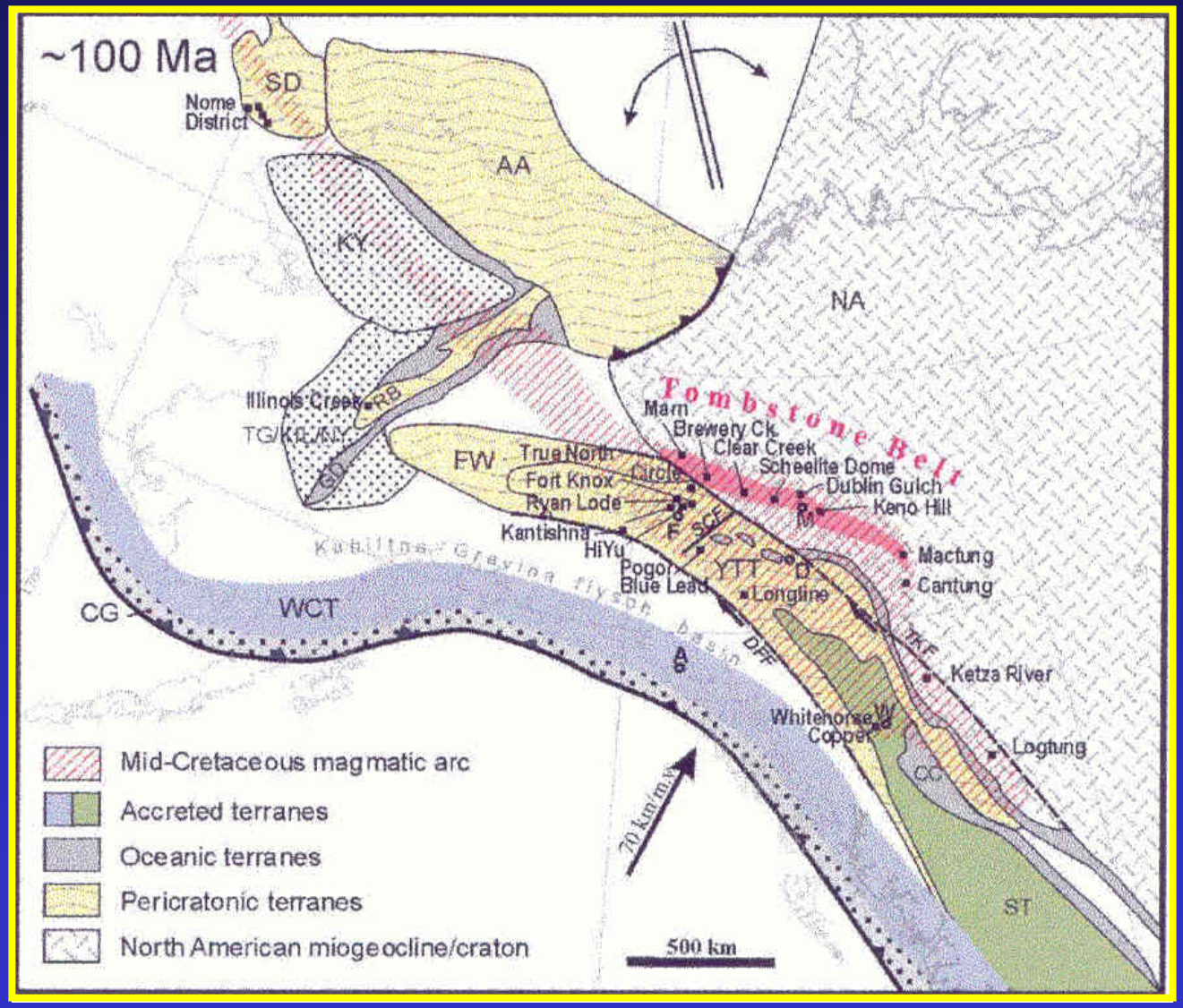
(Flanigan et al., 2000)

TECTONIC SETTING

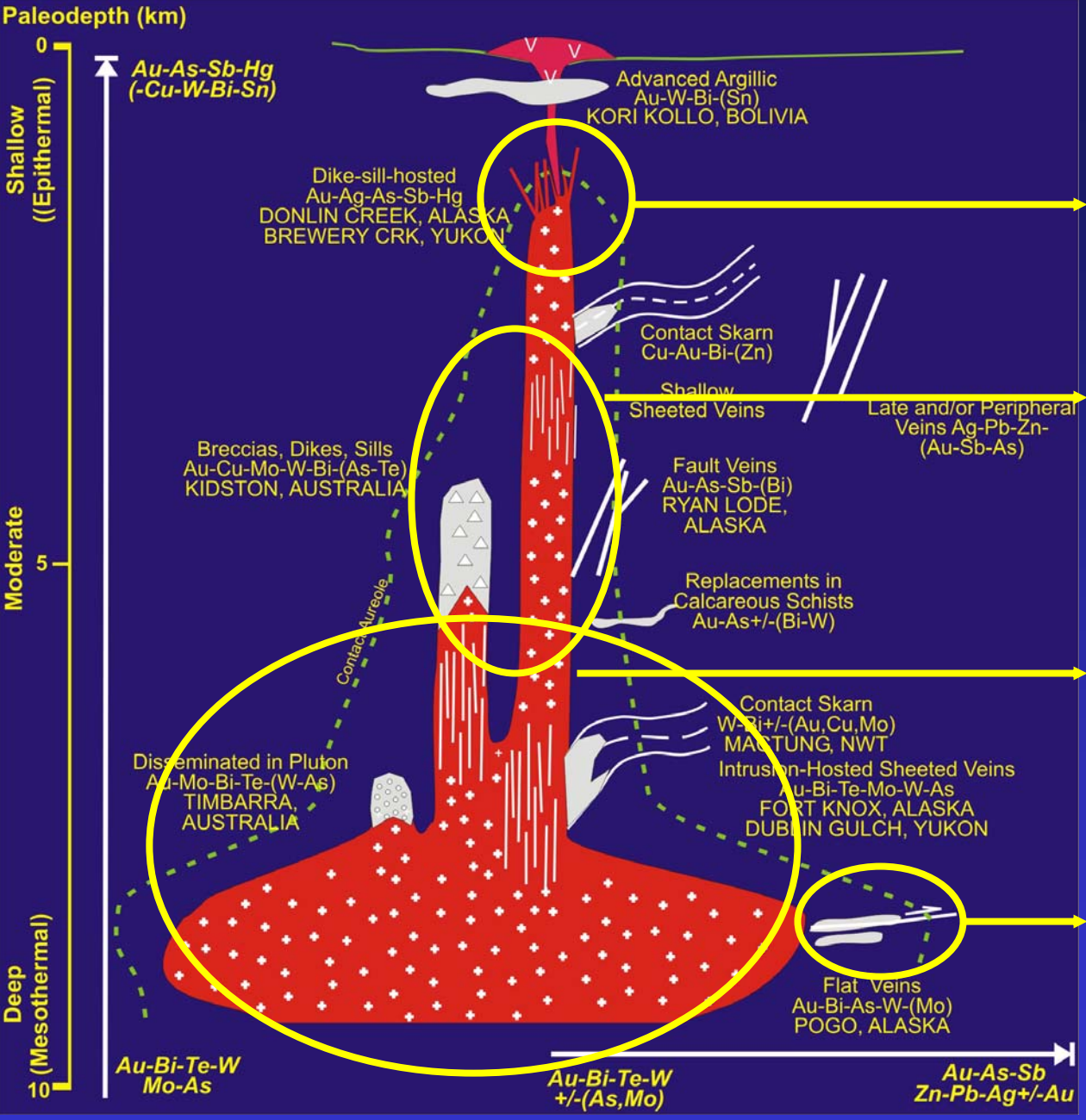
- Central-eastern Alaska & Yukon
  - Orthogonal subduction Farallon plate 115-100 Ma
  - Continued subduction - dextral component 100-85 Ma
  - Coincident magmatism – younging cratonwards
  - Strong crustal component (Nd_T –7.6 to –15; $^{87}Sr/^{86}Sr$ 0.709-0.702)
  - Kula plate oblique subduction,dextral strike-slip 85 Ma
- Western Alaska
  - Magmatic arc 77 to 58 Ma
  - Local N-S compression – plate reorganization ~ 70 Ma
  - Kuskokwim magmatism – shallow at continental margin

(Flanigan et al., 2000; Goldfarb et al., 2000)

TINTINA GOLD BELT



(Goldfarb et al., 2000)



Shallow-level examples

Porphyry-style examples

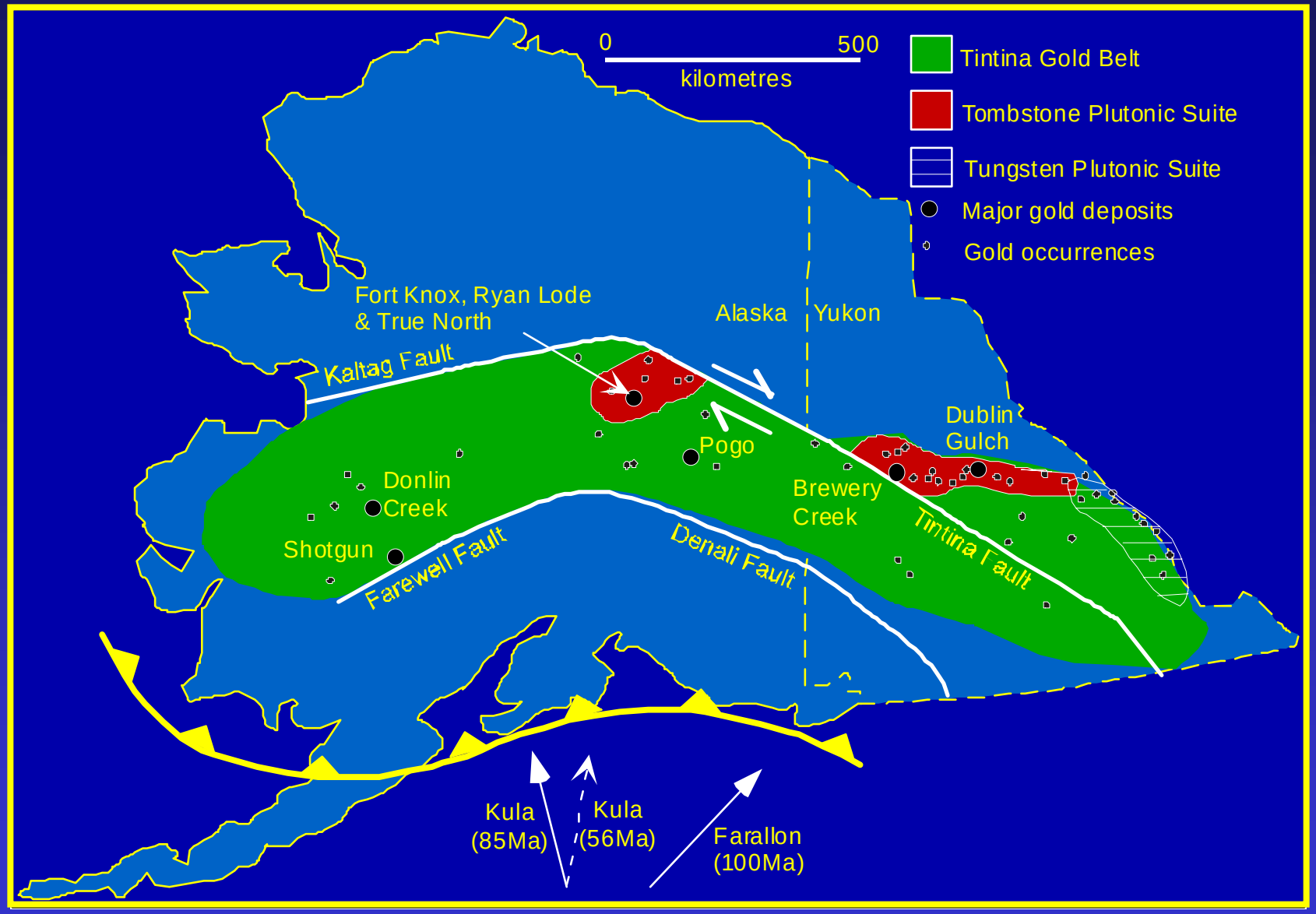
Type-examples

Pogo

GEOLOGICAL EXPLORATION MODEL

TPS WESTERN YUKON

TINTINA GOLD BELT



(Flanigan et al., 2000)

FORT KNOX

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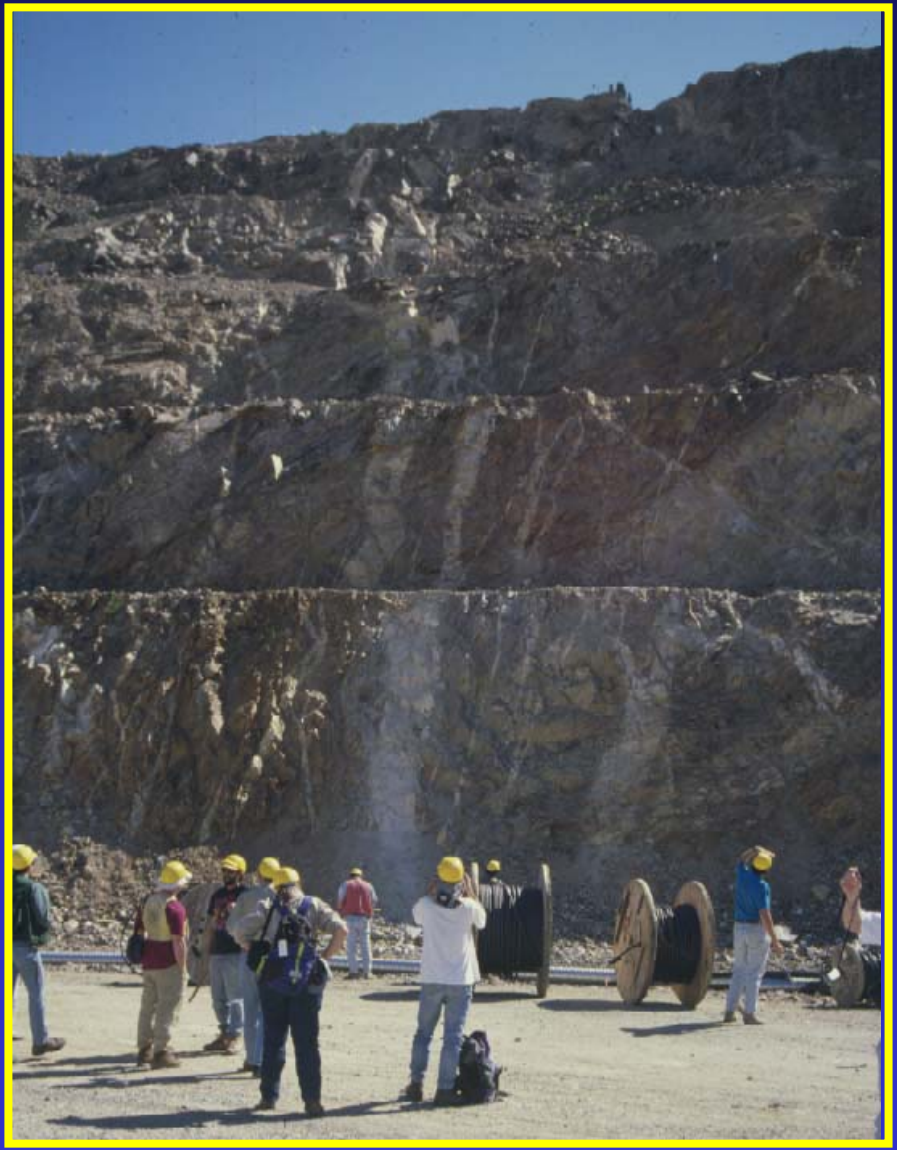


FORT KNOX (7.2 M.oz.)

- Exploration & mining
  - Placer gold 1902 in creeks down stream
  - Au-W veins & skarns 1913 peripheral to FK
  - Bismuthinite with Au 1980 proximal creeks
  - Visible Au in granite 1984
  - Advanced exploration 1987 to 1994
  - Construction 1995; bulk tonnage open pit
  - Production 1996; 169 Mt @ 0.93 g/t
  - 1 M.oz. 1999

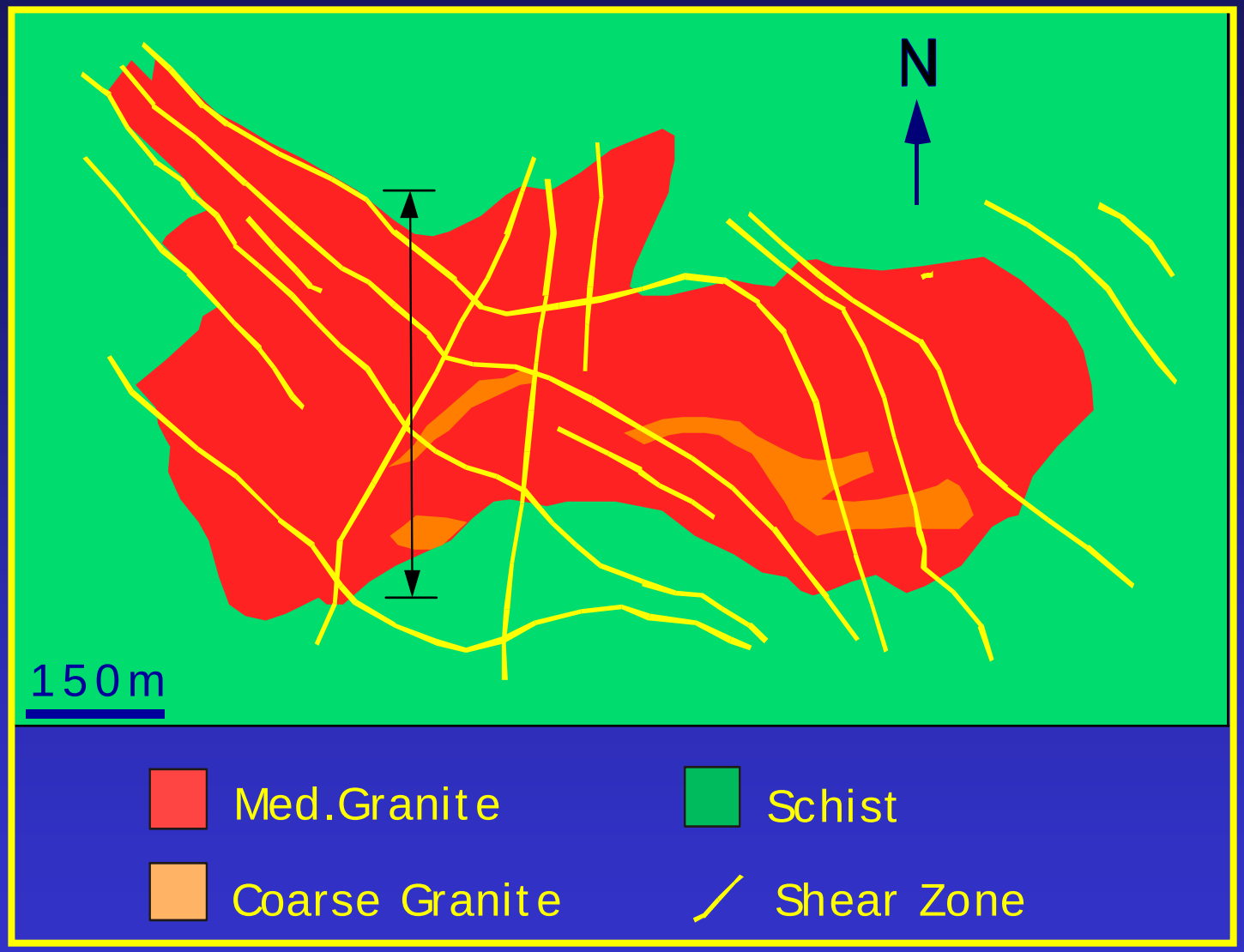
(Bakke, 1994)

FORT KNOX

- Intrusion Characteristics
  - Tombstone suite
  - Granodiorite to granite
  - Ilmenite series, I-type
  - Late aplites & pegmatites
  - Locally UST & brain rock textures
- Age
  - U-Pb 92 Ma - Intrusion
  - Ar-Ar ~88-86 Ma - Muscovite alt.
  - Re-Os 92.5 Ma -Molybdenite

