Genesis of Cu-Ni Deposits Related to Continental Magmatism
与大陆岩浆作用有关的铜镍矿床的成因

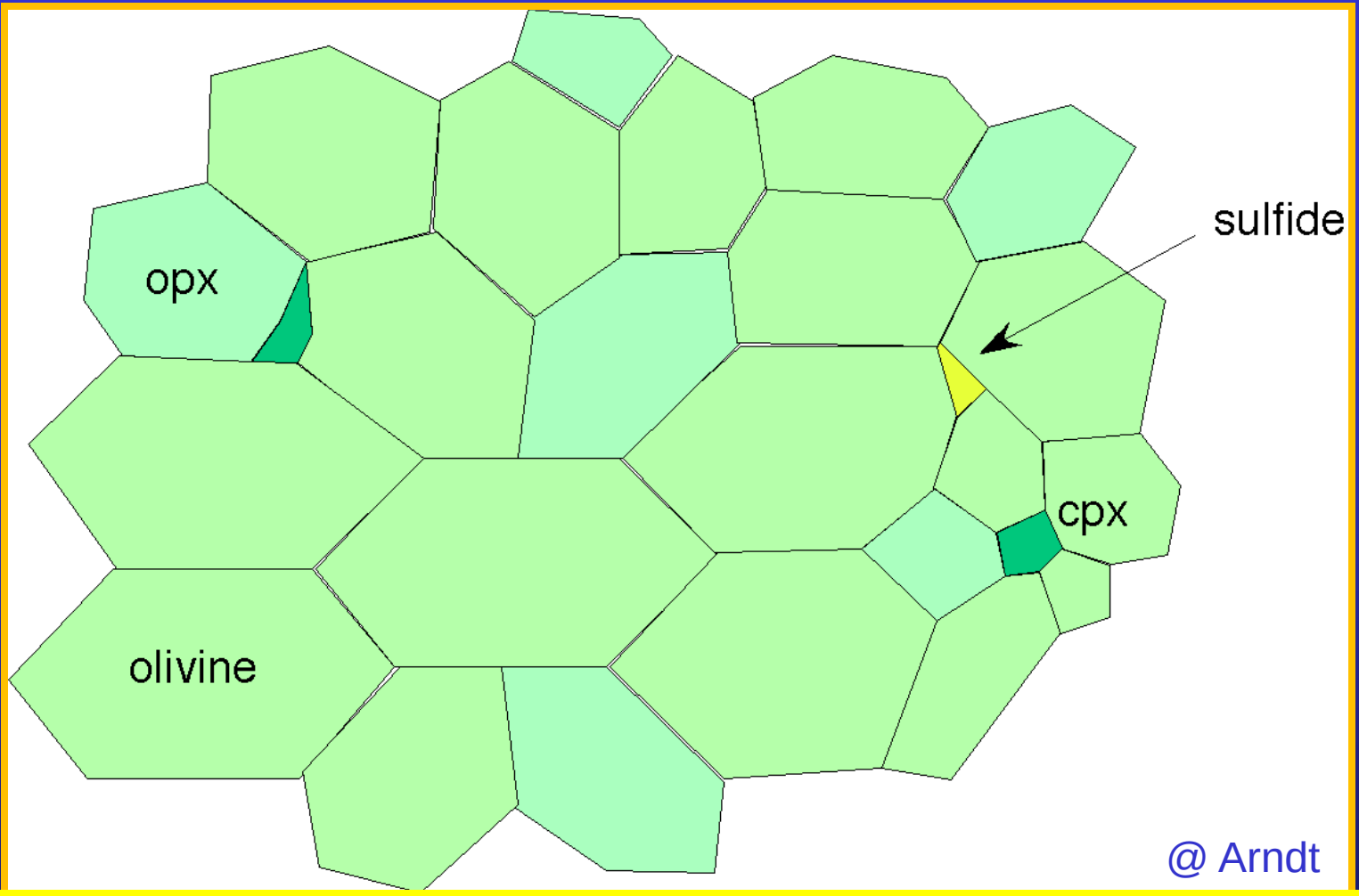
Critical Factors 重要条件

(1) Ni-Cu fertile magma
富铜镍的岩浆

(2) Sulfide saturation at crustal levels
在地壳浅处岩浆中硫化物达到饱和

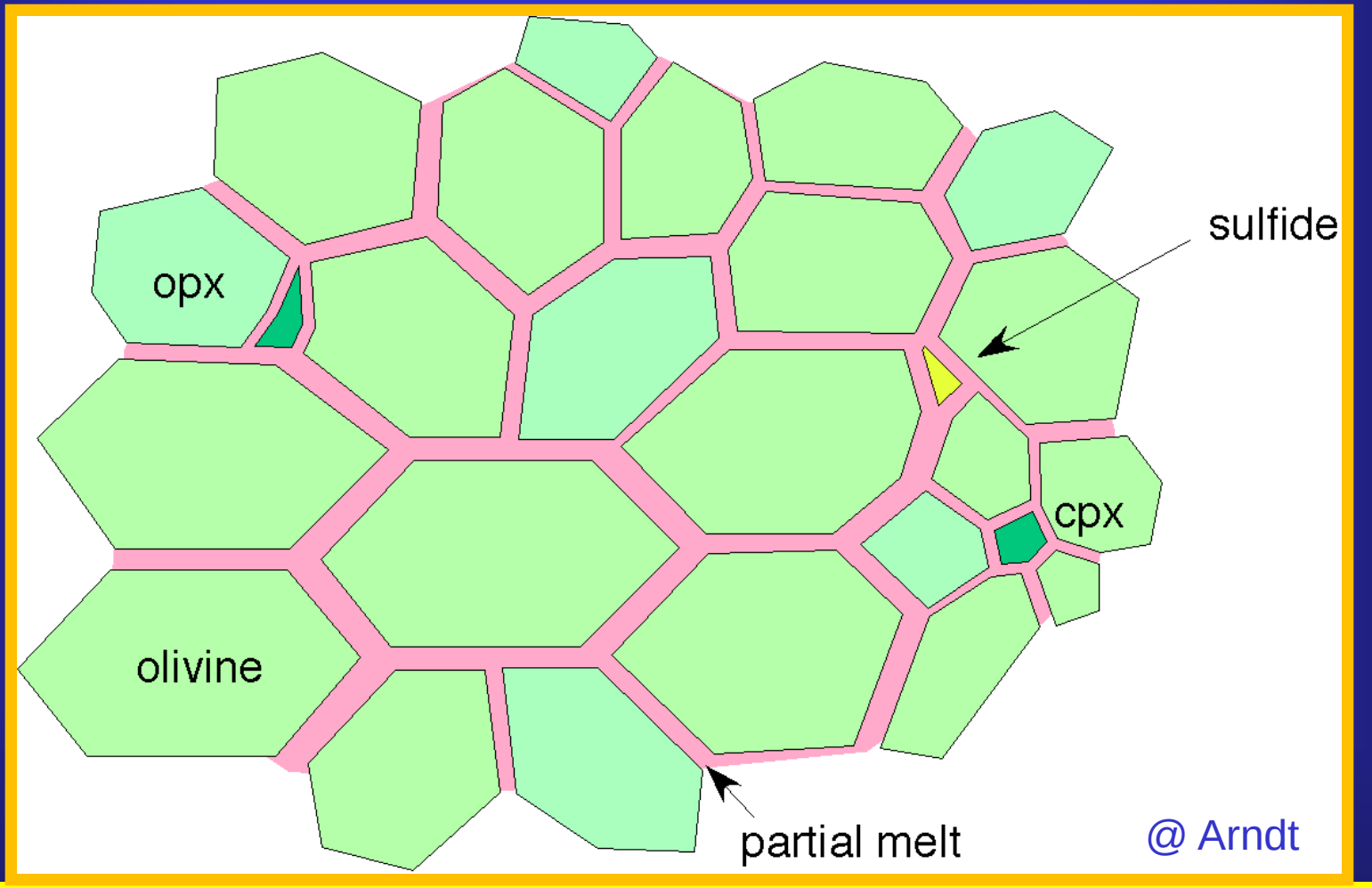
(3) Concentration of sulfide liquid in limited localities
硫化物珠滴在局部富集

