Ore Deposit Models
Their Importance in Research and Exploration
矿床模型
矿床模型在勘探和研究中的重要作用

Noel C White

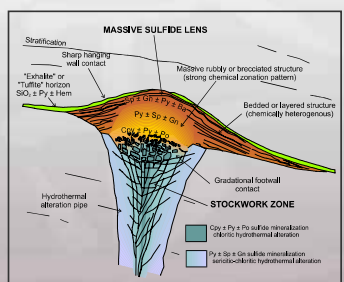
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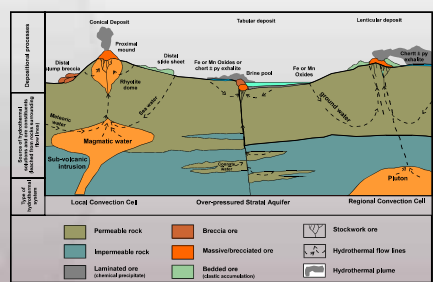
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What is an Ore Deposit Model?
什么是矿床模型?

- It is a synthesis of available information on the deposit type, including the most informative and reliable characteristics recognized on a variety of scales
  矿床模型就是把某一矿床的各种有用的信息的综合,这些信息包括最全面及最可靠的不同尺度上的特征
- Ore deposit models change as our knowledge advances
  矿床模型随着我们的科技的进步而改变

DESCRIPTIVE





GENETIC

Why are Ore Deposit Models Important?
为什么矿床模型如此重要?

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Ore deposits are complex and involve many different characteristics

矿床是复杂多变且包含多方面的特征

- Tectonic setting **构造背景**
- Host environment **地质背景**
- Host rocks **围岩**
- Shape and form of orebody **矿体的形状和形式**
- Textures of ore **矿石结构**
- Mineralogy of ore **矿石的矿物学特征**
- Chemistry of ore **矿石的化学特征**
- Age of host rocks and ore **围岩和矿石的年龄**
- Source and composition of fluids **流体的来源及成分**

Why are Ore Deposit Models Important?
为什么矿床模型如此重要?

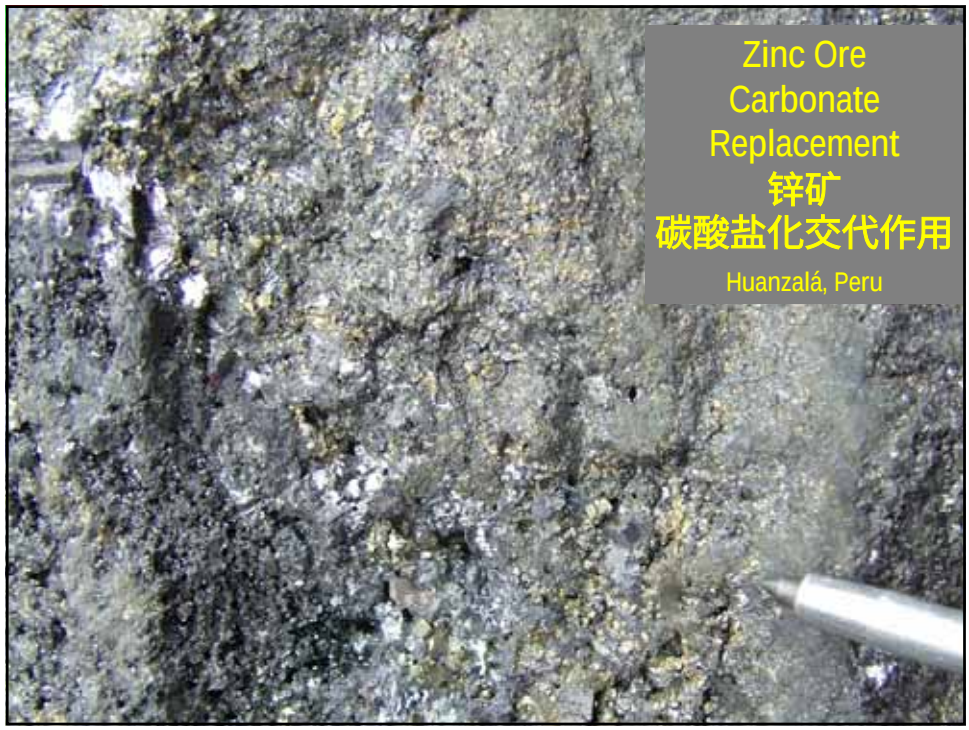
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- Chemical and mineralogical zoning **化学和矿物学分带**
- Hydrothermal alteration mineralogy and zoning **矿物学的热液蚀变及分带**
- Structural setting **构造背景**
- Structural controls **构造控制条件**
- Post-depositional modification (deformation, metamorphism, weathering) **后期沉积变形作用(变形,变质,风化)**
- Geophysical character of ore and host rocks (density, magnetism, chargeability, conductivity) **矿体和围岩的地球物理特点:密度,磁性,荷电率 ,导电率**

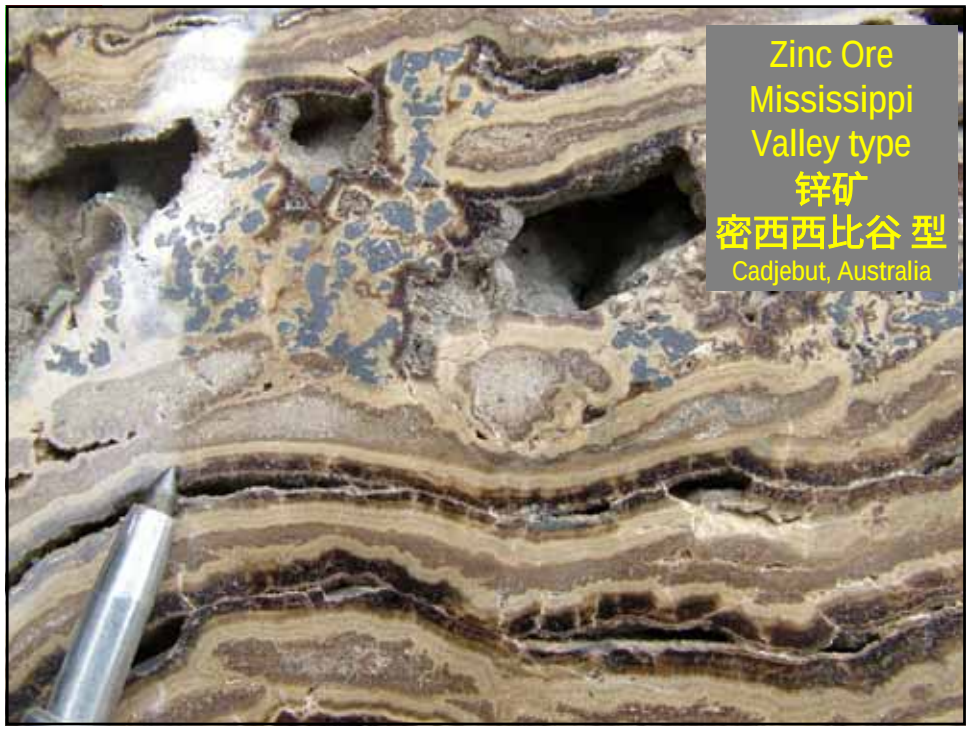
Ore deposit models bring the key characteristics together in a brief and understandable way

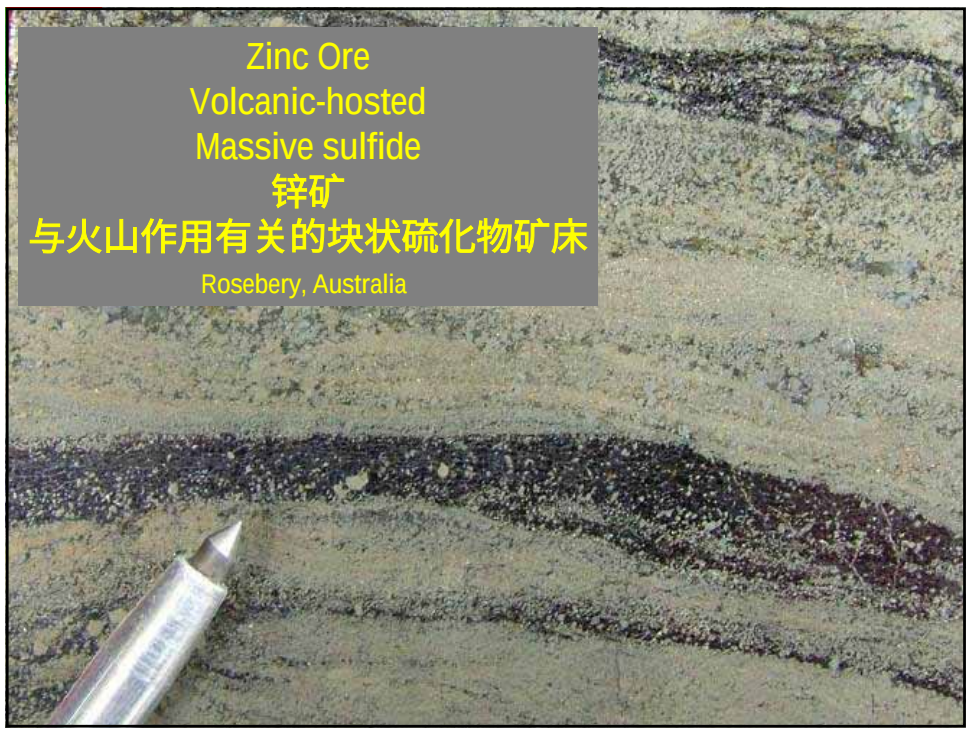
矿床模型就是把矿床的主要特征用简单易懂的方法表示出来

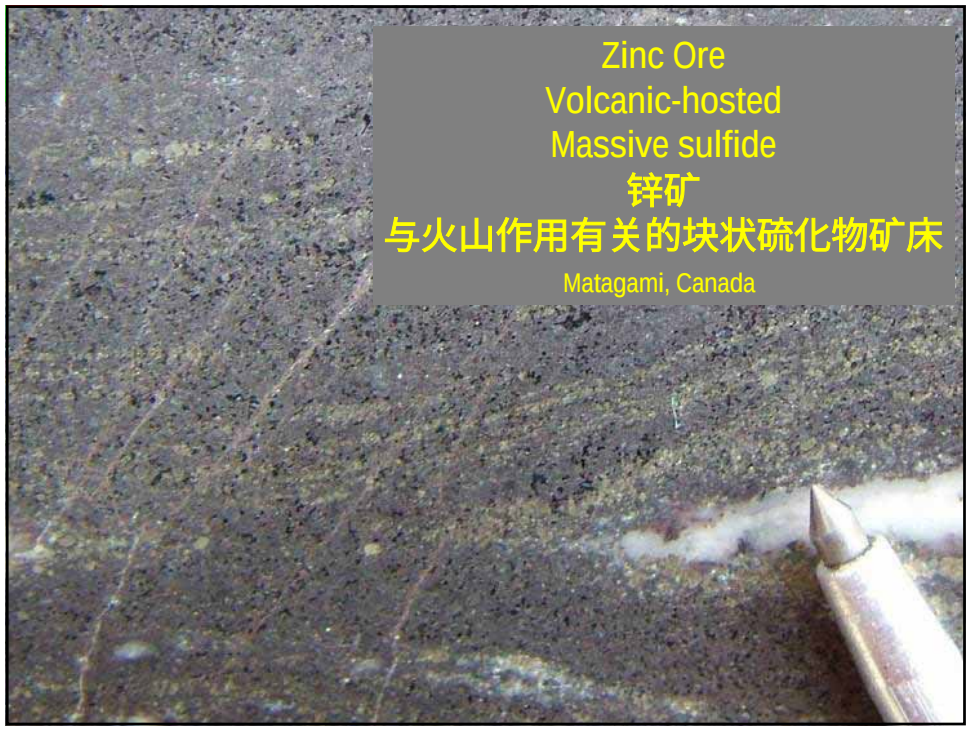
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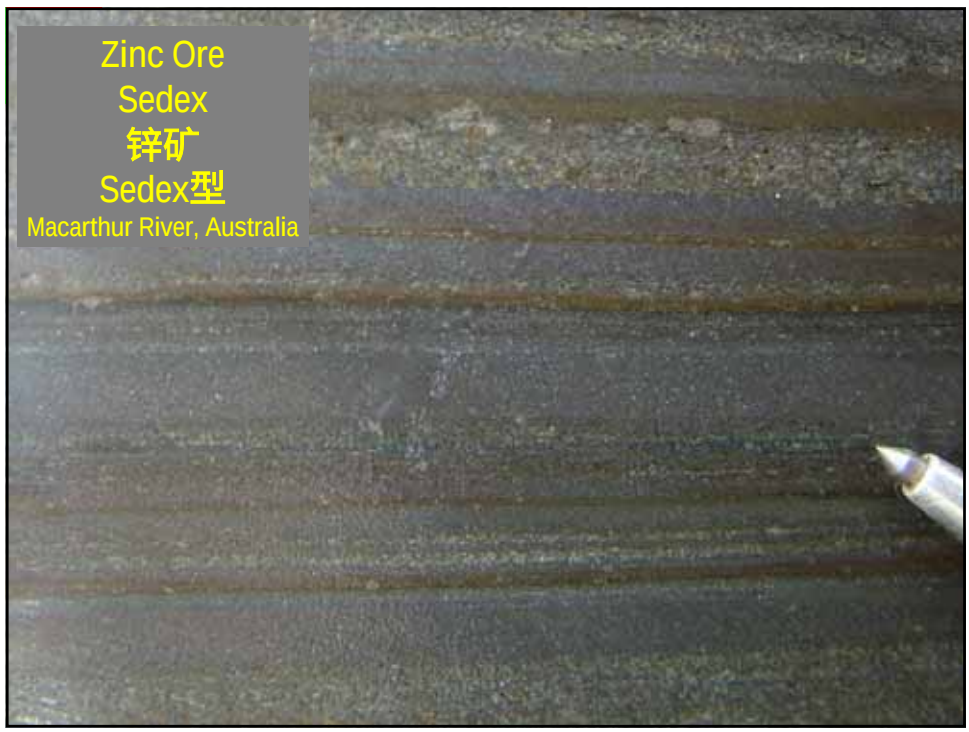

