TALK 4
CONCEPTUAL TARGETING FOR WORLD-CLASS OROGENIC GOLD DEPOSITS

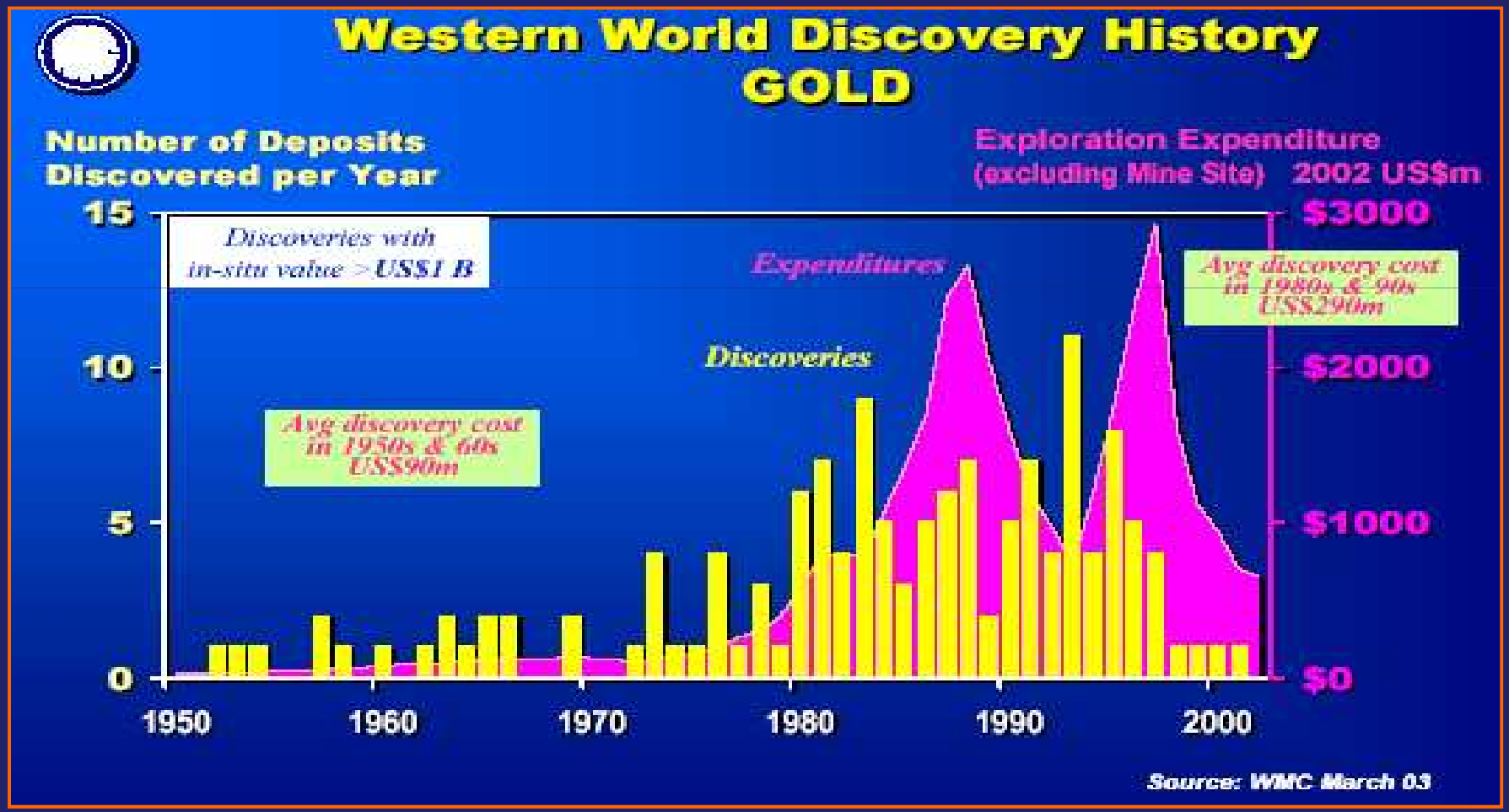
David I. Groves

with contributions from:
Carl Knox-Robinson
Warick Brown
Stephen Gardoll
Paul Hodkiewicz
Grace Yun

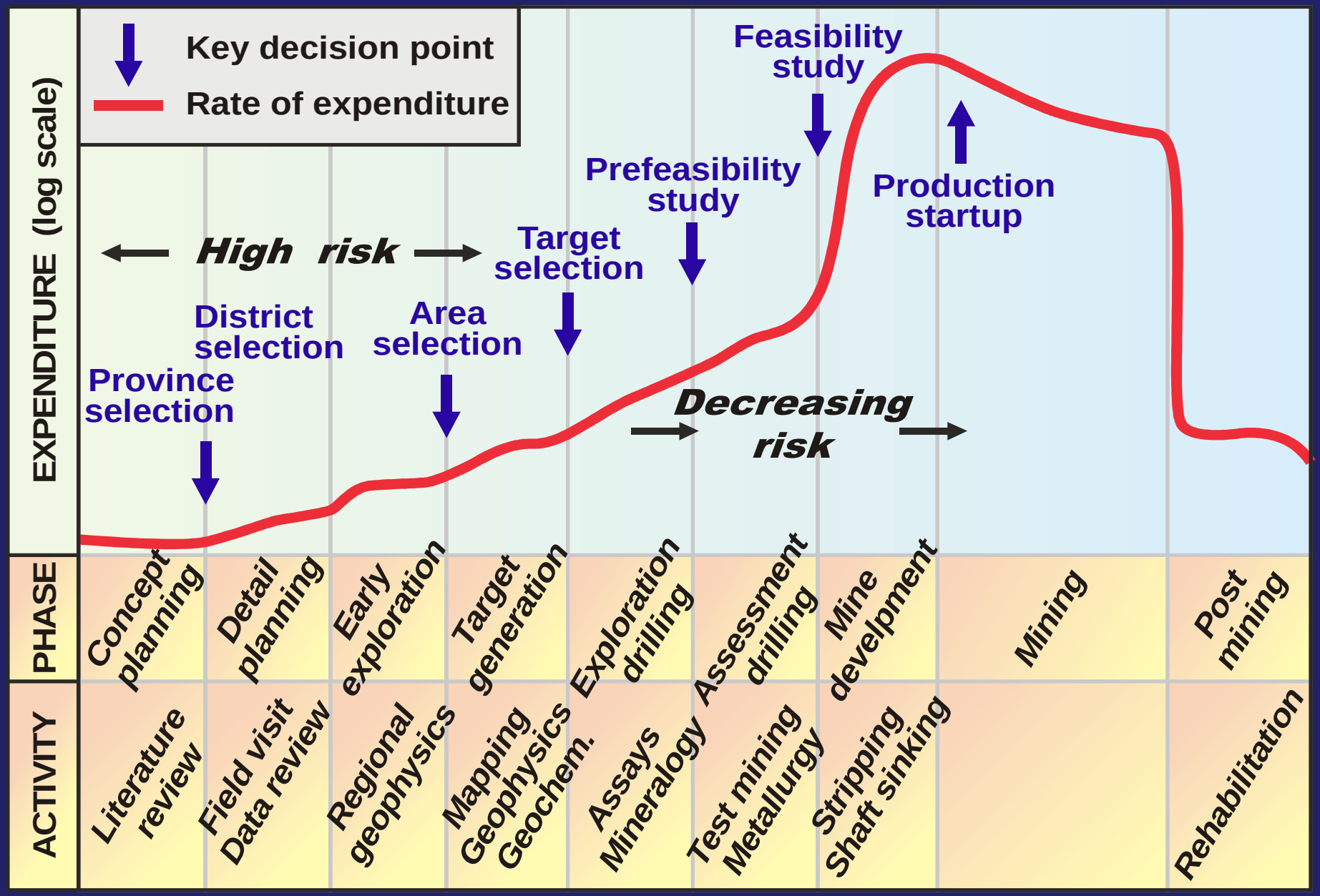
OUTLINE OF CONCEPTUAL TARGETING SEGMENT

1. NEED FOR IMPROVED CONCEPTUAL TARGETING
2. CONTROLS ON WORLD-CLASS OROGENIC GOLD PROVINCES: COMPLEXITY
3. DEFINITION OF CRITICAL PARAMETERS
4. INTEGRATION TO DEFINE CRITICAL CONJUNCTIONS OF PARAMETERS
5. RANGE OF INTEGRATION TOOLS IN GIS ENVIRONMENT
6. ASSESSMENT OF PREDICTIVE CAPACITY AND FUTURE NEEDS

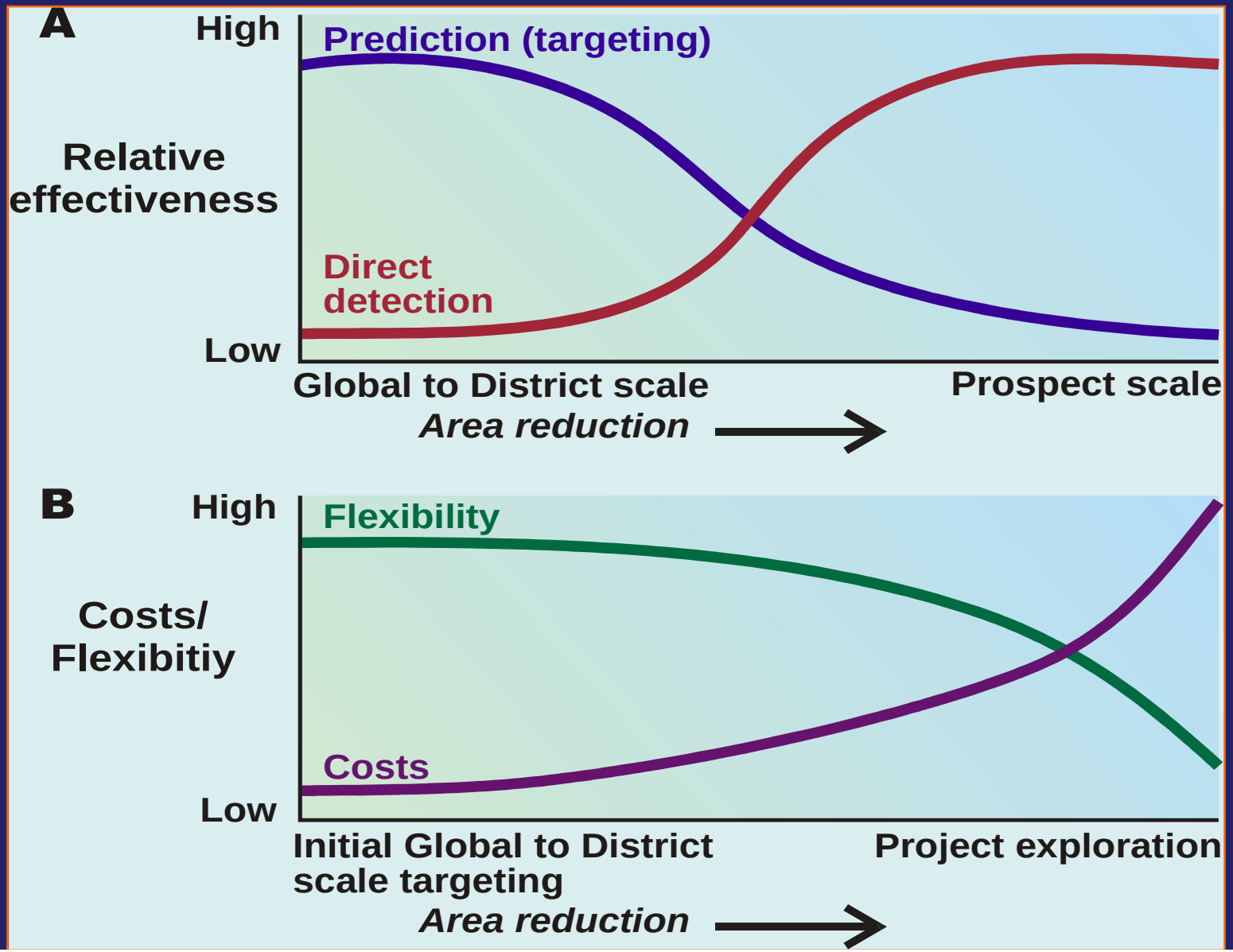
DECLINING MINERAL DEPOSIT DISCOVERIES: GLOBAL GOLD



KEY STAGES AND DECISION POINTS

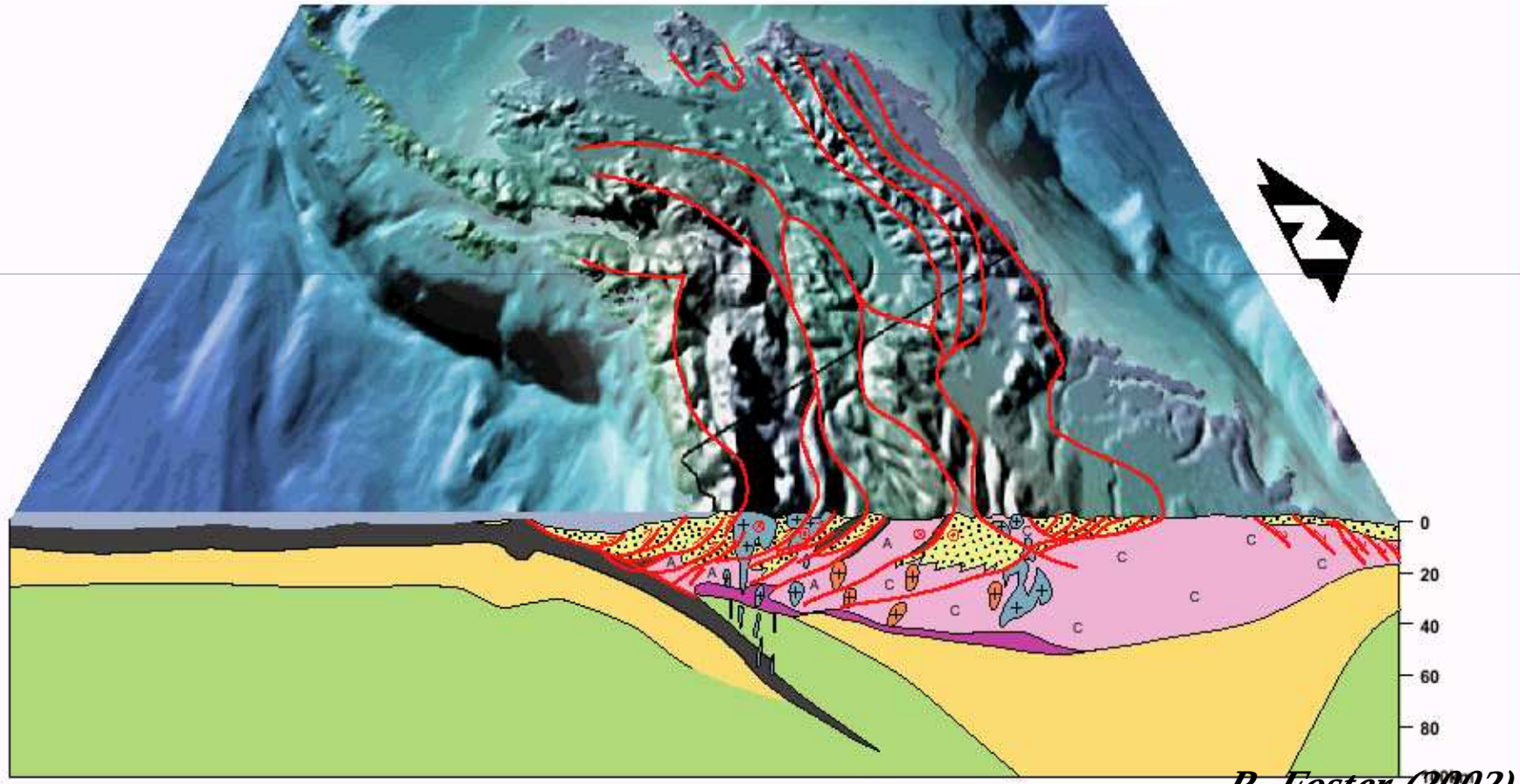


EFFECTIVENESS AND LOW COST OF CONCEPTUAL PHASE OF EXPLORATION

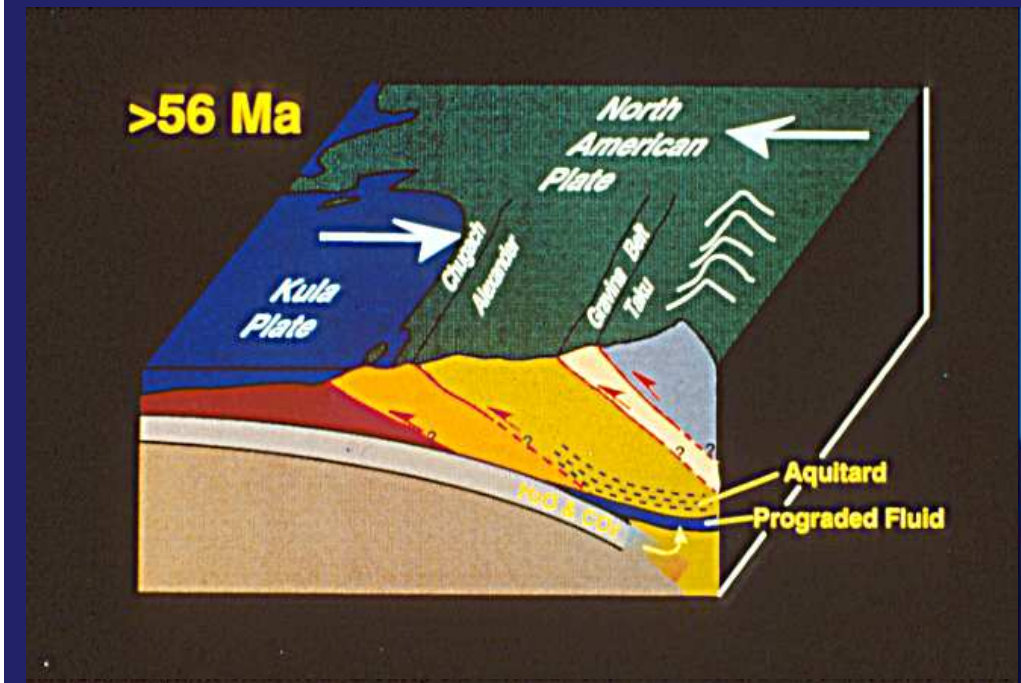


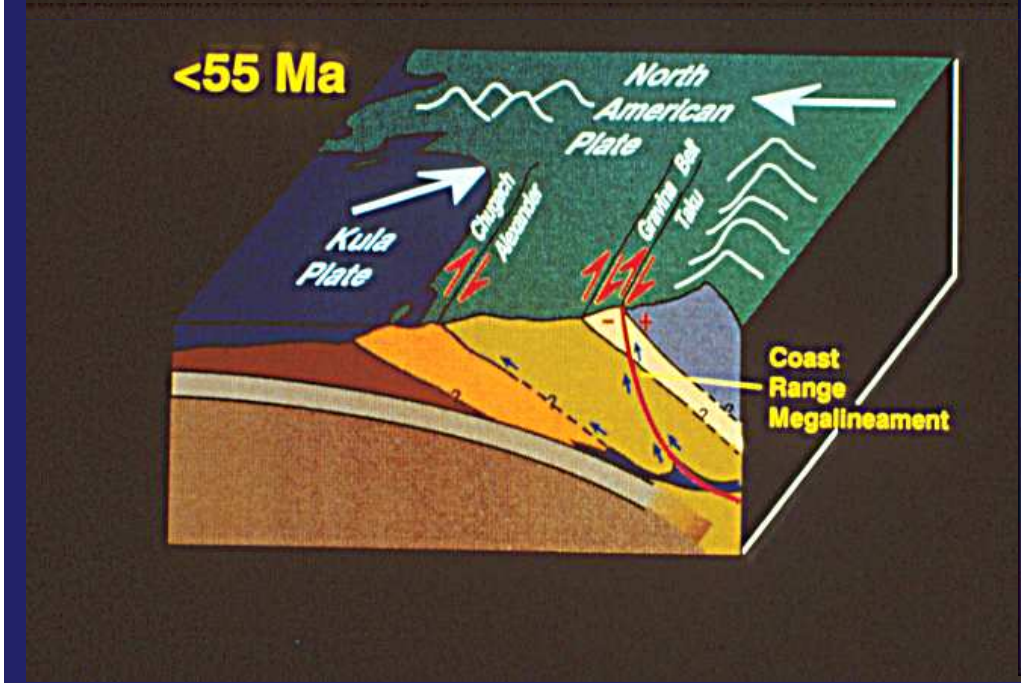
MARKET MOTION MEDIA INC.

