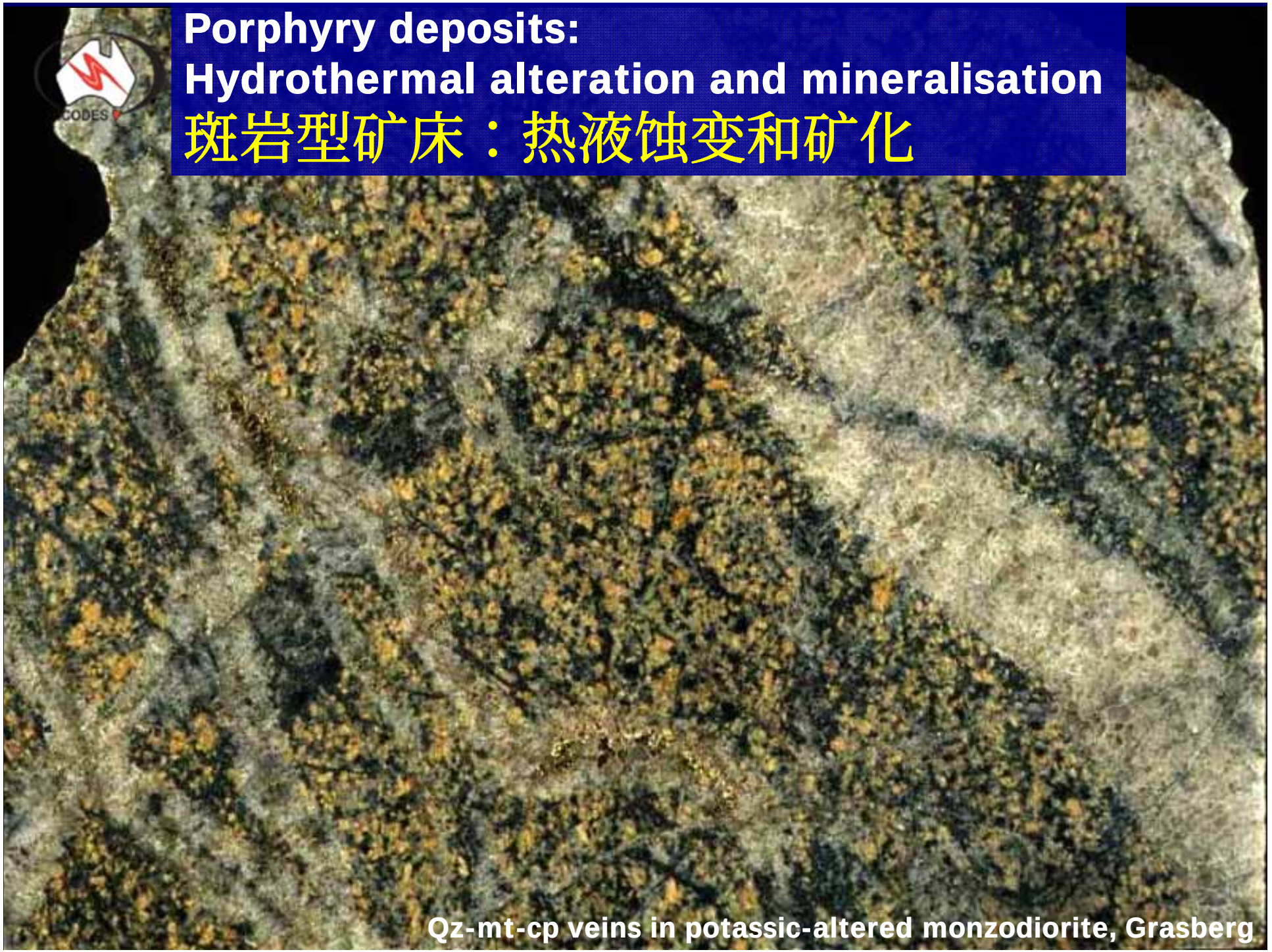
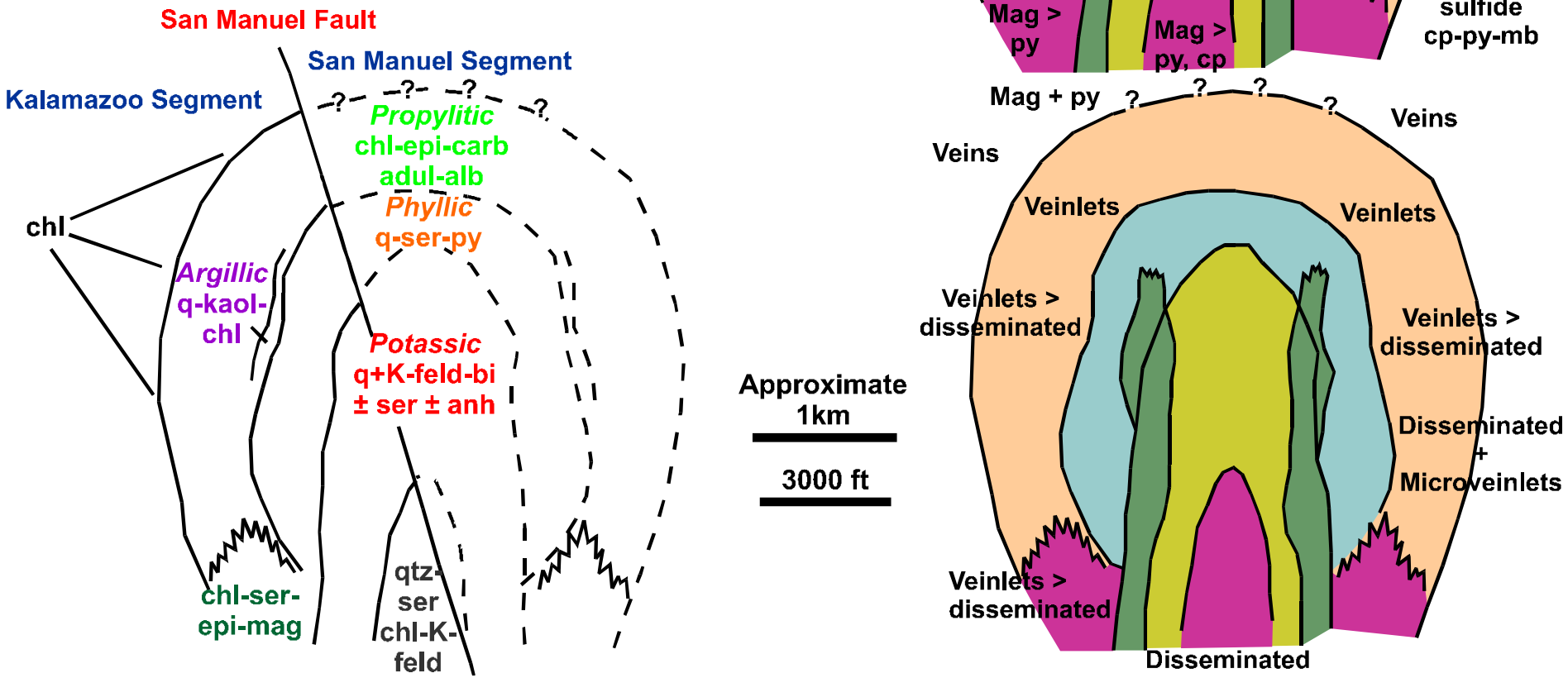
Porphyry deposits: Hydrothermal alteration and mineralisation
斑岩型矿床：热液蚀变和矿化



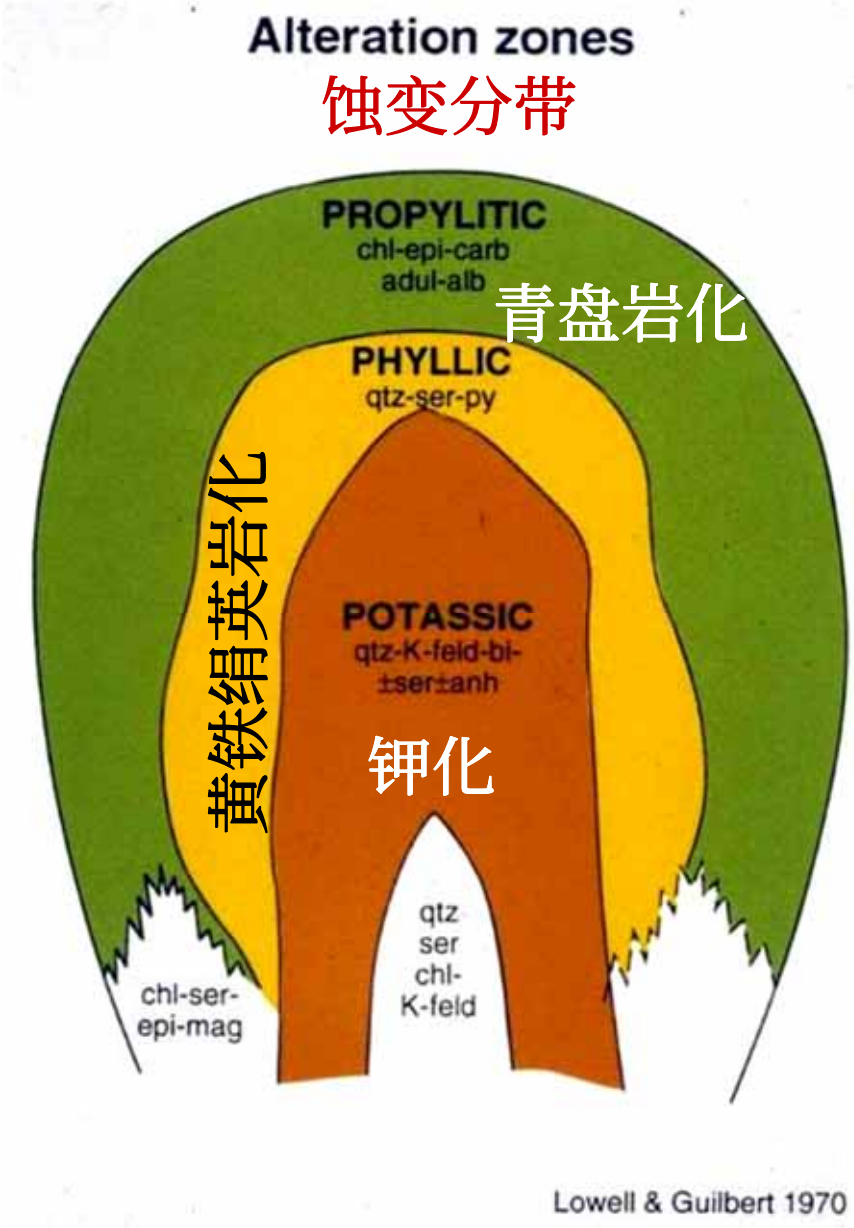
Qz-mt-cp veins in potassic-altered monzodiorite, Grasberg

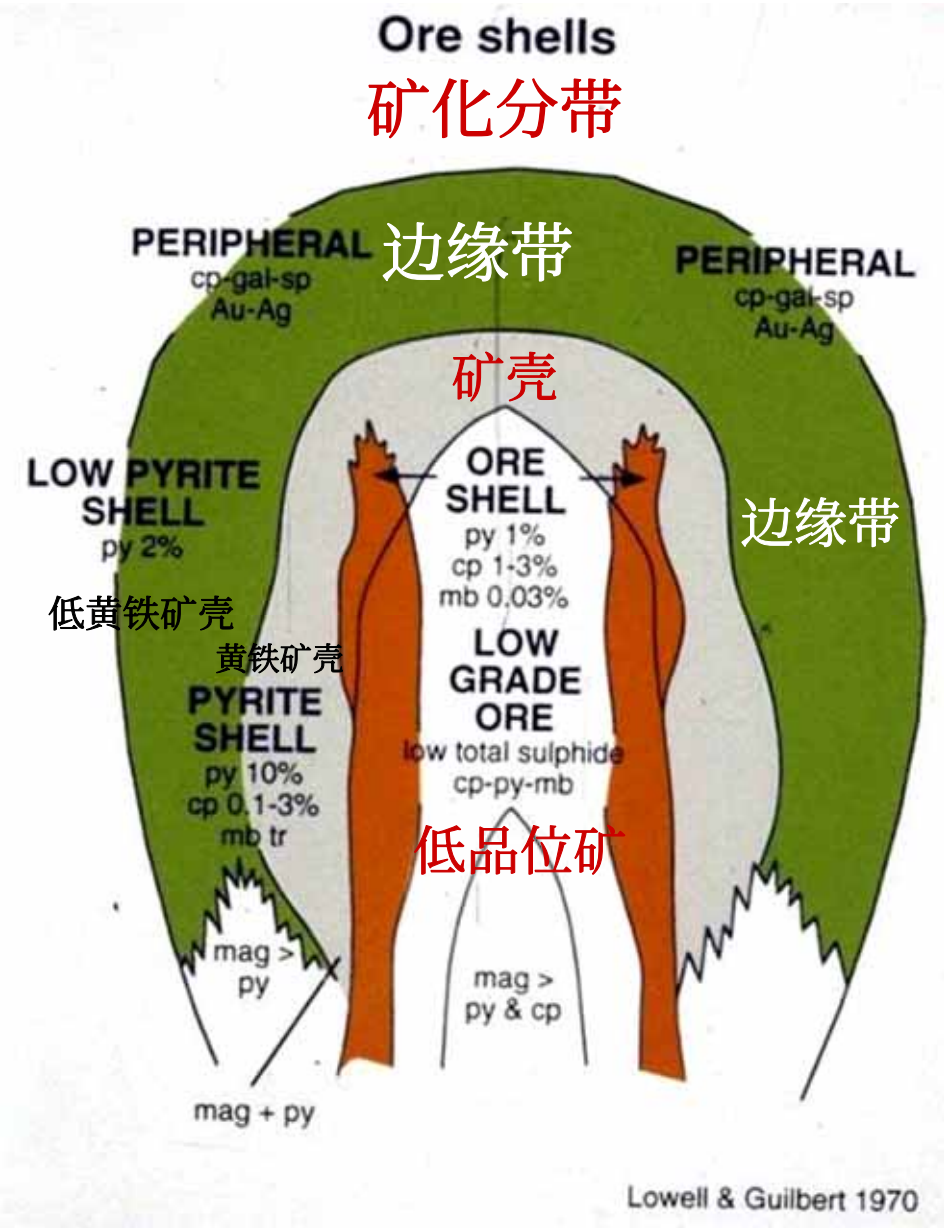
The Porphyry Cu model
(Lowell and Guilbert, 1970)

