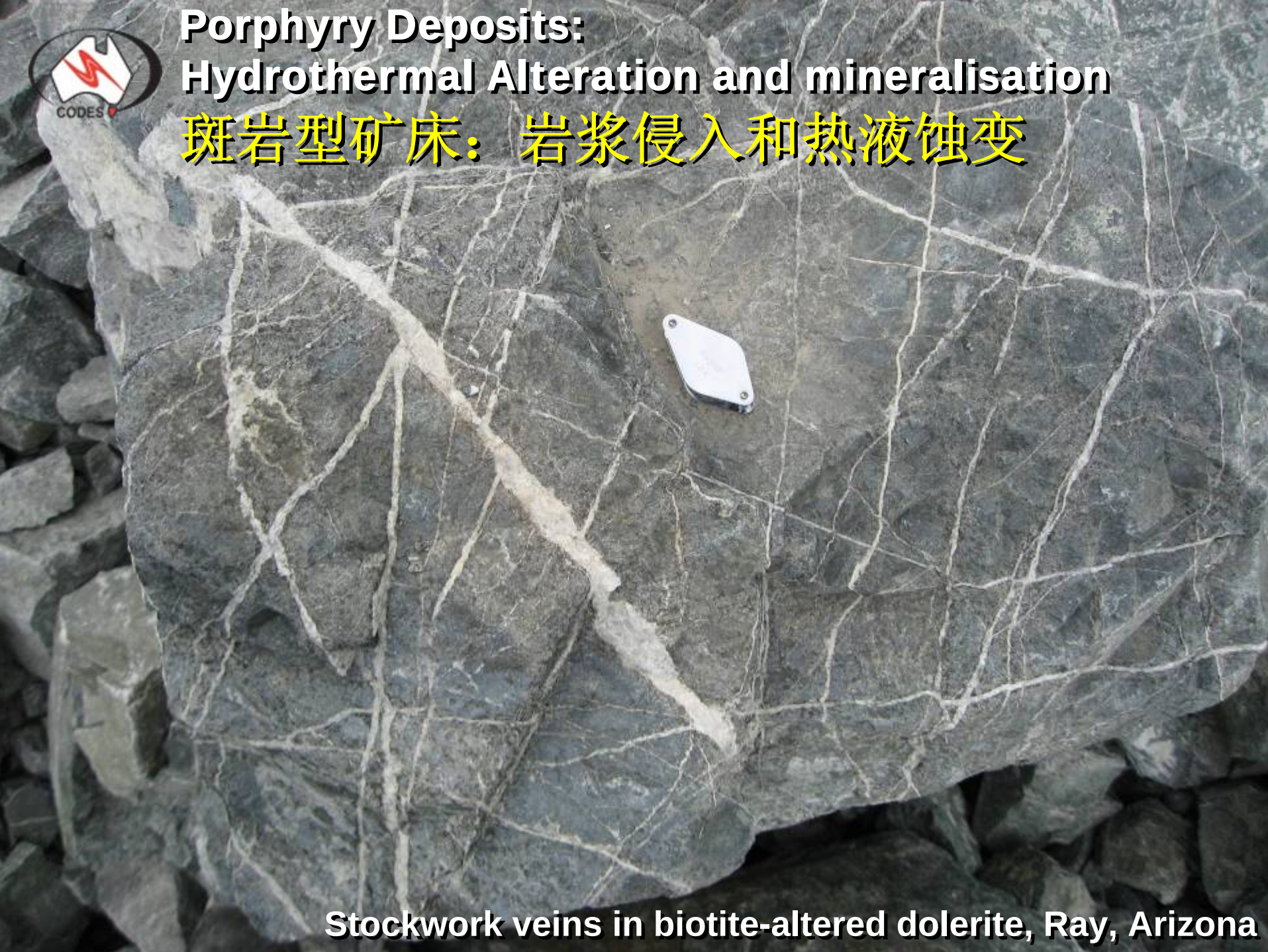
Porphyry Deposits: Hydrothermal Alteration and mineralisation

斑岩型矿床：岩浆侵入和热液蚀变



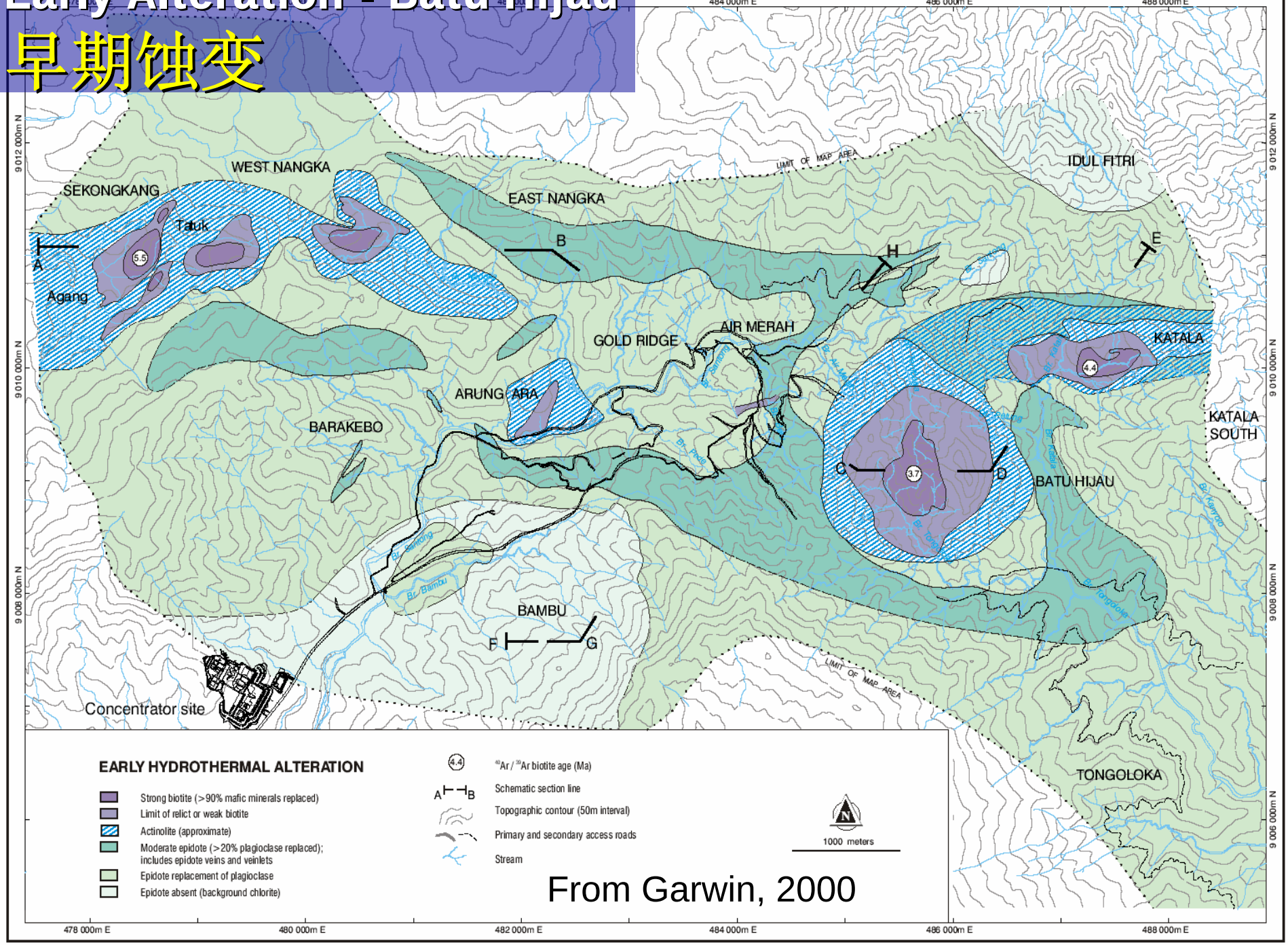
Stockwork veins in biotite-altered dolerite, Ray, Arizona

Hydrothermal Alteration 热液蚀变



Early Alteration - Batu Hijau

早期蚀变



From Garwin, 2000



Biotite-altered trachyandesite and orthoclase-altered monzonite

What characterises potassic alteration?

- **Weakly to intensely developed secondary alteration assemblages that can destroy or preserve primary rock textures**
- **Can occur as pervasive or selectively pervasive replacements, or as vein halos**
- **Associated veins have similar mineralogies**

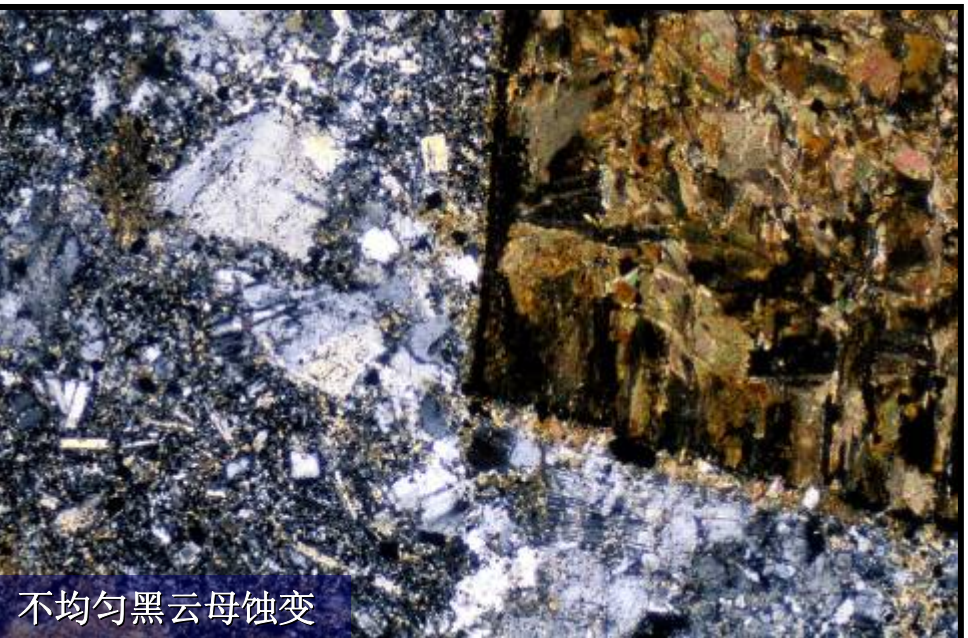
Mineralogy

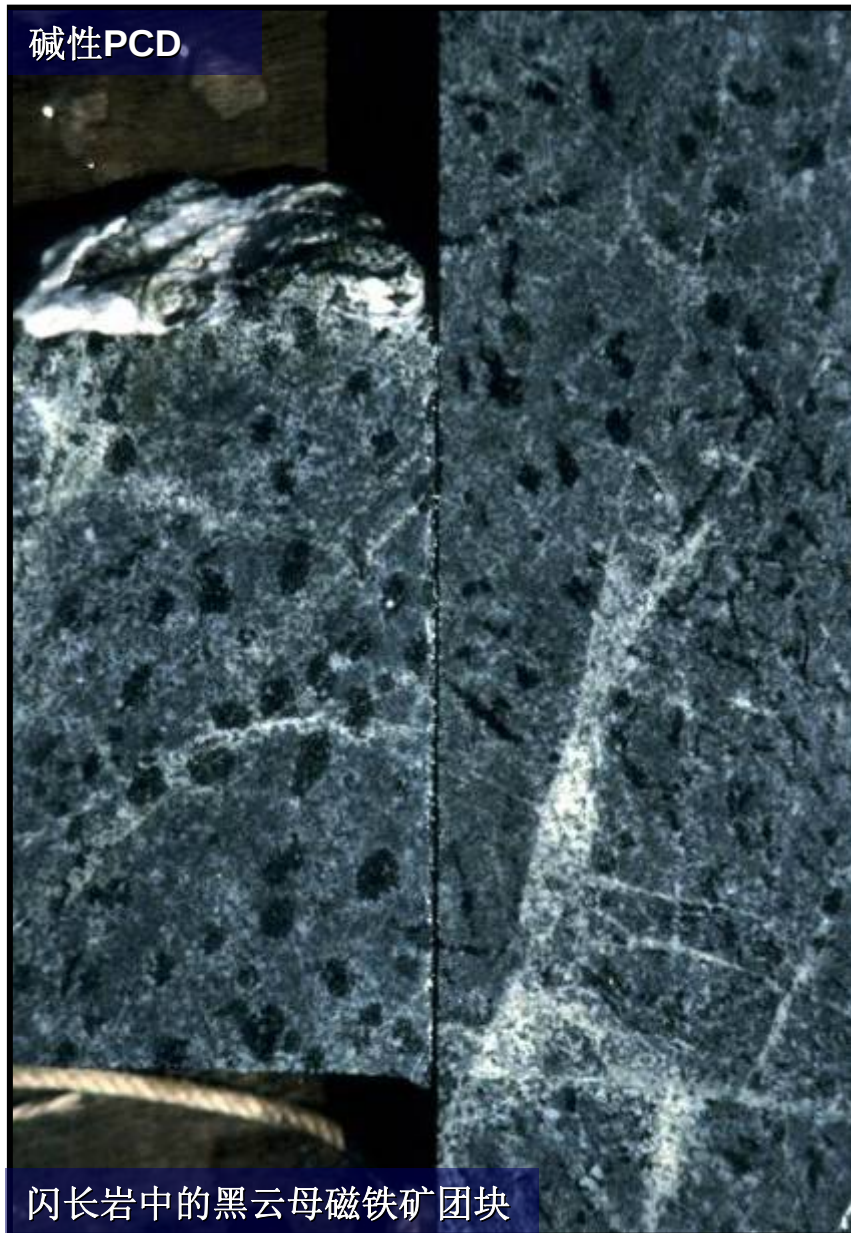
Orthoclase	**$KAlSi_3O_8$**	***(common in felsic rocks)***
Biotite	**$K(Mg,Fe^{2+})_3AlSi_3O_{10}(OH,F)_2$**	***(common in mafic rocks)***
Quartz	**SiO_2**	
Magnetite	**Fe_3O_4**	***(important for exploration)***
Anhydrite	**$CaSO_4$**	
Albite	**$NaAlSi_3O_8$**	
Chalcopyrite	**$CuFeS_2$**	
Bornite	**Cu_5FeS_4**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

Biotite Alteration (Potassic)