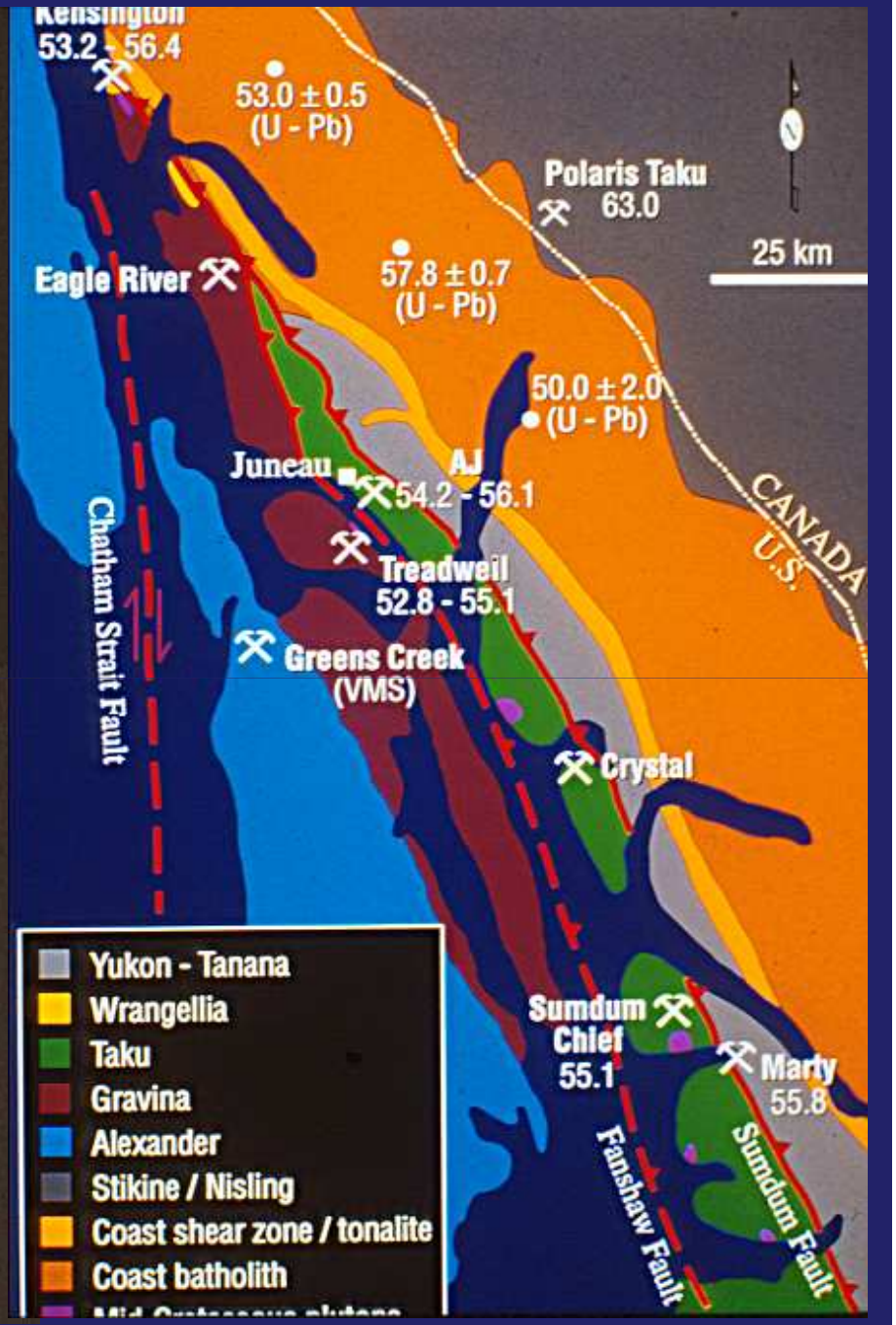
UNCONSOLIDATED OROGENS: ACCRETIONARY ARC COMPLEX



R. Foster (2002)


>56 Ma
North American Plate
Kula Plate
Chugach
Alexander
Gravina Belt
Taku
Aquitard
Prograded Fluid


<55 Ma
North American Plate
Kula Plate
Chugach
Alexander
Gravina Belt
Taku
Coast Range Megalineament


Kensington
53.2 - 56.4
53.0 ± 0.5
(U - Pb)
Polaris Taku
63.0
25 km
Eagle River
57.8 ± 0.7
(U - Pb)
50.0 ± 2.0
(U - Pb)
Juneau
AJ
54.2 - 56.1
Treadwell
52.8 - 55.1
Greens Creek
(VMS)
Chatham Strait Fault
CANADA
U.S.
Crystal
Sumdum Chief
55.1
Marty
55.8
Fanshaw Fault
Sumdum Fault
Yukon - Tanana
Wrangellia
Taku
Gravina
Alexander
Stikine / Nisling
Coast shear zone / tonalite
Coast batholith

SE ASIA RECONSTRUCTIONS
50-0 MA

Adapted from: Robert Hall (1995)

Deposit Data from Petra Rak and Mark Barley

Legend

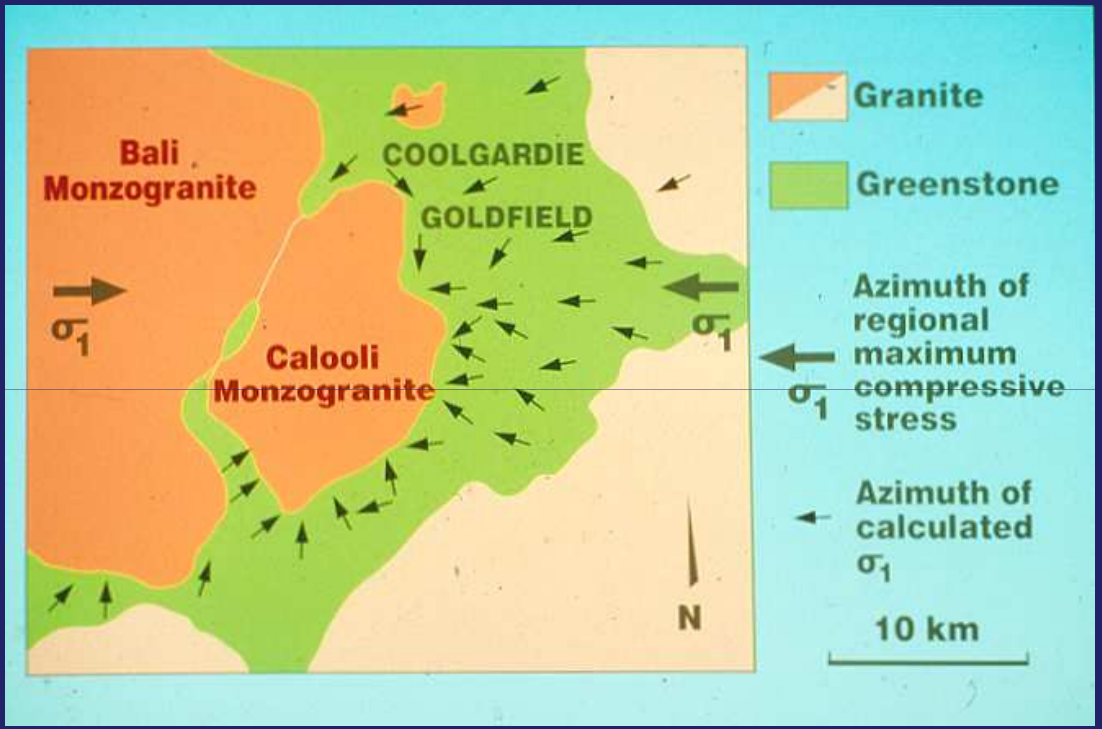
Mineralisation type	<3 My certainty	4 to 6 My certainty
District	■	▮
Porphyry	●	◖
Skarn	▲	◢
Epitherma Low Sulfidation	◆	◀
Epithermal High Sulfidation	▼	◥
Carbonate Base-Metal	★	★

Mineralisation age

- Piocene to Recent (6 to 0 Ma)
- Mid Miocene to End Miocene (17 to 7 Ma)
- Early Miocene to Mid Miocene (23 to 18 Ma)
- Oligocene or older (50 to 22 Ma)

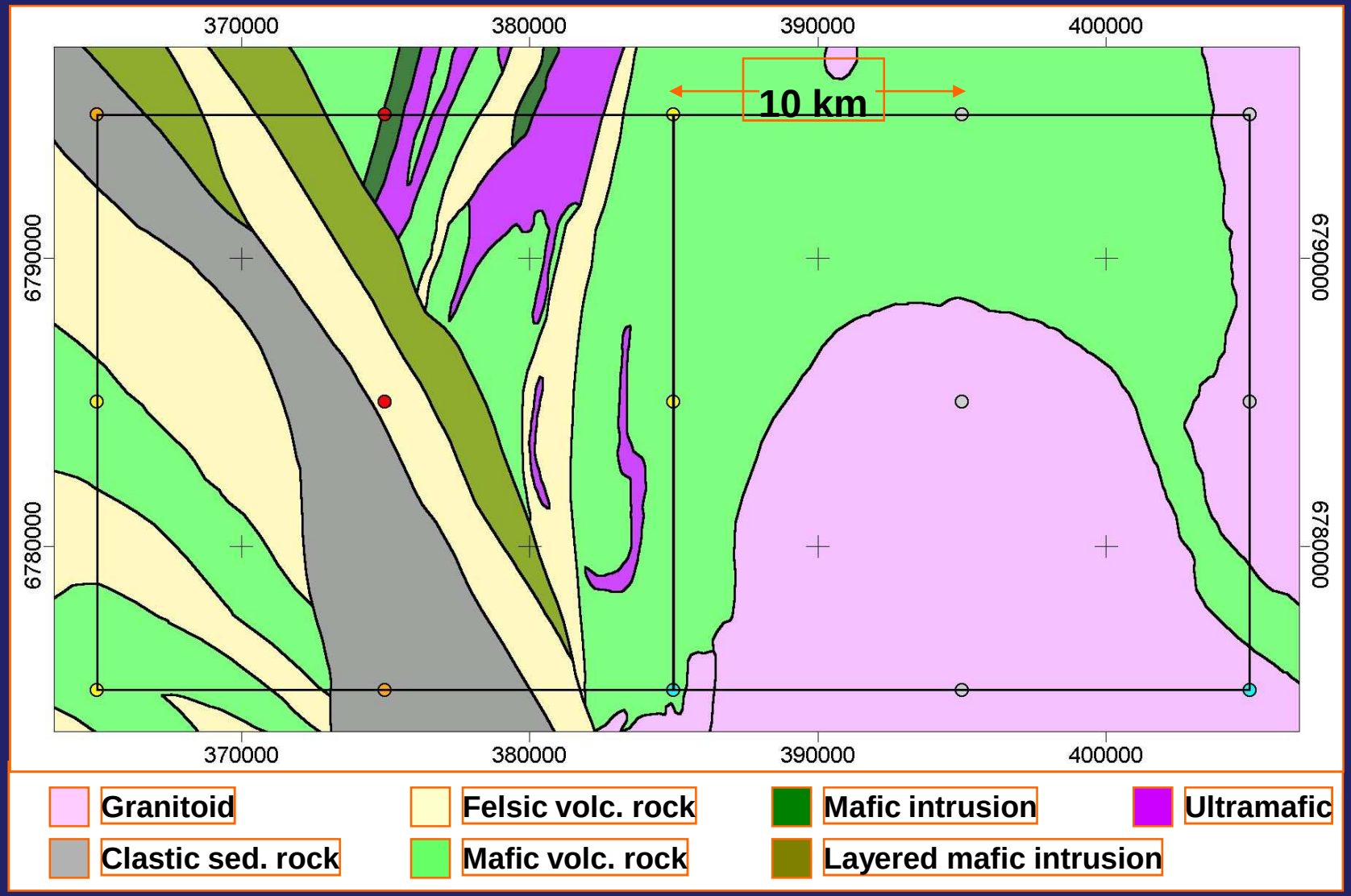
STRUCTURAL SETTING OF OROGENIC GOLD DEPOSITS

- Complexity rules
- Reactivation of pre-existing structures
- Heterogeneous stresses and strain partitioning



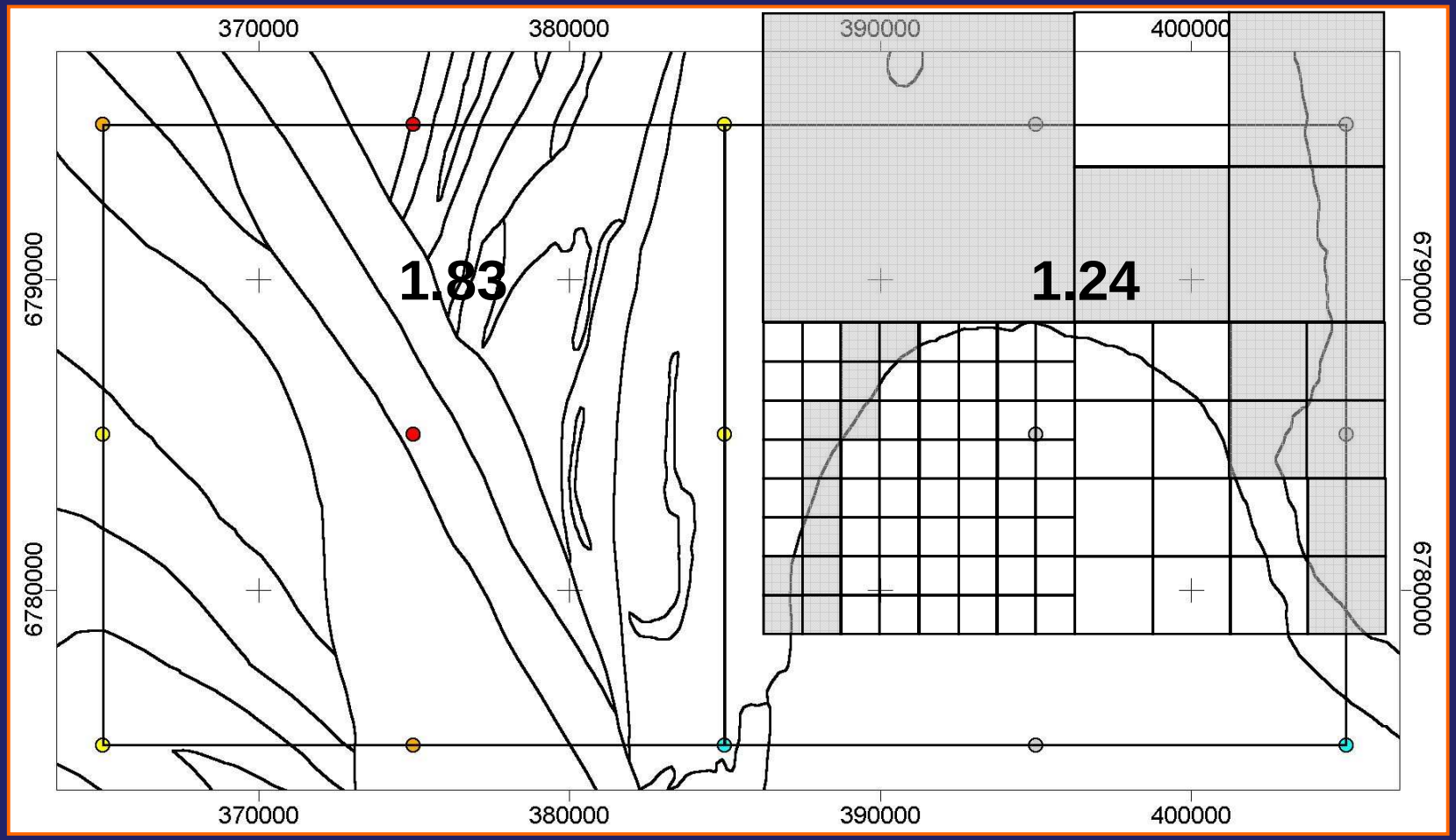
- "Classic" structural analysis may lead to conflicting interpretations
- Geometrical analysis synergetic approach

GIS AND GEOLOGICAL COMPLEXITY

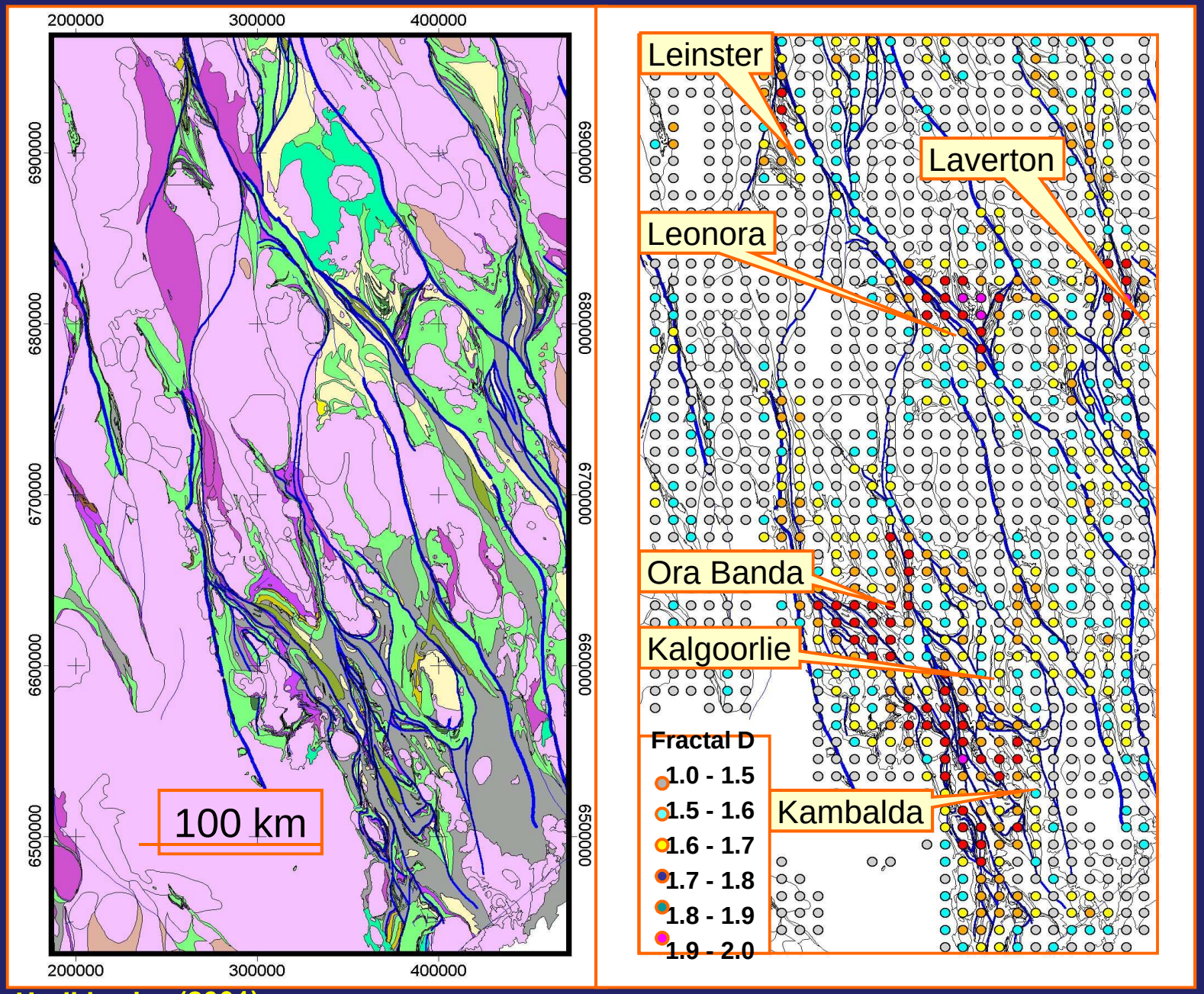


Hodkiewicz (2001)