Zinc Ore
Carbonate
Replacement
锌矿
碳酸盐化交代作用
Huanzalá, Peru


Zinc Ore
Skarn
锌矿
矽卡岩化
Uchucchacua, Peru

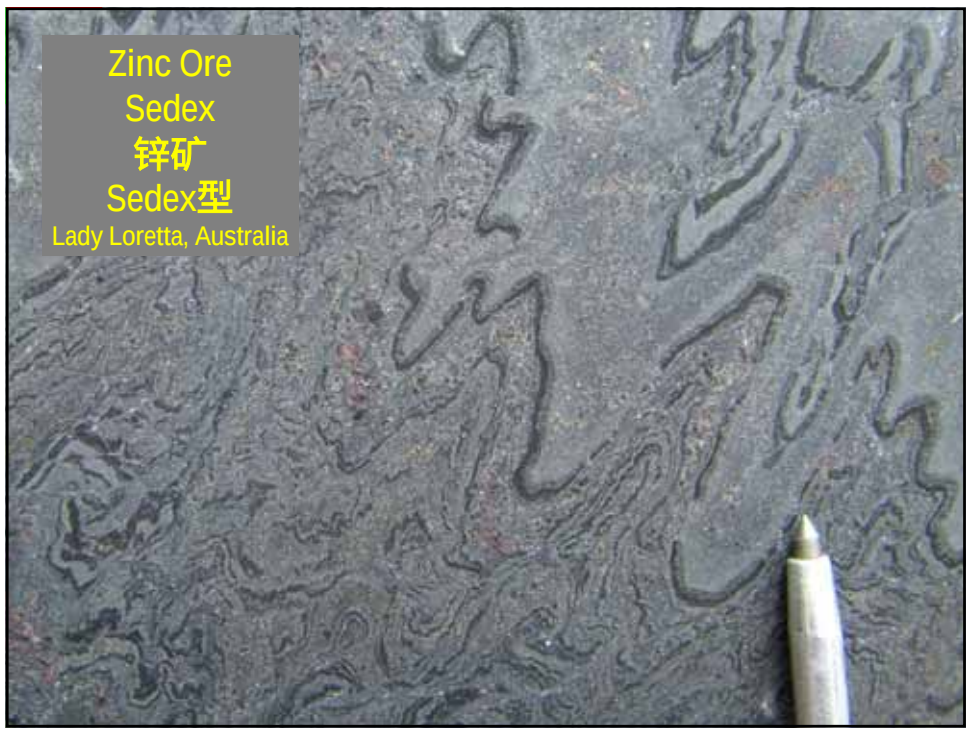

Zinc Ore
Mississippi
Valley type
锌矿
密西西比谷 型
Cadjebut, Australia

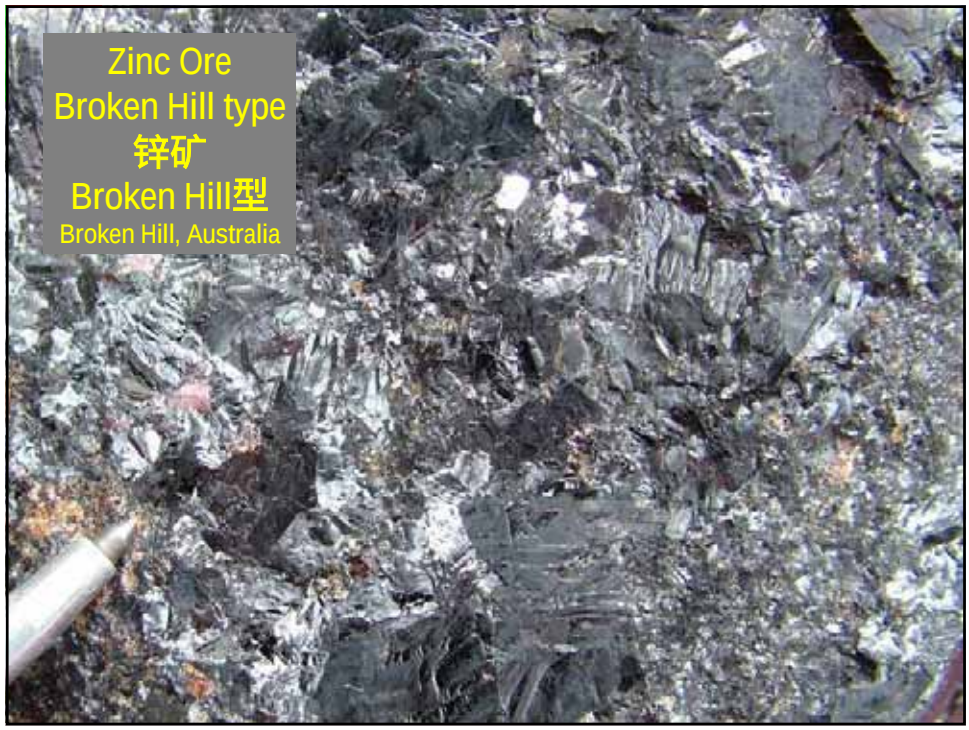

Zinc Ore
Volcanic-hosted
Massive sulfide
锌矿
与火山作用有关的块状硫化物矿床
Rosebery, Australia


Zinc Ore
Volcanic-hosted
Massive sulfide
锌矿
与火山作用有关的块状硫化物矿床
Matagami, Canada


Zinc Ore
Sedex
锌矿
Sedex型
Macarthur River, Australia

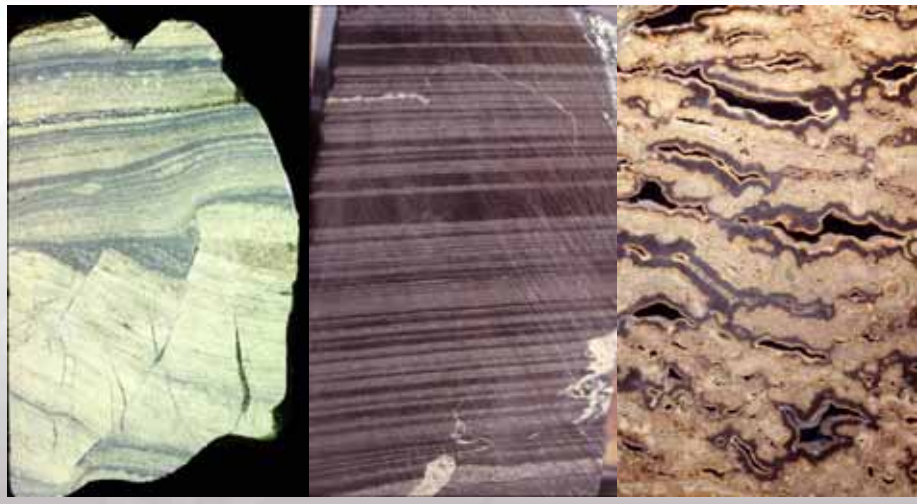

Zinc Ore
Sedex
锌矿
Sedex型
Mount Isa, Australia


Zinc Ore
Sedex
锌矿
Sedex型
Lady Loretta, Australia



Different textures, different models
不同的结构,不同的模型

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VMS | Sedex | MVT

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Why Models can be *Dangerous*
为什么模型会有风险



- Deciding on a model for a deposit should *follow*, not *lead*, study
  决定用某种模型的时候只是参考和学习,但不是照搬
- It is too easy to look at a few superficial characteristics and then *force* a deposit into a preconceived model
  寻找一些表面的特征,然后把它总结为一个预想的成矿模型

Why Models can be *Dangerous*
为什么模型会有风险



- Rather than fairly evaluating a deposit's characteristics, some researchers (and explorers) *force* their observations to fit a model
  比起客观的评估一个矿床的所有特征，是很简单的一件事情。有些学者硬把他们观测的东西硬往某个模型靠
- Not every deposit is adequately described in known models – but – do not casually set up new models without adequate justification
  不是所有的矿床都在已知的模型中有充分的描述，但是，不要随便的建立起一个新的、没有充分证据的新成矿模式。

How to use Models
怎么用矿床模式

Ore deposits are accumulations of specific rocks
矿是在特定岩石中富集形成的
Remember the basics of good geological study:
记住搞好地质研究的基本原则：

1. Carefully describe what you see **仔细观察你看到的**
2. Remove the effects of weathering *(can change mineralogy, texture and composition)* **去除风化因素（可以改变矿物，结构，组成等。）**
3. Remove the effects of deformation *(can change texture)*
   去除变形因素（可以改变结构）
4. Remove the effects of metamorphism *(can change texture and mineralogy)*
   去除变质作用的影响（可以改变结构和矿物学）
5. Remove the effects of hydrothermal alteration *(can change texture, mineralogy and chemistry)*
   去除热液蚀变的影响（可以改变结构，矿物组成，和化学成分）
6. Infer the original rock type, its mineralogy, textures, primary lithology and depositional environment **推断初始岩石类型，它们的矿物组合，结构，原岩和富集环境**
7. Determine timing relations between ore and host rocks
   确定矿石和围岩的时间联系

How to use Models
怎么用矿床模式

Only then can you consider which model it might fit
Do not expect an *exact* fit – all deposits are different, none exactly fits a model
Many characteristics of deposits can change after deposition: give most weight to characteristics that do not readily change
e.g., ore chemistry, host rock lithology, tectonic setting

当你考虑可能适合的时候，别期望这精确的吻合，所有矿床都是不同的，没有一个矿床完全符合某一矿床模型，很多特征在矿床形成之后会改变，我们对那些不易改变的特征多加注意（如矿石化学，围岩岩性，构造环境）

Some Important Models – Gold
对金矿而言，其重要的模型

- Witwatersrand type deposits **兰德型矿床**
- Epithermal gold deposits (high-, intermediate- and low-sulfidation) **浅成低温热液矿床（高，中，低硫化作用）**
- Orogenic gold deposits (mesothermal, slate belt, Archaean lode gold deposits)
  造山型金矿床（中温热液型，绿片岩型，太古代脉型金矿）
- Carlin type gold deposits (and Carlin-like deposits)
  卡林型金矿（似卡林金矿）
- Intrusion-related gold deposits **侵入岩有关的金矿**
- Skarn gold deposits **矽卡岩型金矿**
- Placer gold deposits **沉积型砂金矿**



Goldstrike Gold Mine, Nevada, USA



Some Important Models – Base Metals
一些重要模型-贱金属

Copper: **铜**

- Porphyry copper deposits 斑岩型铜矿
- Zambian-type copper deposits (Kupferschiefer-type, sediment-hosted copper, red-bed copper) 赞比亚型金矿（铜页岩型，沉积型，红层型铜矿）
- Iron Oxide Copper-Gold deposits (Cu ±Au, U) 铁，氧化铜-金型矿床

Zinc-lead:**铅锌矿**

- Sedex zinc-lead deposits 沉积型铅锌矿
- Mississippi Valley type lead-zinc deposits 密西西比谷型铅锌矿

Polymetallic deposits: **多金属矿床**

- Volcanic-hosted massive sulfide deposits (Cu, Cu-Zn, Zn-Pb-Cu, ±Au, Ag 火山岩型块状硫化物矿床（Cu, Cu-Zn, Zn-Pb-Cu, ±Au, Ag）
- Skarn deposits (Cu, Cu-Au, Zn-Pb, Sn, W, Mo, magnetite) 矽卡岩型金矿（Cu, Cu-Au, Zn-Pb, Sn, W, Mo, 磁铁矿）