黑云母蚀变（钾化）

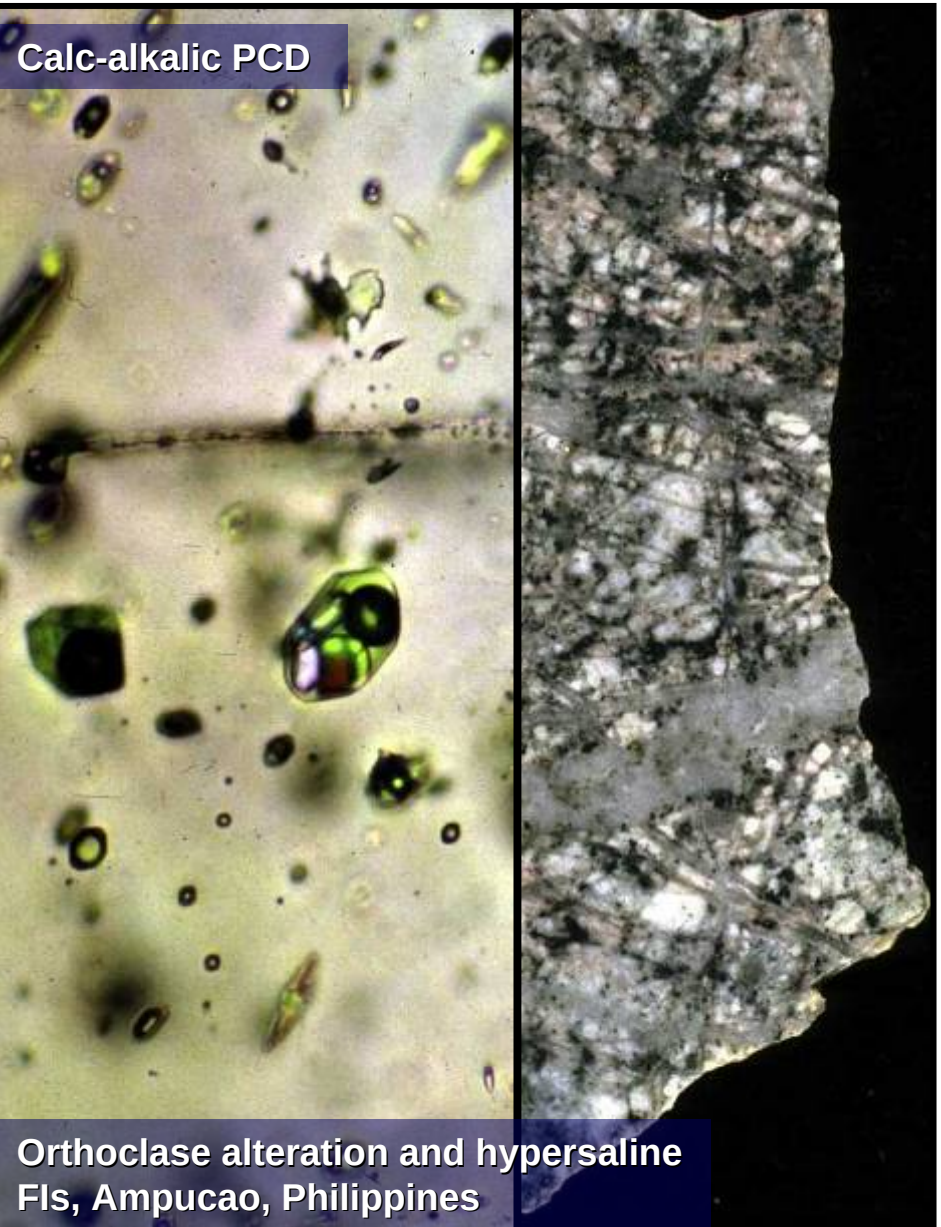


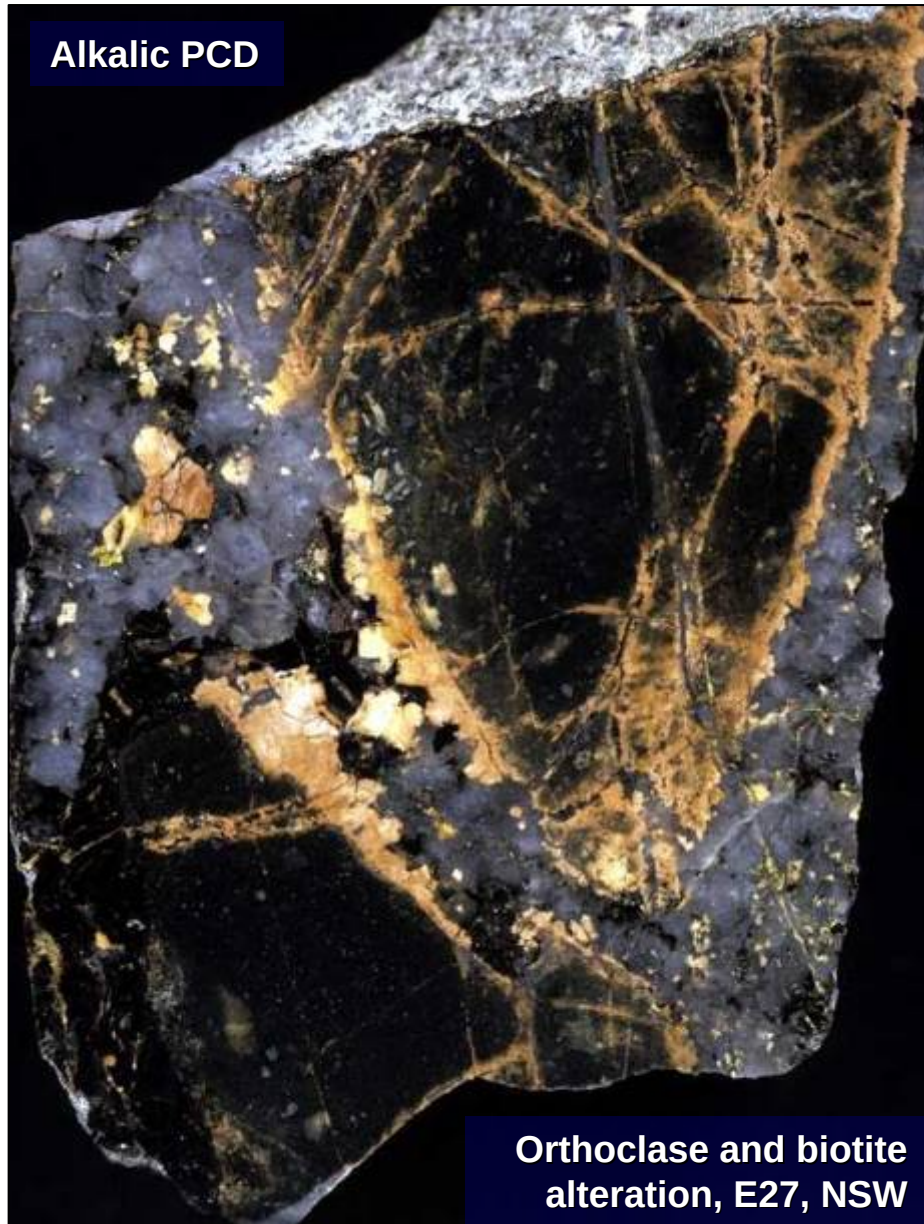




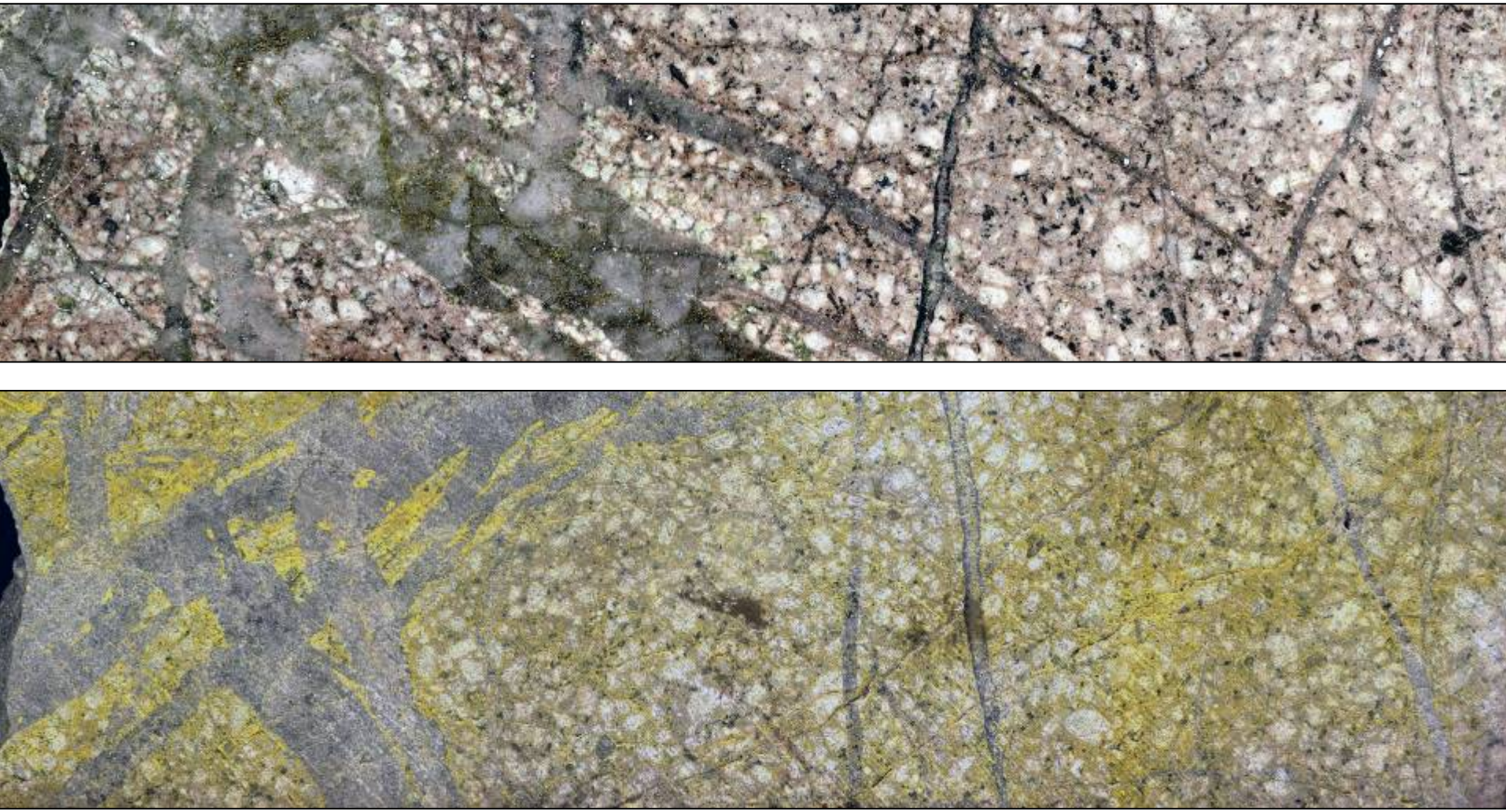
K-Feldspar Alteration (Potassic)

钾长石蚀变（钾化）





K-Feldspar Alteration (Potassic)



Orthoclase alteration and quartz vein stockwork, Boyongan, Philippines

Potassic Alteration



Orthoclase alteration and quartz vein stockwork, Cerro Casale, Chile

Potassic alteration associated with ‘stockwork’ vein arrays

脉体展布方式









Hypogene Mineralisation 深成成矿作用



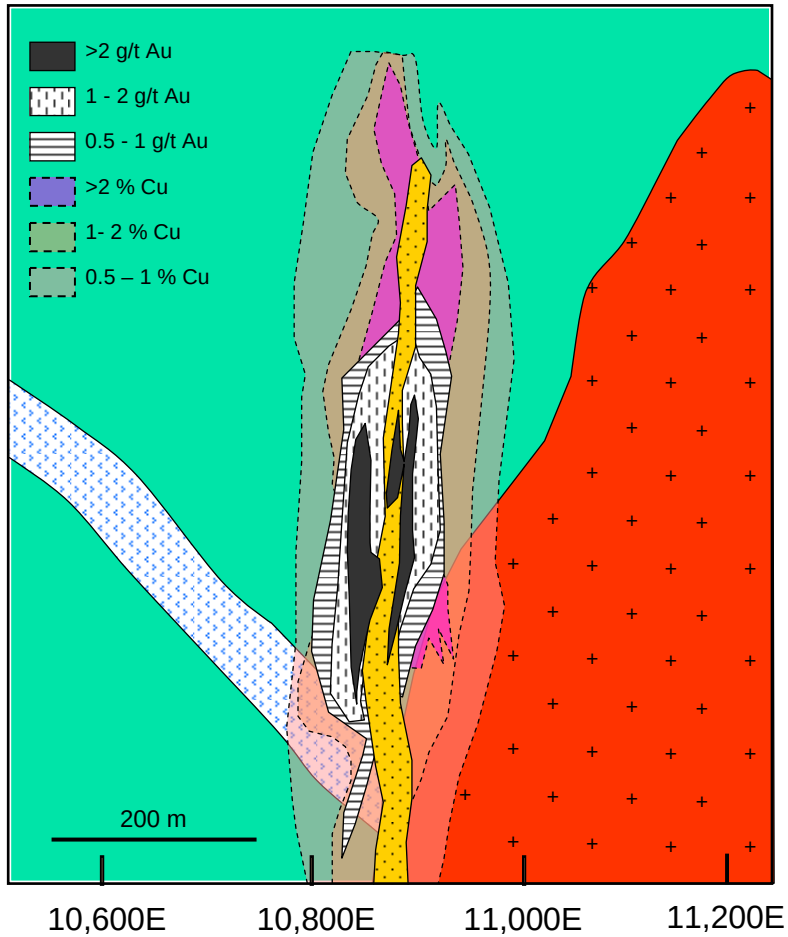
- **Main ore minerals: chalcopyrite, bornite, gold, molybdenite**
  主要矿石矿物：黄铜矿、斑铜矿、金、辉钼矿

- **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

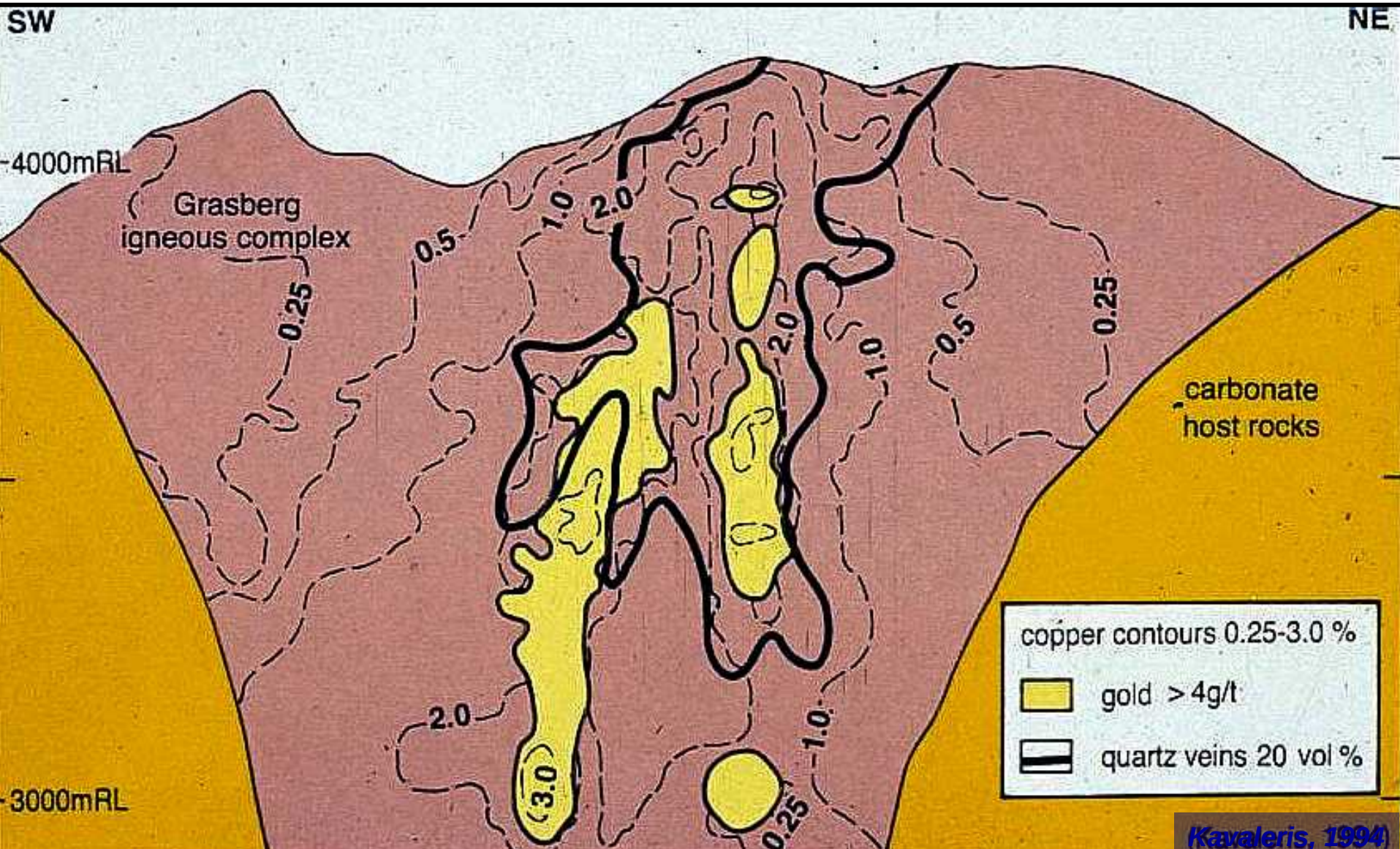
- **Cu-Au rich core surrounded by Mo-rich zone & outer pyrite halo**
  有些矿床内核富**Cu-Au**，核外环绕着中性富钼带和黄铁矿外带

E26 - Cu & Au Grades

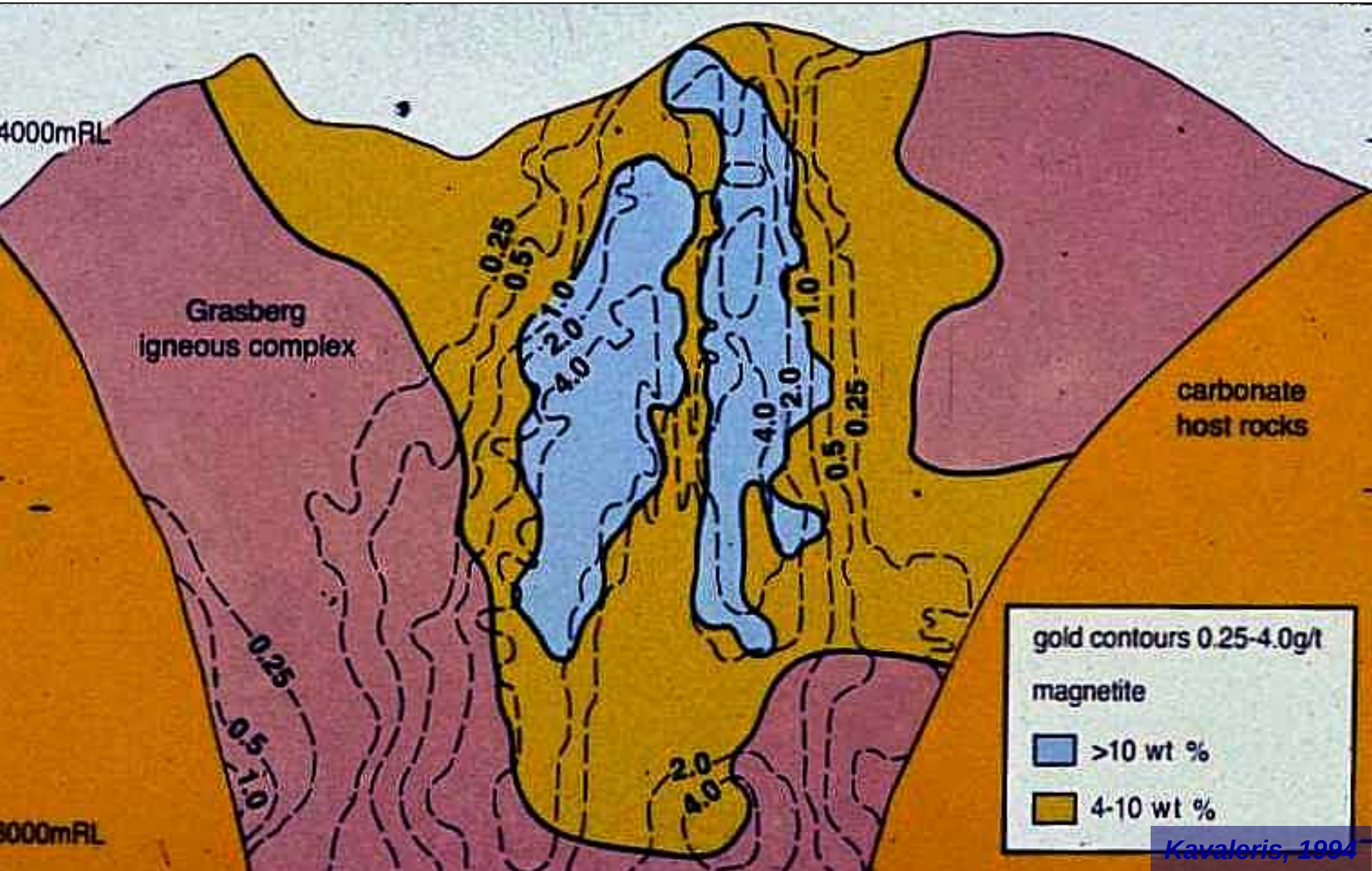


Free gold in qz-mt vein, Ridgeway, NSW 石英－磁铁矿脉不含金

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



Gold and magnetite, Grasberg, Indonesia
金和磁铁矿, Grasberg

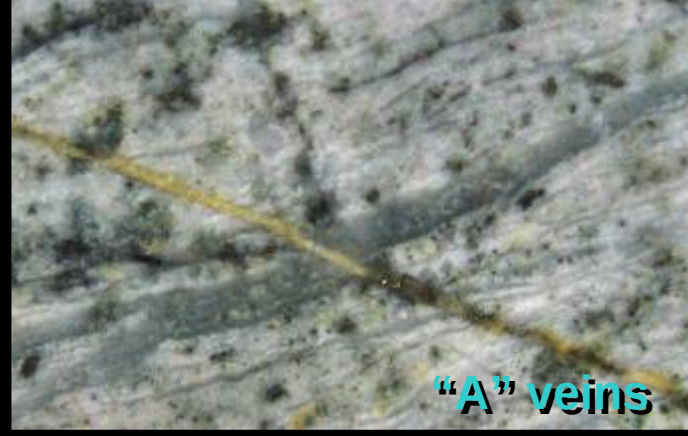


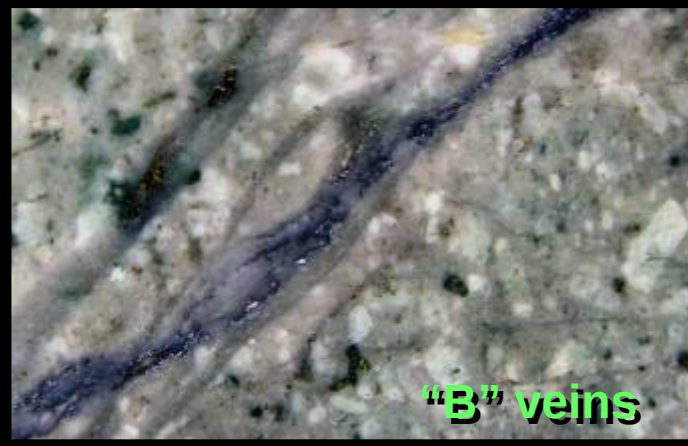
Vein Types *(Gustafson and Hunt, 1975)*

A veins: These are typically granular quartz-K-feldspar-anhydrite-sulfide veins that generally lack internal symmetry, and are irregular and discontinuous

B veins: These transitional quartz veins occupy continuous planar fractures, contain molybdenite, and lack K-feldspar and associated alteration halos