How does mantle peridotite melt?
地幔橄榄岩部分熔融



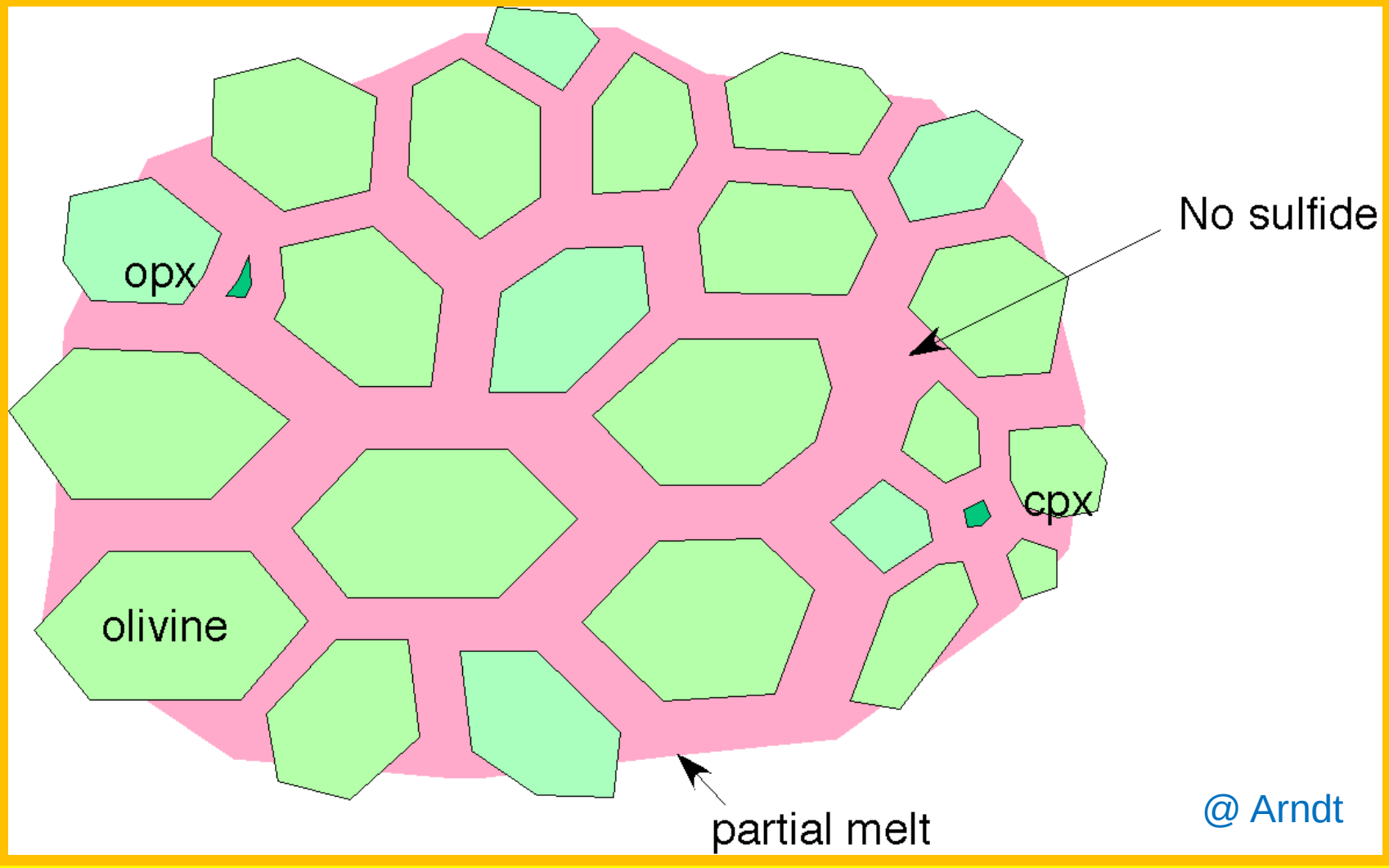
In peridotites, PGE, Cu and Au are mainly in small sulfide or alloy grains; Ni is partitioned between sulfide-alloy and olivine
橄榄岩中, PGE, 铜和金主要存在于硫化物或合金中; 镍分配于硫化物和橄榄石中