FRACTAL DIMENSION



Hodkiewicz (2001)



Hodkiewicz (2001)

OROGENIC GOLD EXPLORATION PROVINCE TO DISTRICT SCALE CONSIDERATIONS

Prospectivity Mapping

or

Endowment Evolution

ENDOWMENT PREDICTION / PROSPECTIVITY MAPPING : CRITICAL STEPS

- **Determination of timing of deposit group: do map data reflect geometry at time of mineralization?**
- Identification of important factors
  - Empirically and on a thematic basis, or
  - Based on conceptual premise
- Quantification of identified or hypothesised spatial relationships
- Integration of relationships into a prospectivity map

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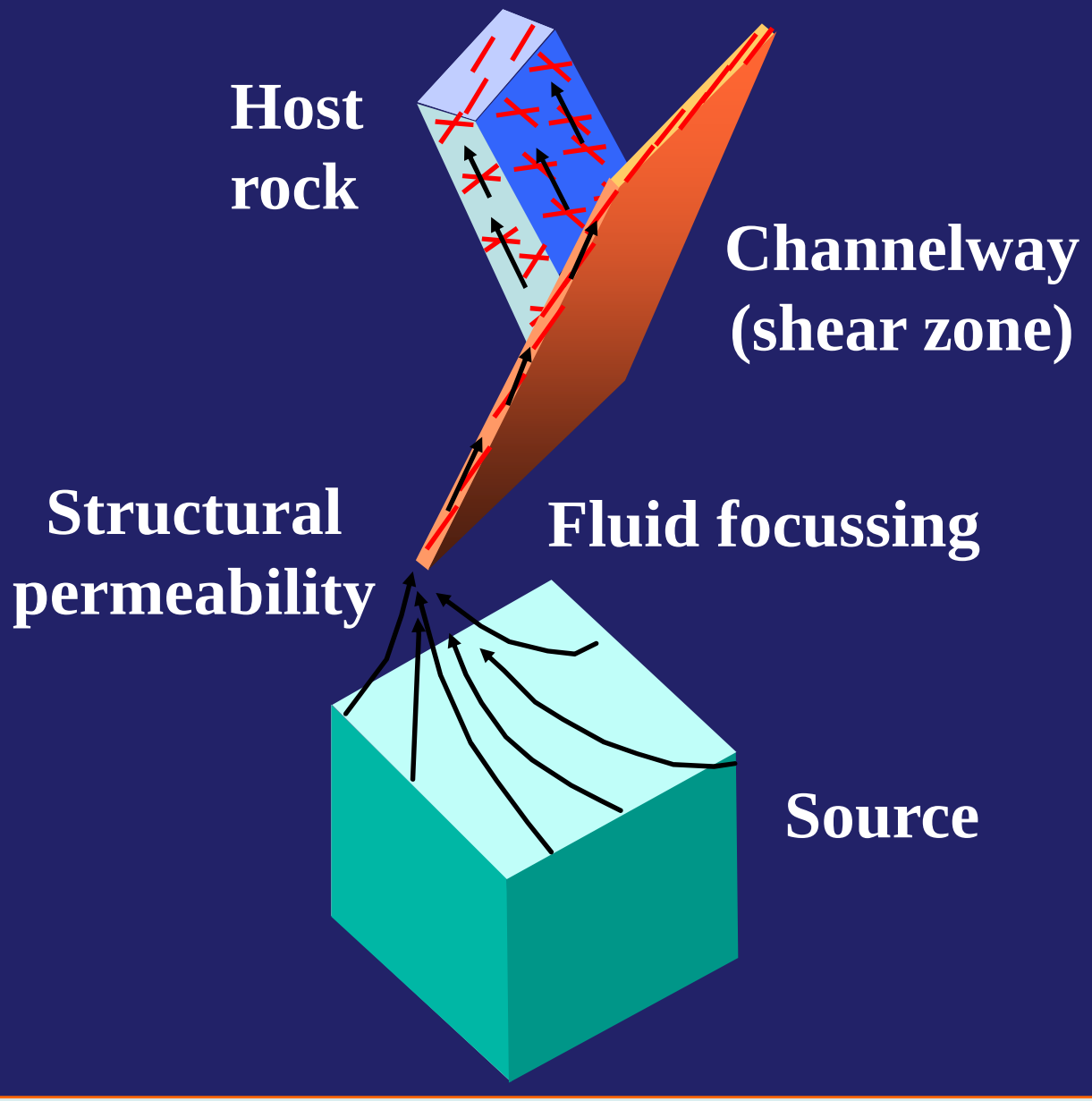
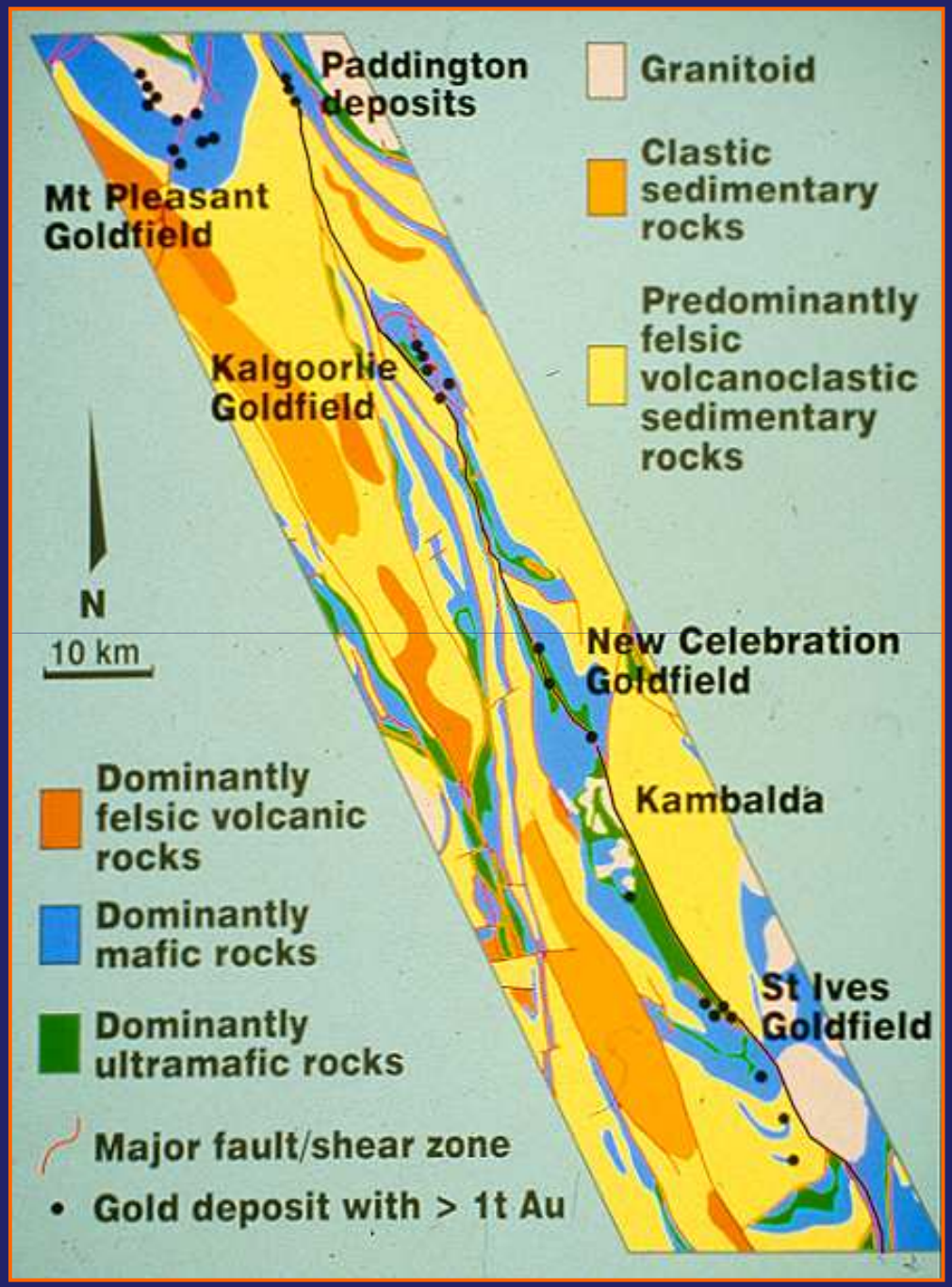
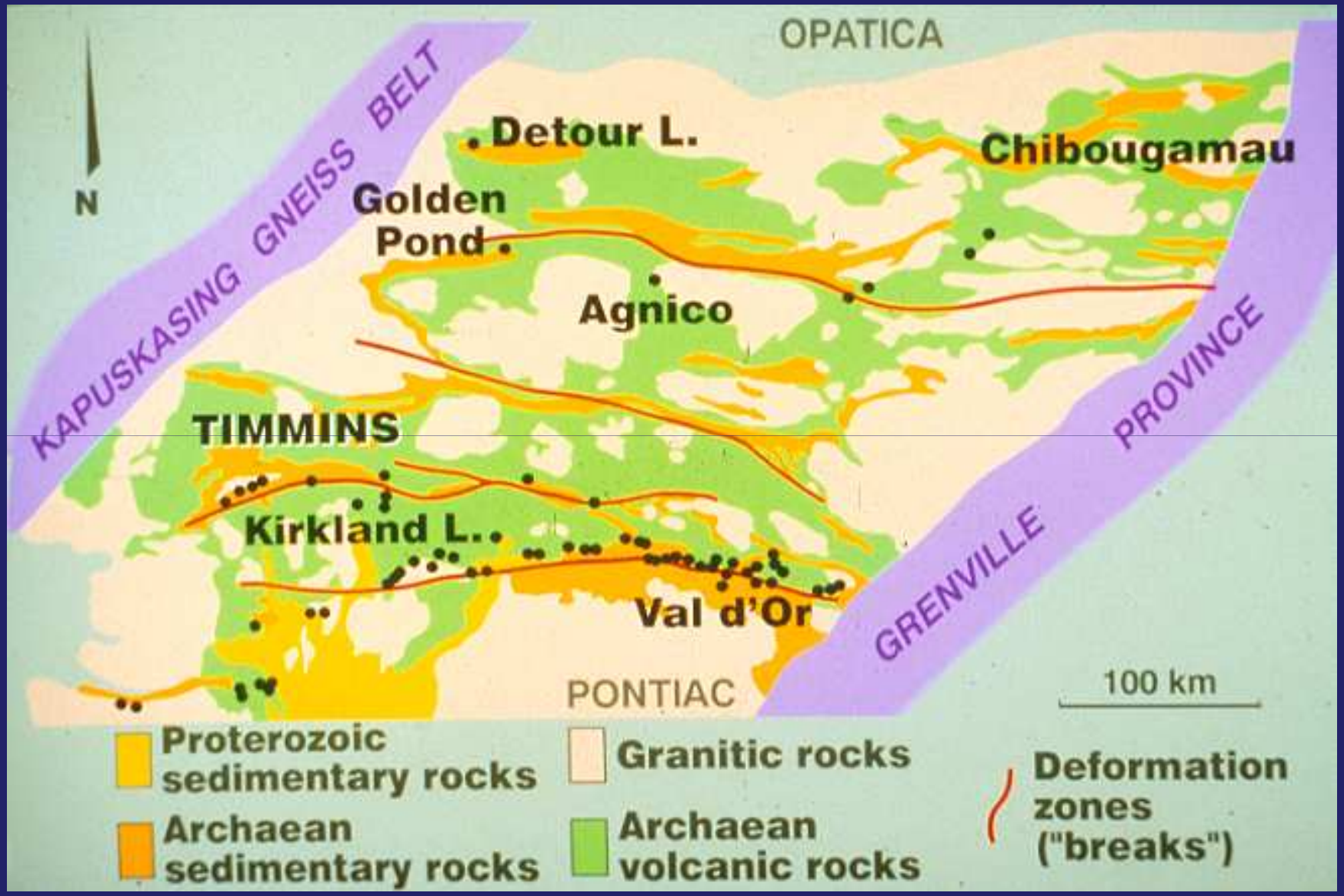


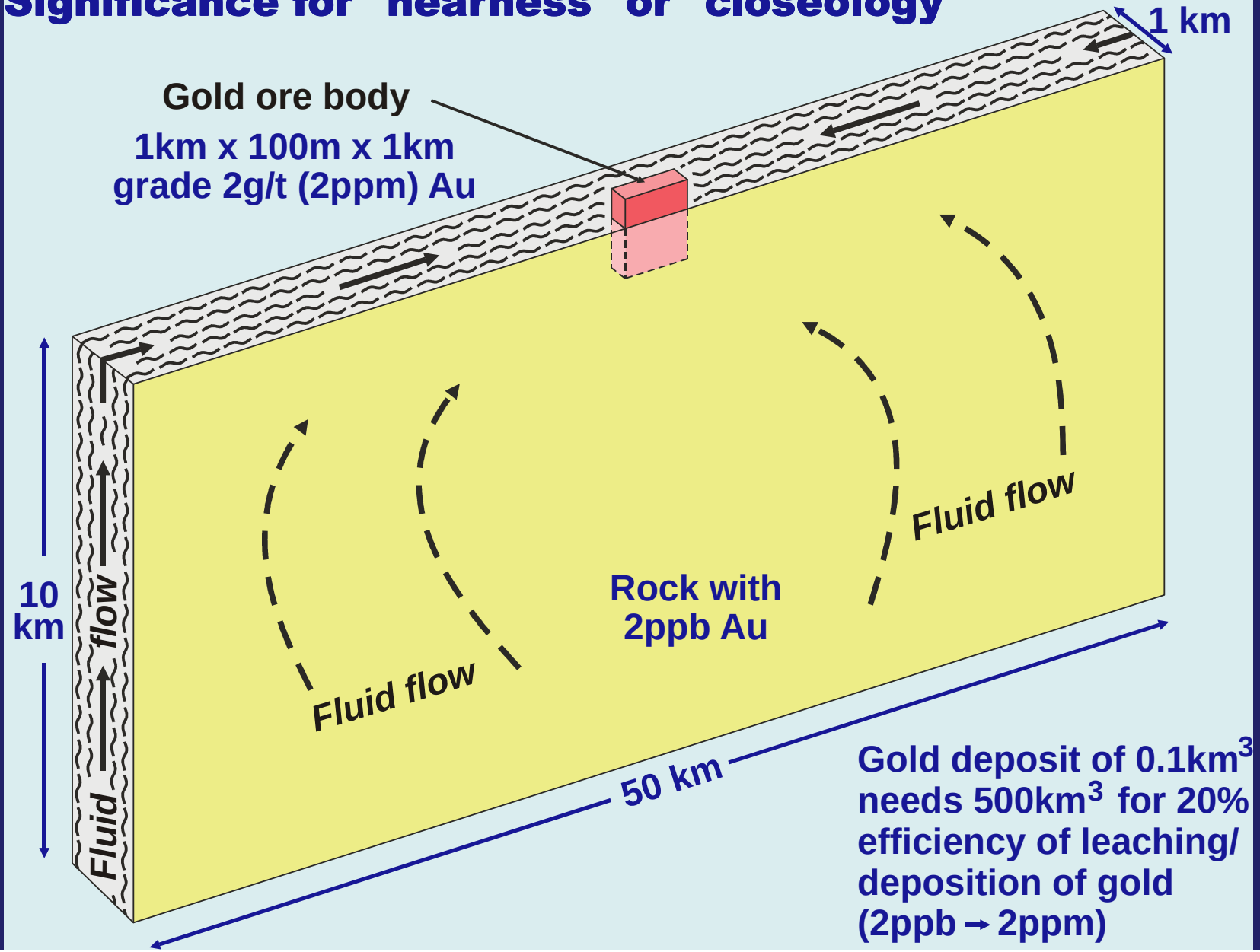
ANATOMY OF A HYDROTHERMAL SYSTEM


Paddington deposits
Granitoid
Clastic sedimentary rocks
Mt Pleasant Goldfield
Predominantly felsic volcanoclastic sedimentary rocks
Kalgoorlie Goldfield
N
10 km
New Celebration Goldfield
Kambalda
Dominantly felsic volcanic rocks
Dominantly mafic rocks
St Ives Goldfield
Dominantly ultramafic rocks
Major fault/shear zone
Gold deposit with > 1t Au