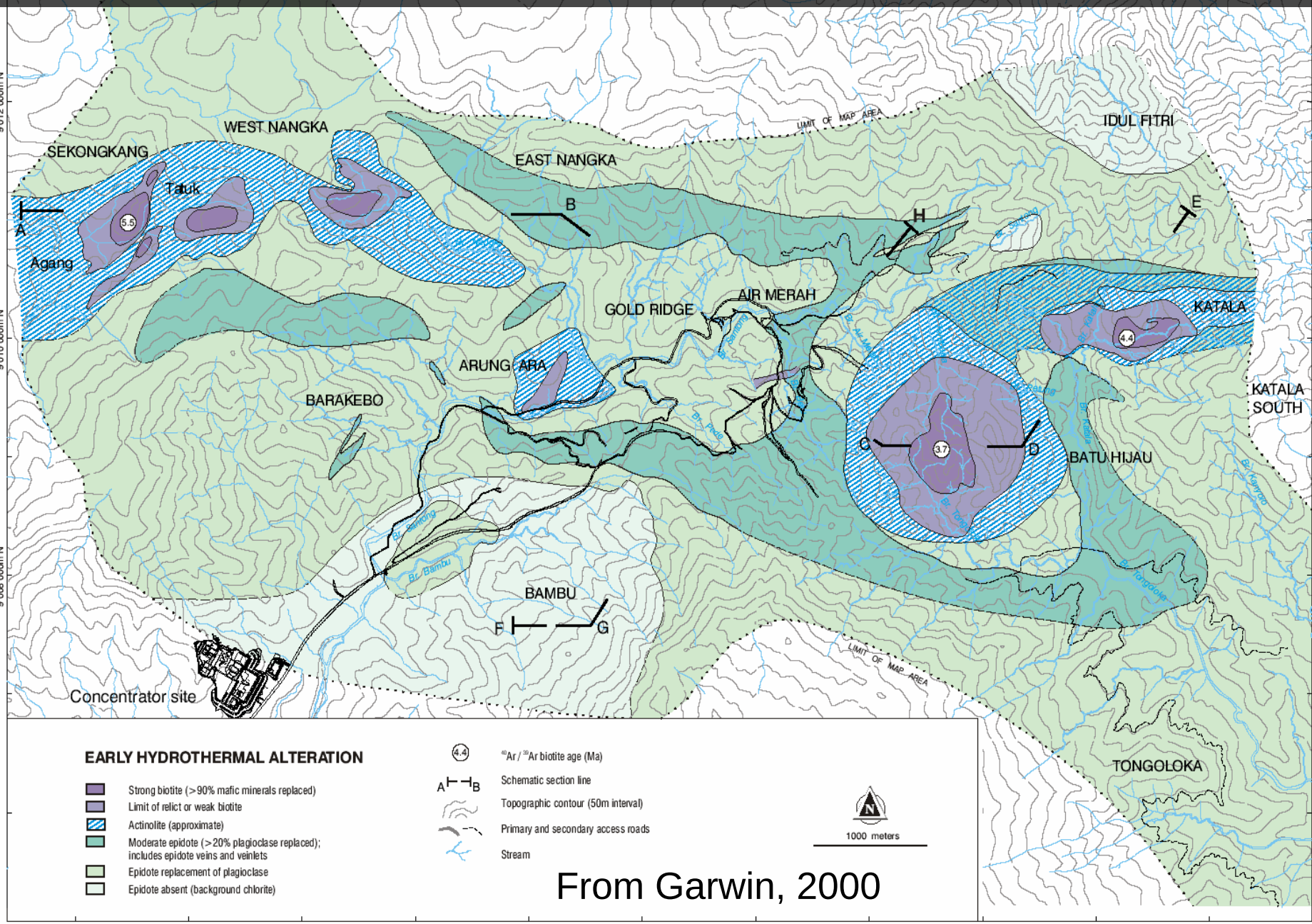
D veins: Late sulfide veins contain pyrite and lesser bornite, chalcopyrite, enargite, tennantite, sphalerite and gl, with quartz-anhydrite gangue and phyllic alteration halos







Potassic and Propylitic Alteration - Batu Hijau



From Garwin, 2000



What characterises propylitic alteration?

- **Weakly to moderately developed secondary alteration assemblage that typically preserves primary rock textures**
- **Can occur as pervasive or selectively pervasive replacements, or as vein halos**
- **Associated veins have similar mineralogies**

Mineralogy

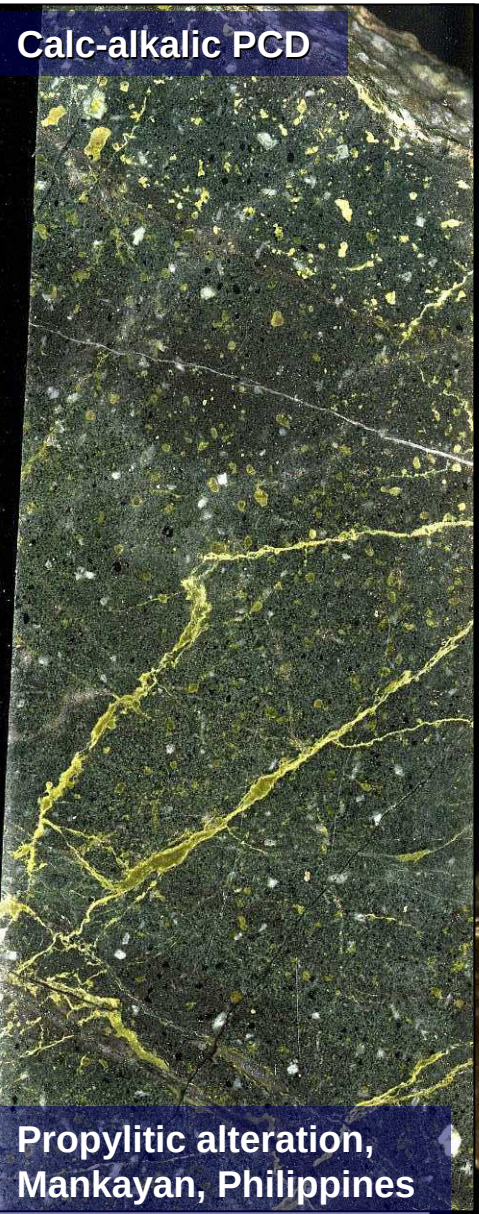
Actinolite	$Ca_2(Mg,Fe^{2+})_5Si_8O_{22}(OH)_2$
Albite	$NaAlSi_3O_8$
Calcite / Mn-calcite	$Ca(Mn)CO_3$
Chlorite	$(Mg,Fe^{2+})_6Al\ Si_3O_{10}(OH)_8$
Hematite	Fe_2O_3
Epidote	$Ca_2(Al,Fe^{3+})_3Si_3O_{12}(OH)$
Pyrite	FeS_2
Smectite	$(Ca,Na)_{0.7}(Al,Mg,Fe)_4(Si,Al)_8O_{20}OH_4{\cdot}H_2O)$

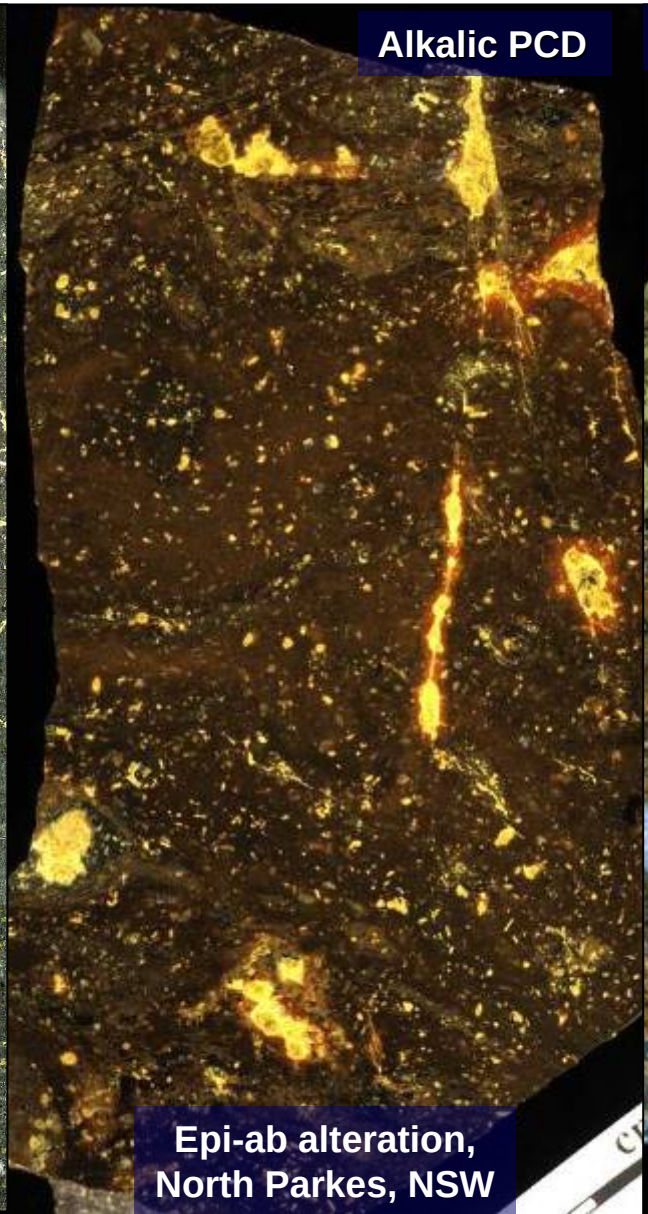
Epidote, Baja California, Mexico. Image from http://www.johnbetts-fineminerals.com

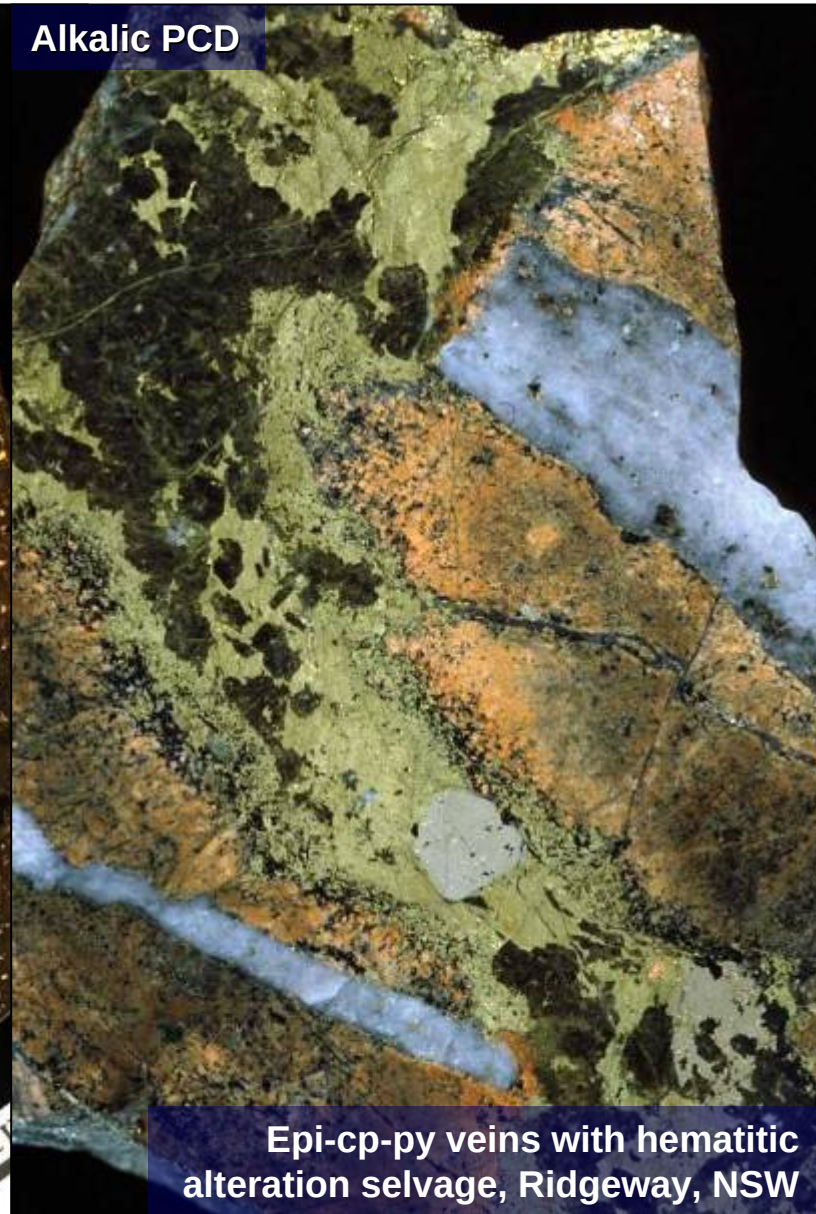
CODES

Propylitic Alteration

青磐岩化蚀变







Lithocap *(pyrite-rich stratabound domains of advanced argillic and residual silicic alteration: chargeability high, magnetic low, silicic zone defines a resistivity high)*

岩盖

The Lithocap Environment

富砷硫铜矿高硫矿化

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)*

黄铁矿带

绿色岩石环境

The Green Rock Environment

Propylitic halo *(epidote subzone)*

青盘岩化带

LS / IS 脉

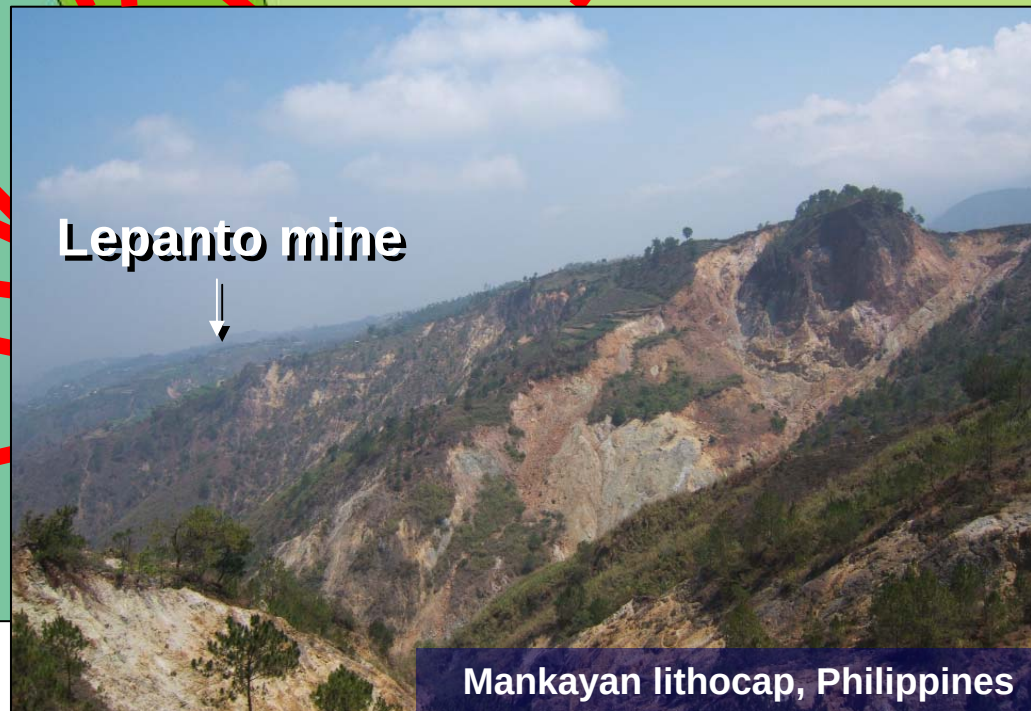
LS / IS vein *(Fault-hosted quartz-carbonate-pyrite-gold vein, Au-Ag-Zn-Pb-Te)*

青盘岩化带

Propylitic halo *(actinolite subzone)*

钾化核

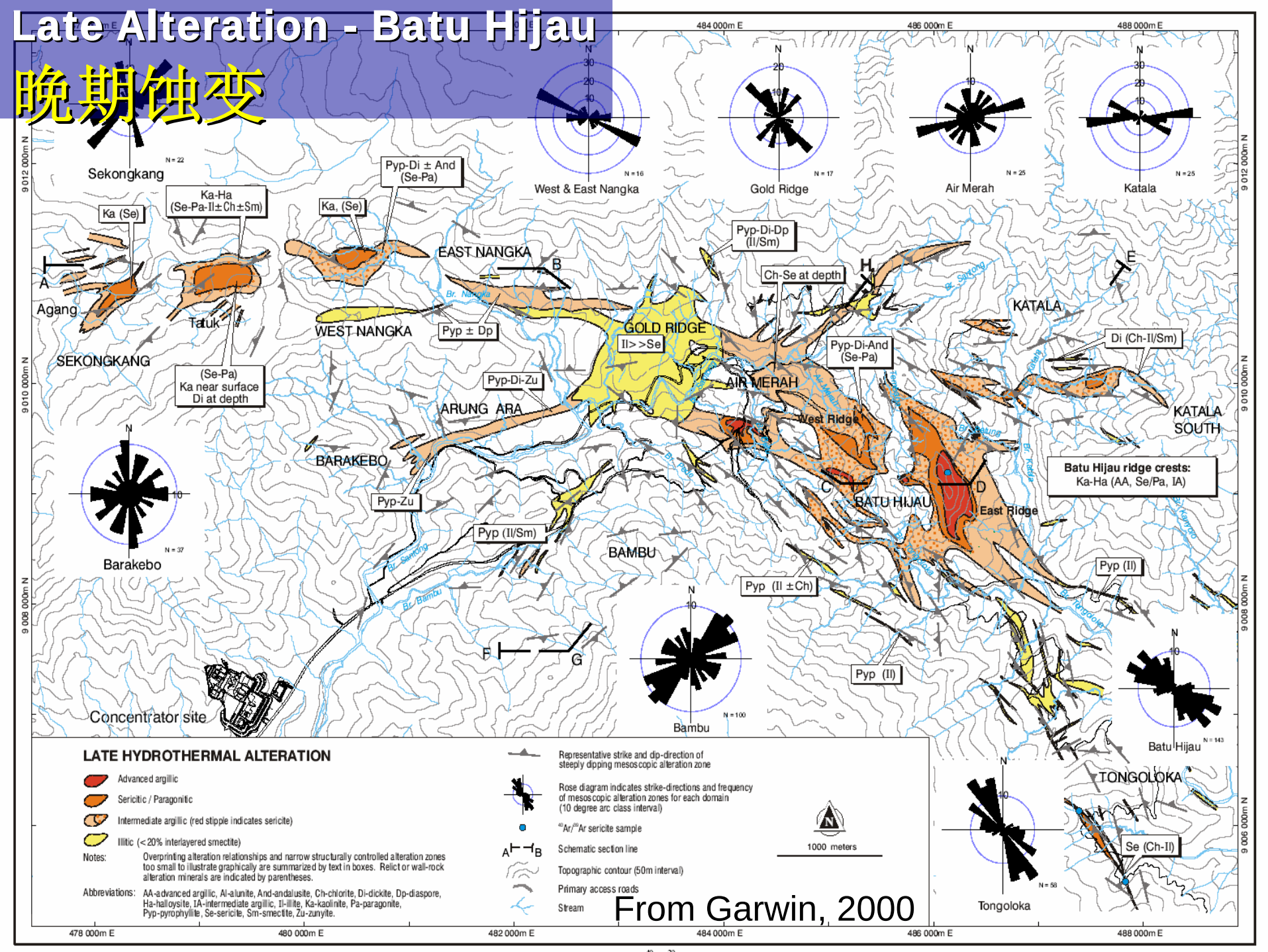
Potassic core *(magnetic high or low, Cu-Au-Mo geochemical anomaly)*