Chuquicamata Porphyry Copper Mine, Chile
智利Chuquicamata斑岩型铜矿山



Some Important Models – Nickel and PGEs
一些镍-铂族元素矿床模式

Nickel: **镍**

- Komatiite-hosted deposits 科马提岩型矿床
- Flood basalt-hosted deposits 溢流玄武岩型矿床
- Ultramafic intrusion-hosted deposits 超基型侵入岩型矿床
- Gabbro-hosted deposits 辉长岩型矿床
- Lateritic deposits 红土型矿床

PGEs: **铂族元素**

- Layered mafic-ultramafic complex-hosted deposits
  层状镁铁质超基性杂岩矿床
- Alaskan-type deposits in small alkaline intrusions
  小型碱性侵入岩中阿拉斯加型矿床

Nickel sulfide ore, Kambalda



Nickel Ore, Fisher Shoot, Kambalda, WA



Some Important Models – Others
其他一些矿床模型

- Unconformity uranium deposits **不整合铀矿床**
- Banded Iron Formation iron deposits **带状铁质建造矿床**
- Kimberlite diamond pipes **金伯利岩筒金刚石矿床**
- Alluvial diamond deposits **冲击层金刚石矿床**
- Greisen tin deposits **云英岩性锡矿床**
- Bauxite deposits (Al) **铝土矿床**

There are many others ***还有很多其他的***

Iron ore mine, Pilbara, Western Australia



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Mt Newman Iron Ore mine, Western Australia
纽曼磁铁矿矿山，西澳大利亚



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Ekati Diamond Mine, Canada



Panda Pit

Processing Plant
炼油厂



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The Role of Models in Exploration
矿床模型在勘探的作用

Ore Deposit Models are important in exploration
矿床模型在勘探过程中是很重要的

- They allow us to convert commodities to geology
  它们能让我们将日常的东西用于地质。
  - *e.g., change "looking for gold" to "looking for an epithermal gold deposit"*
    比如:把找金变为找浅成低温型金矿
- They allow us to select favorable geology to maximize chances of success它们能让我们找到最合适的地质背景去增加成功的机会
  - *Because we know the geological setting and localizing controls on ore*
    因为我们知道地质背景和当地的控矿因素
- They help us to design effective exploration strategies using the most suitable techniques
  它们有利于我们利用最合适的技术来设计有效的开发战略
  - *Because we know the character of the ore and host rocks*
    因为我们知道矿和围岩的特点

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Now....

Other people will explain some important ore deposit models...

其他人会讲一些重要矿床模式

LATER...**稍后**

I will explain how we use them in exploration

我会讲矿床模型在勘探方面的应用



End

Thank you

Ore Deposit Models:

Their Use in Exploration

矿床模型－勘探应用实例

Noel C White

Society of Economic Geologists Thayer Lindsley Lecturer 2008
Guest Professor, China University of Geosciences, Beijing
Adjunct Professor, University of Queensland, Brisbane
Research Associate, Centre of Excellence in Ore Deposits, University of Tasmania

How do we Explore? 我们怎样进行勘探？

Explorers have a choice! 勘探者的选择！

Opportunistic Exploration: look for anything they can dig up

投机勘探，见什么挖什么。

Where: *anywhere!* Who: *anyone!*

Why do we need geologists?

2. Strategic Exploration: look for specific targets with the best chance of success 把握机会,寻找特定目标。

Real success means finding a *profitable mine*

*真正的成功*意味着找到了*具有很大经济意义的矿床*

Where: *in suitable geology!* Who: *specialist explorers!*

在哪里：*有利的地质条件！*谁：*勘探专家！*

This is smart exploration that needs educated people!

This is where we need Ore Deposit Models!

明智的勘探需要受过教育的人来完成！这就是我们为什么需要矿床模型！

The Role of Models in Exploration 矿床模型在勘探过程中作用

Ore Deposit Models are important in exploration 矿床模型很重要

They allow us to convert commodities to geology 它帮助我们把所找的矿种转变成为地质

» *e.g., change "looking for gold" to "looking for an epithermal gold deposit"*

如：把"找金矿"转变成为"找浅成低温热液矿床"

What will we explore for?
勘探什么？

The Role of Models in Exploration 矿床模型在勘探过程中作用

They allow us to select favorable geology to maximize chances of success 它能帮助我们选择有利的地质条件，使成功的机会更大。

» *Because we know the geological setting and localizing controls on ore*

因为我们能够了解地质背景，确定矿的范围。

They help us to design effective exploration strategies using the most suitable techniques 的勘探方案，使用最有效的勘探技术

» *Because we know the character of the ore and host rocks*

因为我们了解矿床及其围岩的特点

Where will we explore?

How will we explore?

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Deciding *WHAT* to Explore For 确定勘探找什么

Is there a particular commodity we *must* find? 是不是必须找某种特定的矿种？

YES: 是的

- What kinds of deposits does it form?什么样的矿
- What geology do those occur in?产出地质条件
- Do we have suitable geology?地质条件是否合适

MODELS

NO: 不

- What commodities would we *like* to find? 想找什么矿
- What kinds of deposits do they form?形成什么矿
- What geology do those occur in?产出地质条件
- Do we have suitable geology?地质条件是否合适

MODELS

Deciding *WHERE* to Explore 确定到哪去找

What is our exploration territory? 勘探地区在哪？

The world? A country? A province? A district?

What geology occurs in that territory? 区内地质情况

What types of deposits are known there? 区内已知矿床类型

What types of deposits *should* occur in that geology? 现有地质条件下可能产出的矿床类型

What types do we want to find?想找什么类型

What controls where they occur?矿床产出的控制因素

MODELS

Identify those places 确定其产出位置

MODELS

EXPLORE THERE!

Deciding *HOW* to Explore 确定怎样勘探

What are the characteristics of our target deposits? 我们要找的矿床所具备的特点

Geological Geochemical Geophysical 地质/地化/地球物理

What is the *most effective* way to explore? 最有效的勘探方法是什么？

Fastest Cheapest Best 快速 低投入 效果好

MODELS

What about local conditions? 当地条件

Modify approach 改进方法

MODELS

Choose *OPTIMUM* exploration strategy 选择有效勘探方案

GO DO IT!

Remember… 牢记

Geology is an *observational* science 地质是观察性科学

Geological truth is found in the rocks 地质事实在岩石中

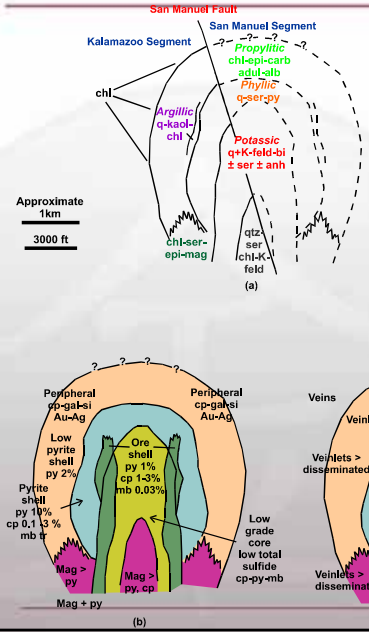
Laboratory studies help, but must illuminate what is in the field 实验室研究很有益，但必须和野外事实一致。

Good geological control *in the field* is essential for all sampling 良好的野外工作是取样工作的基础

What we learn in the laboratory should help us to understand the field 实验室的工作应该有助于理解野外地质事实

Develop and practice good field skills – field studies are the *foundation* of all geology 发挥良好的野外工作技能－野外研究是所有地质工作之基础

History of a Model 模型应用历史



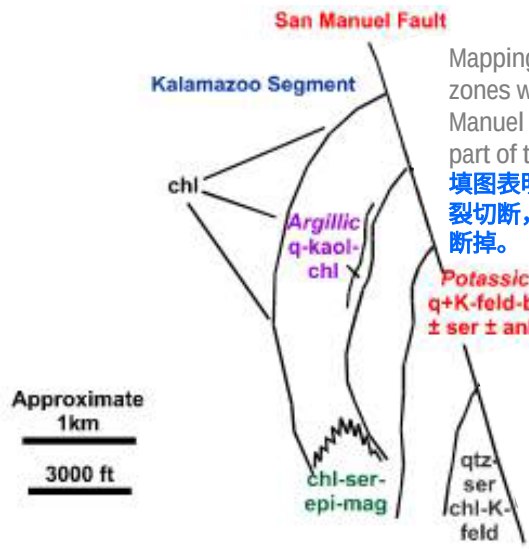
Porphyry Copper Model of Lowell and Guilbert, 1970

1970年的斑岩铜矿模型

This hugely influential model developed from studies of the Kalamazoo porphyry copper mine

该模型基于Kalamazoo斑岩铜矿床的研究成果而建立，已经产生了很大的影响。

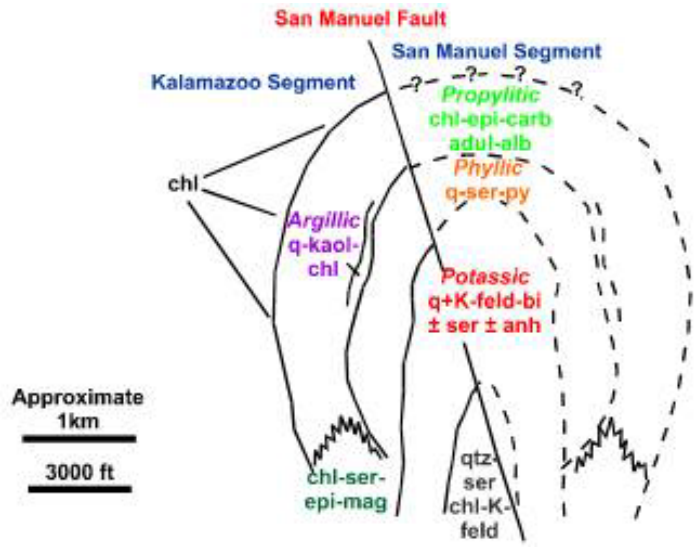
History of a Model 模型应用历史



Mapping showed the alteration zones were truncated by the San Manuel fault. It was inferred that part of the deposit was faulted off. **填图表明蚀变带被San Manuel断裂切断，据此推断部分矿体也被断掉。**

Mapping and drilling subsequently located the missing part, which became the San Manuel mine. **随后填图和钻探结果找到了断失的部**

History of a Model 模型应用历史



History of a Model 模型应用历史

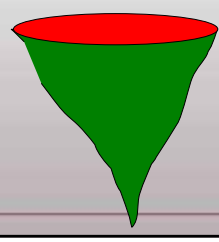
Early workers in Norway and Japan recognised the syngenetic origin of VMS deposits 在挪威及日本，人们早期就已经识别出同生成因的VMS矿床。

In Canada deposits were seen that looked like this:
在加拿大矿床被认为看作是这样了

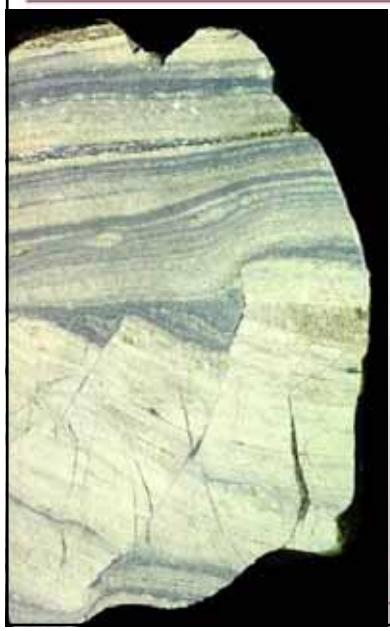


This was interpreted as a mineralized shear zone
这被解释为矿化煎切带。

Work on undeformed deposits in Cyprus in the early 1960s showed that they were syngenetic
60年代早期在塞浦路斯对变形矿床的研究表明，属同生成因。



An Example – Exploring for VMS Deposits
实例—VMS矿床勘探

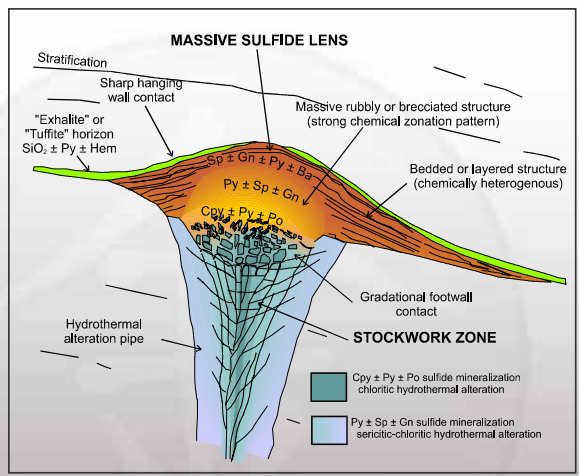


Volcanic massive sulfide deposits are a good example of how we use models in exploration VMS矿床是一类很好的例子，来说明我们怎然在勘探过程中运用模型