10% partial melting
部分熔融



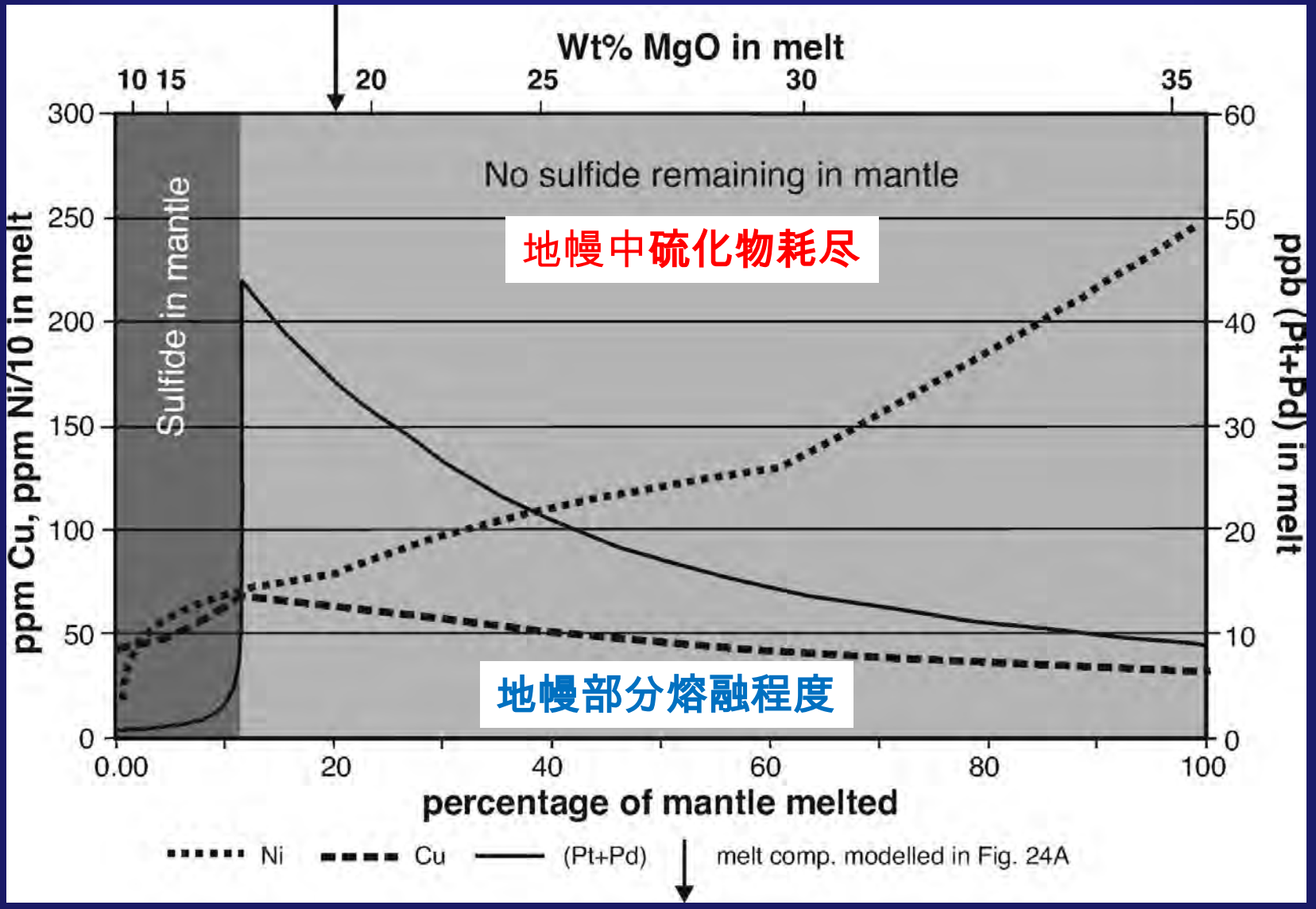
At ~10% melting, PGE, Au and Cu remain in sulfides; Ni is partitioned between sulfide and silicate phases; the melt is poor in Ni and PGE
10%熔融状态下, PGE, 金和铜仍然在硫化物中, 镍位于硫化物和橄榄石中, 岩浆中镍不高, PGE 很低

30% partial melting
部分熔融



At ~30% melting, sulfide is completely resorbed; the melt becomes very rich in PGE+Au and moderately rich in Ni and Cu
在30%熔融状态下, 硫化物全部熔融, 岩浆富含PGE和金, 及较高的镍和铜

Partial Melting of Spinel Lherzolite Mantle
地幔二辉橄榄岩部分熔融



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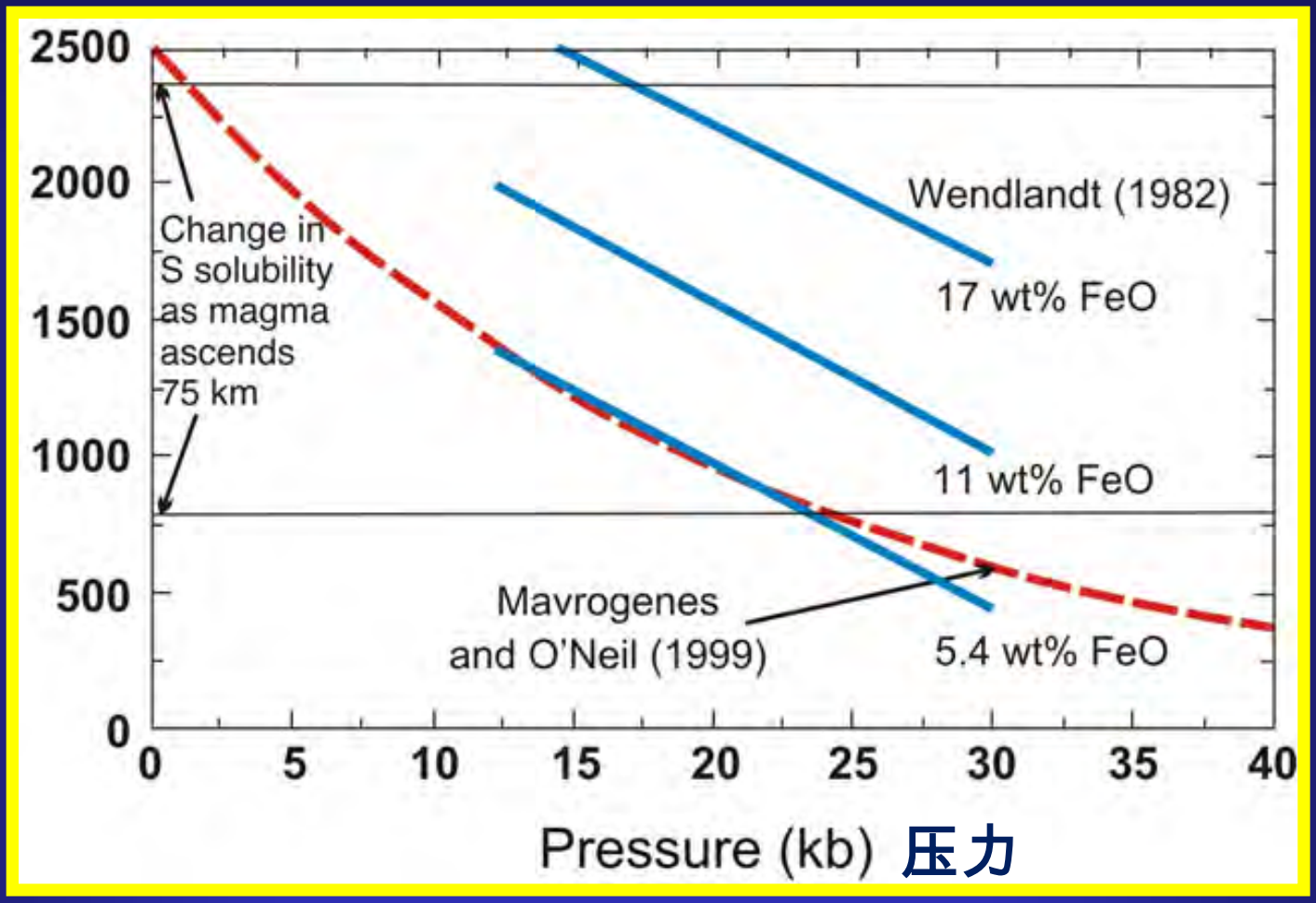
S in magma (ppm) at sulfides aturation
岩浆中硫饱和状态下硫的含量