Mankayan lithocap, Philippines

Late Alteration - Batu Hijau

晚期蚀变



From Garwin, 2000

Intermediate Argillic Alteration

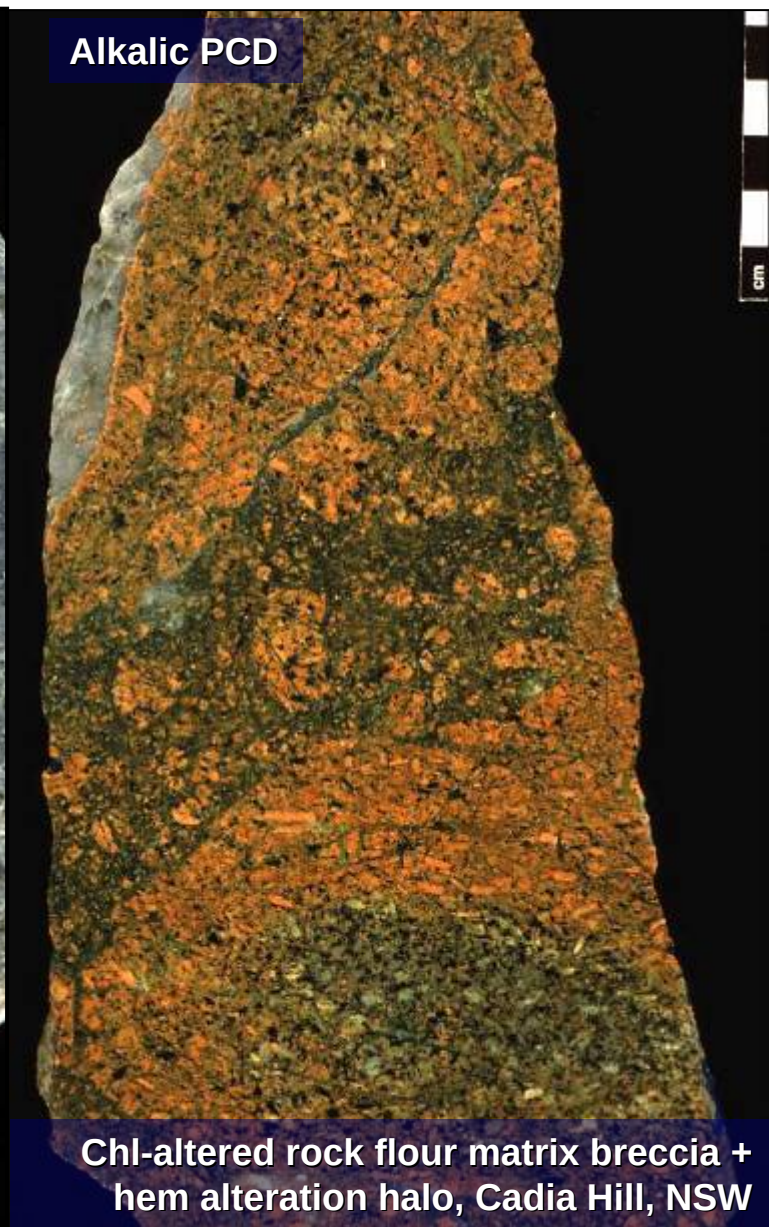
中性泥化蚀变



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

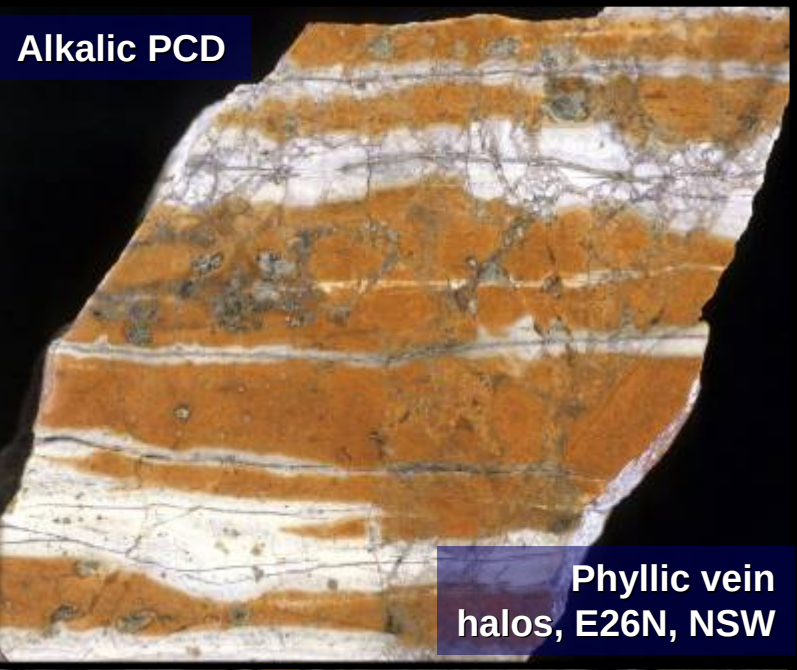


Pervasive int. arg. alteration, Philex, Philippines

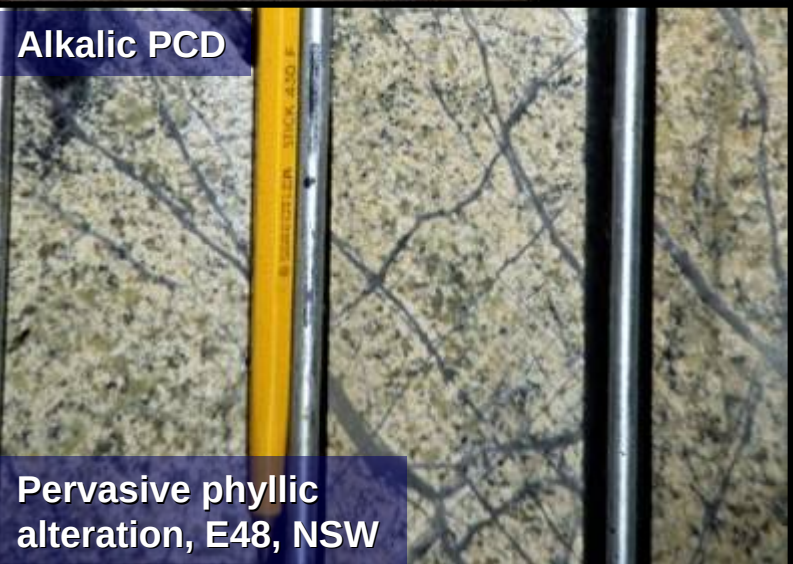


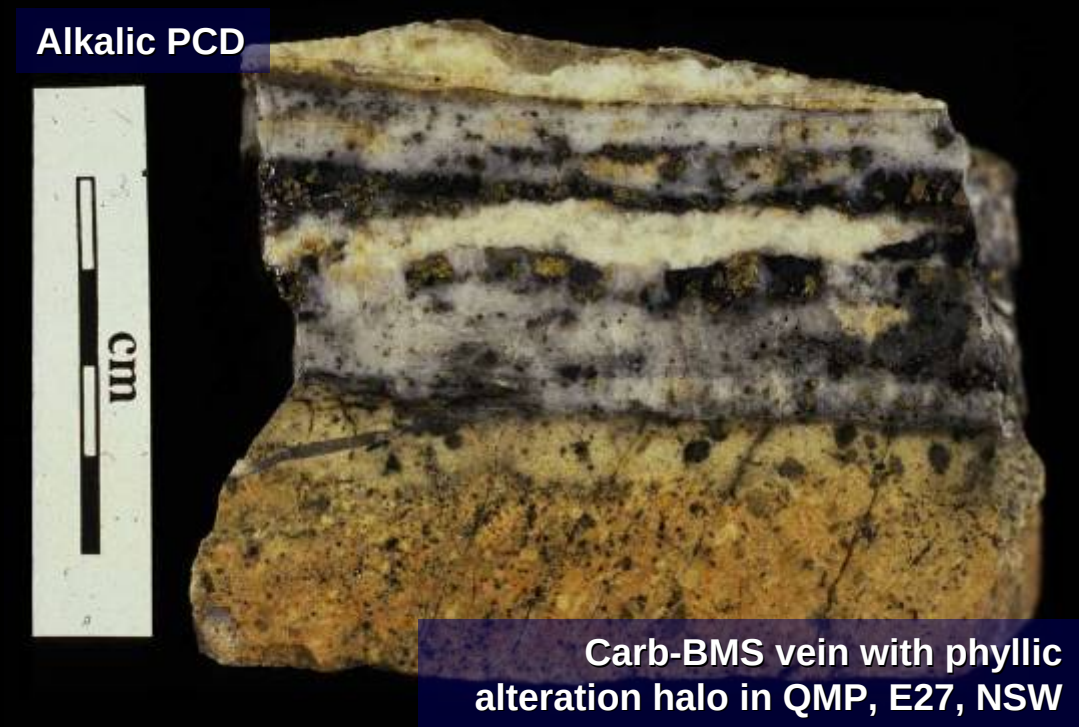
Chl-altered rock flour matrix breccia + hem alteration halo, Cadia Hill, NSW

