Coupled Fluid Flow, Deformation, Heat Transport & Mineral Reactions in Hydrothermal Mineralising Systems

热液成矿系统中流体流动，变形，热传递&矿物反应的耦合过程

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One Hour Presentations

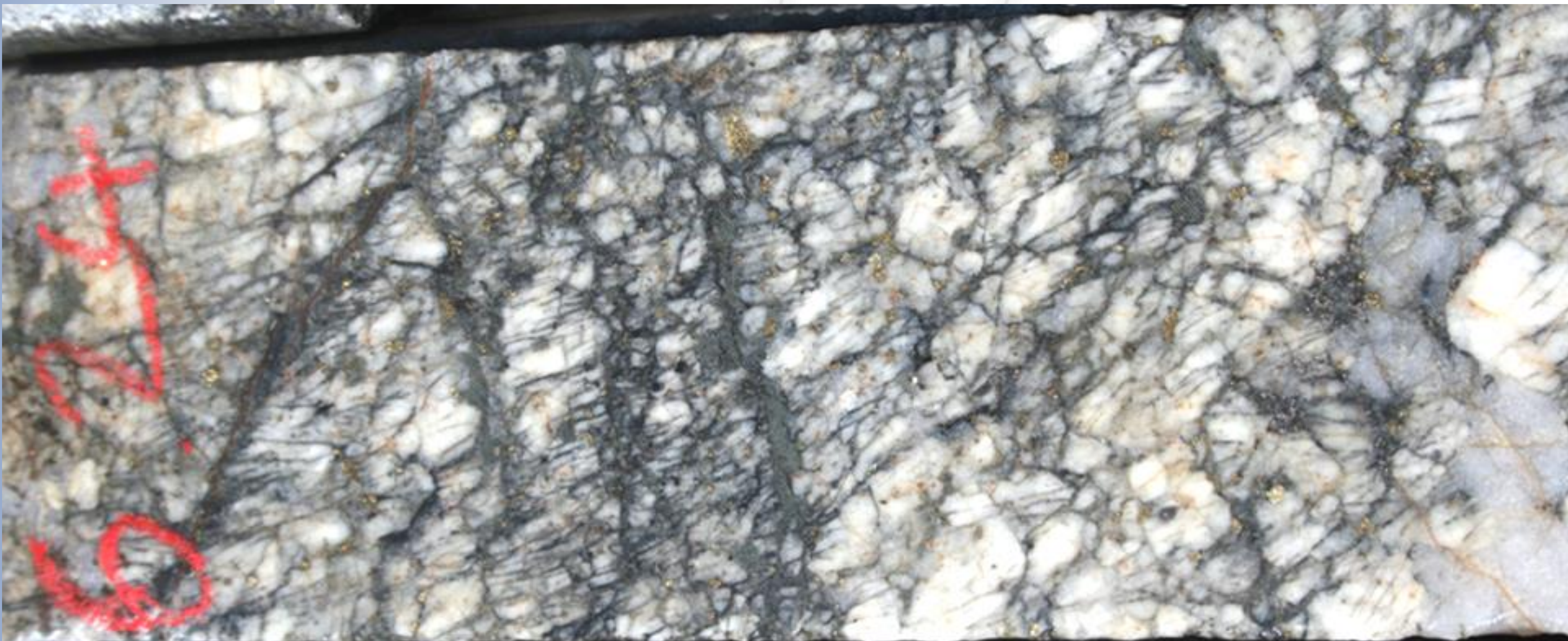
1. A Systems Approach: The 5 Questions
2. Folding & Boudinage
3. **Shear Zones, Fractures, Breccias and Veins.**
4. The Regional Scale – Fundamentals
5. The Regional Scale – Applications
6. Synthesis – The Way Ahead

Brecciation is common in many hydrothermal mineralised systems.

热液成矿系统中普遍发育角砾岩化

Typical are the spectrum of iron oxide copper gold (IOCG) & orogenic gold deposits.

典型的有铁氧化物铜金矿床（IOCG） & 造山型金矿



Core from Tropicana deposit Western Australia. Crackle brecciation with precipitation of biotite and gold bearing pyrite; quartz is dissolving. Grade is 6.24 g tonne^{-1}.

西澳Tropicana矿床

破碎角砾岩化与黑云母及含金黄铁矿沉淀；石英发生溶解；品位6.24克/吨

1

Open versus closed flow systems

封闭及开放流系统

2

The consequences for permeability development of changing temperature and chemical composition

温度及化学成分改变导致渗透率提升

3

Brecciation, the process

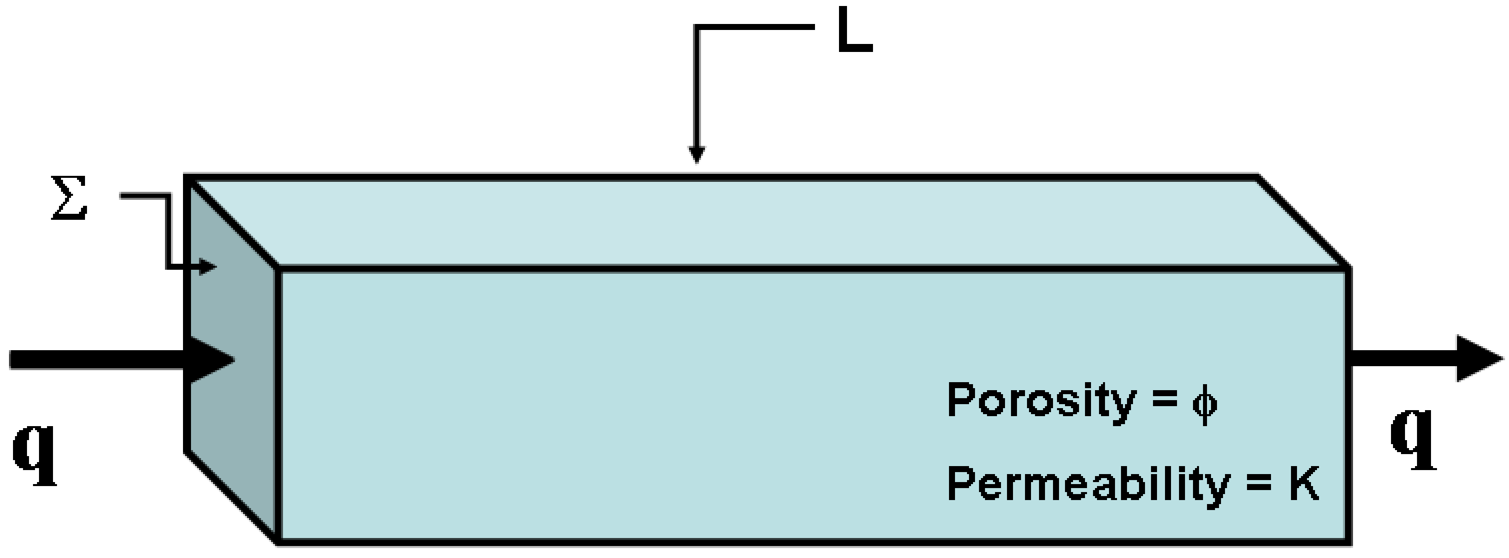
角砾岩化，过程

4

The role of entropy production in the formation of giant hydrothermal mineral systems

巨大热液成矿系统形成中熵增作用

In order to do this, we are going to define a CONTROL VOLUME



This is a body of rock of length L and cross-section area Σ with an instantaneous porosity ϕ, permeability K, and volumetric flow q.

长为L，截面面积为Σ，瞬时孔隙度Φ，渗透率K, 体积流量q

1

Open versus closed flow systems

4 types of thermodynamic systems

1. Isolated or closed system

   孤立或封闭系统

2. Diffusive closed system

   扩散封闭系统

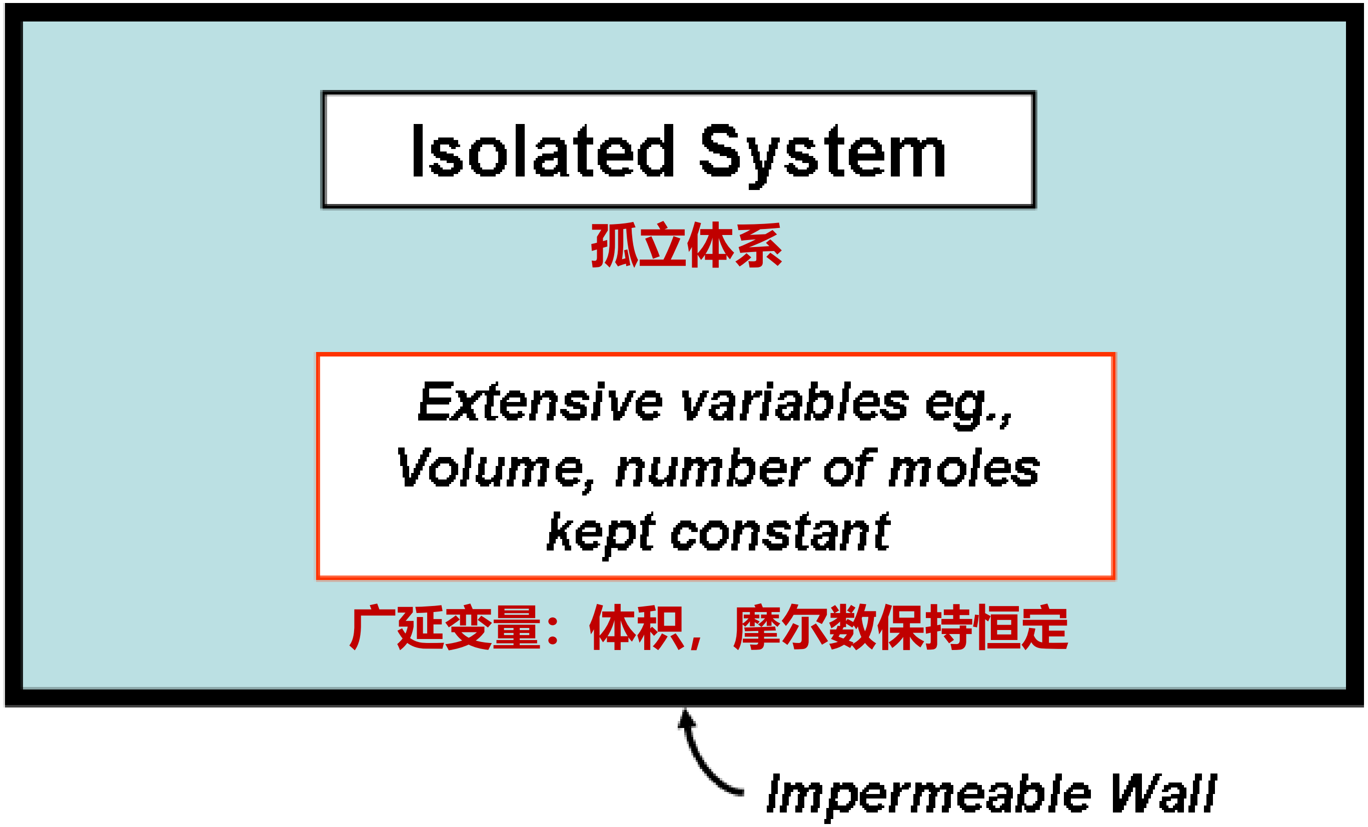
3. Open flow system – controlled by the gradient in hydraulic potential

   开放流系统 – 受水力势能梯度控制

4. Open flow controlled system – controlled by the rate of production of fluid

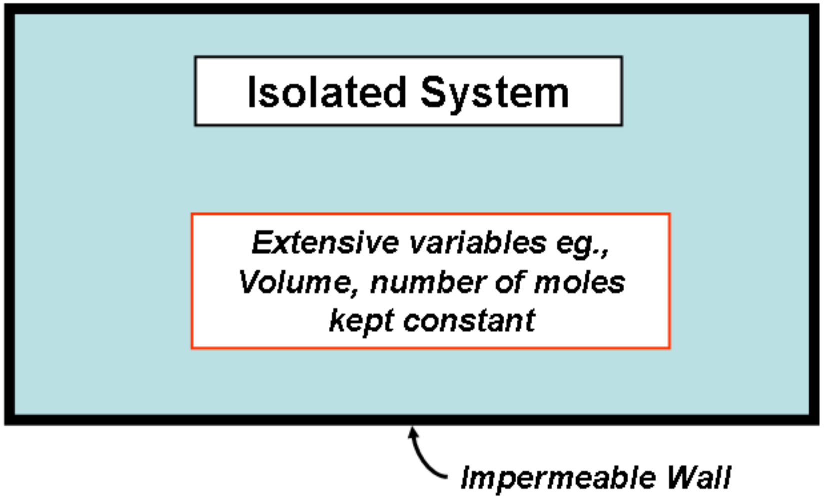
   开放流控系统 – 受流体产出速率控制

1



The only evolutionary path such a system can adopt is to evolve to equilibrium

唯一的演进路线是发展至平衡状态



If the system is perturbed from equilibrium or begins far from equilibrium then the path equilibrium may be tracked.

如果系统平衡受到扰动并开始远离平衡状态，之后达到平衡状态的途径可被追踪

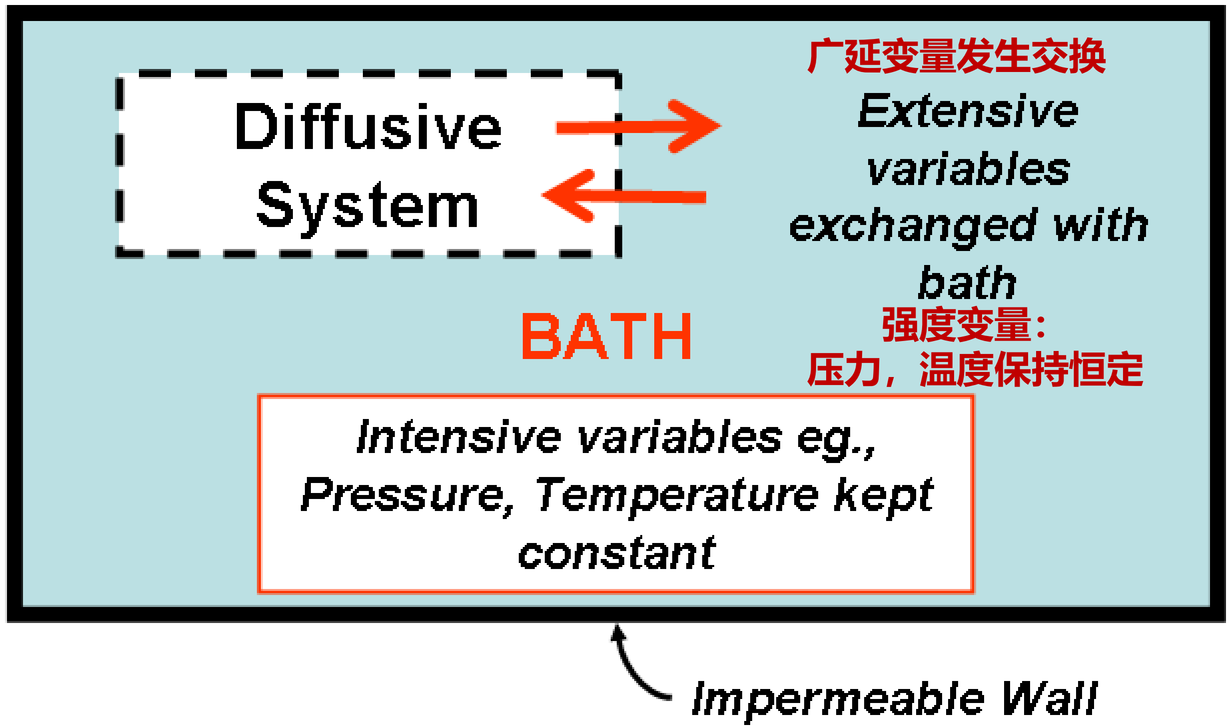
The path from one state to the equilibrium state need not necessarily be steady.

从一个状态到达平衡状态的途径不必稳定

Nevertheless, an isolated or closed system must ultimately proceed smoothly to equilibrium.

然而，孤立或封闭体系最终势必平缓的达到平衡

2



Diffusive systems must also always evolve to equilibrium.

扩散系统必须总是演进至平衡状态

They follow the same rules for doing so as isolated systems.

遵循与孤立系统相同的规律

So although not commonly well defined or emphasized, most considerations of metamorphic mineral reactions assume the system is isolated or diffusive.

尽管通常情况下不明确定义或强调，但大多数变质矿物反应假定是孤立或扩散系统

Open flow systems are a completely different class of system.

开放流系统是一个完全不同类的系统

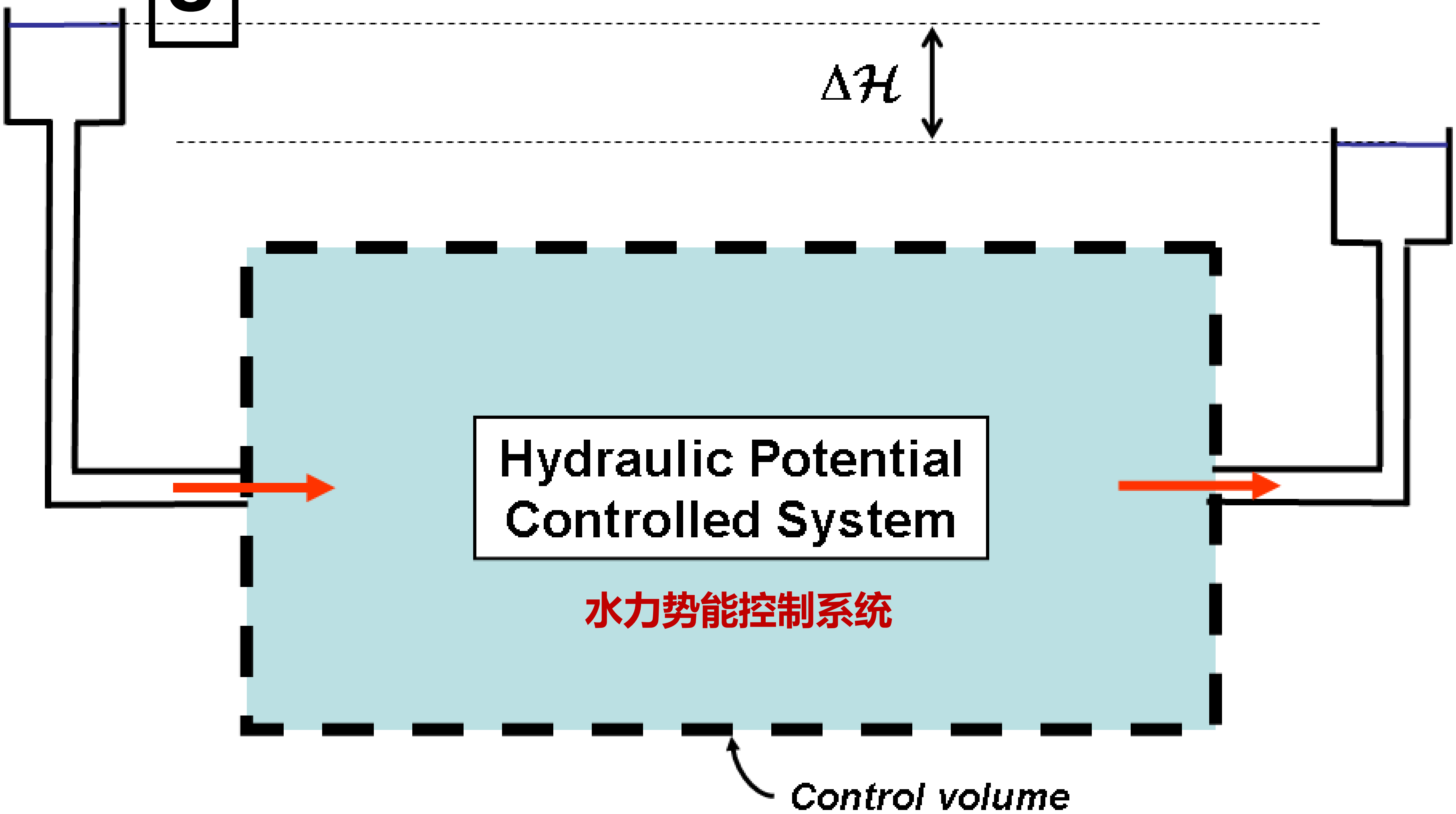
The system comprises an open configuration that can communicate with the surrounding material with or without constraints on flows of mass and heat through the system.