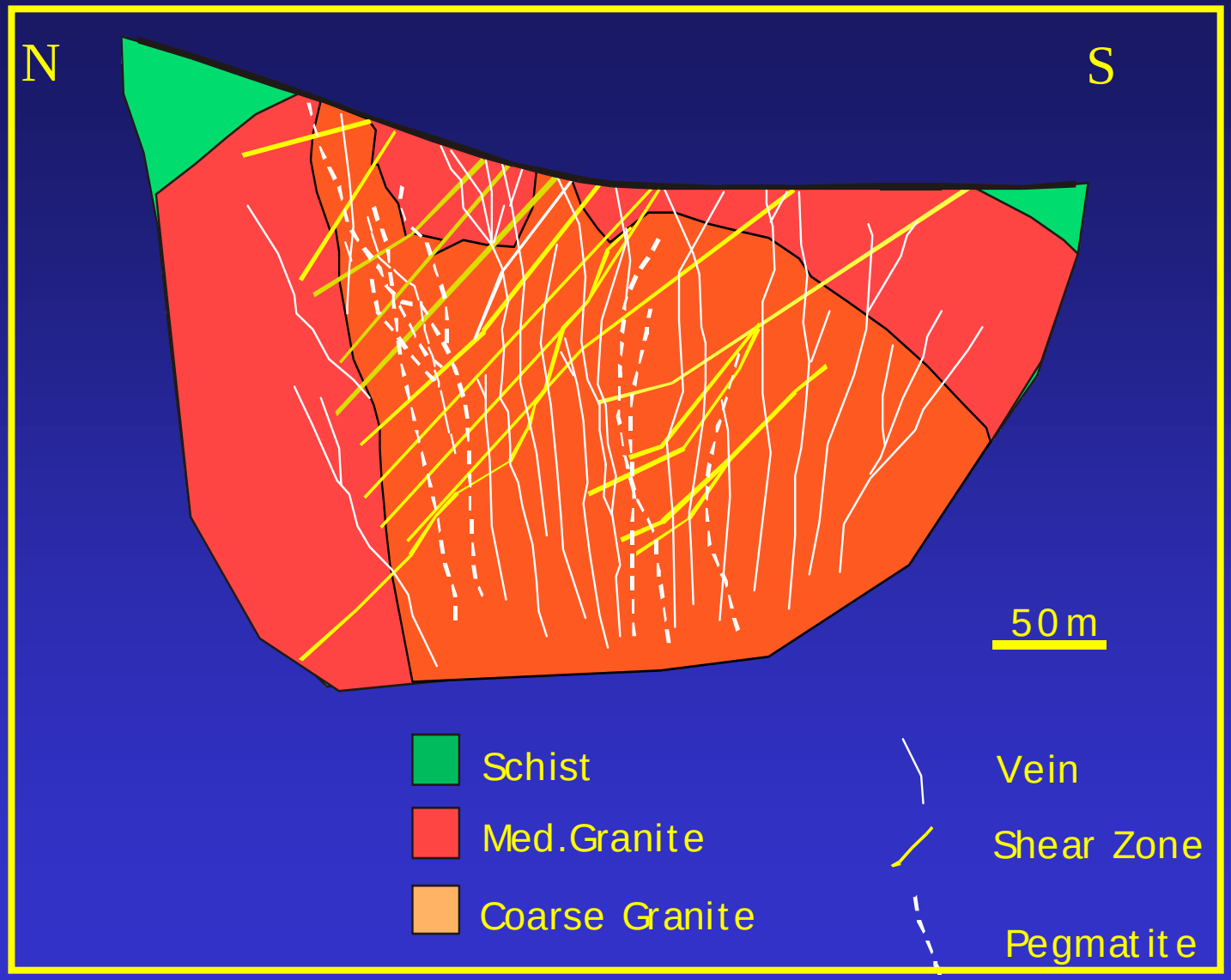
(Bakke, 1994; Hart et al., 2001)

FORT KNOX



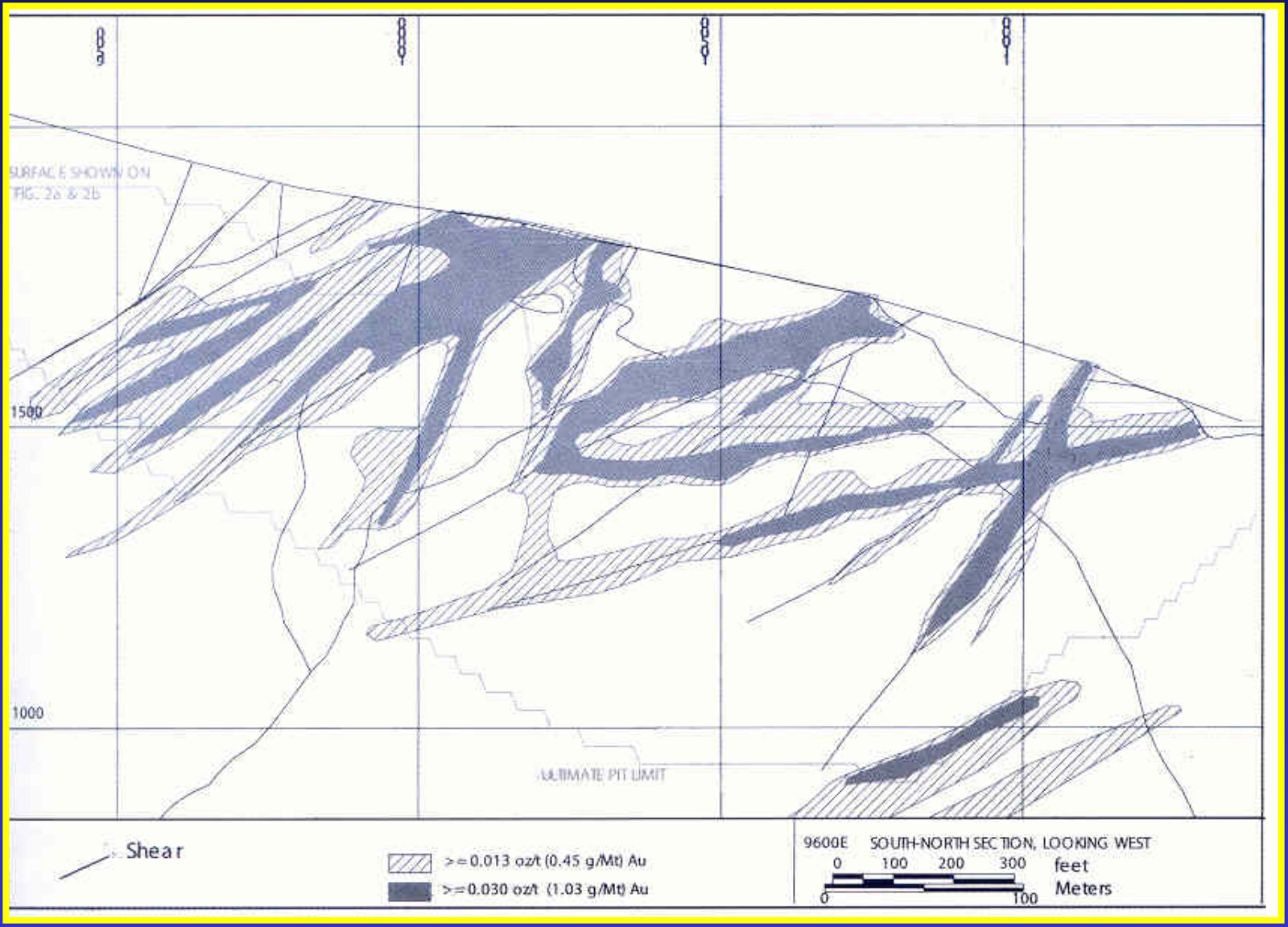
(Bakke, 1994)

FORT KNOX (looking W)



(Bakke, 1994)

FORT KNOX (looking W)



(Bakke, 2000)

FORT KNOX

- Vein Characteristics

  Pegmatites & sheeted veins (min'l)

  Overprinted quartz filled faults (min'l)

  Au-Bi-Te-As-Sb-W-Mo (inc. deeper)

  Sulfide <1% - Py, Po, Apy, Mo, Sch

- Ore Characteristics

  Bi, Bi_2S_3, Bi_2Te_3

  Free Au, ~111microns, >960 fineness

  Au:Bi 0.86

(Bakke, 1994; McCoy et al., 1997)

FORT KNOX

FORT KNOX

FORT KNOX

FORT KNOX

- Alteration

  Early Albite > K-feldspar

  Quartz-Sericite-Carbonate

  Regional propylitic & pyrite halo

- Fluids

  Low salinity aqueous-carbonic

  250-500°C @ >1.5kbar, >5km

  Oxygen isotopes fluid 5 to 10 per mil

  Sulphur isotopes 0±5 per mil

(Bakke, 1994; McCoy et al., 1997)

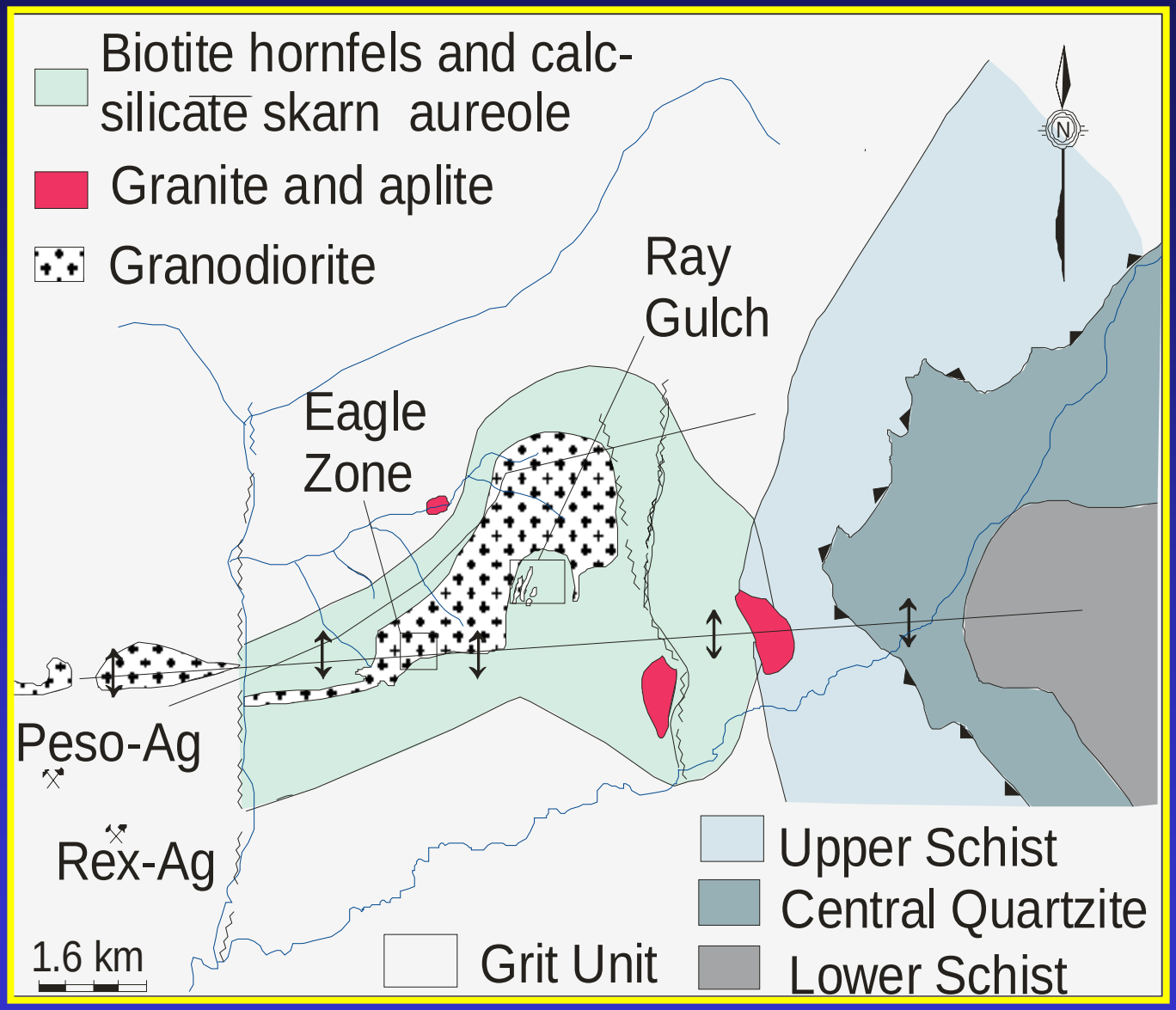
DUBLIN GULCH

DUBLIN GULCH (~2 M.oz.)

- Exploration
  - Placer Au mining established 1895 – 1898;scheelite reported
  - Rex-Peso Pb-Zn-Ag veins explored 1910
  - Cassiterite found – Tin Dome (<0.3 % Sn)
  - Au-W-Bi reported (Boyle, 1965)
  - W-skarn targeted;soil sampling& mapping – 1970-1980
  - Ray Gulch 5.4 Mt.@ 0.82 % WO_3
  - Gold in peripheral veins explored – 1986-1988
  - 1991 to 1996 gold soil anomaly around Eagle Zone drilled

(Maloof et al, 2001)

DUBLIN GULCH



(Maloof et al, 2001)

DUBLIN GULCH

- Intrusion Characteristics

  Granodiorite to granite

  Ilmenite series, I-type

  Late aplites & pegmatites

- Vein & Ore Characteristics

  Predominantly sheeted veins (2 main stages)

  Au-Bi-Te-As-Sb-Pb-W-Mo (inc. deeper)

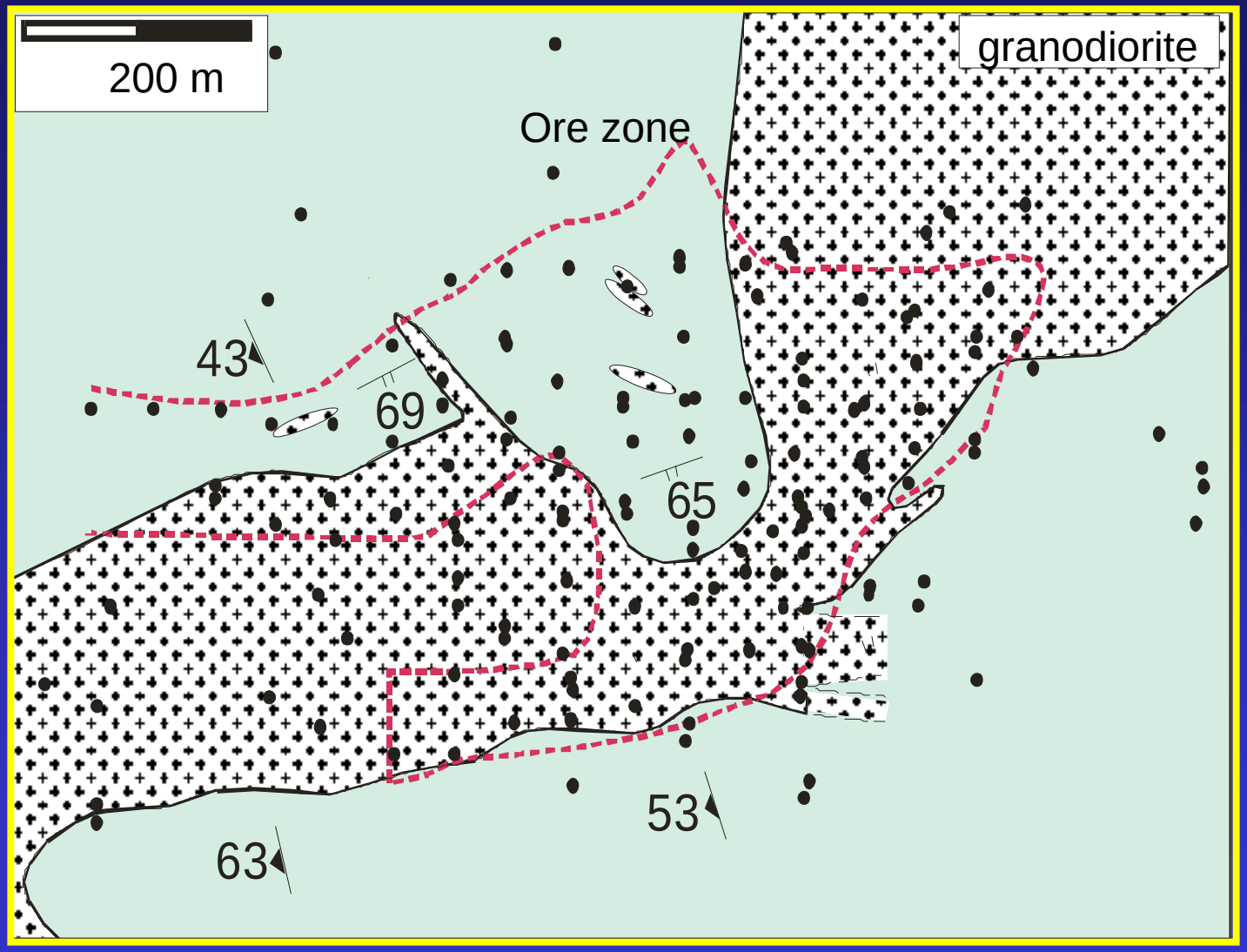
  Sulphide <3% - Py, Po, Apy, Sch, Gal, Au-Pb-Bi-Te-Sb

  Free Au & Au-Bi, ~155microns, ~1000 fineness

  Au:Bi – 0.89

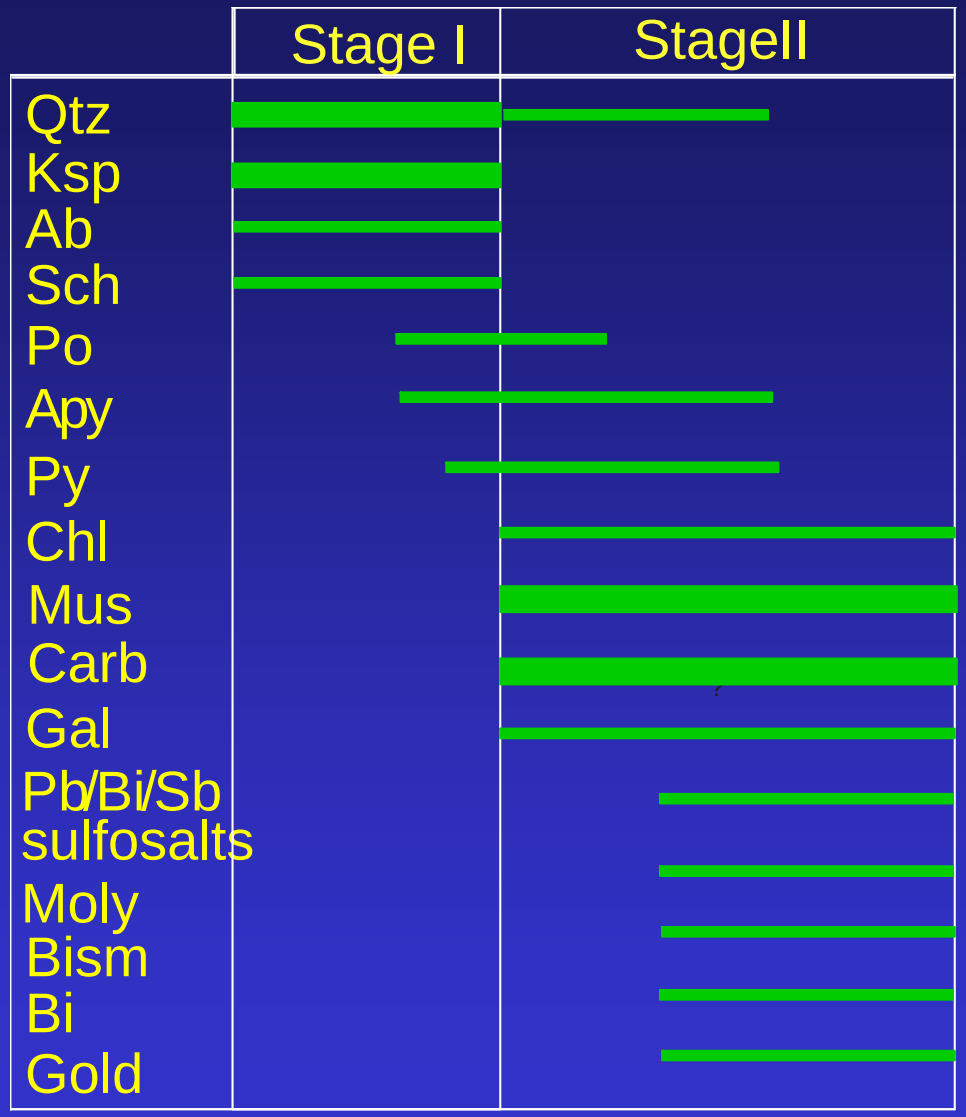
(Maloof et al, 2001)

EAGLE ZONE



(Maloof et al, 2001)

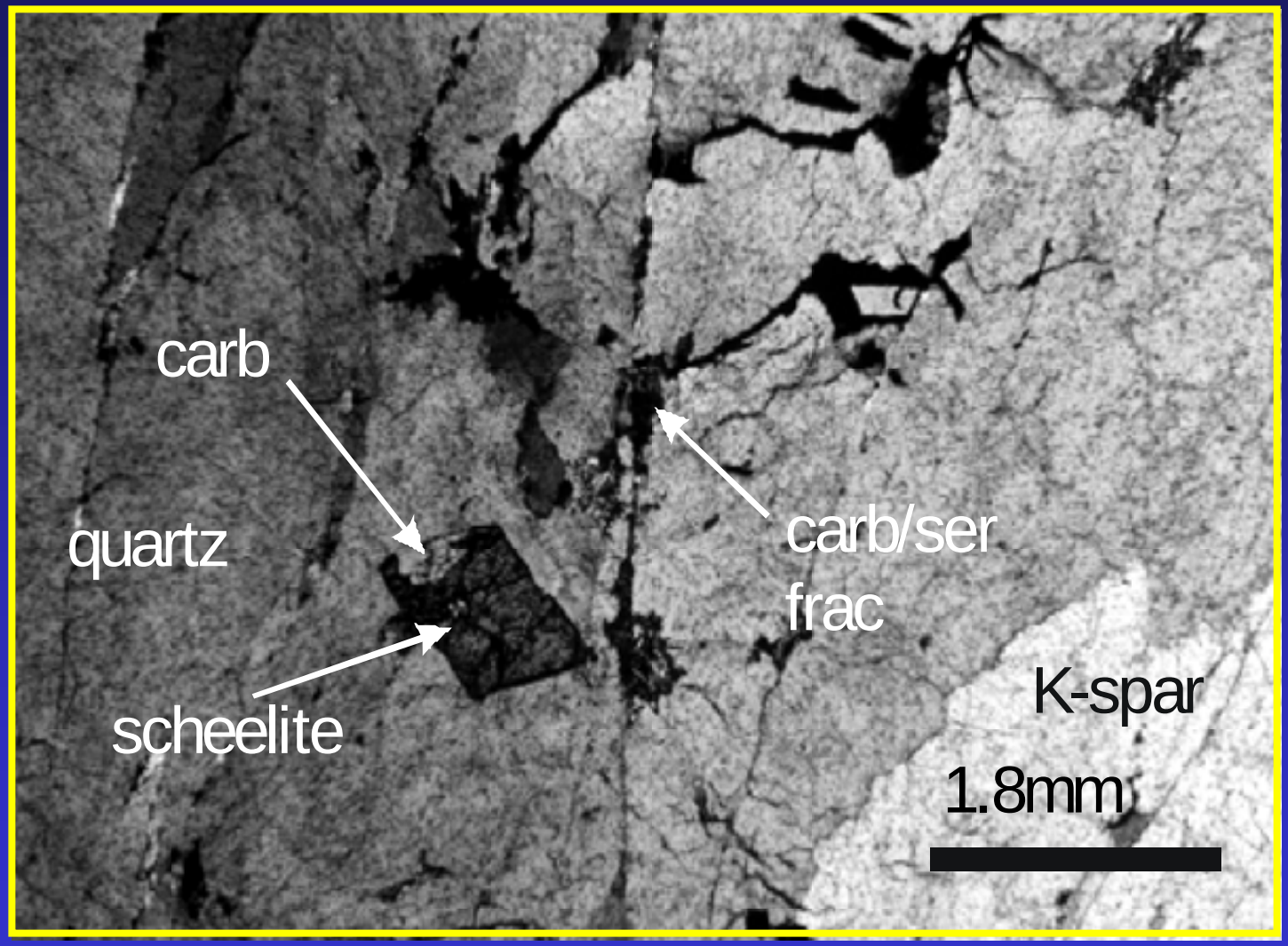
EAGLE ZONE PARAGENESIS



(Maloof et al, 2001)