Phyllic Alteration 绢英岩化蚀变



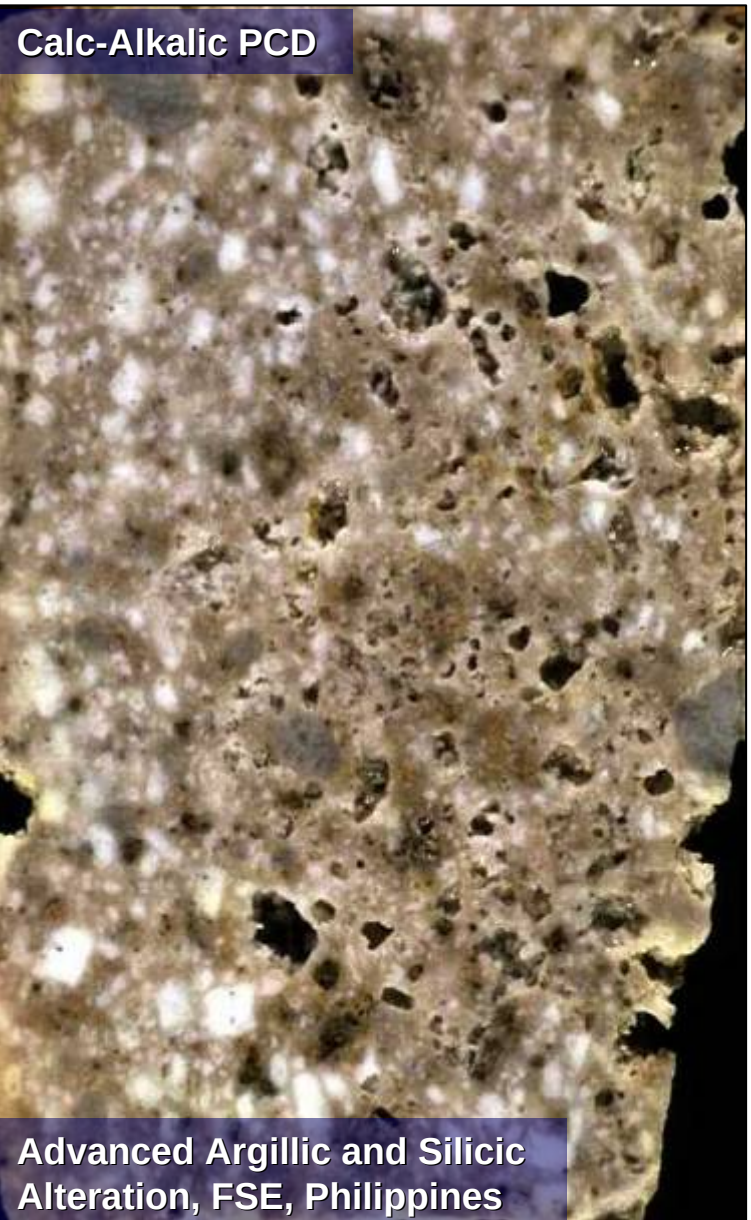


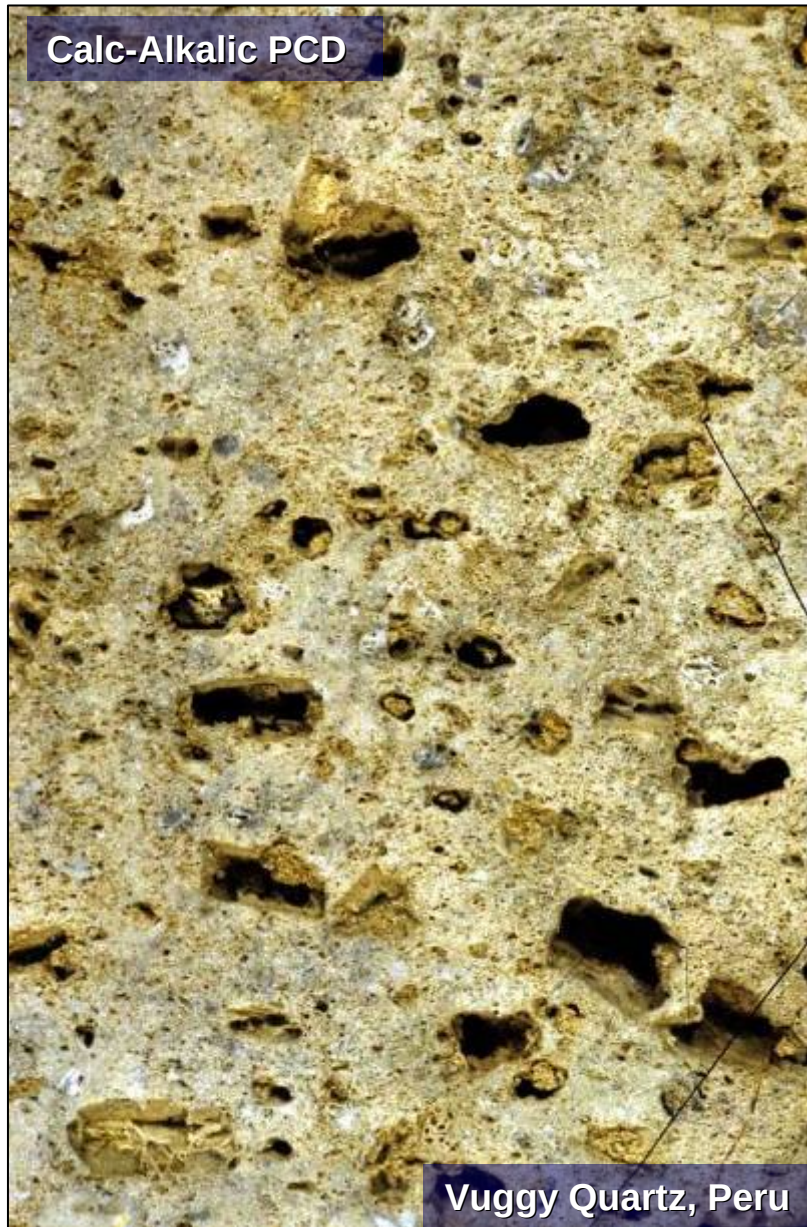




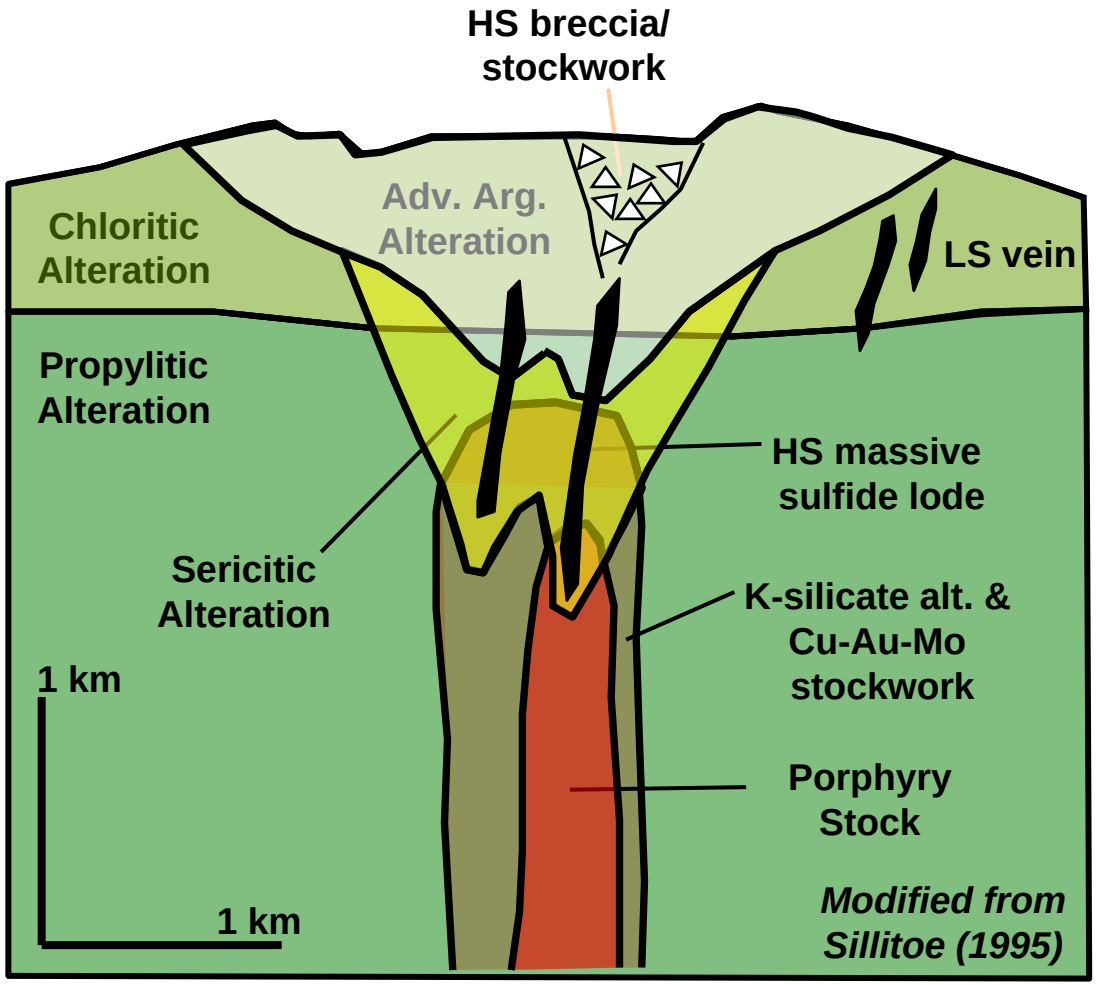
Advanced Argillic Alteration

高级泥化蚀变



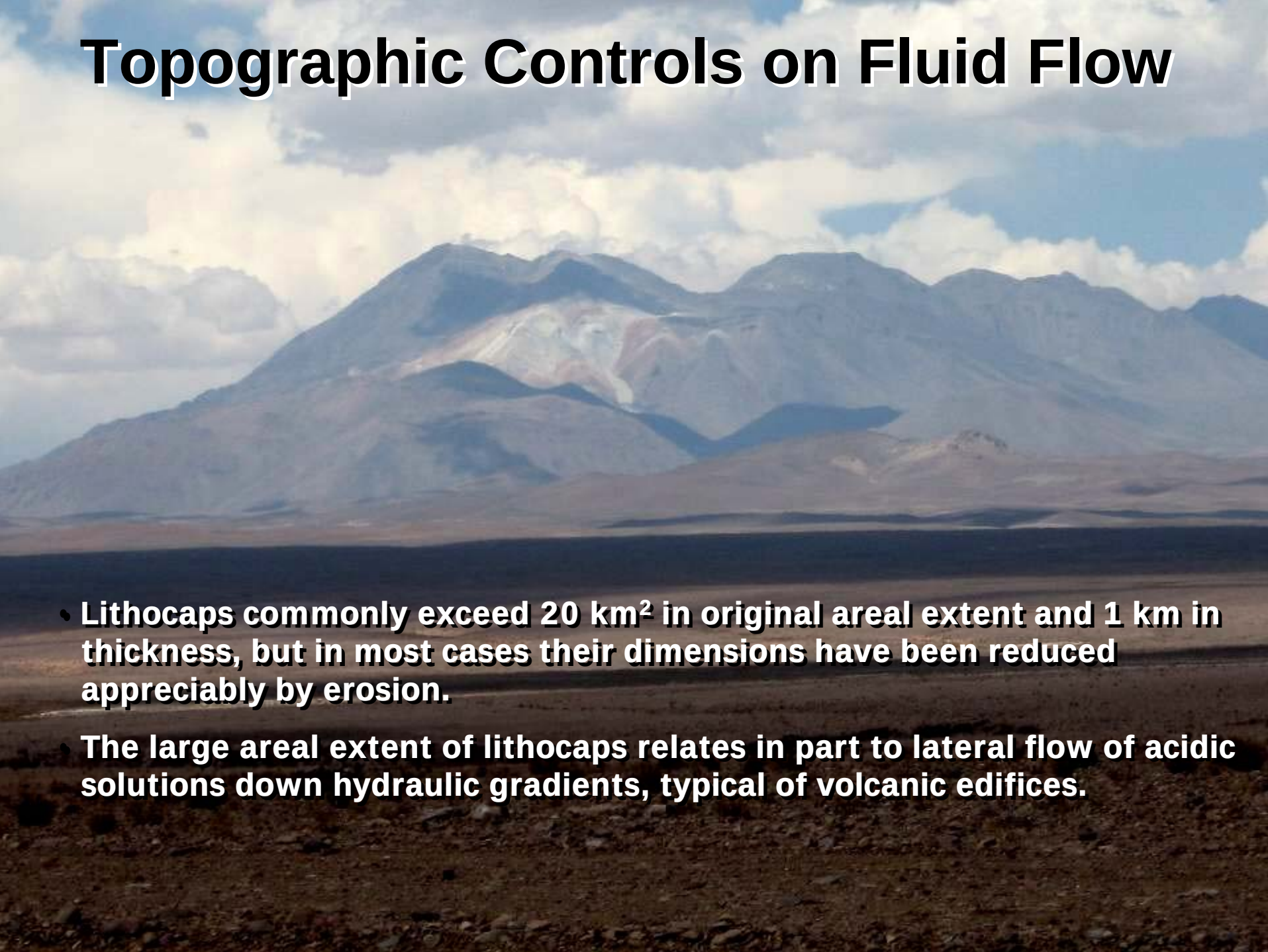


Lithocaps - Sillitoe, 1995



- **Lithocaps are large, topographically prominent masses of pyritic advanced argillic and argillic alteration that form in the shallow subsurface.**
- **They can overlie subvolcanic intrusions that host porphyry Cu, Au, Mo or Sn deposits.**

Topographic Controls on Fluid Flow



- Lithocaps commonly exceed 20 km^2 in original areal extent and 1 km in thickness, but in most cases their dimensions have been reduced appreciably by erosion.
- The large areal extent of lithocaps relates in part to lateral flow of acidic solutions down hydraulic gradients, typical of volcanic edifices.

Mankayan lithocap

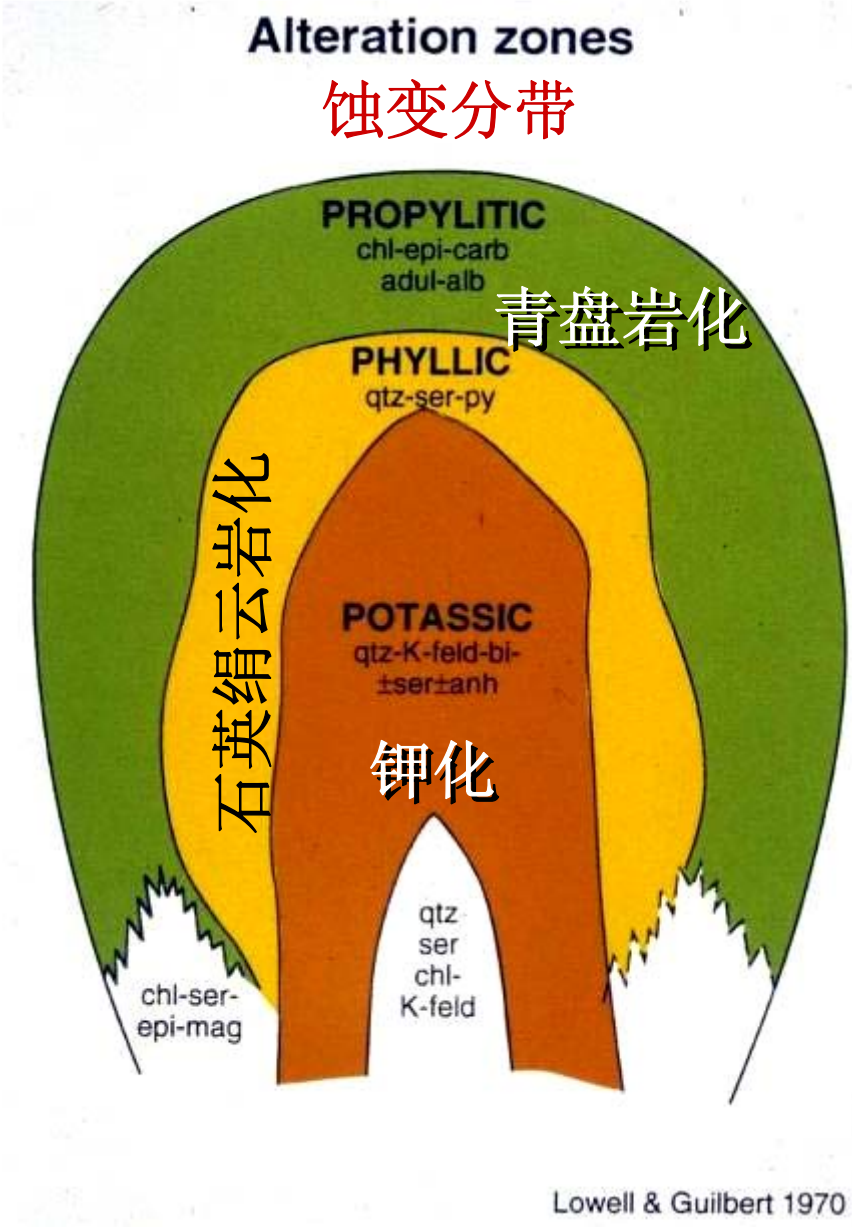


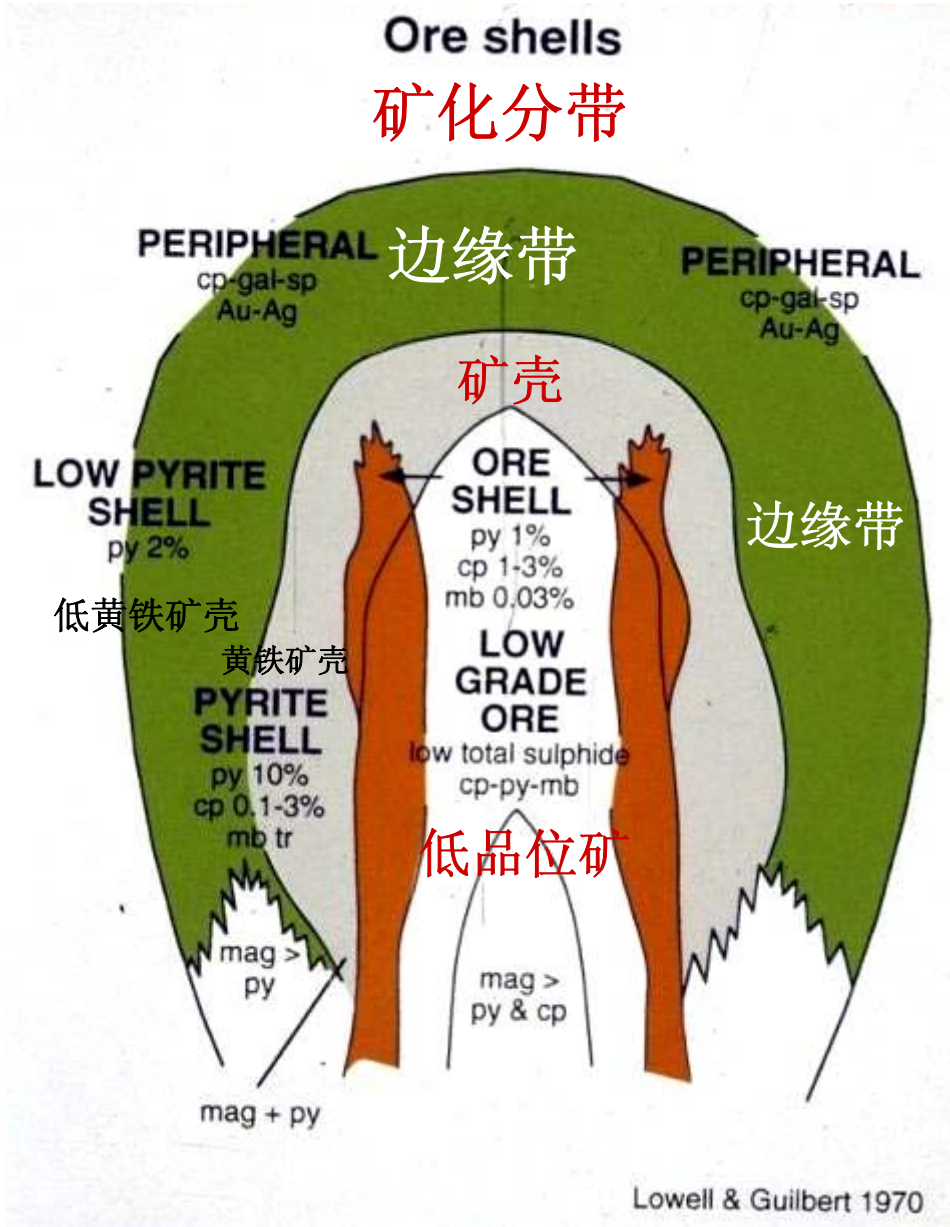
Lithocap, East Asia



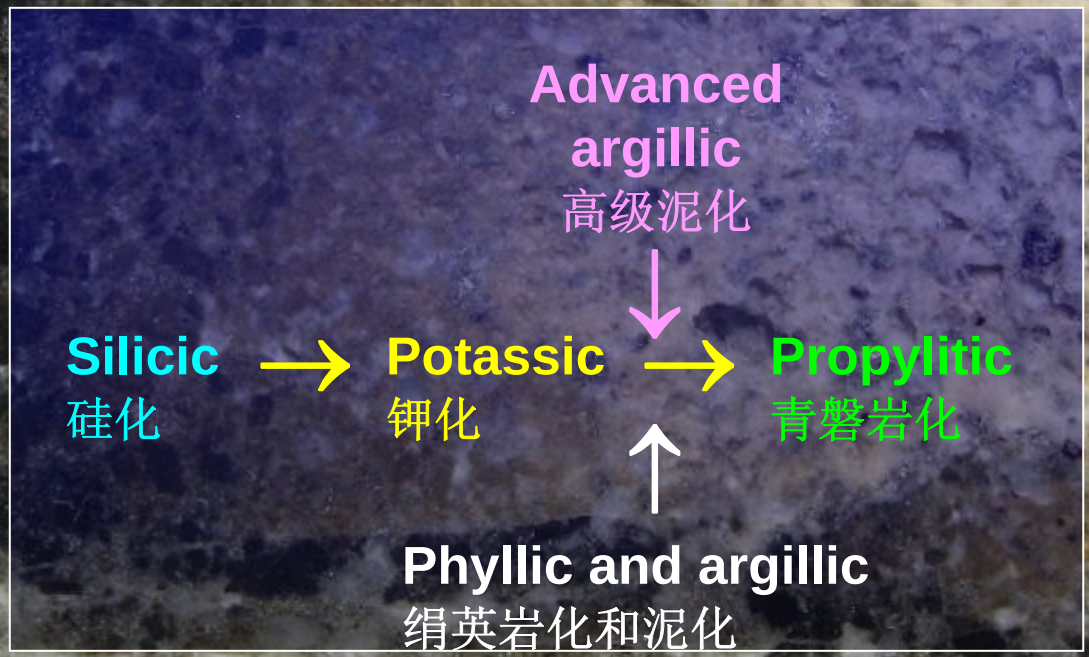
Vuggy quartz-alunite

Alteration Zonation
蚀变分带



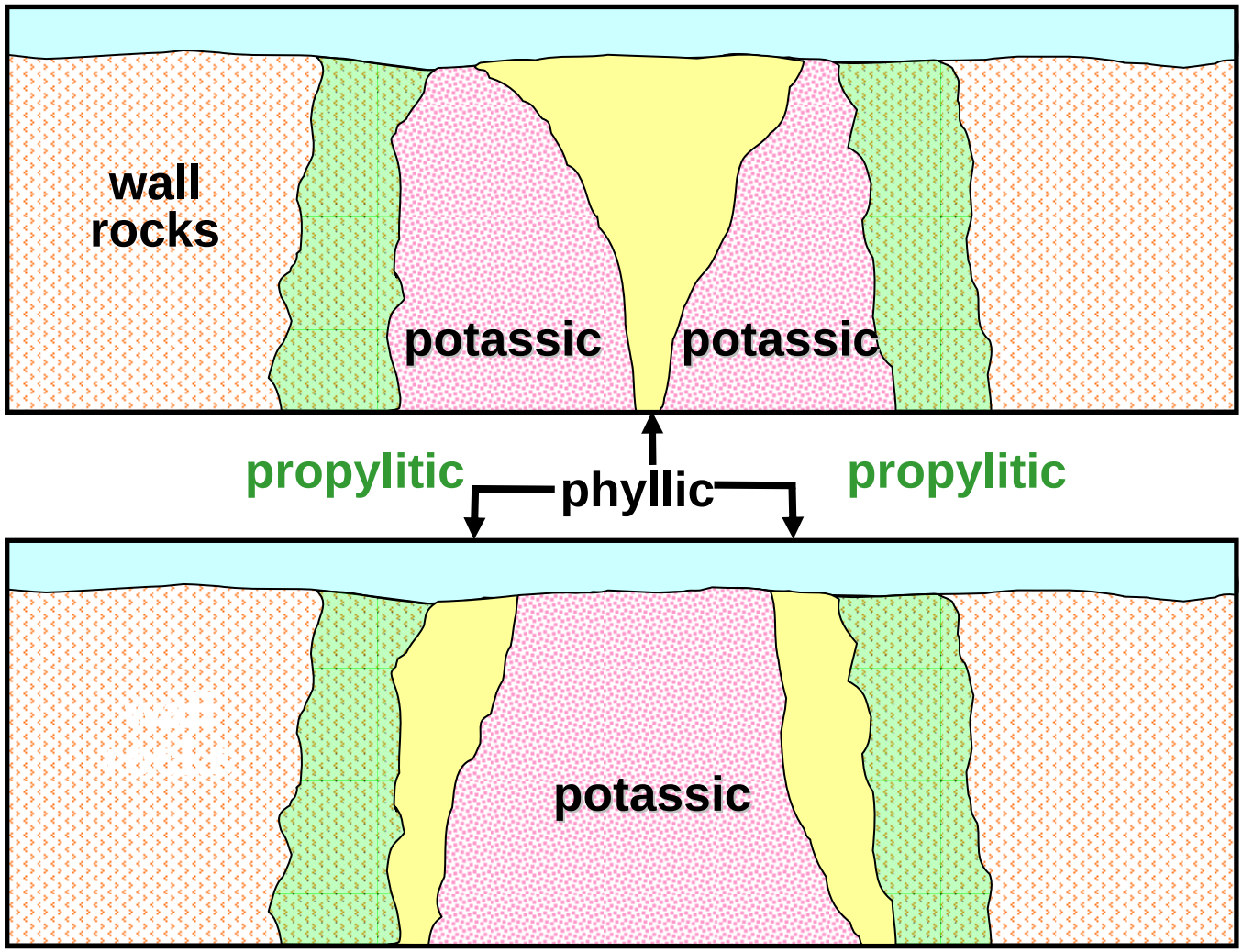


Alteration Zoning
蚀变分带



Alteration Zoning 蚀变分带

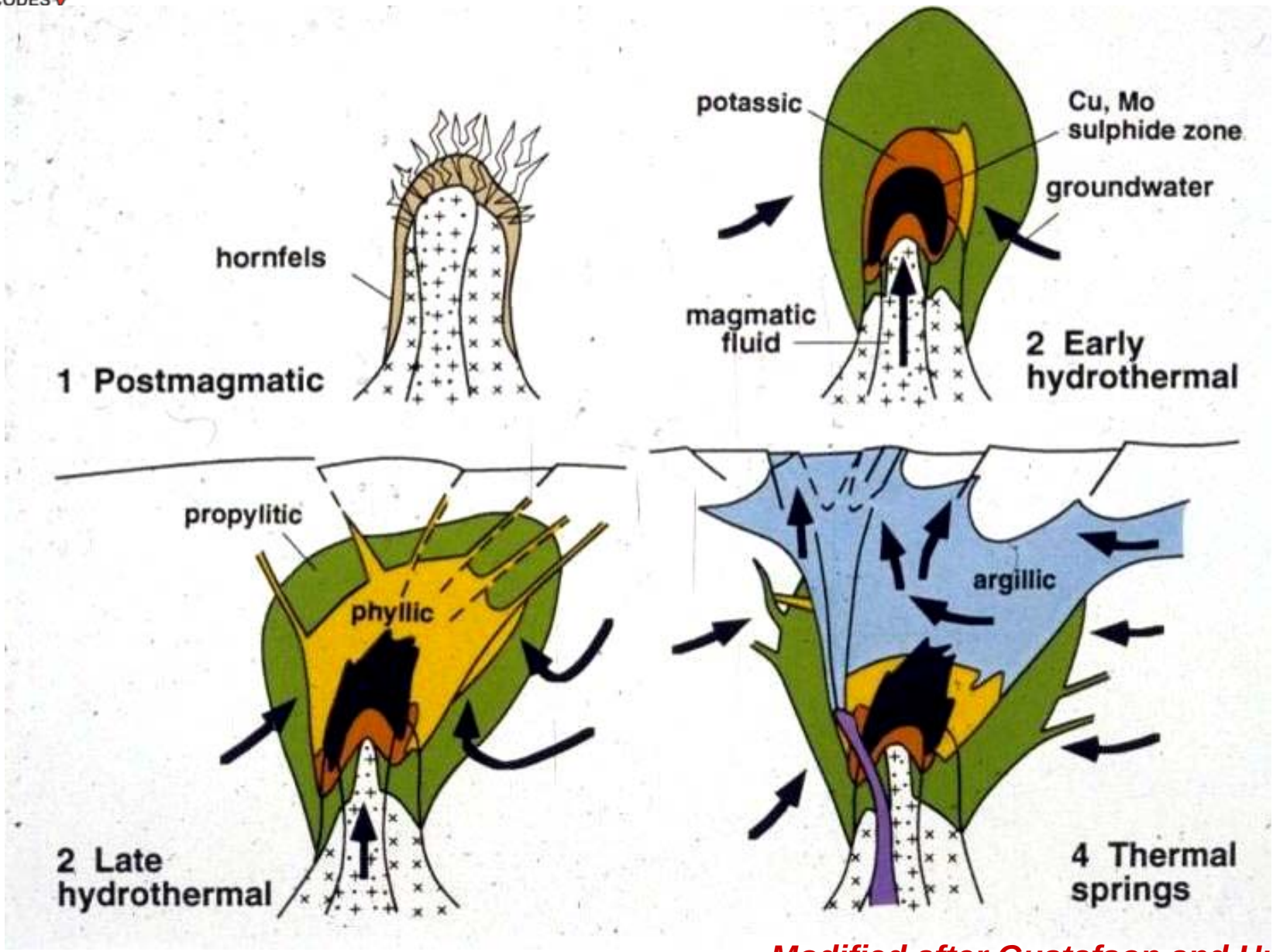
South American porphyry model



Lowell and Guilbert (1970) model

- Phyllic alteration can be produced by magmatic-hydrothermal fluids
- 绢英岩化蚀变由岩浆—热液流体产生
- The phyllic alteration zone can cut through potassic alteration zones, and be independently mineralised
- 绢英岩化蚀变可以切穿钾化，独立形成矿化。