该系统包括一个开放结构，可与周围的物质材料进行交换。交换或有或没有受到系统中质量和热流的约束。

Such systems evolve to a non-equilibrium stationary state so long as the flows are maintained and the system can be held far from equilibrium for the duration of the flows.

只要流动持续，这种系统将发展到一个非平衡稳态，在流动过程中，系统能够很大程度远离平衡状态。

3



The volumetric flow rate in this flow controlled system is imposed by a gradient in the hydraulic potential.

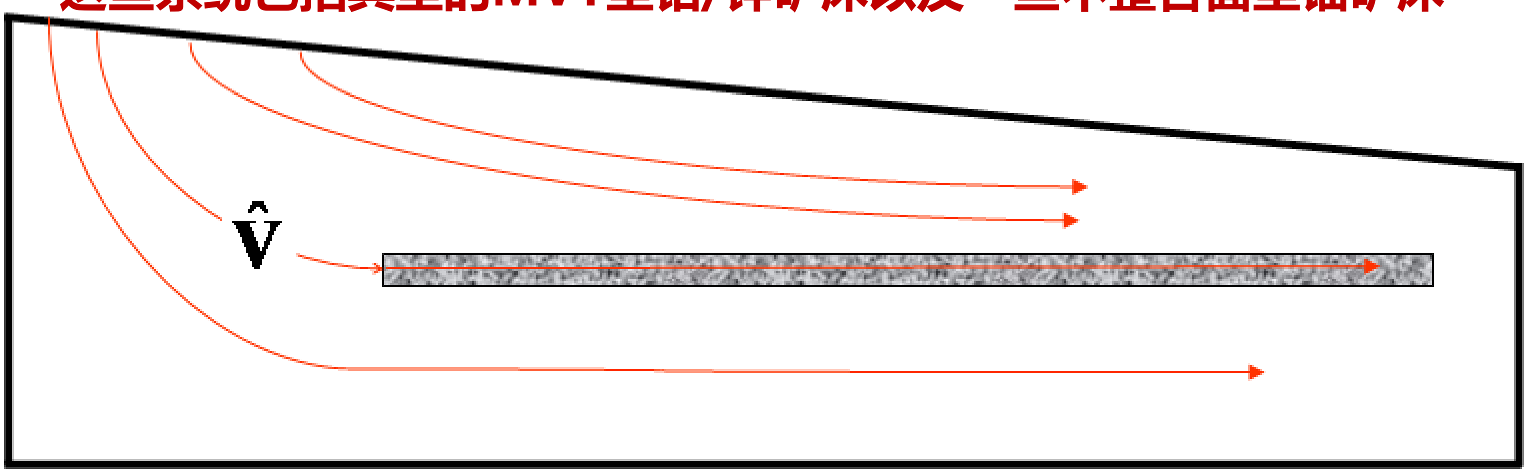
在这种流动控制系统中，体积流率由水力势能梯度施加。

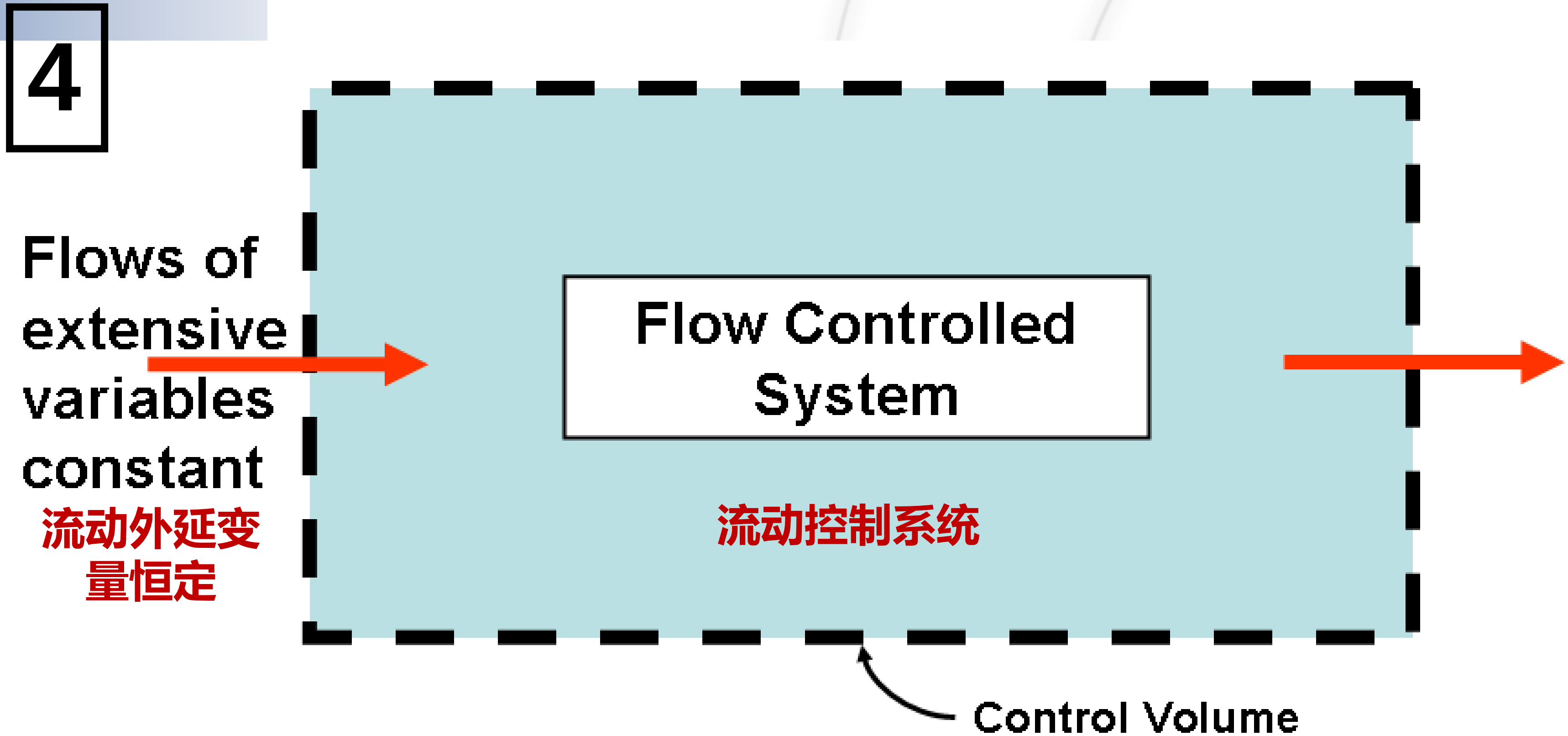
If the hydraulic head is kept constant, the fluid velocity within the system changes as the permeability within the system changes due to chemical precipitation and/or dissolution.

如果水头保持恒定，系统内流体速度如同渗透性一样由于化学沉淀和或溶解而改变。

These kinds of systems lead/zinc deposits are typical of MVT and Irish as well as some uranium unconformity deposits

这些系统包括典型的MVT型铅/锌矿床以及一些不整合面型铀矿床





The fluid input rate is constrained by the rate of production of the fluid.

流体输入率受到流体产出率的约束。

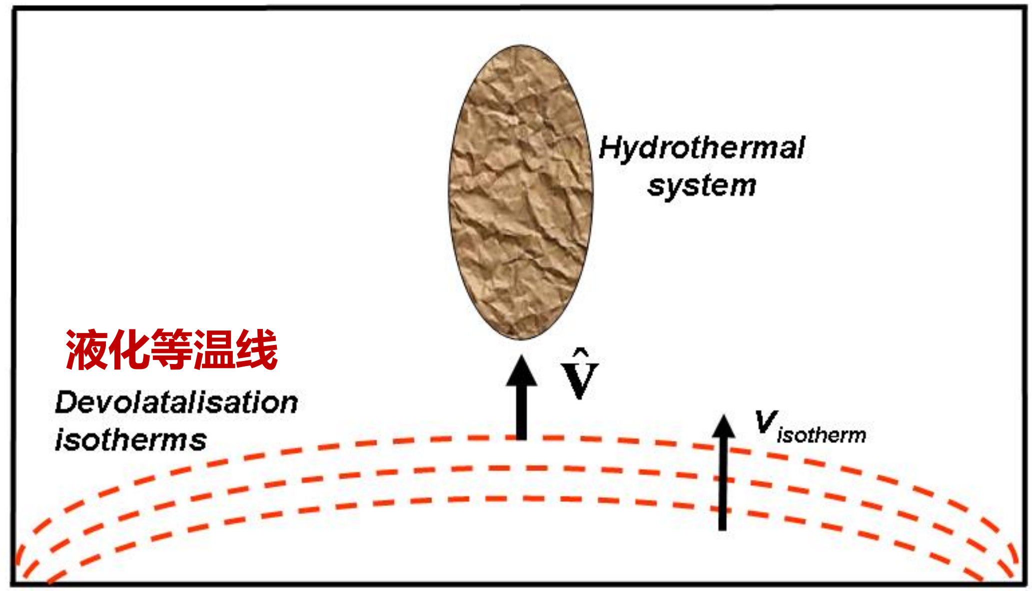
Such systems evolve to a non-equilibrium state so long as the flows are maintained; the system can be held far from equilibrium for the duration of the flows.

只要保持流动，系统将演进至一个非平衡状态，在流动过程中，系统能够很大程度远离平衡状态。

We propose this is the case for

orogenic gold deposits

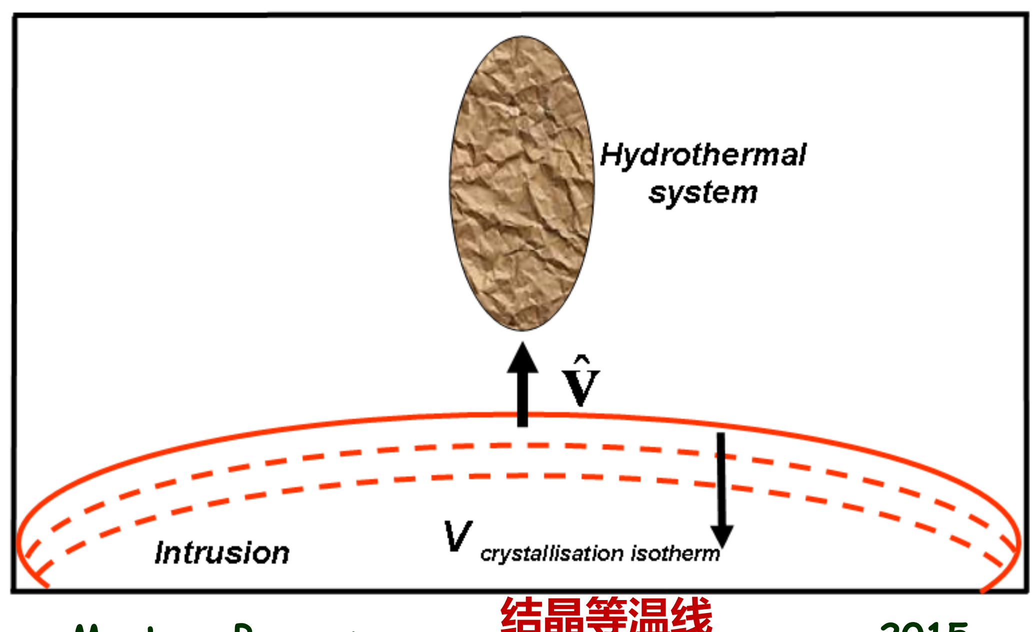
造山型金矿



as well as for

IOCG deposits

IOCG型矿床



If the flow rate is held constant the initial porosity and permeability of the system, in general, needs to adjust to new values by mechanical and/or chemical means to accommodate the constant flow as the system evolves.

如果系统中流动速率保持恒定，通常在系统的演进过程中，初始孔隙度和渗透率需要基于力或者化学的方式进行调整以适应流动的恒定

For a mineralising system which is flow controlled to be really large, processes must continue to accommodate the relentless supply of fluid at a given temperature and composition.

一个流动控制的矿化系统实际上很大，
其过程必须适应在给定的温度和组分条件下流体的补充

This is commonly accomplished by processes such as fracturing and brecciation.

通常通过诸如断裂和角砾岩化完成

2

The consequences for permeability development of changing temperature and chemical composition

温度和化学成分的改变导致渗透率发生变化

A fundamental process in open flow controlled systems is the maintenance and evolution of permeability.

开放流动控制系统的基本过程是渗透率的保持和演进

Darcys Law for fluid flow in flow controlled systems says that the fluid pressure gradient is very sensitive to changes in fluid density and fluid viscosity.

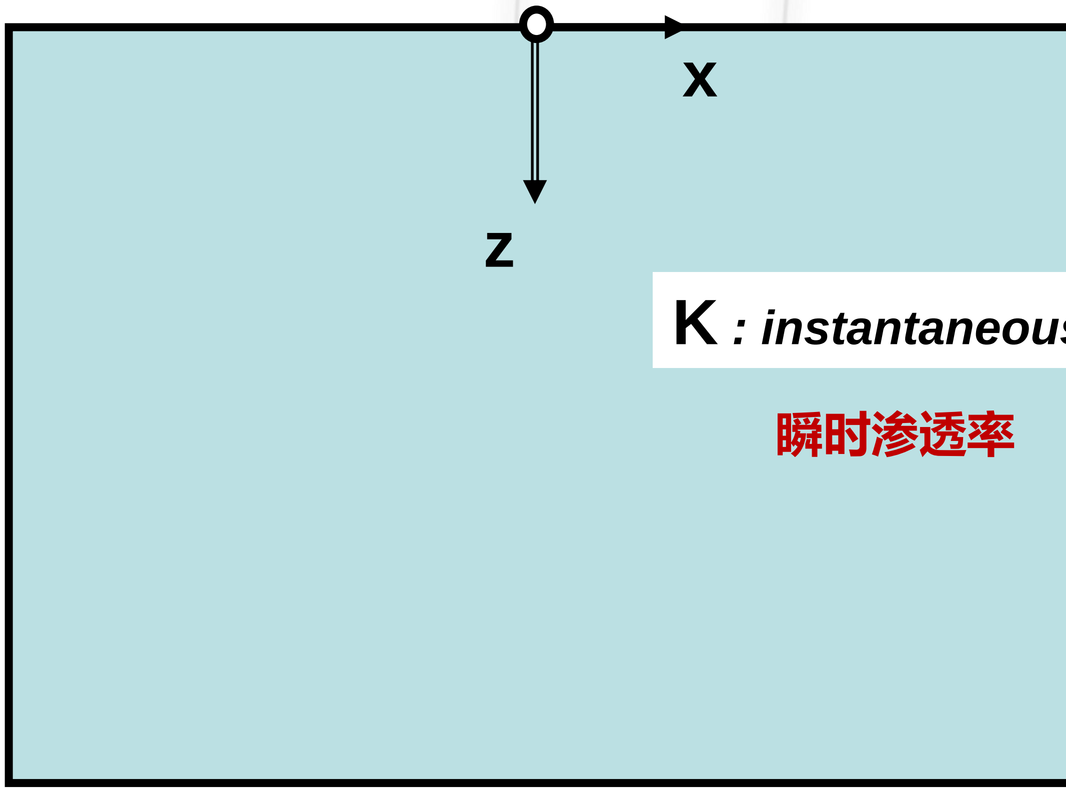
流动控制系统中达西定律表明，流体压力梯度对于由于流体密度及粘度的变化非常敏感

Thus in flow controlled systems any change in fluid temperature or composition is reflected in a mandatory and rapid change in permeability.