EAGLE ZONE VEIN

EAGLE ZONE PARAGENESIS



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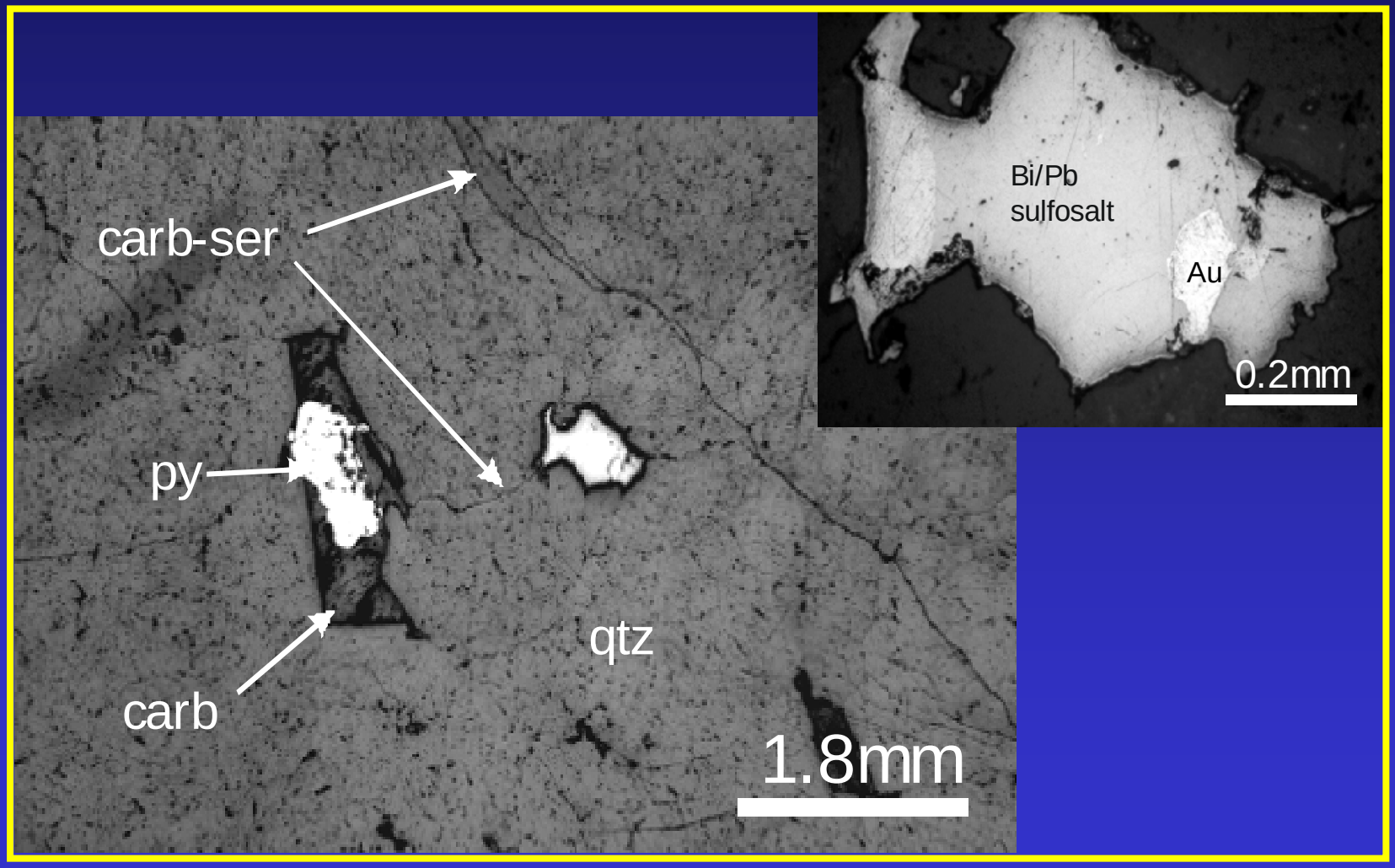
EAGLE ZONE PARAGENESIS



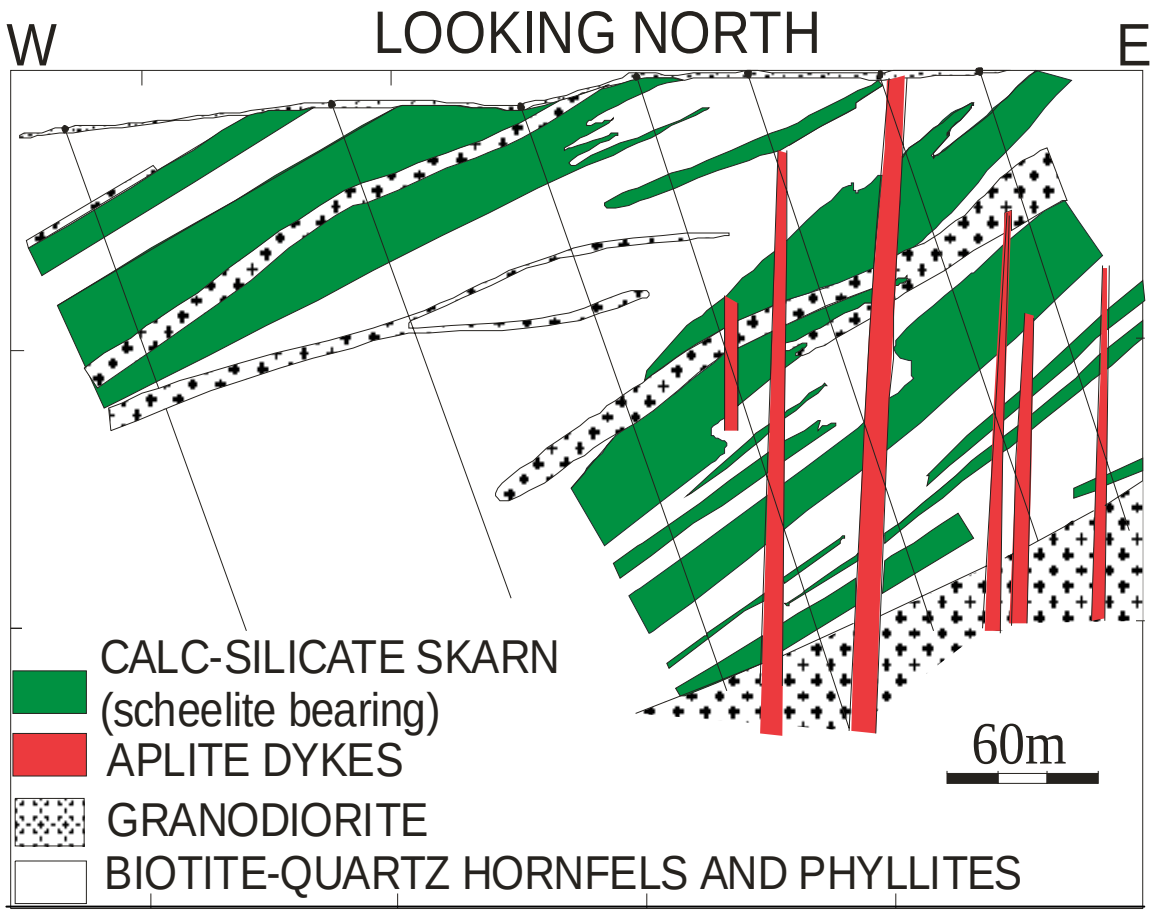
(Maloof et al, 2001)

EAGLE ZONE GEOCHEMISTRY

	Au	Bi	As	Sb	Ag	Mo	W	Zn	Pb
Cu	0.14	0.15	0.59	0.56	0.63	0.23	0.00	0.59	0.64
Pb	0.08	0.07	0.68	0.89	0.89	0.08	0.00	0.93	
Zn	0.03	0.02	0.58	0.74	0.77	0.10	0.00		
W	0.03	0.00	0.00	0.00	0.00	0.55			
Mo	0.15	0.17	0.07	0.04	0.07				
Ag	0.24	0.21	0.79	0.85					
Sb	0.07	0.05	0.61						
As	0.28	0.24							
Bi	0.90								

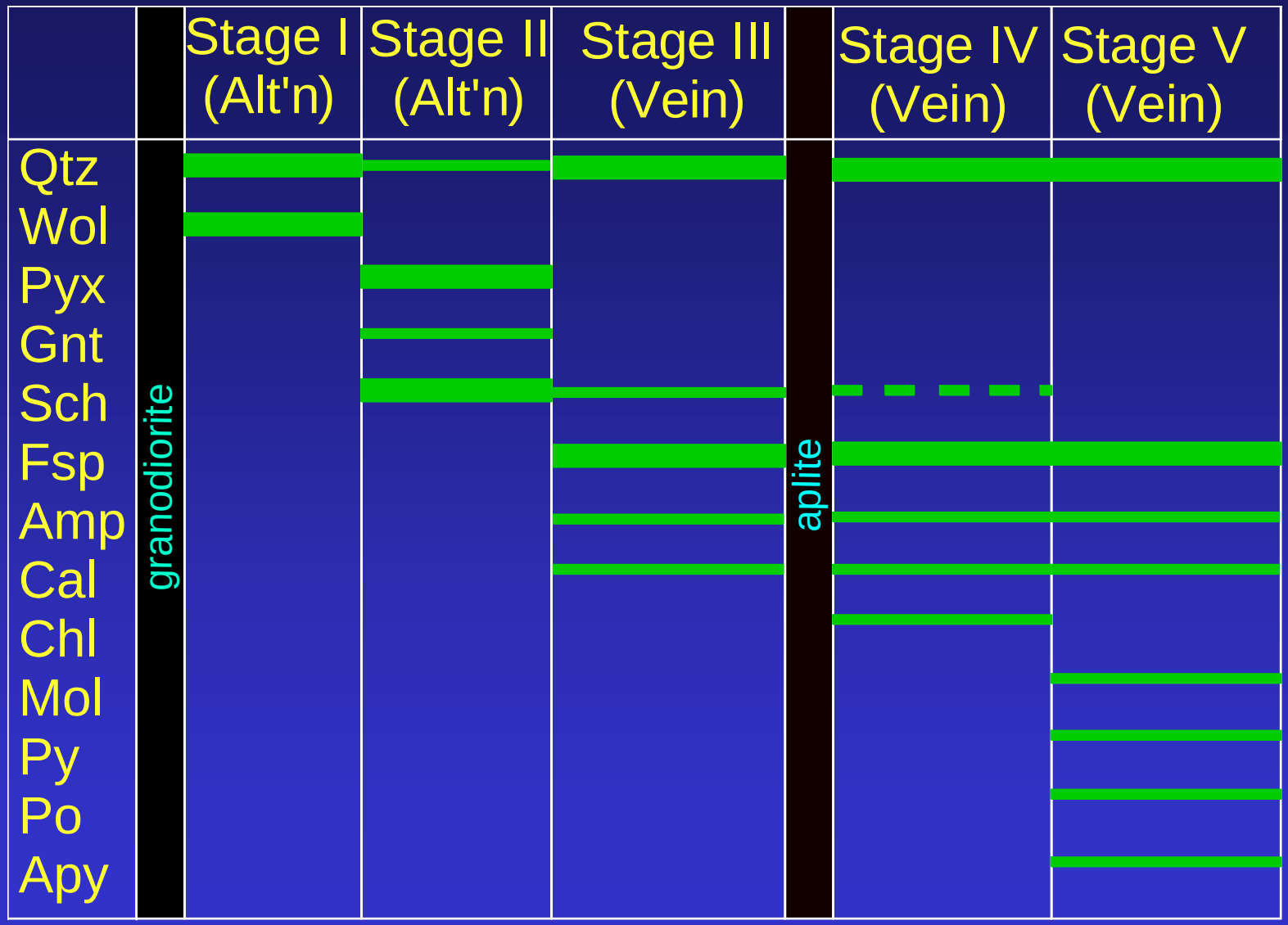
(Maloof et al, 2001)

RAY GULCH



(Brown et al, 2001)

RAY GULCH PARAGENESIS



(Brown et al, 2001)

EAGLE ZONE GEOCHEMISTRY

		Ave.
Au	up to 40 g/t	0.83
Bi	up to 500 ppm	19
W	up to 2000 ppm	11
Mo	up to 700 ppm	6
As	up to & >10,000 ppm	195
Pb	up to & >10,000 ppm	59
Zn	up to & >10,000 ppm	108
Sb	up to 5,000 ppm	11
Cu	up to 355 ppm	34

(Maloof et al, 2001)

RAY GULCH GEOCHEMISTRY

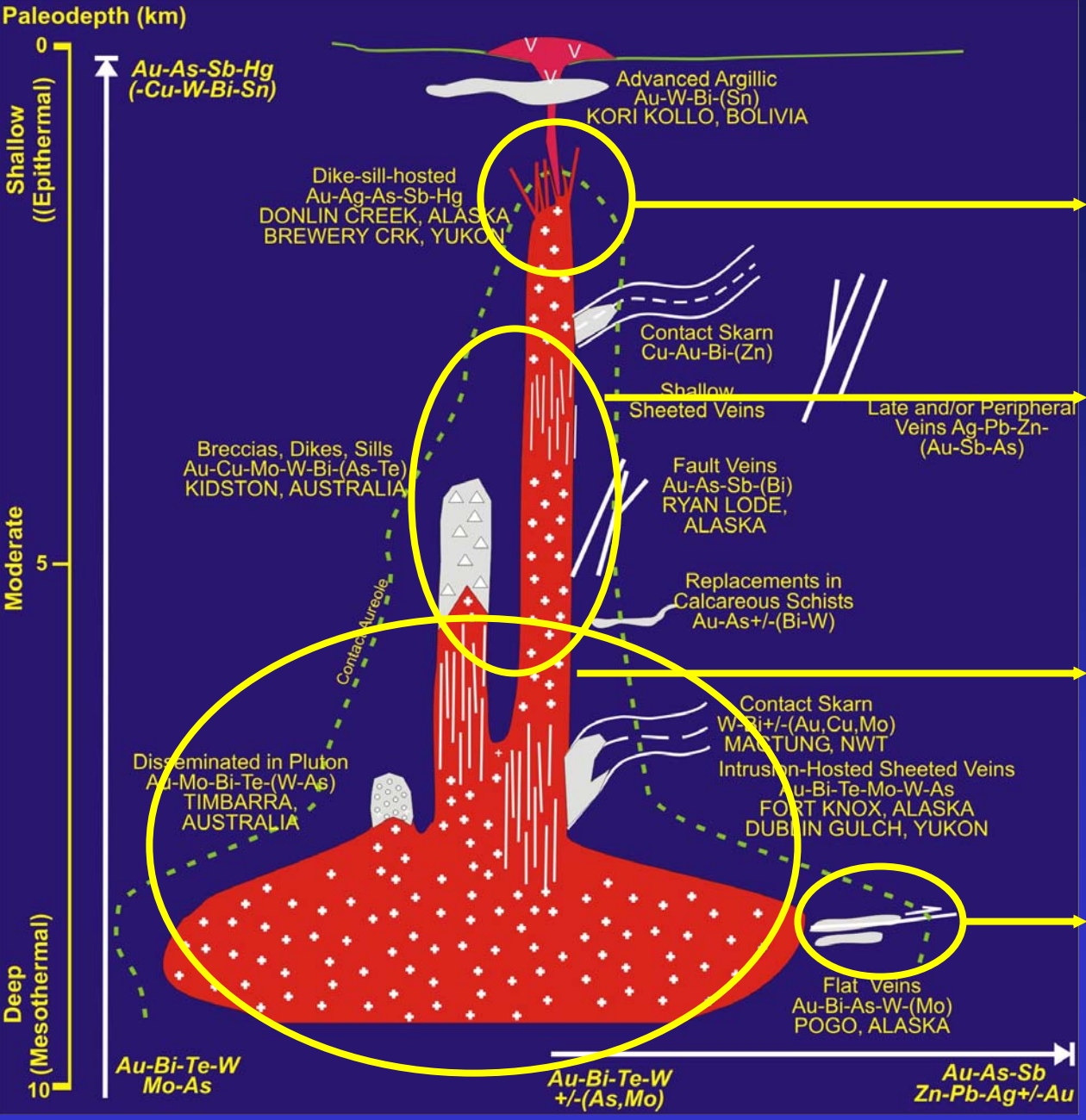
	W	Mo	Sn	Au (ppb)	Bi	Sb	As	Zn	Ag
Wol-Qtz Skarn (n=2)	<334	<6	bd	bd	<1	<0.5	1-5	bd	bd
Pyx Skarn (n=9)	200 to 50000	<180	bd	bd (10, 38, 13)	<1	<5	<5	<300	bd
Vein (n=14)	0 to >100000	<90	bd	bd (148)	<1	<5	<14	<150	bd

(Brown et al, 2001)

RAY GULCH VS EAGLE ZONE

- RG skarn replacement > vein (~10 vol. %)
- EZ sheeted veins
- EZ Stage II key – Au-Bi event
- Stage missing in RG skarn
- Stage III-V RG = Stage I EZ – Qtz-Fsp-Sch

(Brown et al, 2001)