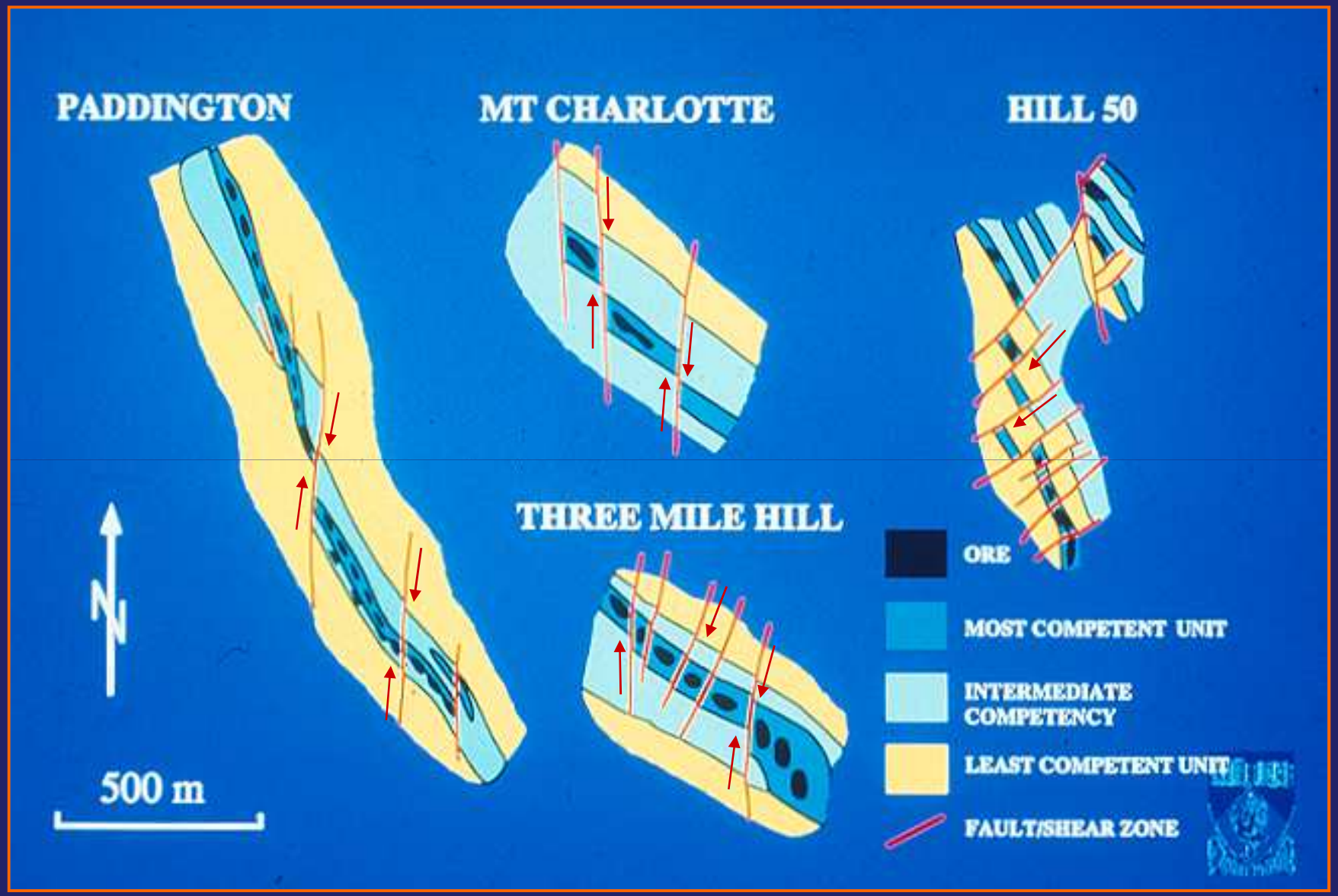

OPATICA
KAPUSKASING GNEISS BELT
N
Detour L.
Chibougamau
Golden Pond
Agnico
TIMMINS
Kirkland L.
Val d'Or
GRENVILLE PROVINCE
PONTIAC
100 km
Proterozoic sedimentary rocks
Granitic rocks
Deformation zones ("breaks")
Archaean sedimentary rocks
Archaean volcanic rocks

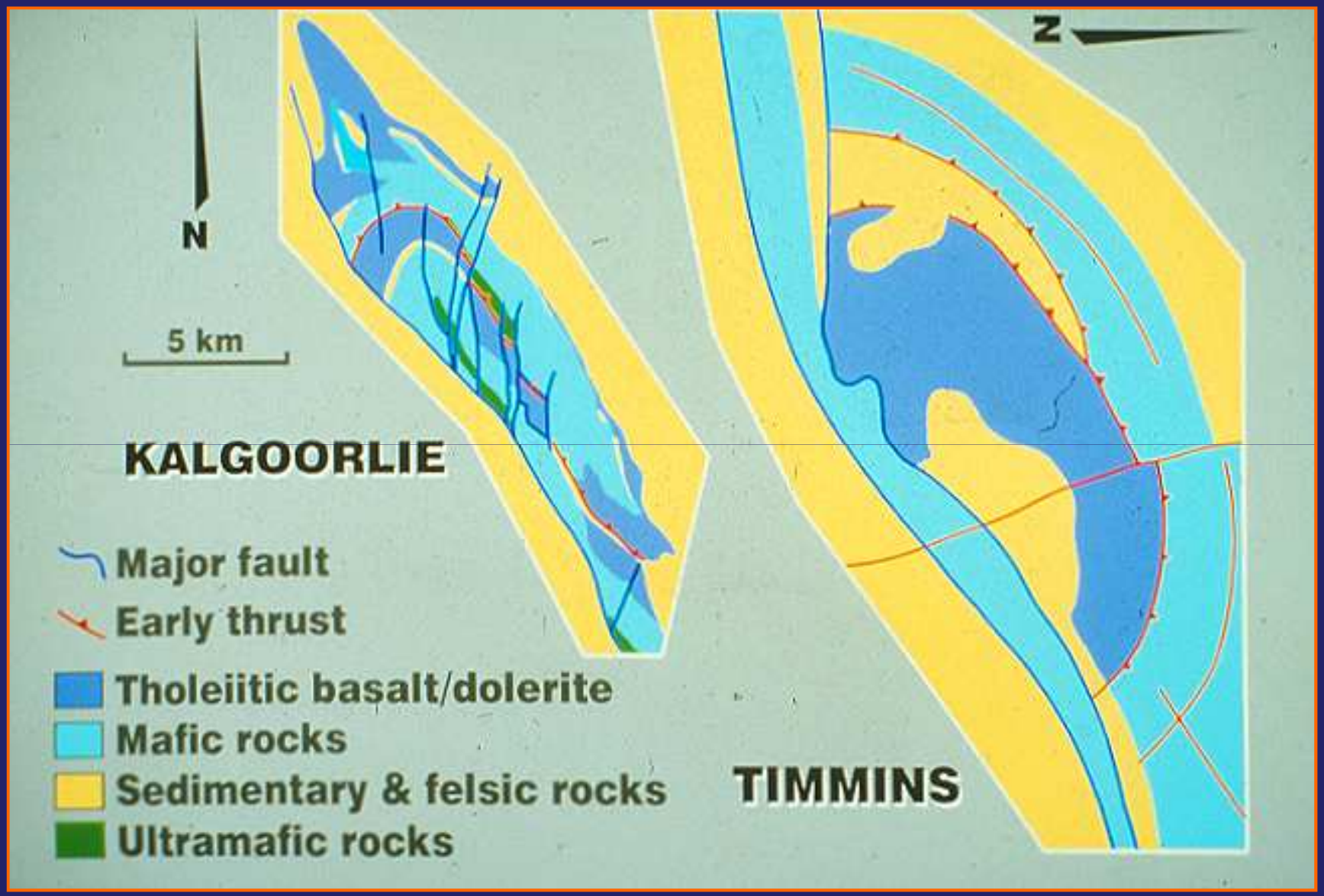
FLUID FLOW & FORMATION OF GOLD DEPOSIT IN FAULT ZONE

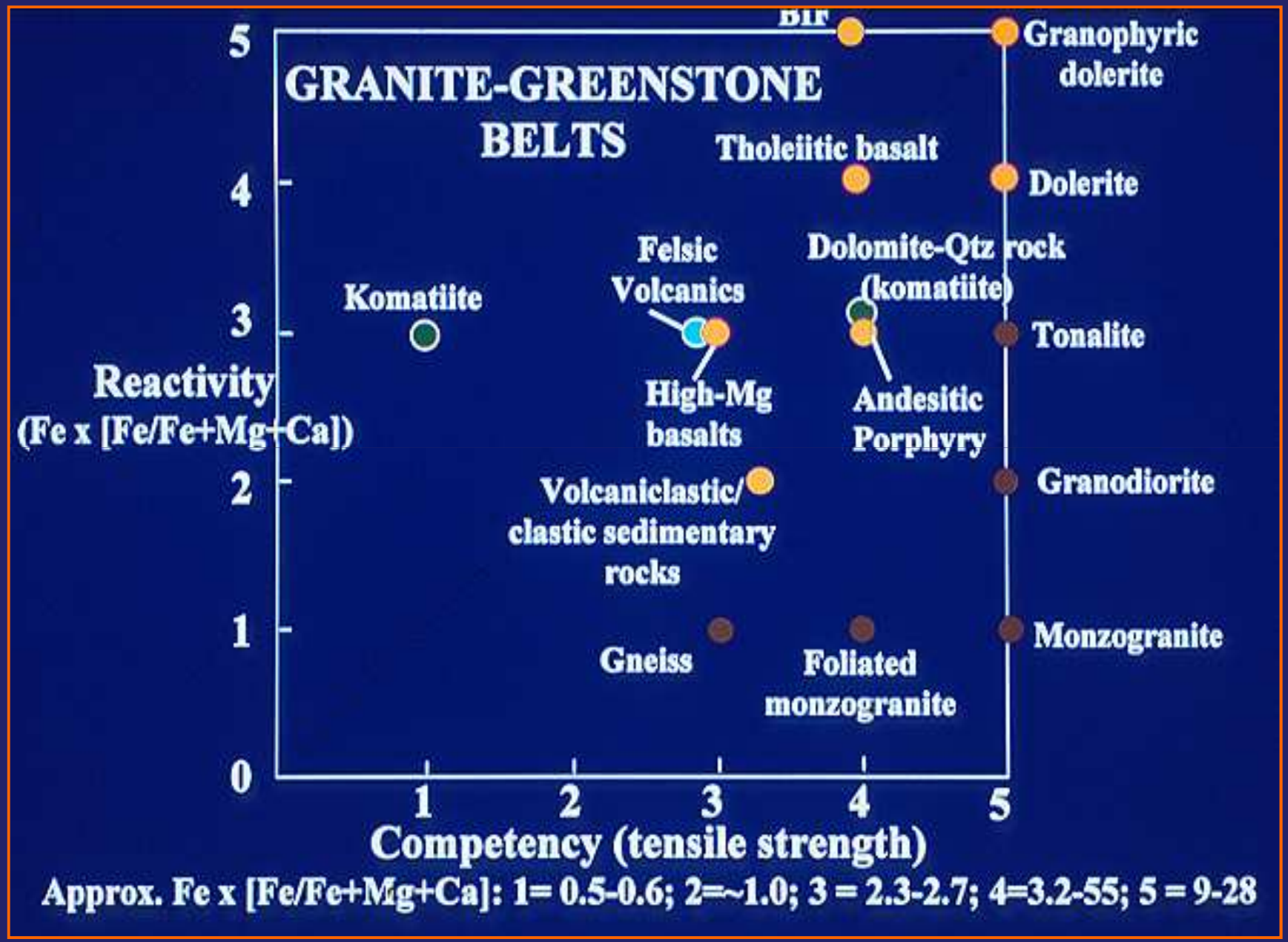
Significance for "nearness" or "closeology"



Gold deposit of 0.1km^3 needs 500km^3 for 20% efficiency of leaching/ deposition of gold (2ppb → 2ppm)


PADDINGTON
MT CHARLOTTE
HILL 50
THREE MILE HILL
N
500 m
ORE
MOST COMPETENT UNIT
INTERMEDIATE COMPETENCY
LEAST COMPETENT UNIT
FAULT/SHEAR ZONE


N
5 km
KALGOORLIE
Major fault
Early thrust
Tholeiitic basalt/dolerite
Mafic rocks
Sedimentary & felsic rocks
Ultramafic rocks
N
TIMMINS


GRANITE-GREENSTONE BELTS
BIF
Granophyric dolerite
Tholeiitic basalt
Dolerite
Felsic Volcanics
Dolomite-Qtz rock (komatiite)
Komatiite
Tonalite
High-Mg basalts
Andesitic Porphyry
Granodiorite
Volcaniclastic/ clastic sedimentary rocks
Monzogranite
Gneiss
Foliated monzogranite
Reactivity (Fe x [Fe/Fe+Mg+Ca])
Competency (tensile strength)
0
1
2
3
4
5
Approx. Fe x [Fe/Fe+Mg+Ca]: 1= 0.5-0.6; 2=~1.0; 3 = 2.3-2.7; 4=3.2-55; 5 = 9-28

ENDOWMENT PREDICTION / PROSPECTIVITY MAPPING : CRITICAL STEPS

- Determination of timing of deposit group : do map data reflect geometry at time of mineralization?
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  - **Empirically and on a thematic basis, or**
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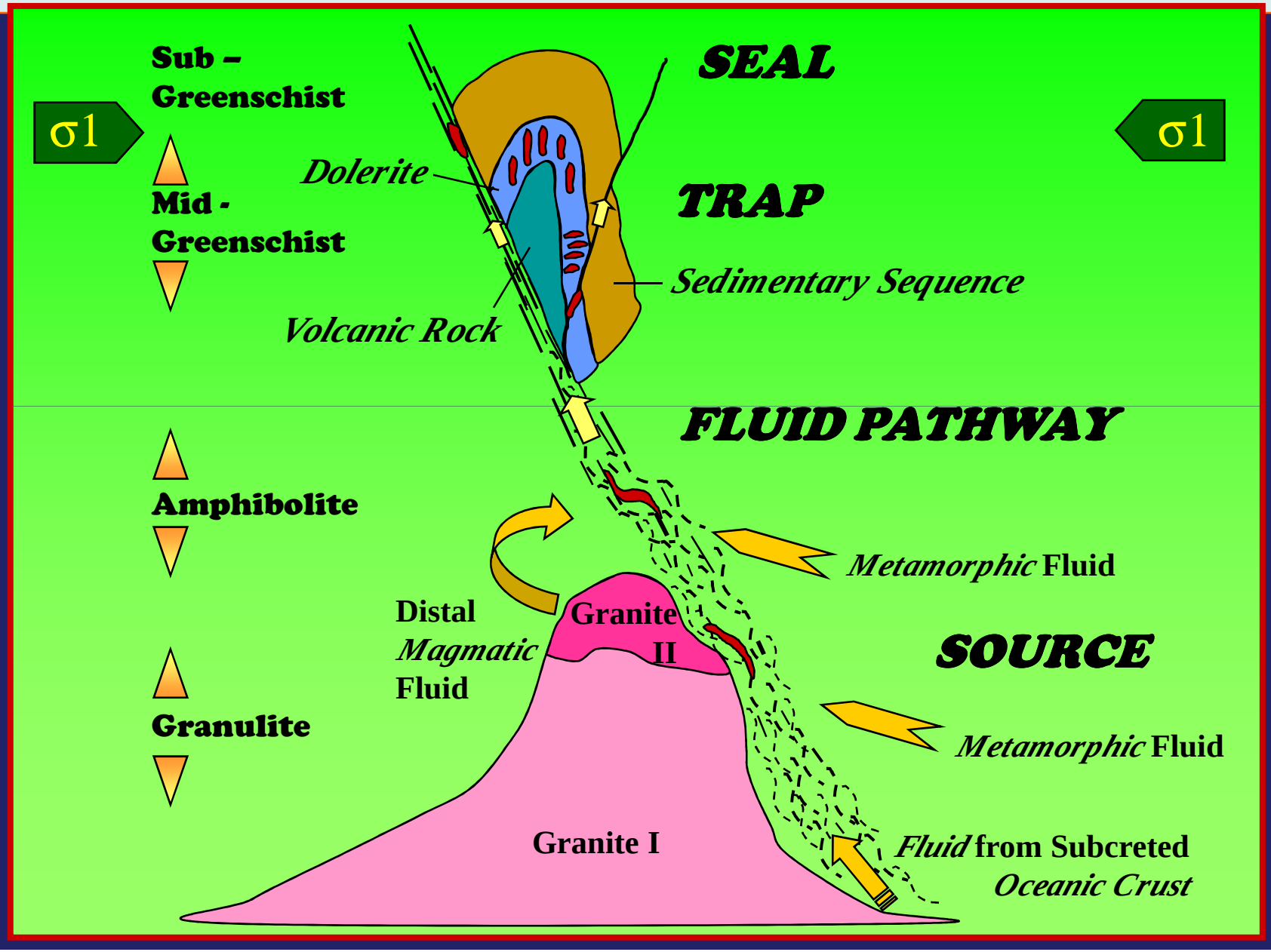
SIMPLE MINERAL SYSTEM MODEL AT DISTRICT SCALE: ARCHAEAN OROGENIC GOLD DEPOSITS



POTENTIAL CONTROLLING PARAMETERS IN TERMS OF A MINERAL SYSTEM AT DISTRICT SCALE: SOME EXAMPLES - 1

Source

- Greenschist facies metamorphic domains (metamorphic model)
- Porphyry or syenite stocks, lamprophyre dykes (magmatic model)

Fluid Pathways

- Crustal-scale deformation zones, particularly flexures
- Clusters of oblique regional-scale faults
- Pre-existing thrust or strike-slip duplexes
- Pressure shadows of granitoid intrusions
- Small rigid bodies in more ductile sequences

POTENTIAL CONTROLLING PARAMETERS IN TERMS OF A MINERAL SYSTEM AT DISTRICT SCALE: SOME EXAMPLES - 2

Depositional Site (Trap)

- Tip zones of fluid pathways
- Anticlinal, particularly domal, structures
- Reactive rock sequences (high Fe or C)
- Anomalous fluid chemistries (only known at advanced stage)

Fluid Caps (Seal)

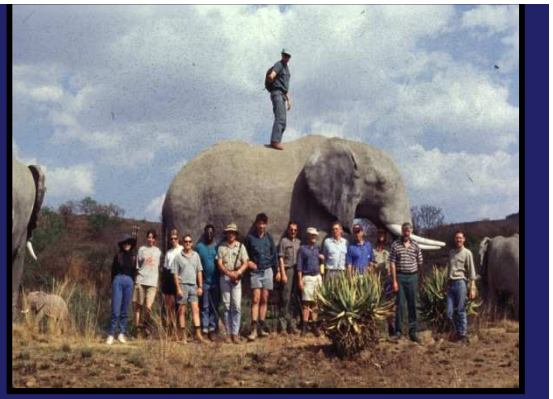
- Upper sedimentary sequences capping volcanic rocks
- Thrust stacks including impermeable rocks
- Regional-scale alteration / metal dispersion zones

MUST HAVE POSITIVE FACTORS FOR SOURCE + PATHWAYS + TRAPS + SEALS

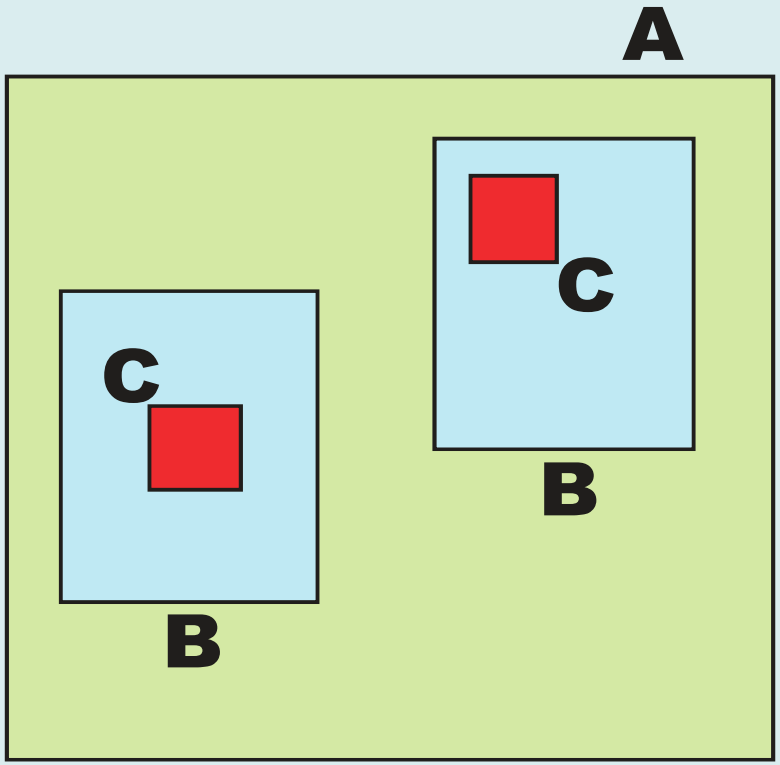
TYPES OF GIS ANALYSIS

1. Association	:	**lithology, metamorphic domain, alteration domain**
2. Proximity	:	**crustal- to regional-scale faults**
	:	**lithological contacts (rheology indexed!)**
	:	**granitiod contacts**
	:	**anticlinal hinges/uplifted zones**
3. Trend	:	**all faults and contacts (jogs, orientation for reactivation)**
4. Abundance	:	**all faults and contacts (intersections)**
	:	**porphyry-lamprophyre dykes**
5. Complexity	:	**granitiod contacts (heterogeneous stress)**