- **This hugely influential model developed from studies of the Kalamazoo porphyry copper mine, Arizona**

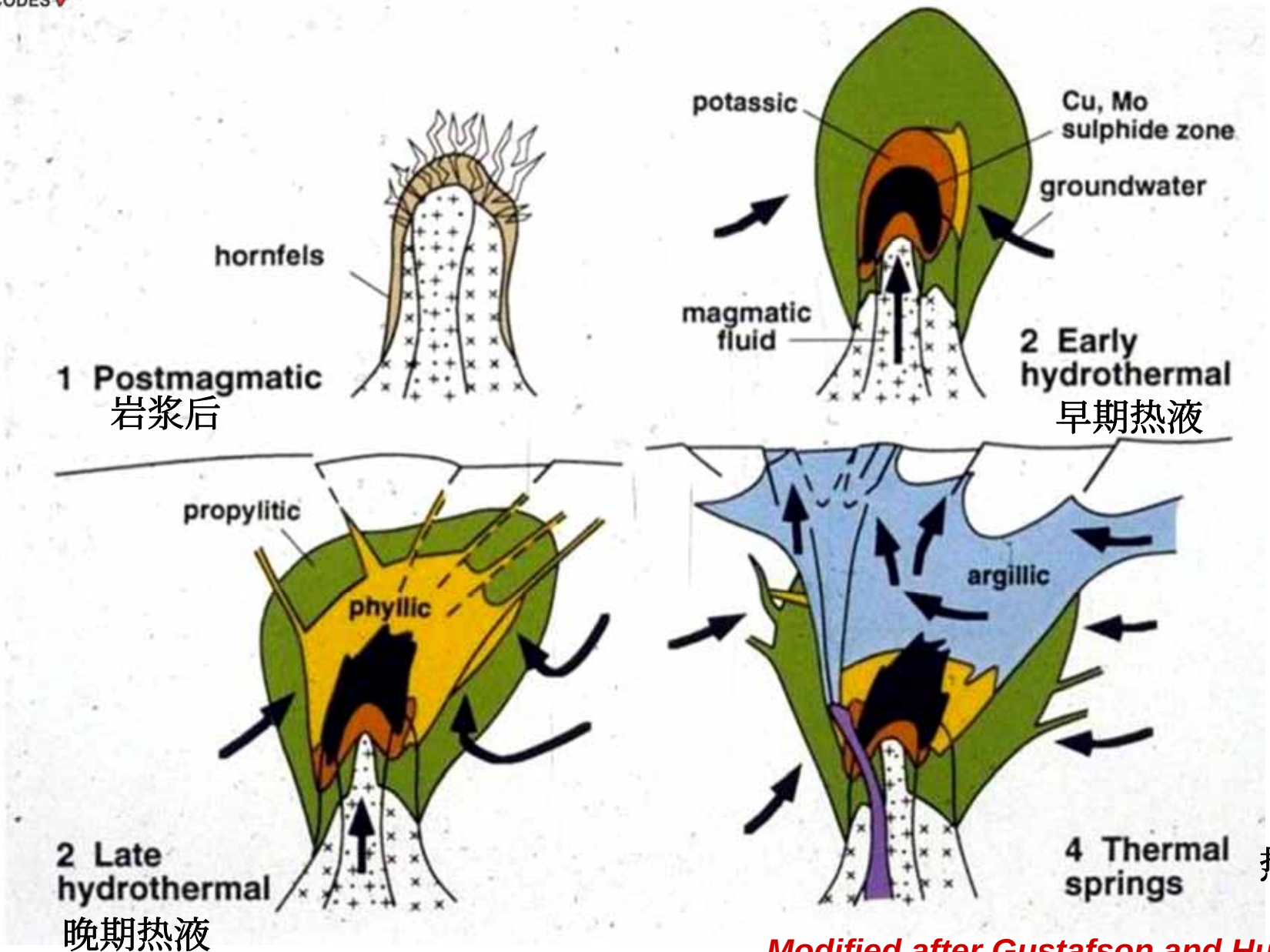


Alteration Zonation
蚀变分带



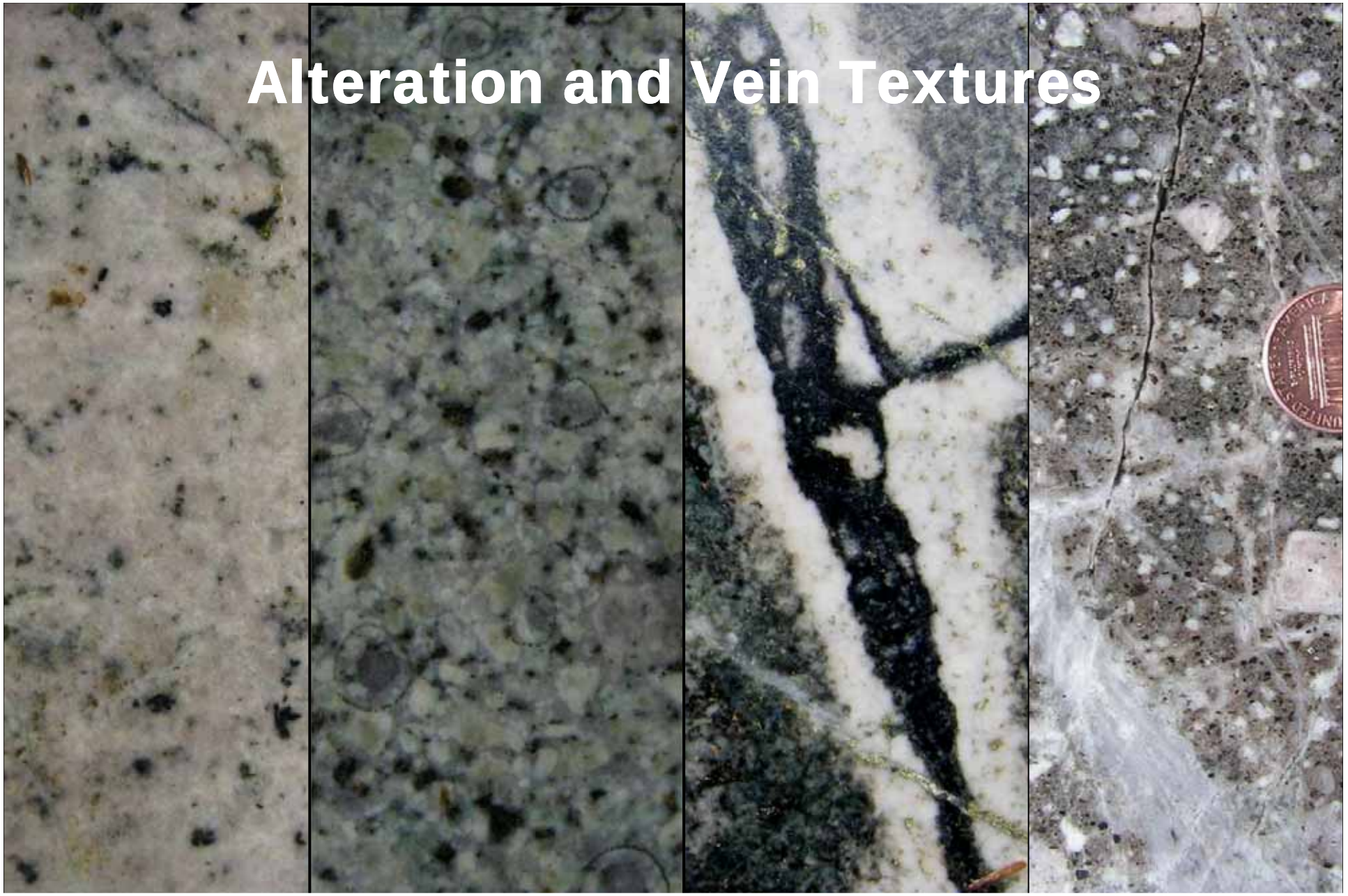


Alteration Overprinting 蚀变叠加



Modified after Gustafson and Hunt 1975

Alteration and Vein Textures



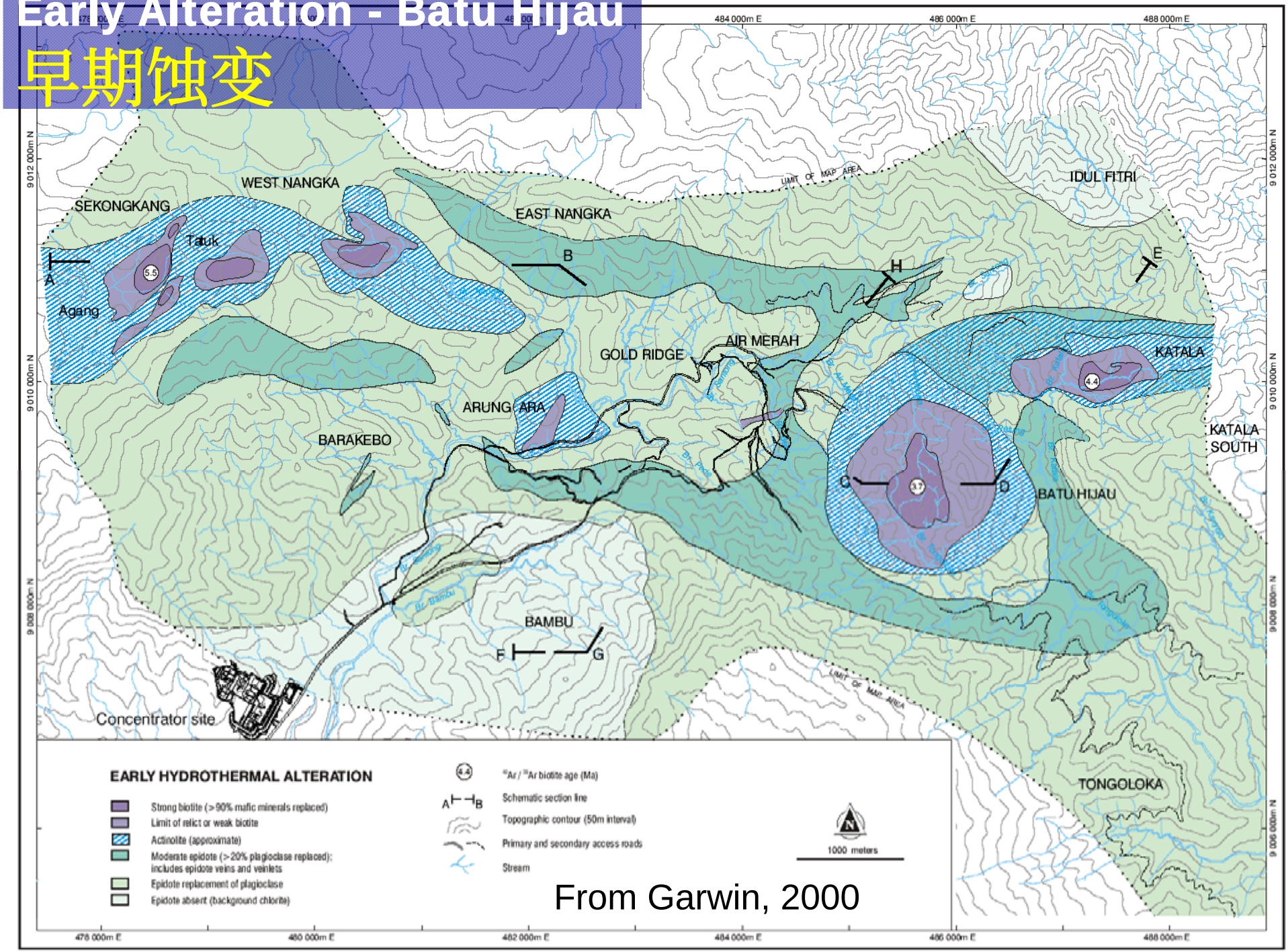
Pervasive
(Strong Kf alt)

Selective
(chl-alt mafics, ser-chl alt fsp)

Vein Halo
(Kf selvage to tourmaline vein)

Vein
(qtz stockwork)

Early Alteration - Batu Hijau
早期蚀变



From Garwin, 2000



Biotite-altered trachyandesite and orthoclase-altered monzonite

What characterises potassic alteration? 钾化蚀变有何特征？

- **Weakly to intensely developed secondary alteration assemblages that can destroy or preserve primary rock textures** 微弱到强烈的次生蚀变，可破坏或保留原岩结构
- **Can occur as pervasive or selectively pervasive replacements, or as vein halos** 可以呈弥漫状、选择性弥漫状或脉的晕
- **Associated veins have similar mineralogies** 相关的脉体有相似的矿物组合