在流体控制系统中，流体温度或者组分的改变将反应为渗透率的强制的、迅速的变化

$$\hat{V} = \frac{K}{\eta}\left(-\frac{\partial p}{\partial z} + \rho^{fluid} g\right)$$

Darcy's Law 达西定律



K *: instantaneous permeability*

瞬时渗透率

P: ***fluid pressure*** 流体压力

η: ***fluid viscosity*** 流体粘度

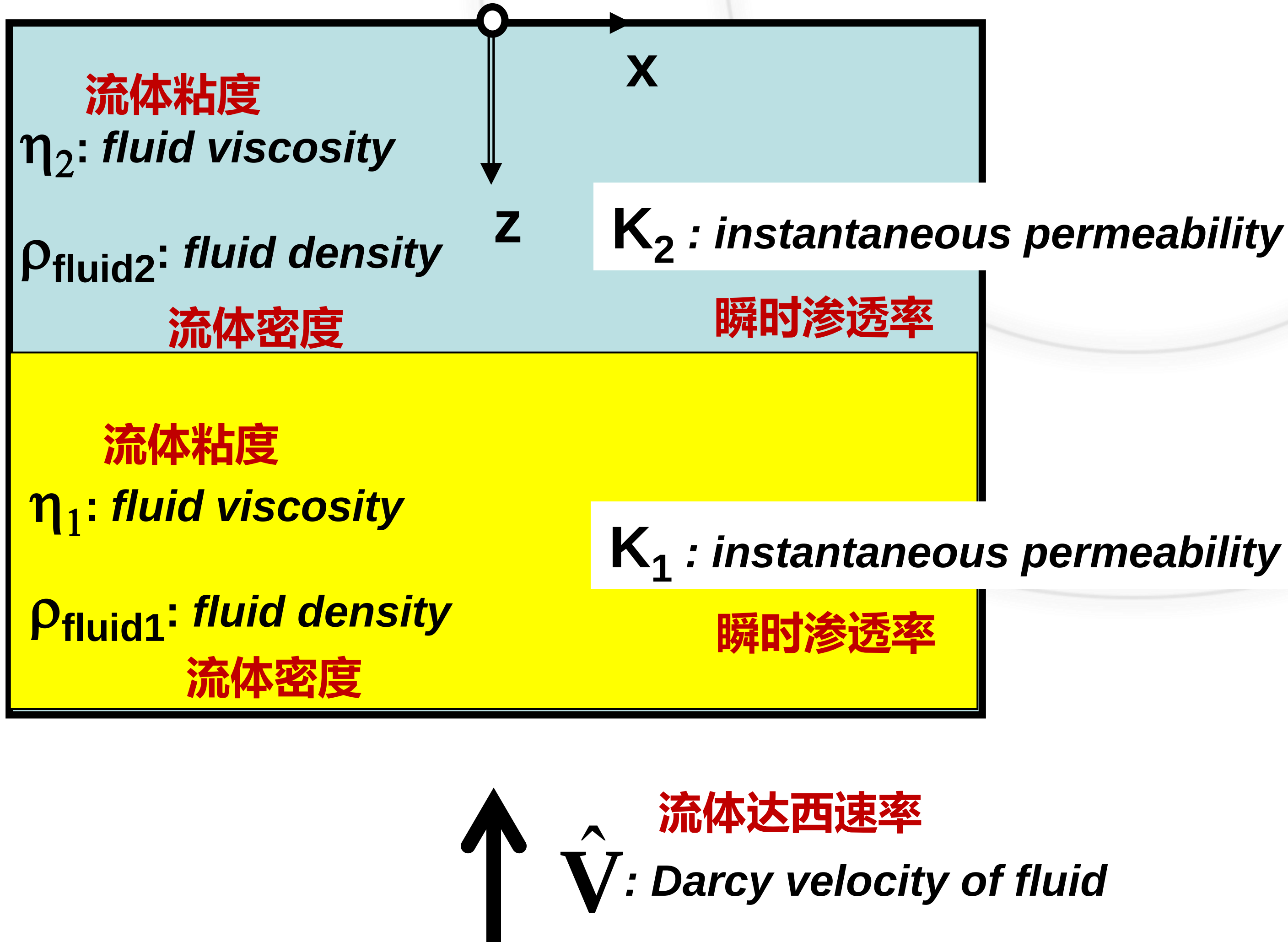
ρ_{fluid}: ***fluid density*** 流体密度

$\hat{V}$: ***Darcy velocity of fluid***

流体达西速率

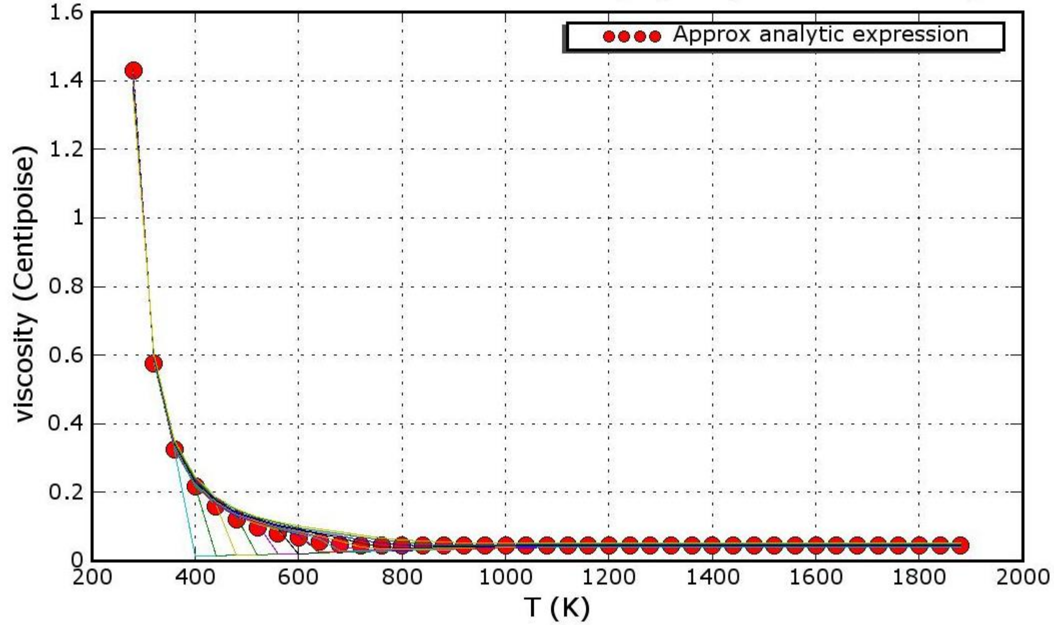
$$\hat{V} = \frac{K}{\eta}\left(-\frac{\partial p}{\partial z} + \rho^{fluid} g\right)$$

Darcy's Law **达西定律**



Viscosity

粘度



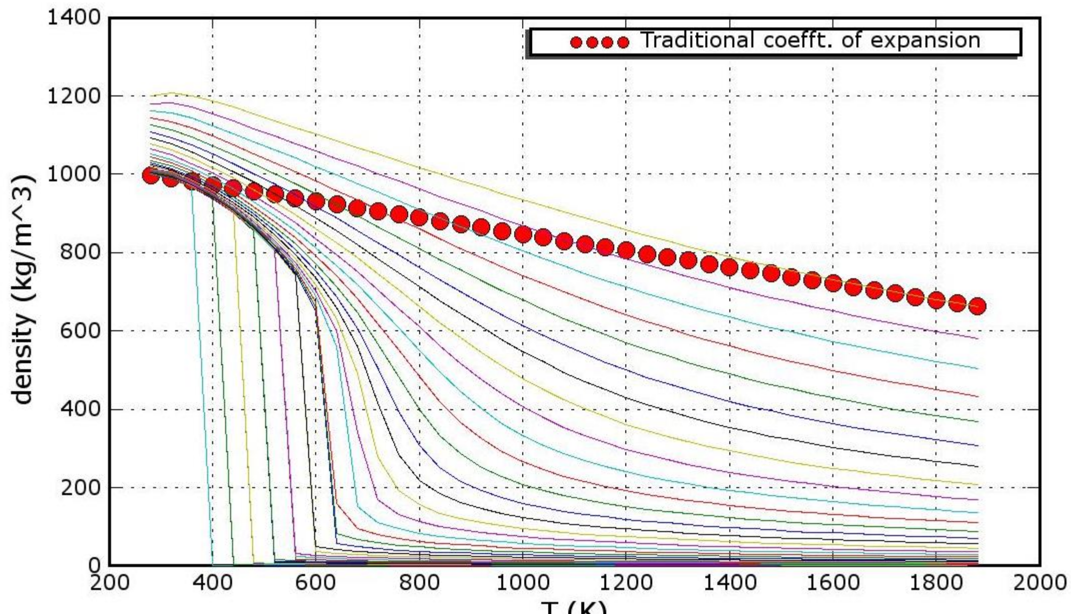
Pressures from 1 to 10K bar

压力从 1 到 10K bar

(log steps of 1.258925)

Density

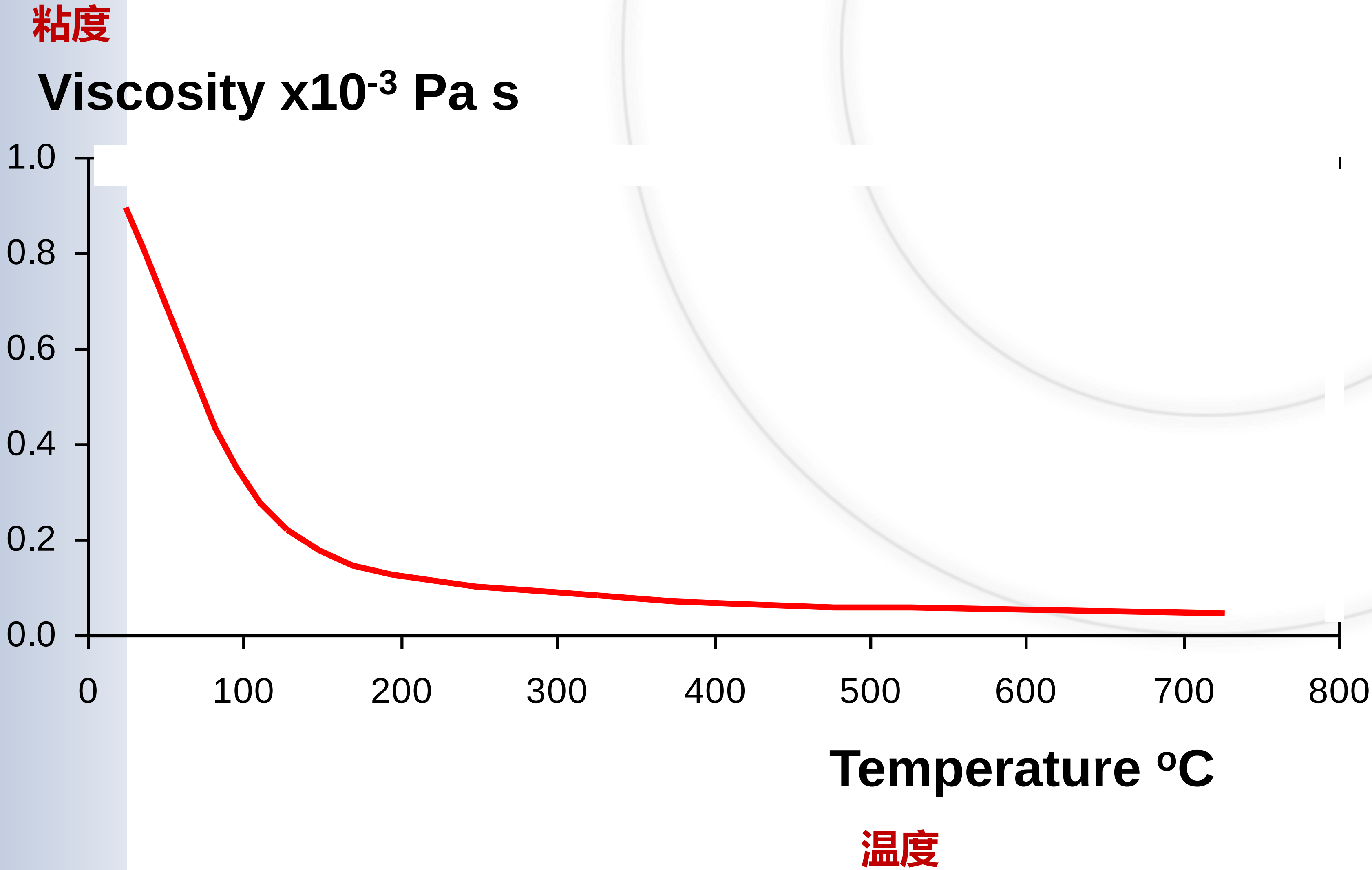
密度



Temperature **温度**

Peter Hornby

Viscosity of pure water



General case where density, permeability and viscosity are different in the two layers:

一般情况下，两层中的密度、渗透率和粘度不同

$$\hat{V} = -\left(\frac{\partial p_1}{\partial z} - \rho_1{}^{fluid} g\right)\frac{K_1}{\mu_1} = -\left(\frac{\partial p_2}{\partial z} - \rho_2{}^{fluid} g\right)\frac{K_2}{\mu_2}$$

Case where density and permeability are the same in the two layers:

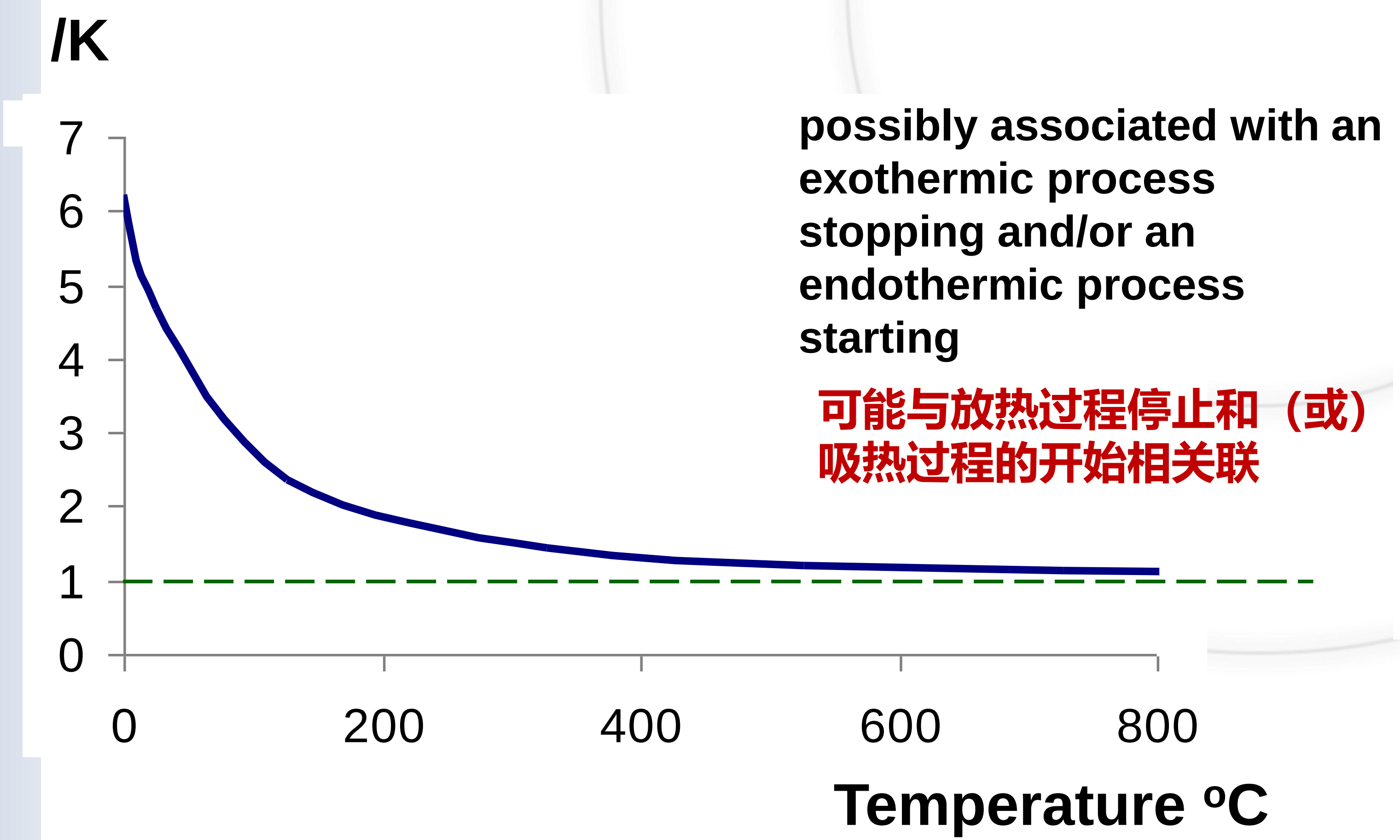
对于两层中的密度渗透率相同的情况

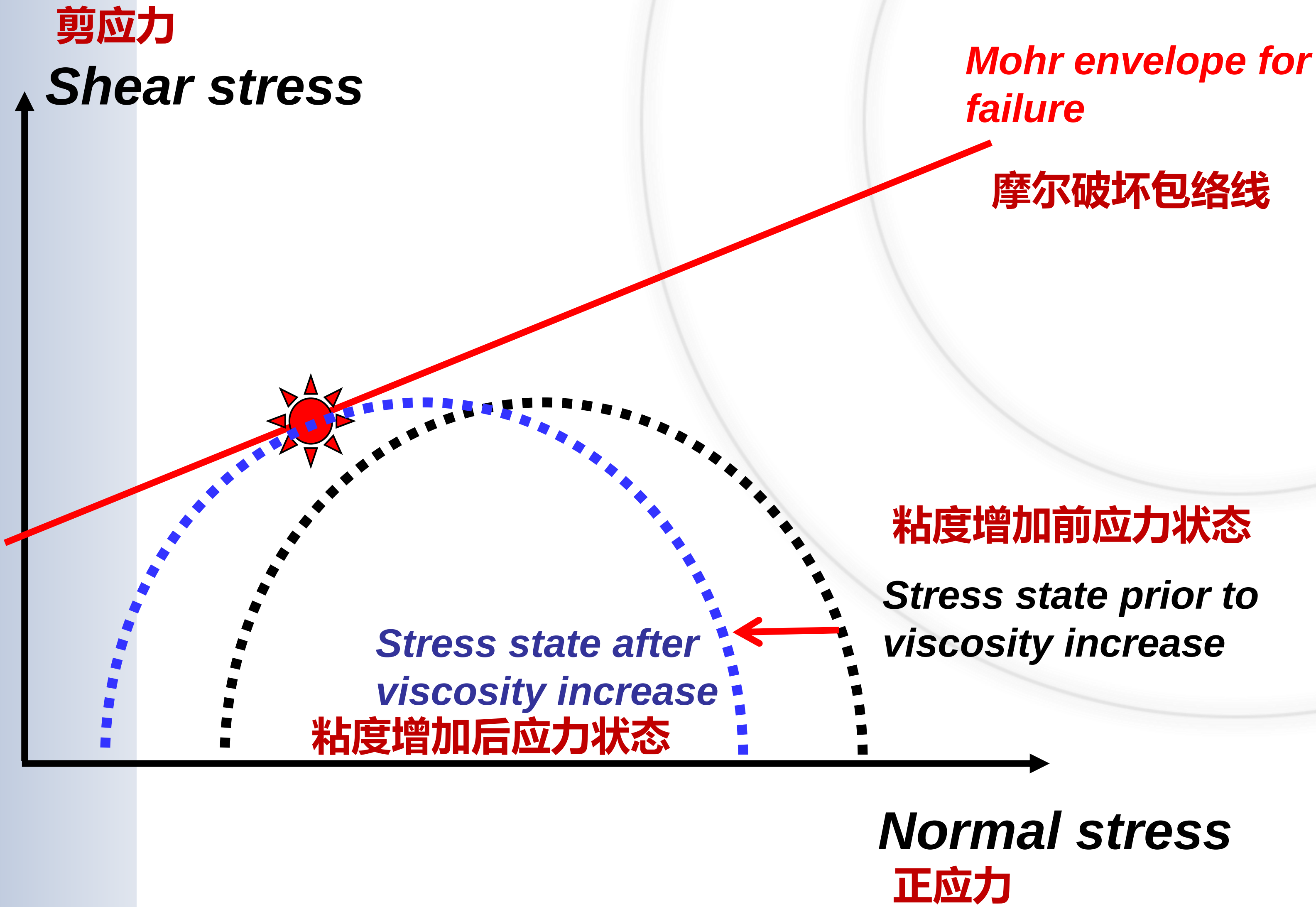
$$\frac{\partial p_2}{\partial z} = \frac{\mu_2}{\mu_1}\frac{\partial p_1}{\partial z} + \rho^{fluid} g\left(1 - \frac{\mu_2}{\mu_1}\right)$$

If $\frac{\partial \hat{p}_1}{\partial z}$ is lithostatic & $\frac{\mu_2}{\mu_1}$ is 1.1 then $\frac{\partial \hat{p}_2}{\partial z}$ is 1.06 lithostatic

纯水的粘度绝对增加，但在达到1000摄氏度时陡然下降

Absolute increase in the viscosity of pure water for a drop in temperature of 1 K




剪应力
Shear stress
Mohr envelope for failure
摩尔破坏包络线
粘度增加前应力状态
Stress state prior to viscosity increase
Stress state after viscosity increase
粘度增加后应力状态
Normal stress
正应力

To conclude this part of the talk, it is of fundamental importance to distinguish between open flow systems that are hydraulic-potential controlled (constant hydraulic potential) and those that are flow controlled (constant flux).