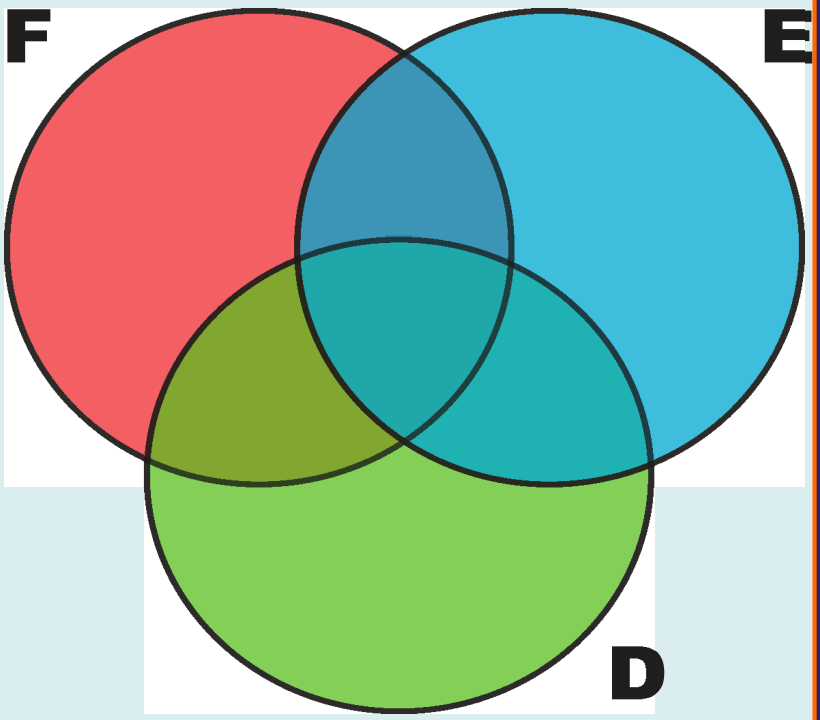
1. ELEPHANT COUNTRY STRATEGY (uses Venn-diagram approach)
2. FIRST MOVER or FAST FOLLOWER STRATEGY (uses hierarchical approach)



Two end-member approaches to target definition

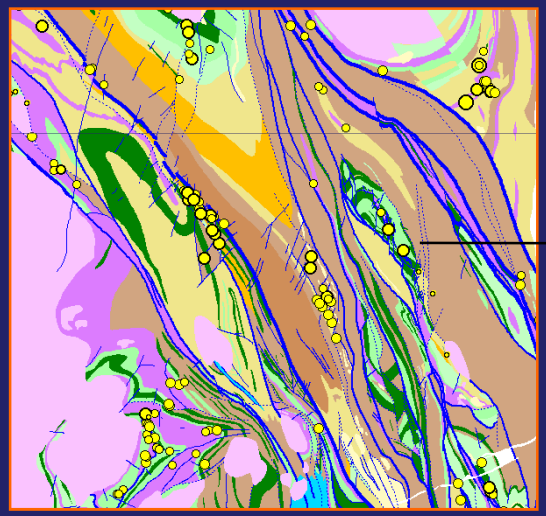


Hierarchical approach

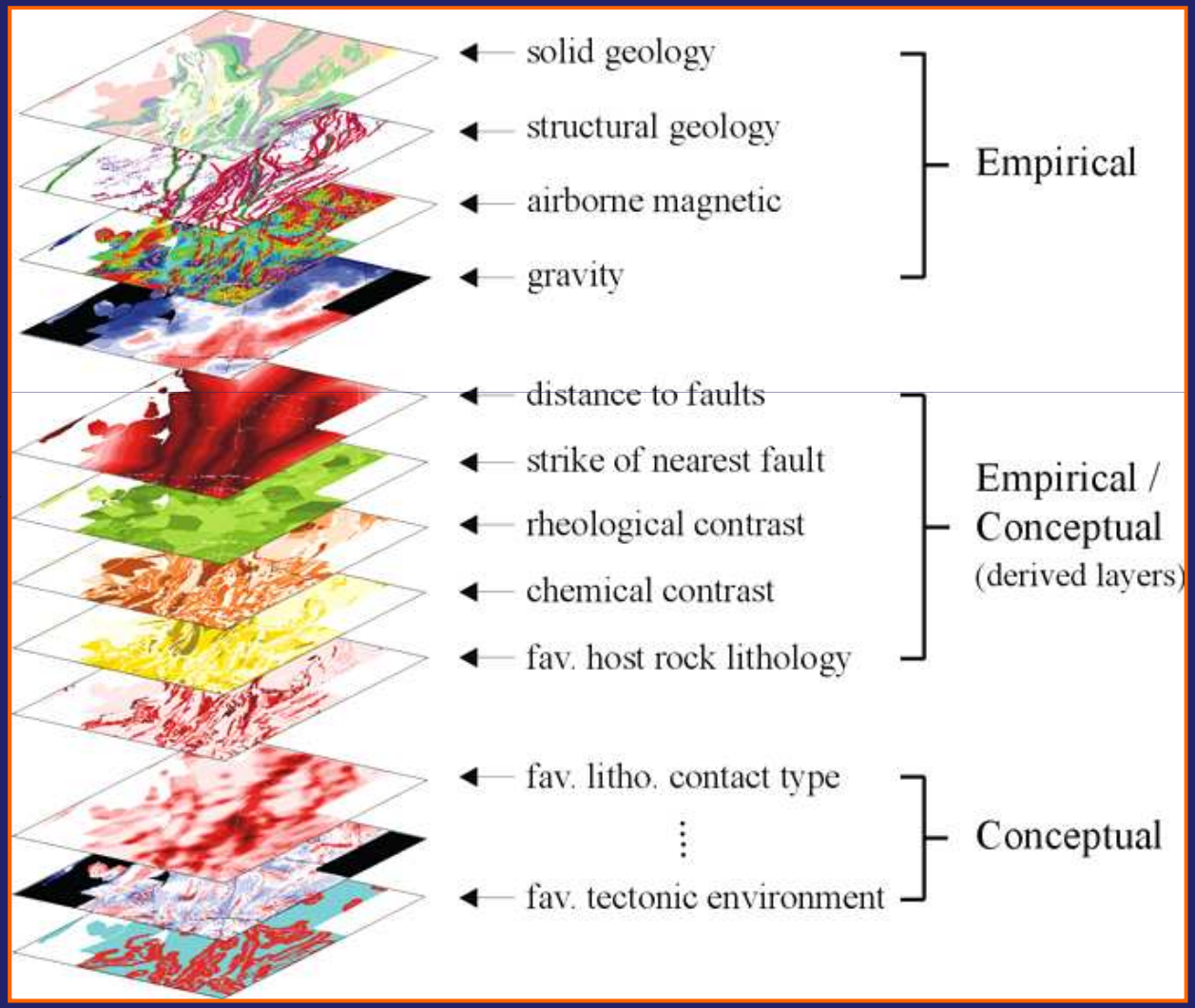


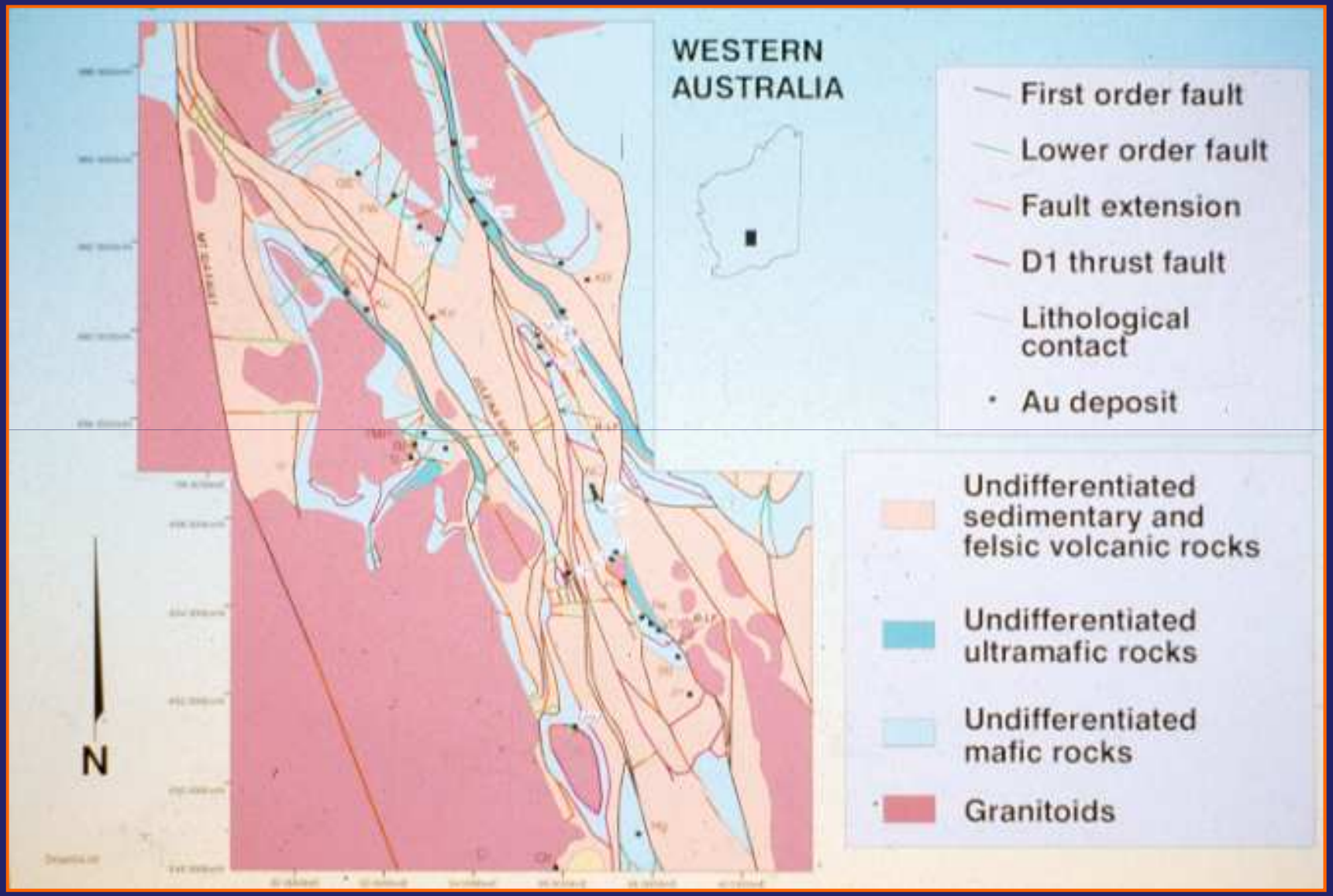
Venn-diagram approach

DATA LAYERS FOR 2D PROSPECTIVITY/ENDOWMENT ANALYSIS



Kalgoorlie Terrane

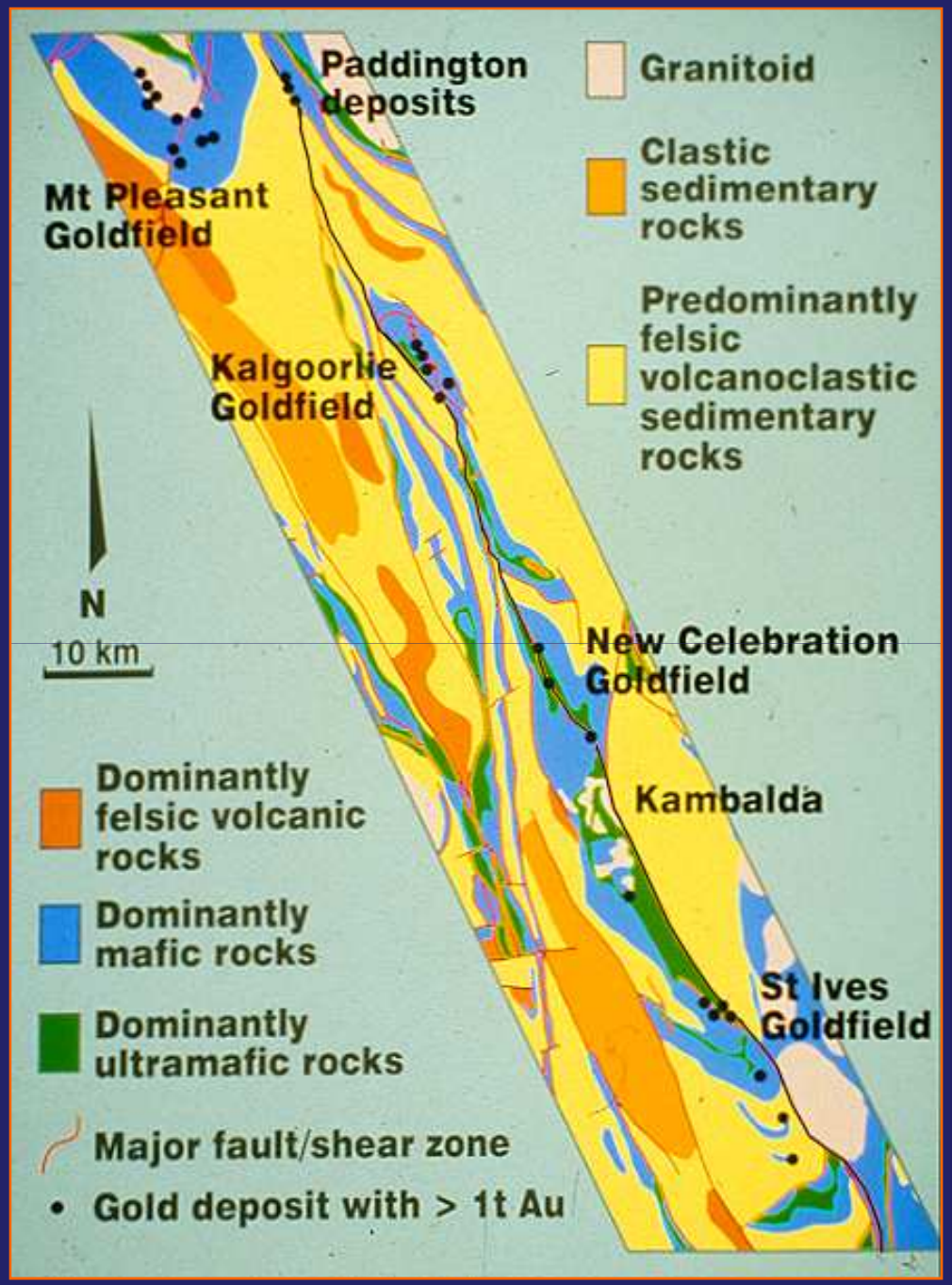



WESTERN
AUSTRALIA
First order fault
Lower order fault
Fault extension
D1 thrust fault
Lithological contact
Au deposit
Undifferentiated sedimentary and felsic volcanic rocks
Undifferentiated ultramafic rocks
Undifferentiated mafic rocks
Granitoids
N