Mineralogy

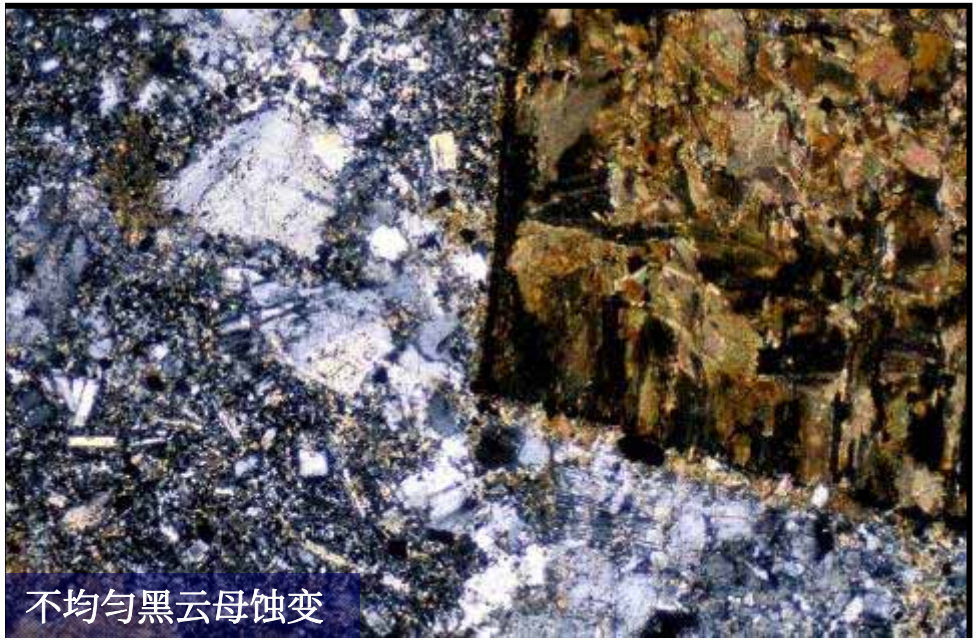
Orthoclase	**$KAlSi_3O_8$**	***(common in felsic rocks)***
Biotite	**$K(Mg,Fe^{2+})_3AlSi_3O_{10}(OH,F)_2$**	***(common in mafic rocks)***
Quartz	**SiO_2**	
Magnetite	**Fe_3O_4**	***(important for exploration)***
Anhydrite	**$CaSO_4$**	
Albite	**$NaAlSi_3O_8$**	
Chalcopyrite	**$CuFeS_2$**	
Bornite	**Cu_5FeS_4**	
Molybdenite	**MoS_2**	

Biotite Alteration (Potassic)