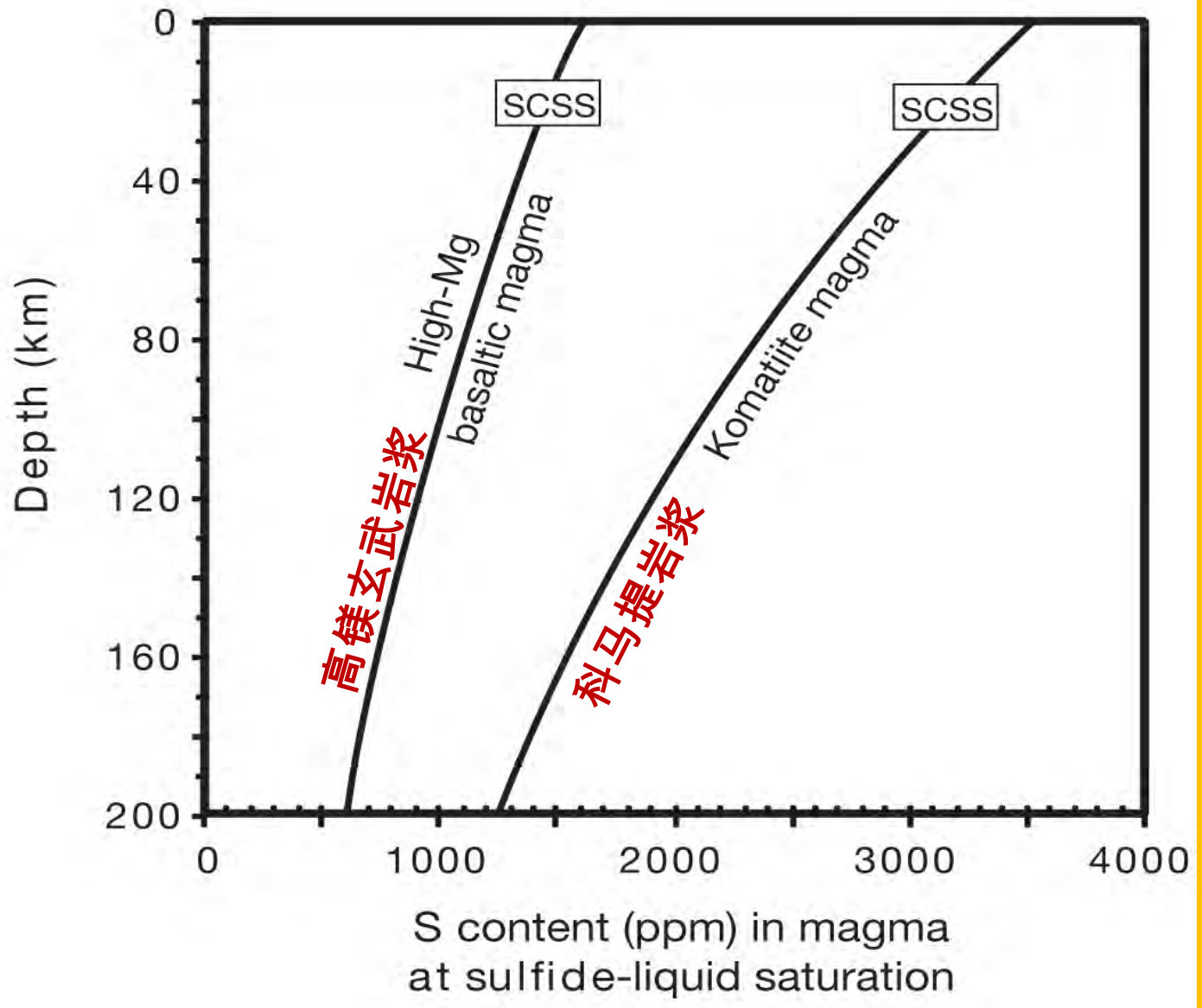


$$ln\ X_S = -1.76 - 0.474\ (10^4/T) - 0.021\ P + 5.559\ X_{FeO} + 2.565\ X_{TiO_2} + 2.709\ X_{CaO} - 3.192\ X_{SiO_2} - 3.049\ X_{H_2O}$$