Alteration Overprinting 蚀变叠加

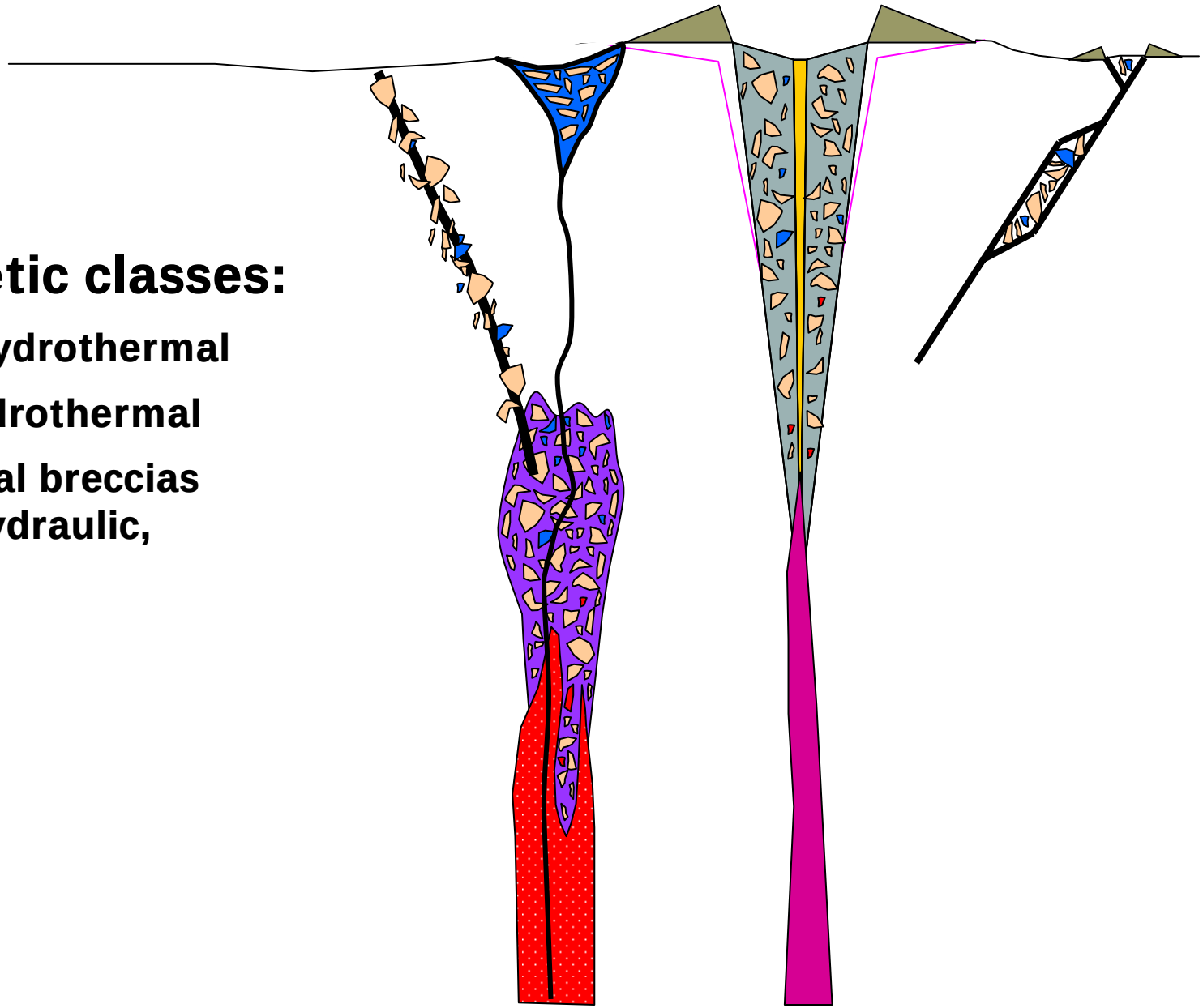


Modified after Gustafson and Hunt 1975

Breccias in Magmatic - Hydrothermal Systems

Major genetic classes:

- **Magmatic-hydrothermal**
- **Volcanic-hydrothermal**
- **Hydrothermal breccias (phreatic, hydraulic, corrosive)**
- **Tectonic**

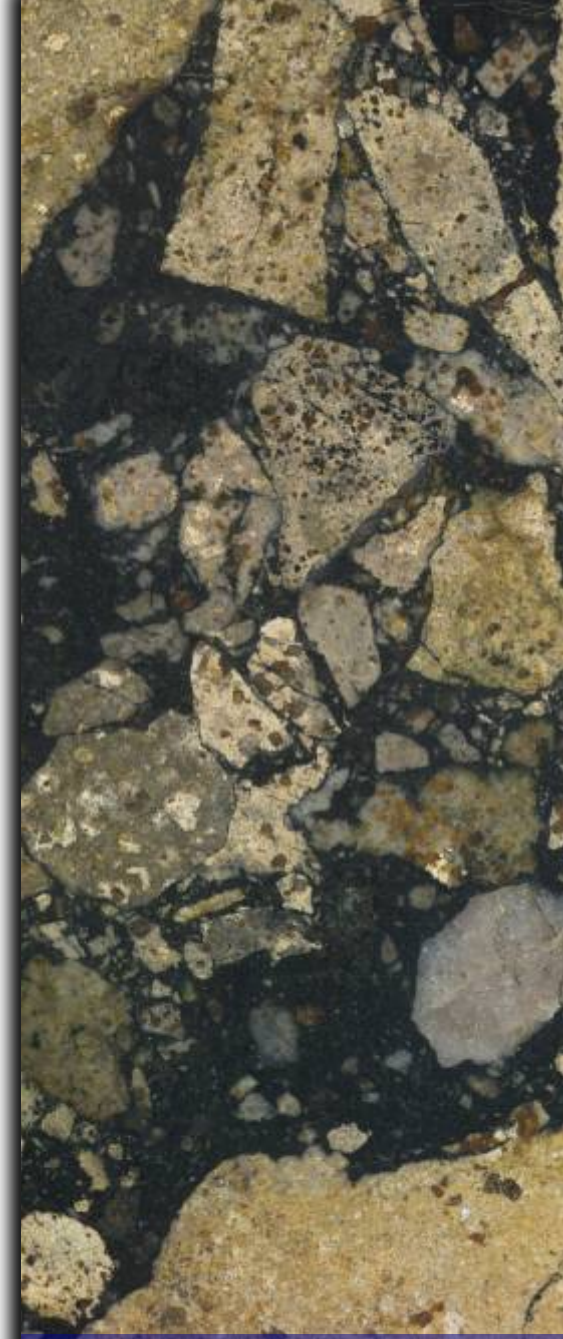


Magmatic-hydrothermal breccias

- Generated by explosive fluid release from crystallising porphyry
- Angular clasts -implies limited clast transport & abrasion
- High temperature alteration rinds *(clasts)* and altered matrix
- Sulfide cement



Tourmaline-chalcopyrite cement, Rio Blanco



Polymict tourmaline breccia, Sierra Gorda, Chile

Sulfide Mineralisation Styles 硫化物矿化类型



Tourmaline breccia,
Río Blanco, Chile

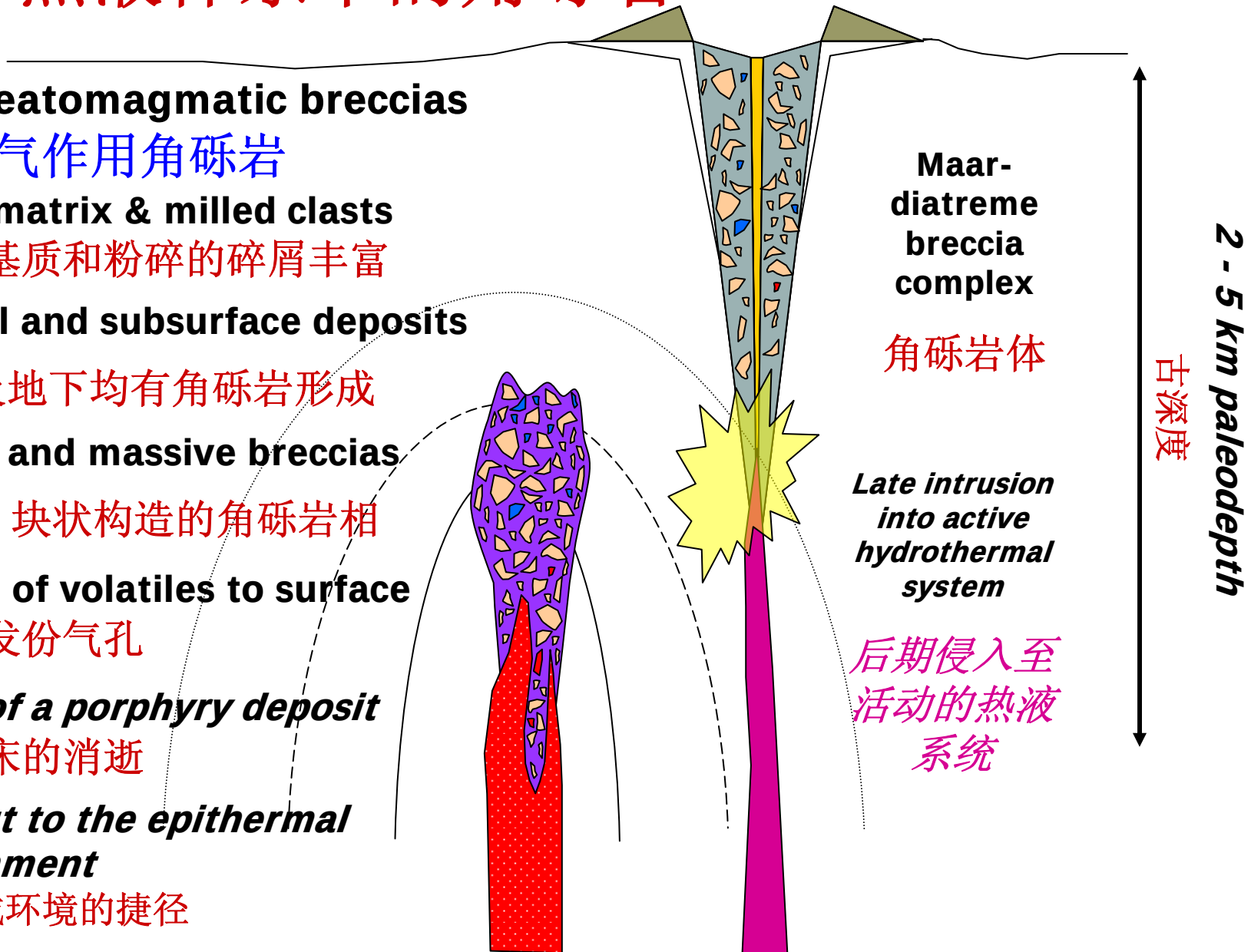
Breccias in Hydrothermal Systems
热液体系中的角砾岩

2 – Phreatomagmatic breccias
岩浆蒸气作用角砾岩

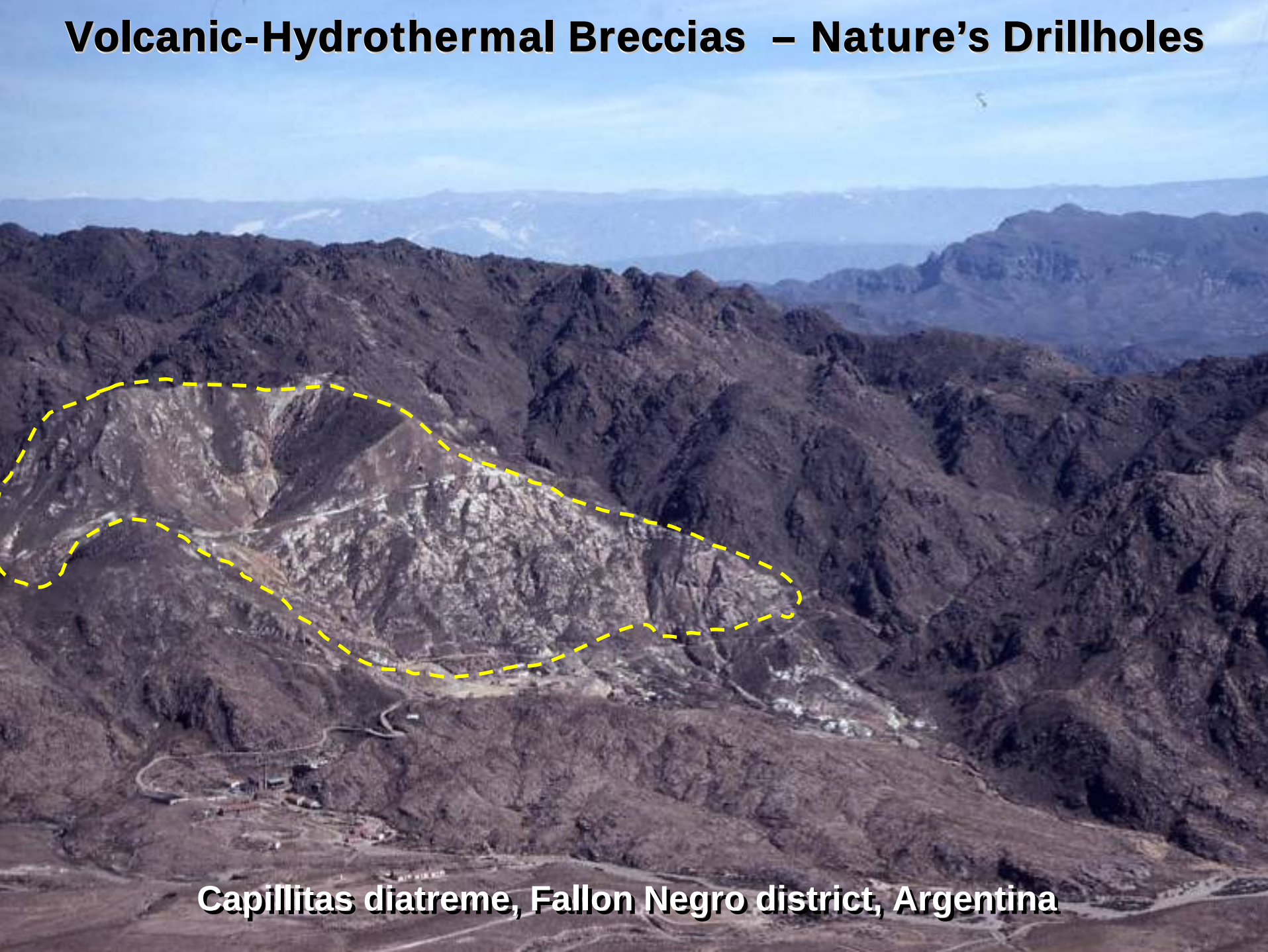
- **Clastic matrix & milled clasts**
  碎屑状基质和粉碎的碎屑丰富
- **Surficial and subsurface deposits**
  在地表及地下均有角砾岩形成
- **Bedded and massive breccias**
  条带状、块状构造的角砾岩相
- **Venting of volatiles to surface**
  地表挥发份气孔