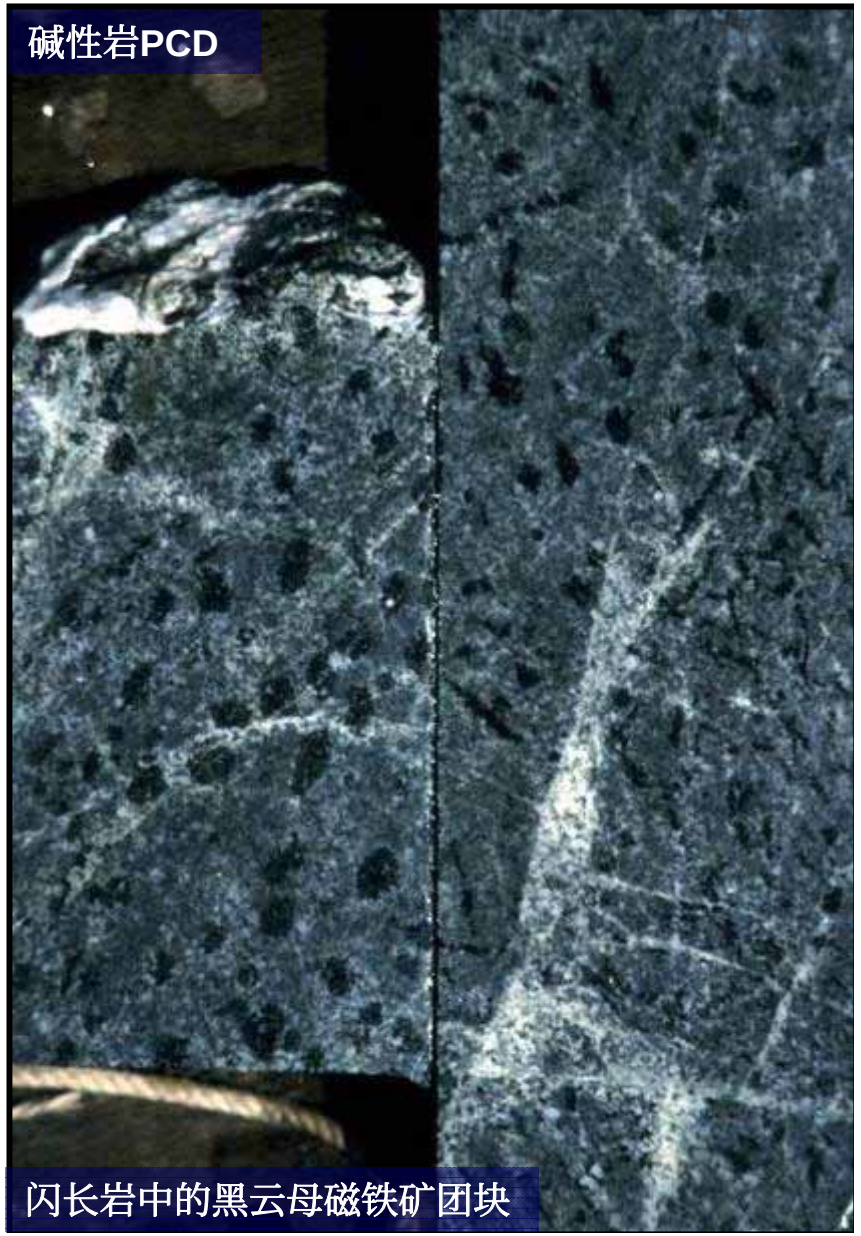
黑云母蚀变（钾化）



钙碱性斑岩铜矿



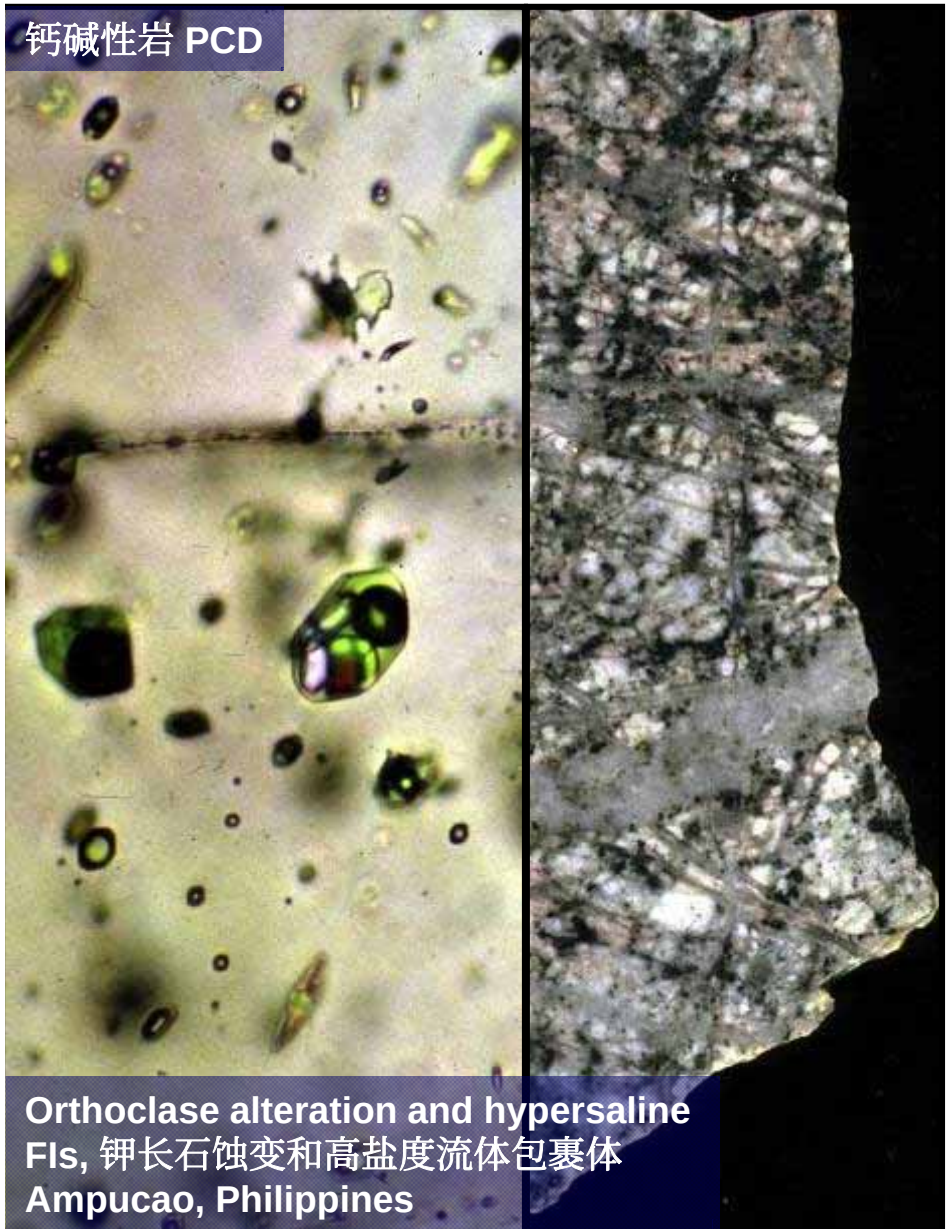
不均匀黑云母蚀变



碱性岩PCD

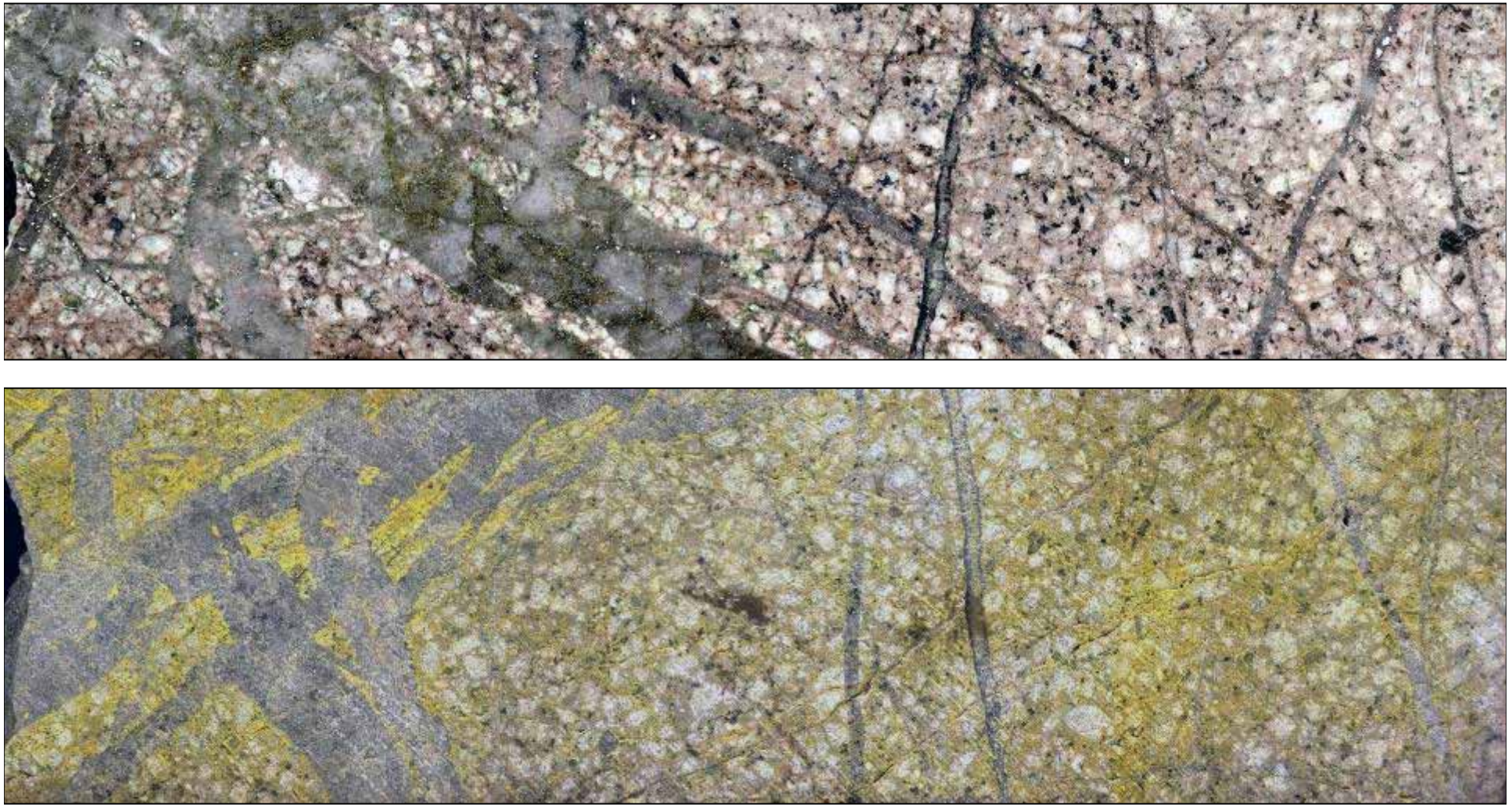
闪长岩中的黑云母磁铁矿团块

K-Feldspar Alteration (Potassic)
钾长石蚀变（钾化）





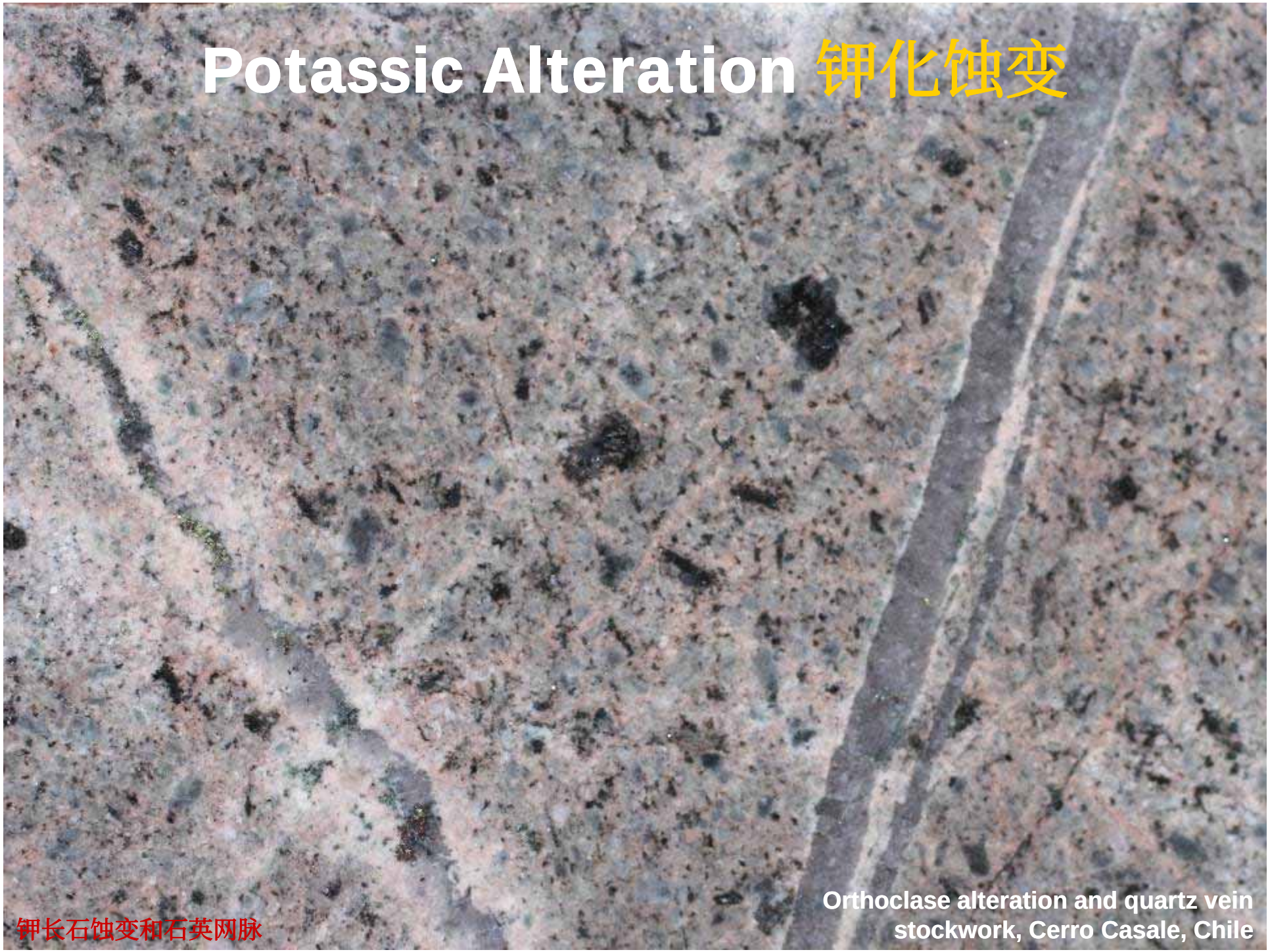
K-Feldspar Alteration (Potassic)
钾长石蚀变（钾化）



钾长石蚀变和石英网脉,
Boyongan, 菲律宾

Orthoclase alteration and quartz vein stockwork, Boyongan, Philippines

Potassic Alteration 钾化蚀变



Orthoclase alteration and quartz vein stockwork, Cerro Casale, Chile

钾长石蚀变和石英网脉

Potassic alteration associated with ‘stockwork’ vein arrays

与石英网脉有关的钾化蚀变









Hypogene Mineralisation 原生成矿作用

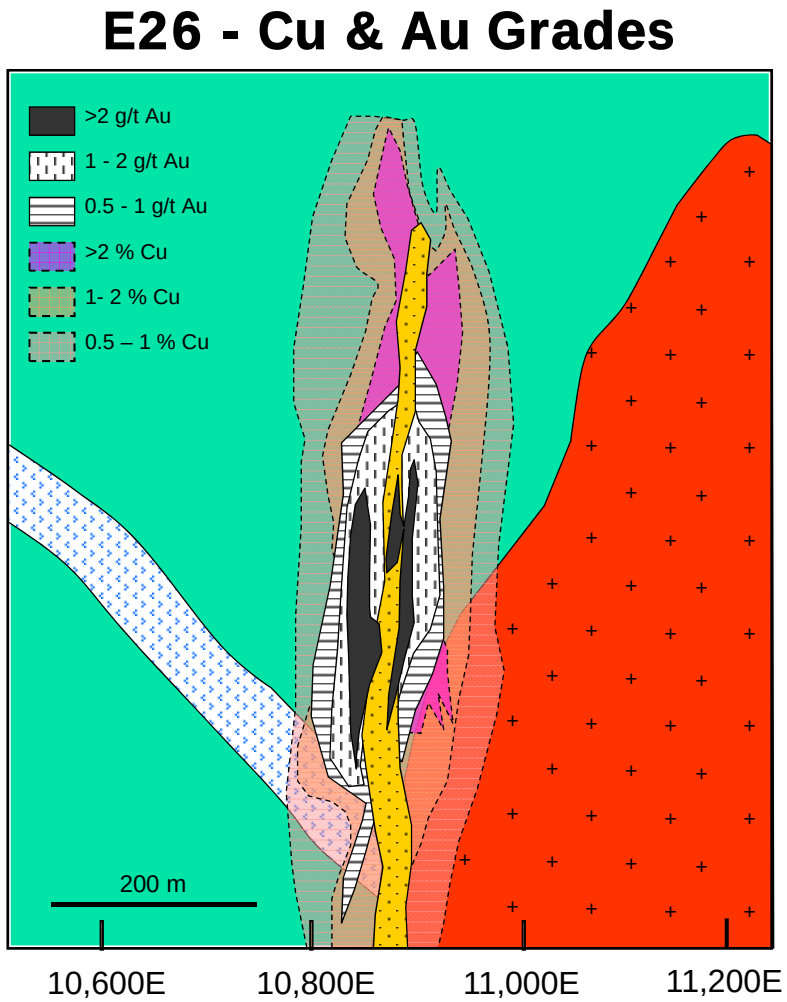


- Main ore minerals: chalcopyrite, bornite, gold, molybdenite
  主要矿石矿物：黄铜矿、斑铜矿、金、辉钼矿

- Gangue: qz, or, anh, mt, bt ± ser ± py 脉石：石英、正长石、硬石膏、磁铁矿、黑云母＋绢云母＋黄铁矿

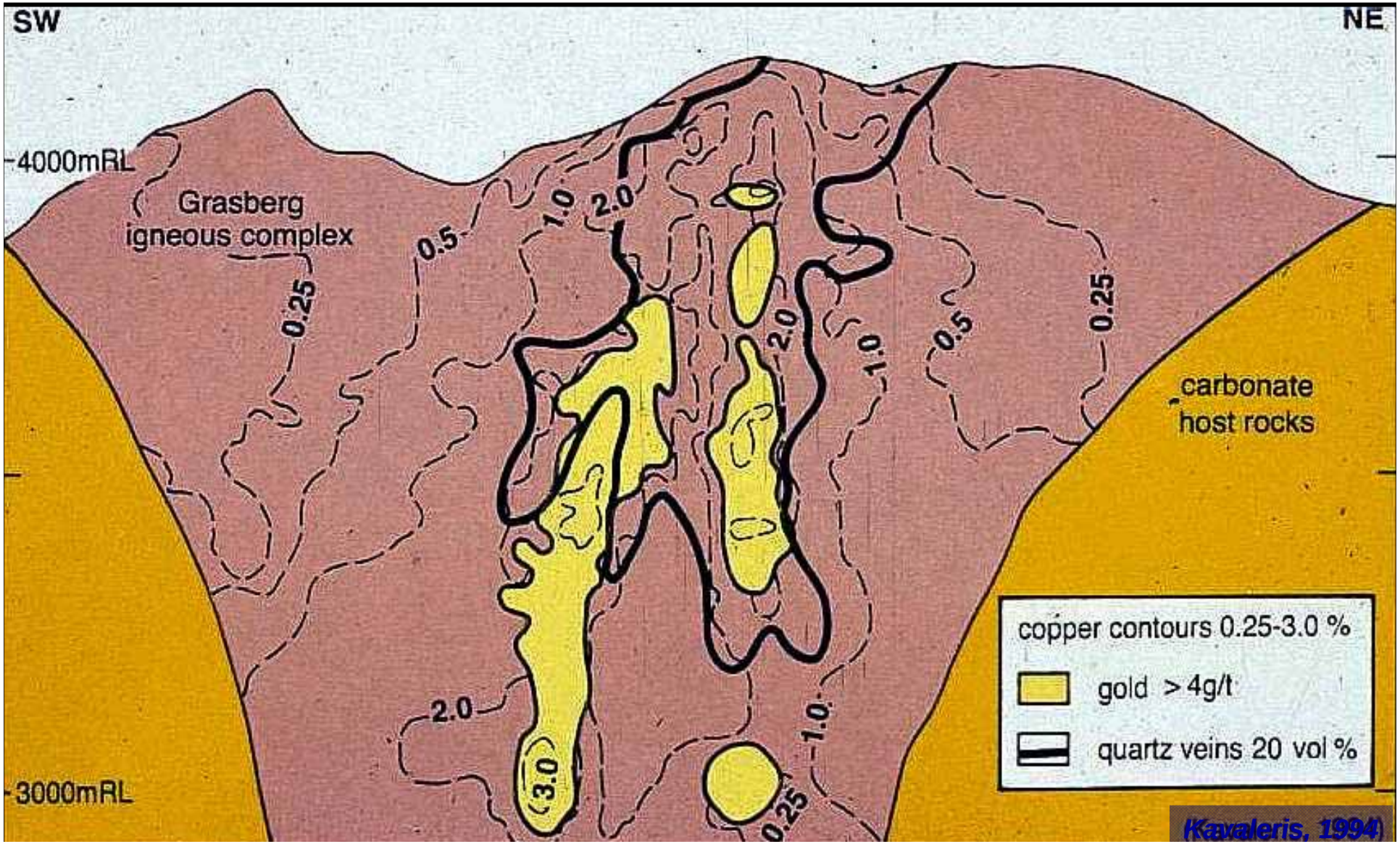
- Within deposit zonation
  在矿化带内:
  - low pyrite, Cu-rich core
    贫黄铁矿、富铜内核,
  - outer pyrite-rich halo
    富黄铁矿外带

- Cu-Au rich core surrounded by Mo-rich zone & outer pyrite halo
  富Cu-Au内核，之外为富钼带，再向外有黄铁矿晕