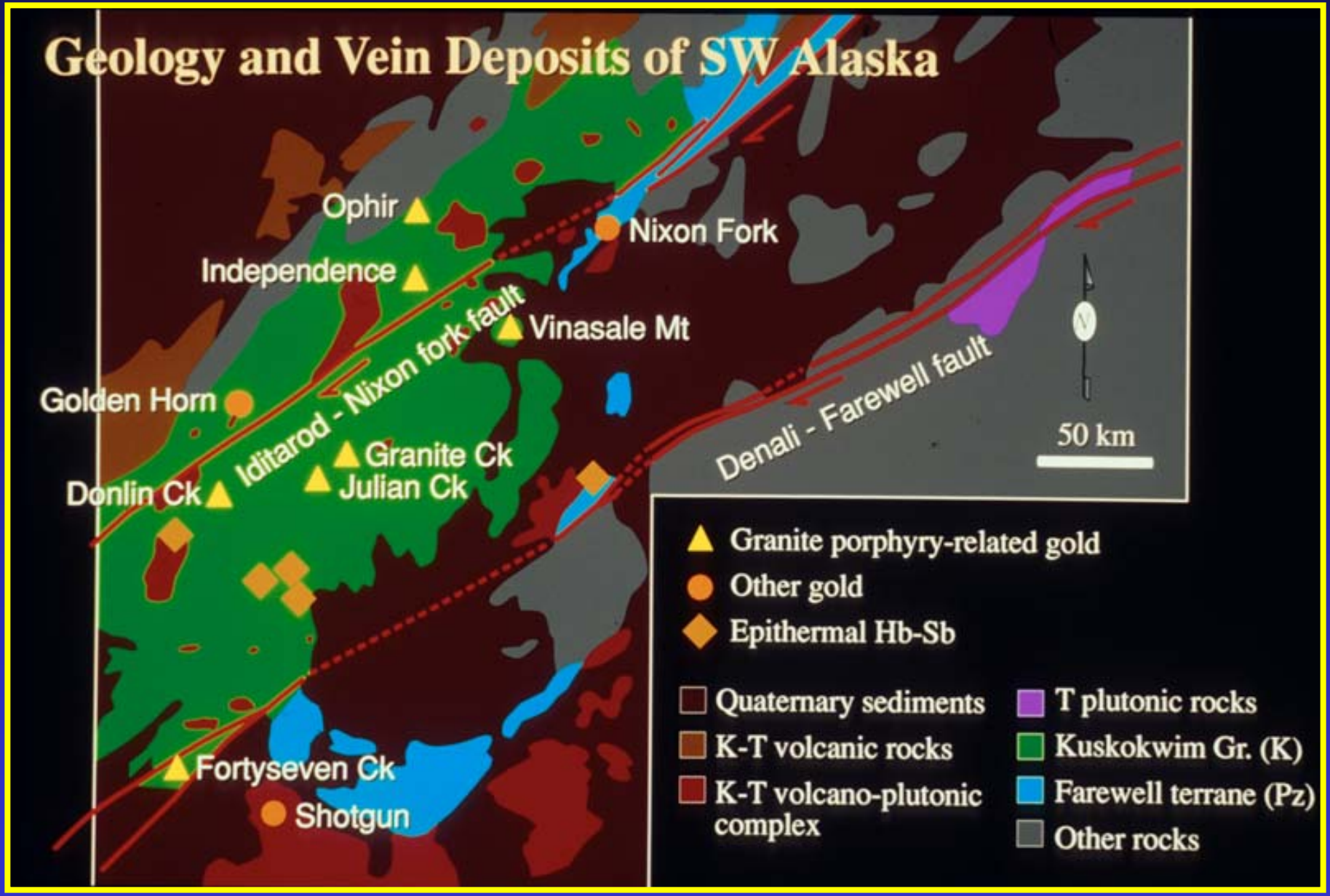
3. Shallow-level examples

2. Porphyry-style examples

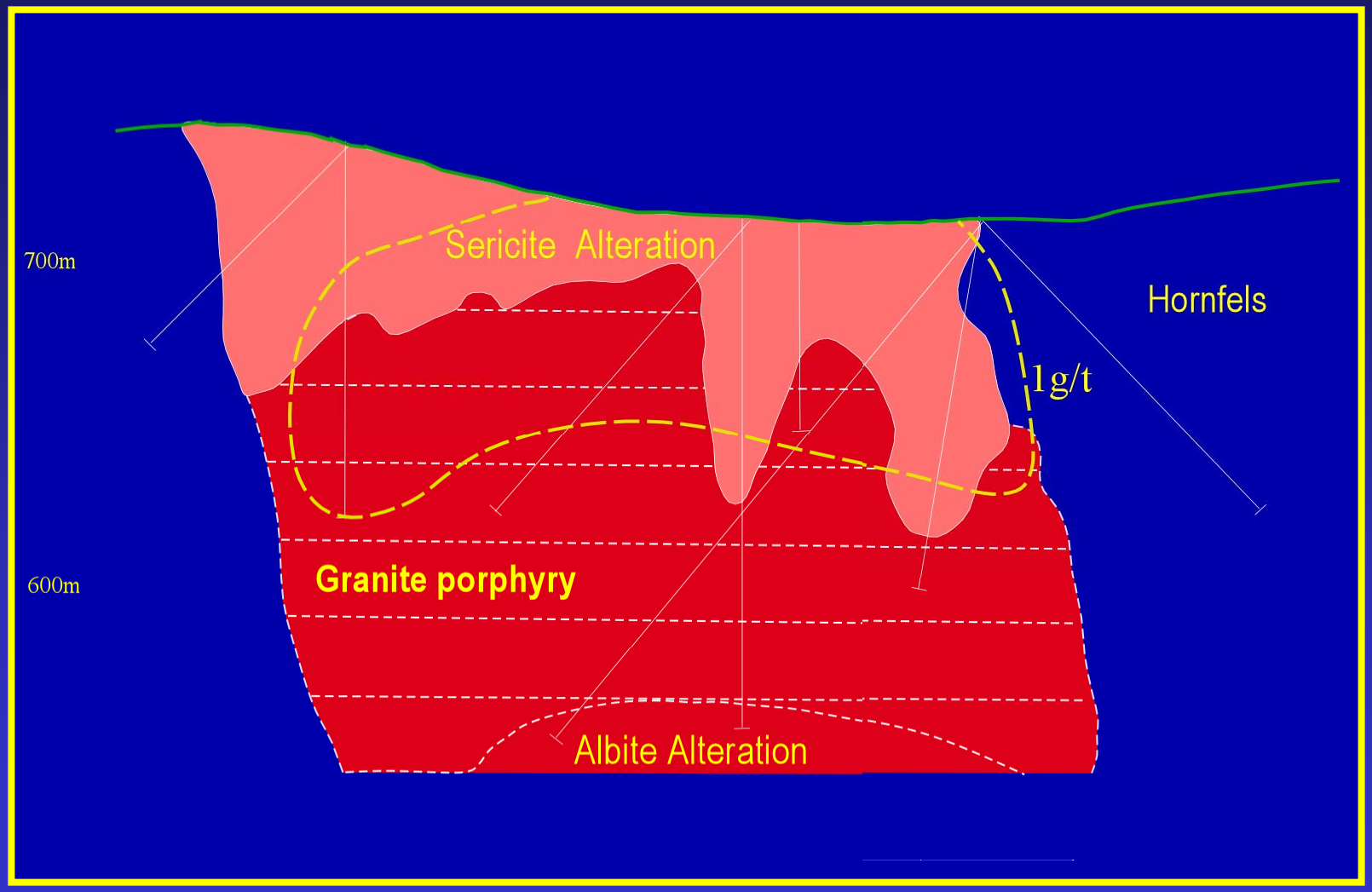
1. Type-examples

4. Pogo

OUTLINE OF EXAMPLES IN SHORTCOURSE


Geology and Vein Deposits of SW Alaska
Ophir
Nixon Fork
Independence
Vinasale Mt
Iditarod - Nixon fork fault
Golden Horn
Granite Ck
Julian Ck
Donlin Ck
Denali - Farewell fault
50 km
Fortyseven Ck
Shotgun
Granite porphyry-related gold
Other gold
Epithermal Hb-Sb
Quaternary sediments
K-T volcanic rocks
K-T volcano-plutonic complex
T plutonic rocks
Kuskokwim Gr. (K)
Farewell terrane (Pz)
Other rocks

SHOTGUN (~1 M.oz.)



(Rombach & Newberry, 2001)

SHOTGUN

- Geology & Mineralization
  - Granite porphyry (70 Ma)
  - Stockwork & breccia; local UST/brain rock
  - Early albite, later sericite-carbonate
  - Apy-Py-Po-Loel-Cpy-Mo-Bn-Sch
  - Au-Bi-Te (Au:Bi 0.76)

(Rombach & Newberry, 2001)

SHOTGUN

- Fluids
  - Reduced ore assemblages (δS –5.5 to –5.0)
  - Fluid inclusions: vapour & brine; 300-600C
  - Vapour: $H_2O > CO_2 > CH_4$, low salinity
  - Brine: 40-60 wt.% NaCl equiv.
  - Pressure/depth: ~0.5 kbar/ ~2 km
  - O, H, S isotopes & fluids = magmatic

(Rombach & Newberry, 2001)

SHOTGUN PARAGENESIS

	Early →				Late
Sulfide assemblage(s)	asp+lo+po+ cpy*±cb±bn#	asp+po+cpy, cpy+bn#	py+asp+cpy ±spl	py+cpy±bn ±spl	none
Alteration assemblage (plus quartz vein)	albite±tourm (biotite, K-spar)	albite±sericite ±(rutile±tour± chlorite)	sericite±carb (±rutile)	sericite±carb	calcite
Gold assemblage	Au°+Bi-Te, Au_2Bi	Au-Ag°+Bi_2S_3±, Bi-Te sulfide	Au-Ag°+Bi_2S_3	?	none?
Vein styles	Veinlet, disseminated	Vein, veinlet, breccia	Vein	Vein	Veinlet
Gold occurrence	Inclusions in arsenopyrite	Isolated grains	?	?	?
Approximate temperature range	>500°C	500 to 400°C	400 to 350°C	<350°C	?

(Rombach & Newberry, 2001)

SHOTGUN TEXTURES

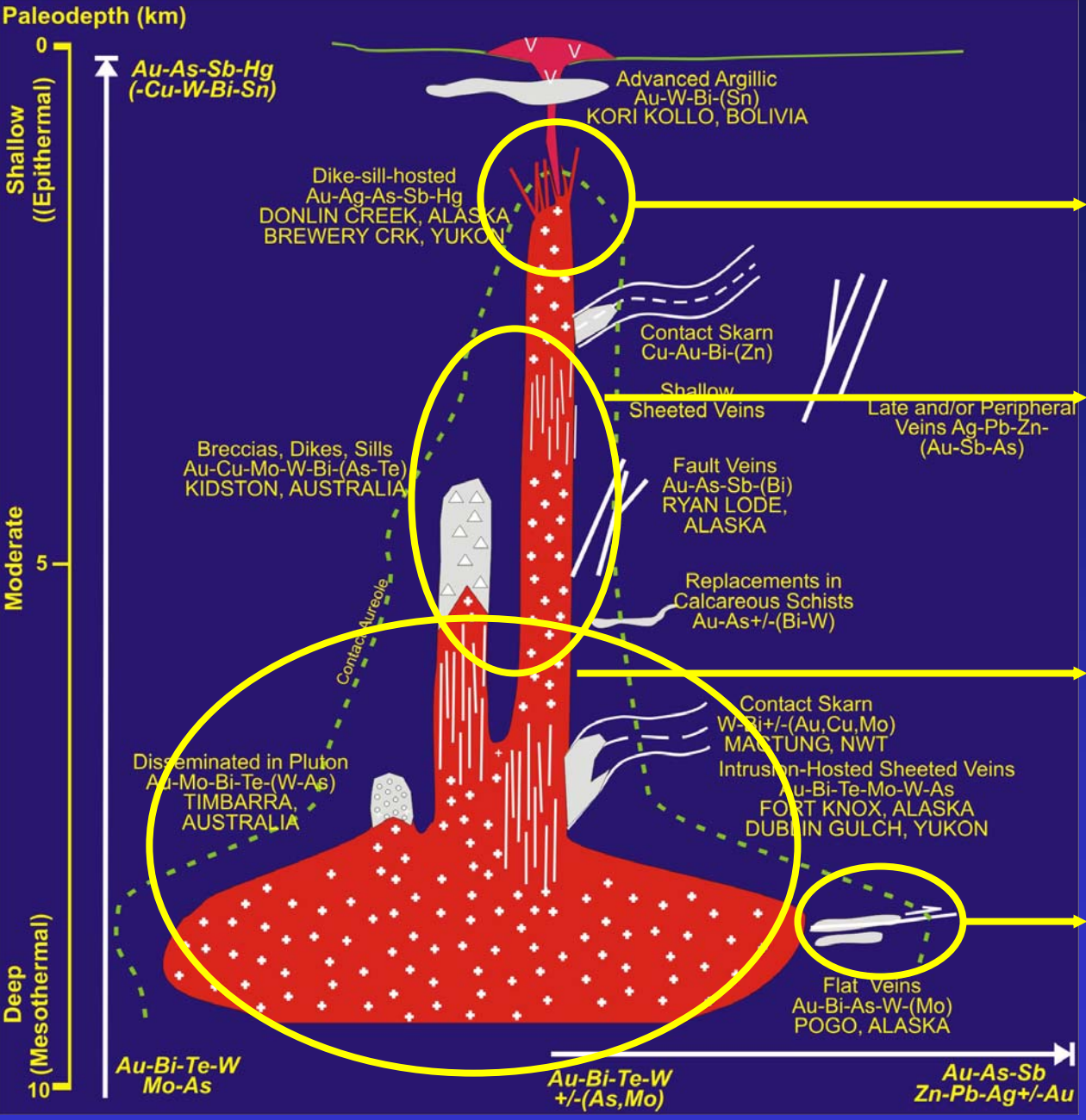
A - Stockwork

C - Breccia

D - UST/brain rock

Au-Bi – 0.73

(Rombach & Newberry, 2001)



3. Shallow-level examples

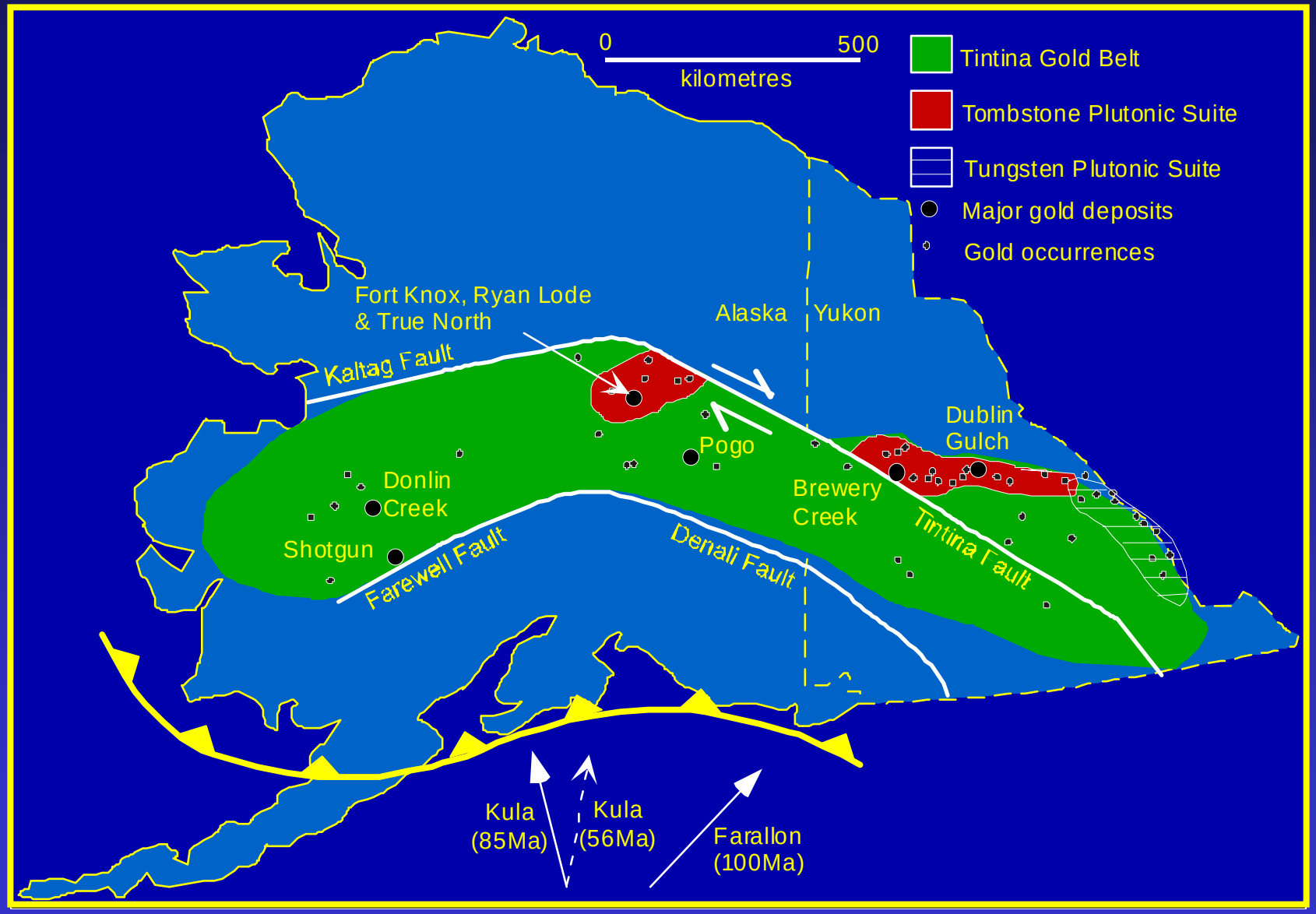
2. Porphyry-style examples

1. Type-examples

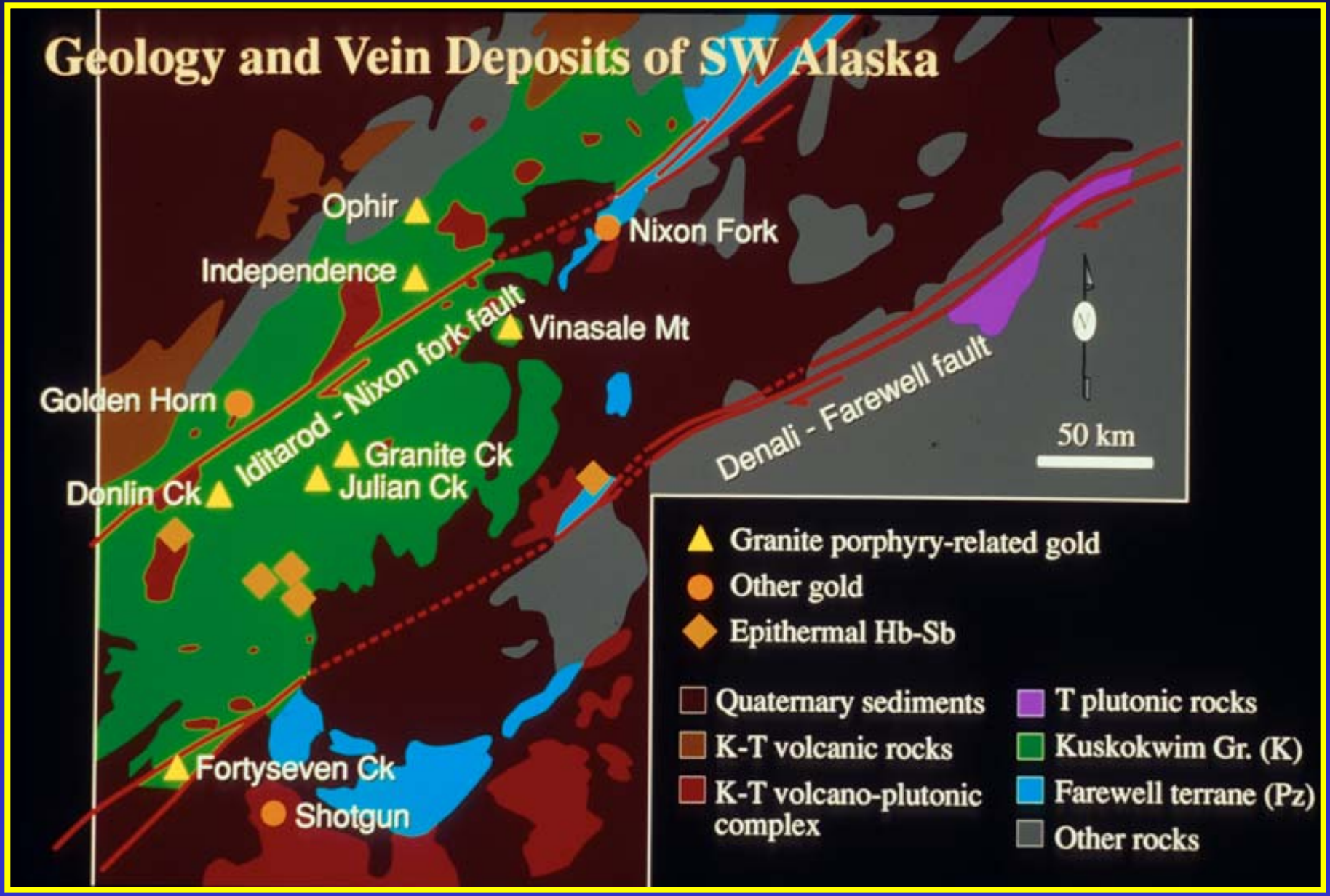
4. Pogo

OUTLINE OF EXAMPLES IN SHORTCOURSE

TINTINA GOLD BELT



(Flanigan et al., 2000)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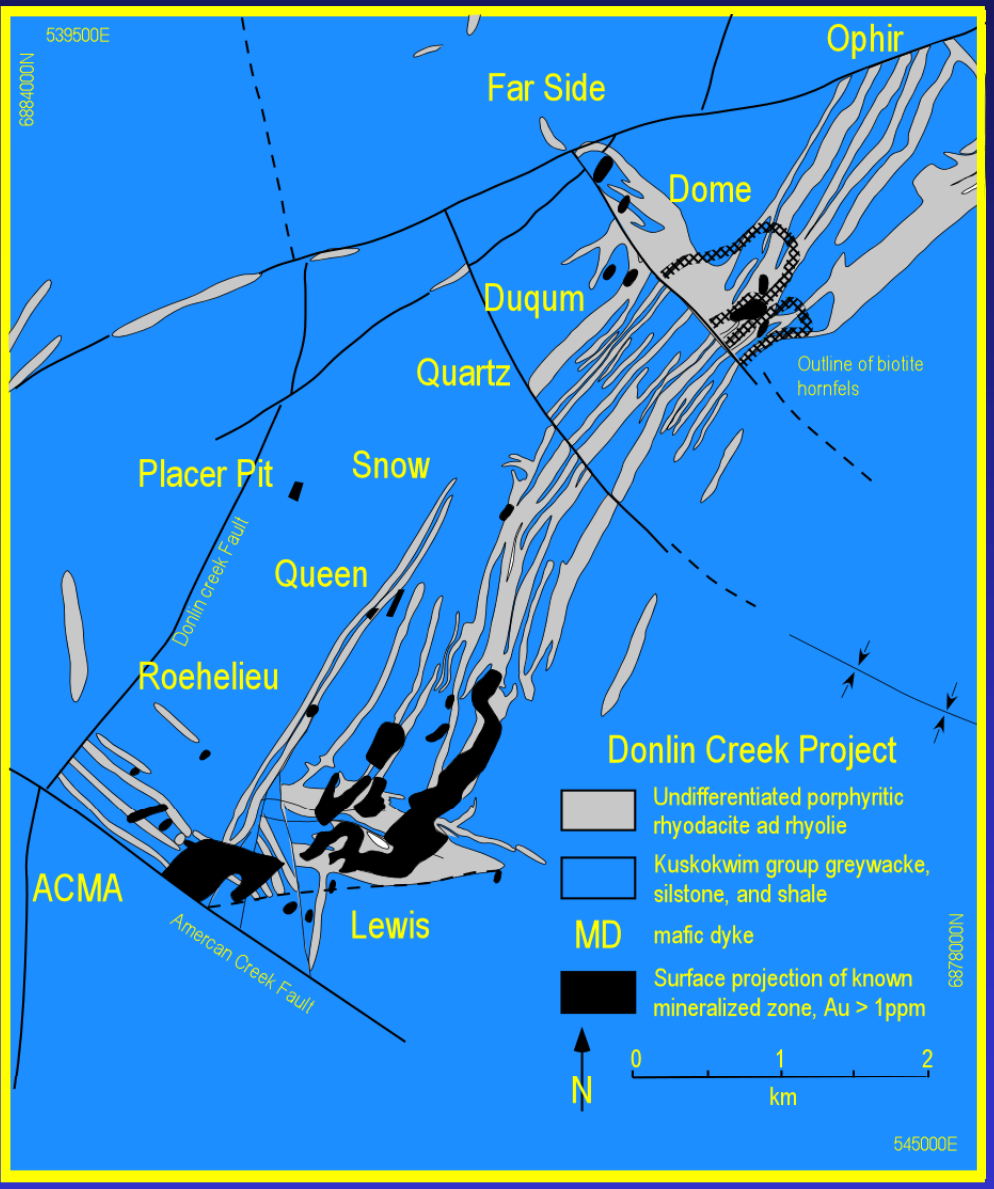
Quaternary sediments
K-T volcanic rocks
K-T volcano-plutonic complex
T plutonic rocks
Kuskokwim Gr. (K)
Farewell terrane (Pz)
Other rocks

DONLIN CREEK (28 M.oz.)