区分多个开放流动系统非常基础和重要，例如区分水力势能控制系统（恒定水力势能）和其他流动控制系统(恒定流量)

The evolution of these two types of flow systems is quite different.

这两种类型的流动系统的演变是完全不同的

The hydraulic head-controlled systems must adjust their permeability structure to account for clogging of their porosity by new minerals if the system is to continue to operate and such adjustments may be solely chemical in nature.

如果水头控制系统继续运行，则系统必须调整自己的渗透结构去抵消新矿物堵塞的孔隙，这种调整在自然界可能是仅与化学相关

The flow-controlled systems must adjust their permeability structure (and hence porosity structure) to account for changes in the physical characteristics (density, viscosity) of the fluid. This can promote widespread fracturing, veining and brecciation.

流动控制的系统必须调整其渗透结构（孔隙结构）去抵消物理特性产生的变化（密度，粘度）。这种过程可以促进生成大范围裂隙，脉和角砾岩。

3

Brecciation

The process

角砾岩化

过程

PFC2D 3.10

Step 116000 15:50:44 Wed Feb 21 2007

View Size:
X: -2.188e-001 <=> 3.763e-001
Y: -1.000e-002 <=> 6.200e-001

Wall

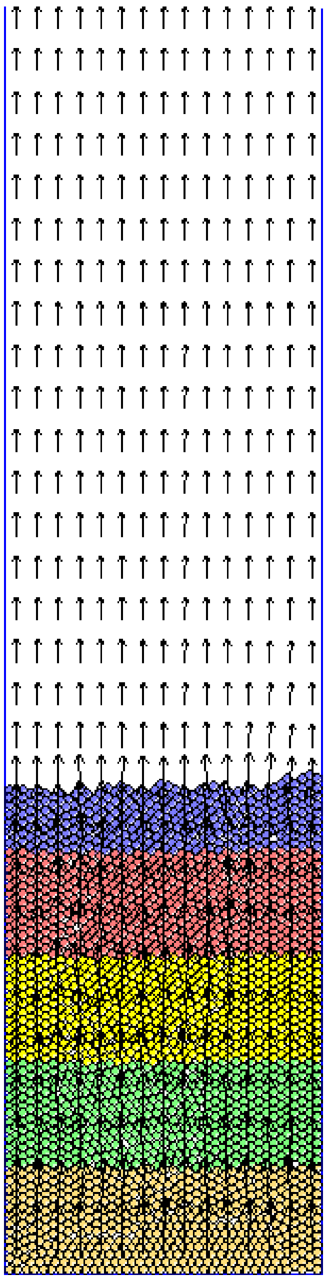
Ball

FISH function crk_item

Fluid Velocity
Maximum = 7.302e+000
Linestyle

Job Title: P bonds: n,s strength 4.30000000000e+000, n,s stiff 5.70000000000e+0

View Title: Injecting Air 1.80000000000e-001 m/s



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View Size:
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Y: -1.000e-002 <=> 6.200e-001

Wall

Ball

FISH function crk_item

Fluid Velocity

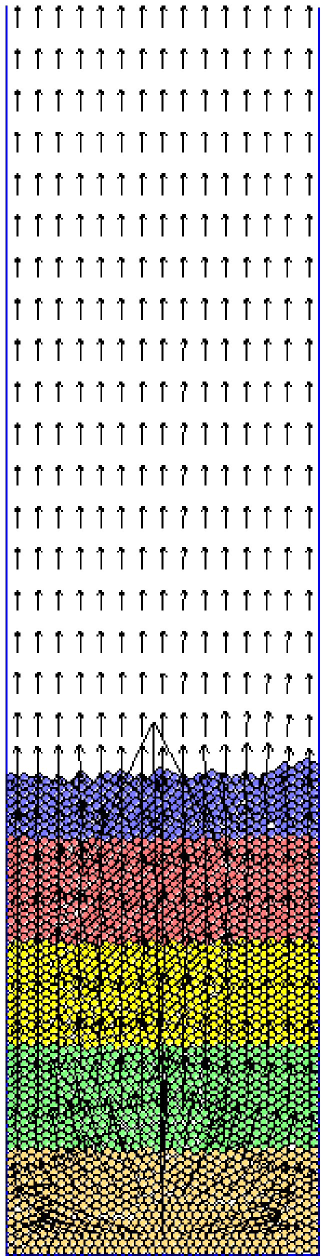
Maximum = 8.306e+001

Scale to Max = 1.000e+001

Linestyle

Job Title: P bonds: n,s strength 4.30000000000e+003, n,s stiff 5.70000000000e+0

View Title: Jet:Injecting Air 3.50000000000e+000 m/s



Method of fluid introduction affects migration patterns,

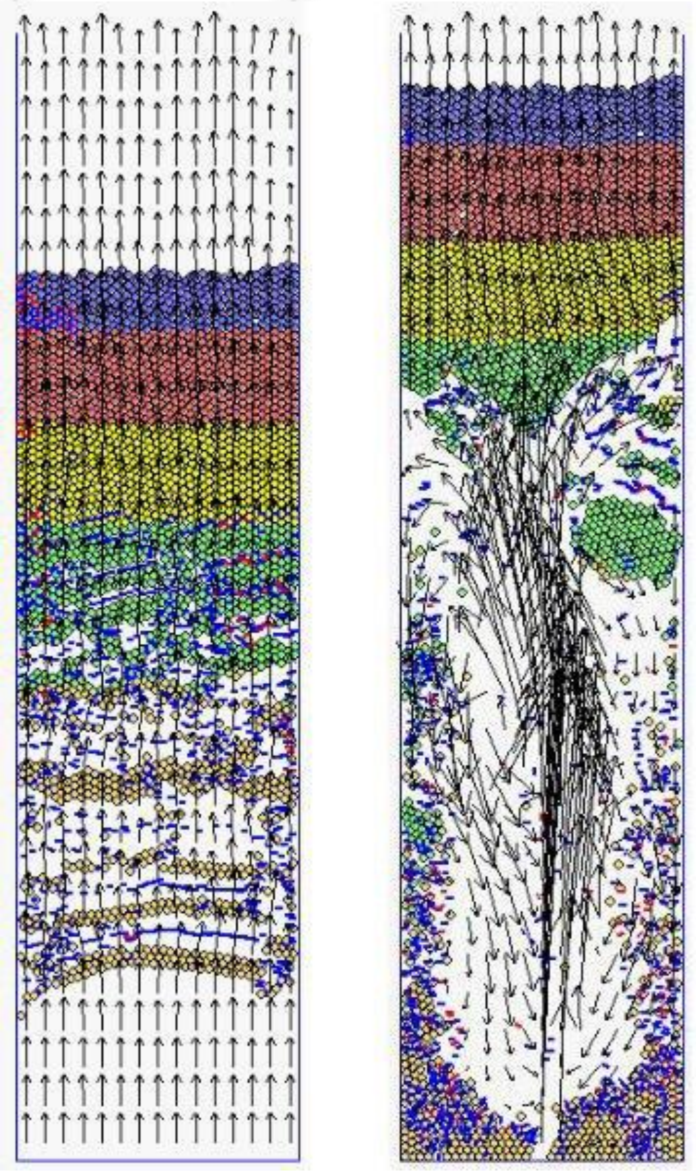
影响运移模式

with unfocused flow (left) resulting in sheet-like uniform motion,

与非汇聚流（左）导致片状匀速运动

& focused flow (right) encouraging turbulence and migration of fragments to the bottom of the box.

汇聚流（右）促使湍流和碎片迁移到盒子的底部



Parameters of Interest

- Fluid flow rate

流体流率

- Rock strength

岩石强度

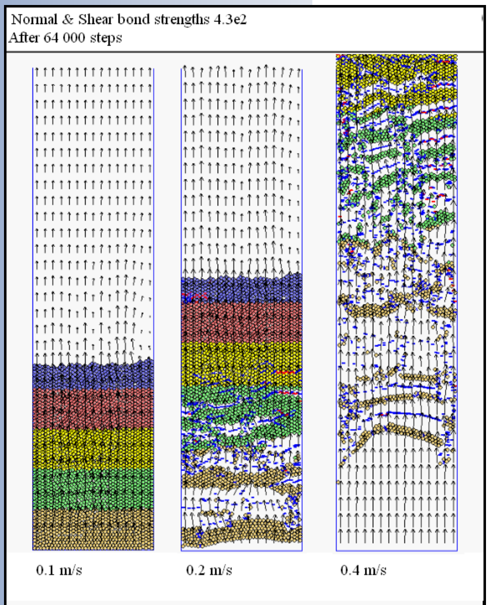
- Fluid mechanism: **introduced uniformly or from a point source.**

流体机制： 均匀或者来自点源

- Boundary conditions: **unconfined or confined.**

边界条件：无限制及限制

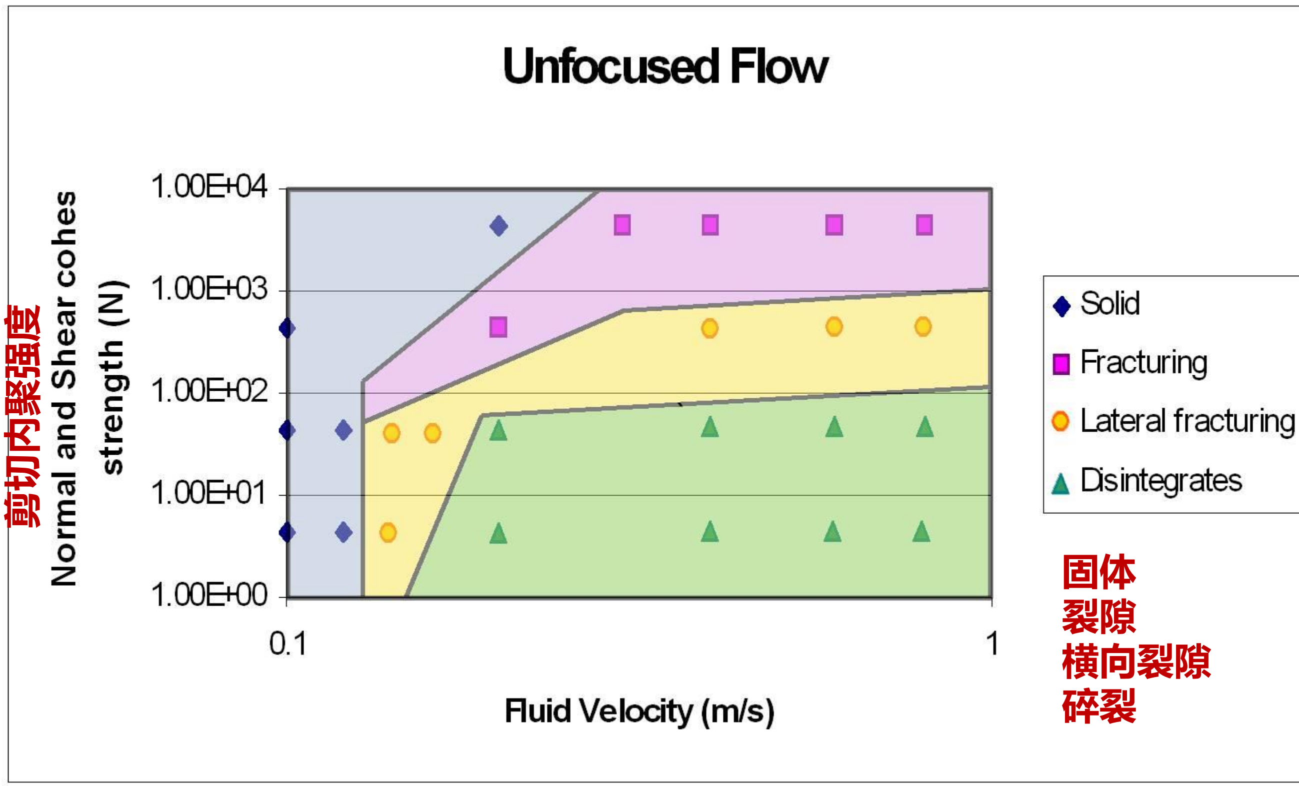
Unfocused Flow 非汇聚流



Example of the effect of varying fluid velocity through 0.1m/s, 0.2m/s, 0.4m/s.

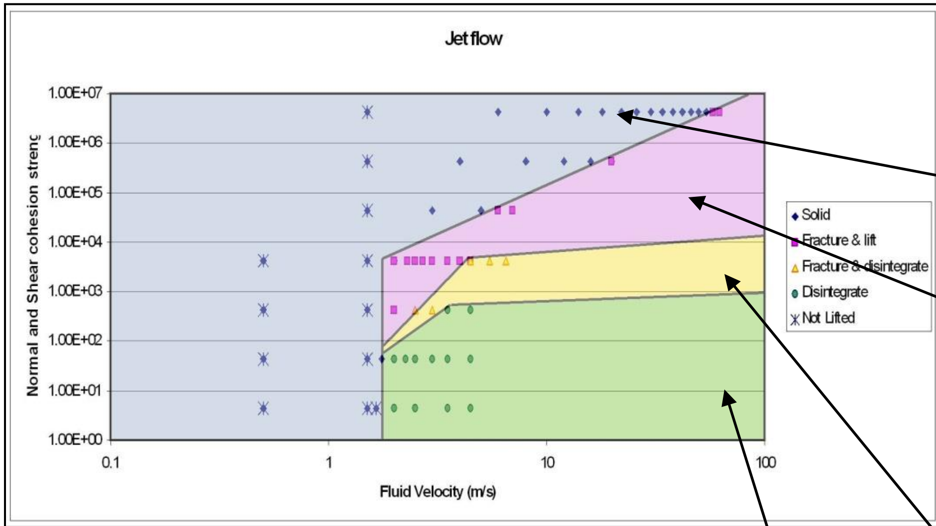
改变流体速率：0.1米/秒，0.2米/秒，0.4米/秒

Behaviour map for unfocused fluid flow



Unconfined Models

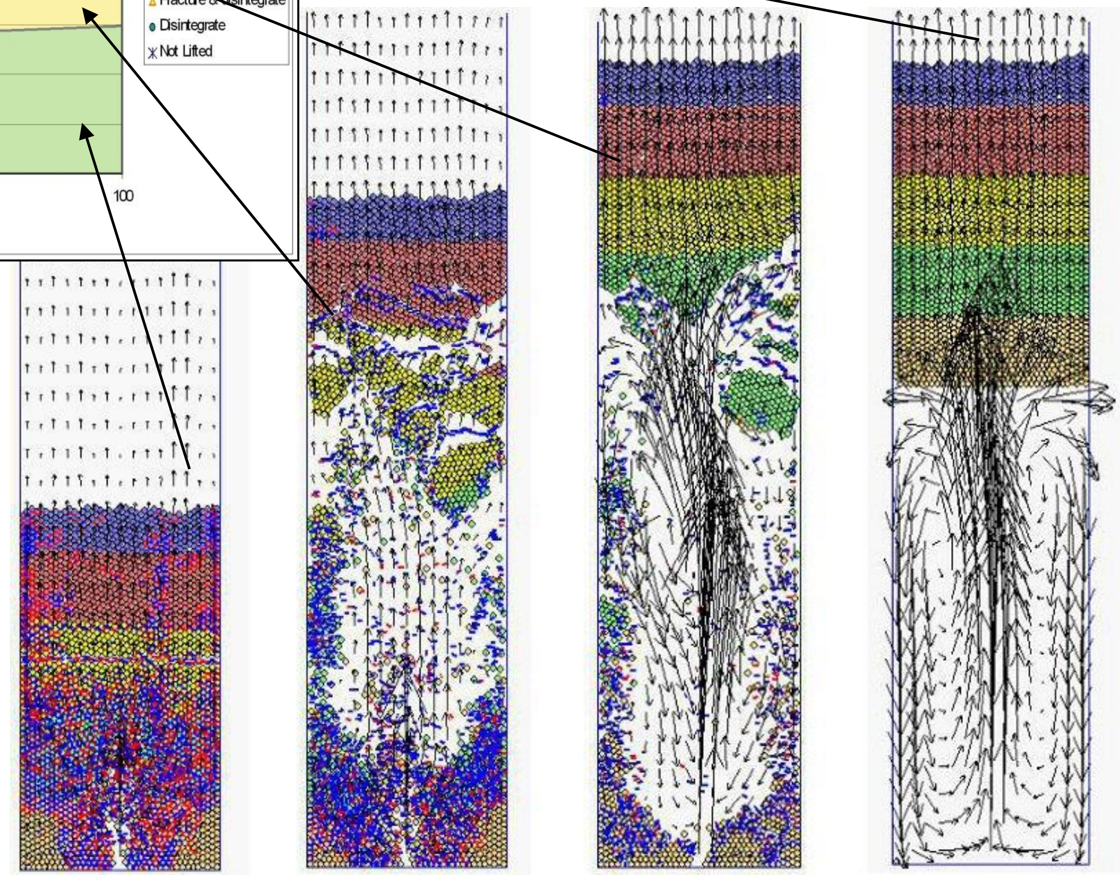
非限制模型



Investigations reveal a cohesion-fluid flow rate relationship where rock has the capacity to break into breccia-resembling pieces in terms of size and/or shape.