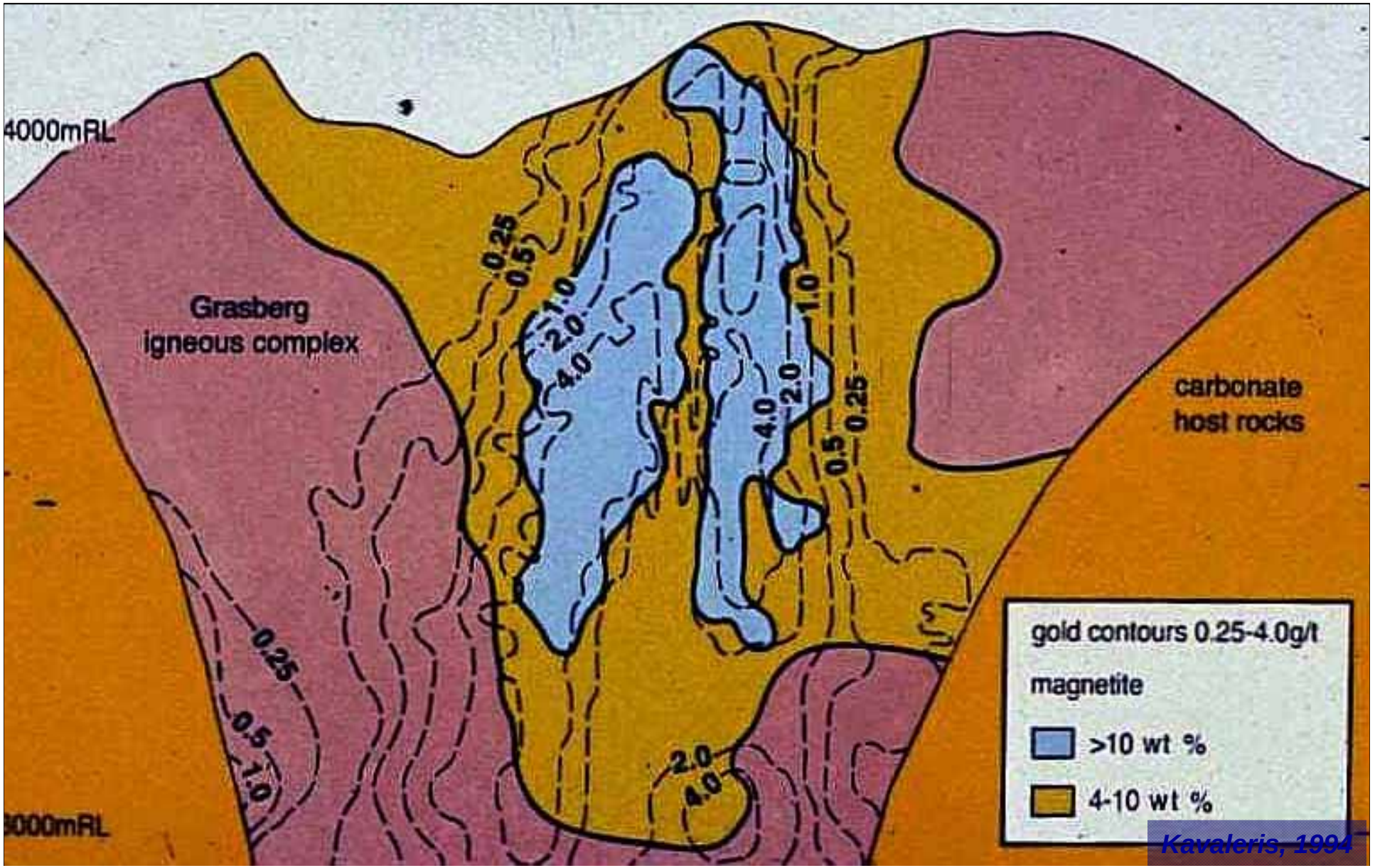


Free gold in qz-mt vein, Ridgeway, NSW 石英—磁铁矿脉中的自然金

Cu, Au and quartz veins, Grasberg
铜、金和石英脉, Grasberg



Gold and magnetite, Grasberg, Indonesia
金和磁铁矿, Grasberg, 印度尼西亚

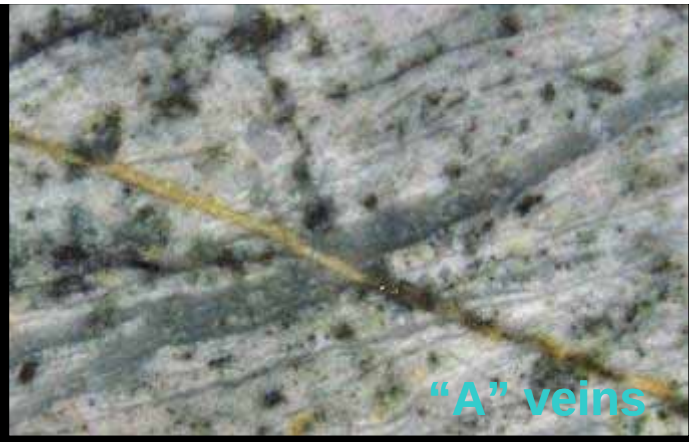


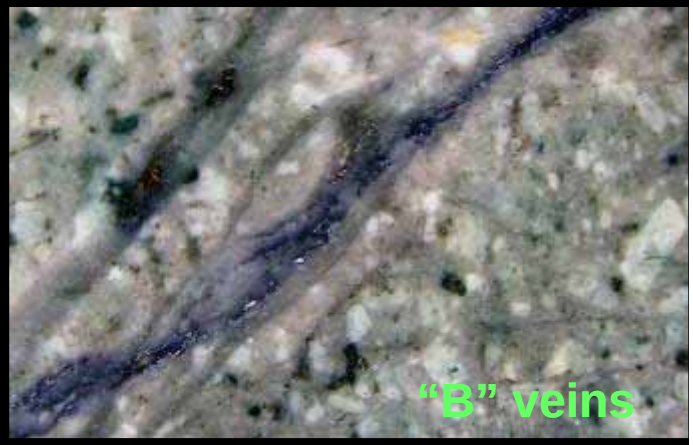
Vein Types *(Gustafson and Hunt, 1975)* 脉的类型

A veins: These are typically granular quartz-K-feldspar-anhydrite-sulfide veins that generally lack internal symmetry, and are irregular and discontinuous 脉由等粒状石英、钾长石、硬石膏-硫化物组成，内部不对称，边界不规则，不连续

B veins: These transitional quartz veins occupy continuous planar fractures, contain molybdenite, and lack K-feldspar and associated alteration halos 过渡石英脉，连续，边界平直，含辉钼矿，缺少钾长石和相关蚀变晕

D veins: Late sulfide veins contain pyrite and lesser bornite, chalcopyrite, enargite, tennantite, sphalerite and gl, with quartz-anhydrite gangue and phyllic alteration halos 后期硫化物脉，含黄铁矿，较少的斑铜矿、黄铜矿、硫砷铜矿、砷黝铜矿、闪锌矿和方铅矿，脉石为石英和硬石膏，有绢英岩化蚀变晕

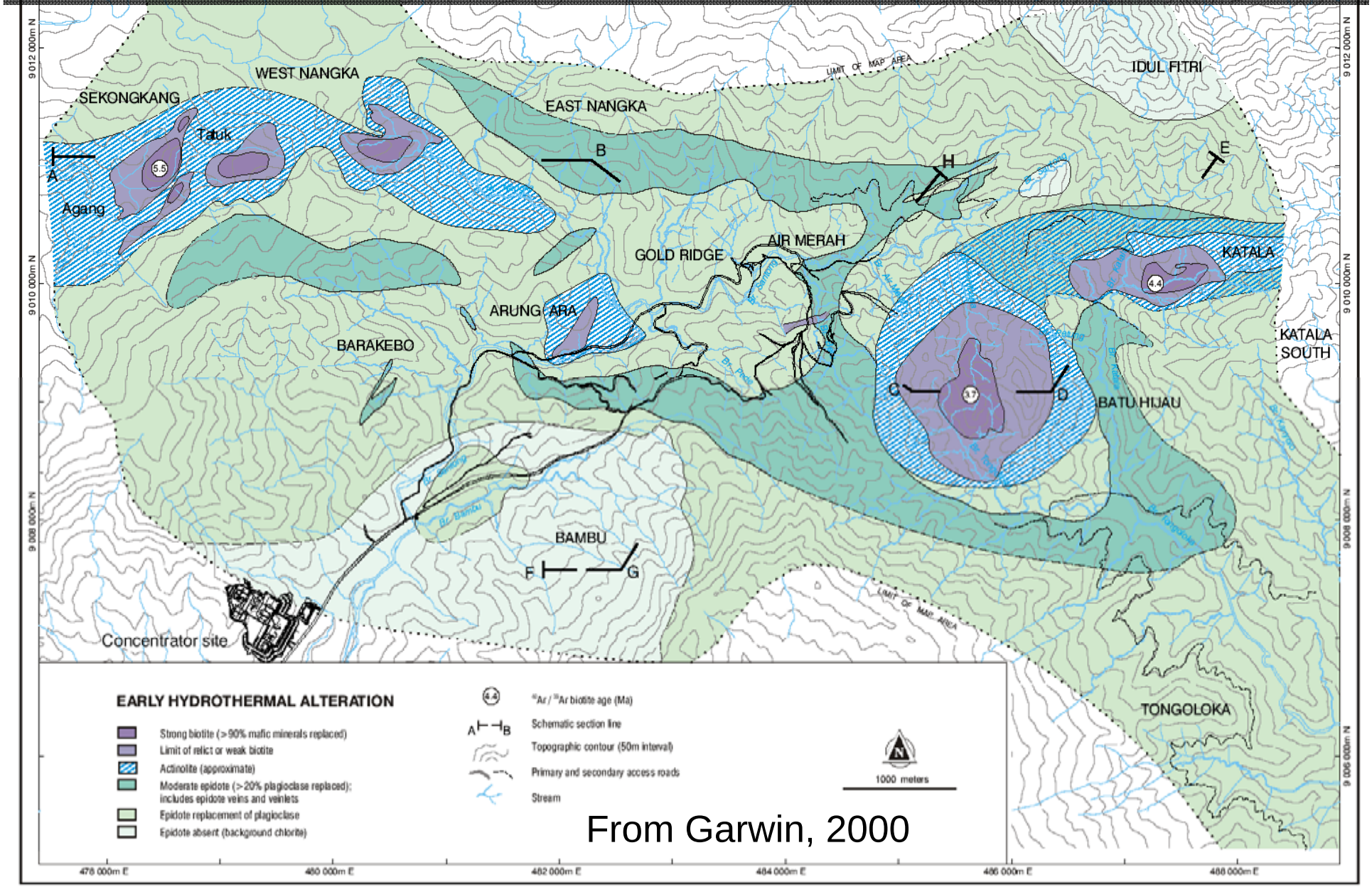






Potassic and Propylitic Alteration - Batu Hijau

钾化和青磐岩化蚀变 – Batu Hijau



From Garwin, 2000



What characterises propylitic alteration? 青磐岩化蚀变有何特征？

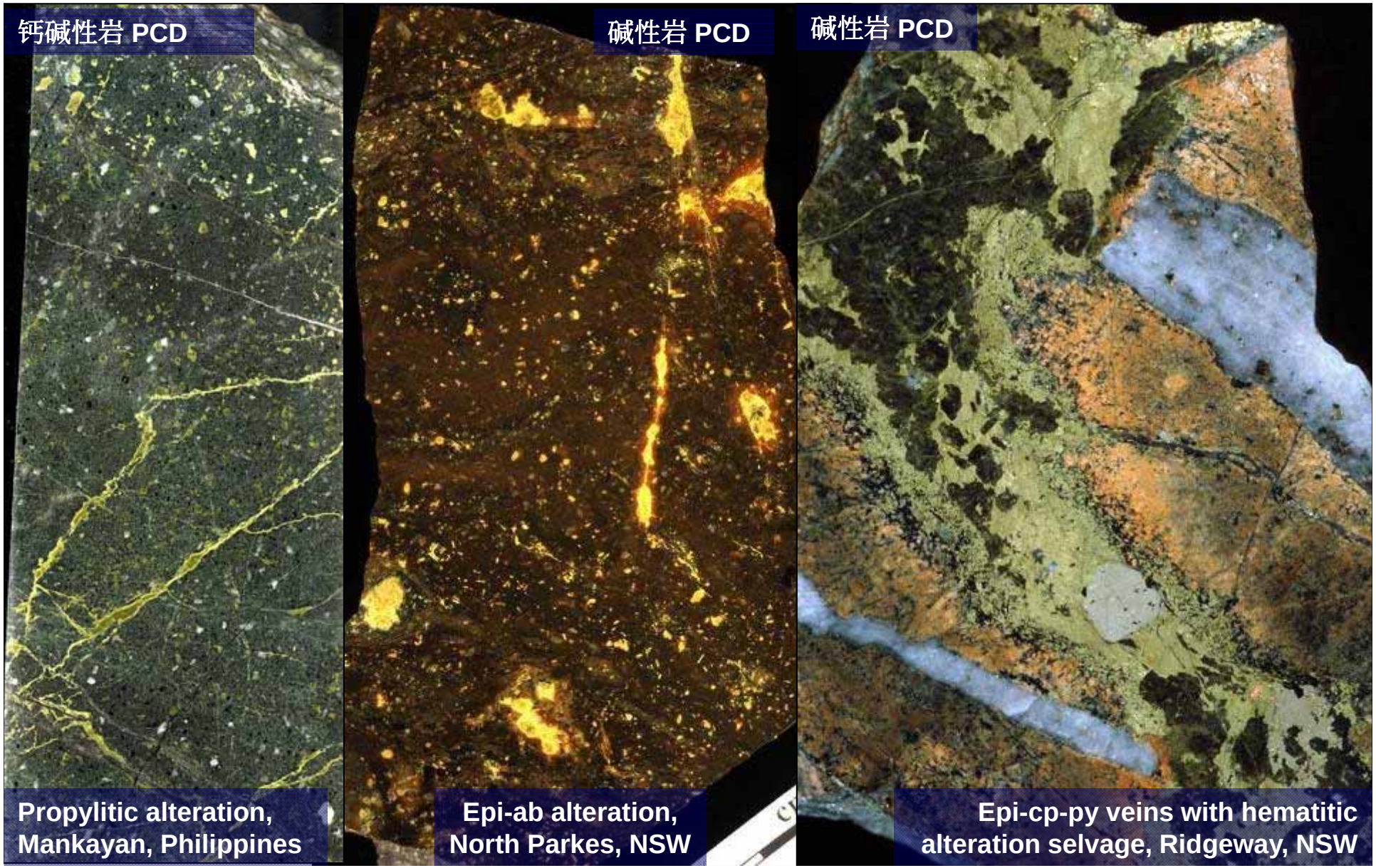
- **Weakly to moderately developed secondary alteration assemblage that typically preserves primary rock textures** 微弱到中等发育的次生蚀变，一般保留原岩结构
- **Can occur as pervasive or selectively pervasive replacements, or as vein halos**可以呈弥漫状、选择性弥漫状或脉的晕
- **Associated veins have similar mineralogies**相关的脉体有相似的矿物组合

Mineralogy

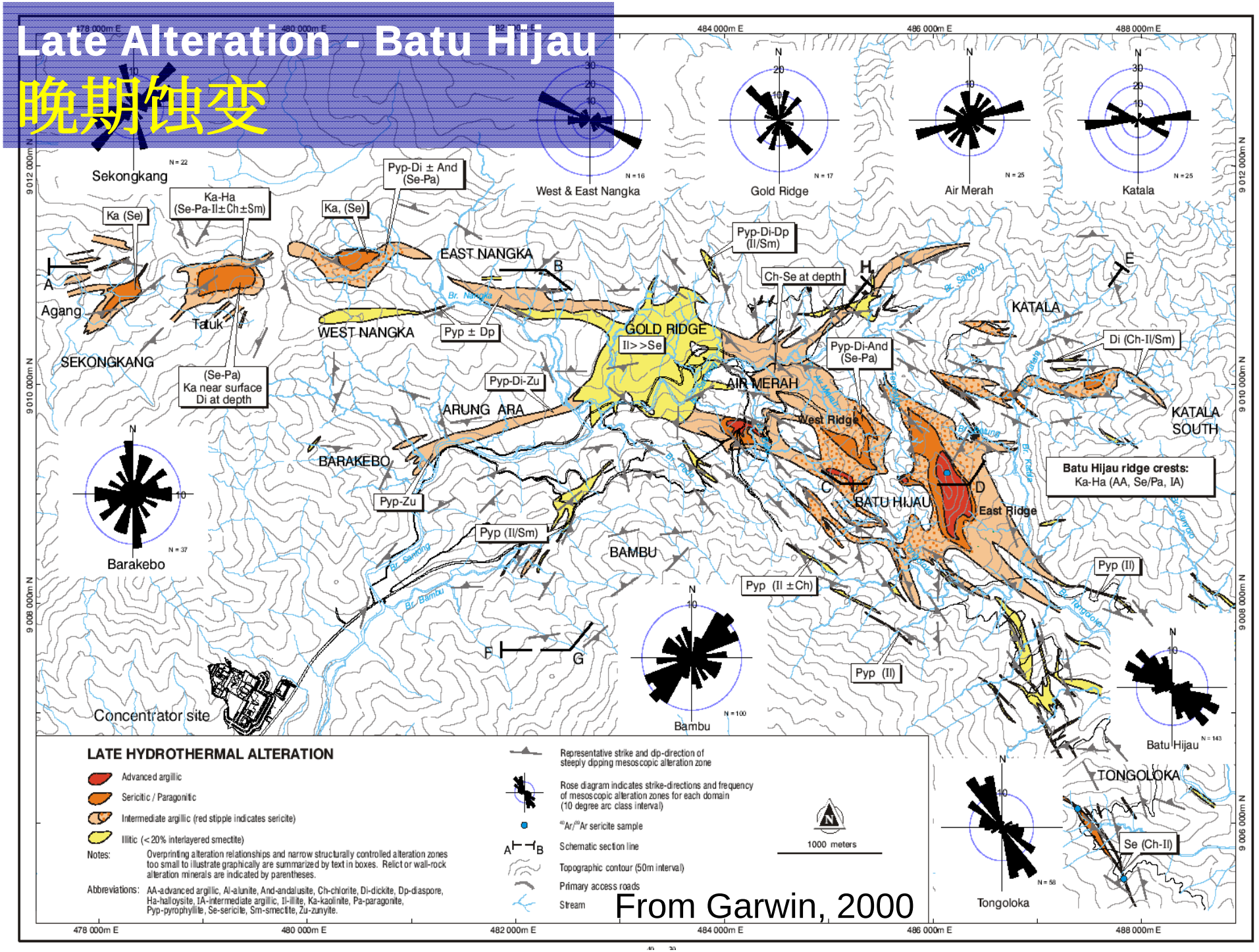
Actinolite	$Ca_2(Mg,Fe^{2+})_5Si_8O_{22}(OH)_2$
Albite	$NaAlSi_3O_8$
Calcite / Mn-calcite	$Ca(Mn)CO_3$
Chlorite	$(Mg,Fe^{2+})_6Al\ Si_3O_{10}(OH)_8$
Hematite	Fe_2O_3
Epidote	$Ca_2(Al,Fe^{3+})_3Si_3O_{12}(OH)$
Pyrite	FeS_2
Smectite	$(Ca,Na)_{0.7}(Al,Mg,Fe)_4(Si,Al)_8O_{20}OH_4{\cdot}H_2O)$