Li & Ripley 2009

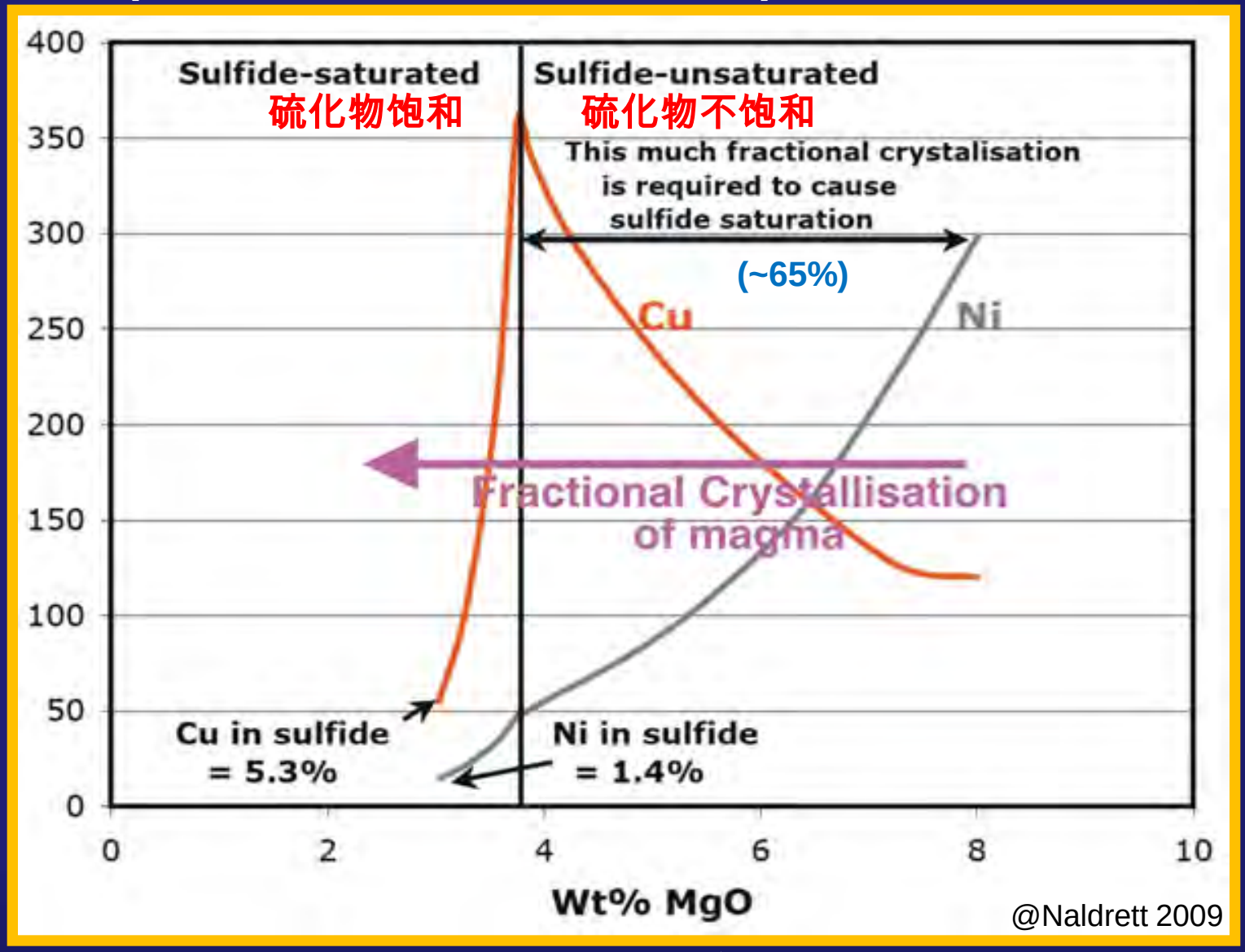
T in Kevin, *P* in kb, *X* = mole fraction

深度 (公里)



岩浆中硫饱和状态下硫的含量 (ppm)

Consequence of fractional crystallization of magma formed by 18% mantle lherzolite partial melting
岩浆(18%地幔二辉橄榄岩部分熔融)分离结晶作用的后果