揭示内聚力-流体流率关系

岩石破碎为角砾岩-根据大小和形态组成碎片



Disintegrates | Lifts & disintegrates | Fractures & lifts | Lifts solidly

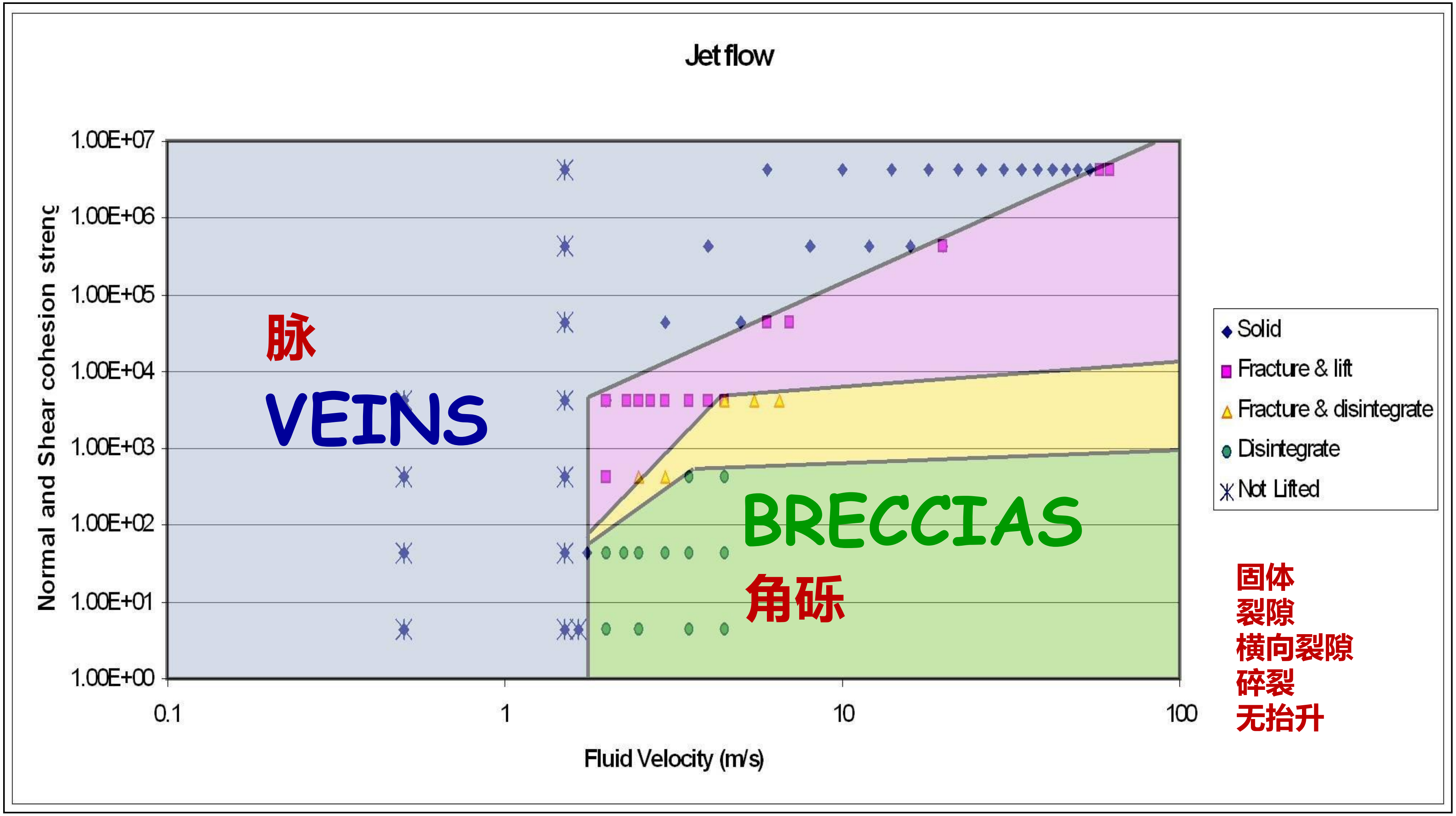
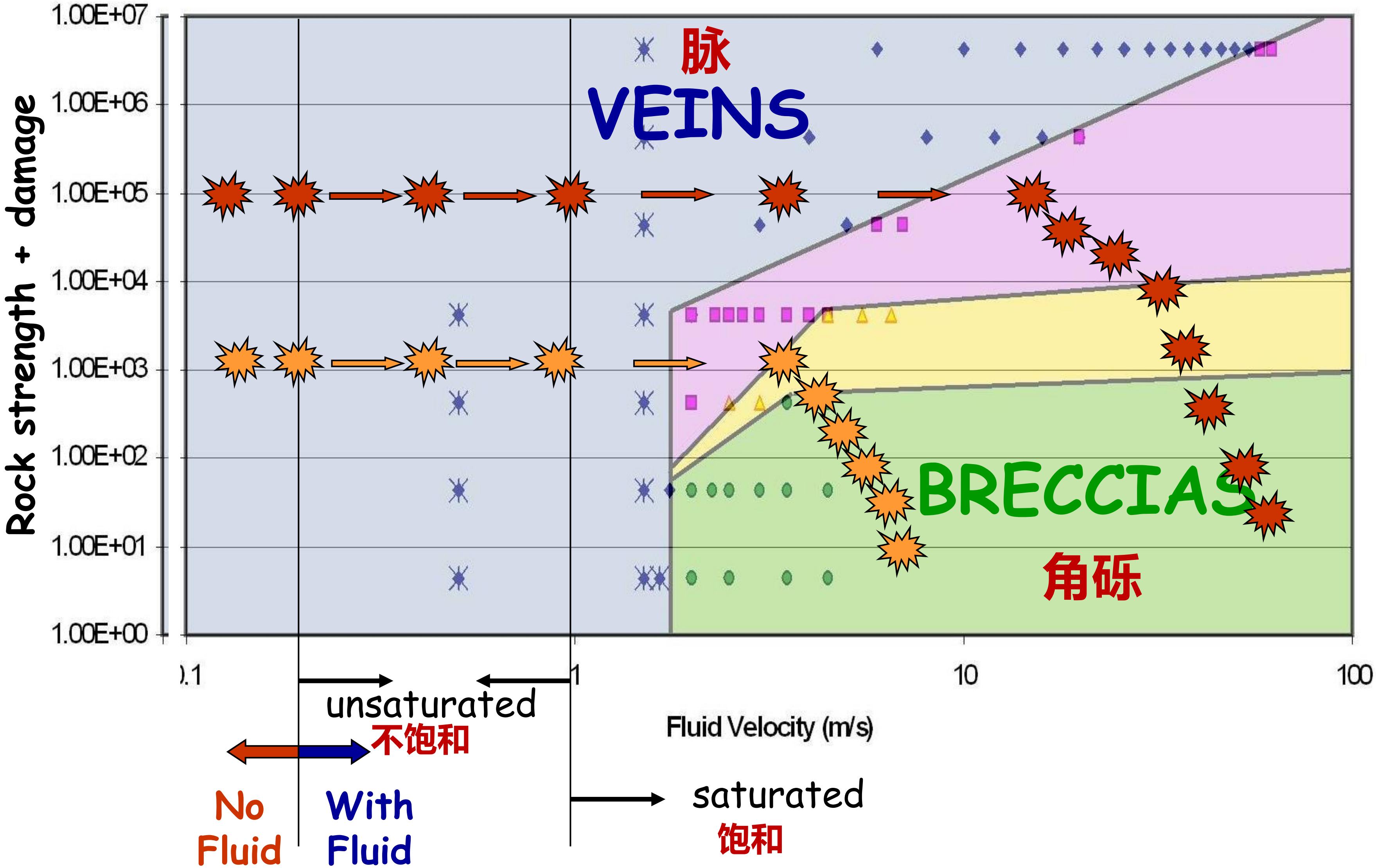


Figure demonstrates the consequences of the fluid flow being less than (veins) or greater than (breccias) the fluid flow predicted through Darcys Law for a given permeability and fluid pressure gradient.

在给定的渗透率和流体压力梯度下，流体流动的结果可以小于（脉）或者高于（角砾）通过达西定律预测的流体流动。

Evolutionary paths 演进路径

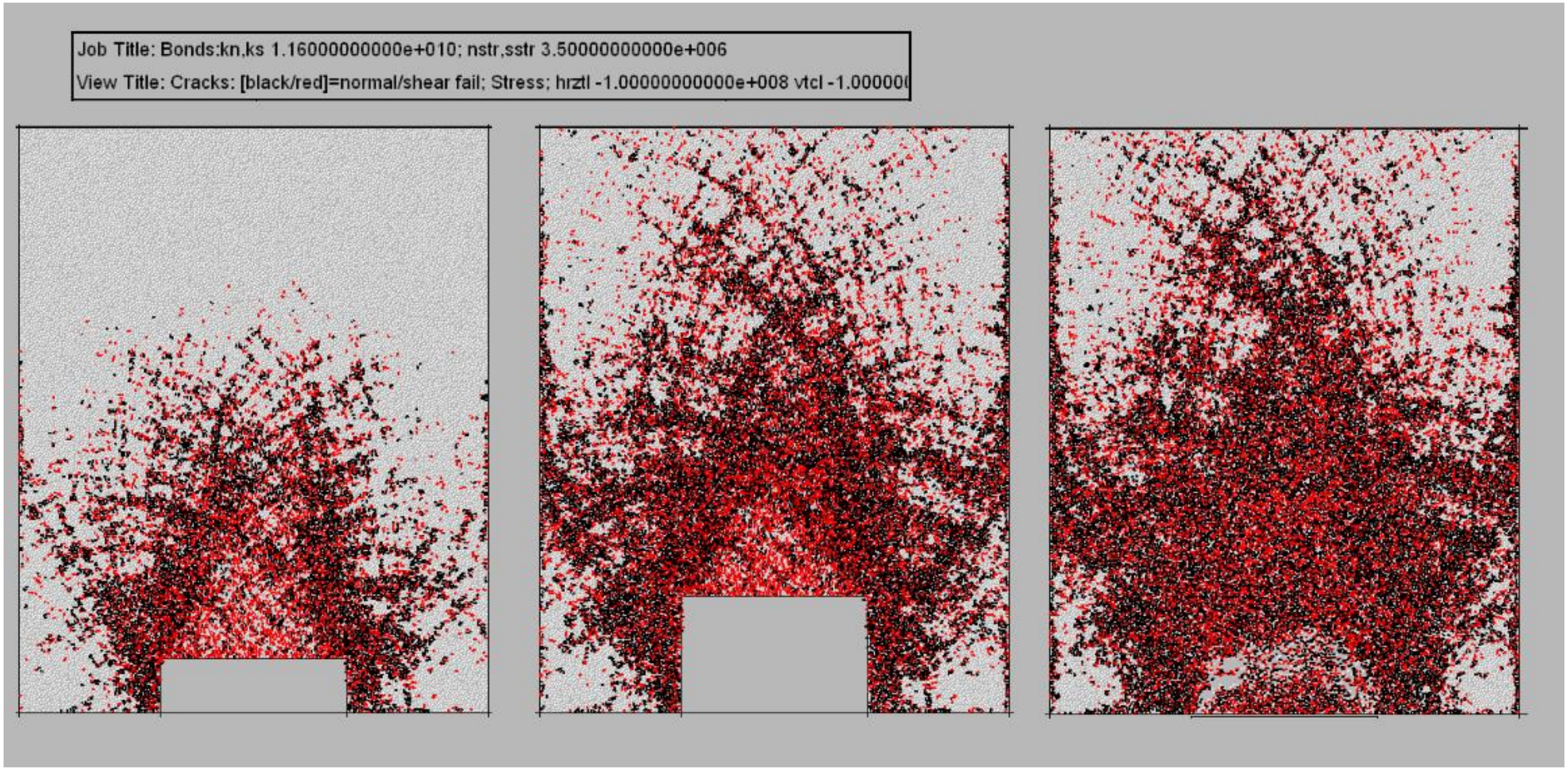


Application of an isolated pulse of over-pressured fluid to the base of the model

在模型底部施加一个孤立脉冲式的超压流体

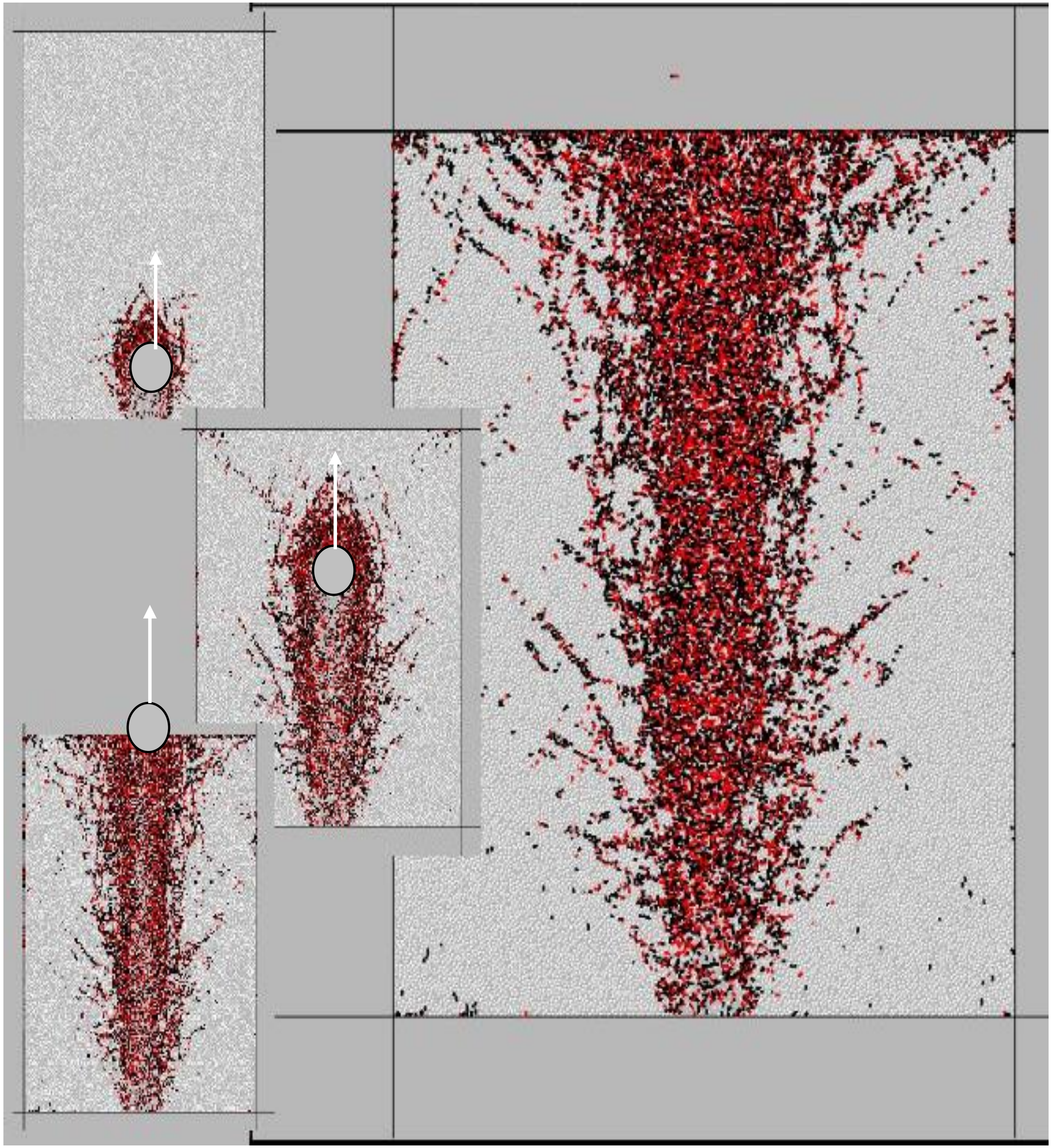
Fracturing occurs ahead of the migrating fluid pulse with subsequent collapse of the fractured rock into the space left in the wake of the pulse

裂隙发育在流体迁移脉冲前，之后裂隙岩石紧随脉冲进入遗留空间



Brecciation caused by upward migration of fluid pulse.

流体脉冲向上迁移引发角砾岩化



PFC2D 3.10

ep 12810 15:25:49 Thu Jan 11 2007

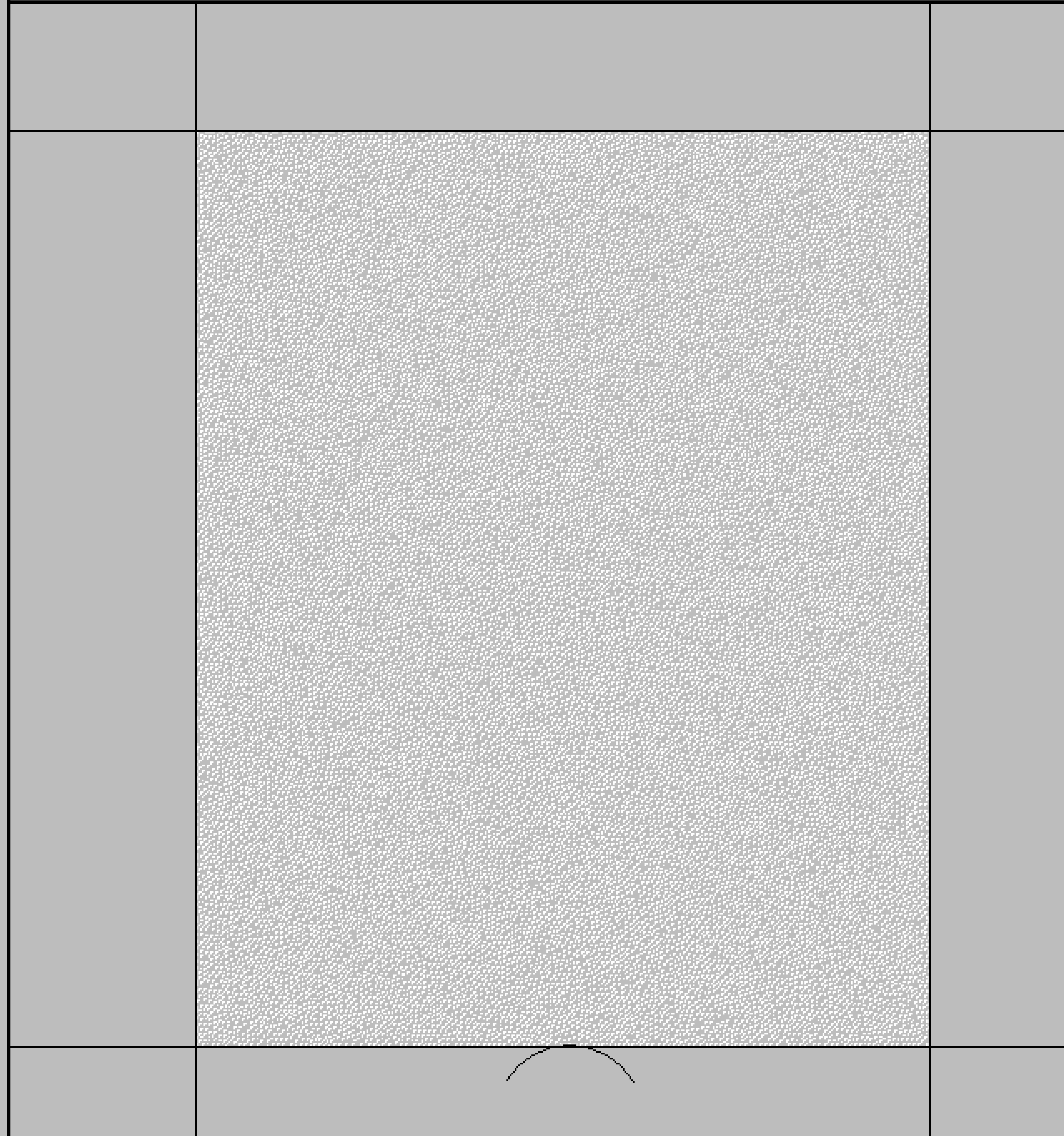
ew Size:
: -2.175e-001 <=> 1.017e+000
: -1.537e-001 <=> 1.154e+000