Epidote, Baja California, Mexico. Image from http://www.johnbetts-fineminerals.com

Propylitic Alteration
青磐岩化蚀变



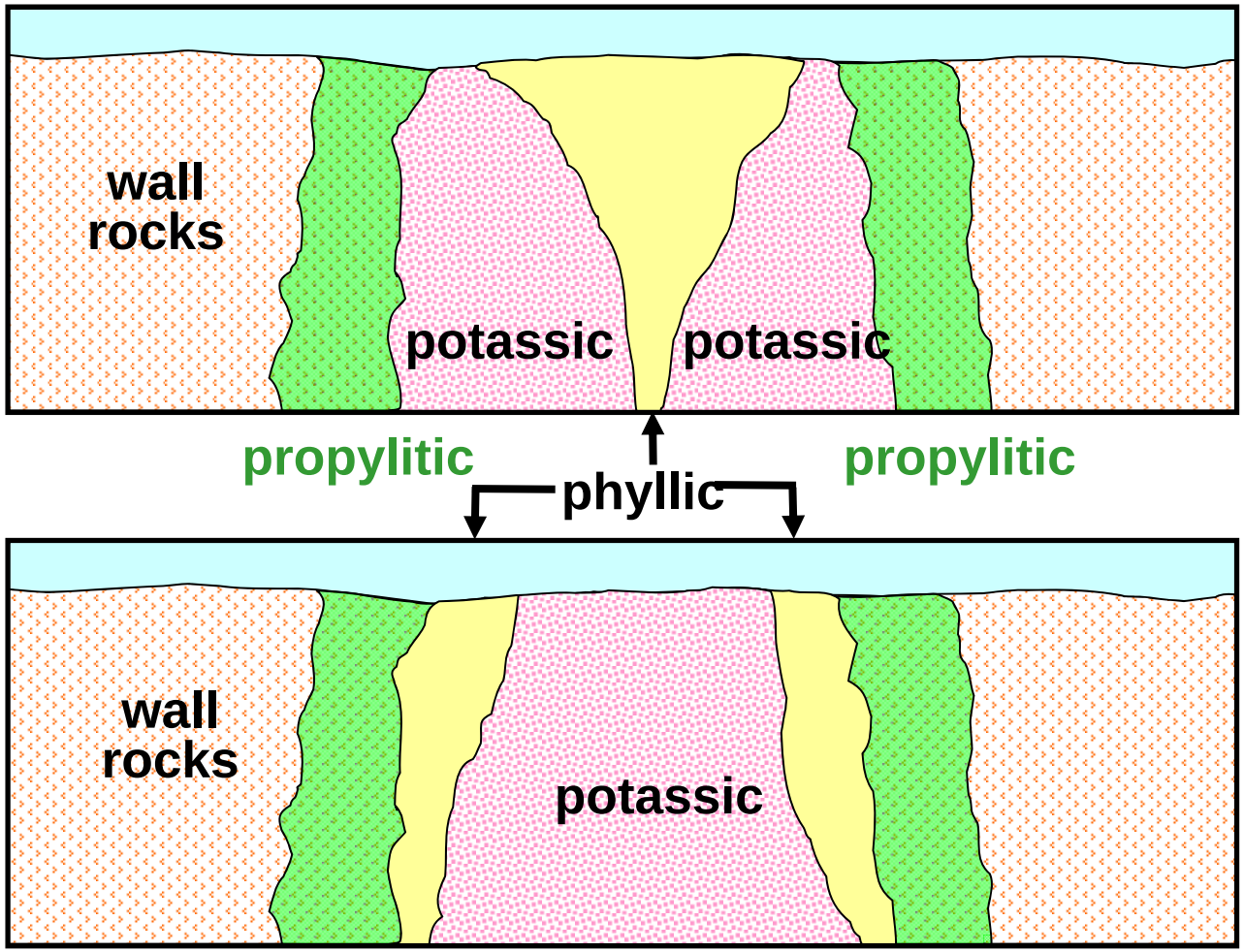
Late Alteration - Batu Hijau
晚期蚀变



From Garwin, 2000

Alteration overprinting relationships

South American porphyry model



Lowell and Guilbert (1970) model

- **Phyllic alteration cuts the potassic alteration zones, and can be independently mineralised**
- **Phyllic alteration is typically magmatic-hydrothermal in origin *(not meteoric)***
- **It may relate to periods when magmatic gases dominate the system**

Intermediate Argillic Alteration
中级泥化蚀变



Int arg alt cut by qz-il alteration, FSE, Philippines



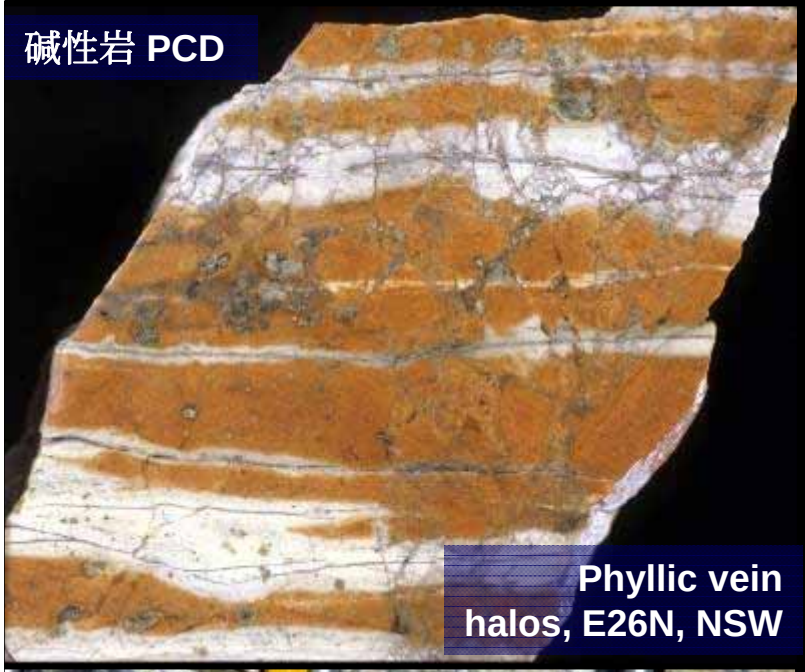
Pervasive int. arg. alteration, Philex, Philippines