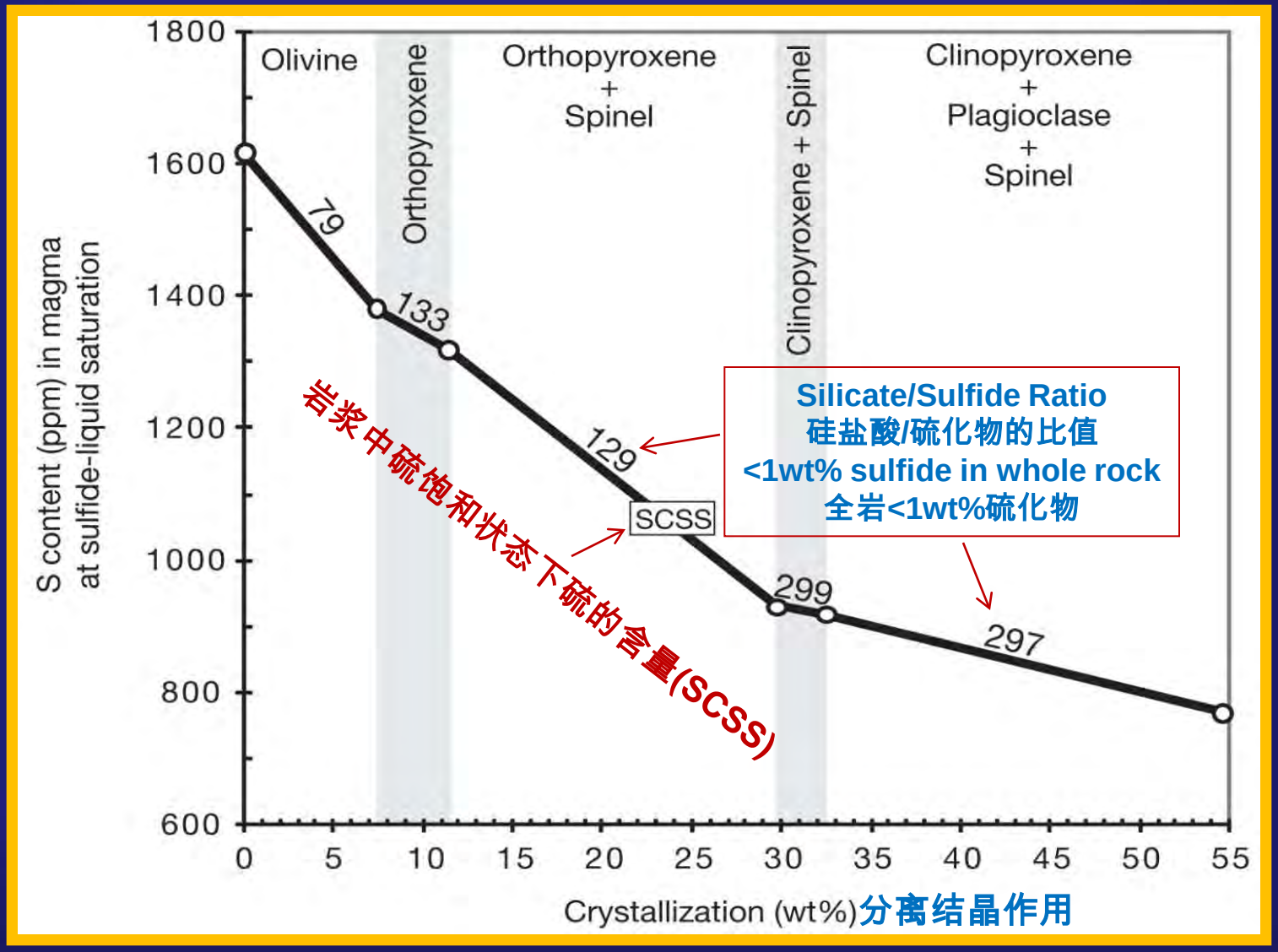


Cu and Ni in magma (ppm)
岩浆中 Cu, Ni 含量

岩浆中 MgO含量 (wt%)

Variation of silicate/sulfide ratio during fractional crystallization of sulfide-saturated magma with composition similar to the parental magma of the Lower zone of the Bushveld Complex

硫化物饱和岩浆分离结晶过程硅盐酸/硫化物的比值



Magma Mixing 岩浆混合作用

The amount of sulfide that may be produced by magma mixing is too small to form a Ni-Cu deposit but may be enough to form a PGE deposit

岩浆混合作用产生的硫化物量少, 可能形成铂族元素矿床, 但很难形成 Cu-Ni 矿床

Oxidation 氧化作用

Oxidation (e.g. CO_2 addition) decreases S solubility in magma mainly because some FeO is converted into Fe_2O_3

氧化作用(例如CO_2的加入)**减少硫的溶解度, 主要是因为岩浆中部分FeO被转化成Fe_2O_3**

Addition of Crustal Sulfur

地壳硫的加入

Selective assimilation of S-bearing phases in country rocks

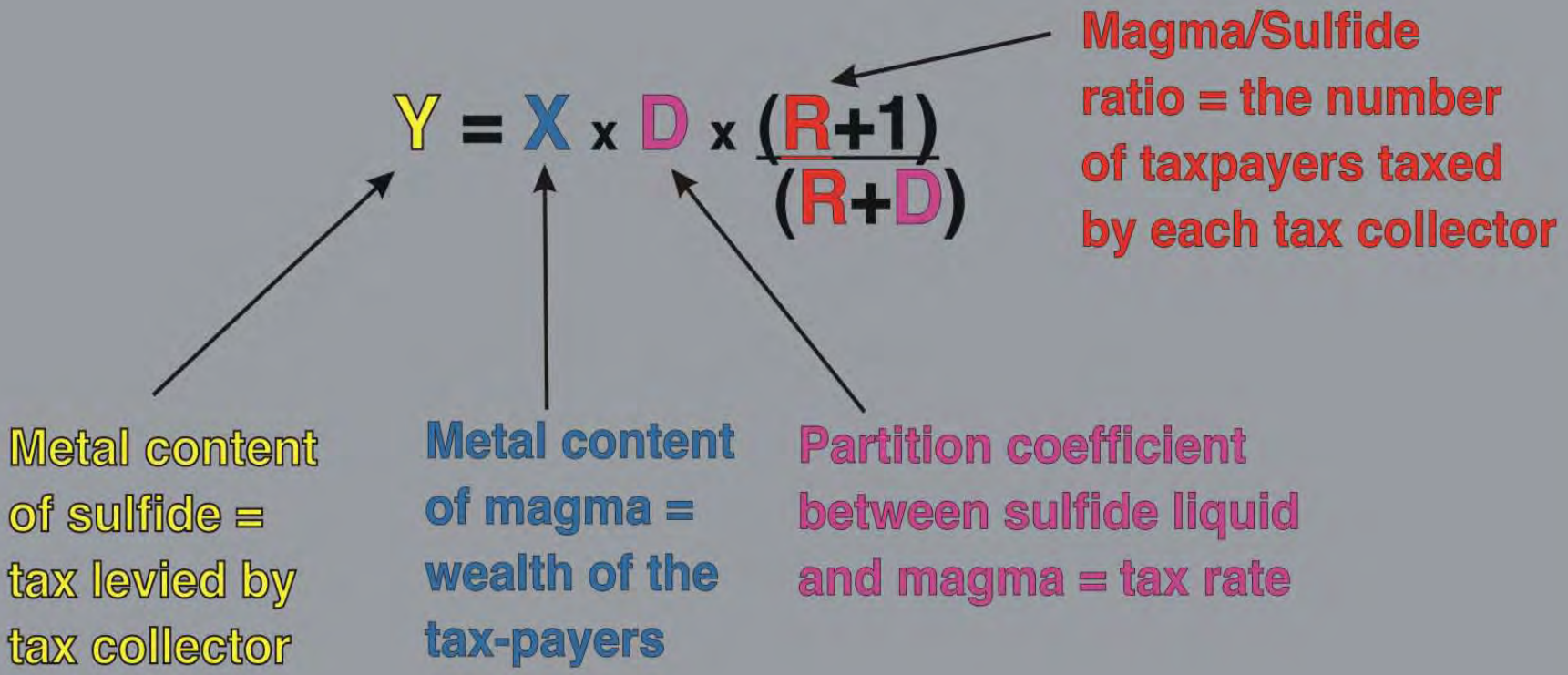
围岩中含硫相的选择性同化作用

Fluid or vapor transportation of S released from footwall

下盘围岩释放出的硫通过流体或蒸汽相加入到岩浆里

R 因子方程式
THE R FACTOR EQUATION

Sulfides extract metal from a silicate magma just as a tax collector extracts money from tax payers