all

Vall

SH function crk_item

View Title: Cracks: [black/red]=normal/shear fail; Stress; hrztl -1.00000000000e



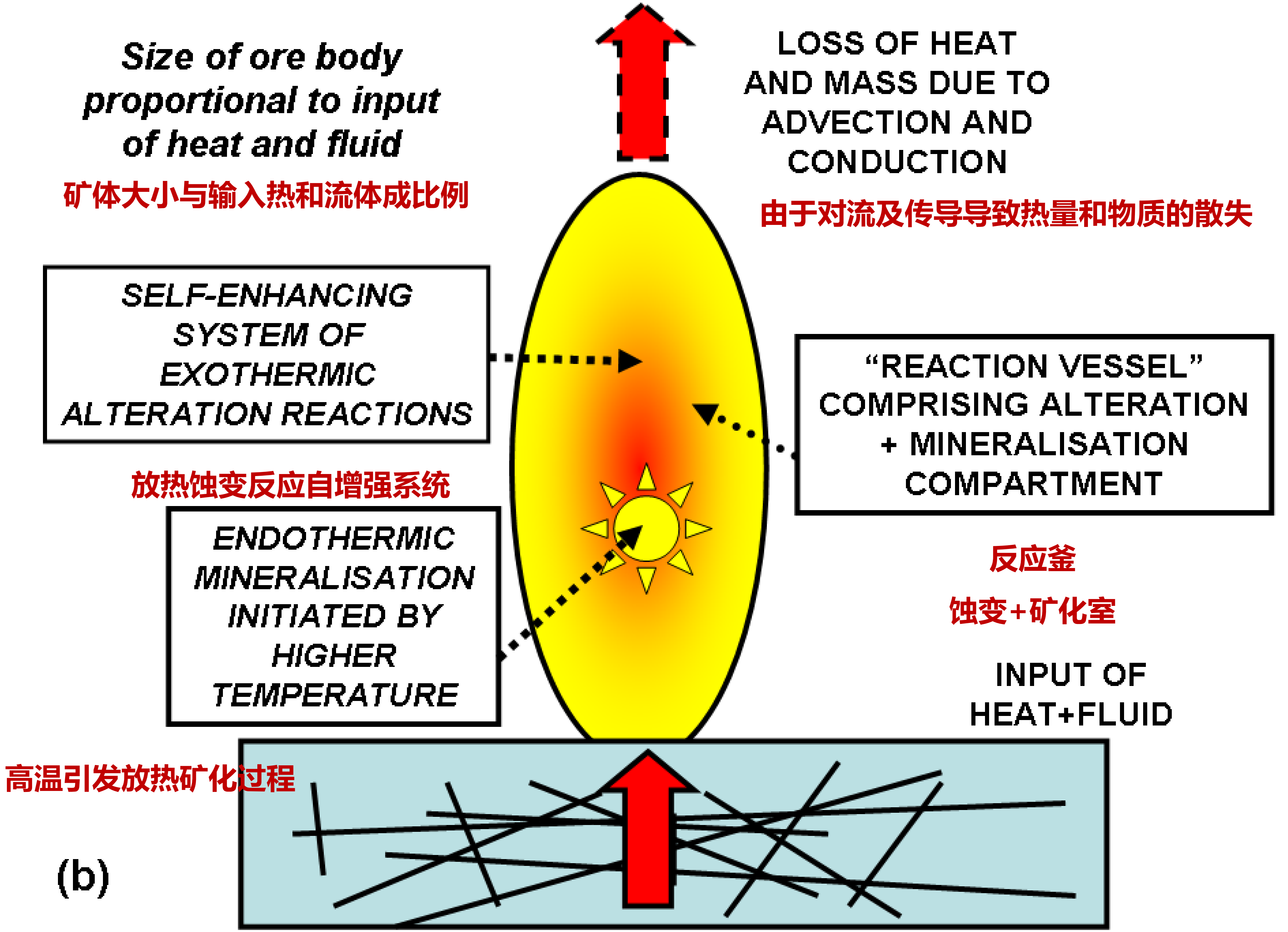
The preparation of such flow regime maps is fundamental to the interpretation of breccia textures in the field since one can position a particular texture within a rock strength/fluid velocity/porosity field on the map.

因为可以在一个岩石强度/流体速度/孔隙度场图中定位一个特殊的纹理，因此流型图是解释野外角砾岩纹理的基础

4

The role of entropy production in the evolution of giant hydrothermal mineral systems

巨型热液矿物系统演化中的熵增作用


Size of ore body proportional to input of heat and fluid
矿体大小与输入热和流体成比例
LOSS OF HEAT AND MASS DUE TO ADVECTION AND CONDUCTION
由于对流及传导导致热量和物质的散失
SELF-ENHANCING SYSTEM OF EXOTHERMIC ALTERATION REACTIONS
放热蚀变反应自增强系统
"REACTION VESSEL" COMPRISING ALTERATION + MINERALISATION COMPARTMENT
反应釜
蚀变+矿化室
ENDOTHERMIC MINERALISATION INITIATED BY HIGHER TEMPERATURE
INPUT OF HEAT+FLUID
高温引发放热矿化过程
(b)

Such systems are maintained far from equilibrium as long as the input of heat and mass is maintained but are forced to proceed through a number of stages as either

(i)reactants within the system are exhausted and/or

(ii) as the input flow conditions (temperature and fluid composition) evolve.

高温引发放热矿化过程只要热量和质量保持输入，这种系统能够持续远离平衡，但系统会被迫使经历多个阶段

(i) 反应物耗尽和（或）

（ii）作为输入流条件（温度和流体组合物）演变。

Although the transition from one stage to another is transient the system ultimately adjusts to a steady state once a new stage in development is reached

虽然从一个阶段到另一个的过渡是瞬时的，但是一旦在发展中达到一个新的阶段，系统最终会调整到稳定状态。

The principles involved in defining these steady states are outlined and depend primarily on whether the processes involved are exothermic or endothermic but are also very sensitive to the local permeability structure.

指出了定义稳态的原则，主要取决于过程是否放热或吸热，

但对于局部渗透结构非常敏感

Alteration such as the development of hydrous phases, carbonates and iron oxides are exothermic processes whilst the precipitation of sulphides and silicates is commonly endothermic.

蚀变，例如含水相的发展，碳酸盐和铁氧化物是放热过程，而硫化物和硅酸盐的

沉淀通常是吸热的

An additional highly exothermic process is brecciation.

另一个高度放热的过程是角砾岩化

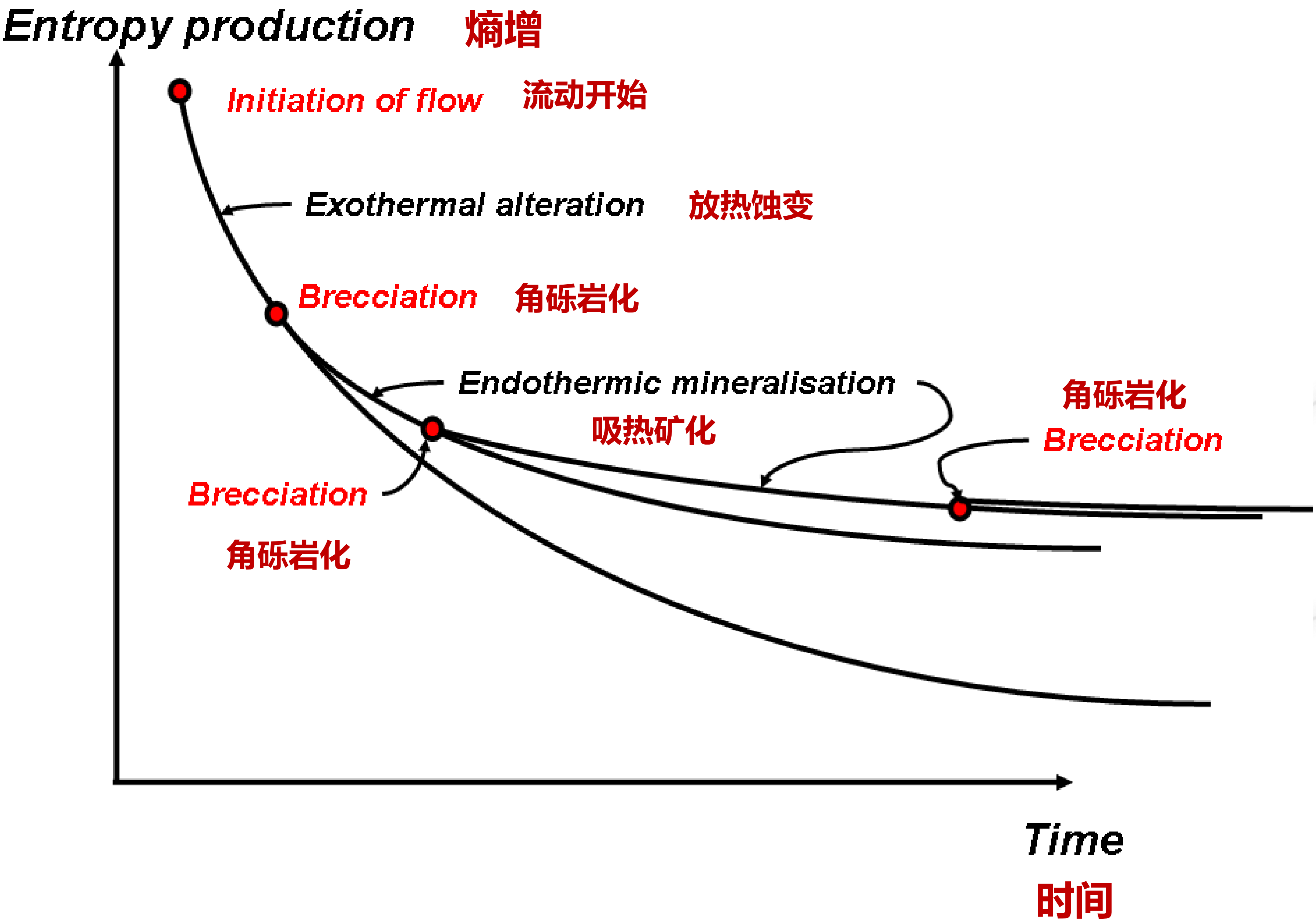
Exothermic processes (such as alteration) are important since the rates involved are thermally activated and once they begin they are self-enhancing.

放热过程（如蚀变）非常重要，速率会被热量激活，

一旦开始就会发生自增强作用

Endothermic processes (such as mineralisation) tend to quench the system.

吸热过程（比如矿化）往往会终止系统。



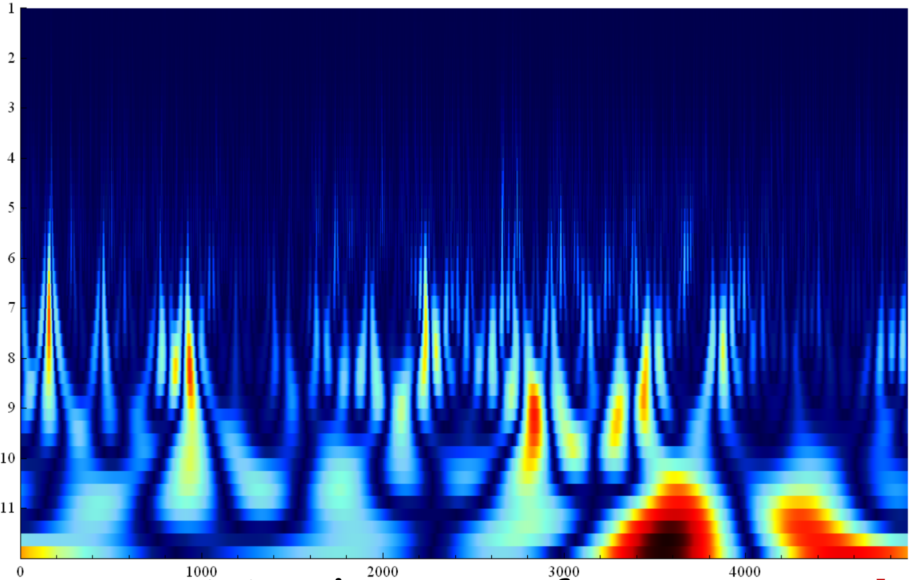
Entropy production 熵增
Initiation of flow 流动开始
Exothermal alteration 放热蚀变
Brecciation 角砾岩化
Endothermic mineralisation
吸热矿化
角砾岩化
Brecciation
Brecciation
角砾岩化
Time
时间

The successive development of mineralising systems such as Olympic Dam and the Yilgarn gold deposits within the above non-equilibrium framework for open flow systems emphasises the fundamental thermodynamic role that brecciation plays in the overall development of these mineralising systems.

矿化系统连续发展，比如Olympic Dam和伊尔干金矿床，都是建立在非平衡框架上的开放流动系统，重点强调热力学基本作用，角砾岩化在整个矿化系统演化中的作用。

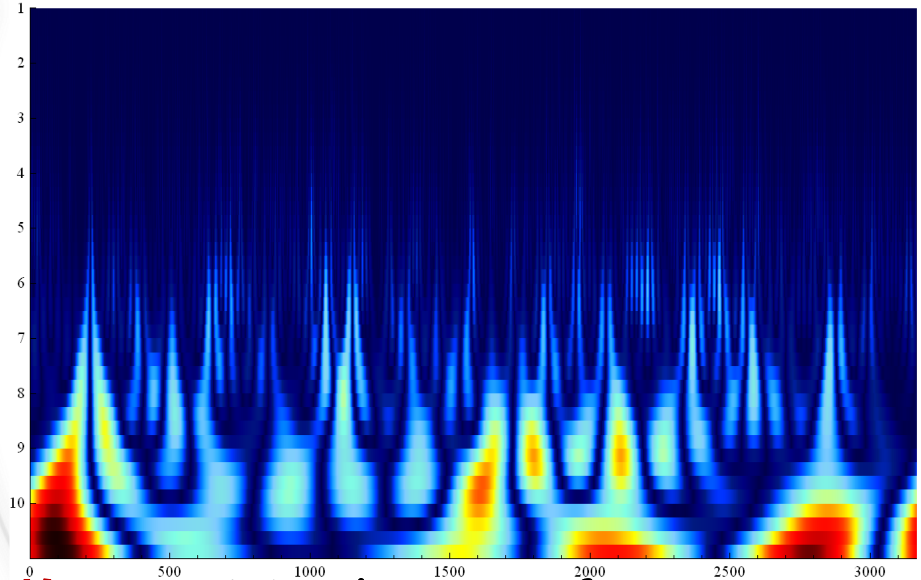
Observed in breccias are:
• multiple sets of veins
• multiple phases of fragmentation
• multifractal geometries
all interpreted as over-printing in time as well as in space.

角砾岩中观察得到：
•多组脉
•多期破碎
•分形几何特征
都可以解释为时空上的叠合



Wavelet Transform

小波变换



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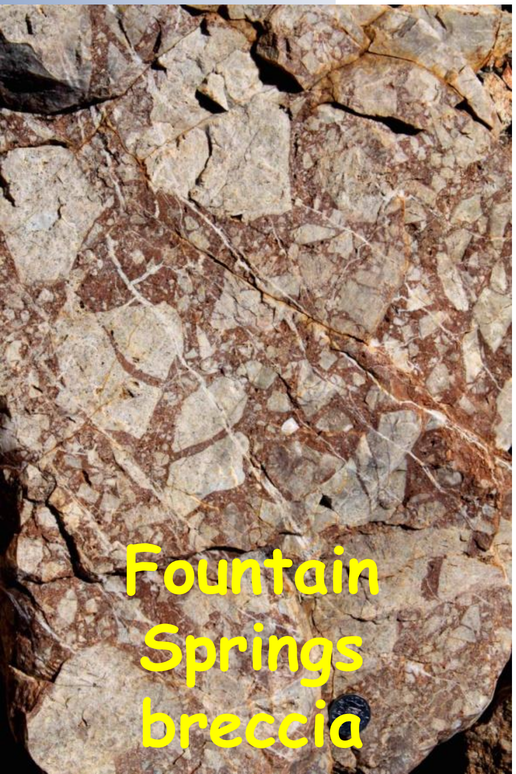
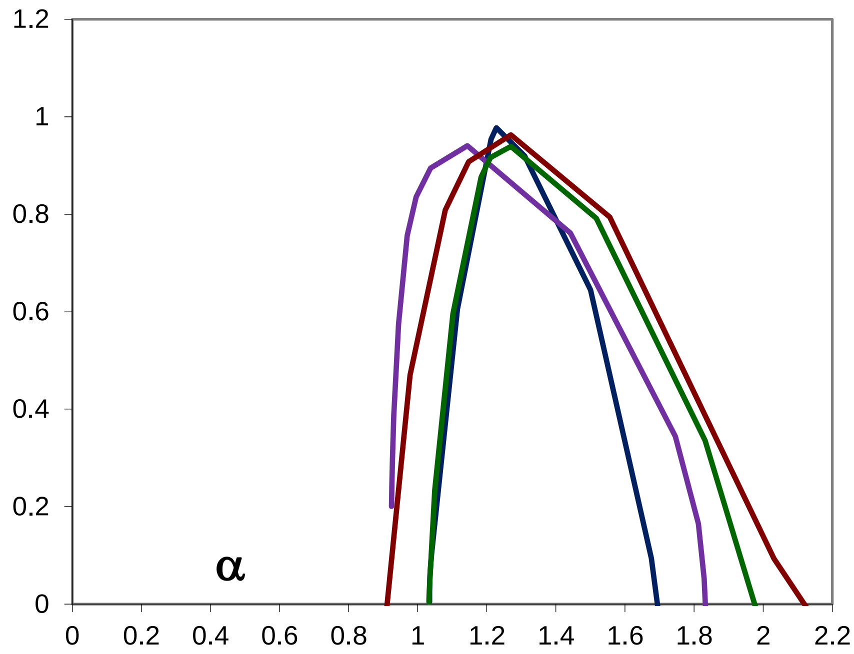