OROGENIC GOLD EXPLORATION

PROVINCE TO DISTRICT SCALE

FLUID PATHWAY PARAMETERS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Granitoid
Clastic sedimentary rocks
Mt Pleasant Goldfield
Predominantly felsic volcanoclastic sedimentary rocks
Kalgoorlie Goldfield
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10 km
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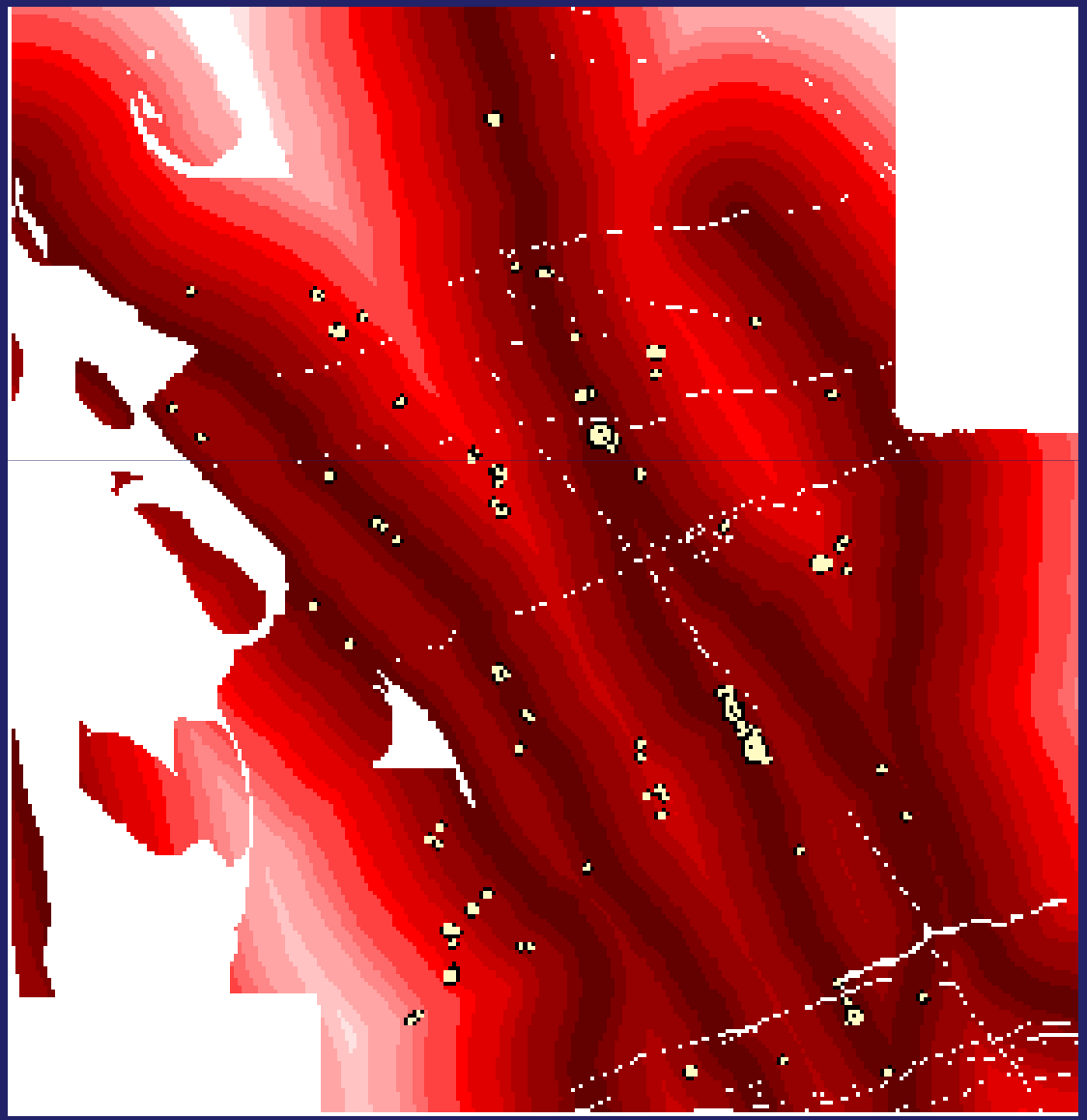
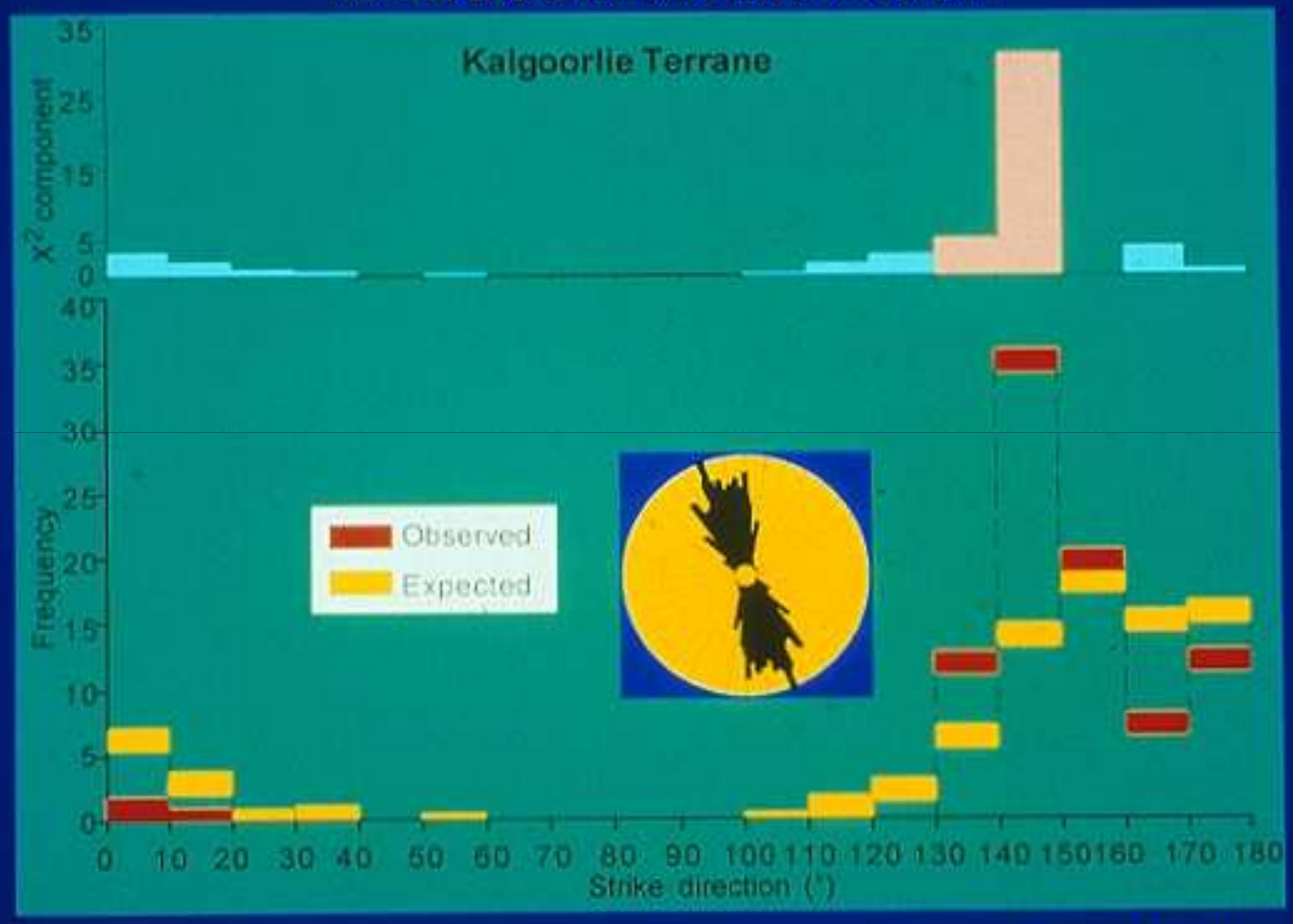
Kambalda
Dominantly felsic volcanic rocks
Dominantly mafic rocks
St Ives Goldfield
Dominantly ultramafic rocks
Major fault/shear zone
Gold deposit with > 1t Au

INPUT: DISTANCE TO CRUSTAL-SCALE FAULTS



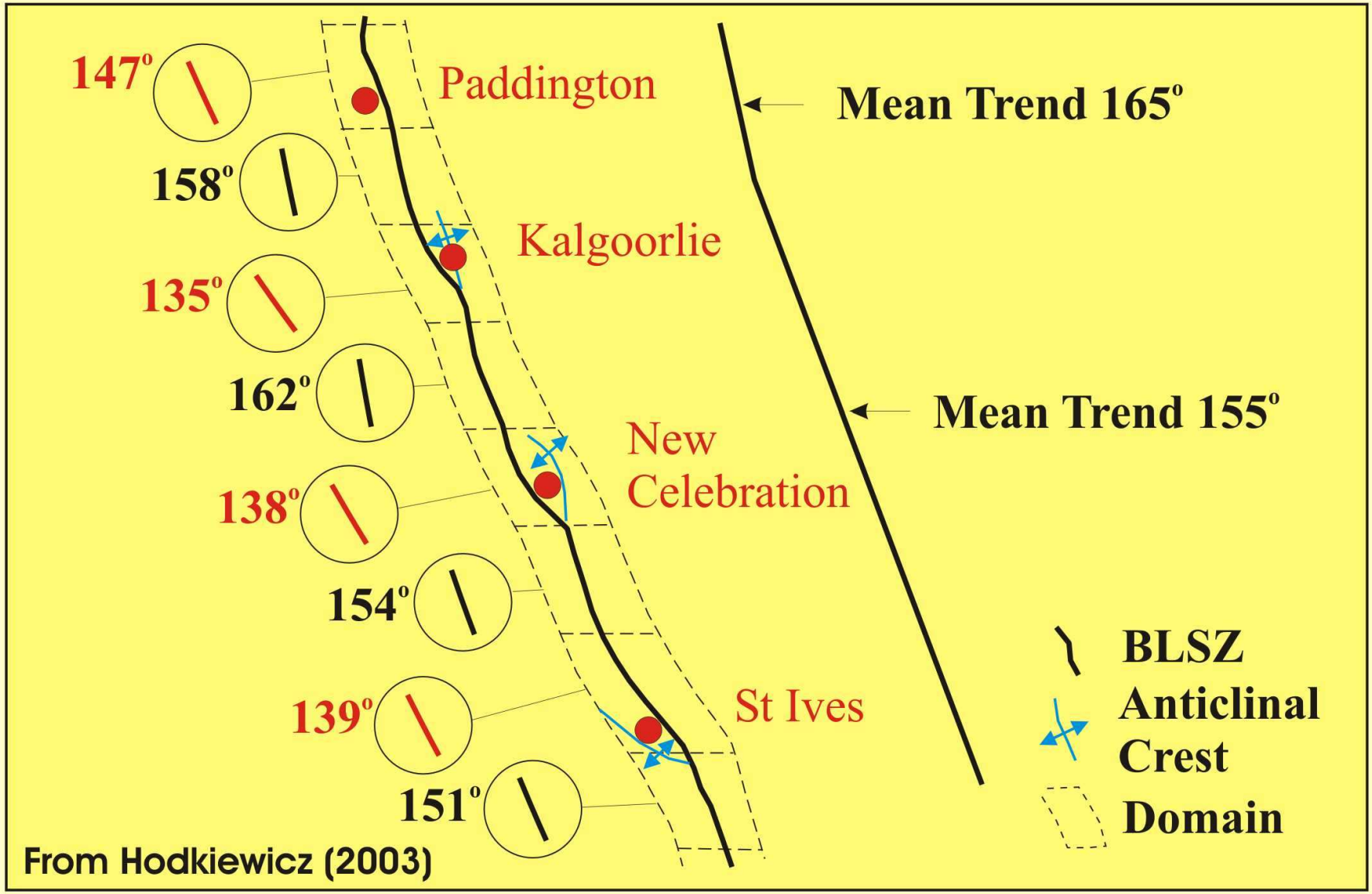
Warick Brown, 2002,
PhD thesis, UWA

CRUSTAL FAULT ORIENTATION - KALGOORLIE TERRANE



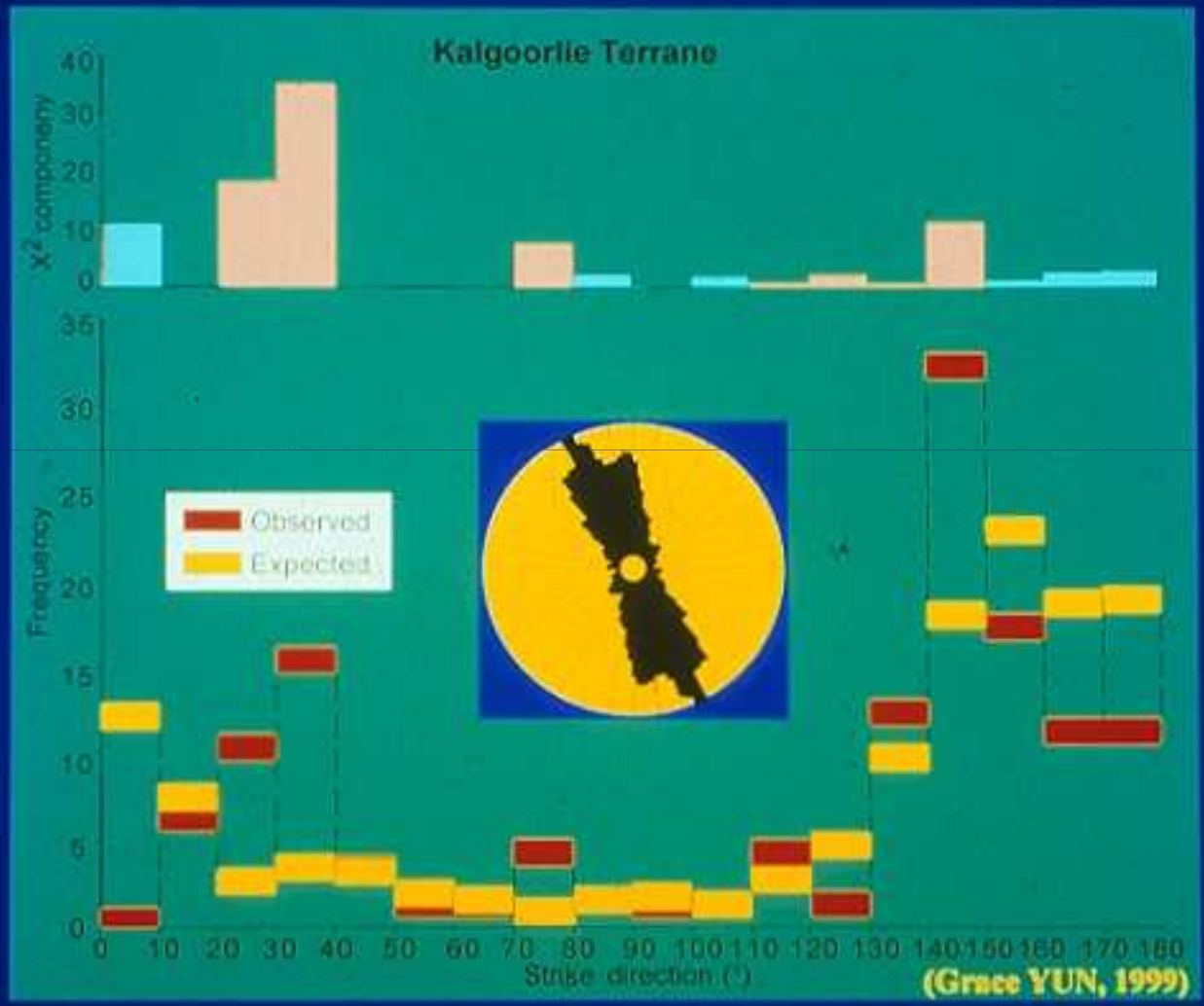
(Grace YUN, 1999)

TRENDS ALONG BOULDER-LEFROY SHEAR ZONE (BLSZ)



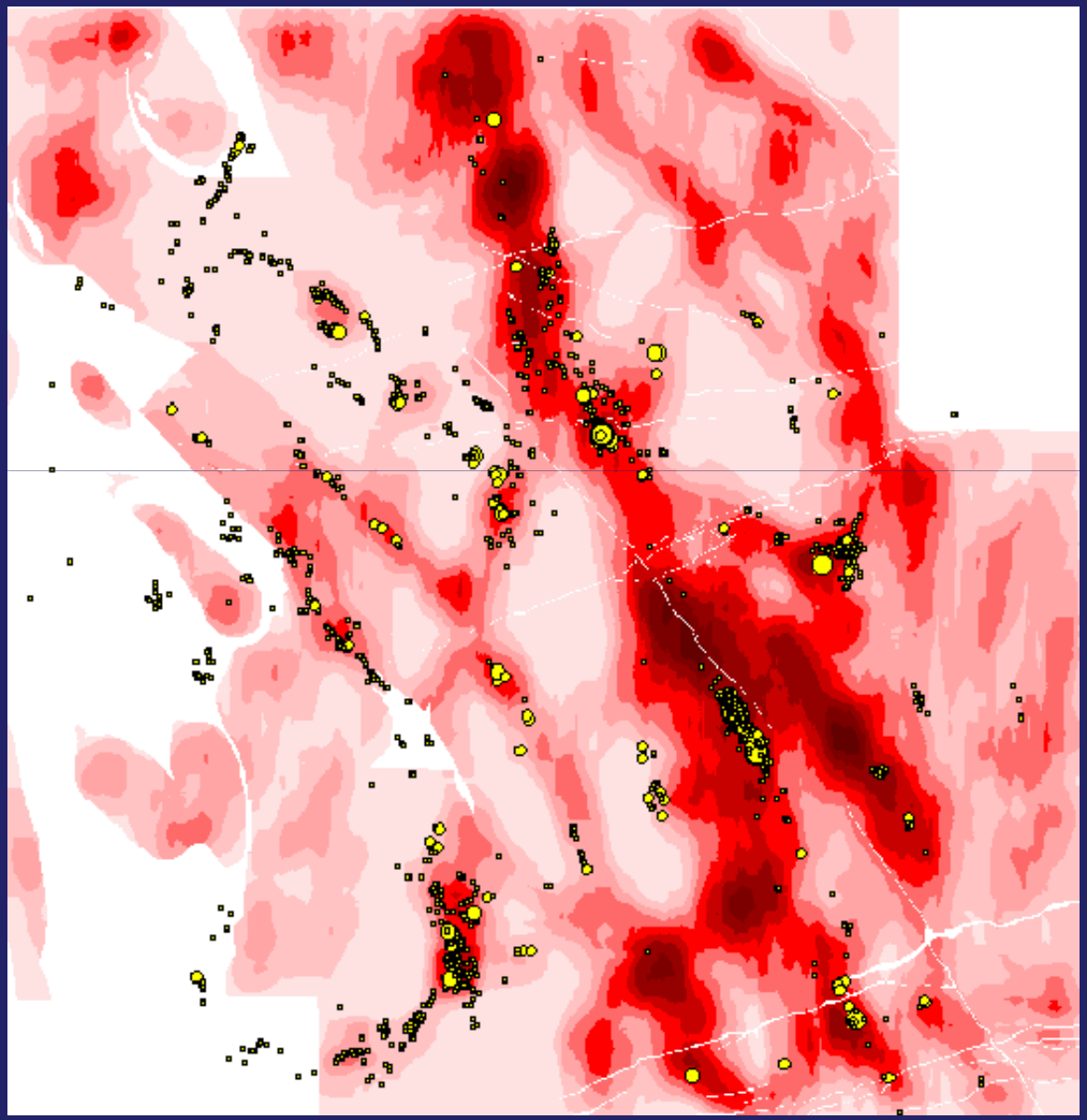
From Hodkiewicz (2003)

REGIONAL FAULT ORIENTATION - KALGOORLIE TERRANE



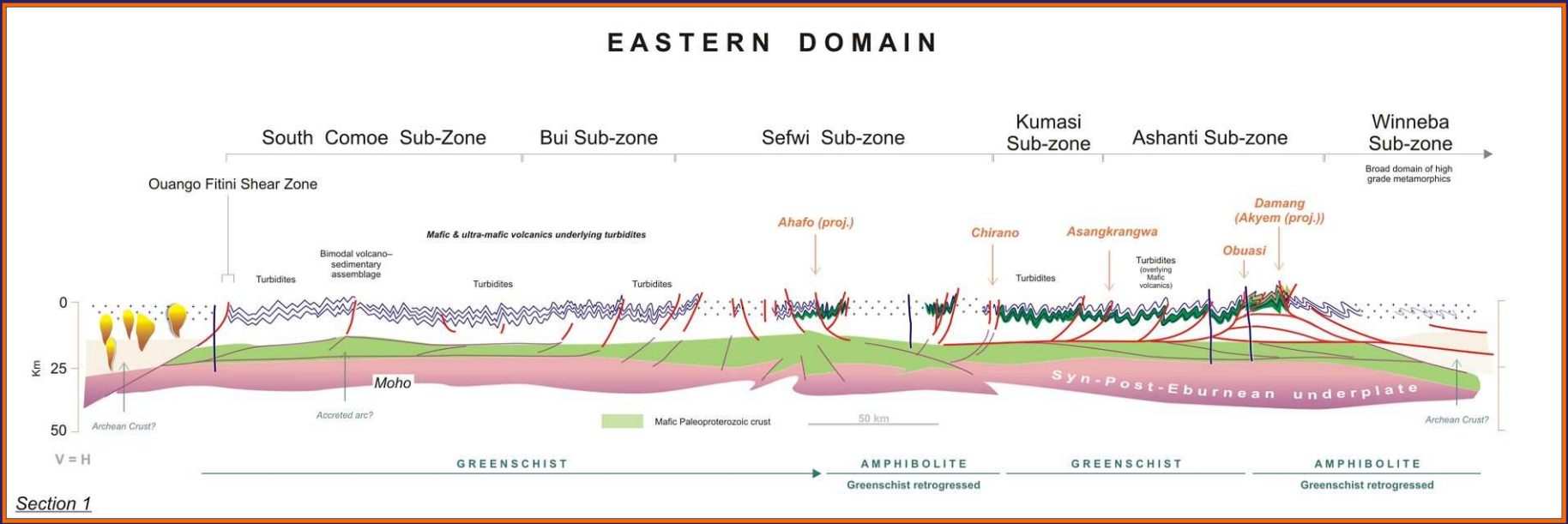
(Grace YUN, 1999)