硫化物从岩浆中提取金属元素
就像税务所向个人收税一样

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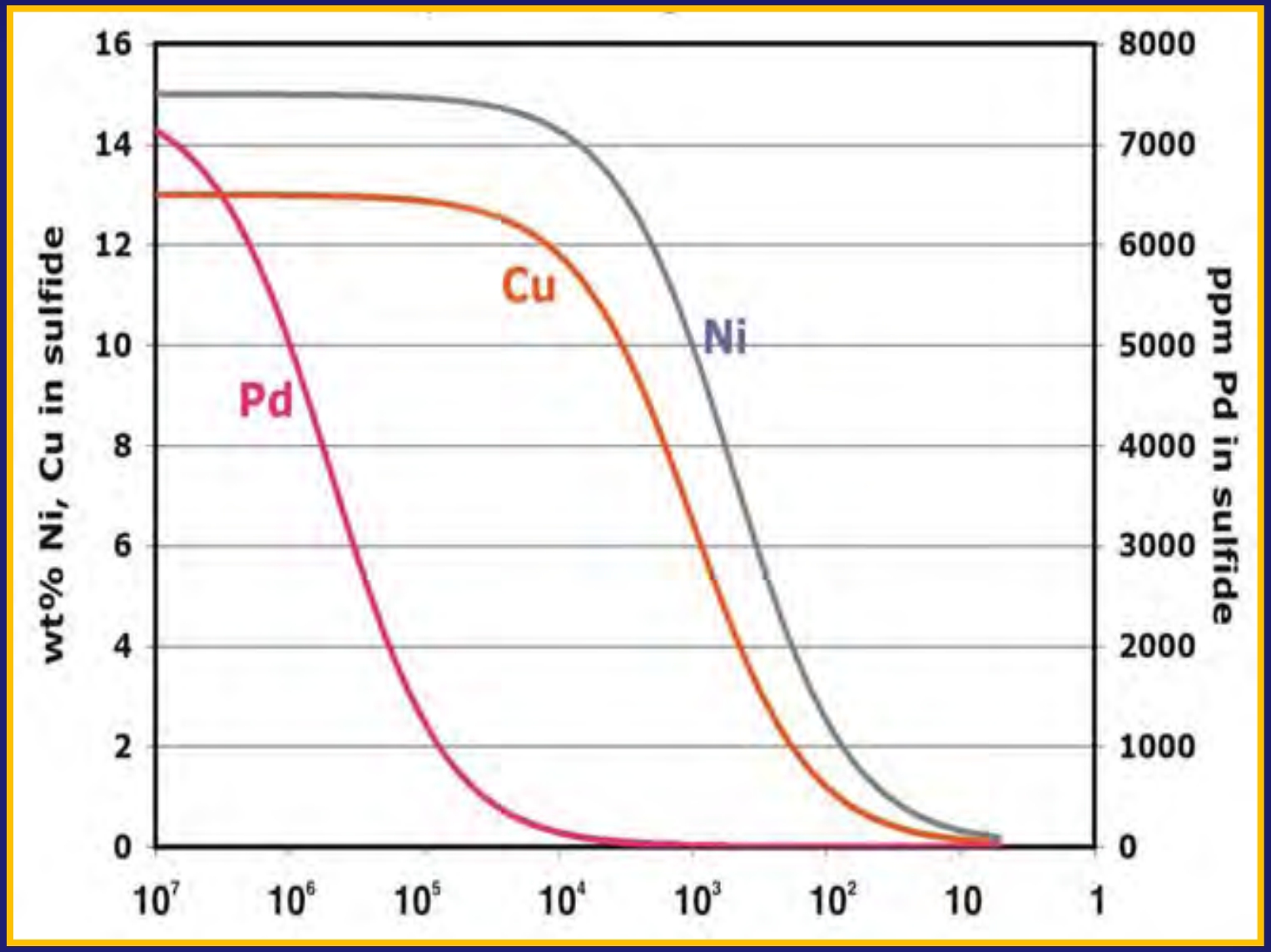
R 效应 (The Effect of R)



硫化物中Ni, Cu含量 (wt%)

硫化物中Pd含量 (ppm)

R = Magma/Sulfide Ratio
岩浆与硫化物比值

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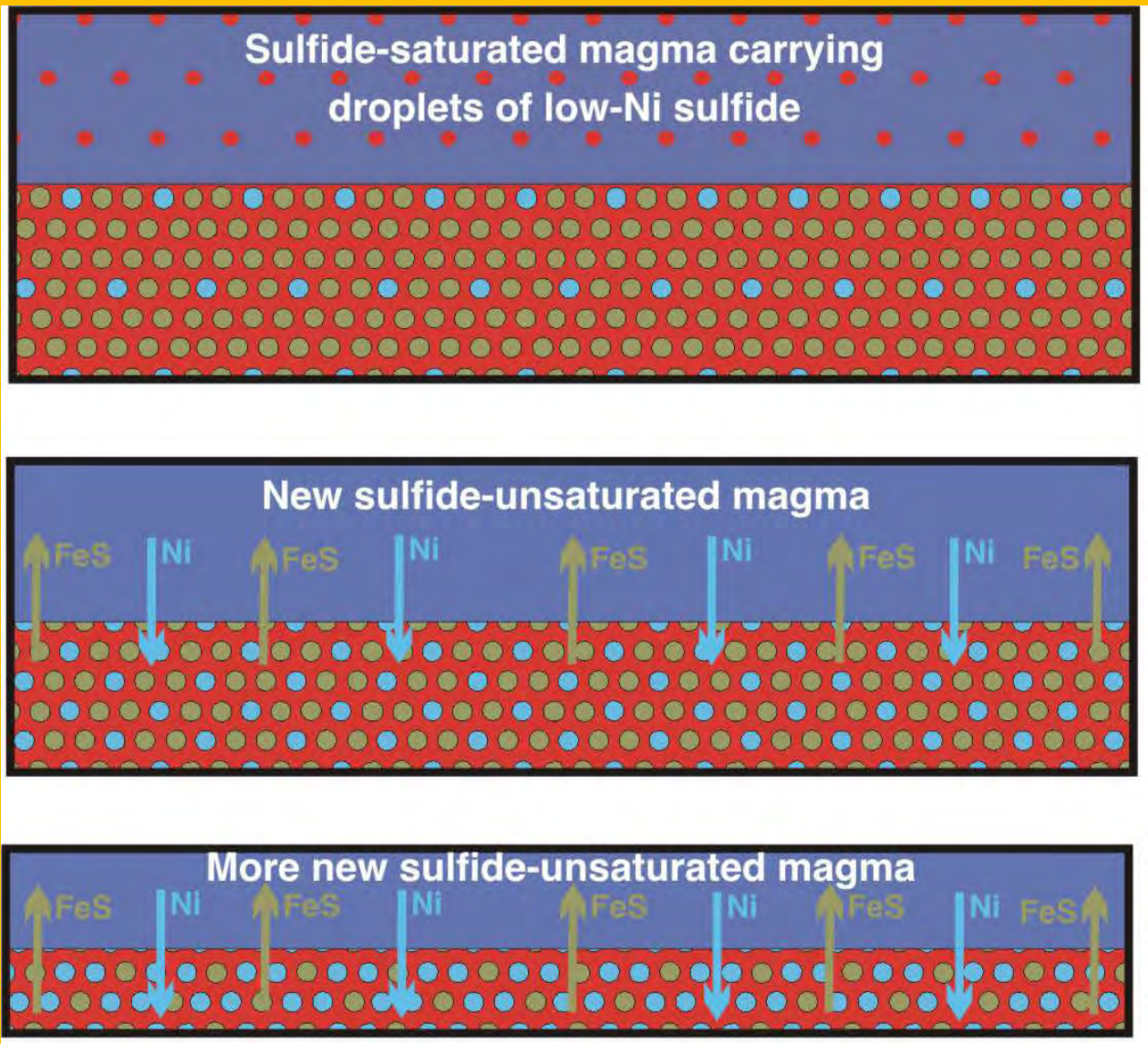
Metal Upgrading 提高硫化物中金属含量