⇒ ***death of a porphyry deposit***
斑岩矿床的消逝

⇒ ***shortcut to the epithermal environment***
形成浅成环境的捷径

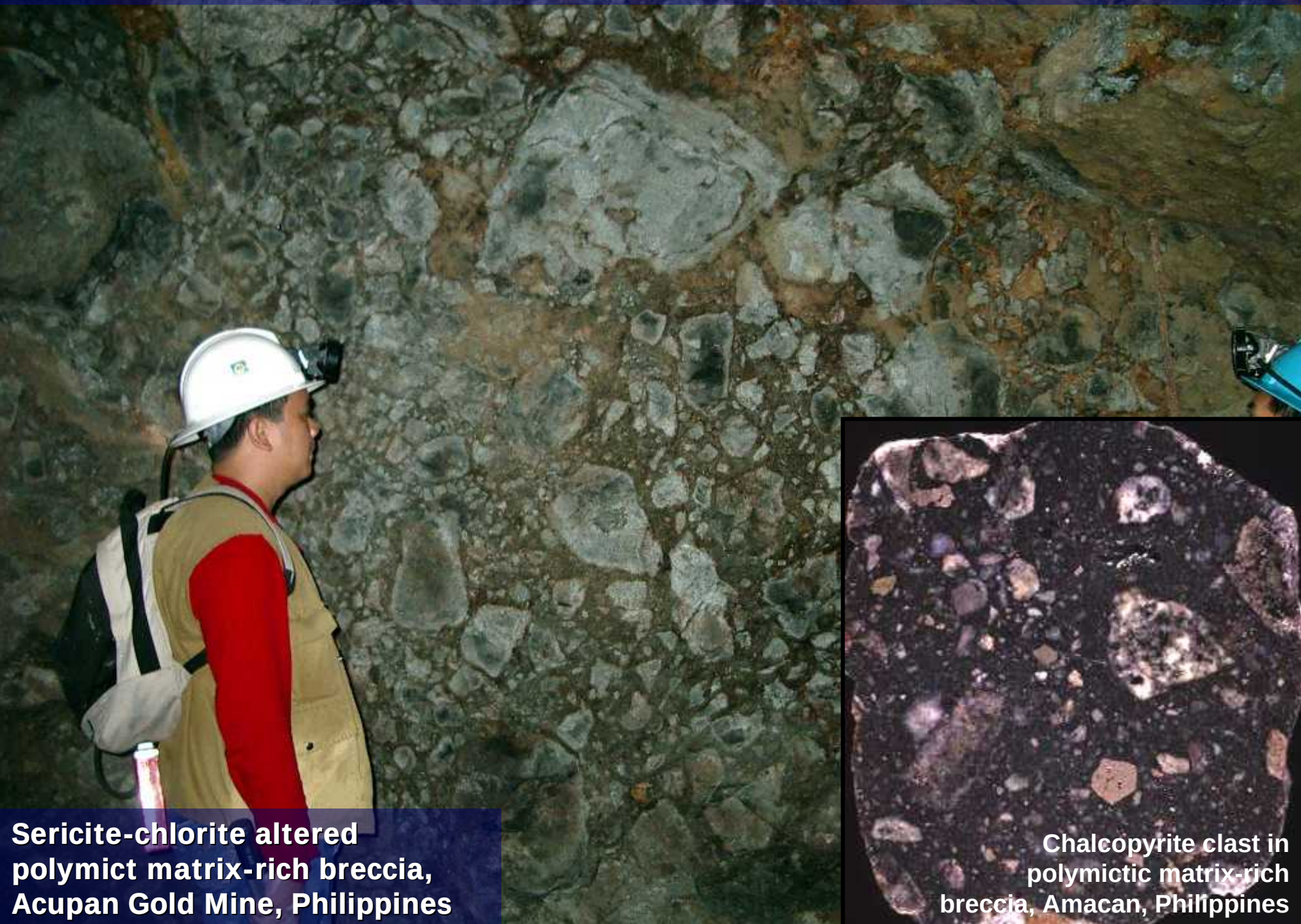


Volcanic-Hydrothermal Breccias – Nature's Drillholes



Capillitas diatreme, Fallon Negro district, Argentina

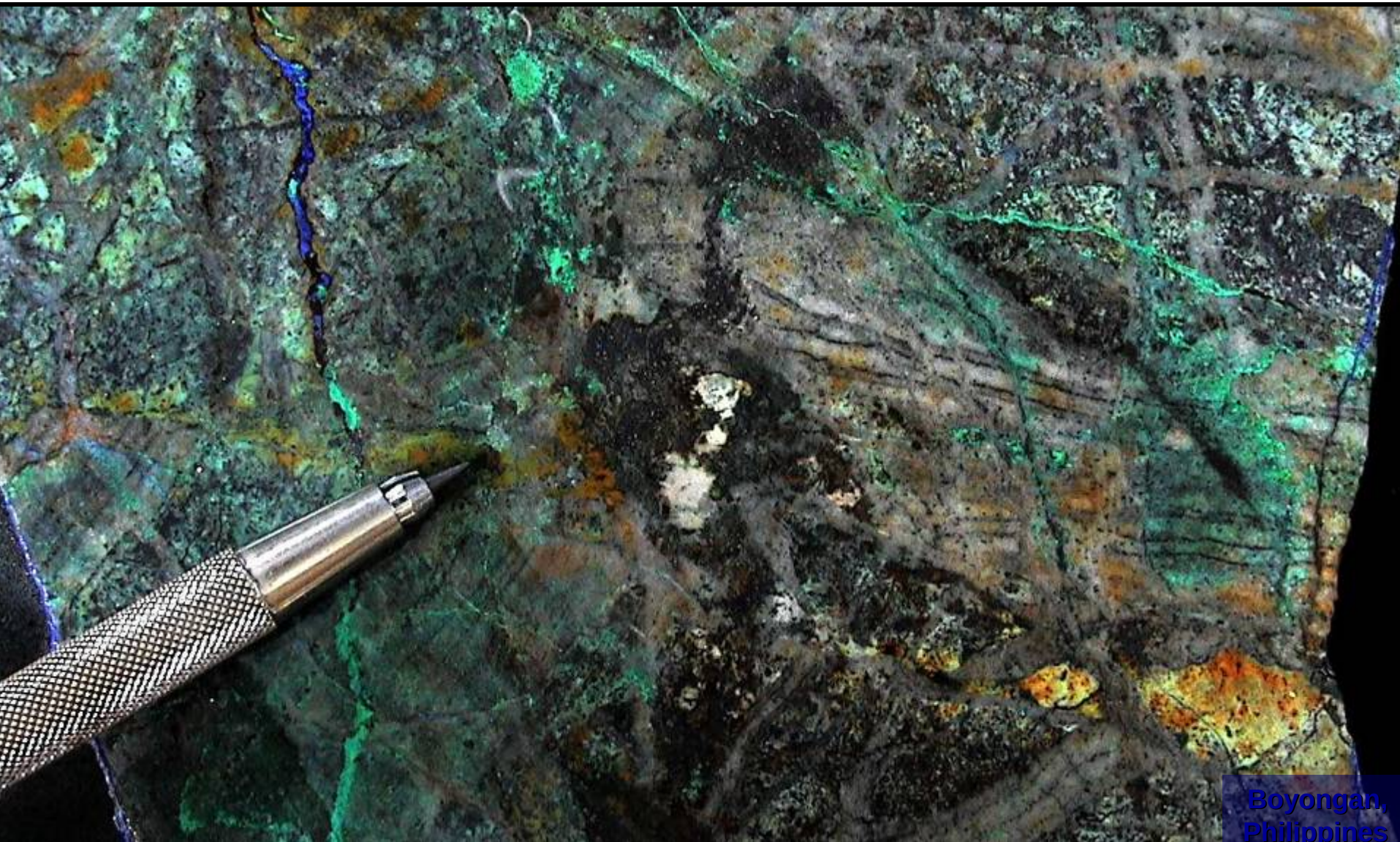
Late-stage diatreme breccia at Acupan Au-Ag mine, Philippines



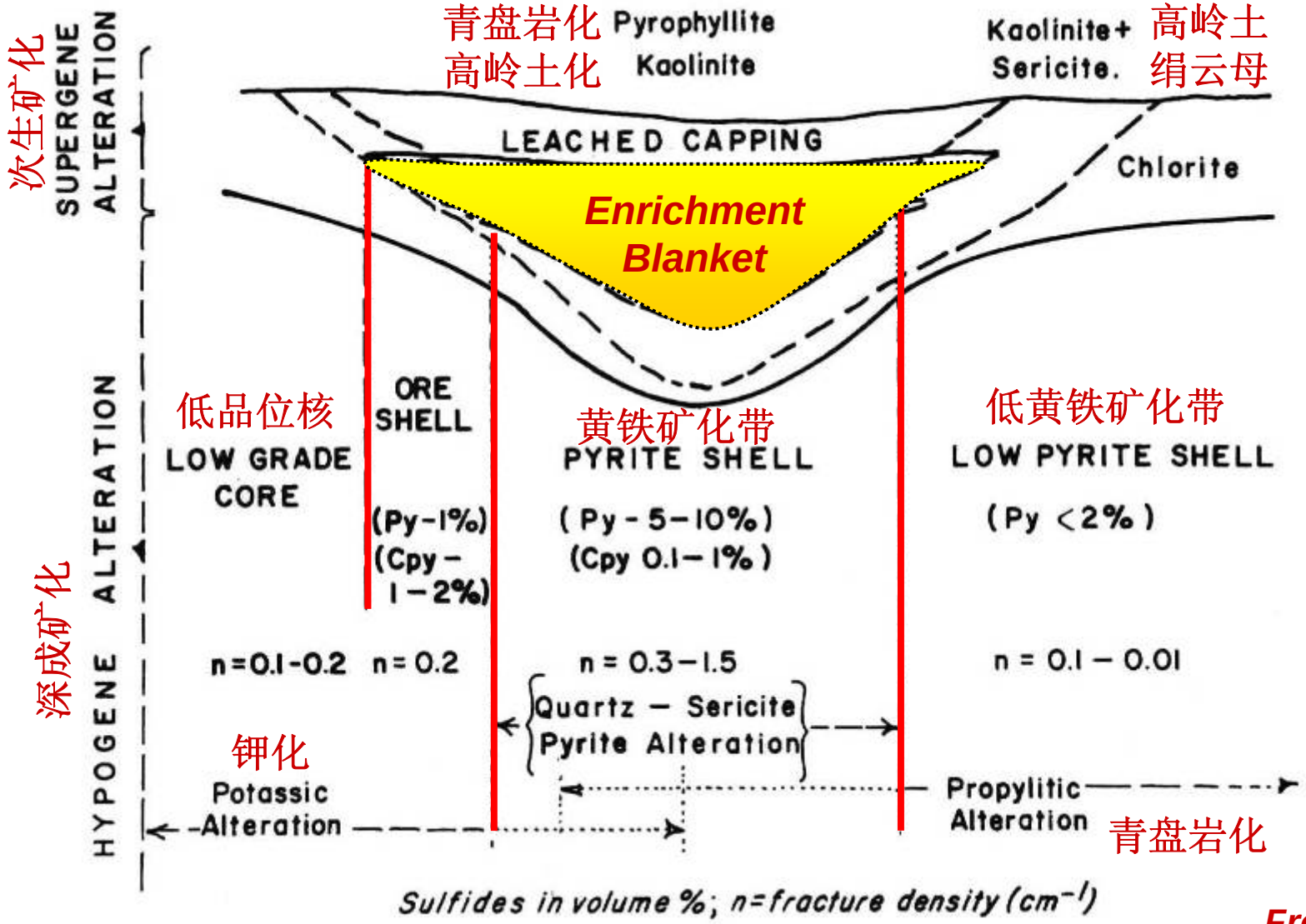
Sericite-chlorite altered polymict matrix-rich breccia, Acupan Gold Mine, Philippines

Chalcopyrite clast in polymictic matrix-rich breccia, Amacan, Philippines

Supergene Mineralisation
次生成矿作用

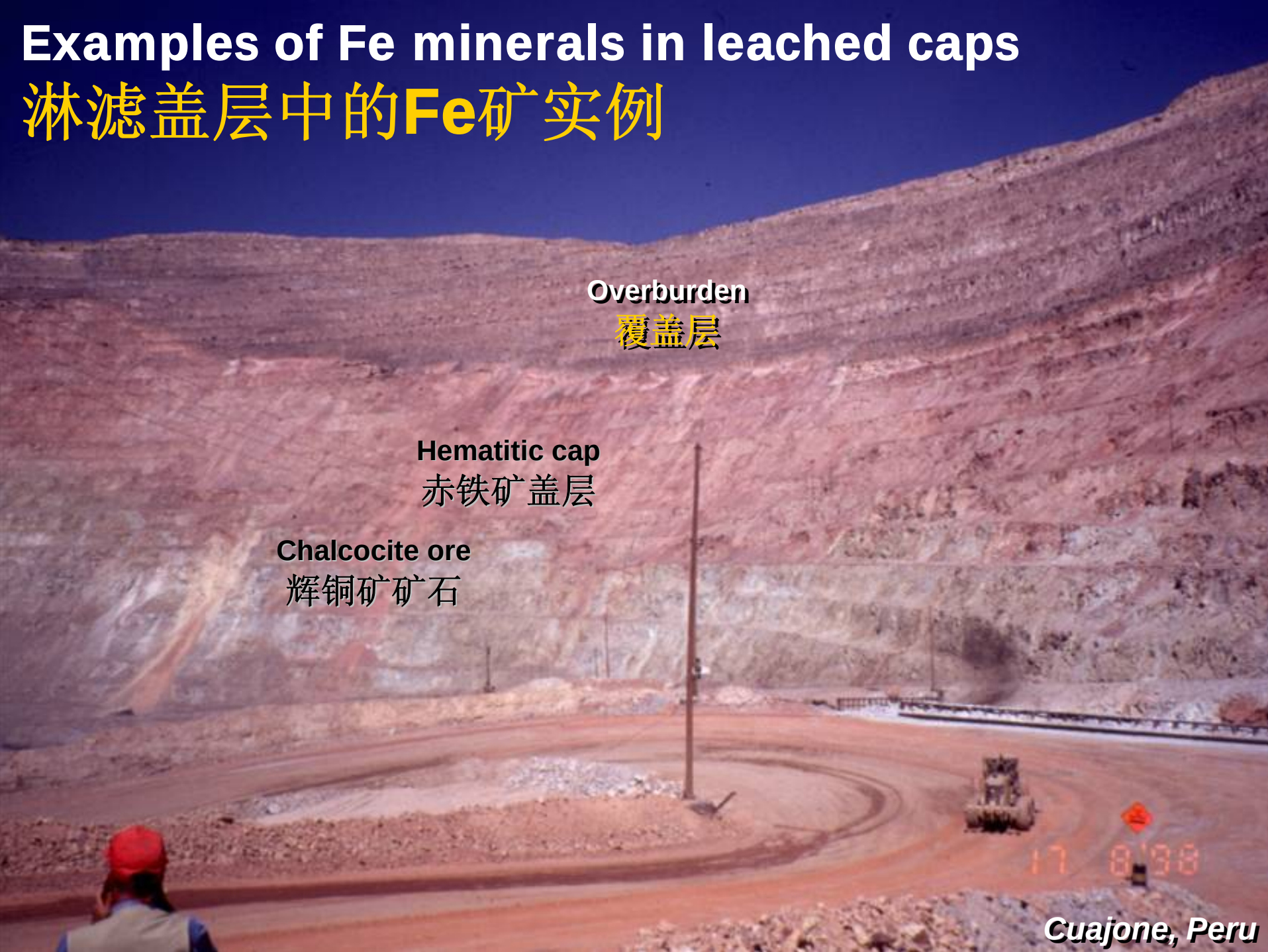


Idealised supergene enrichment blanket
次生矿床富集层位理想模式



From Titley, 1982

Examples of Fe minerals in leached caps
淋滤盖层中的Fe矿实例



Examples of Fe minerals in leached caps

淋滤盖层中的Fe矿实例



Jarositic leached cap in a highly pyritic Ag-Au bearing epithermal system, Bolivia

含Ag-Au的富黄铁矿浅成热液矿床 中的黄钾铁钒淋滤层



Goethitic leached cap above a pyritic Sn-Ag porphyry system, Bolivia

含Sn-Ag黄铁矿 斑岩体系上的针铁矿淋滤层

Identifying residuals minerals in leached caps

淋滤盖层中的残留矿的鉴别

Limonites 褐铁矿:

–From Peterson and Chavez (2002).

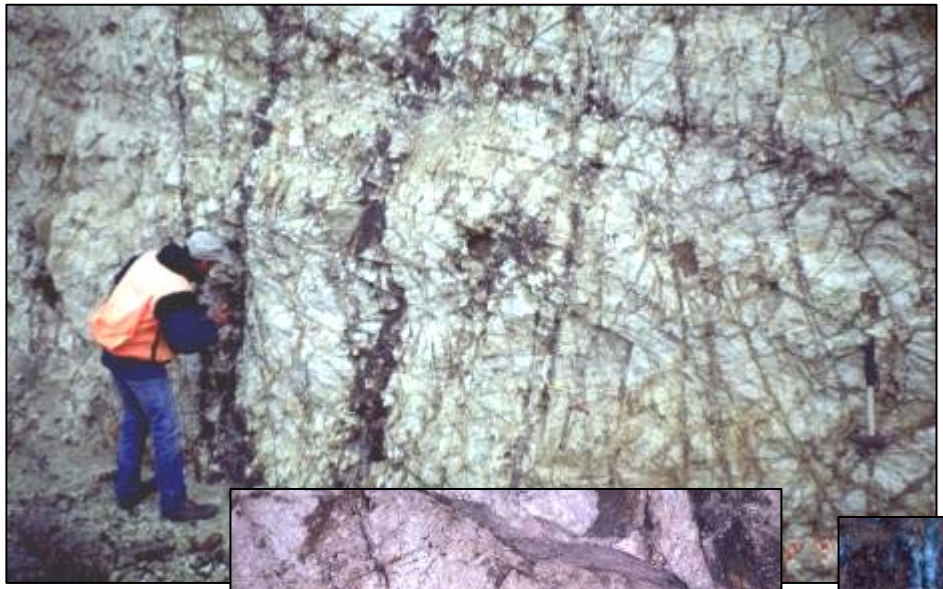


Hematite 赤铁矿 **Goethite** 针铁矿 **Jarosite** 黄钾铁钒

- **Iron oxide characterization chart for comparing smudges from leached outcrops and drill holes intervals**
  氧化铁特征图，用于对比经淋滤的露头与钻孔中的烟灰色差异
- **Mixtures of red hematite, goethite and jarosite will produce gradational colors as shown in the standard box**
  用红色赤铁矿、针铁矿及黄钾铁矾进行混合，会产生象标准图标中一样的颜色等级
- **Note that the standard smudges are derived from leached capping environments and represents XRD analyzed end-member iron oxides**
  注意，标准的烟灰色淋滤层环境，代表经**XRD**分析了的铁氧化物的一个端元

Examples of Cu minerals in leached caps

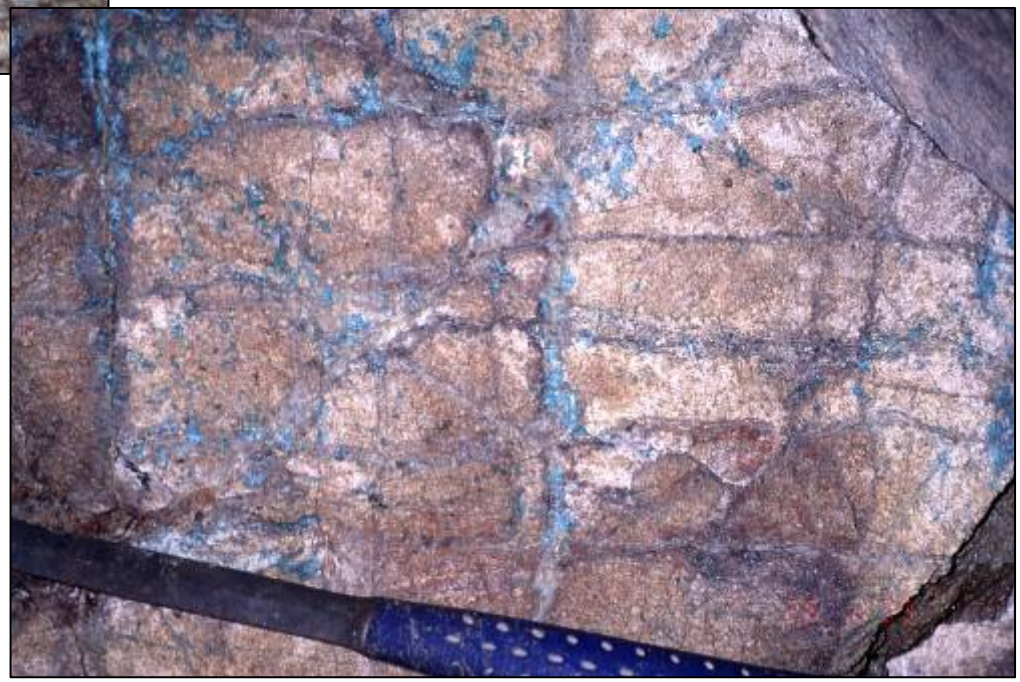
淋滤盖层中的Cu矿





Neotocite on fractures in phyllic altered quartz monzonite porphyry, Quellaveco, Peru

绢英岩蚀变石英二长斑岩裂隙中的硅锰矿



Brochantite along oxidised qtz-cp veins in quartz monzonite porphyry Quellaveco, Peru