INPUT: FAULT DENSITY, CRUSTAL, REGIONAL I & II

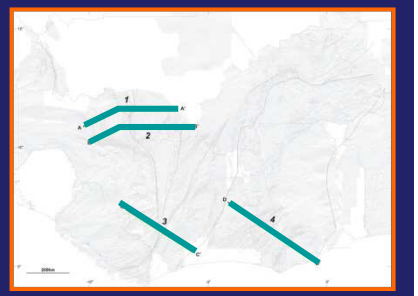


Warick Brown, 2002,
PhD thesis, UWA

SECTIONS ACROSS GHANA

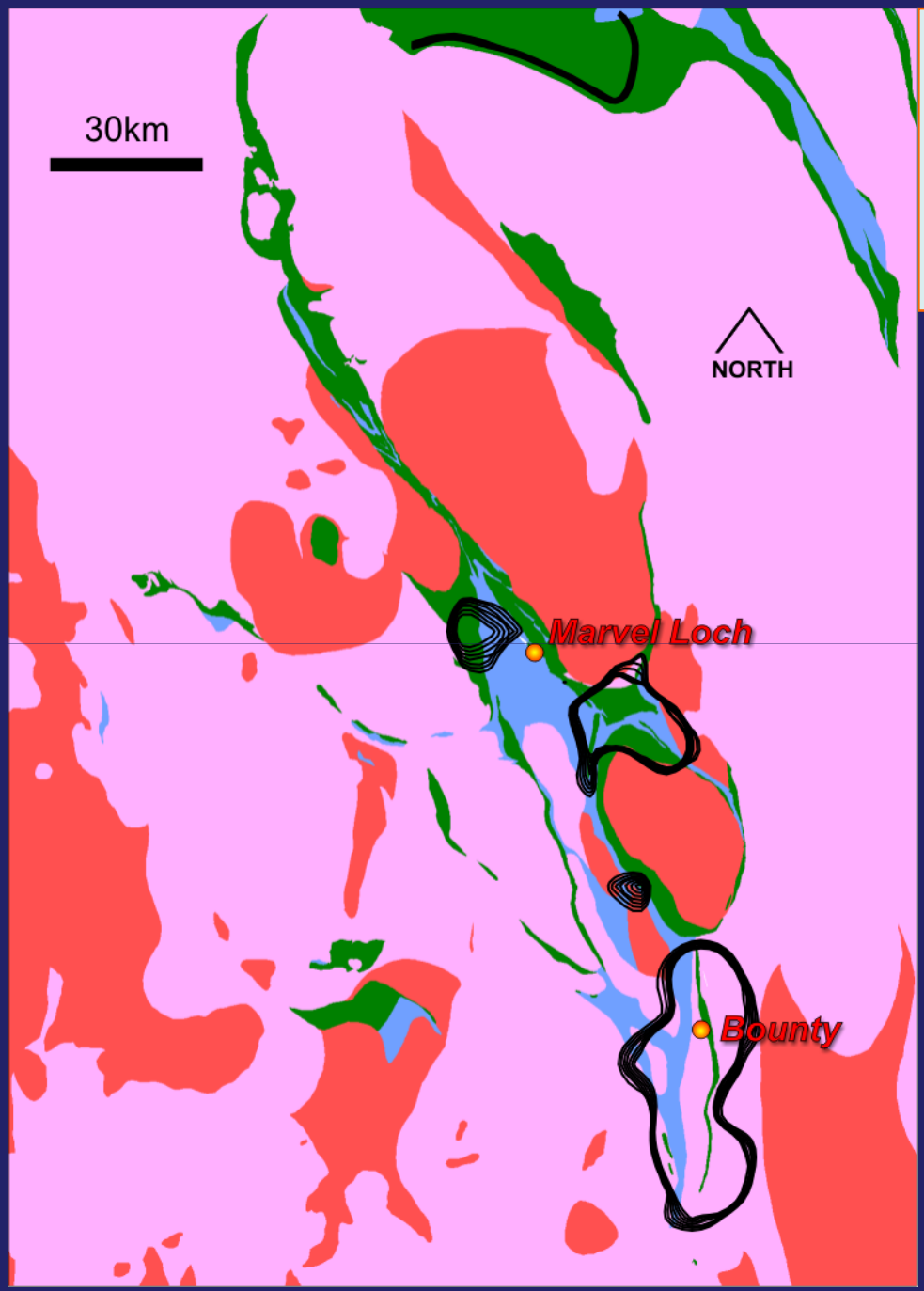


– Sections highlight fold-thrust belt architecture



From Brett Davies

SOUTHERN CROSS GEOLOGY/MINES AND GRAVITY

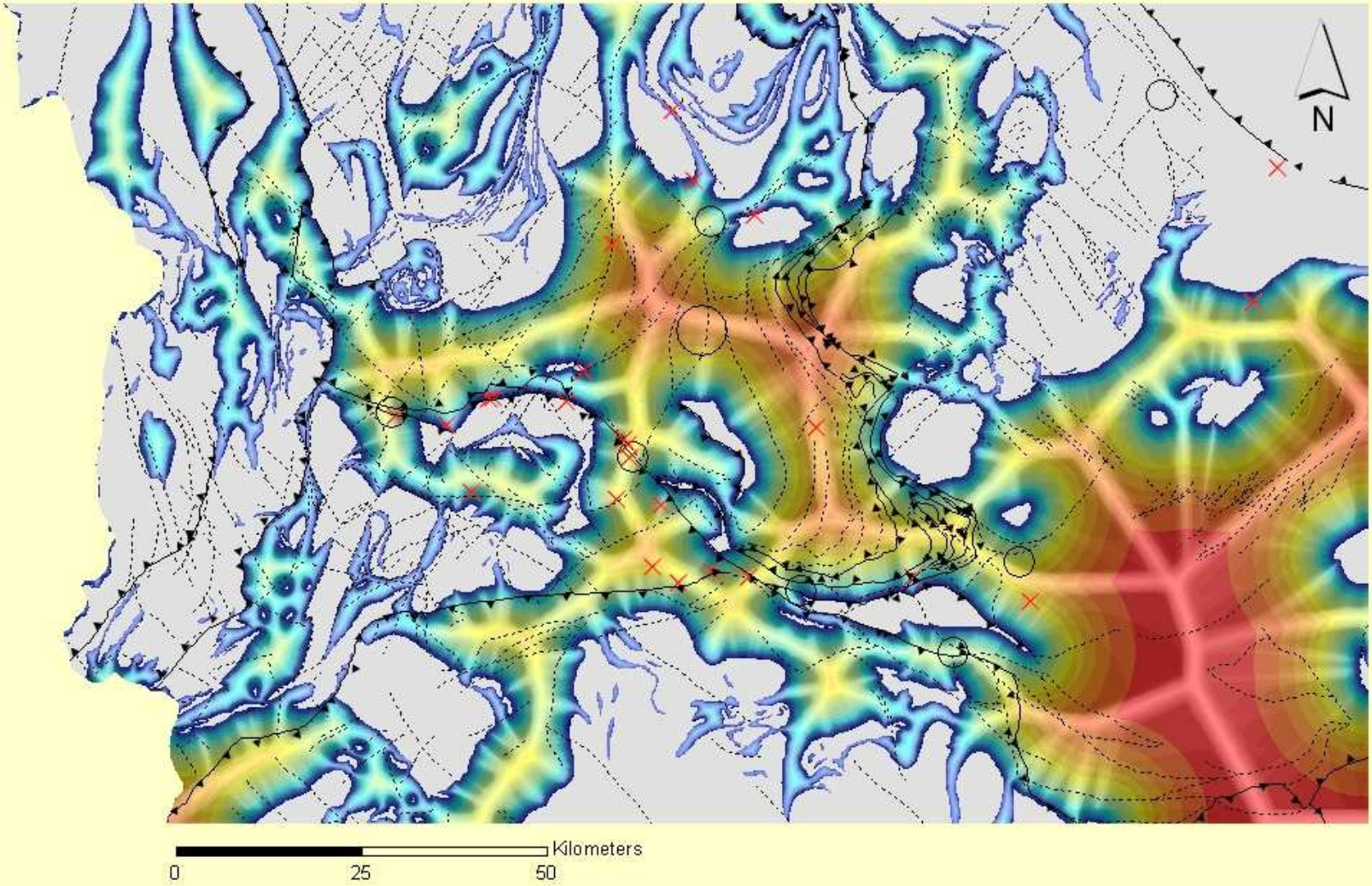


LEGEND

- Granitoid
- Gneiss
- Sedimentary
- Felsic volcanics
- Mafic volcanics
- Mines
- Gravity gradients

NEWMONT

DISTANCE FROM GRANITE MIDPOINTS: ZONES OF CONVERGENT/DIVERGENT FLOW; CENTRAL LAPLAND



OROGENIC GOLD EXPLORATION

PROVINCE TO DISTRICT SCALE

TRAP & SEAL PARAMETERS

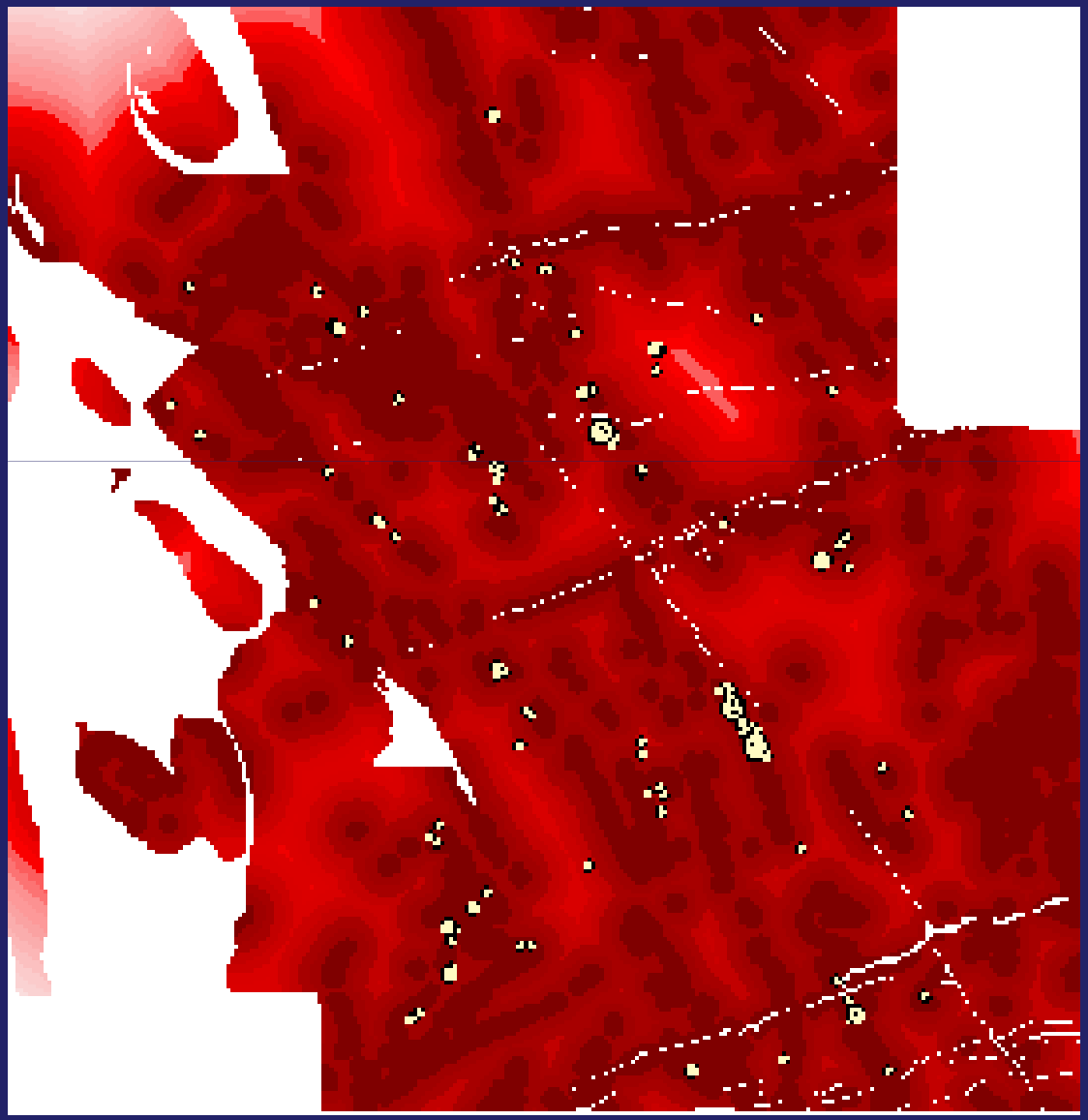
HOST ROCKS - KALGOORLIE TERRANE

(Grace YUN, 1999)