Chl-altered rock flour matrix breccia + hem alteration halo, Cadia Hill, NSW

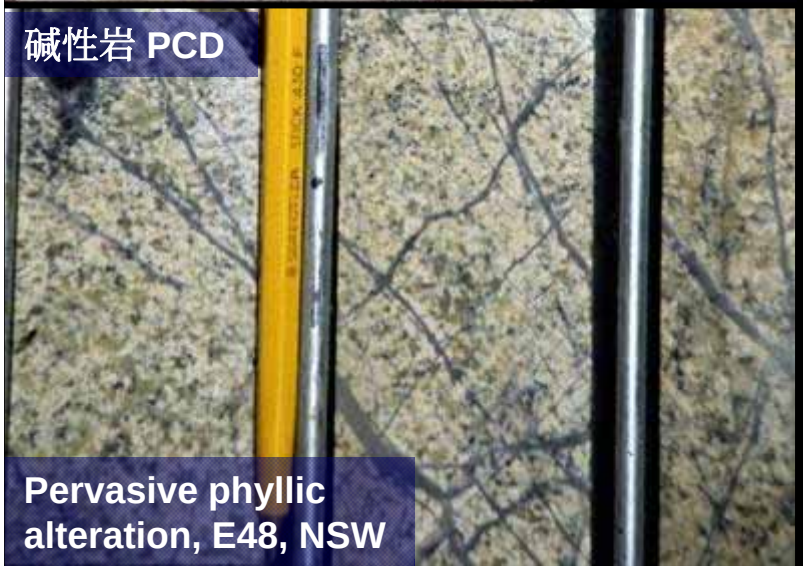
Phyllic Alteration 绢英岩化蚀变

碱性岩 PCD



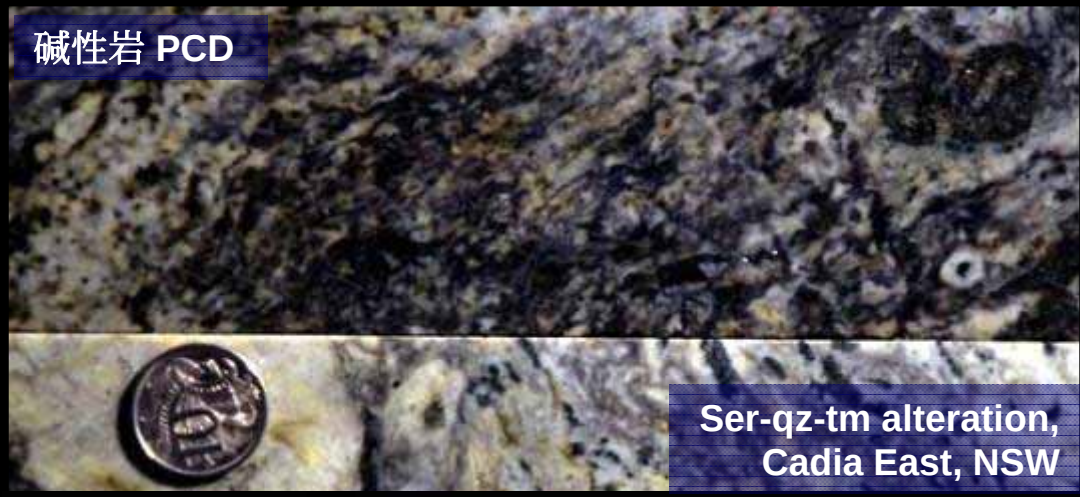
Phyllic vein halos, E26N, NSW

碱性岩 PCD



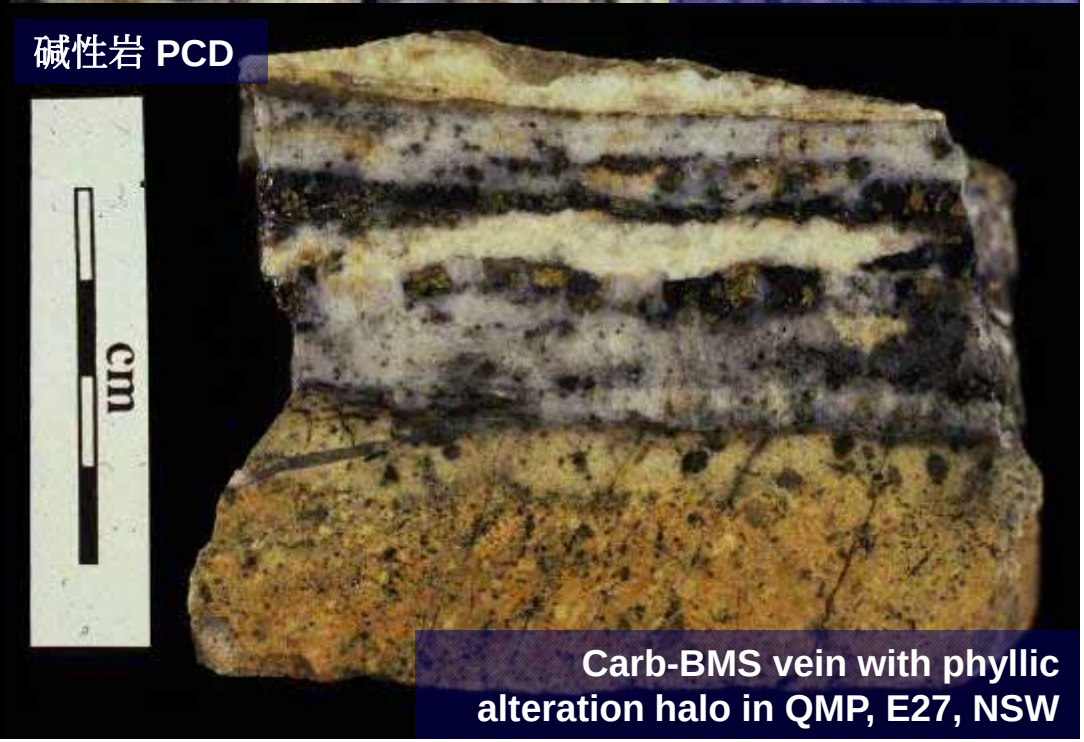
Pervasive phyllic alteration, E48, NSW

碱性岩 PCD



Ser-qz-tm alteration, Cadia East, NSW

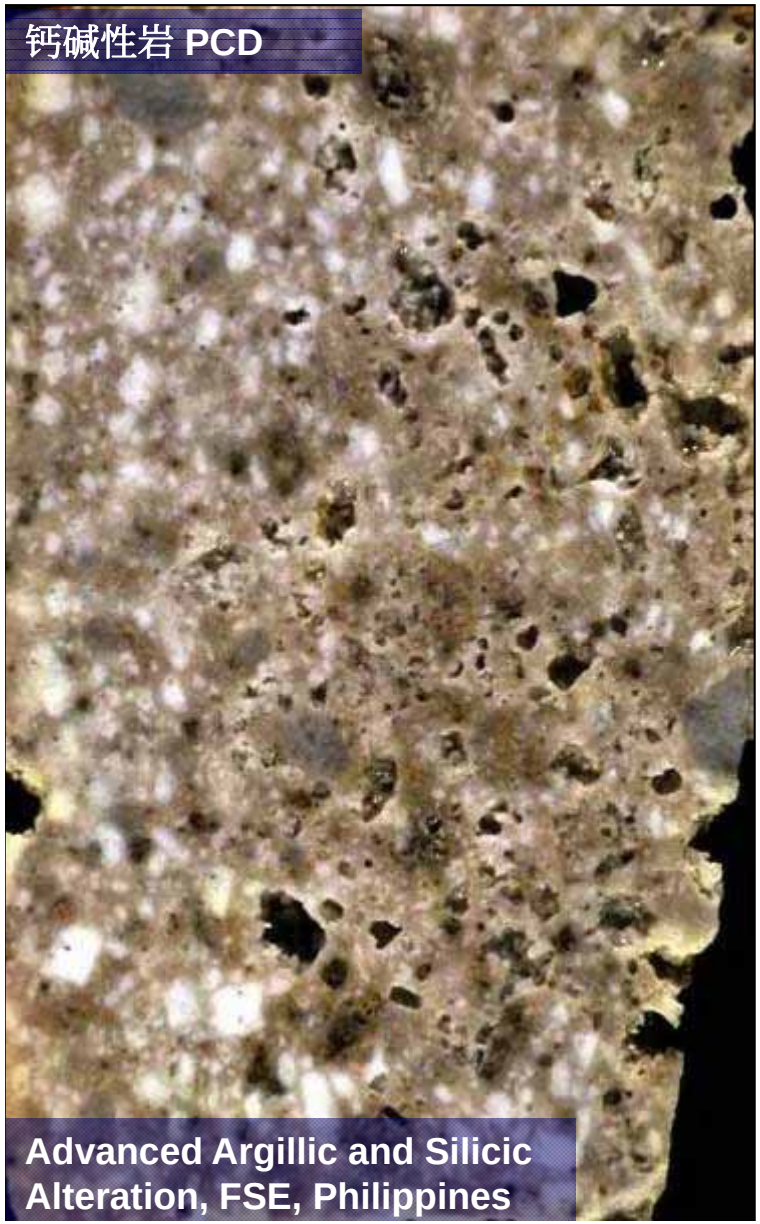
碱性岩 PCD



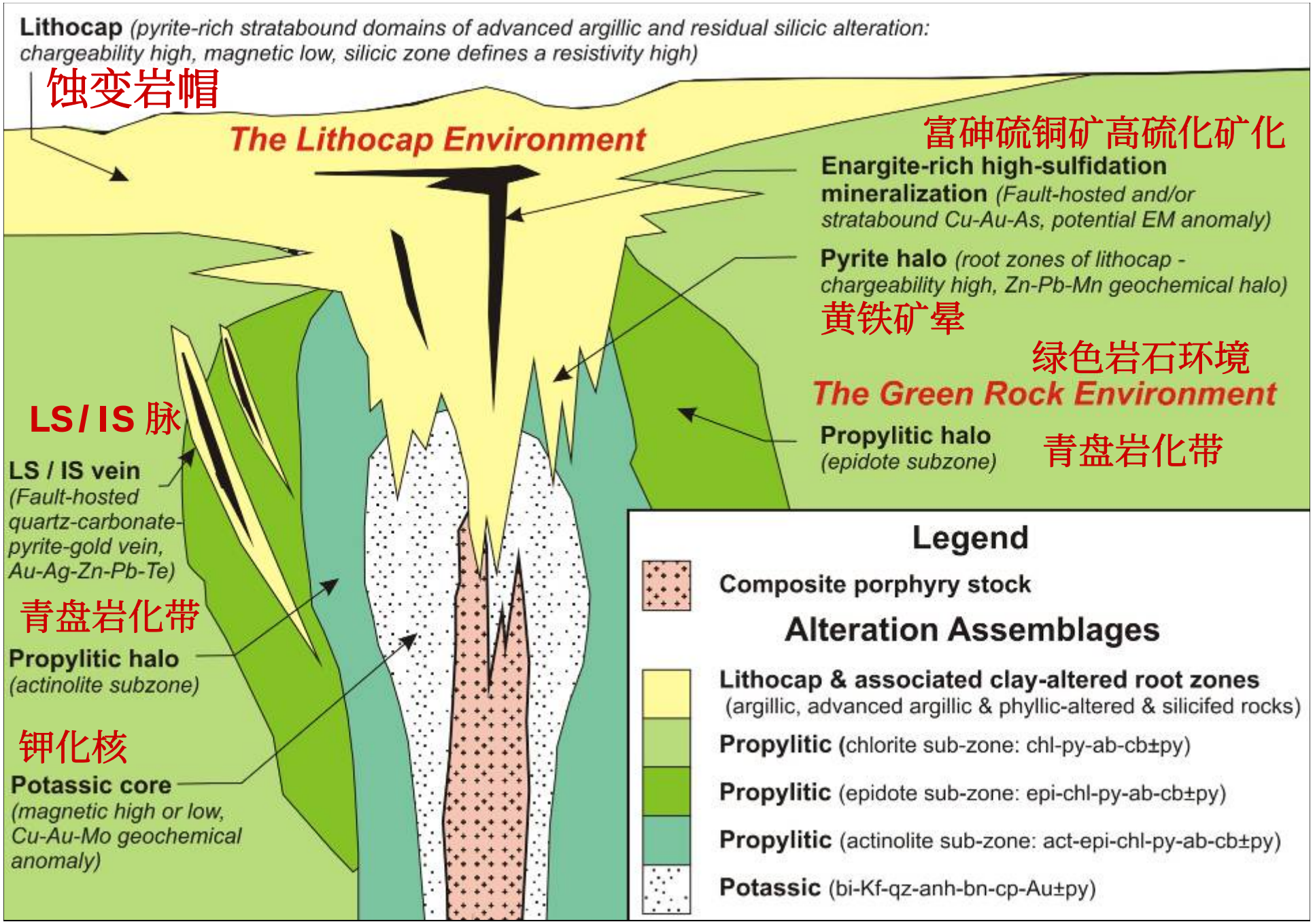
Carb-BMS vein with phyllic alteration halo in QMP, E27, NSW

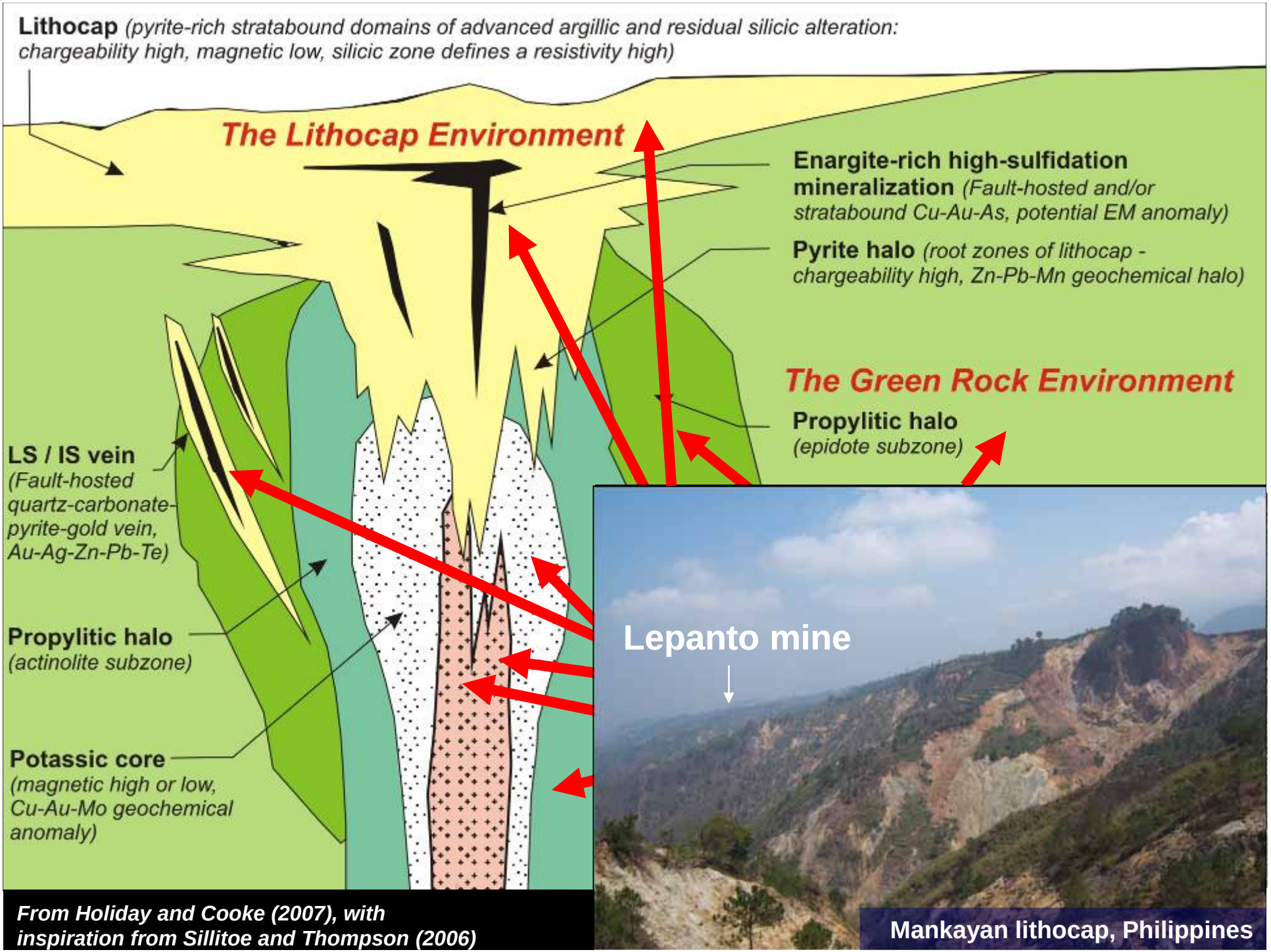
Advanced Argillic Alteration

高级泥化蚀变





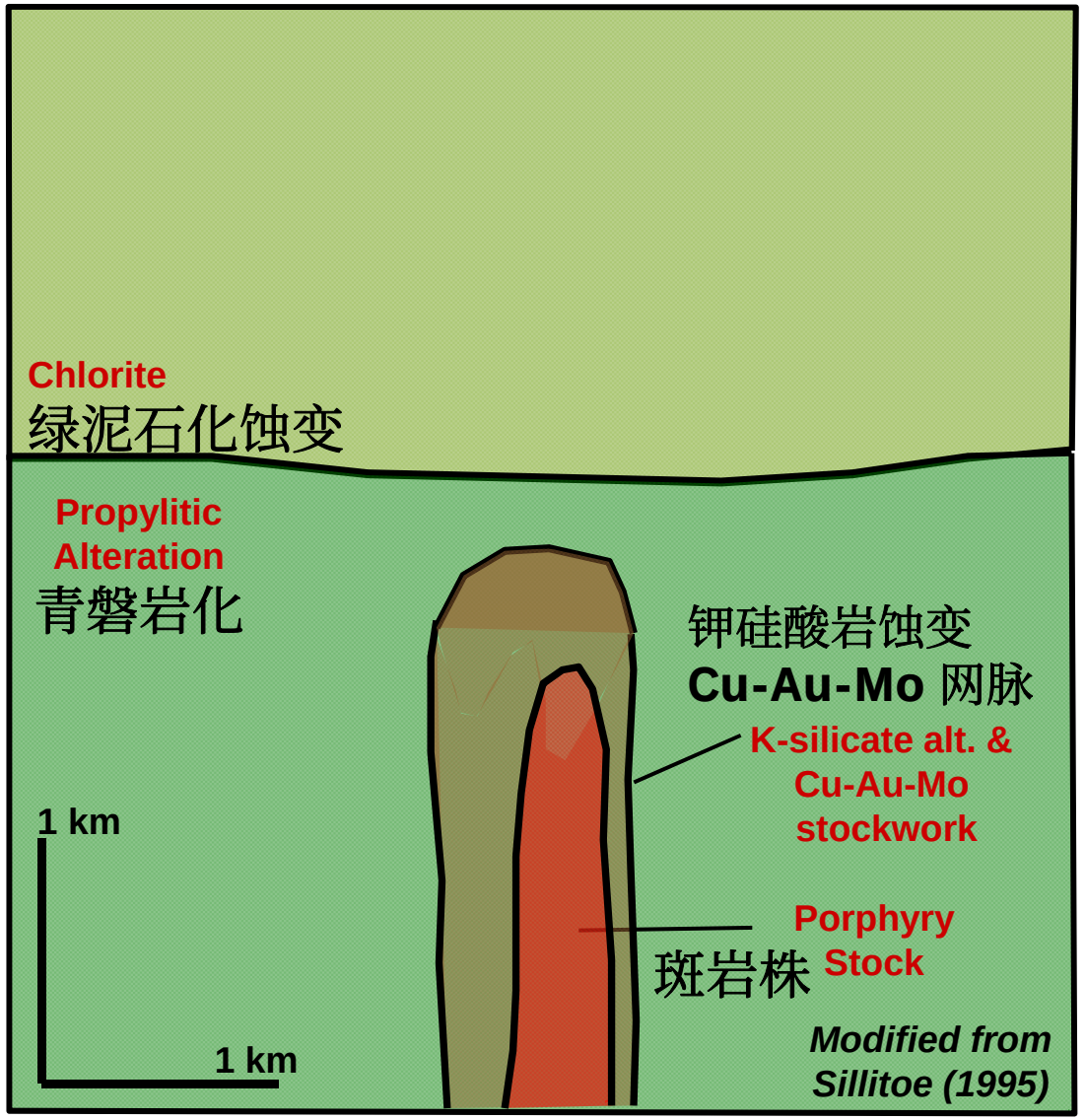

Lithocap (pyrite-rich stratabound domains of advanced argillic and residual silicic alteration: chargeability high, magnetic low, silicic zone defines a resistivity high)
蚀变岩帽
The Lithocap Environment
富砷硫铜矿高硫化矿化
Enargite-rich high-sulfidation mineralization (Fault-hosted and/or stratabound Cu-Au-As, potential EM anomaly)
Pyrite halo (root zones of lithocap - chargeability high, Zn-Pb-Mn geochemical halo)
黄铁矿晕
绿色岩石环境
The Green Rock Environment
Propylitic halo (epidote subzone)
青盘岩化带
LS/IS 脉
LS / IS vein (Fault-hosted quartz-carbonate-pyrite-gold vein, Au-Ag-Zn-Pb-Te)
青盘岩化带
Propylitic halo (actinolite subzone)
钾化核
Potassic core (magnetic high or low, Cu-Au-Mo geochemical anomaly)
Legend
Composite porphyry stock
Alteration Assemblages
Lithocap & associated clay-altered root zones (argillic, advanced argillic & phyllic-altered & silicifed rocks)
Propylitic (chlorite sub-zone: chl-py-ab-cb±py)
Propylitic (epidote sub-zone: epi-chl-py-ab-cb±py)
Propylitic (actinolite sub-zone: act-epi-chl-py-ab-cb±py)
Potassic (bi-Kf-qz-anh-bn-cp-Au±py)