- » Model is well-developed **模型完善**
- » Examples are widespread **类型广泛分布**
- » Exploration uses diverse techniques **勘探应用多种技术**
- » *HOW* you use the techniques can make the difference between success and failure
  技术应用的方式决定了勘探的成败

Zn-Pb-Cu, Rosebery Mine, Tasmania

Exploring for VMS Deposits VMS矿床勘探



DESCRIPTIVE MODEL

- Tells us what to look for
- Not where to look
- Helpful when you have a prospect to explore

描述性模型

- **告知寻找什么**
- **但不能确定到哪里去找**
- **因此，对耙区内勘探帮助很大**

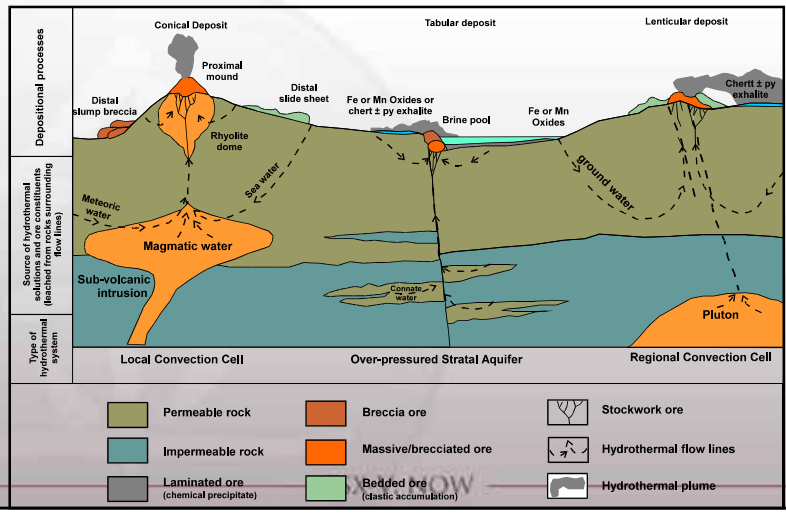
Exploring for VMS Deposits VMS矿床勘探

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GENETIC MODEL 成因模型

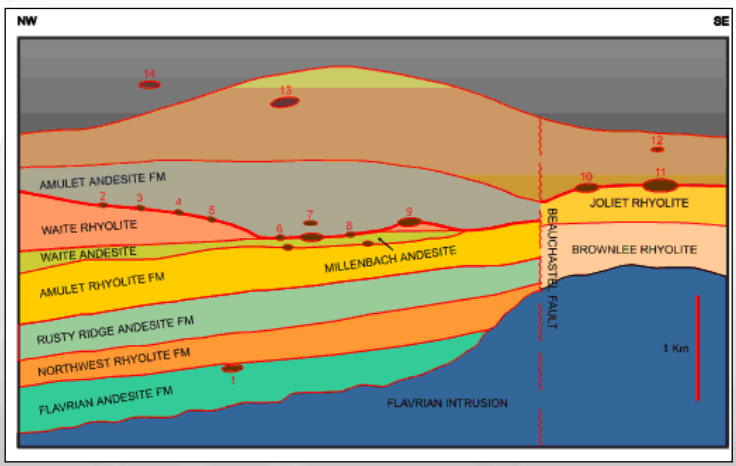
Tells us how the deposit got there, not where to find it

告知如何找到目标但不能确定到哪里去找



Exploring for VMS Deposits VMS矿床勘探

ASIA NOW RESOURCES CORP



Noranda District

加拿大Noranda地区

Canada

Distribution model

分布模型

THE IMPORTANT FEATURES:

1. Volcanic host rocks
2. Diverse lithologies
3. One main ore horizon

重要特征：1、火山岩为围岩；

2、岩性复杂多变；3、含矿层单一。

Exploring for VMS Deposits VMS矿床勘探

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MUST HAVE **必须具备**

1. Volcanic host sequence: calc-alkaline or tholeiitic
   火山围岩层序：钙碱性或拉斑玄武岩
2. Submarine setting (deep water best) **海水环境（最好是深水）**

WANT TO FIND **要找到**

Favorable horizon to focus exploration
有利的含矿层，并集中勘探

- Known deposits (local) **已知矿床（局部）**
- Exhalites (extensive) **喷气岩（大范围）**
- Footwall alteration (local to extensive) **下盘蚀变（局部－大范围）**

FOCUS EXPLORATION ON PARTS WITH **集中勘探**

- Favorable geochemistry **地球化学异常有利**
- Intense footwall alteration **强烈的下盘分异**
- Evidence for sulfides (e.g., gossans) **硫化物证据（如铁帽）**

Exploring for VMS Deposits VMS矿床勘探

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HOW DO WE EXPLORE? **如何勘探?**

GEOLOGY **地质方面**

- Map exhalite distribution, facies and thickness
  填图确定喷出岩的分布、岩相及其厚度
- Map alteration mineralogy, intensity and zoning
  填图区分蚀变矿物、强度和分带性
- Map sulfide distribution (look for gossans)
  填图查明分别硫化物的分布（寻找铁帽）

GEOCHEMISTRY **地球化学方面**

- Metal zoning (local Cu, Au, Pb, more widespread Zn)
  金属矿物分带（局部Cu、Au，Pb和分布较广的Zn

GEOPHYSICS **地球物理方面**

- Magnetics (local strong highs, extensive footwall lows)
  磁性（局部高强度、大范围的下盘低异常）
- Electromagnetics (find conductive massive sulfides)
  电磁性（针对高导块状硫化物）
- Induced polarization (find disseminated sulfides)
  激发激化（针对浸染状硫化物）
- Radiometrics (K-depleted footwall alteration, local highs)
  放射性（K亏损下盘蚀变，局部高异常）

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Exploring for VMS Deposits VMS矿床勘探

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INTEGRATE *all* data into a model (do not force it!)
综合各类数据成一个模型（不要牵强）

PREDICT where ore should occur using your model
用你的模型预测矿体应该出露的位置

TEST your predictions (*drill!*) 验证预测结果（打钻！）

REVISE the model based on results
根据验证结果修正模型

TEST AGAIN 再验证

VMS ore, Sunny Corner, NSW, Australia



Other Base Metal Models 其它贱金属模型

ASIA NOW RESOURCES CORP

How helpful models are for exploration varies widely
模型对勘探的有用程度变化很大

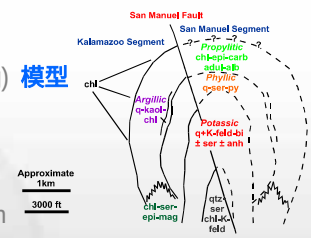
Porphyry Copper Model斑岩铜矿模型

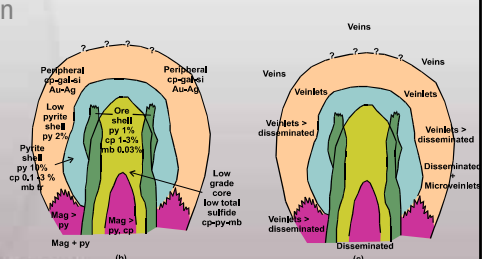
Well-developed model (but still developing) 模型很好（但还值得完善）

- Characteristic setting 特定背景
- Large scale characteristic alteration 大规模的特征蚀变
- Large-scale characteristic mineralization 大规模的特征矿化

Model provides good guides for exploration
模型对勘探提供了很好的指导作用







TSX-V: NOW

Lowell and Guilbert, 1970

Other Base Metal Models 其它贱金属模型

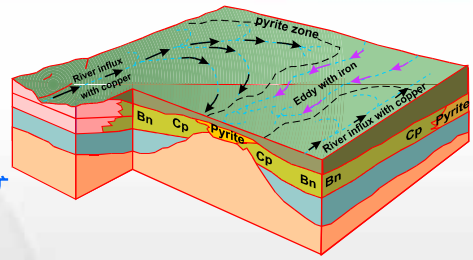
ASIA NOW RESOURCES CORP

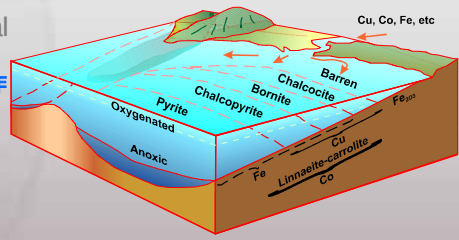
Zambian-type copper deposits 赞比亚型铜矿

Model still developing
模型正在完善

- Setting reasonably defined
  产出背景的合理确定
- Deposit characteristics broadly defined 矿床特征变化很大
- Favorable setting readily recognized有利的构造背景识别
- Sites for ore deposits difficult to locate 很难确定矿床的产出部位

Model provides regional guides, but not local guides for exploration
模型对勘探提供了区域性的而不是具体的指导作用





Other Base Metal Models 其它贱金属模型

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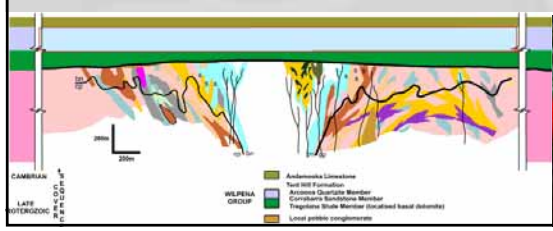
Iron Oxide Copper-Gold deposits 氧化铁铜－金矿

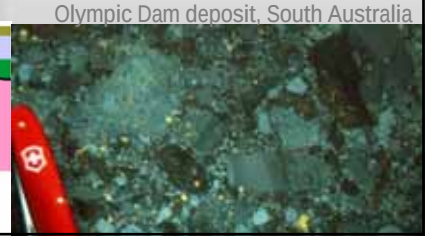
Model too broad and all-encompassing, probably includes diverse deposits 模型太泛和概括，可能包括不同的矿床

- Broad characteristics reasonably defined and recognizable
  广泛特点的合理确定和识别
- Settings not well characterised 背景不能很好地确定
- Genesis remains contentious 成因尚存争议

Model does not provide clear guides for exploration at any scale apart from empirical use of geophysics
模型对勘探在任何尺度都没有提供一个明确的指导作用

Olympic Dam deposit, South Australia





Other Base Metal Models 其它贱金属模型

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Sedex zinc-lead deposits

Sedex Zn-Pb矿

Good descriptive and genetic models 很好的描述性和成因模型

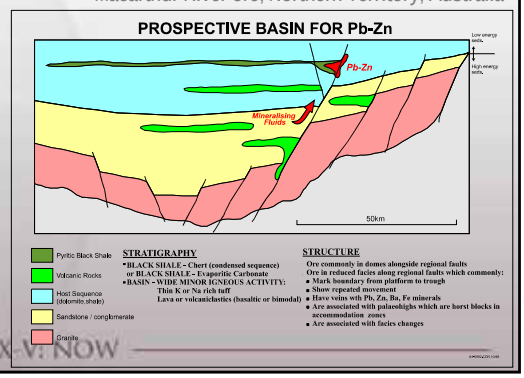
- General setting defined
  总体背景确定
- General deposit characteristics defined
  总体矿床特征确定
- Search criteria poorly developed
  找矿标志不易确定

Model provides conceptual guide for exploration, but not good targeting criteria – a very difficult target for exploration

模型对勘探提供了概念性指导，不是很好的确定靶区的依据，因此很难确定勘探靶区



Macarthur River ore, Northern Territory, Australia



Other Base Metal Models 其它贱金属模型

ASIA NOW RESOURCES CORP

Mississippi Valley type deposits

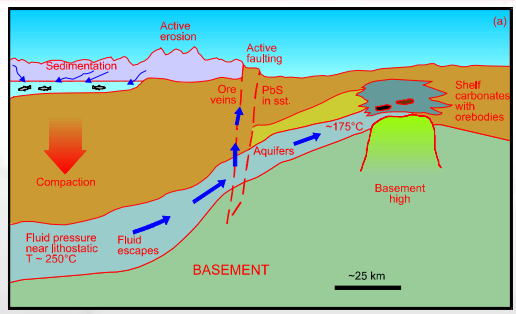
MVT型矿床

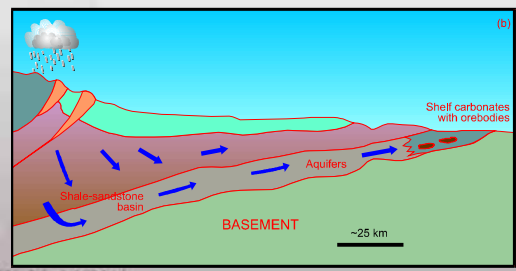
Good descriptive and genetic models 很好的描述性和成因模型

- General setting defined
  总体背景定义
- General deposit characteristics defined
  总体矿床特征确定
- Search criteria developed but very difficult
  具有寻找标志但很难应用