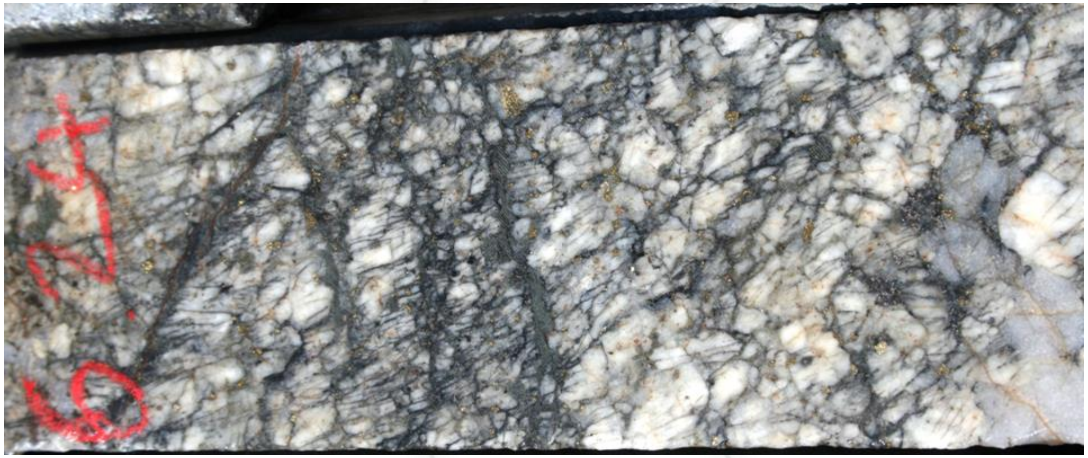
多重分形谱

f(α) Multifractal Spectrum

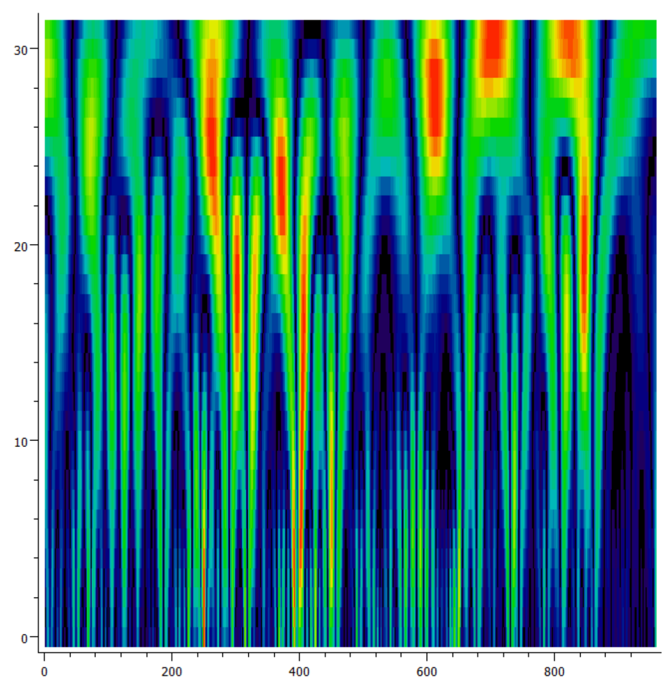


Tropicana breccia

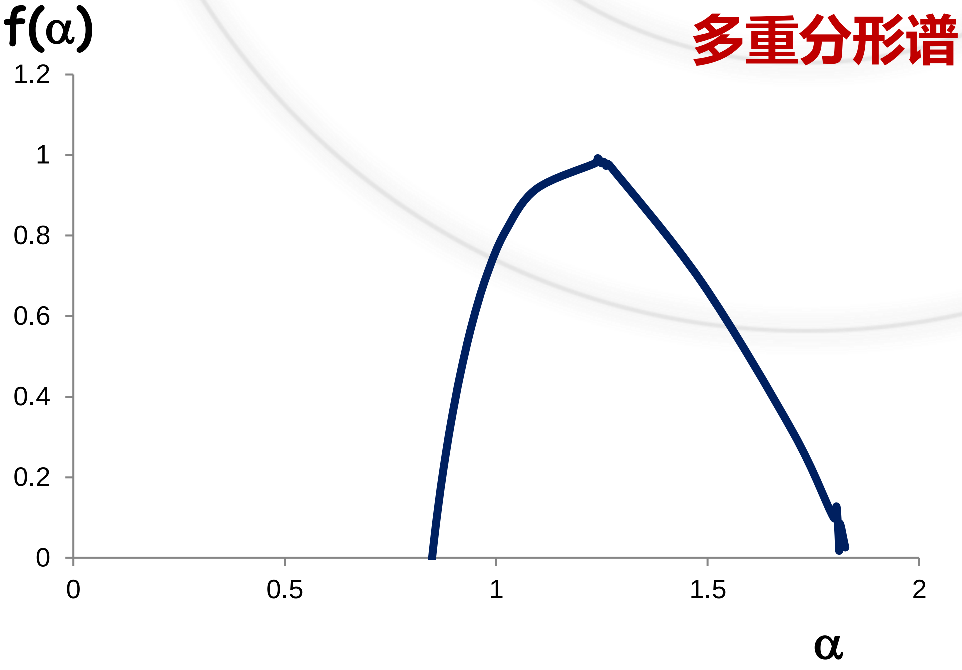
Tropicana 角砾岩



Wavelet Transform 小波变换



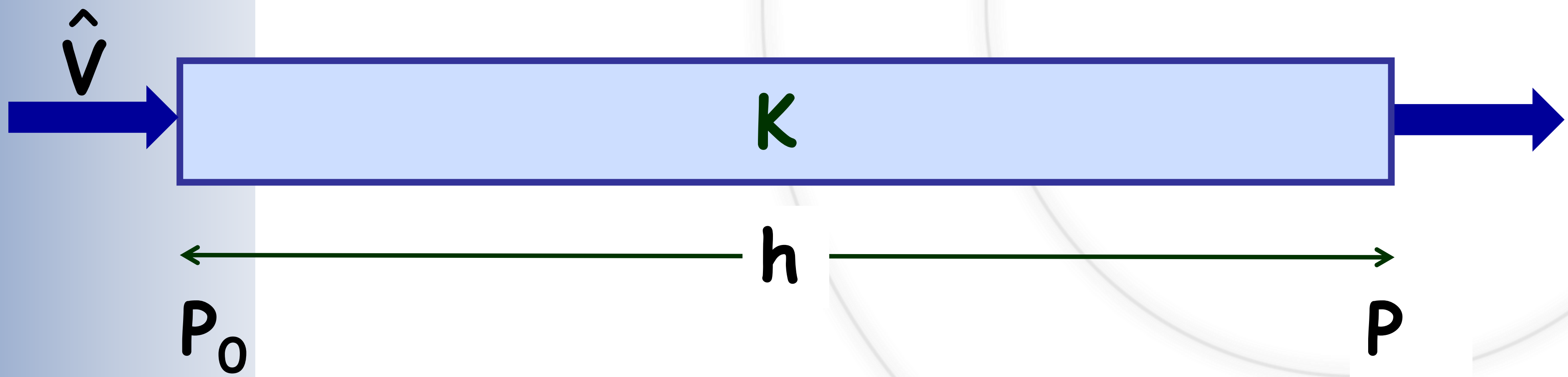
Multifractal Spectrum



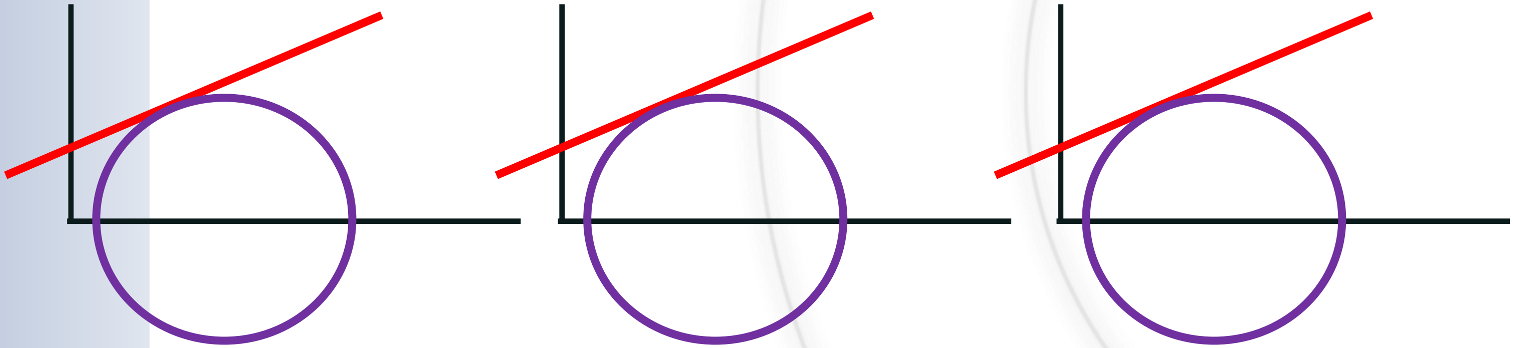
We seek the simplest system that will produce multiple episodes of brecciation and a multifractal geometry.

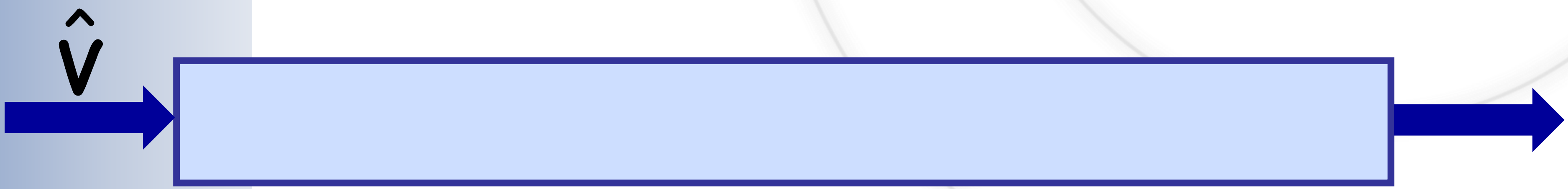
追求最简单的系统能够产生多期次的角砾岩化及分形几何特征

The Problem



$$\triangle P=(P_0-P)/h$$





How do we maintain yield throughout the material for an open flow system?

对于一个开放流动系统，如何维持材料的屈服度

For yield throughout the system and for over-printing, we require evolution of the mechanical properties and/or the hydrological properties, in time as well as in space.

对于整个系统的屈服及叠加，要求我们在时空间上研究力学属性和（或）水文特征演化。

The simplest approach, and that explored here, is represented by the following two feedback loops

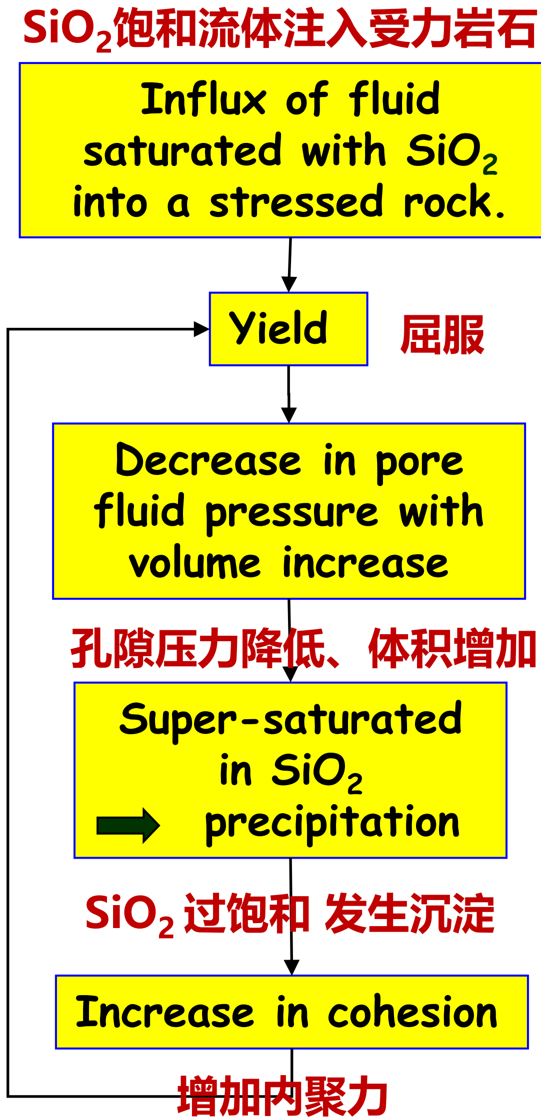
最简单的方法由以下两个反馈循环表示

which are based around the evolution of the cohesion of the material.

基于材料内聚力的演变

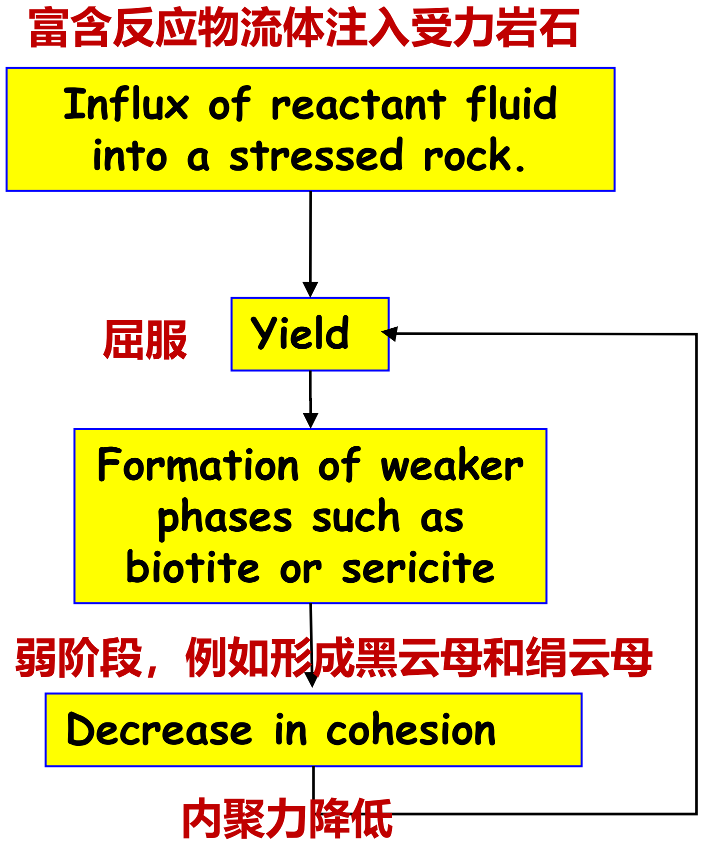
If cohesion softening, expect more localised behaviour than if cohesion hardening.

内聚力软化相比硬化将产生更多的局部作用



Cohesion hardening

内聚力硬化



Cohesion softening

内聚力软化

Fountain Springs, Queensland, Australia

石英网脉

Quartz matrix

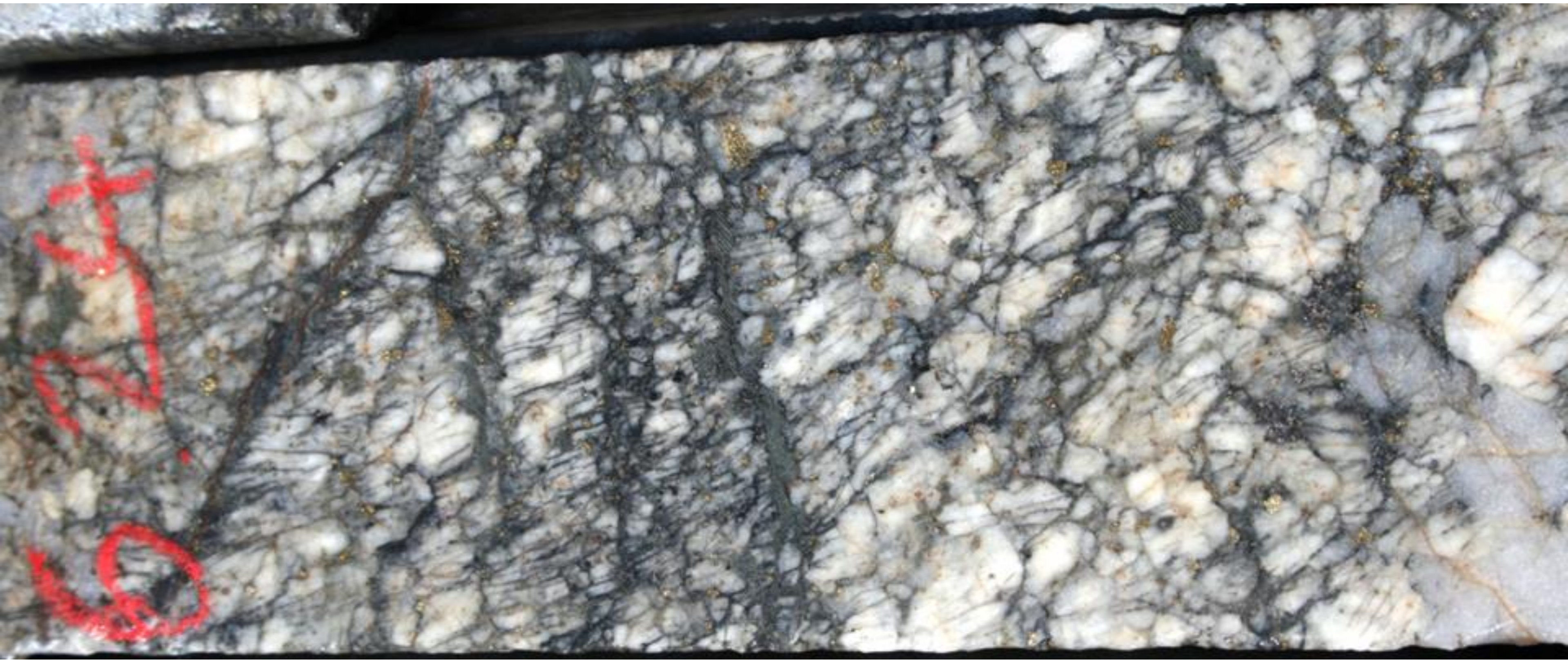
Presumed cohesion hardening behaviour

推测为内聚力硬化作用

Breccia from Tropicana, Western Australia

黑云母网脉

Biotite matrix



Presumed cohesion softening behaviour

推测为内聚力软化作用

Because this is an iterative process, we expect multifractal behaviour, and indeed, this is what we observe.