Lithocap (pyrite-rich stratabound domains of advanced argillic and residual silicic alteration: chargeability high, magnetic low, silicic zone defines a resistivity high)
The Lithocap Environment
Enargite-rich high-sulfidation mineralization (Fault-hosted and/or stratabound Cu-Au-As, potential EM anomaly)
Pyrite halo (root zones of lithocap - chargeability high, Zn-Pb-Mn geochemical halo)
The Green Rock Environment
Propylitic halo (epidote subzone)
LS / IS vein (Fault-hosted quartz-carbonate-pyrite-gold vein, Au-Ag-Zn-Pb-Te)
Propylitic halo (actinolite subzone)
Potassic core (magnetic high or low, Cu-Au-Mo geochemical anomaly)
Lepanto mine
From Holiday and Cooke (2007), with inspiration from Sillitoe and Thompson (2006)
Mankayan lithocap, Philippines

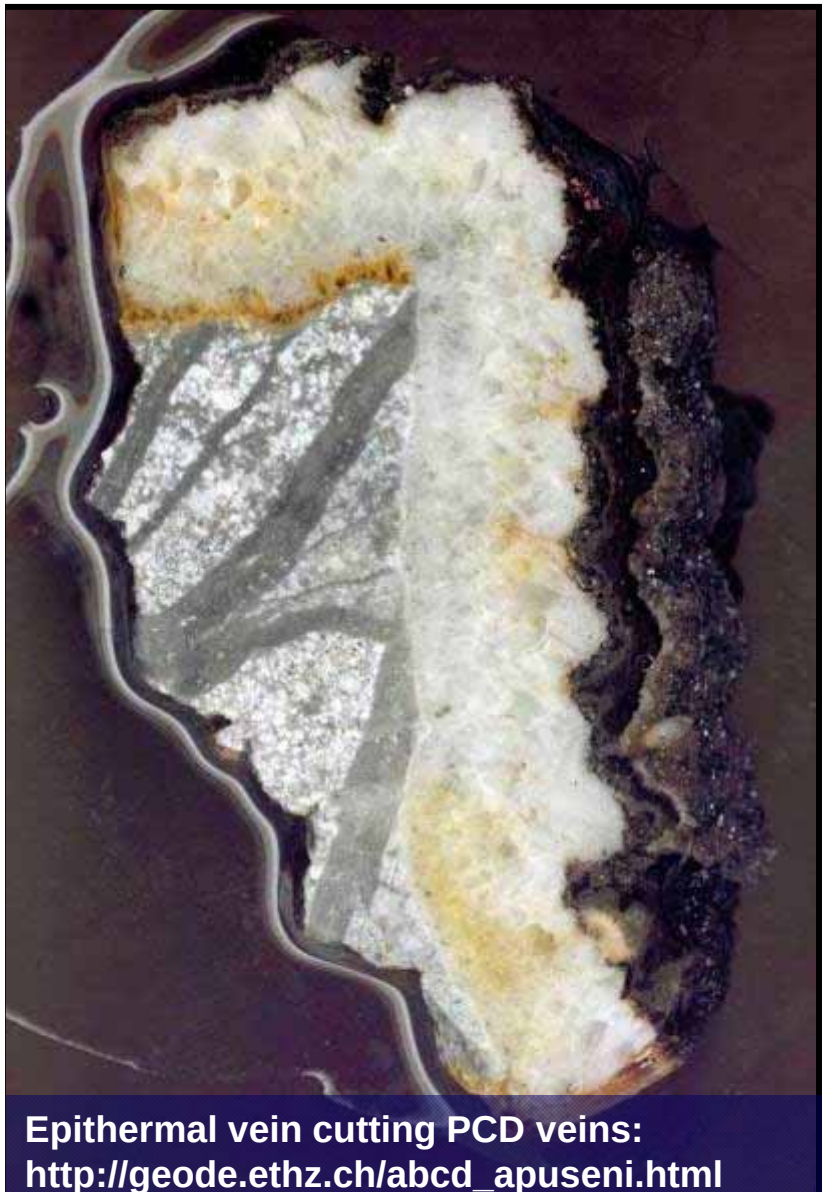
Uplift and Exhumation 隆升和剥蚀



Qz-bn-cp veins cut by epi vein, Ridgeway



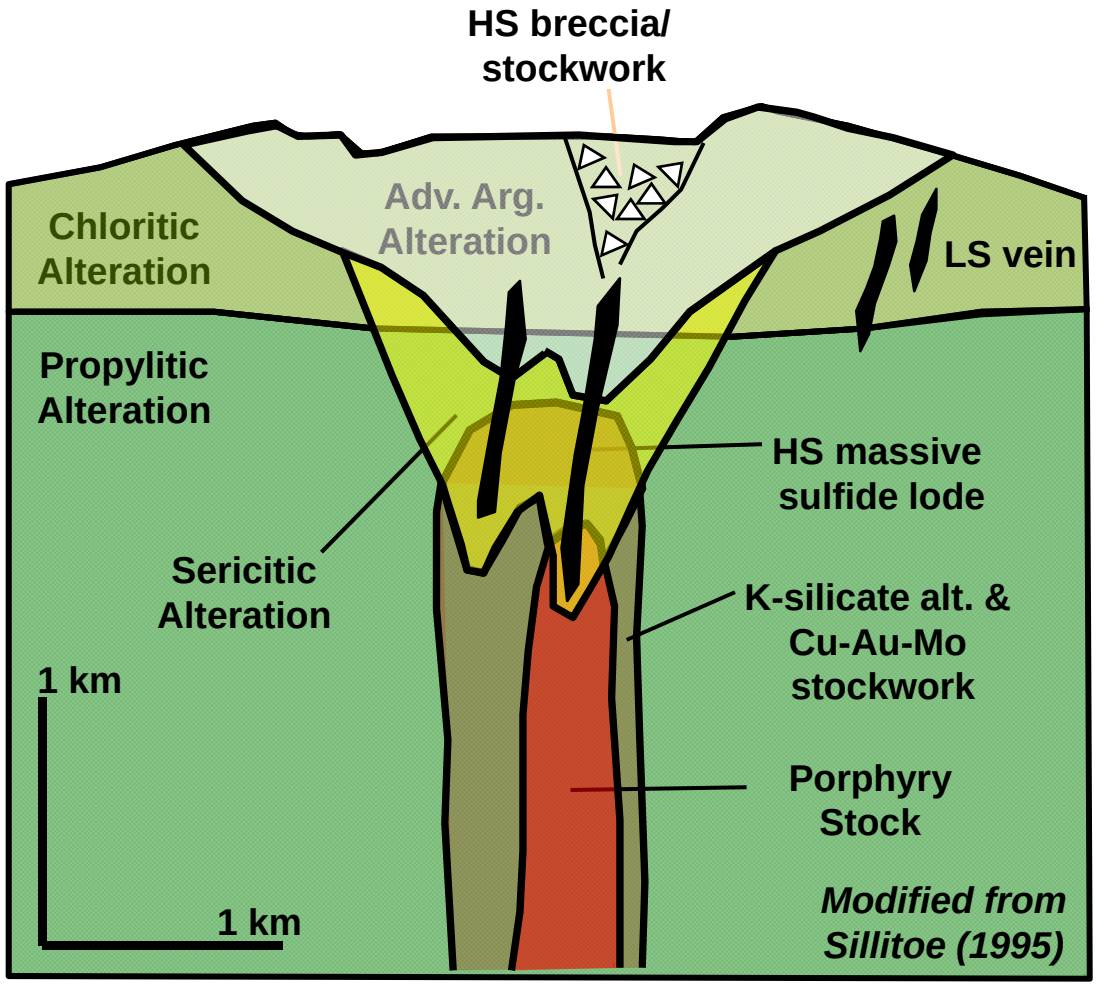
Epithermal Superposition 浅成热液叠加



Epithermal vein cutting PCD veins:
http://geode.ethz.ch/abcd_apuseni.html

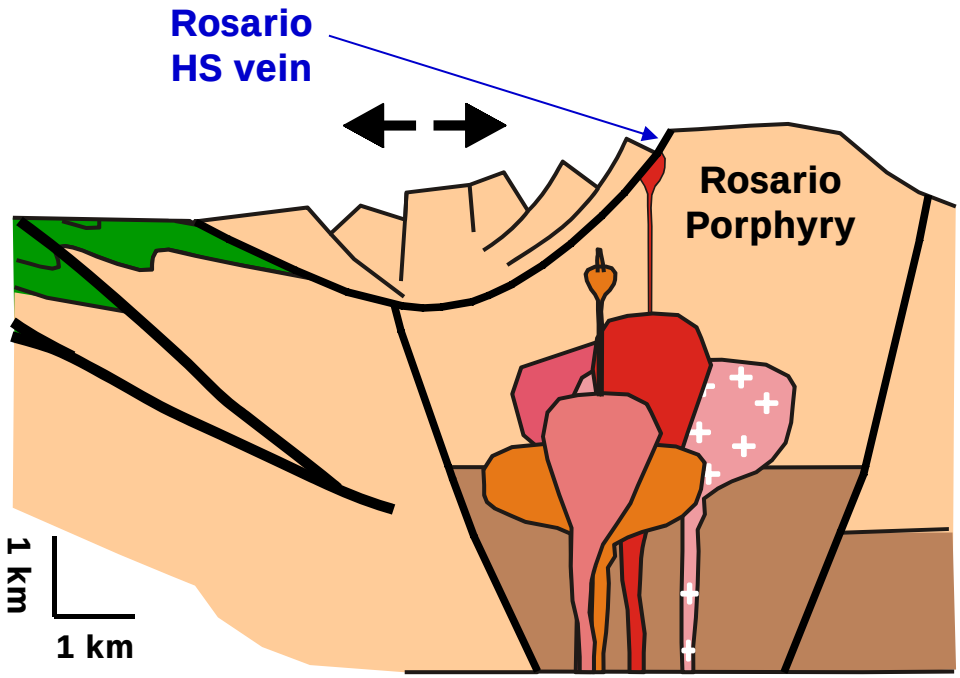
Progressive uplift & erosion 逐步隆升和剥蚀

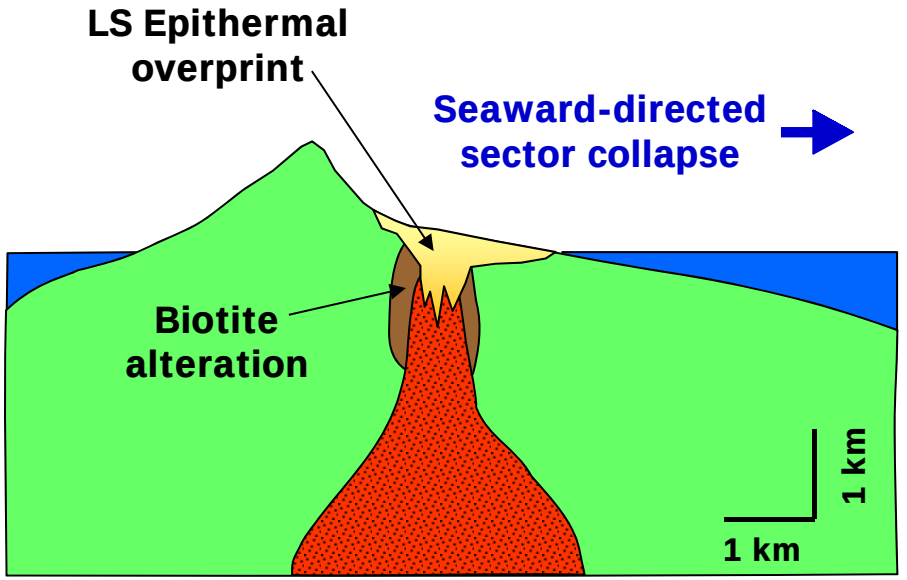
Change from lithostatic to hydrostatic load
从静岩压力变为静水压力载荷



Telescoping mechanisms

Progressive uplift and erosion during magmatic-hydrothermal activity promotes transition from lithostatic to hydrostatic load and epithermal overprinting





Gradual transition

e.g., gravitational collapse of an uplifted mountain range

Collahuasi, Chile (Masterman et al, 2005)

Instantaneous transition

e.g., sector collapse of an altered volcanic edifice

Lihir, PNG (Sillitoe, 1994)