Model provides guides for exploration, but search and targeting criteria are weak – very difficult to explore

模型为勘探提供了很好的指导，但找矿和确定靶区的标志不清，很难用于勘探



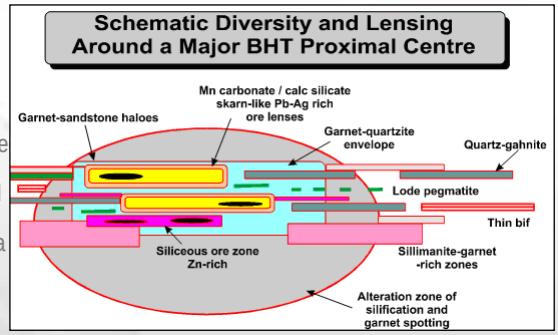


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Other Base Metal Models 其它贱金属模型

Broken Hill type deposits
Broken Hill型矿床
Good descriptive models
很好的描述性模型
- » Geological setting well-describe
  地质背景描述清楚
- » Character of ore well-described
  矿体特点描述清楚
- » Useful empirical search criteria available
  经验型找矿标志可行

Model useful for exploration, but genesis remains contentious
模型可用于勘探，但成因尚存争议





Massive Ag-Pb-Zn ore, Broken Hill, Australia

Some Important Models – Gold 一些重要模型-金

Witwatersrand type deposits 兰德型
Epithermal gold deposits (high-, intermediate- and low-sulfidation)
浅成低温型（由分高、中、低硫化作用）
Orogenic gold deposits (mesothermal, slate belt, Archaean lode gold deposits)
造山带型（中温、板岩带、太古宙脉岩型金矿）
Carlin type gold deposits (and Carlin-like deposits)
卡林型（类卡林型）
Intrusion-related gold deposits 侵入岩有关金矿
Skarn gold deposits 矽卡岩型
Placer gold deposits 砂金

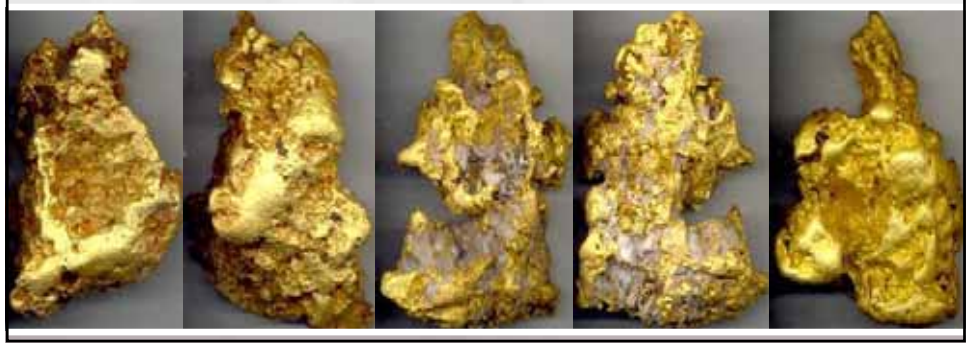


A Simple Test! 简单测试

For some deposit types, e.g., Orogenic and Skarn gold deposits

No alluvial gold = no deposit

对造山带型和矽卡岩型金矿，没有砂金＝没有金矿



A Simple Test! 简单测试

But some deposit types may have little or no alluvial gold, e.g., Carlin type and Carlin-like gold deposits, and epithermal gold deposits (high-, intermediate- and low-sulfidation)

而一些矿床类型可能很少或者没有砂金，如卡林型、类卡林型金矿、浅成低温热液型金矿（高硫化型、中硫化型和低硫化型）



Gold Models 金矿模型

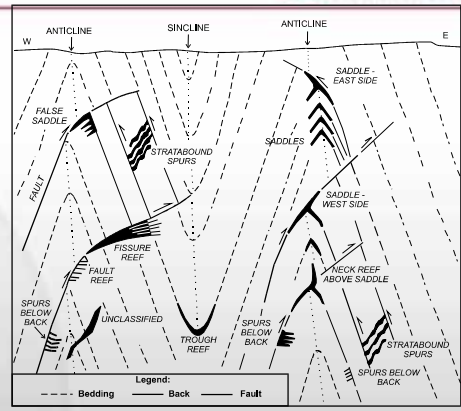
ASIA NOW RESOURCES CORP.

Orogenic gold deposits
造山带型

Model well-developed **模型很完善**

- » General setting well-described
  总体背景描述清楚
- » Excellent deposit descriptions
  矿床描述非常清楚
- » Characteristics well-defined
  矿体特征很确定
- » Genesis remains in dispute
  成因尚存争议

Model aids discovery, but remains a difficult target to explore due to complexity and economic criteria
模型有助于发现矿体，但由于其复杂性和经济指标等因素，很难确定勘探靶区。





Hope Bay, NWT, Canada

Gold Models 金矿模型

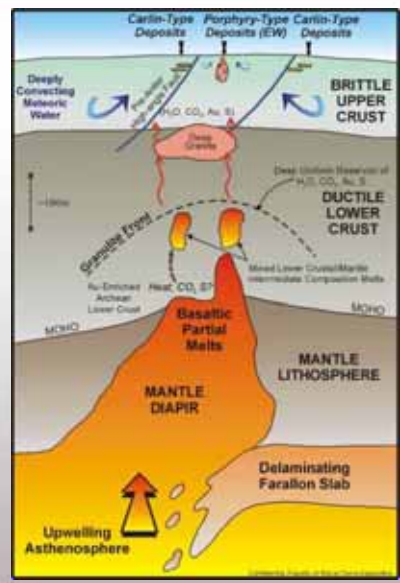
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Carlin-type gold deposits
卡林型

Model well-developed **模型很完善**

- » General setting well-described
  总体背景描述清楚
- » Excellent deposit descriptions
  矿床描述非常清楚
- » Characteristics well-defined
  矿床特征明确
- » Genesis remains in dispute
  成因尚存争议

Model does not provide clear aids to discovery; a difficult target to explore



TSX-V: NOW

Gold Models 金矿模型

ASIA NOW RESOURCES CORP

Skarn gold deposits

矽卡岩型金矿

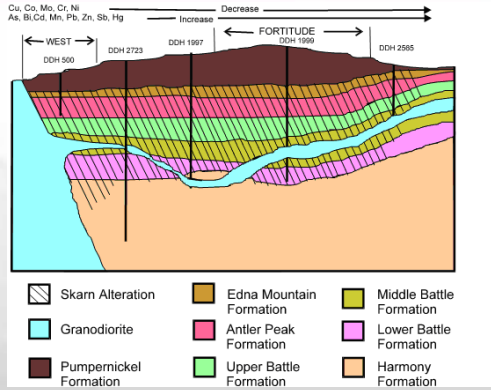
Model well-developed

模型完善

- General setting well-described **总体背景描述清楚**
- Excellent deposit descriptions **矿床描述详细**
- Characteristics well-defined **矿床特点明确**

Model provides useful guides to locating and exploring deposits, but made difficult by very irregular metal distribution

模型对确定矿床位置和矿床勘探有用，但由于金属不规则分布，困难很大。



Fortitude deposit, Battle Mountain, Nevada

Gold Models 金矿模型

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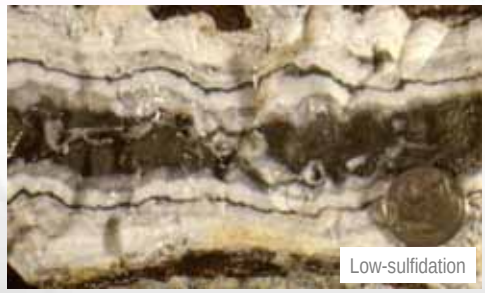
Epithermal gold deposits

浅成低温型

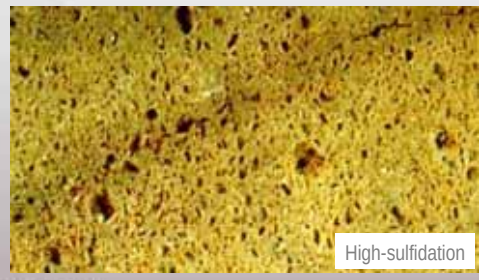
Model well-developed, but confusing (due to multiple sub-types) **模型很完善，但由于亚类较多，容易混淆**

- General setting well-described **总体背景描述清楚**
- Excellent deposit descriptions **矿床描述非常好**
- Characteristics well-defined **特征明确**
- Genesis remains in dispute for some sub-types **部分亚类的成因尚存争议**

Model provides useful guides to locating and exploring deposits, but made more difficult by insufficient differentiation of sub-types **模型对矿床定位和勘探很有用，但因不能准确鉴别亚类也很难进行勘探。**



Low-sulfidation



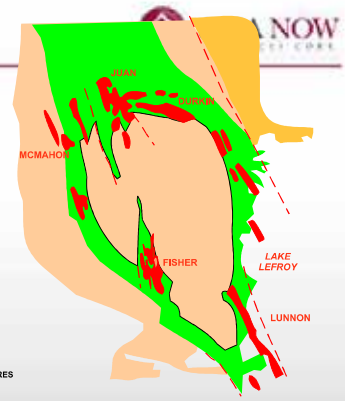
High-sulfidation

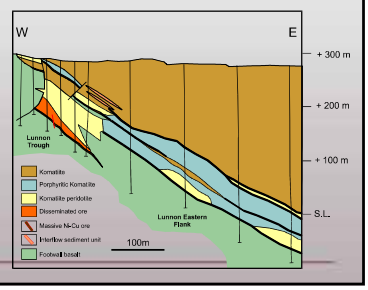
TSX-V: NOW

Volcanic-hosted nickel deposits
火山成因Ni矿床

Model well-developed
模型完善
- » General setting well-described 地质背景描述清楚
- » Excellent deposit descriptions 矿床描述详细
- » Characteristics well-defined 矿床特点明确

Model provides excellent guides to locating and exploring deposits
模型对确定矿化位置及矿床勘探非常有用。





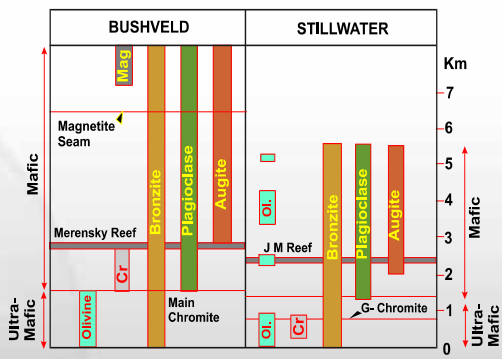
Kambalda, Western Australia

TSX-V: NOW

Layered intrusion PGE deposits 层状侵入体PGE矿床

Model well-developed
模型完善
- » General setting well-described 背景清楚
- » Excellent deposit descriptions 矿床描述详细
- » Characteristics well-defined 矿床特点明确

Model provides useful guides to locating and exploring deposits
模型对确定矿化位置和矿床勘探提供有益指导作用。



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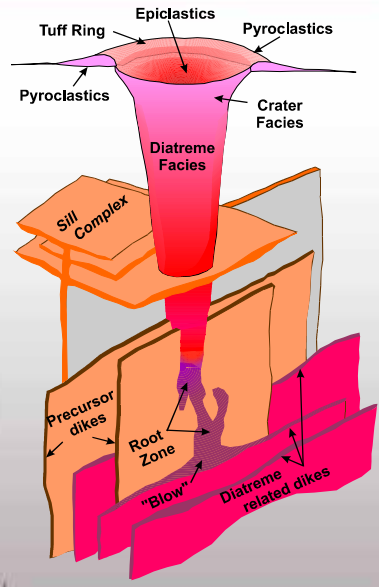
Kimberlite-hosted diamond deposits
金伯利岩中的金刚石矿床

ASIA NOW

Model well-developed
模型完善

- General setting well-described **地质背景描述清楚**
- Excellent deposit descriptions **矿床描述详细**
- Characteristics well-defined **特点明确**

Model provides useful guides to locating and exploring deposits
模型对矿化定位和矿床勘探提供有用的指导作用。



Ore Deposit Models 矿床模型

ASIA NOW

Models are a way for researchers to summarise and present diverse information about deposits
模型可以作为一种工具，它可以让研究人员总结和展示矿床的各类信息。

Models can be an important aid to exploration, but their effectiveness varies widely
模型对勘探可以提供重要的辅助作用，但其作用效力变化很大

It is important that models are carefully constrained by field mapping and descriptions, as well as by laboratory studies
重要的是，模型应该根据野外填图和描述，以及实验室研究来具体限定。



Ore Deposit Models 矿床模型

Models should be used with care; fit models to your observations, not the opposite

使用模型应该谨慎，要根据野外观察来改变模型，不能生搬硬套。

Not all deposit styles are covered by current models, so new models will appear, but should only be erected after careful study

目前，并非所有的矿床都有矿床模型，因此一些新的矿床模型将不断出现，应该在细心研究之后，才能确定矿床模型。



You are welcome to contact me by email on

欢迎发E-Mail与我联系

noelcwhite@hotmail.com

I always answer!