- Exploration
  - Placer gold 1909
  - Lode ore found 1940 above placer fields
  - Ongoing exploration 1970-1990's
  - Rock chip & soil sampling (>250ppb over ore)
  - RC & diamond drilling

(Ebert et al., 2000)

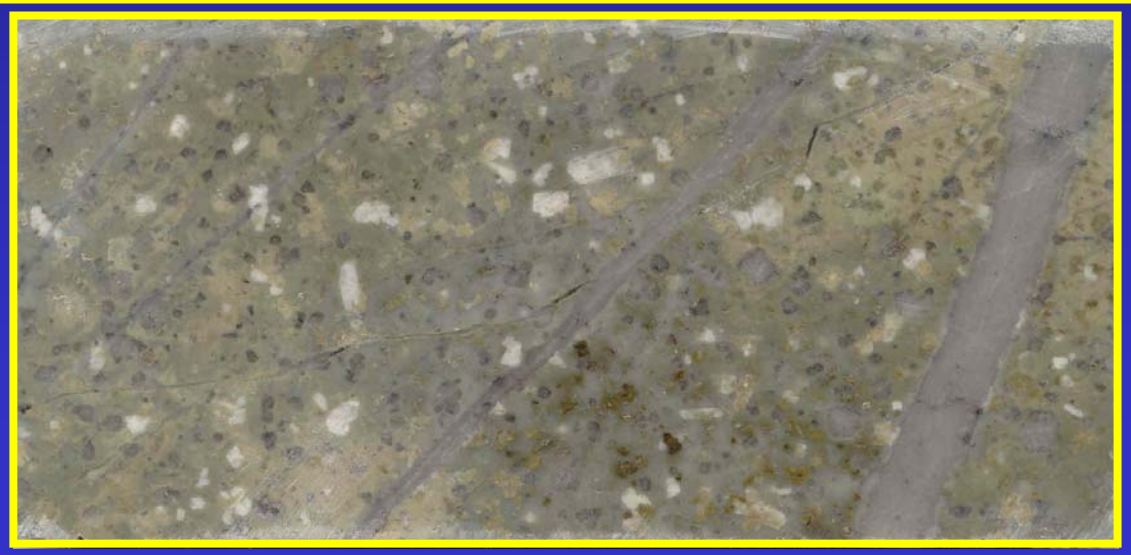
DONLIN CREEK



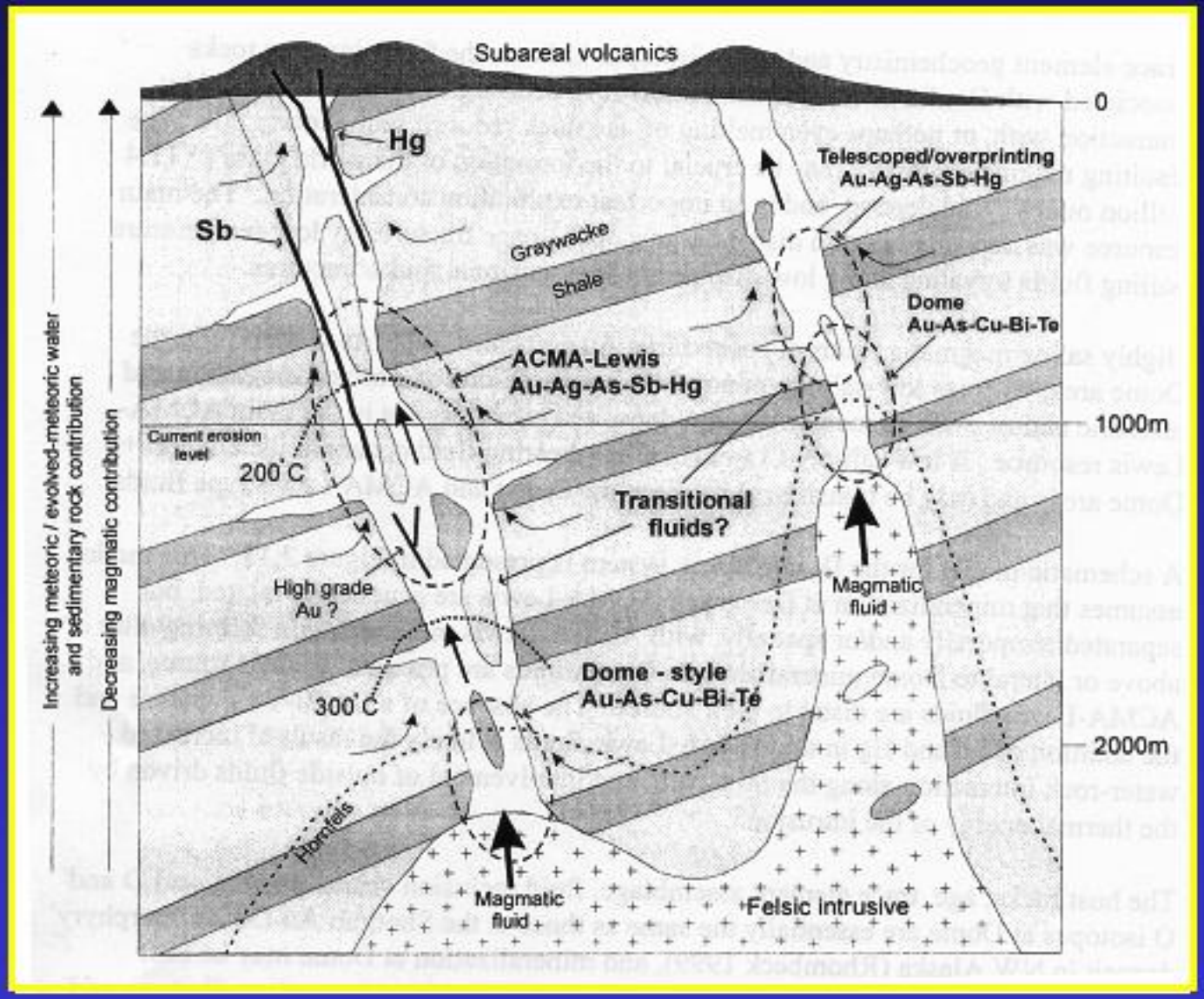
- Geology & mineralization
  - – Rhyolite dykes hosted in reduced flysch sediments
  - – Magmatism & mineralization 71 to 66 Ma
  - – Fault controlled NE & NW strike-slip
  - – Narrow Au-As-Sb-Hg veins in dykes>sediments
  - – Ore within NNE extensional fracture zone
  - – Epithermal/epizonal characteristics

(Ebert et al., 2000)

DONLIN CREEK VEINS

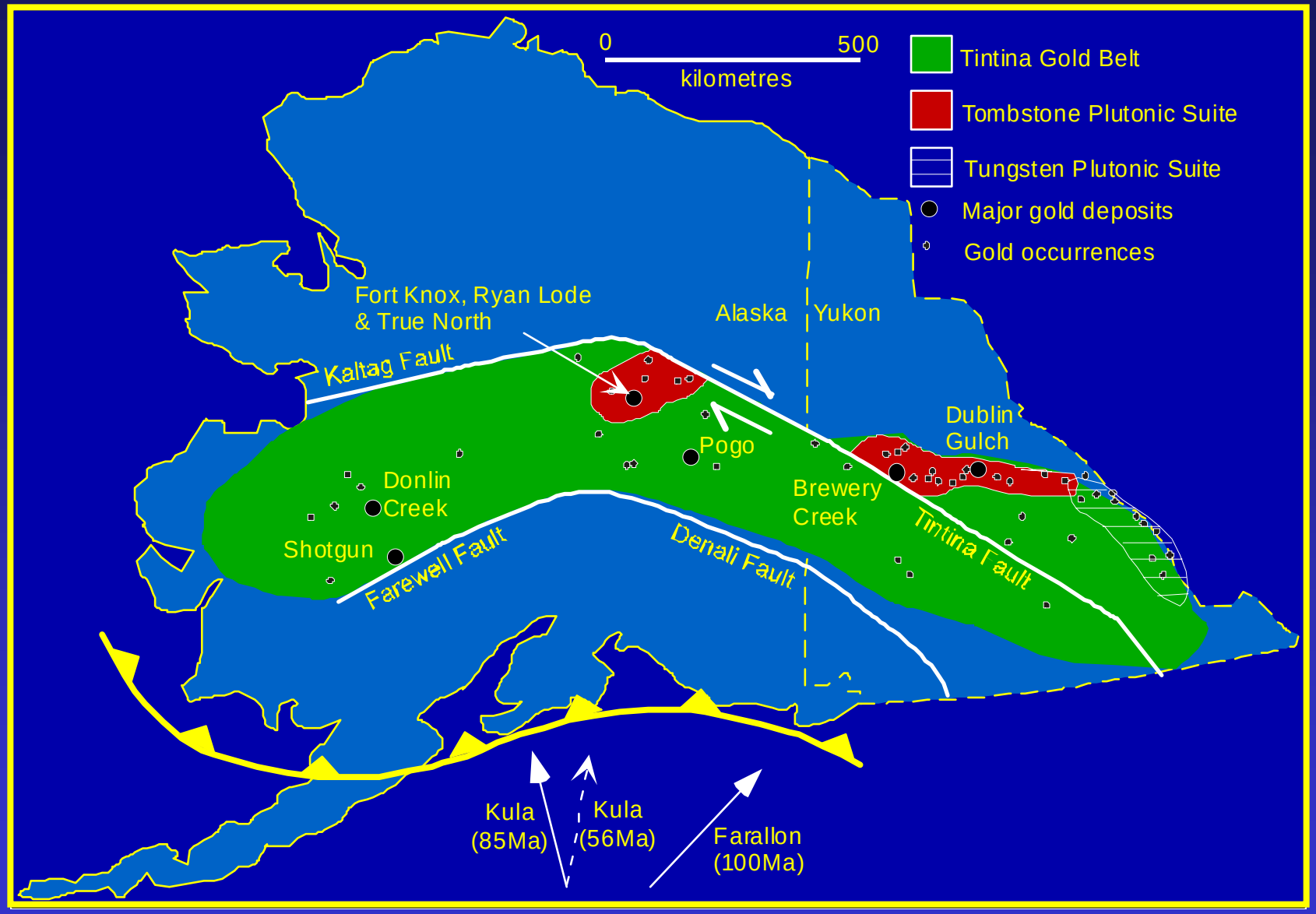


DONLIN CREEK MAGMATIC MODEL



(Ebert, 2001)

TINTINA GOLD BELT



(Flanigan et al., 2000)

BREWERY CREEK (1.4 M.oz.)

- Exploration
  - Discovered in 1987
  - Soil geochemistry
  - >25ppb over 12km strike
  - Reserve trend ~12 major gold zones
  - Open pit mining between 1997 & 2001

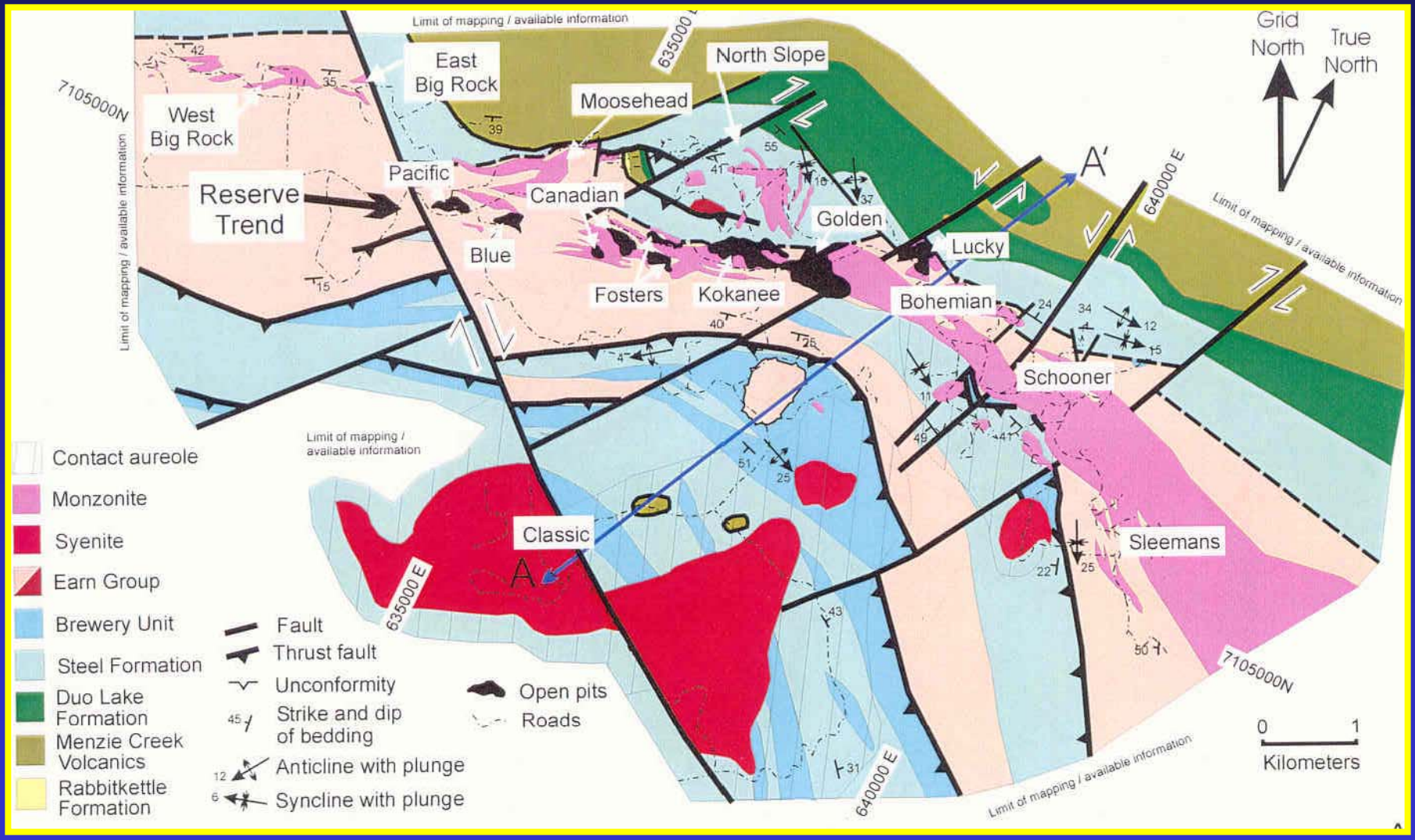
(Diment, 1996)

BREWERY CREEK

- Geology
  - 80 % ore hosted in Tombstone suite intrusions
  - 20 % hosted in Cambrian-Carboniferous sediments
  - Reserve trend comprises
    - Lies outside magnetic high (aureole/intrusion)
    - E-W monzonite
    - Normal, dip-slip E-W, NW & NNE brittle faults
    - Veins & ore trend E-W with NNE component

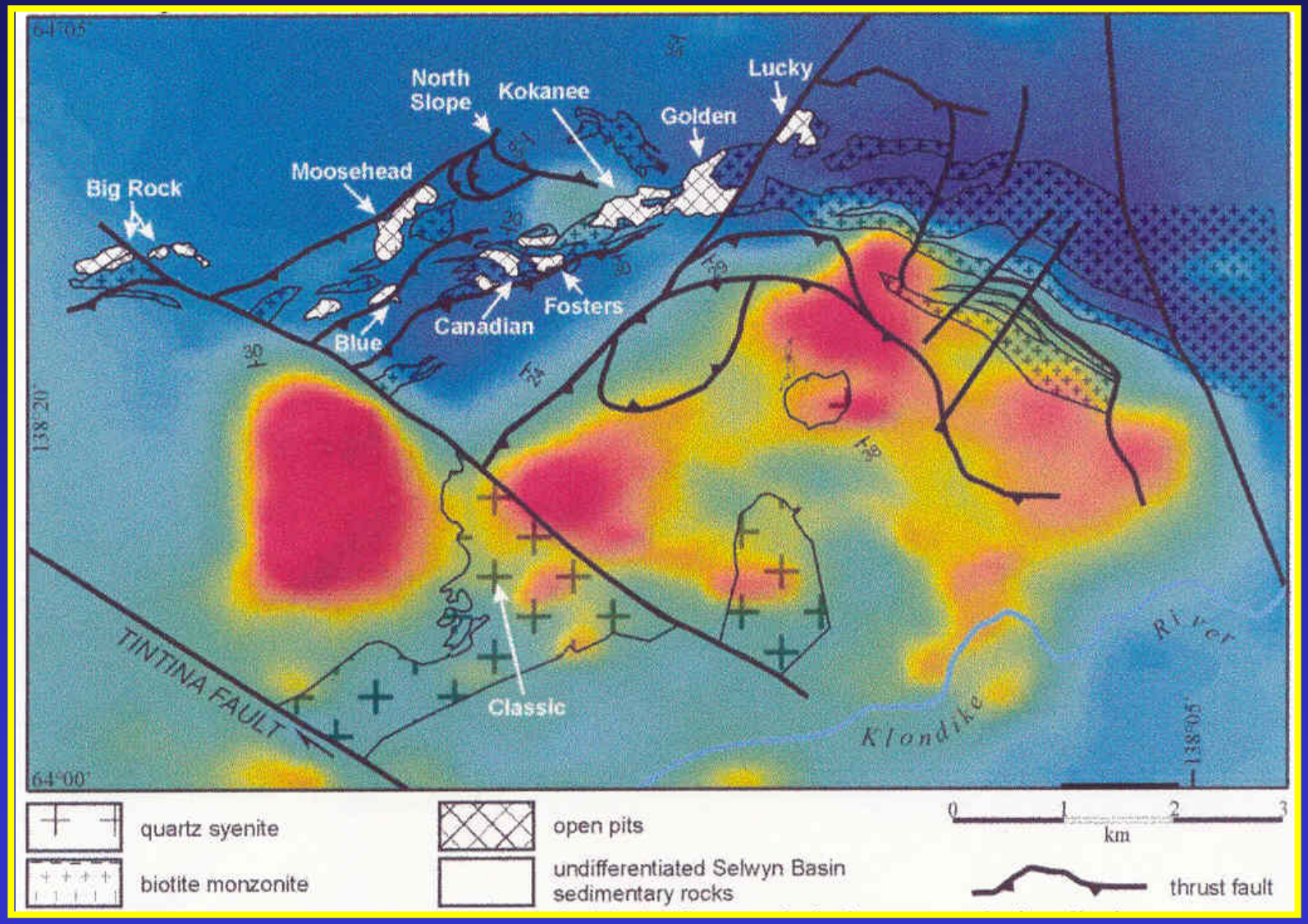
(Lindsay, 2002)

BREWERY CREEK MAP



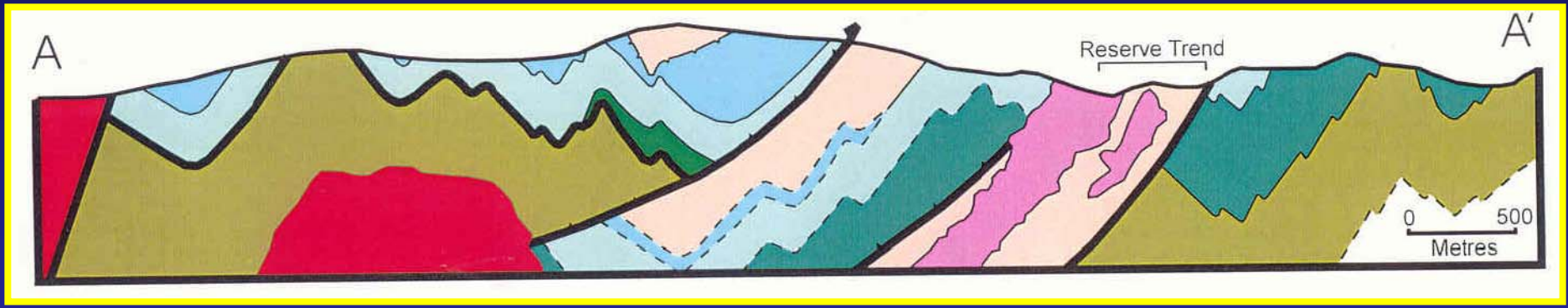
(Lindsay, 2002)

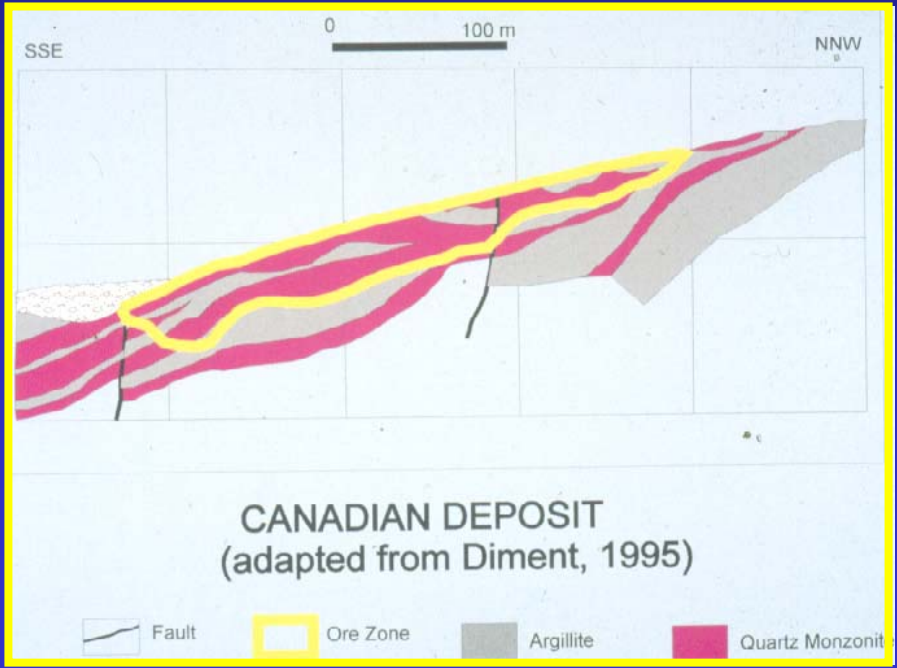
BREWERY CREEK MAGNETICS



(Hart et al., 2000)