INPUT: CHEMICAL CONTRAST, FE/(FE + MG + CA), 1KM

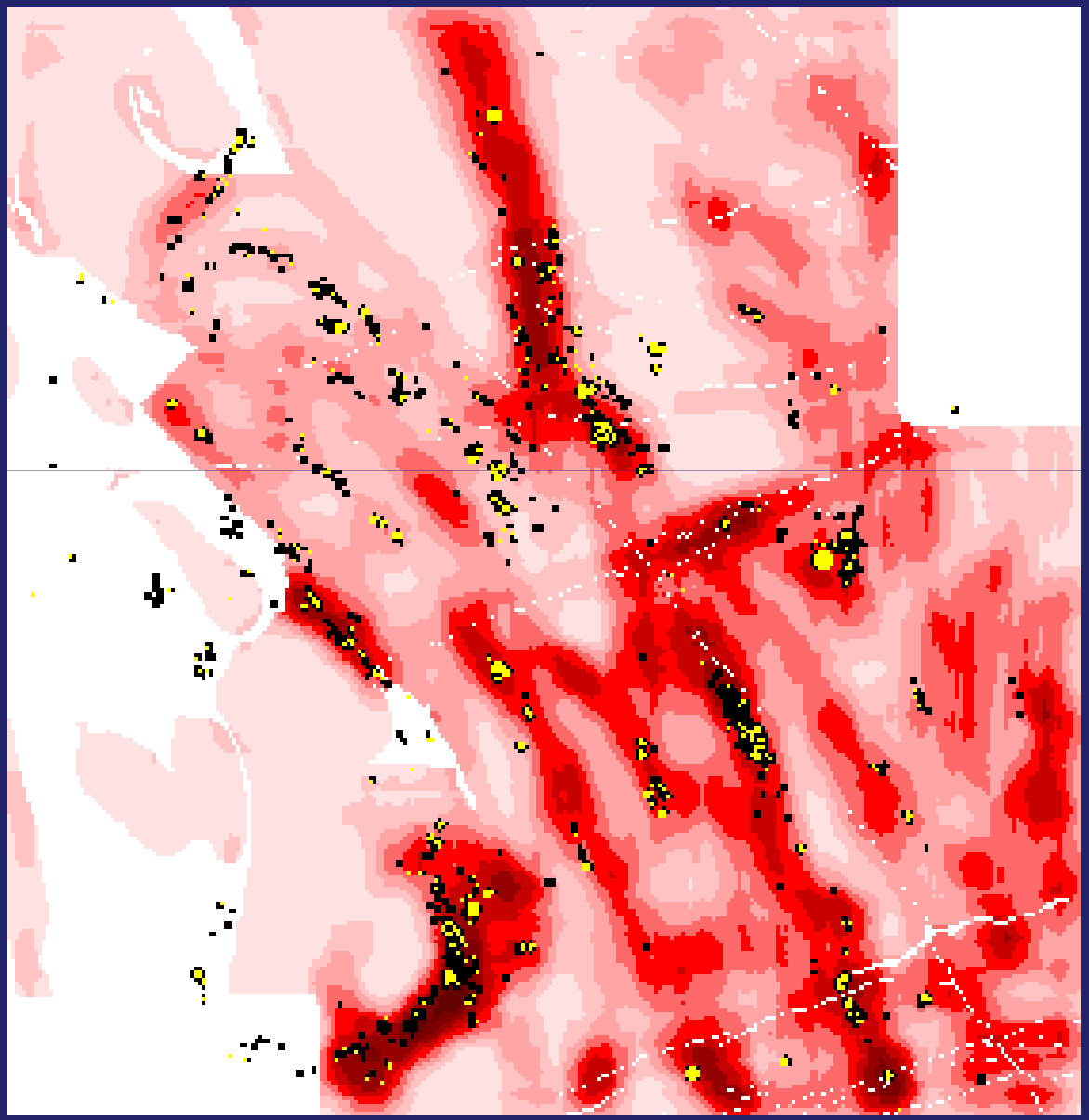
Warick Brown, 2002,
PhD thesis, UWA

INPUT LAYER: DIST. TO MAG ANOMALIES, RTP, Z >= 2



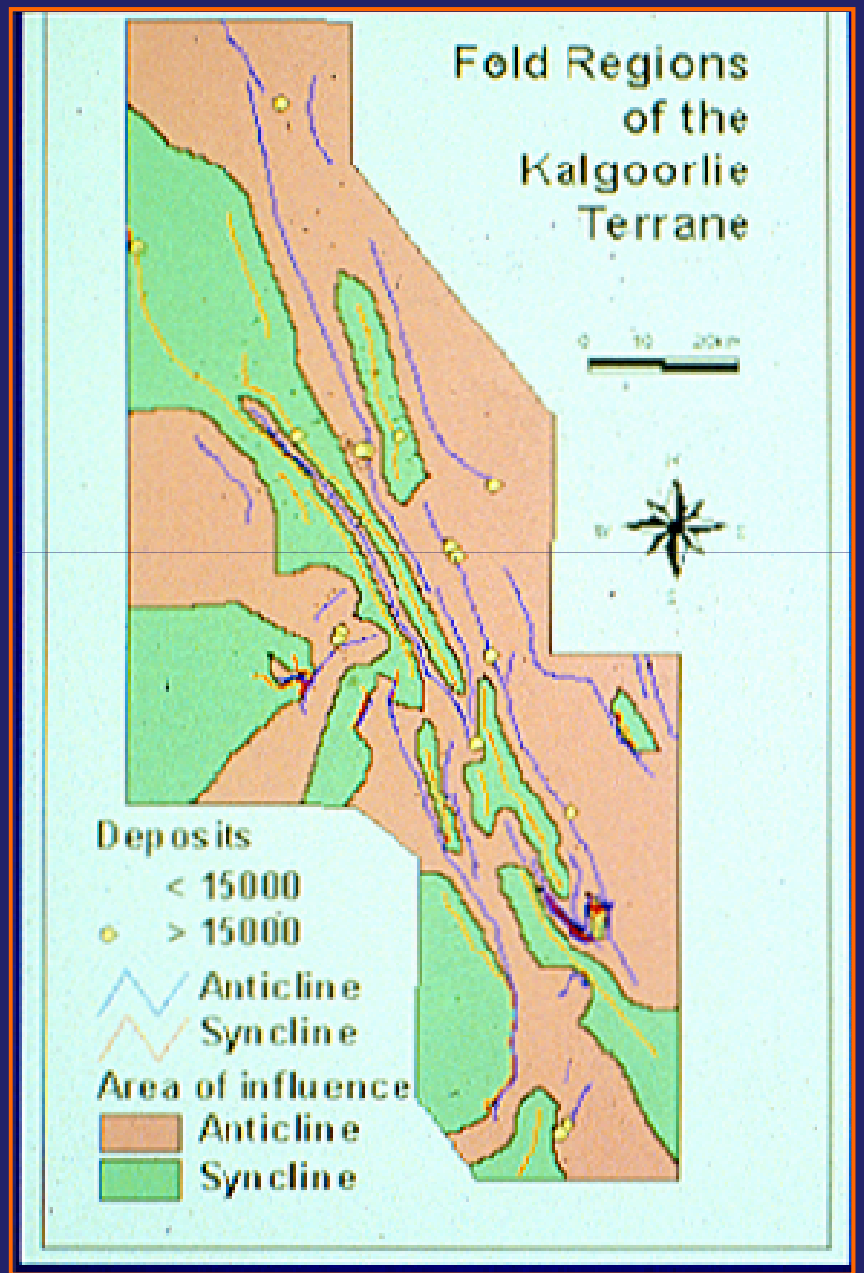
Warick Brown, 2002,
PhD thesis, UWA

INPUT: LITHOLOGICAL DIVERSITY



Warick Brown, 2002,
PhD thesis, UWA

ANTICLINAL vs SYNCLINAL ZONES

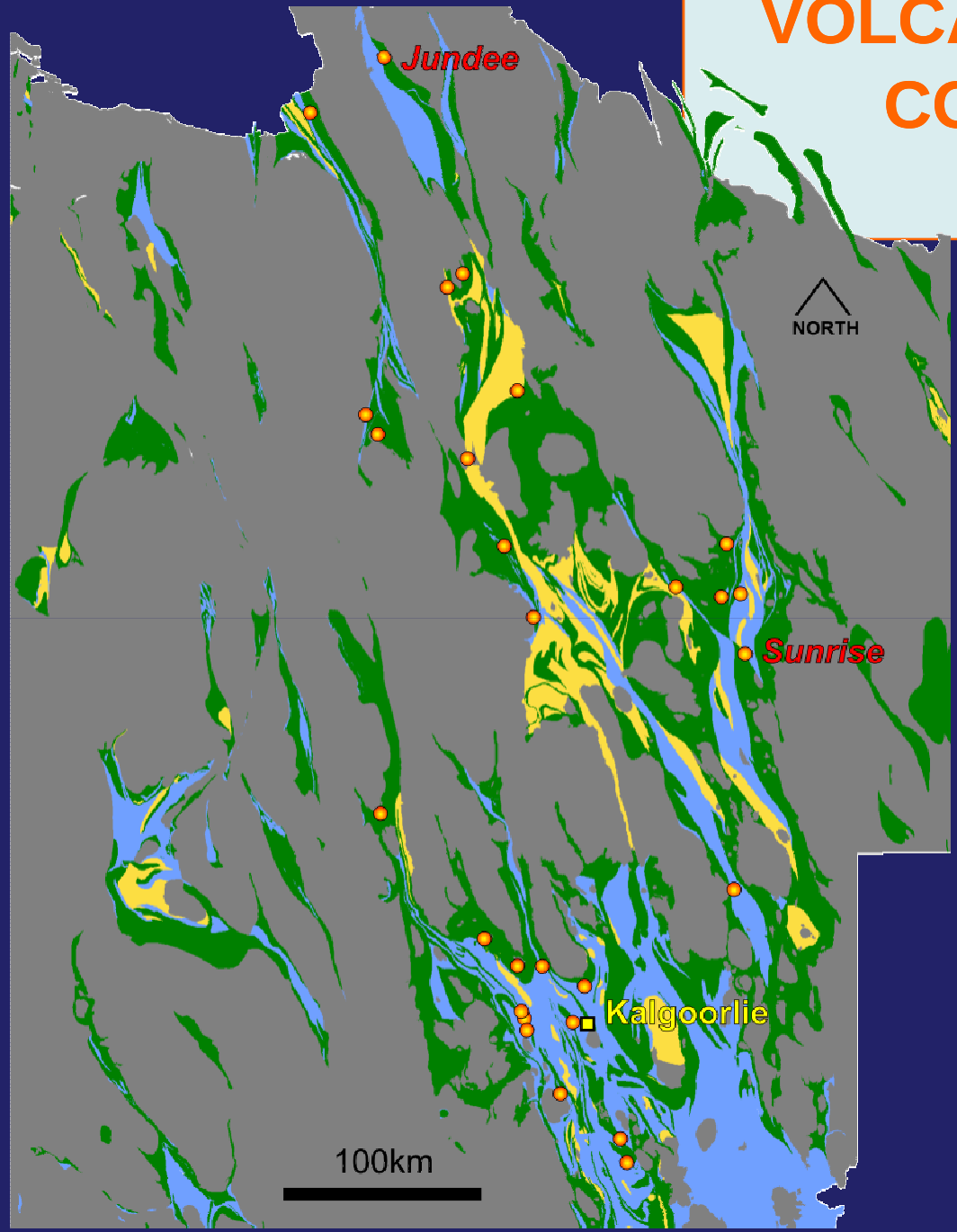


Production / Productivity of Greenstones

***Anti*clinal Zones**
~ 2245 t Au or
240 kg Au/km^2

***Syn*clinal Zones**
~ 185 t Au or
35 kg Au/km^2

VOLCANIC-SEDIMENTARY CONTACTS: FLUID CAP/SEALS



LEGEND

- Granitoid
- Sedimentary
- Felsic volcanics
- Mafic volcanics
- Mines

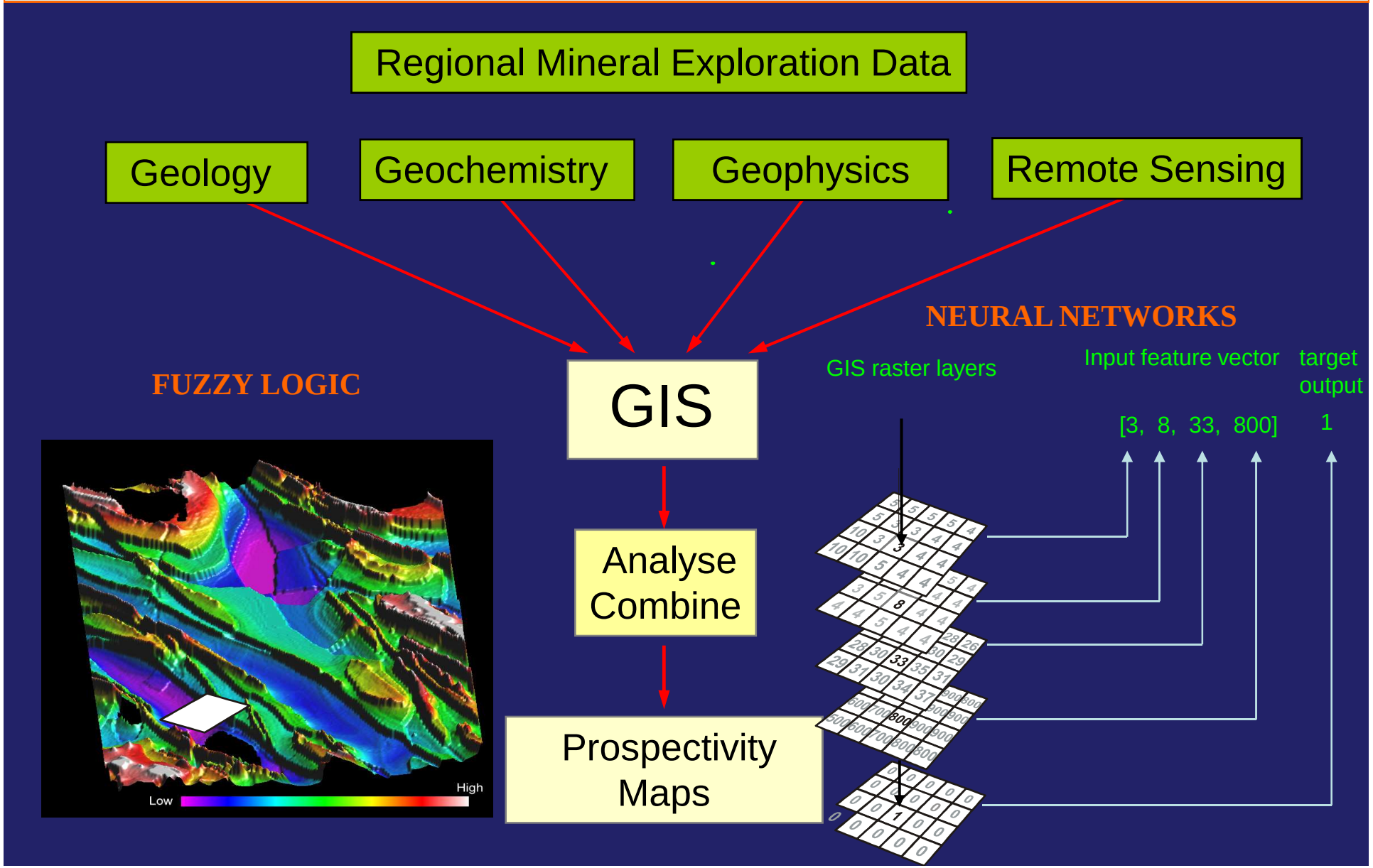
DEFINITION OF CRITICAL PARAMETERS

- At this stage, can statistically define critical controlling parameters (W. Brown, 2003)
- Can then use these to develop more robust predictive models or as data input for quantitative modelling (pmd*CRC)
- And/or can integrate these to produce Prospectivity or endowment maps

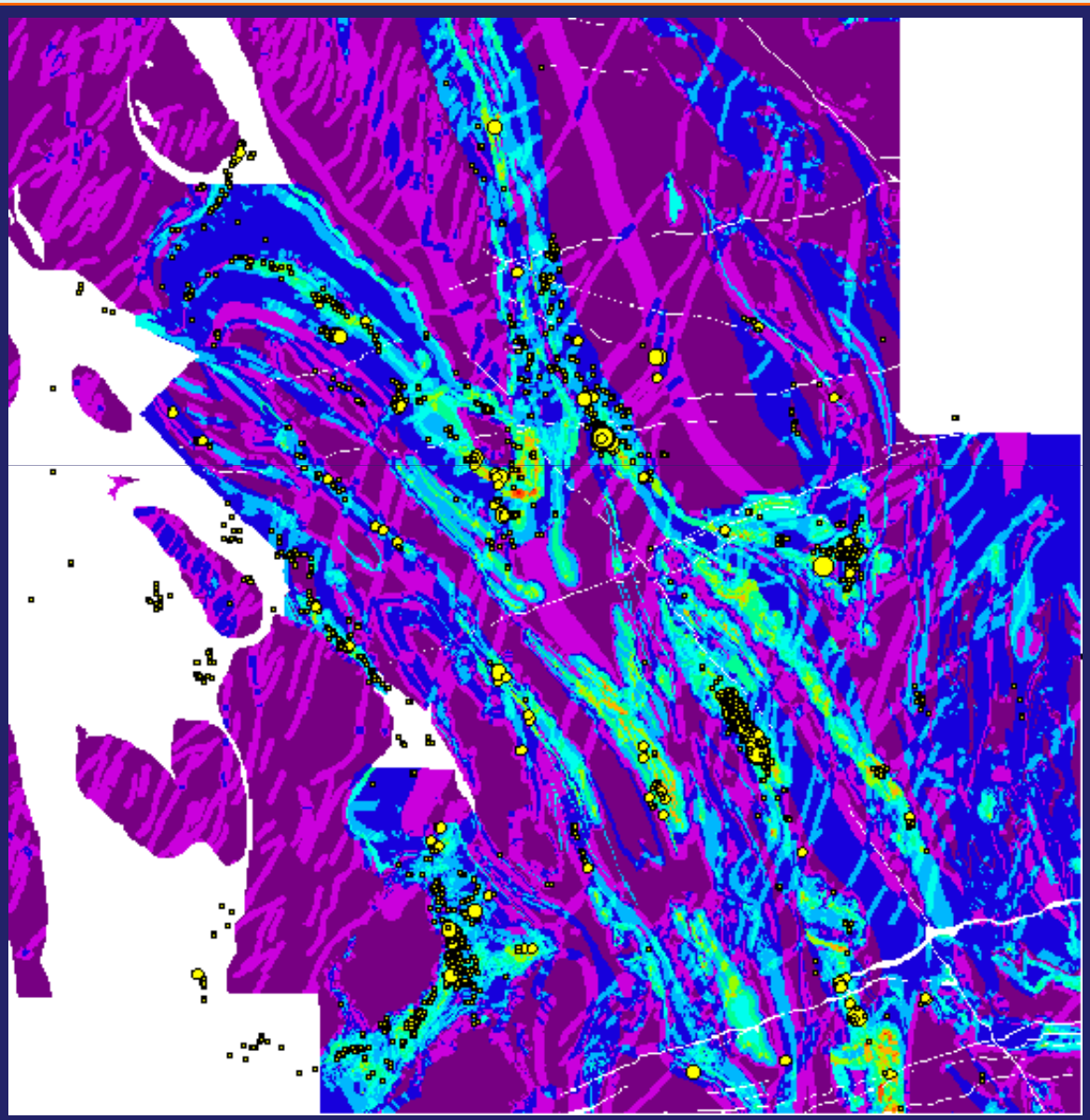
ENDOWMENT PREDICTION / PROSPECTIVITY MAPPING : CRITICAL STEPS

- Determination of timing of deposit group : do map data reflect geometry at time of mineralization?
- Identification of important factors
  - Empirically and on a thematic basis, or
  - Based on conceptual premise
- Quantification of identified or hypothesised spatial relationships
- **Integration of relationships into a prospectivity map**

INTEGRATION OF CRITICAL PARAMETERS INTO PROSPECTIVITY MAP



PROSPECTIVITY MAP USING 10 LAYERS FOR KALGOORLIE TERRANE



Warick Brown, 2002,
PhD thesis, UWA

HOW GOOD IS PROSPECTIVITY / ENDOWMENT PREDICTION?

- Highest prospectivity “zones” occupy < 0.5% of Terrane
- Contain >80% of known gold resource
- Include only 15 gold deposits/camps
- Hence, tend to define larger, potentially world-class, deposits and discriminate against small uneconomic deposits
- This is because world-class deposits require the conjugation of more critical parameters than smaller deposits
- Methodology transportable to other greenstone belts, globally.

CONCLUSIONS

- For late deposits, high-quality maps are important exploration tools
- Complex conjunction of critical controls requires GIS-based analysis
- Such analysis helps confirm genetic or deposit models and provide confidence for conceptual targeting
- Integration using fuzzy logic or neural networks can provide superior prospectivity maps
- Can integrate other methodologies (e.g. stress mapping) or other data sets

CONCLUSIONS

- Can export criteria from data-rich provinces to data-poor provinces
- Can adapt to other deposit styles but need different criteria (e.g. redox state, sedimentary facies, specific intrusions)
- Need to extend to 3D and apply quantitative modelling in data-rich brownfields areas

ASSESSMENT OF PROSPECTIVITY TERRANE – PROVINCE SCALE

MINERALS SYSTEM PARAMETER	SETTING / PROCESS	PARAMETER	PROXY / SIGNAL	GEOPHYSICAL RESPONSE
HEAT AND FLUID SOURCE: TECTONIC ENGINE	**Tectonic Setting: Source Region**	Inverted backarc-continental margin (high Au + S contents) Greenstone belt (high Fe, varied rocks) Accretionary fore-arc	Back-arc basalts and flysch Classic greenstone belts Turbidite sequences BIFs	
	Thermal Engine	Metamorphic gradients Granitoid magmatism; batholith complexes	Prehnite-pumpellyite through amphibolite facies reactions Abundant granitoids: crustally or mantle derived	*Aeromagnetic intensity/ signal contrasts* *Aeromagnetic and gravity patterns*
PLUMBING SYSTEM	**Deep Plumbing Systems**	Crustal-scale deformation zones/ma crustal breaks (terrane boundaries) Lithospheric / asthenospheric magmatism	>100km long shear zones Lamprophyres / alkalic rocks (especially sodic rocks)	*Aeromagnetic lineaments (linear lows)* *gravity gradients*
	Effective Plumbing Systems	relatively high-strain shear zones in low strain belts	Well-preserved structures/ textures in rocks: no schist belts	*Aeromagnetic linears and intervening "quiet" magnetic texture*

ASSESSMENT OF PROSPECTIVITY DISTRICT TO PROSPECT SCALE

MINERALS SYSTEM PARAMETER	SETTING / PROCESS	PARAMETER	PROXY / SIGNAL	GEOPHYSICAL RESPONSE
HEAT, FLUID AND GOLD SOURCE	**Metamorphism**	Greenschist domains in terranes with variable grade	Greenschist facies metamorphic assemblages	*Aeromagnetic texture and intensity*
	Magmatism	Broadly synchronous crustally derived granitoids or lamprophyres	Geochronology and field relationships	*Aeromagnetic and gravity signals*
	Enriched Source Rocks	Gold-enriched backarc basalts, flysc or alkalic rocks: SEDEX to VMS go in continental margins	Gold and S analyses of relatively unmetamorphosed country rocks	
PLUMBING SYSTEMS	**District-Scale Plumbing Systems**	High damage zones of low-order faults adjacent to crustal-scale shear zones Tip zones of thrust systems Intersecting faults Rotation of pre-existing structures between corridors of faults with same kinematics	Angular variations of 10-20º from mean regional strike of 1st order faults: jogs Thrust duplexes High density of faults Geometrical pattern of fault arrays: mineralised fault corridors	*Change in geometry of aeromagnetic linears: resistive zones?* *Gravity gradients* *Aeromagnetic linears* *Aeromagnetic linear corridors of offsets*
	Deep Penetration	Lithospheric magmas	Lamprophyres and alkalic rocks	
	Gold-Bearing Systems	Gold within systems	Gold and/or As anomalies or gold anomalies along strike	*Airborne hyperspectraldata (mineral abundance maps)*

ASSESSMENT OF PROSPECTIVITY DISTRICT TO PROSPECT SCALE

MINERALS SYSTEM PARAMETER	SETTING / PROCESS	PARAMETER	PROXY / SIGNAL	GEOPHYSICAL RESPONSE
TRAP SITES	**Structural Traps**	Anomalous relationships between adjacent rigid granitoids	Changes from "convergent" to "divergent" flow regimes: domal culminations	*Steep gravity gradients: complex aeromagnetic signatures*
		Locked-up anticlinal or domal structures	Generally 30º to 40º apical angles in asymmetrical folds: steep back limb	*Repitition of aeromagnetic signatures*
TRAP SITES	**Structural Traps**	Thrust or oblique-slip duplexes	Thickening and repetition of sequences	*Gravity gradients and aeromagnetic complexity*
		Folded thrust systems	Complex Kalgoorlie and Timmins like geometries	*Aeromagnetic complexity*
		Small rigid bodies	Granitoid stocks or thick dykes	*Aeromagnetic and gravity anomalies*
	Uplift Zones	Major vertical displacement of sequences	Late conglomerates against basal volcanic sequences	*Aeromagnetic and gravity contrasts*
	Stratigraphic Traps	Rheology contrasts	Contacts between competent and incompetent units: granitoid contacts	*Subtle aeromagnetic signatures*
		Reactive host rocks	High Fe/Fe + Mg ratios: high C contents	*High magnetic intensity pixels for Fe-rich units*

ASSESSMENT OF PROSPECTIVITY DISTRICT TO PROSPECT SCALE

MINERALS SYSTEM PARAMETER	SETTING / PROCESS	PARAMETER	PROXY / SIGNAL	GEOPHYSICAL RESPONSE
SEALS/CAPS AND OUTFLOWS	**District-Scale Seals**	Sedimentary rocks	Impermeable sedimentary rocks over fractured volcanic rocks	*Aeromagnetic signature*
		Structural seals	Upper thrust plates of impermeable rocks	*?*
	Outflow Zones?	Large alteration zones (Could be inflow zones)	Anomalous Au, As, Sb, Te, Hg and W geochemistry	*Zones of lowered magnetic intensity; IP surveys (disseminated/ replacement style ores)*
TRAP SITES	**Structural/Alteration Signatures**	Adjacent mechanically weak shear zones and chemically reactive carbonate or sulphide zones and resistant silification or quartz veins	More extreme topography in bedrock below weathered zone due to anomalous contrasts	*Magnetic, gravity and EM anomalies due to complex weathering and channel development*