有问必答！

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Iron Ore Deposits
铁矿

Noel C. White
Society of Economic Geologists Thayer Lindsley Lecturer 2008
Asia Now Resources Corporation, Toronto, Canada
China University of Geosciences, Beijing, China
CODES, University of Tasmania, Hobart, Australia

Why does everyone want iron ore?
为什么每个人都想拥有铁矿石？

In the past people said "*Steel is finished*, we *want aluminium and magnesium*."
在过去有人説"钢铁的时代结束了，我们需要铝和镁合金。
What changed?
发生了什么改变？

- Rapid growth in demand for heavy construction – *steel is strong*
  大型建筑需求量的迅速增长——*钢铁足够坚固*
- Major increase in energy costs – *steel needs less energy*
  主要是在能源方面的花费增加-钢铁需要很少的能源

More demand for steel = More demand for iron ore

需求更多的钢铁=需求更多的铁矿石

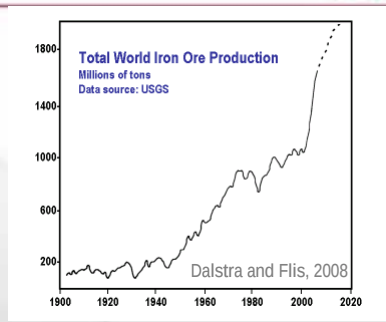
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- ~~Big demand can only be satisfied by big supply~~
  大量的需求只能通过大量的供应来满足
- Big consumers need
  大宗消费者的需求
  - » Reliable supply
    可靠的供给
  - » Consistent high quality
    持续的高质量
  - » Predictable price
    可预言的价格
- They *cannot* get those from 1000s of little mines
  这种要求是数以千计的小矿山不能满足的
- Only *BIG* mines working *BIG* deposits can deliver
  只有在大型矿山运营巨型矿床才能满足

Iron Ore Production and Demand
铁矿石的生产量和需求量

Country	Production Million tonnes
China	520
Brazil	300
Australia	270
India	150
Russia	105
Ukraine	73
USA	54
South Africa	40
Canada	33
Sweden	24
Venezuela	20
Iran	20
Kazakhstan	15
Mauritania	11
Others	43
World Total	1690

Year 2006: Source USGS



2005: China imported 275 million tonnes of iron ore (52.5% of its needs)

2005：中国进口275百万吨的铁矿石（占需要量的52.5%）

2010: China will import 540 million tonnes (62.9% of its needs)

2010：中国将进口540百万吨，（占需求量的62.9%）

The World's *Big* Iron Ore Deposits
世界上的大型铁矿床

Major iron ore deposits occur as several distinct deposit types:

主要的铁矿床以下列几种矿床类型出现：

1. Enriched banded iron formation (BIF) **富铁的条带状建造（BIF）**
2. Channel iron ore **槽钢铁矿**
3. Magnetite skarn **矽卡岩磁铁矿**
4. Lateritic iron ore **红土型铁矿**

...plus many other smaller ones...

加上许多其他的小矿床

I will talk about the first two...

我会首先讨论前两类

What is Banded Iron Formation?
什么是条带状磁铁矿建造？

- BIF is a sedimentary rock consisting of alternating layers of iron minerals (oxides, silicates, sulfides and carbonate), quartz and carbonate

  BIF是由含铁矿物（氧化物，硅酸盐，硫化物和碳酸盐），石英和碳酸盐互层所组成的沉积岩
- Common names for BIF include taconite (in North America), jaspilite (in Australia) and itabirite (in Brazil)

  BIF的通常名称包括铁燧岩（北美），碧玉铁质岩（澳大利亚）
- BIF ages range from early Archean to Devonian, but it is most abundant in late Archean and early Proterozoic sequences

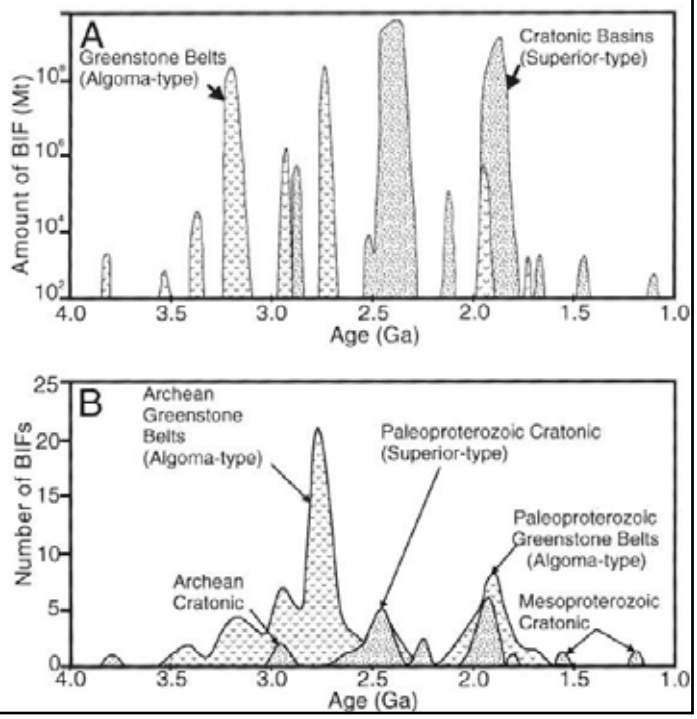
  BIF的年龄范围从早太古代到泥盆纪，但是最集中在从晚太古代到早元古代的层序中

Age and Frequency of BIF BIF年龄和成矿周期



Wilgena Hill Jaspilite
Middleback Ranges
South Australia 南澳中部山脉**Wilgena Hill** 碧玉铁质岩

Beukes and Gutzmer, 2008





Brockman Iron Formation, Pilbara, Western Australia



BIF Outcrop

BIF露头

Near Newman
Western Australia

西澳Newman附近

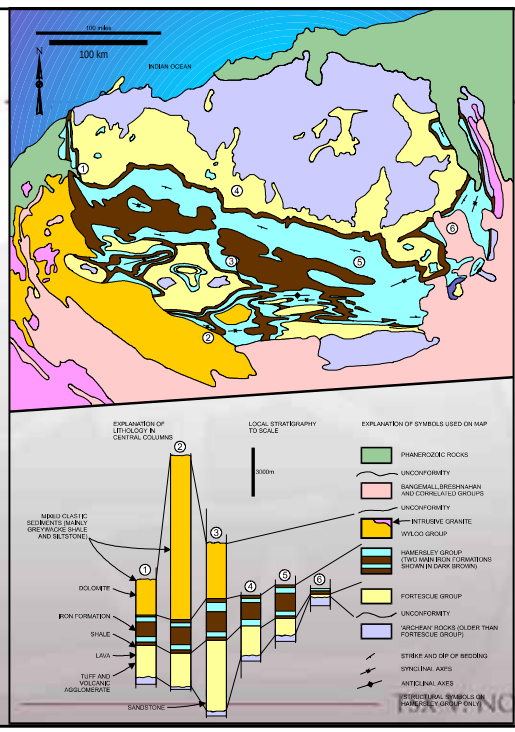


Archean BIF, Yalgoo Greenstone Belt, Western Australia 3.2 By old

太古代BIF， Yalgoo绿岩带，西澳，３２亿年

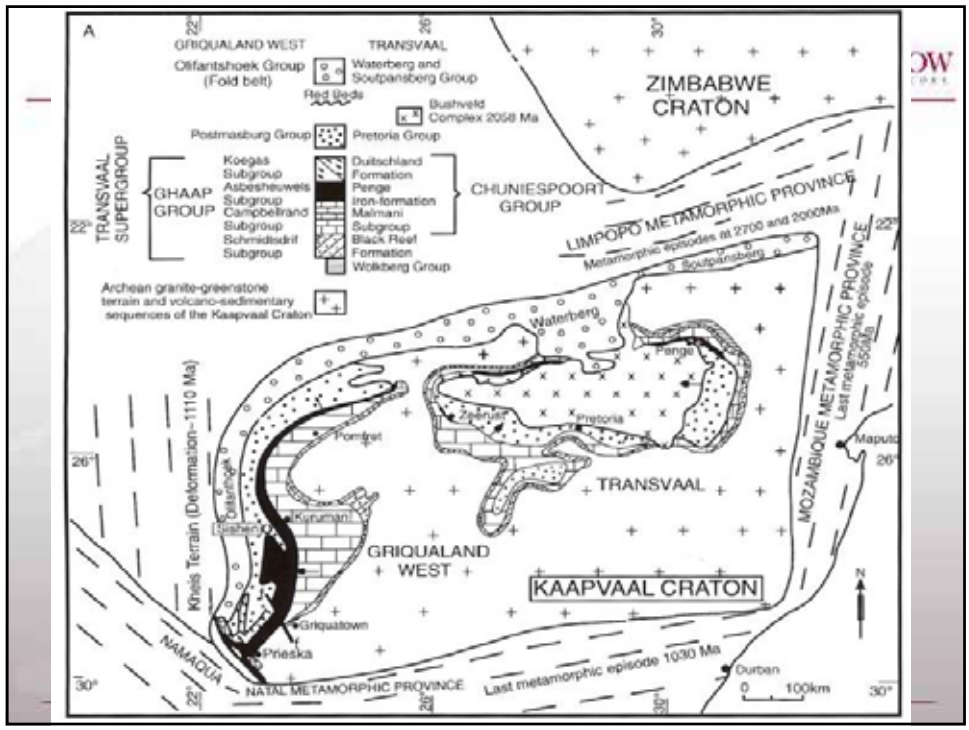
What is Banded Iron Formation?
什么是条带状磁铁矿建造？

- Its thickness ranges from of <1 m. to several hundred metres
  它的厚度变化范围从＜１m到数百米
- Its lateral extent varies from <1 km. to many hundreds of kilometres
  它在横向上的延伸变化范围从＜１ｋm的数百千米
- Its mineralogy is dominated by magnetite, hematite, siderite, iron silicates (e.g., stilpnomelane, riebeckite), quartz and dolomite
  它的矿物学受磁铁矿，赤铁矿，菱铁矿，铁硅酸盐（例如，黑硬绿泥石，钠闪石），石英和白云石所控制



Geology of the Hamersley Basin, Western Australia
西澳Hamersley盆地的地质图

Note the lateral extent of the banded iron formations in brown
褐色标记了条带状磁铁矿建造的横向延伸

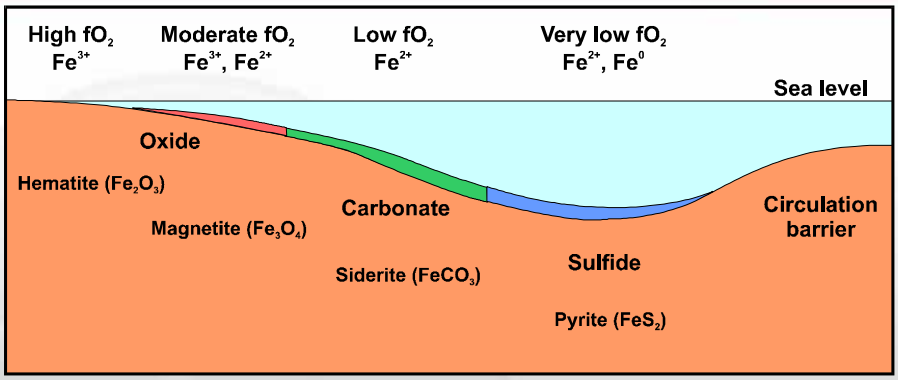


What is Banded Iron Formation?

- BIF formed as a chemical precipitate from iron-rich seawater – the iron is probably of hydrothermal origin, dispersed in marine basins before precipitating over large areas

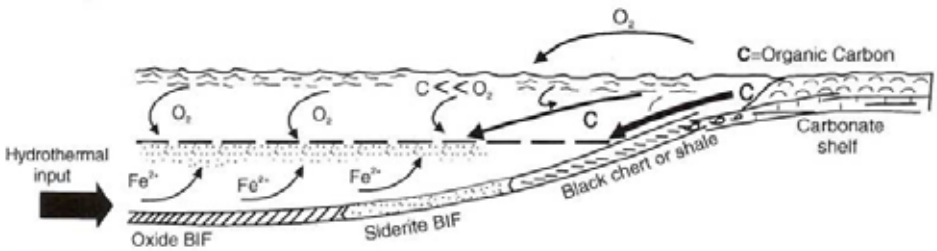
  BIF以化学沉积物从富铁的海水（这些铁质可能是热液来源）中形成
- The major BIFs deposited under very quiet conditions, resulting in fine bedding that can be traced in detail over hundreds of kilometres

  BIF型主要在非常平静的环境中沉积，最后导致可以形成几百公里的岩床



Model for the origin of facies of iron formation in Archean greenstone belts. The different iron minerals are believed to result from different water depths and consequently different availability of oxygen.