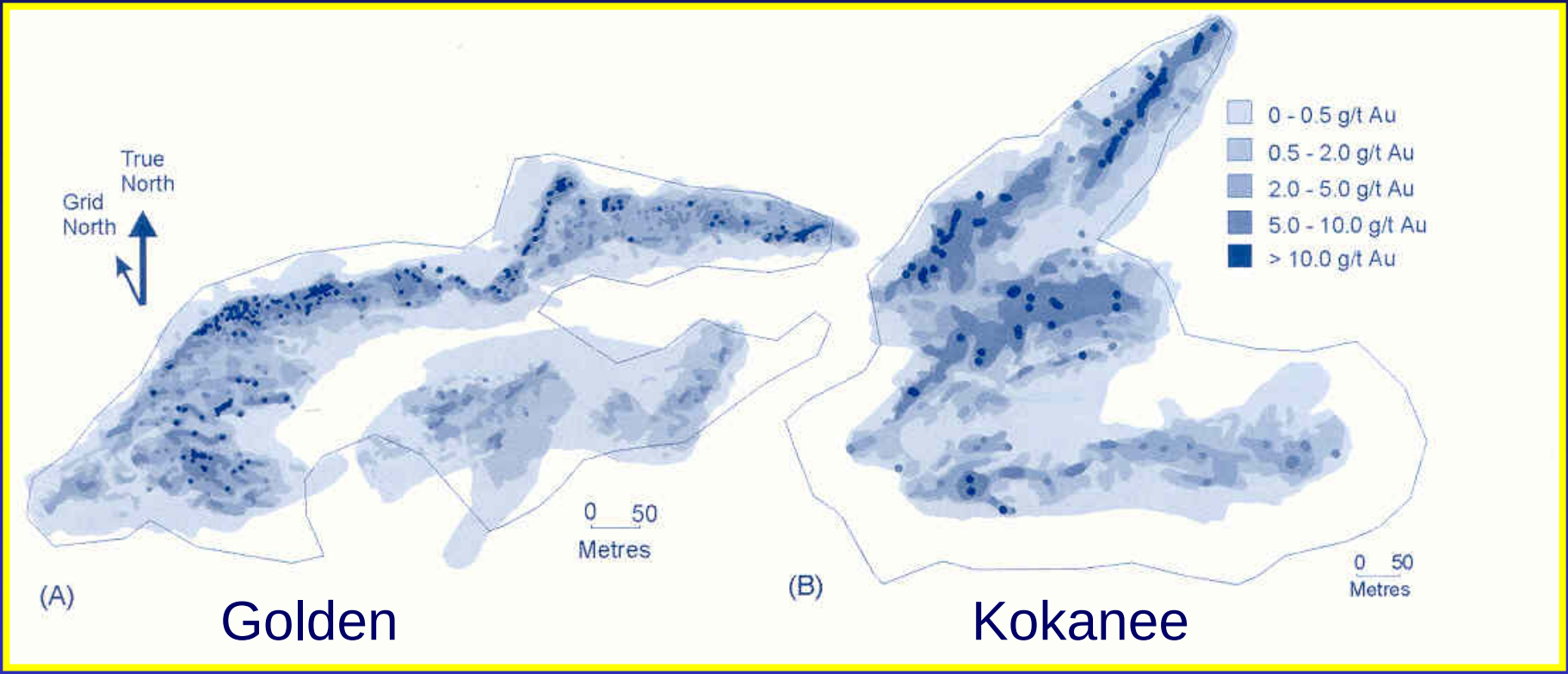
BREWERY CREEK CROSS SECTION

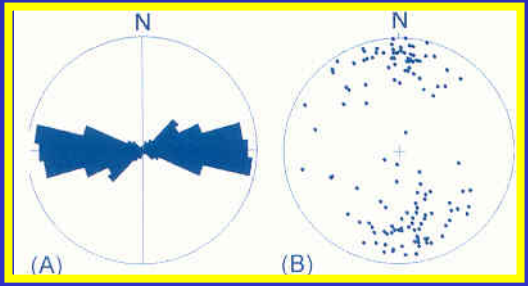




(Diment, 1995; Lindsay, 2002)

BREWERY CREEK GRADE TRENDS





(Lindsay, 2002)

BREWERY CREEK

- Ore
  - Mineralization in monzonite, 3 vein stages

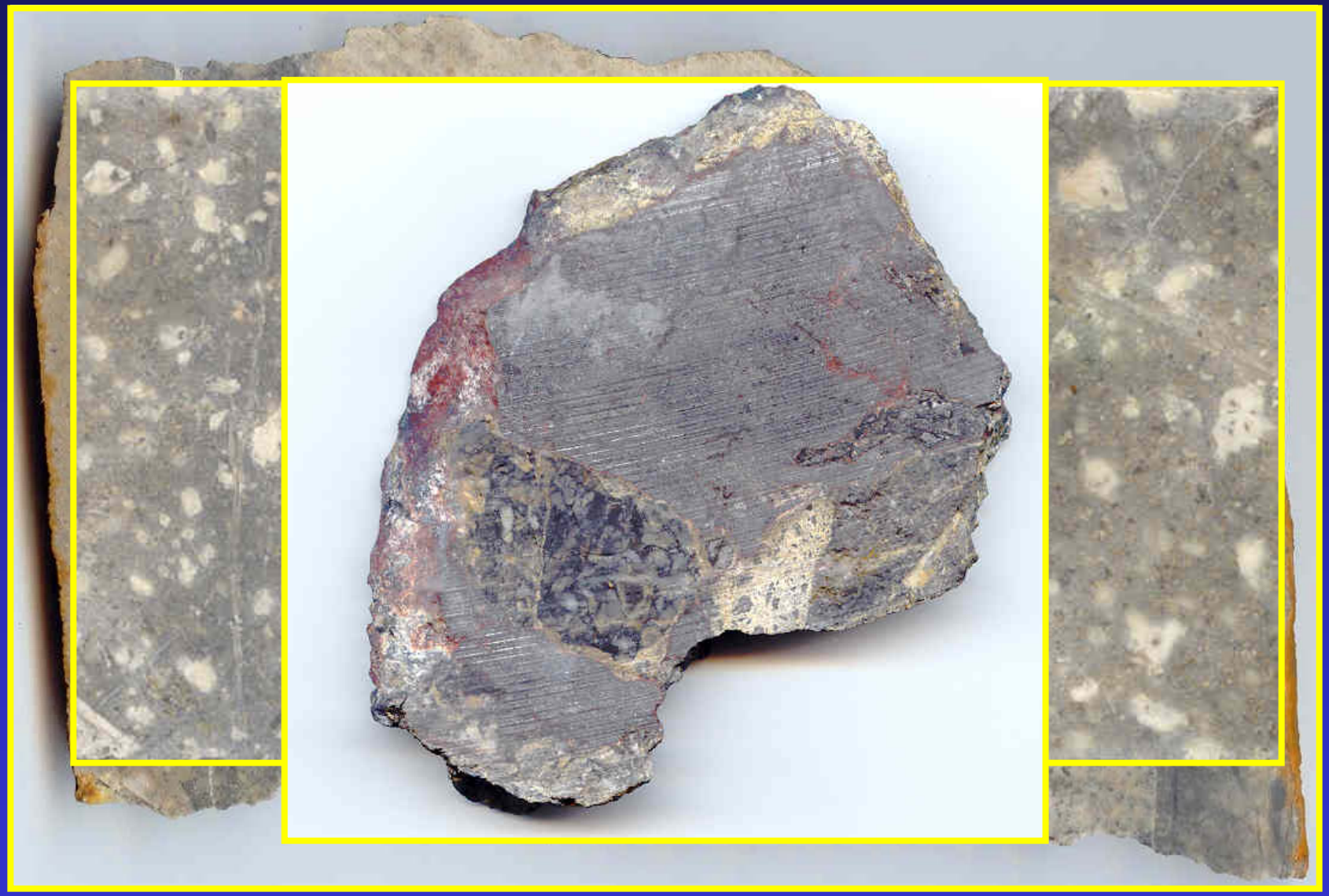
    1) pyrite-quartz-carbonate-roscoelite

    2) arsenopyrite-carbonate-quartz-gold

    3) stibnite-quartz-carbonate-adularia
  - Only oxide ore processed (weathering ~10-30m)
  - Hypogene gold in arsenopyrite & arsenian pyrite

(Mark, 2002)

BREWERY CREEK PARAGENESIS



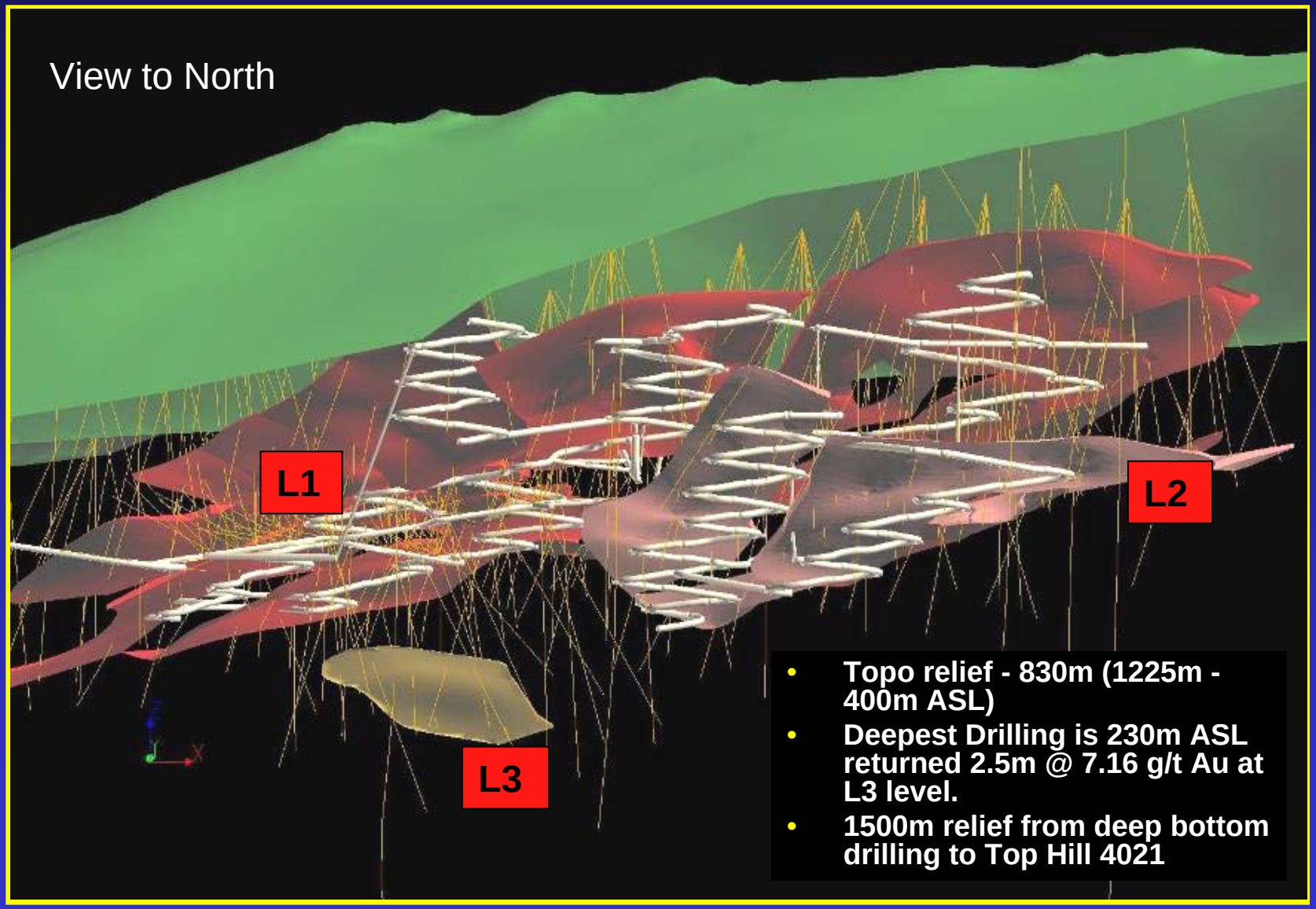
BREWERY CREEK

POGO (> 5 M.oz.)

- Exploration
  - Geochemical sampling Goodpaster River 1981
  - Au, As, W anomalies in Pogo & Liese Creeks
  - Soil sampling & surface-exploration 1993
  - >100ppb Au in soils anomaly 2km^2
  - Drilling soil anomaly 1994 – Liese zone
  - Drive developed 1999-2000
  - Pour first gold end 2005

(Smith et al., 1999)

POGO



- Topo relief - 830m (1225m - 400m ASL)
- Deepest Drilling is 230m ASL returned 2.5m @ 7.16 g/t Au at L3 level.
- 1500m relief from deep bottom drilling to Top Hill 4021

(Roberts, 2005)

POGO

POGO

- Host rocks
  - L. Proterozoic - M. Paleozoic gneiss
    - Amphibolite facies
  - M. Cretaceous granite dykes, aplites & pegmatites
    - Reduced I-type, 15% vol.
  - Post-mineralization dolerites
- Age
  - U-Pb 107 to 93 Ma – Intrusions
  - Ar-Ar ~91-92 Ma - Mica alt
  - Re-Os ~104Ma - Molybdenite

(Smith et al., 1999; Selby et al., 2002)

POGO (> 5 M.oz.)

(Smith et al., 1999; Selby et al., 2002)

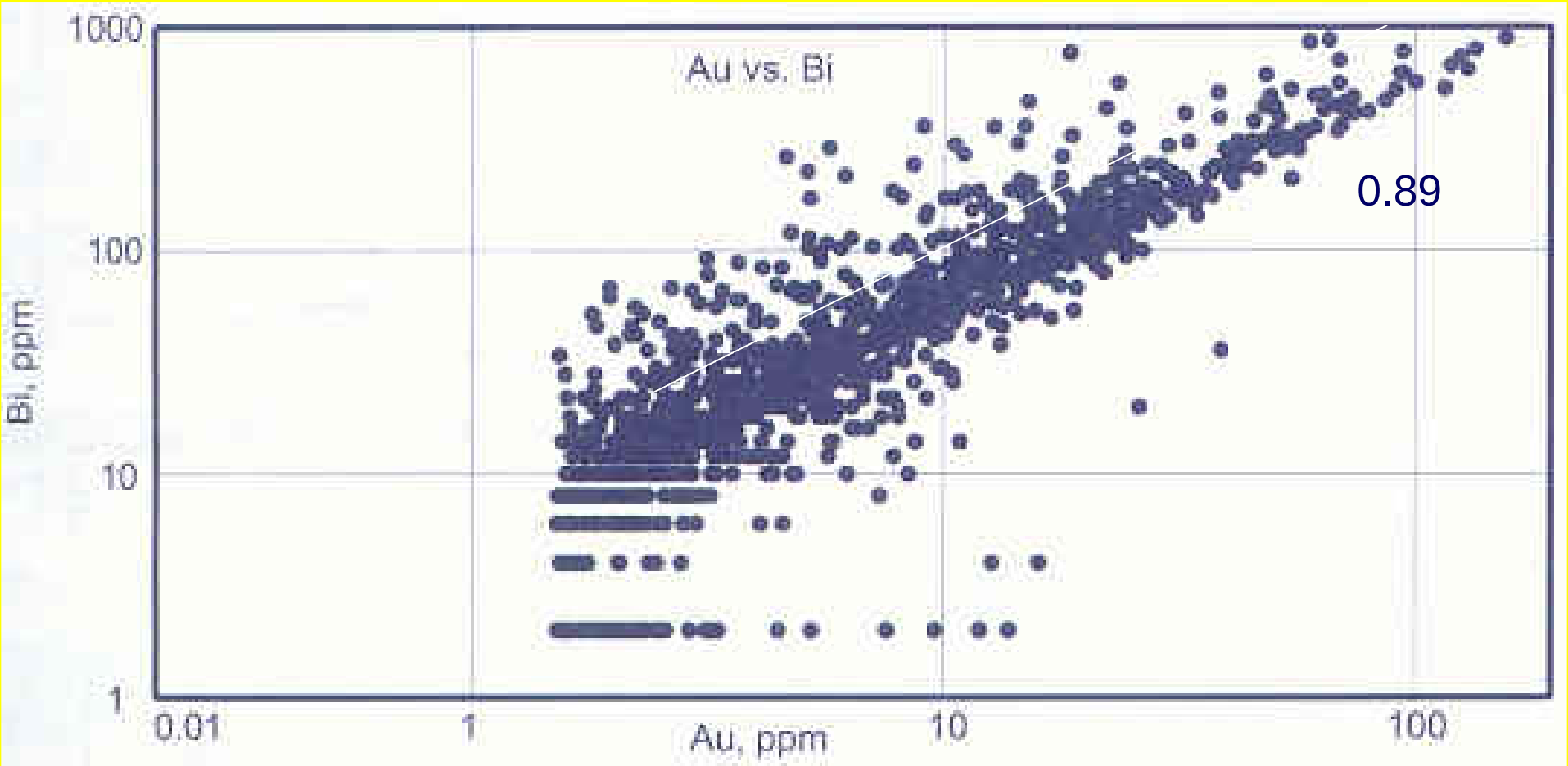
POGO

- Ore

  Sulphide ~3%

  Reduced assemblage: Po-Lo-Apy-Py-Ccp

  Au-Bi-Pb-*Te-Ag*-S phases; Au:Bi 0.89



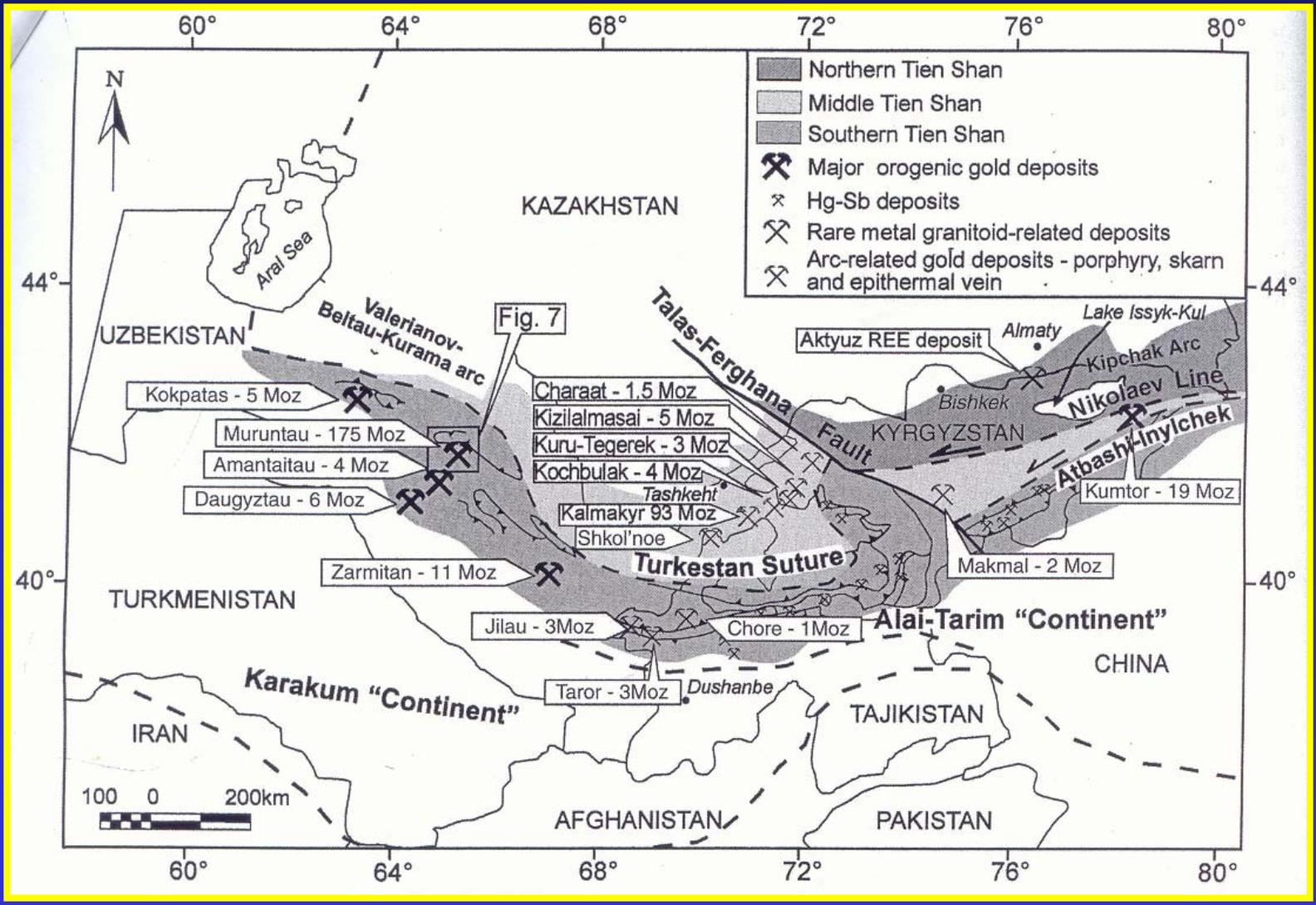
OVERVIEW

- Part 1: Classification, nomenclature & deposit comparison

- Part 2: Examples: Tintina Gold Province

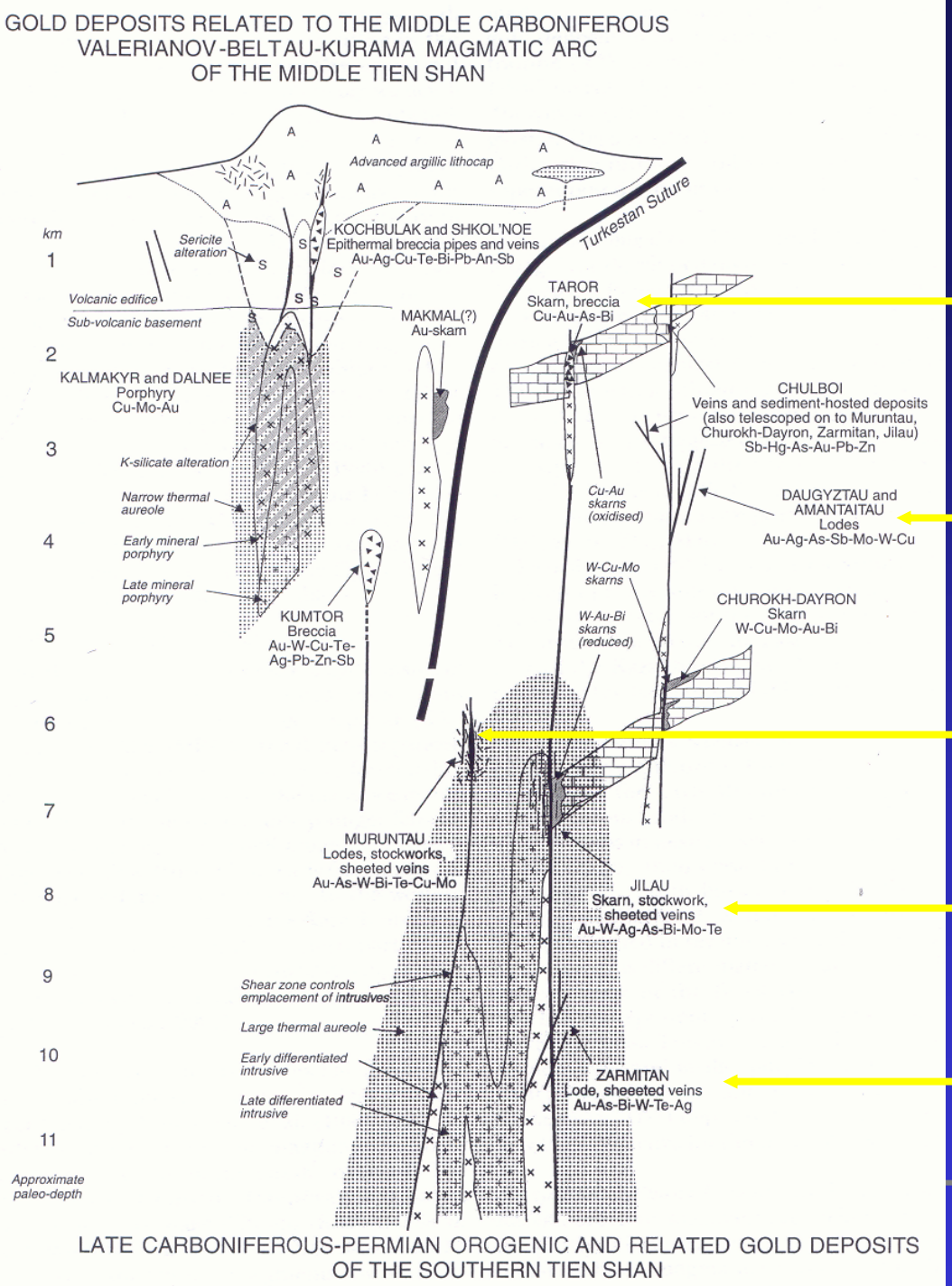
- Part 3: Other examples & exploration

Late Paleozoic gold deposits, Tien Shan



(Yakubchuk et al., 2002)

Gold deposit model Tien Shan



Taror 3 M.oz.