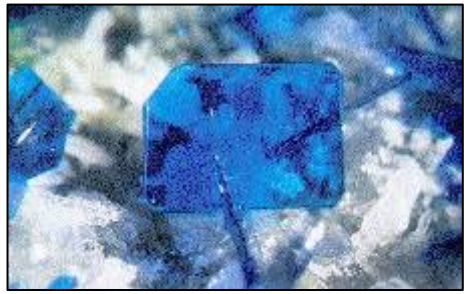
氧化脉中的水胆矾

Examples of Cu minerals in leached caps

淋滤盖层中的Cu矿石



Antlerite



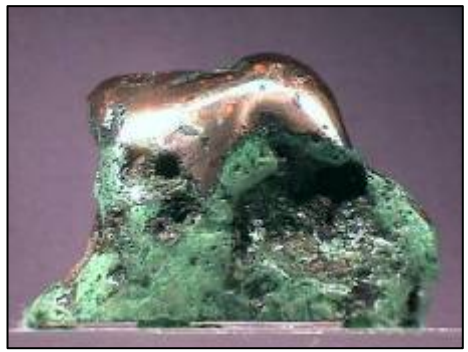
Azurite 蓝铜矿



Azurite on fractures from in-situ oxidation of chalcocite, Escondida, Chile



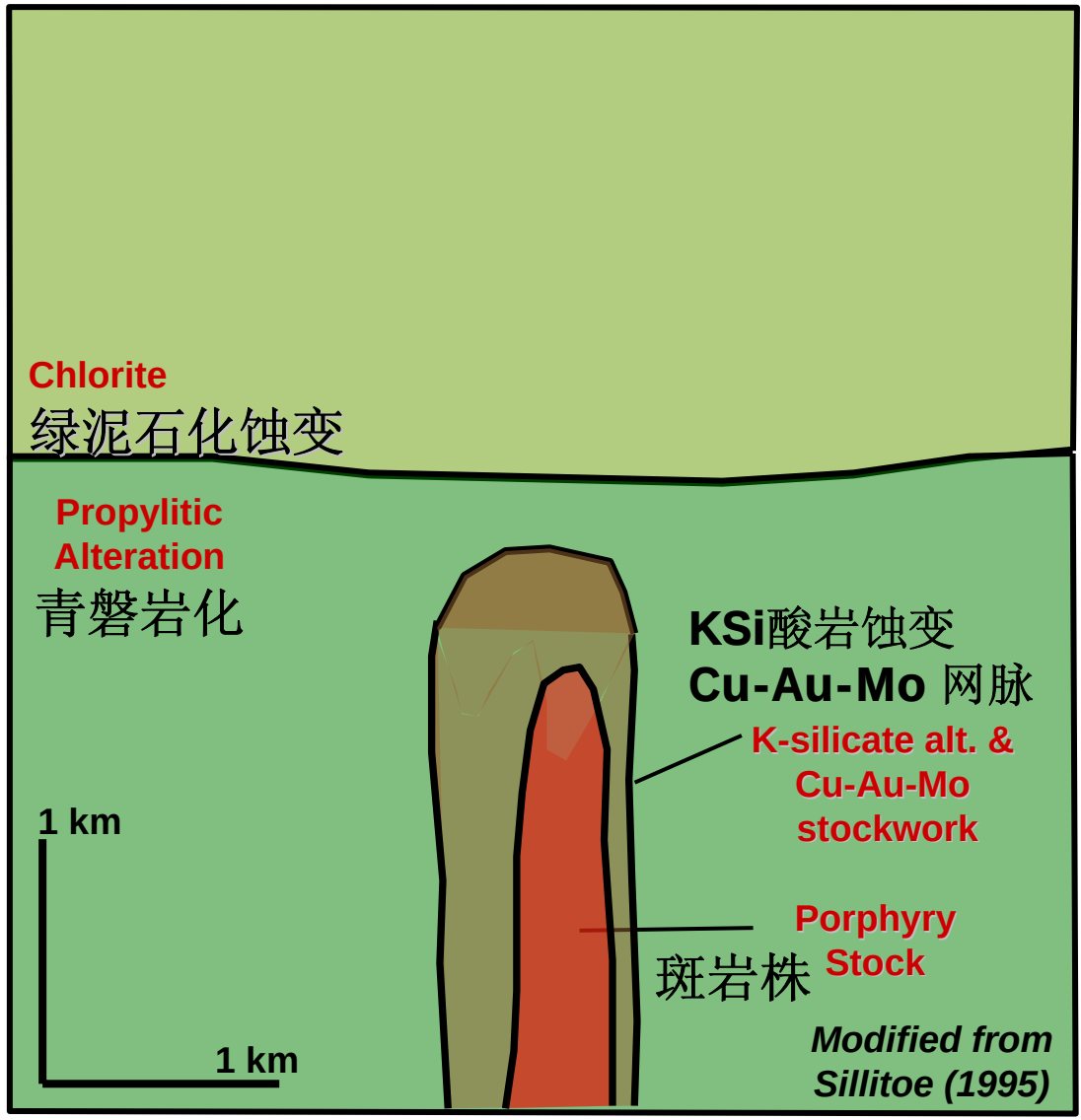
Turquoise 绿松石



Native Cu
自然铜

Uplift and Exhumation 隆升和剥蚀





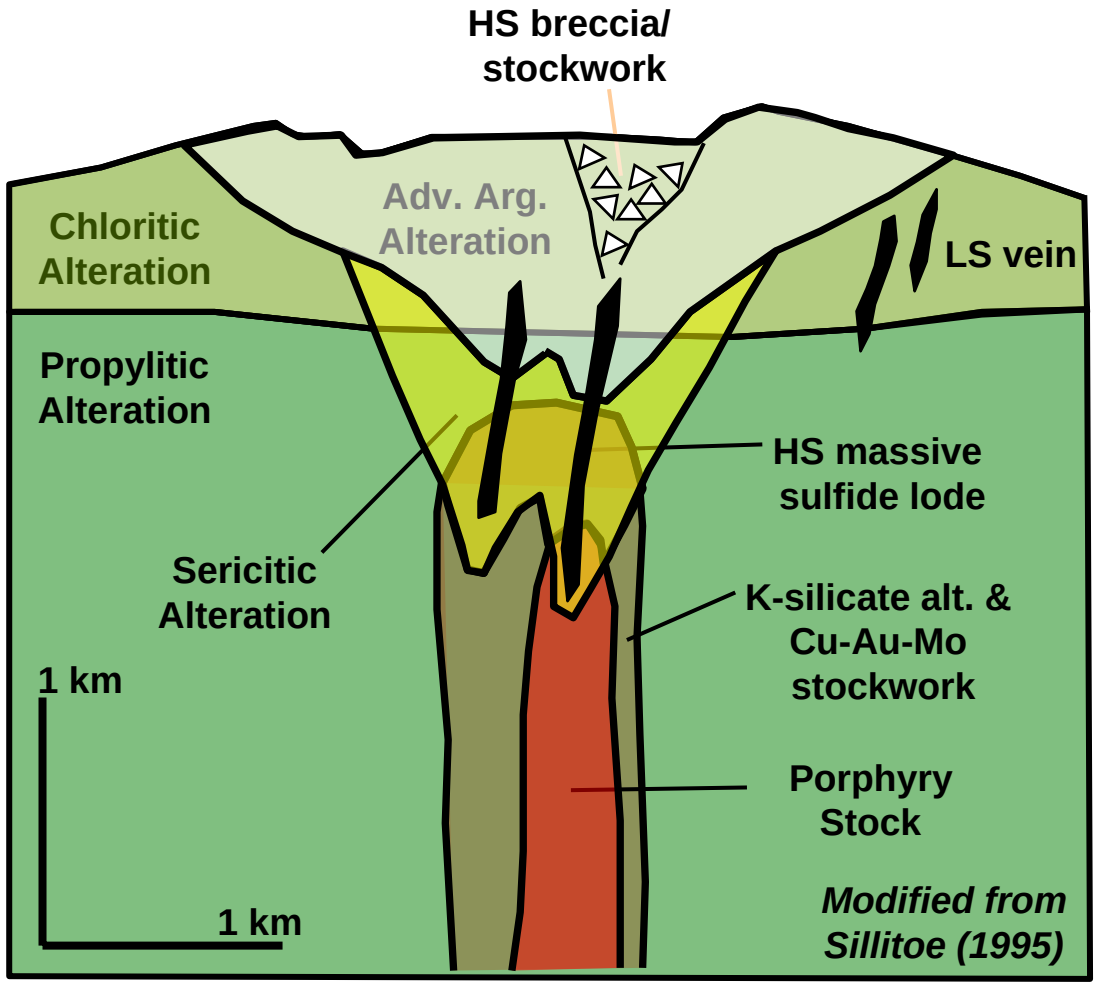
Epithermal Superposition 浅成热液叠加



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



Porphyry deposit discoveries since 1992



Map source: http://www.gebco.net



Porphyry discoveries since 1992

- **More discoveries have been made in covered geological settings than in the past**
  - ***e.g., Spence***
  - ***Toki***
  - ***Cadia East***
  - ***Pebble East***
  - ***Hugo Dummett***
- **These covered deposits are mostly being discovered in near-mine *(brownfields)* areas rather than virgin *(greenfields)* areas**

Biotite alteration halo in albite-sericite altered quzrtz monzonite porphyry, E48, NSW

Exploration 勘探活动

Explore near known systems thoroughly

在查明系统附近进行全面勘查

Regional-scale structures

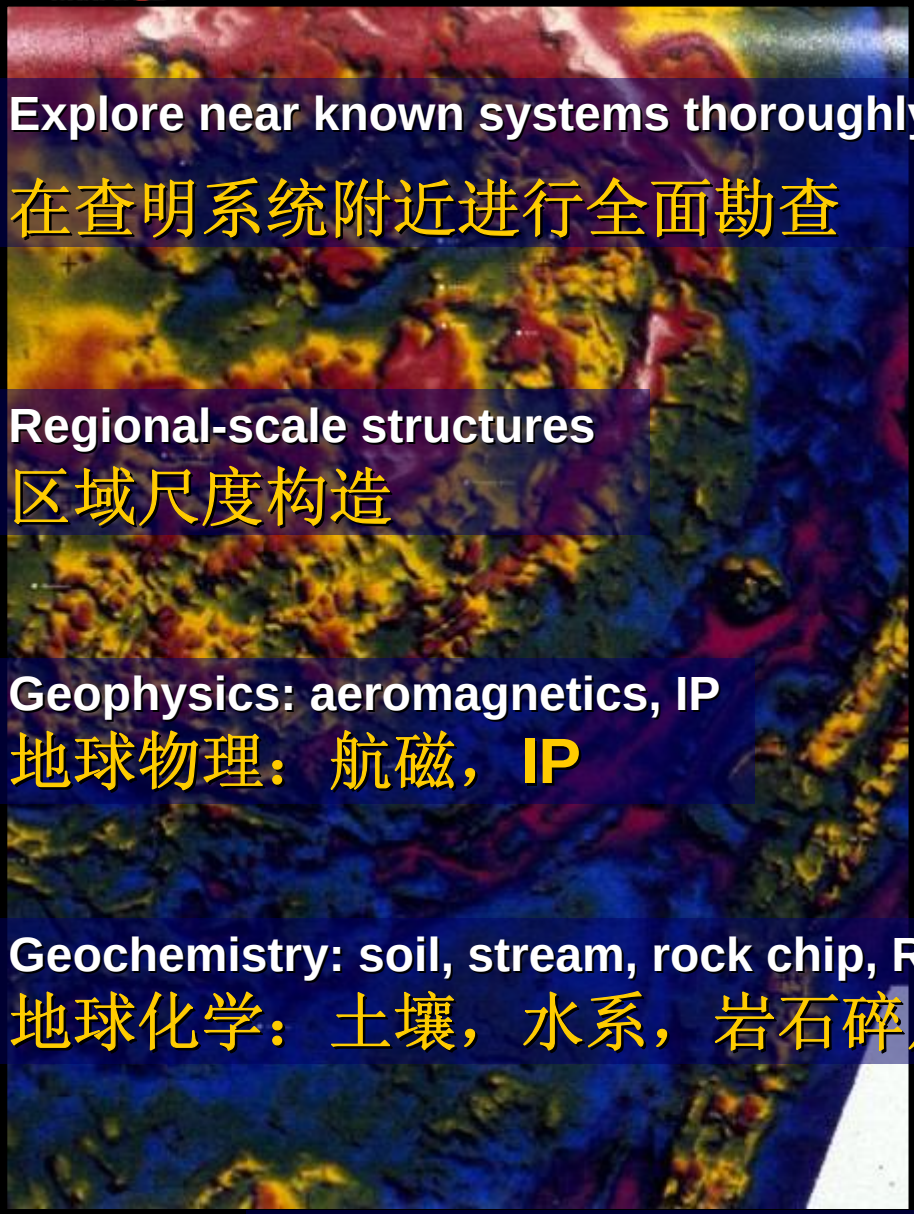
区域尺度构造

Geophysics: aeromagnetics, IP

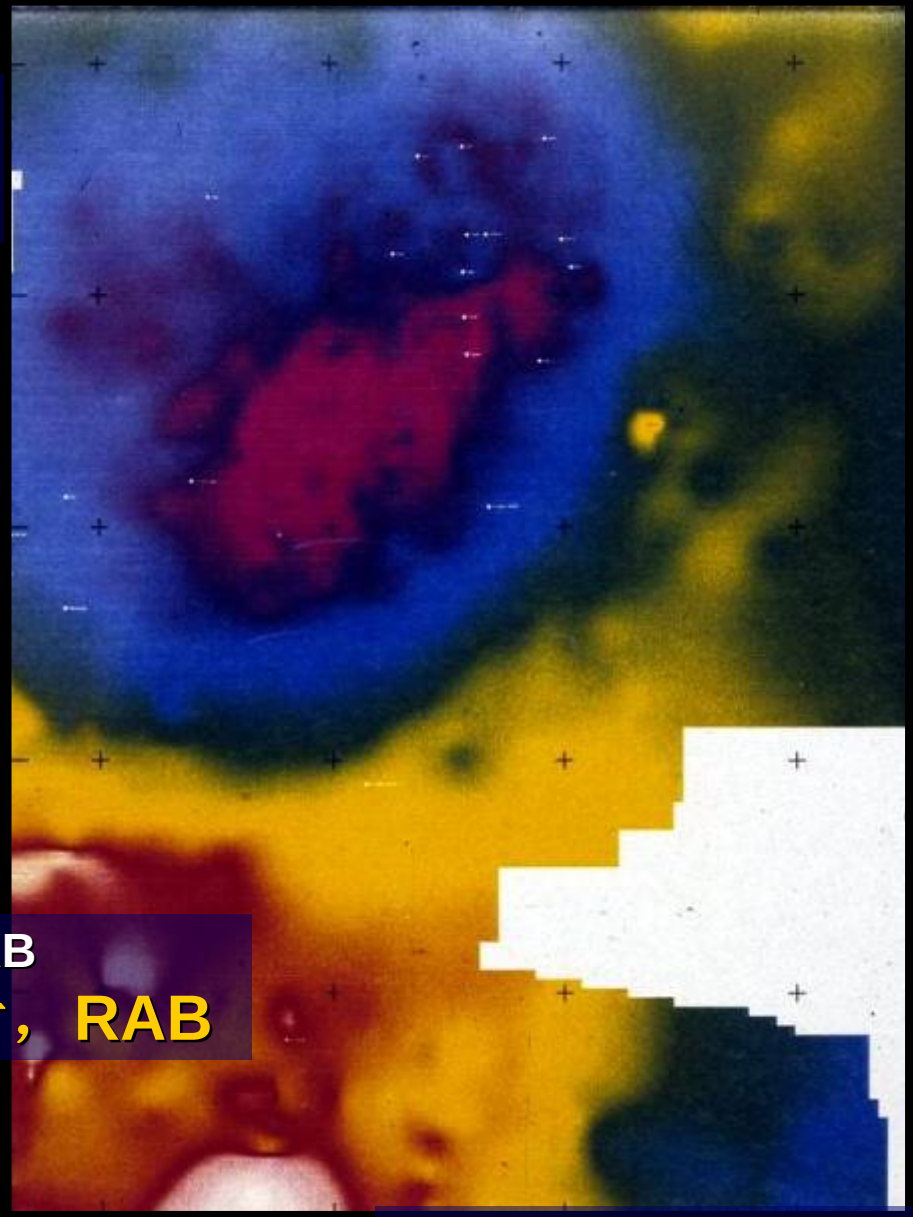
地球物理：航磁，IP

Geochemistry: soil, stream, rock chip, RAB

地球化学：土壤，水系，岩石碎片，RAB

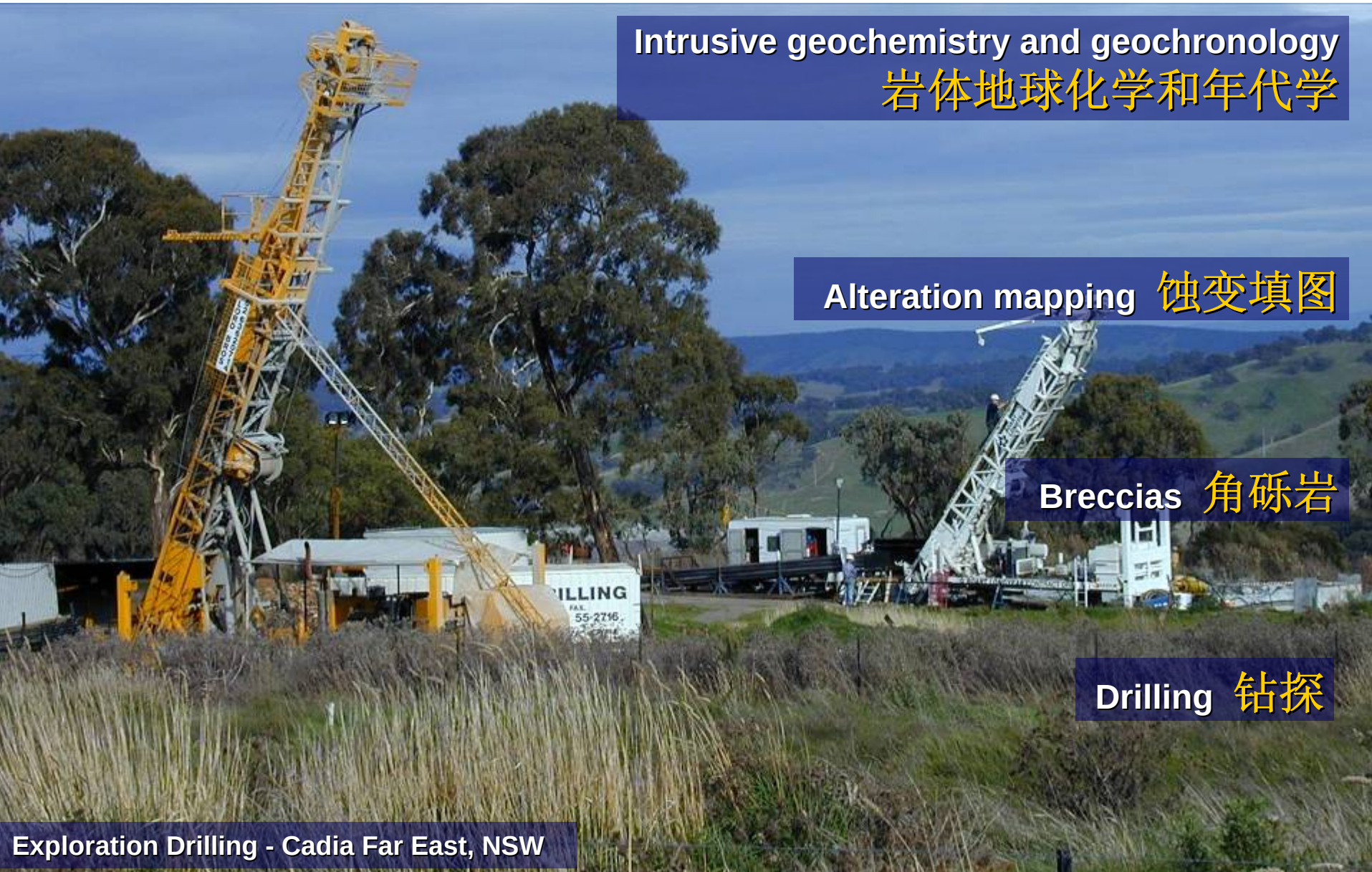


Aeromagnetics - North Parkes, NSW



Gravity - North Parkes, NSW

Exploration 勘探活动



Exploration Drilling - Cadia Far East, NSW