太古宙绿岩带铁建造相的成因模型，不同的铁矿物被认为是由不同水体深度和不同的氧化作用产生的



Model for the origin of facies of iron formation in cratonic basins. The stratified ocean system has low organic matter production in the open marine environment but high on the carbonate shelf. Beukes and Gutzmer, 2008.

在克拉通盆地铁建造的相的来源的模型。分层的海洋系统在开阔的海洋环境生产很少的有机物但是在碳酸盐台地却很高。Beukes and Gutzmer, 2008.



BIF and Carbonate Platform BIF和碳酸盐台地

Bedded BIF and dolomite, with rip-up clasts of BIF Near Yandicoogina, Western Australia

西澳层状BIF碎屑和白云岩及BIF碎屑

When is BIF Iron Ore?

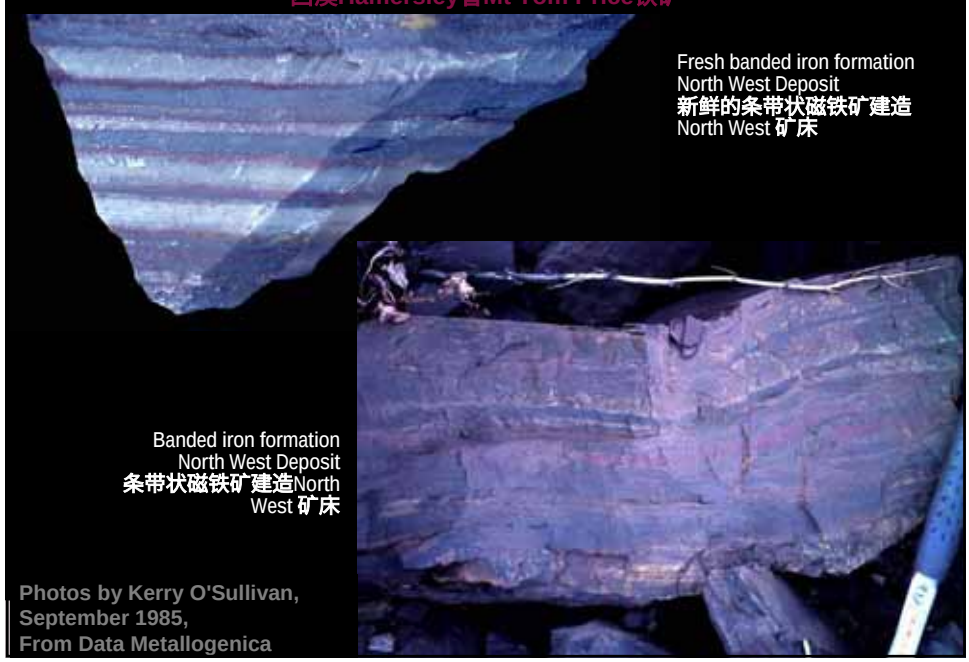
BIF铁矿石是什么时候的？

- Most BIF is *not* iron ore
  大部分的BIF不是铁矿石
- It may be iron ore when its Fe content > 25% (as magnetite) with low P and S
  当铁含量＞25%（磁铁矿）低P和S时，才是铁矿石。
- Oxide facies BIF is dominated by magnetite so it can be mapped using magnetic surveys
  氧化相的BIF以磁铁矿为主，所以可以用磁法测量来填图。
- The very big iron ore deposits occur in the BIF stratigraphy, but are *not* magnetic
  非常大的铁矿床出现在BIF地层中

The *MAJOR* BIF-hosted iron ore deposits

- Are local major accumulations of hematite and goethite
  局部赤铁矿和针铁矿主要的聚积物
- They occur in the BIF stratigraphy
  他们出现在BIF的地层中
- They are structurally controlled
  他们受构造控制
- They result from hypogene and supergene processes overprinted onto the BIF
  深成和浅生过程都在BIF上留下了印记
- The causes for enrichment can be different in different deposits, but the products are similar in all deposits
  富集的原因根据不同的矿床而不同，但是产物在所有矿床中都是类似的

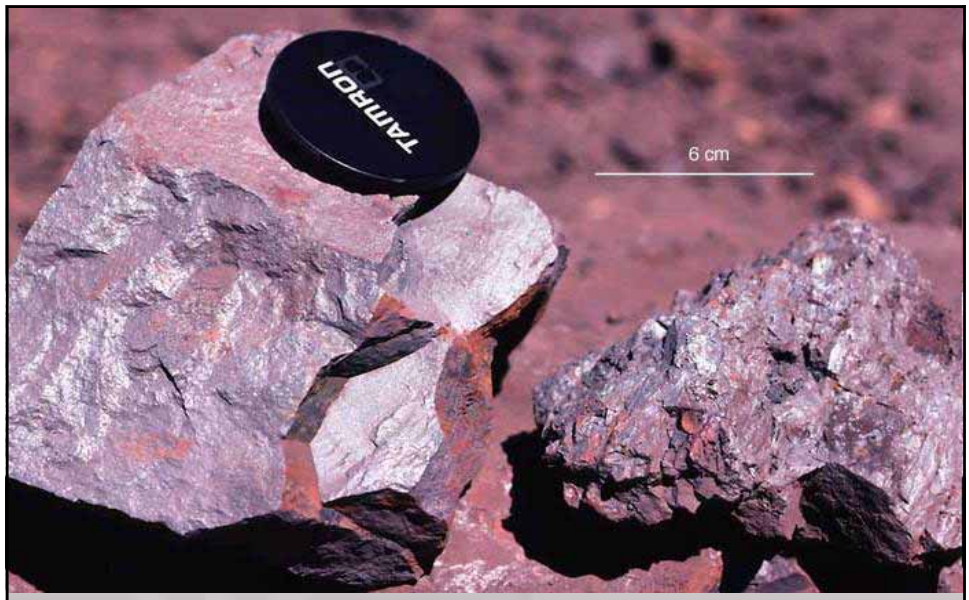
Mt Tom Price Iron Ore Mine, Hamersley Province, Western Australia
西澳Hamersley省Mt Tom Price铁矿



Fresh banded iron formation
North West Deposit
新鲜的条带状磁铁矿建造
North West 矿床

Banded iron formation
North West Deposit
条带状磁铁矿建造North
West 矿床

Photos by Kerry O'Sullivan,
September 1985,
From Data Metallogenica



Mt Tom Price Iron Ore, Hamersley Province, Western Australia

西澳Hamersley省Mt Tom Price铁矿

SE Prong: H1C hard conchoidal ore

Photo by Kerry O'Sullivan, September 1986, From Data Metallogenica

TSX.V: NOW

ASIA NOW



Mt Tom Price Iron Ore Mine

Hamersley Province, Western Australia

西澳Hamersley省Mt Tom Price铁矿

Panoramic view south over Tom Price operations

Photo by Peter Laznicka, July 2001

From Data Metallogenica

TSX.V: NOW



ASIA NOW

Mt Tom Price Iron Ore Mine
Hamersley Province
Western Australia
西澳Hamersley省Mt Tom Price铁矿

Aerial view east along axis of South East Prong

Photo by Kerry O'Sullivan
September 1985
From Data Metallogenica
Kerry O'Sullivan拍摄于１９８５年月，来自Data Metallogenica

NOW



Mt Tom Price Iron Ore Mine, Hamersley Province, Western Australia
西澳Hamersley省Mt Tom Price铁矿
View north-east to Mt Nameless, Photo by Kerry O'Sullivan, September 1985, From Data Metallogenica
从北东方向观察Mt Nameless， Kerry O'Sullivan拍摄于１９８５年十月，来自Data Metallogenica

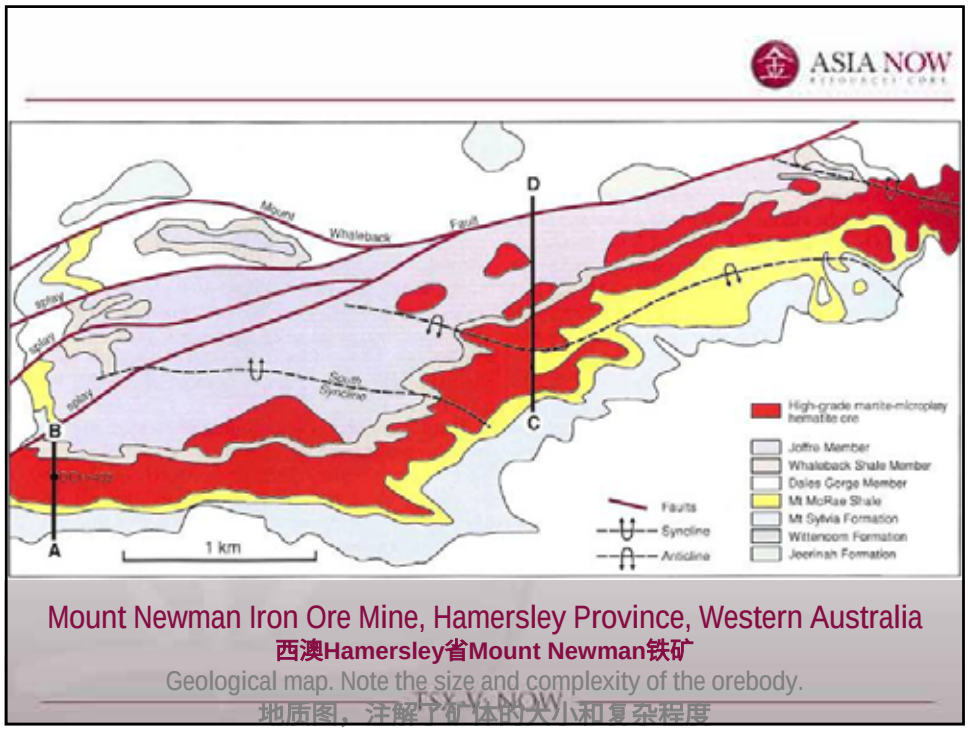


Mt Tom Price Iron Ore Mine, Hamersley Province, Western Australia
西澳Hamersley省Mt Tom Price铁矿
View west from Synclines. North West Deposit, low rise middle distance centre with drilling rig. West Pit to right of scene. The end of Southern Ridge to left of scene.
Photo by Kerry O'Sullivan, September 1985, From Data Metallogenica

TSX-V: NOW

Mount Newman Iron Ore Mine, Hamersley Province, Western Australia, 1998
西澳Hamersley省Mount Newman铁矿,1998



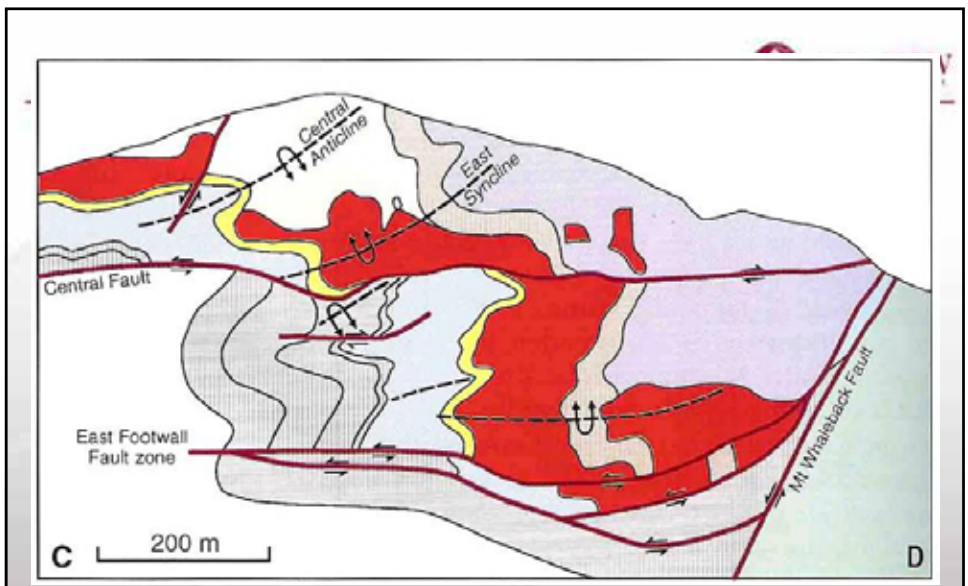


Mount Newman Iron Ore Mine, Hamersley Province, Western Australia

西澳Hamersley省Mount Newman铁矿

Geological map. Note the size and complexity of the orebody.