Amantaitau 4 M.oz.

Muruntau 175 M.oz.

Jilau 3 M.oz.

Zarmitan 11.3 M.oz.

(Yakubchuk et al., 2002)

LOCATION OF MAJOR INTRUSION RELATED GOLD DEPOSITS

(Lang & Baker, 2001)

KIDSTON (4 M.oz.)

- Regional Geology
  - Kennedy Igneous Province
  - Mid-Carboniferous-Permian intrusions
  - I-type granites, crustally derived
  - Similar tectonic setting to TGB?
  - Regional Au-Sn-W-Bi-Mo-As-Sb

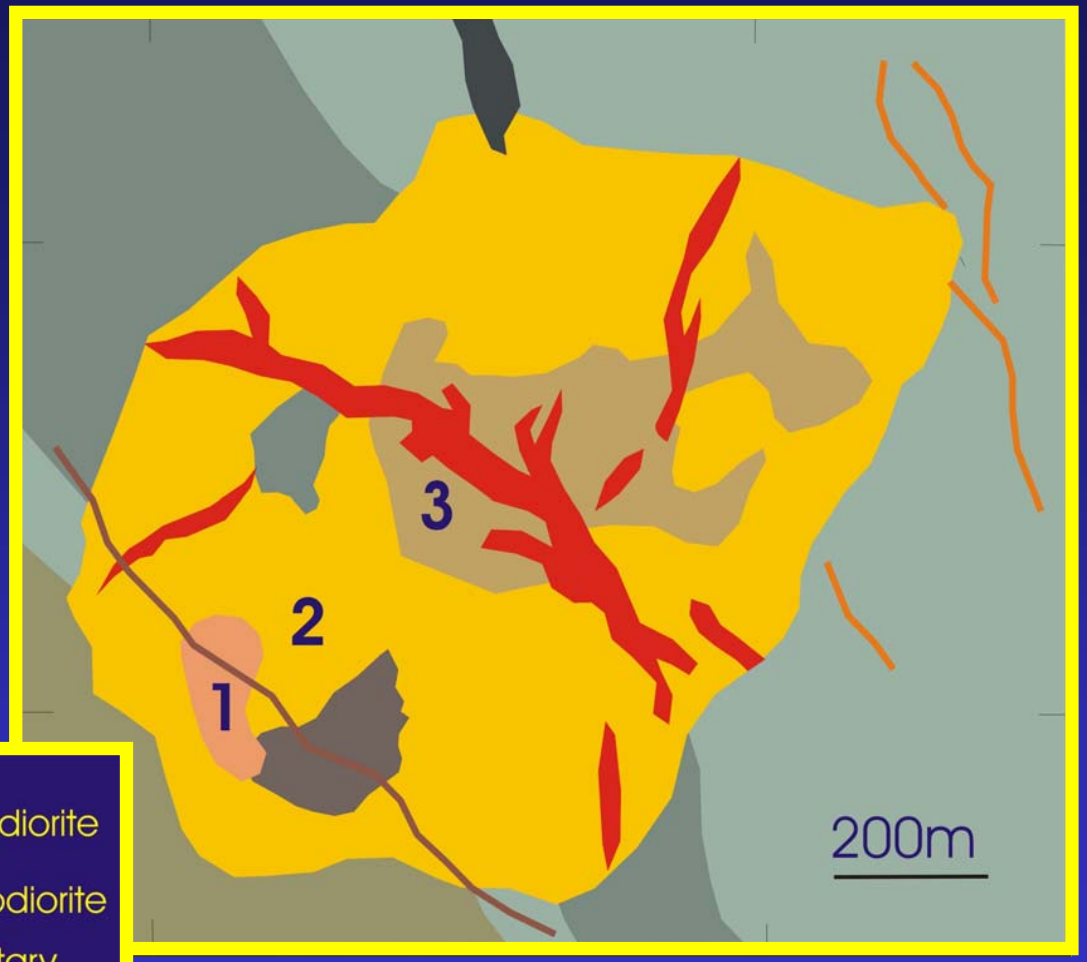
(Baker & Andrew, 1991)

KIDSTON

- Deposit Geology
  - Magmatic-hydrothermal breccia pipe
  - Intrudes Proterozoic granitoid & gneiss
  - Gold in breccia & sheeted veins
  - Rhyolite sills & dykes
  - Py-Po-Sph-Ccp-Mo-Gal-Apy-Bi; zoned
  - Deeper Mo-W mineralization
  - Ser-Carb-Qtz alteration

(Baker & Andrew, 1991)

KIDSTON MAP



PERMO-CARB
- Andesite Dyke
- Rhyolite Dyke
- Qtz-Fsp Porphyry
- Rhyolite
- Rhyolite Dyke

SILURO-DEVONIAN
- Foliated granodiorite
- Porphyry granodiorite
- Metasedimentary rocks

1 Breccia I
2 Breccia II
3 Breccia III

(Baker & Andrew, 1991)

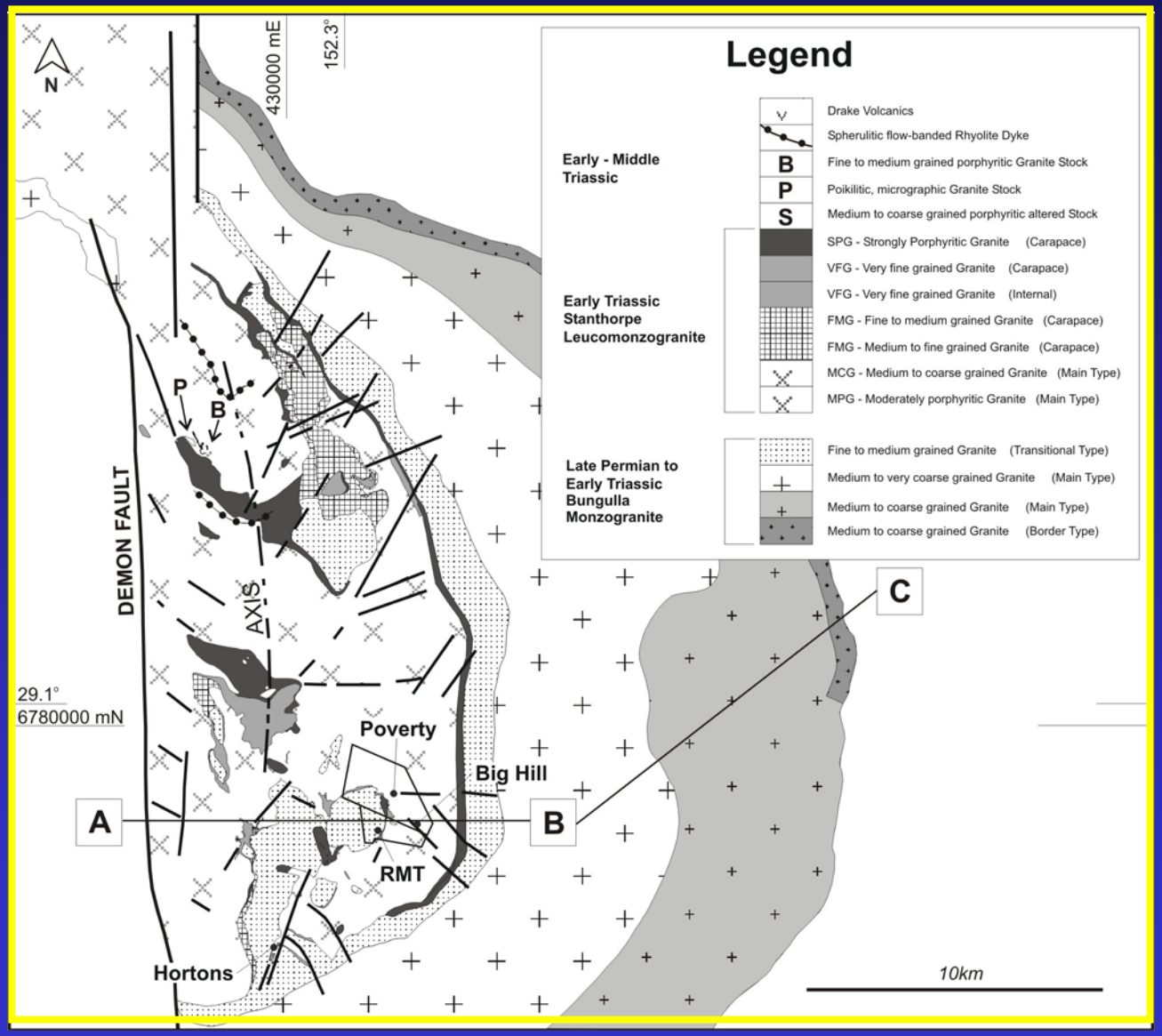
KIDSTON TEXTURES

TIMBARRA (0.4 M.oz.)

- Geology & Mineralization
  - Zoned granite pluton (250-245 Ma)
  - Age ore & alteration = intrusion
  - Disseminated Au-Bi-Ag-Te-(Mo-As-Sb)
  - Sulfide < 1%; Apy-Py-Moly-Au-Bi-Te-Ag
  - Magmatic-hydrothermal transition

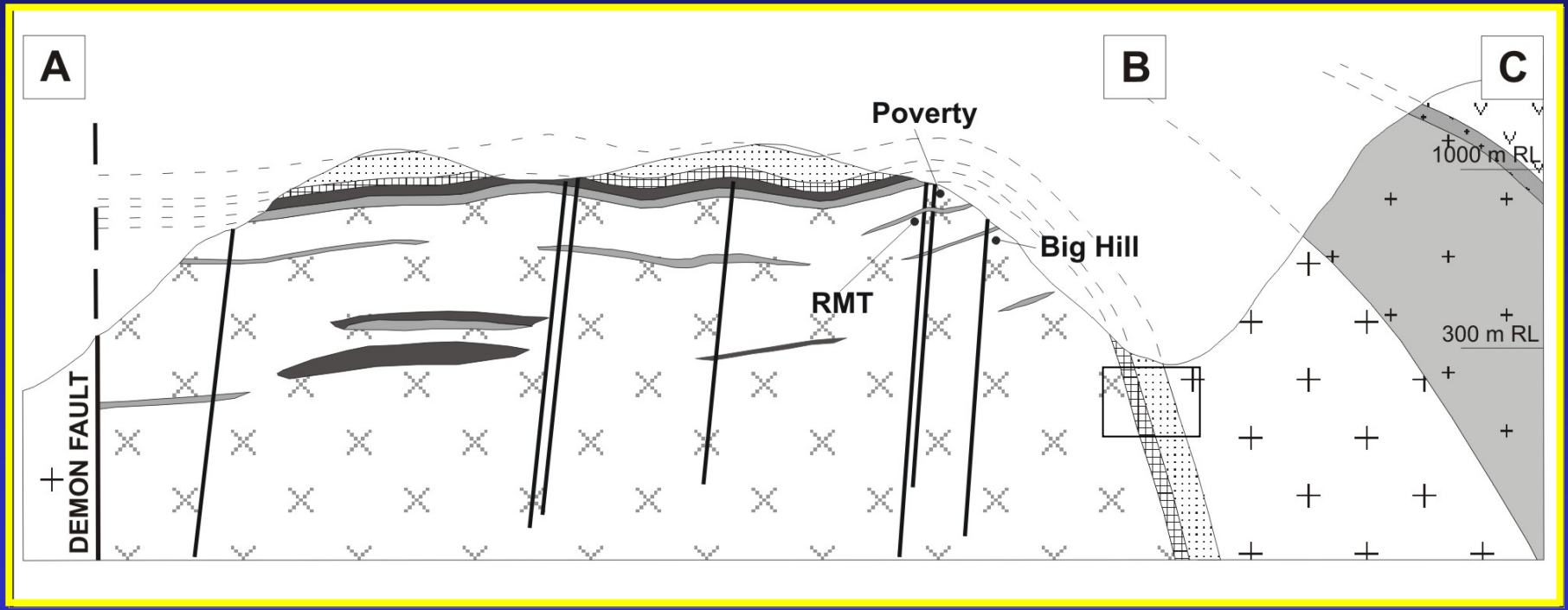
(Mustard, 2001)

TIMBARRA MAP



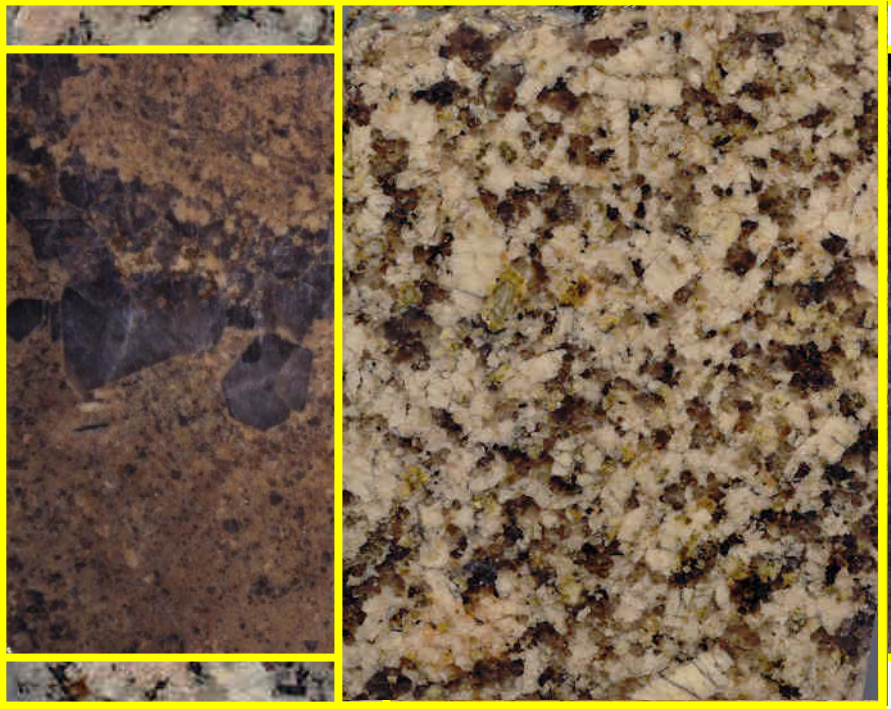
(Mustard, 2001)

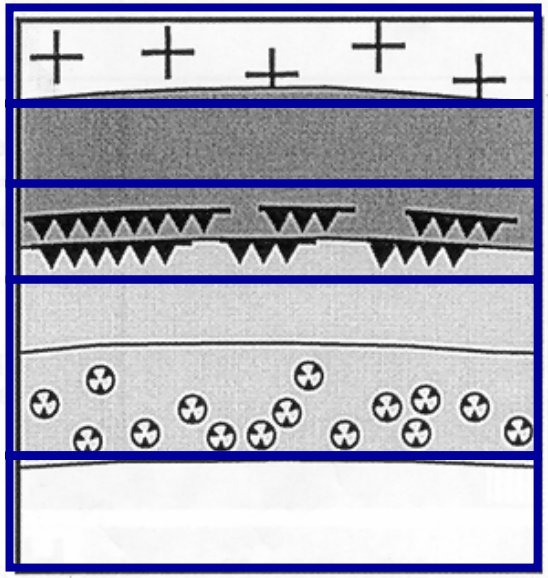
TIMBARRA CROSS SECTION



(Mustard, 2001)

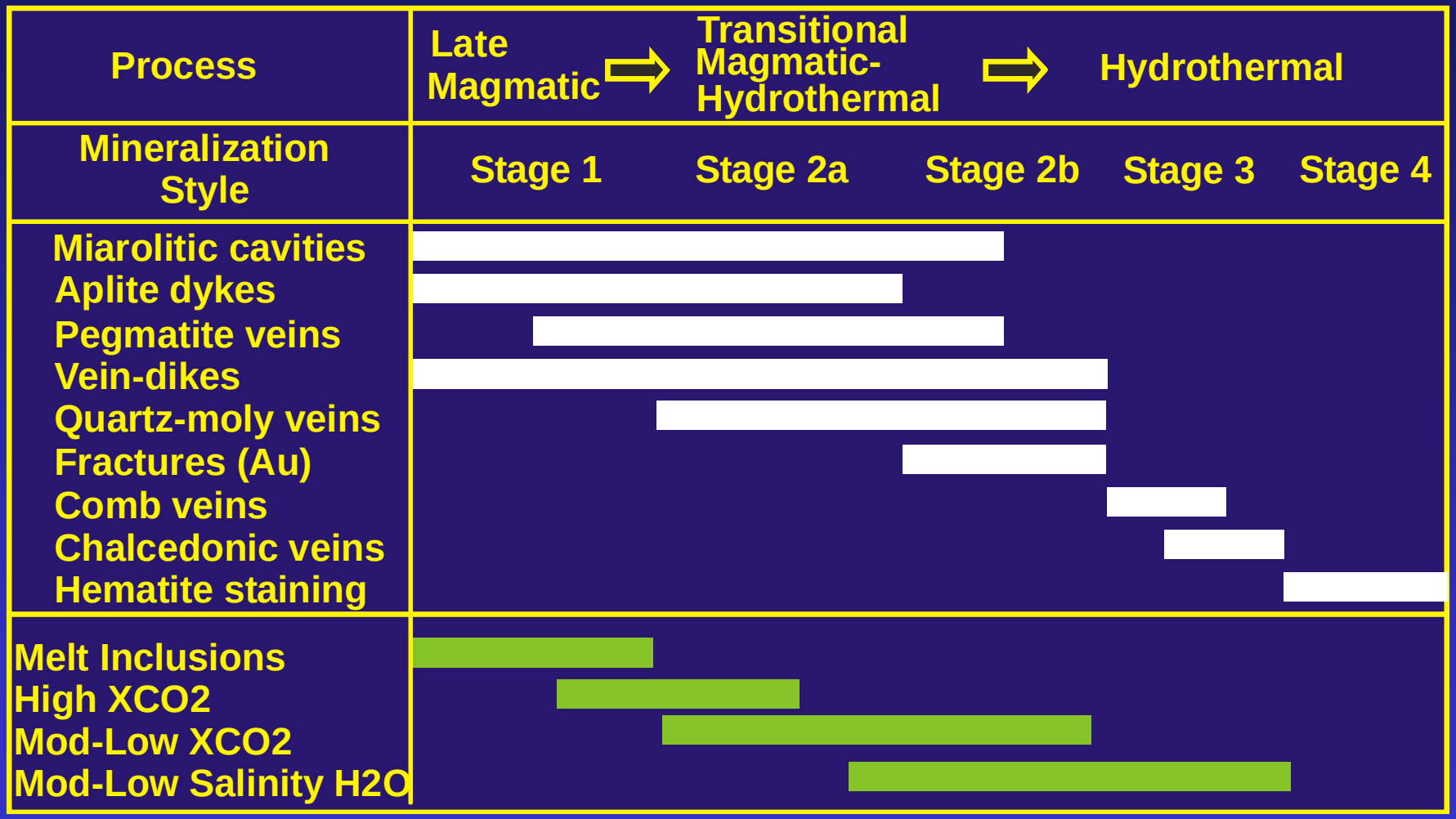
TIMBARRA GRANITE FACIES & Au





(Mustard, 2001)

TIMBARRA PARAGENESIS & FLUIDS



(Mustard, 2001; Mustard, 2000)

SUMMARY CHARACTERISTICS

	Style	Alteration	Metals	Fluids
Shallow (<3km, <1 kbar)	• veinlets, stockwork, breccia • dikes, stocks, sills	• clays, carb, fsp	• As,Sb,Hg • Bi, Te	• brine, CO_2-vapour • late H_2O