Initial magma has reacted with much sulfide so that Ni (and Cu&PGE) tenors are low [low R factor]

Continued flow of fresh, sulfide-unsaturated magma dissolves FeS and donates Ni (and Cu&PGE) to sulfide (because Ni, Cu&PGE are much more chalcophile than Fe)

The process continues but, because sulfide is being removed, the total amount of sulfide decreases. However, the Ni, Cu & PGE tenors are higher

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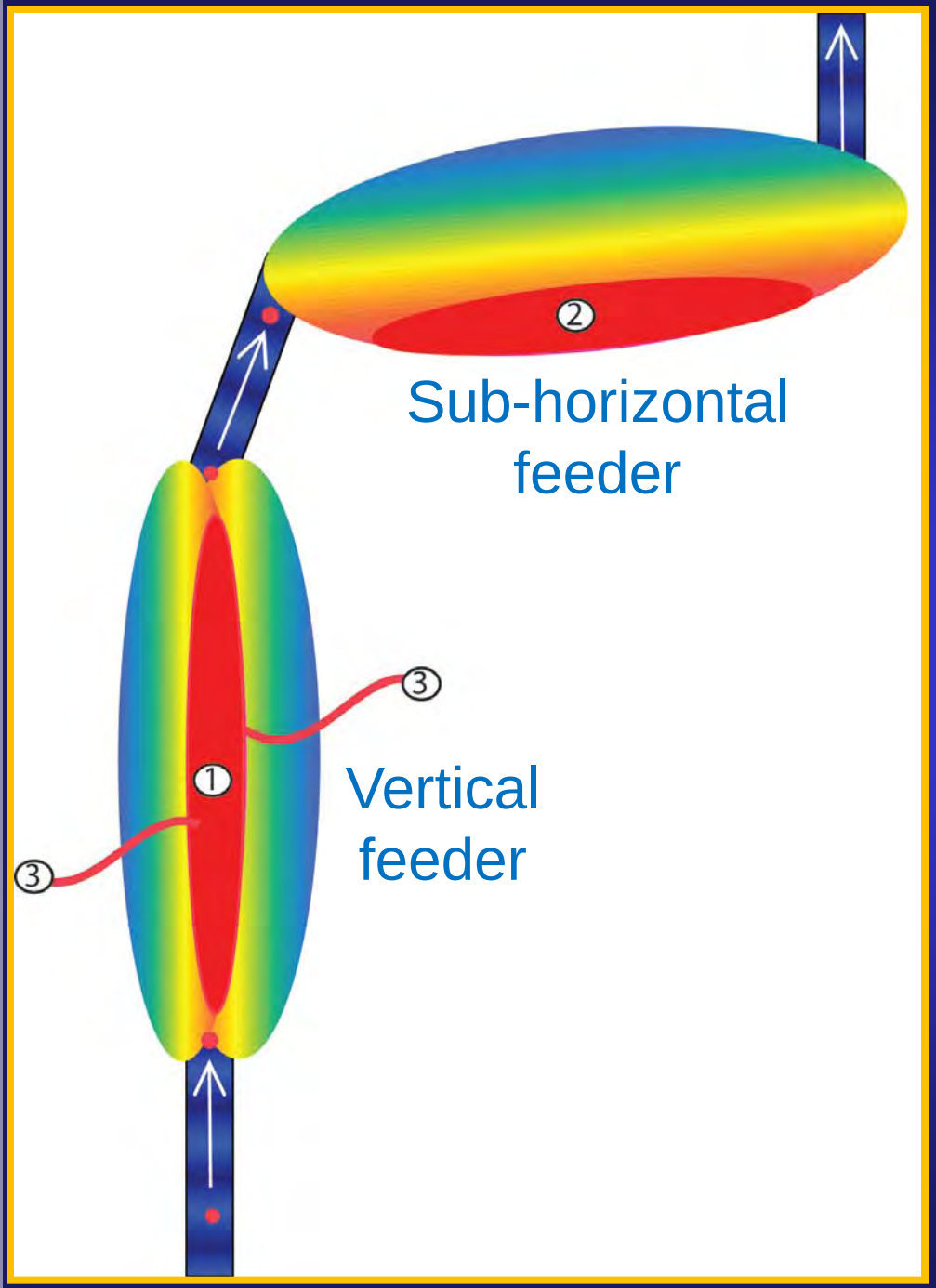

Sulfide Concentration
硫化物富集作用

(1) Flow Concentration
流动富集作用

(2) Gravitational Settling
重力富集作用

(3) Capillary Suction
细管吸取作用
Injection/Leaking