地质图，注解了矿体的大小和复杂程度

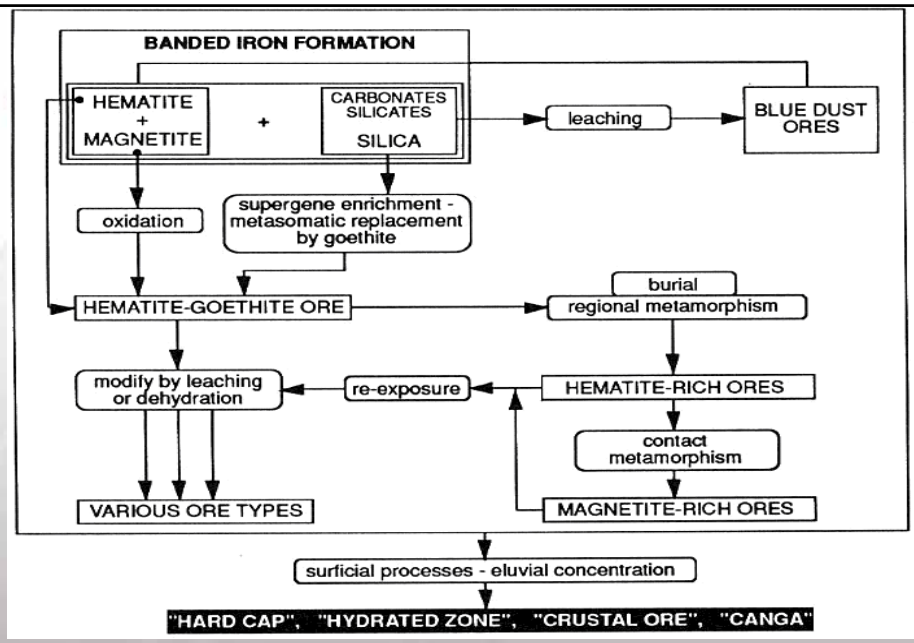


Mount Newman Iron Ore Mine, Hamersley Province, Western Australia

西澳Hamersley省Mount Newman铁矿

Geological cross-section. Note complexity of the orebody and relation to structures.

地质剖面，矿体的复杂程度与构造有关



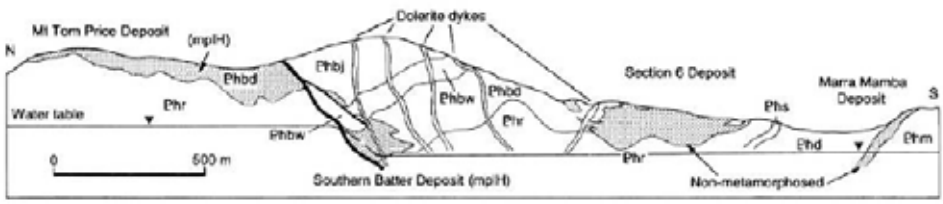
Genetic model for major BIF-hosted iron ores of the world

http://www.ga.gov.au/about/corporate/ga_authors/ajagg_1_1/RC_Morris_ajagg174.jsp

Exploration – What to look for
勘探—寻找什么

ASIA NOW

- BIF horizons – the thicker the better 水平的BIF—越厚越好
- Synforms and structures in BIF BIF 中的向形和构造
- Post-BIF unconformities and weathered surfaces
  Post-BIF 的不整合面和风化表面
- Burial metamorphism produces premium ore
  埋藏变质生产出额外的矿石



Generalised section at Mt Tom Price showing metamorphosed ore deposits (mpIH) in the Brockman Iron Formation and non-metamorphosed deposits in the Brockman and Marra Mamba Iron Formations

Mt Tom Price的 Generalised截面显示变质矿床在Brockman 含铁建造中和无变质矿床

Channel Iron Ore Deposits
槽钢铁矿床

- Occur in iron-rich districts with BIF and/or laterite
  与BIF及红土型铁矿一起出现在富铁区
- Can occur in same districts as enriched BIF-hosted deposits
  可以出现在与富BIF矿床同一区域
- Originally filled mature valleys in low-relief paleotopography
  最初淤积在低地貌古地形的成熟山谷中
- Now may be in the bottoms of valleys, or may form mesas resulting from topographic inversion due to erosion
  现在有可能在山谷的底部，或者出现在由于剥蚀导致的地形倒置形成的台地上

Channel Iron Ore Deposits

- Can be major deposits with reserves of billions of tonnes >50% Fe, low P and S
  主要矿床有数十亿吨的铁含量>50%，低P 和 S
- Consist dominantly of secondary hematite and limonite coating and replacing detrital fragments (including fossil wood)
  由次级的赤铁矿和褐铁矿被覆和替代岩屑碎片的（包括木化石）组成

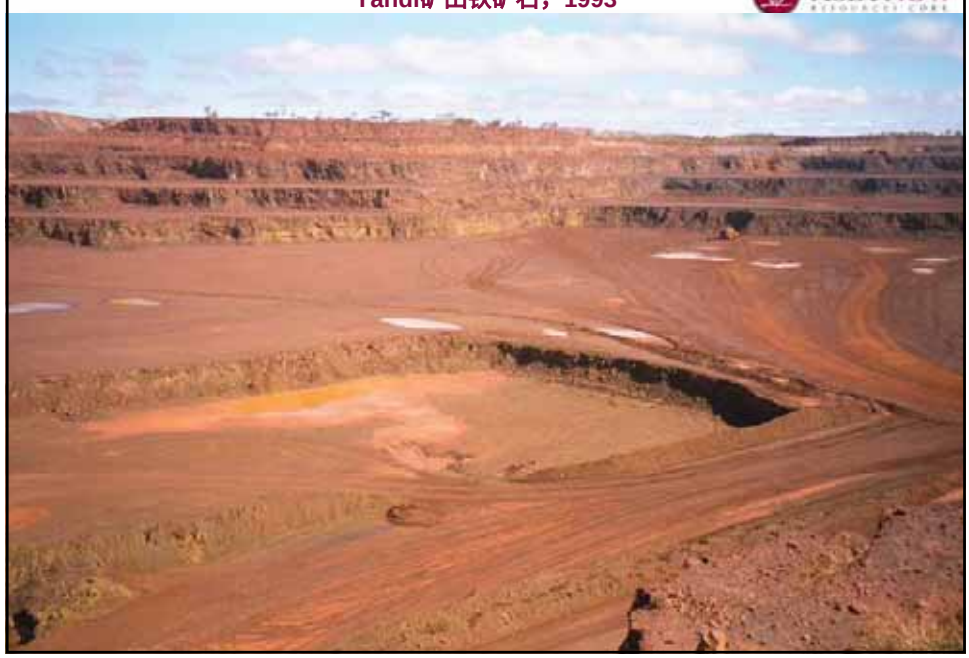
Yandi Iron Ore Mine, 1993

Yandi矿田铁矿石，１９９３



Yandi Iron Ore Mine, 1993

Yandi矿田铁矿石，1993



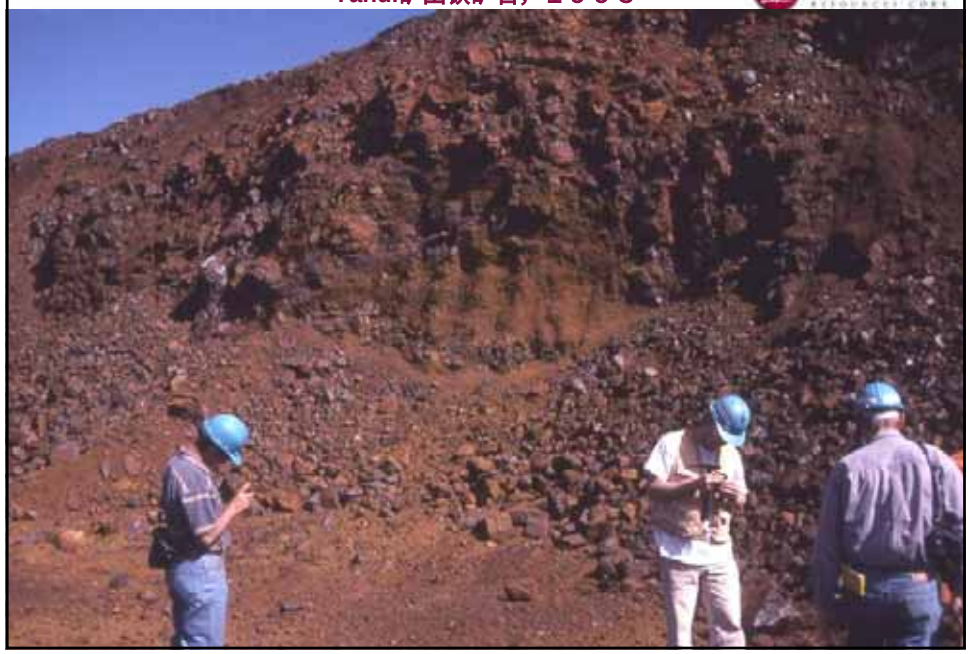
Yandi Iron Ore Mine, 1993
Yandi矿田铁矿石，１９９３



Yandi Iron Ore Mine, 1993
Yandi矿田铁矿石，１９９３



Yandi Iron Ore Mine, 1993
Yandi矿田铁矿石，１９９３



Yandi Iron Ore Mine, 1993
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Yandi Iron Ore Mine, 1993
Yandi矿田铁矿石，１９９３



Yandi Iron Ore Mine, 1993
Yandi矿田铁矿石，１９９３



Yandi Iron Ore Mine, 1993
Yandi矿田铁矿石，１９９３



The following papers come from this important new publication:
Hagemann, S., Rosière, C.A., Gutzmer, J., and Beukes, N.J. (Editors), 2008: Reviews in Economic Geology, Vol. 16, Society of Economic Geologists, Littleton

1. Beukes, N.J., and Gutzmer, J., 2008, Origin and paleoenvironmental significance of major iron formations at the Archean-Paleoproterozoic boundary, p. 5-48.
2. De Kock, M.O., Evans, D.A.D., Gutzmer, J., Beukes, N.J. and Dorland, H.C., 2008, Origin and timing of banded iron formation-hosted high-grade hard hematite deposits – a paleomagnetic approach, p. 49-72.
3. Dalstra, H.J., Rosière, C.A., 2008, Structural controls on high-grade iron ores hosted by banded iron formation: a global perspective, p. 73-106.
4. Lobato, L.M., Figueiredo e Silva, R.C., Hagemann, S, Thorne, W., and Zucchetti, M, 2008, Hypogene alteration associated with high-grade banded iron formation-related ore, p. 107-128.
5. Ramanaidou, E., Wells, M., Belton, D., Verral, M., and Ryan, C., 2008, Mineralogical and microchemical methods for the characterisation of high-grade bended iron formation-derived iron ore, p. 129-156.
6. Gutzmer, J., Chisonga, B.C., Beukes, N.J., Mukhopadhyay, J., 2008, The geochemistry of banded iron formation-hosted high-grade hematite-martite ores, p. 157-184.
7. McLellan, J.G., and Oliver, N.H.S., 2008, Application of numerical modeling to extension, heat and fluid flow in the genesis of giant banded iron formation-hosted hematite ore deposits, p. 185-196.
8. Thorne, W., Hagemann, S., Webb, A., and Clout, J., 2008, Banded iron formation-related iron ore deposits of the Hamersley province, Western Australia, p. 197-222.
9. Rosière, C.A., Spier, C.A., Rios, F.J., and Suckau, V.E., 2008, The itabirites of the Quadrilatero Ferrifero and related high-grade iron ore deposits: an overview, p. 223-254.
10. Figueiredo e Silva, R.C., Lobato, L.M., Rosière, C.A., Hagemann, S., Zucchetti, M., Baars, F.J., Morais, R., and Andrade, I., 2008, A hydrothermal origin for the jaspilite-hosted, giant Serra Norte iron ore deposits in the Carajás Mineral Province, Pará State, Brazil, p. 255-290.
11. Mukhopadhyay, J., Gutzmer, J., Beukes, N.J., and Bhattacharya, H.N., 2008, Geology and genesis of the major banded iron formation-hosted high-grade iron ore deposits of India, p. 291-316.
12. Alchin, D., Lickfold, V., Mienie, P.J., Nel, D., and Strydom, M., 2008, An integrated exploration approach to the Sishen South iron ore deposits, northern Cape Province, South Africa, and its implications for developing a structural and/or resourcemodle for these deposts, p. 317-338.
13. Cope, I.L., Wilkinson, J.J., Boyce, A.J., Chapman, J.B., Herrington, R.J., and Harris, C.J., 2008, Genesis of the Pic de Fon iron ore deposit, Simadou Range, Republic of Guinea, West Africa, p. 339-260.
14. Brown, P.E., 2008, A brief history of high-grade iron ore mining in North America (1848-2008), p. 361-380.
15. Flis, M., 2008, Advances in geophysics applied to the search for banded iron formation-related, high-grade hematite iron ore, p. 381-392.
16. Dalstra, H., and Flis, M., 2008, High-grade iron ore exploration in an increasingly steel-hungry world: the past, current, and future role of exploration models and technological advances, p. 393-410.