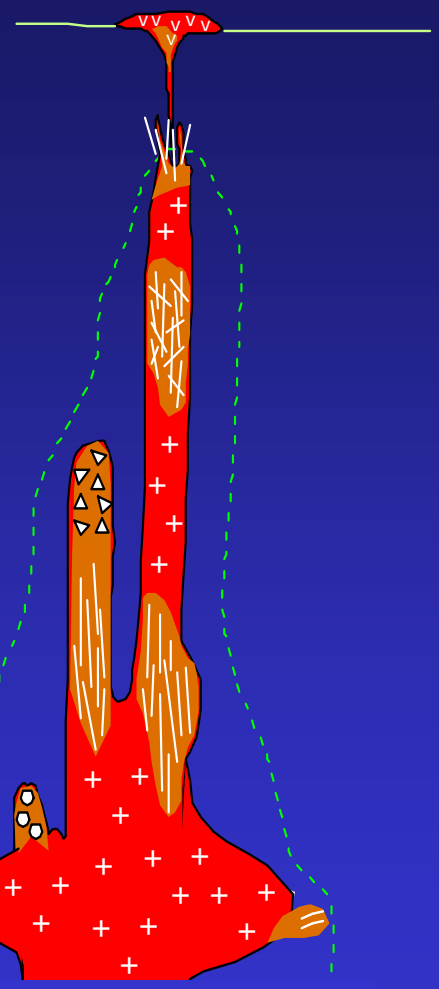
Strong evidence for major magmatic input, epithermal/porphyry style characteristics

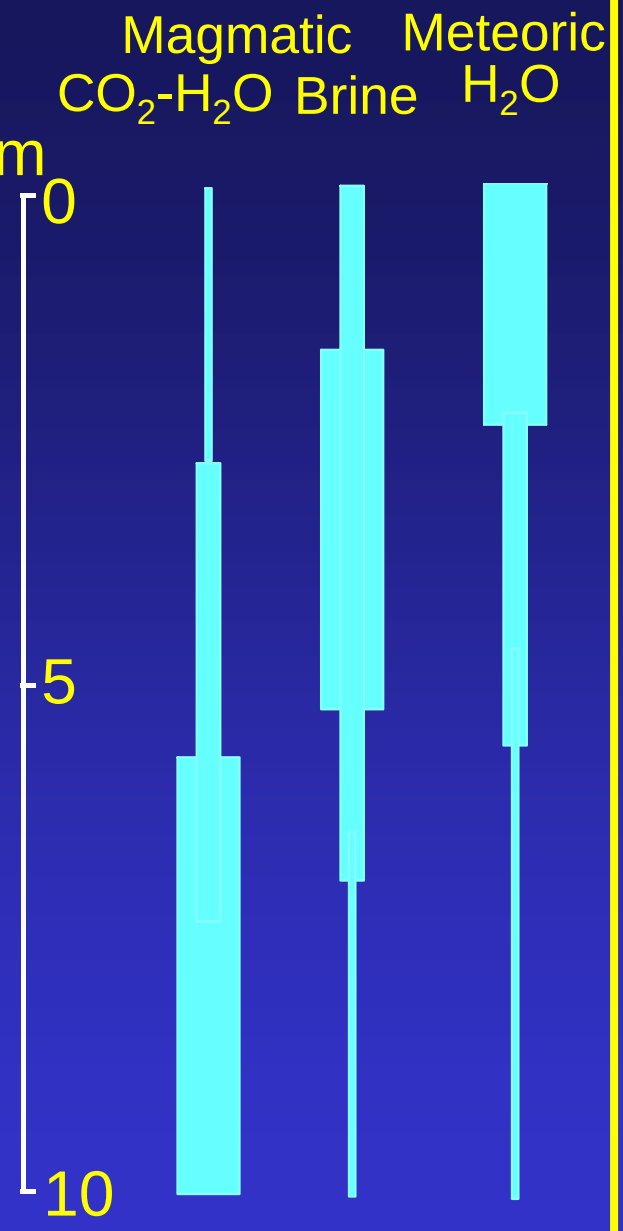
	Style	Alteration	Metals	Fluids
Deep (>3km, >1 kbar)	• sheeted, disseminated • stocks, plutons	• fsp, carb	• W, Mo • Bi, Te	• CO_2-H_2O • some late brine

(Baker, 2002)

DEPTH-FLUIDS MODEL FOR IRGS

Style	Example
Epithermal	
Dyke, sill, dome	Brewery Creek
Veins	Donlin Creek
Dis'minated	
Porphyry	Kidston
Stocks, plugs	Shotgun
Breccias	
Stockwork	
Mesothermal	Fort Knox
Plutons	Dublin Gulch
Sheeted	Timbarra
Dis'minated	Pogo





(Baker, 2002)

IMPLICATIONS

- IRG possess range in characteristics
- Variation in part reflects depth of emplacement
- Magmatic carbon dioxide critical role
  - High pressure devolatilzation
  - Effect on other volatiles
  - Volatile composition varies with depth
- Continuum of deposit types reflect depth & fluid composition
- Exploration criteria will vary between deep, shallow, proximal, distal

EGRU

ROLE OF BISMUTH

- Au-Bi-W-Mo-As geochemistry
- Spatial & temporal link to intrusions
- In detail spatial & temporal differences
  - W early
  - Au-Bi late
  - Main ore zones spatially separate
  - Re-emphasizes Bi association

EGRU

ROLE OF BISMUTH

- Bi significant in ppt. Au
- Bi low melting point (274C), dec. with inc. pressure
- Bi will ppt. as a liquid rather than solid
- Experiments @ 300C show strong partitioning Au in Bi liquid
- Bi may concentrate Au in fluids with very low Au contents
- Low melting point Bi, Au-Bi will be late

(Douglas et al, 2000)

APPLICATION OF KEY EXPLORATION CHARACTERISTICS

- Vertical & lateral zonation about mod-reduced granitic intrusions
- Set of pathfinder elements including Au, Bi, Te, As, W, (Mo, Sn, Sb)
- Variety of target types within IRGS

EGRU

EXAMPLE OF IRGS EXPLORATION CHARACTERISTICS: NORTH QLD

- Reviewed mineral occurrence data sheets & 1:500,00 scale maps (Hogdkinson Province)
- Regional Scale: Tectono-Magmatic Setting
  - Continental arc environment
  - Numerous W-Sn-Mo-Bi-As & Au occurrences
  - Permo-Carb Kennedy Igneous Provence (KIP)

EXAMPLE OF IRGS EXPLORATION CHARACTERISTICS: NORTH QLD

- Regional Scale: Intrusive types
  - Wide range of granite suites
  - Including mod reduced I-types & transitional I-S to S types
  - Highly fractionated components
  - Magmatic-hydrothermal transition textures

EXAMPLE OF IRGS EXPLORATION CHARACTERISTICS: NORTH QLD

- Regional Scale: Variety of crustal levels exposed
  - Contact aureole development (& P-T information)
  - Presence/absence syn-intrusive volcanic rocks
  - Mineral occurrence styles
- Local Scale: Mineral Occurrence Data & Past Exploration
  - Past Au exploration focussed on Kidston-breccia styles &/or porphyry Cu-Au systems
  - Wider range of IRGS styles not widely tested
  - W-Bi-As-(Mo,Sn) prospects poorly tested for Au

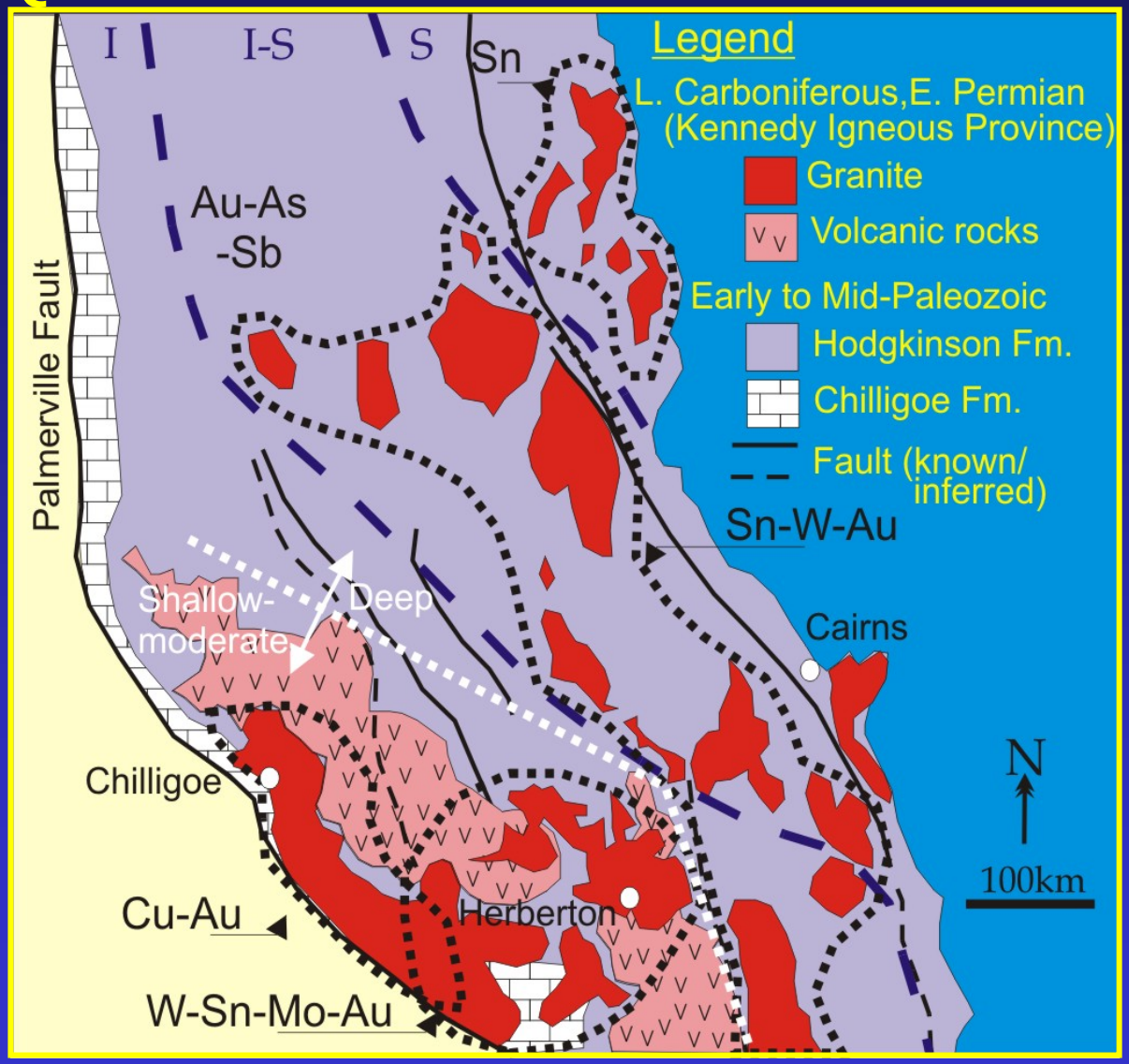
EGRU

EXAMPLE OF IRGS EXPLORATION CHARACTERISTICS: NORTH QLD

- Local Scale: Target Criteria
  - Spatial associated with mod-red I-type KIP intrusives
  - Geochemistry of mineral occurrences (including placer)
    - Au-Bi ±(W-Sn-Mo-Cu-Pb-As) – highest potential
    - Au-W (Bi commonly n/a)
    - Bi±(W-Sn-Mo±Cu - no recorded Au – commonly n/a)
    - Au-As-Sb – distal from intrusives, mesothermal-epithermal
  - Target type
    - Shallow (Donlin Creek-style); Mod-Deep proximal (Fort Knox-style); Mod-Deep distal (Pogo-style)

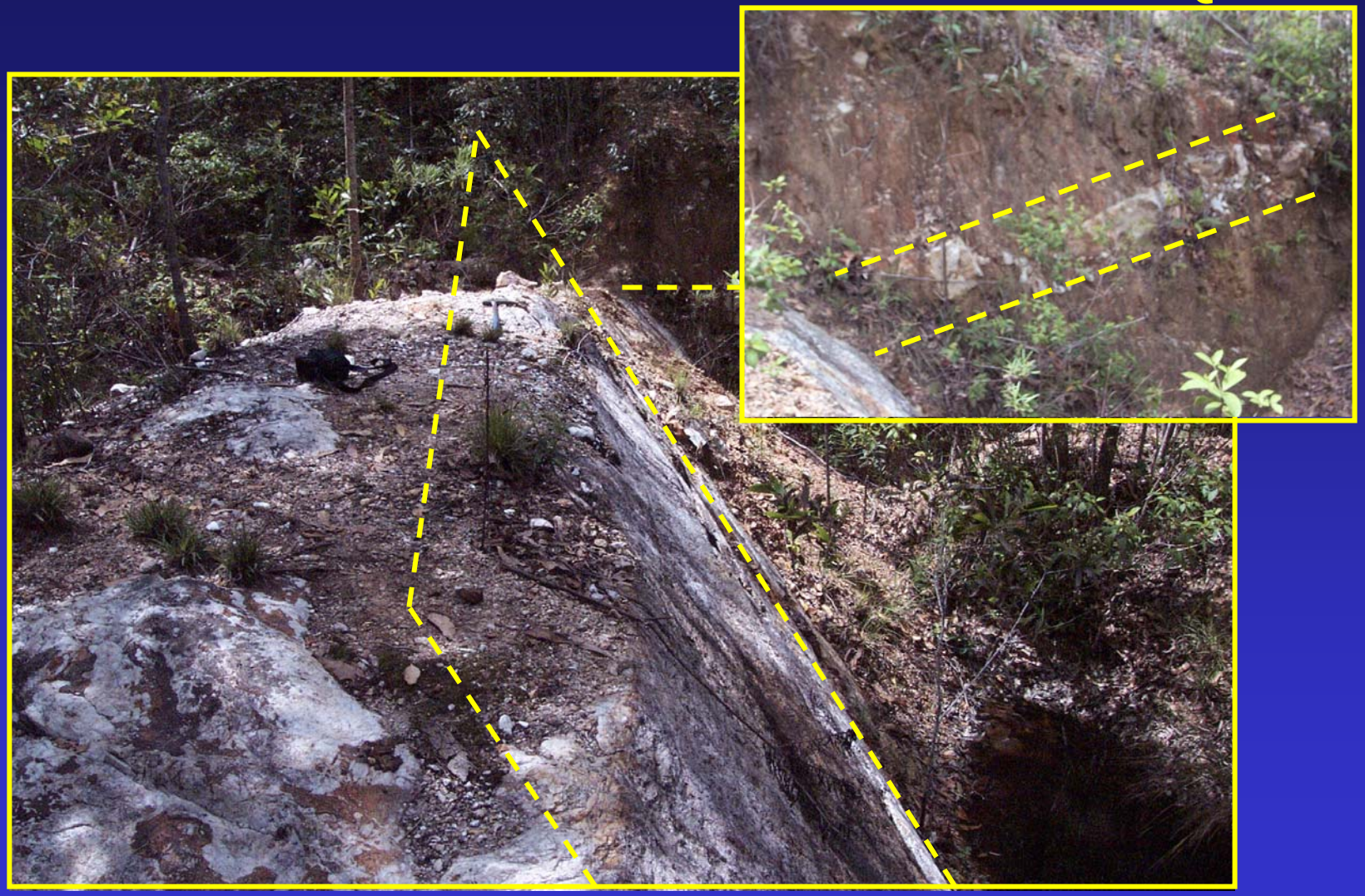
EGRU

N QLD HODGKINSON PROVINCE



(modified from Garrad & Bultitude, 1999)

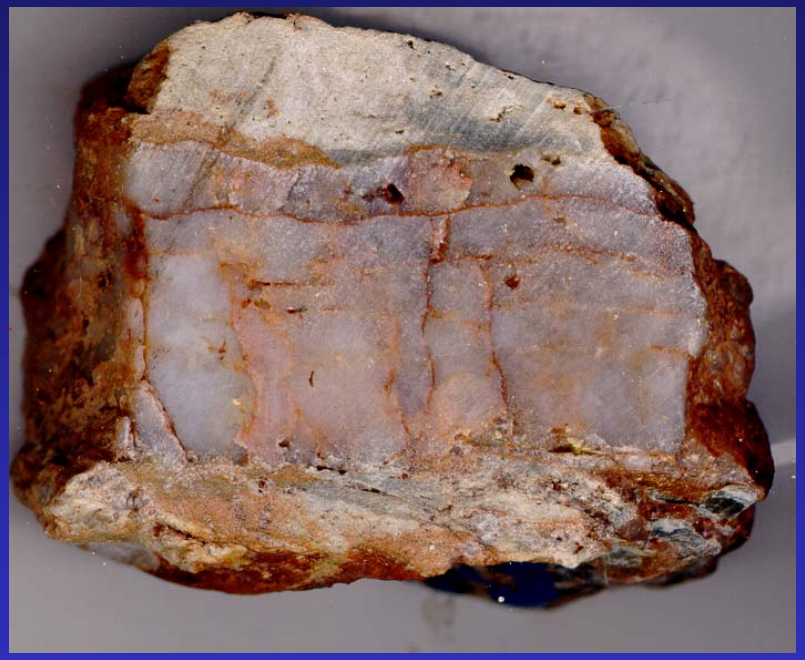
EXAMPLE OF IRGS EXPLORATION CHARACTERISTICS: NORTH QLD



EGRU

EGRU

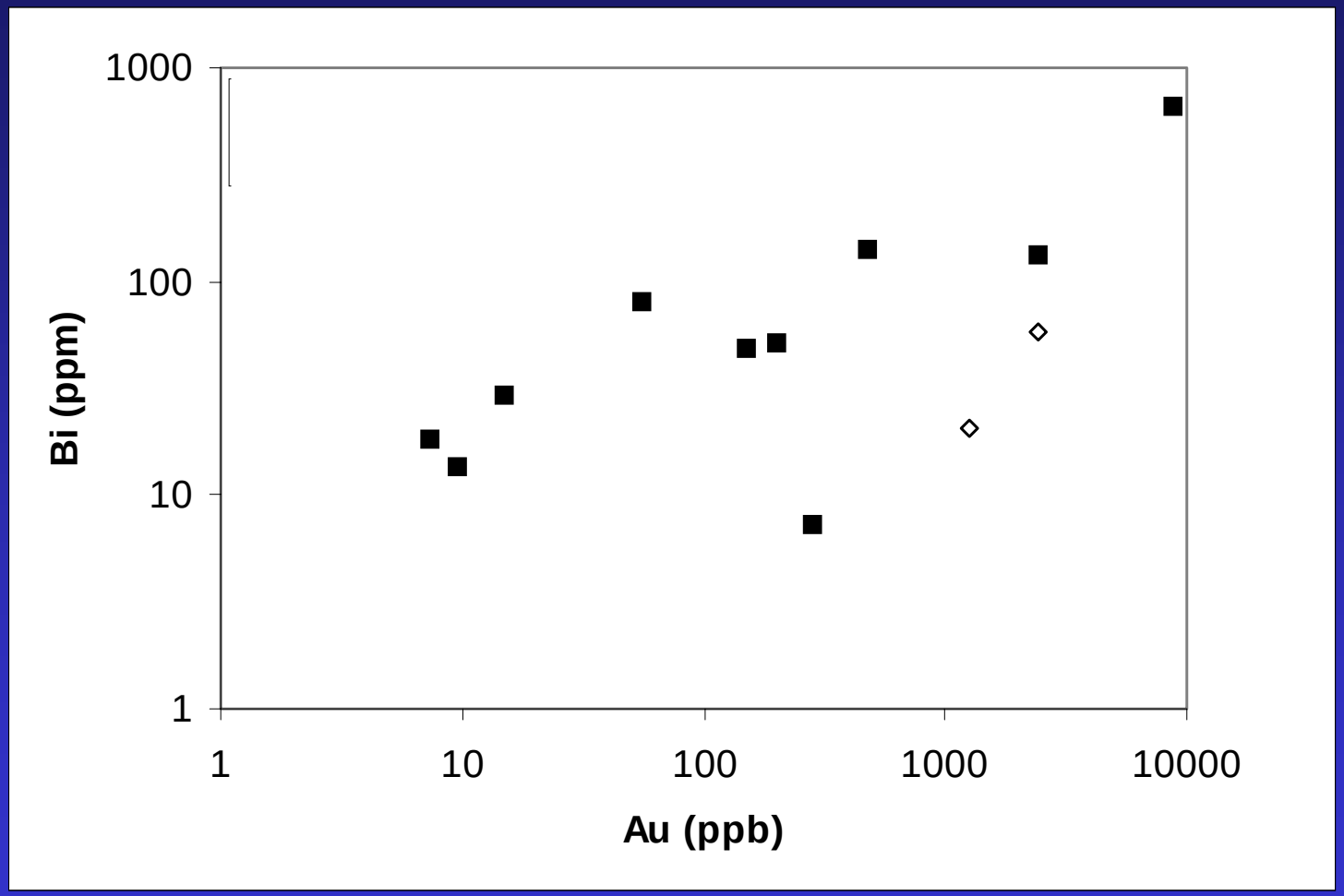
EXAMPLE OF IRGS EXPLORATION CHARACTERISTICS: NORTH QLD



M5: 8.6ppm Au, 657ppm Bi

M2: 0.5ppm Au, 140ppm Bi

EXAMPLE OF IRGS EXPLORATION CHARACTERISTICS: NORTH QLD



EXAMPLE OF IRGS EXPLORATION CHARACTERISTICS: NORTH QLD

T14 (1.26 ppm Au; 20.71 Bi)
Quartz-muscovite vein with narrow muscovite (greisen-like) alteration halo
Tinaroo Creek

T18 (2.42 ppm Au; 58 ppm Bi)
Quartz-muscovite pegmatite -like vein

CONCLUSIONS I

- IRGS have a coherent, useable set of empirical exploration characteristics
- Critical features include
  - Vertical & lateral zonation about mod-reduced granitic intrusions
  - Set of pathfinder elements including Au, Bi, Te, As, W, (Mo, Sn, Sb)
  - Variety of target types within IRGS

CONCLUSIONS II

- Belts known for magmatic related W-Mo-Sn systems are high priority target areas
  - Au-(Bi-W) placer occurrences provide good indicator
  - Such regions commonly lack thorough testing of IRGS model
  - Commonly not sampled for Au & Bi
- Many regions can be regionally evaluated quickly through database searches & GIS approaches