这是一个迭代过程，我们预期为多维分形作用特征，

我们确实也观察到了这些。

The Model

物理尺度

Physical size

计算尺度

Computational size

力学水文学属性

Mechanical & hydrological properties

Homogeneously distributed 均匀分布

Shear modulus 剪切模量
Bulk modulus 体积模量
Density 密度
Cohesion 内聚力
Dilation angle 扩容角

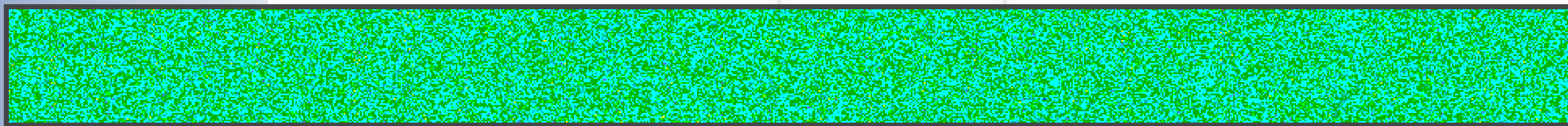
Water bulk modulus 水体积模量
Water density 水密度
Permeability 渗透率
Porosity 孔隙度

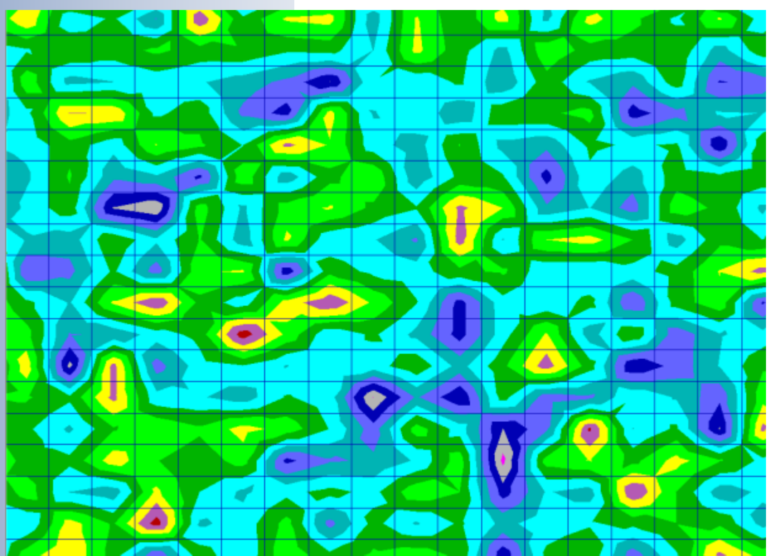
Heterogeneously distributed 非均匀分布

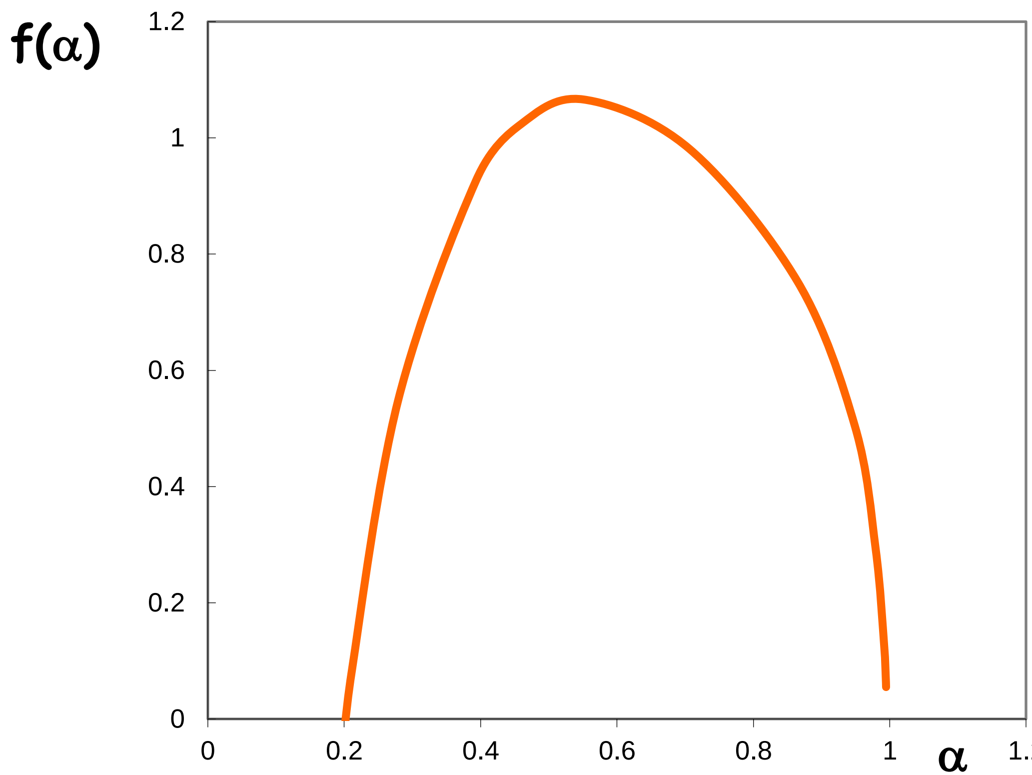
Friction angle 摩擦角

Friction angle

摩擦角

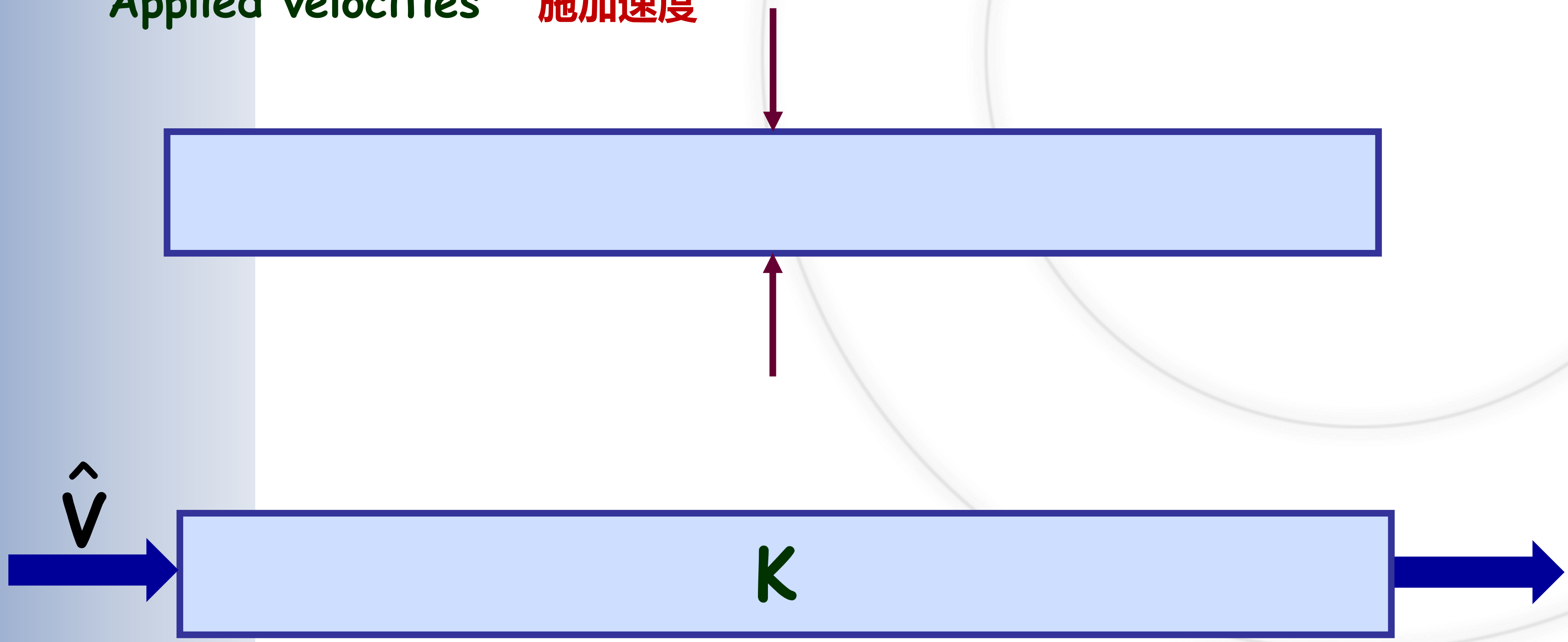


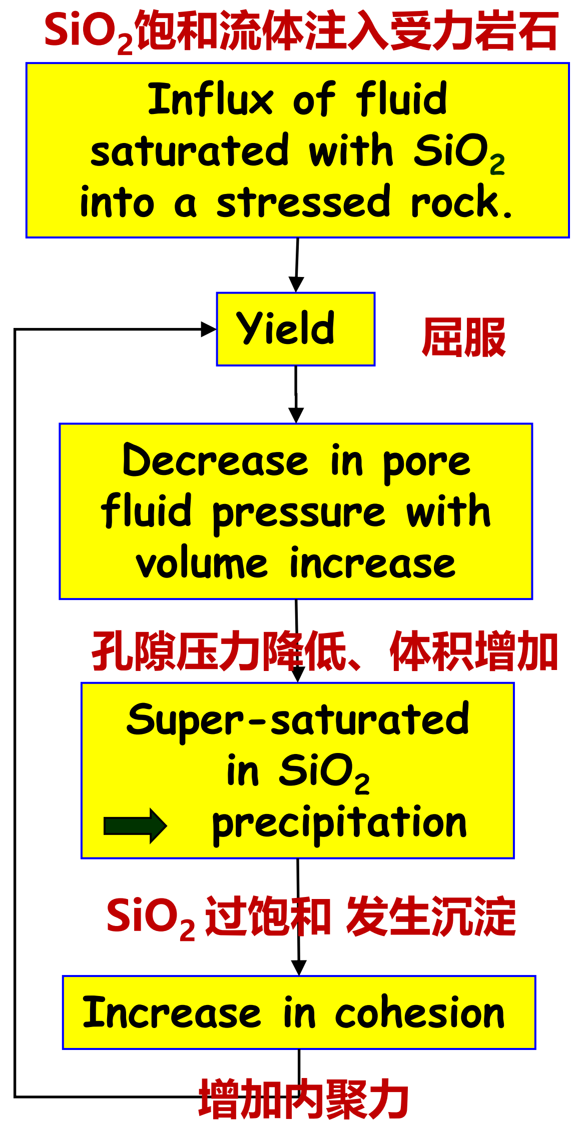




Boundary conditions 边界条件

Applied velocities 施加速度



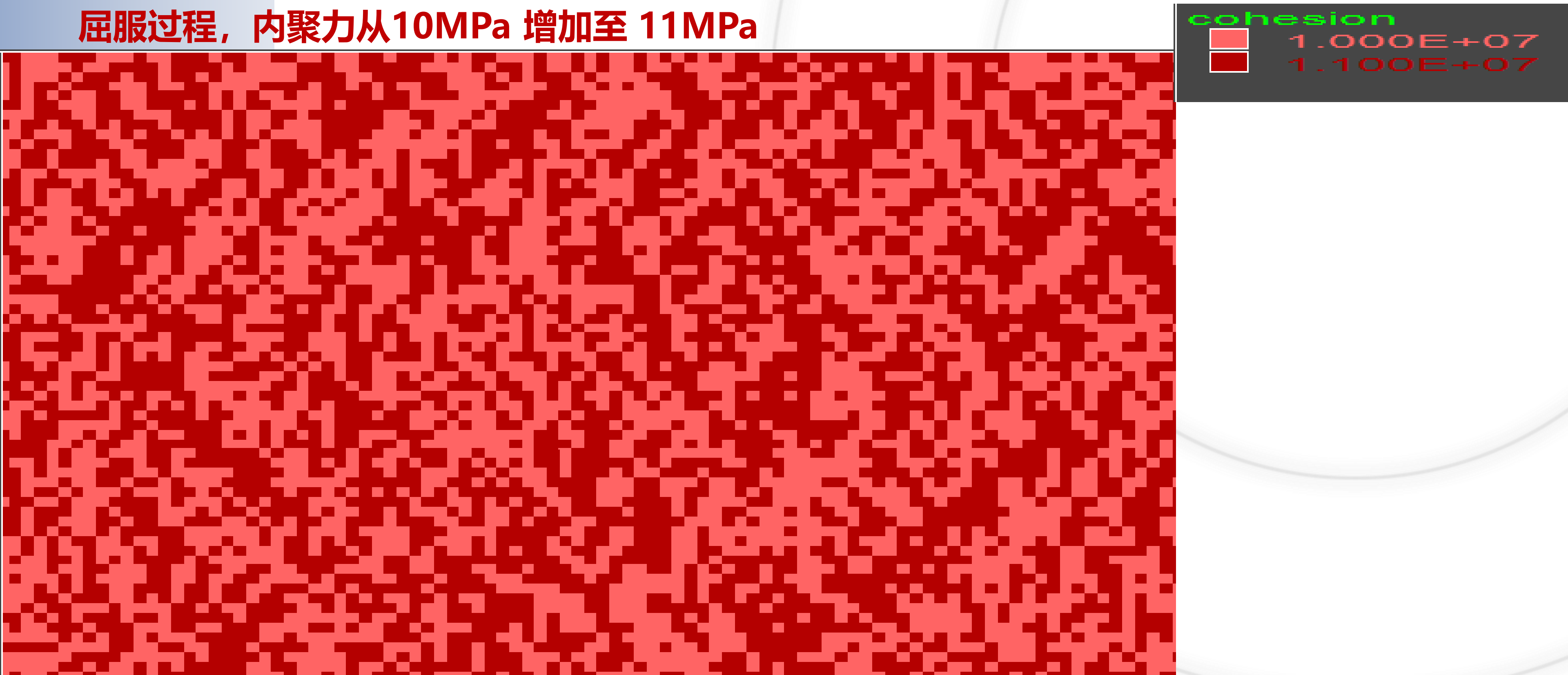


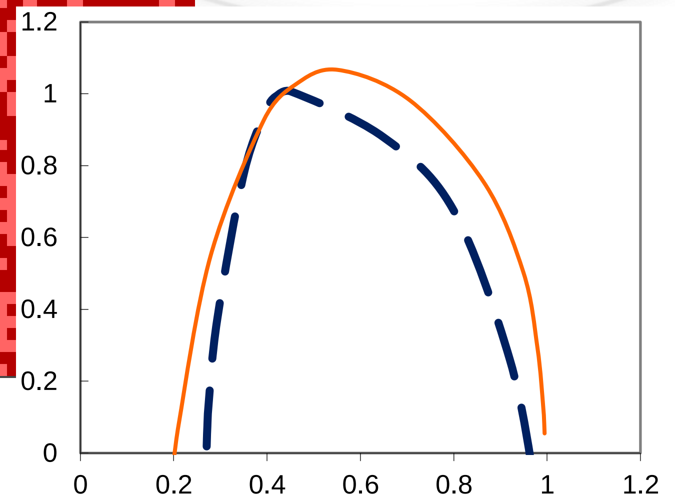
Cohesion hardening

内聚力硬化

On yield, cohesion increases from 10MPa to 11MPa

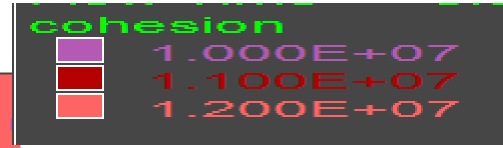
屈服过程，内聚力从10MPa 增加至 11MPa

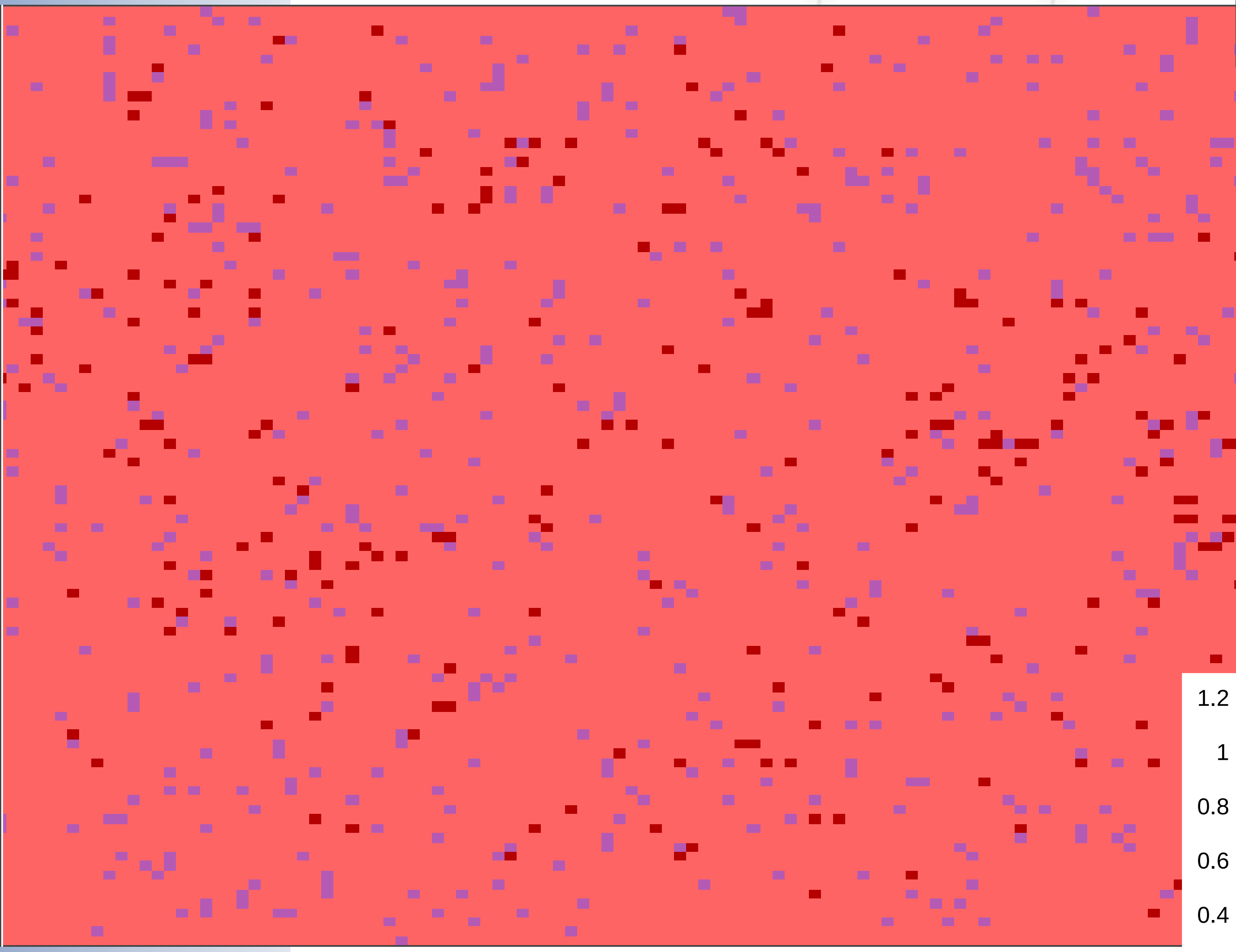


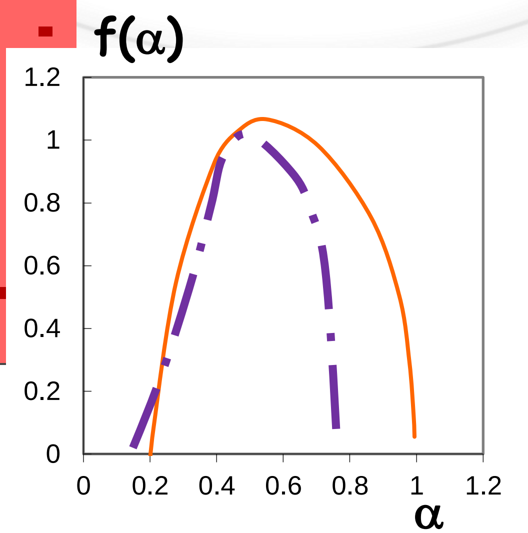


On yield, cohesion increases from 11MPa to 12MPa

屈服过程，内聚力从11MPa 增加至 12MPa

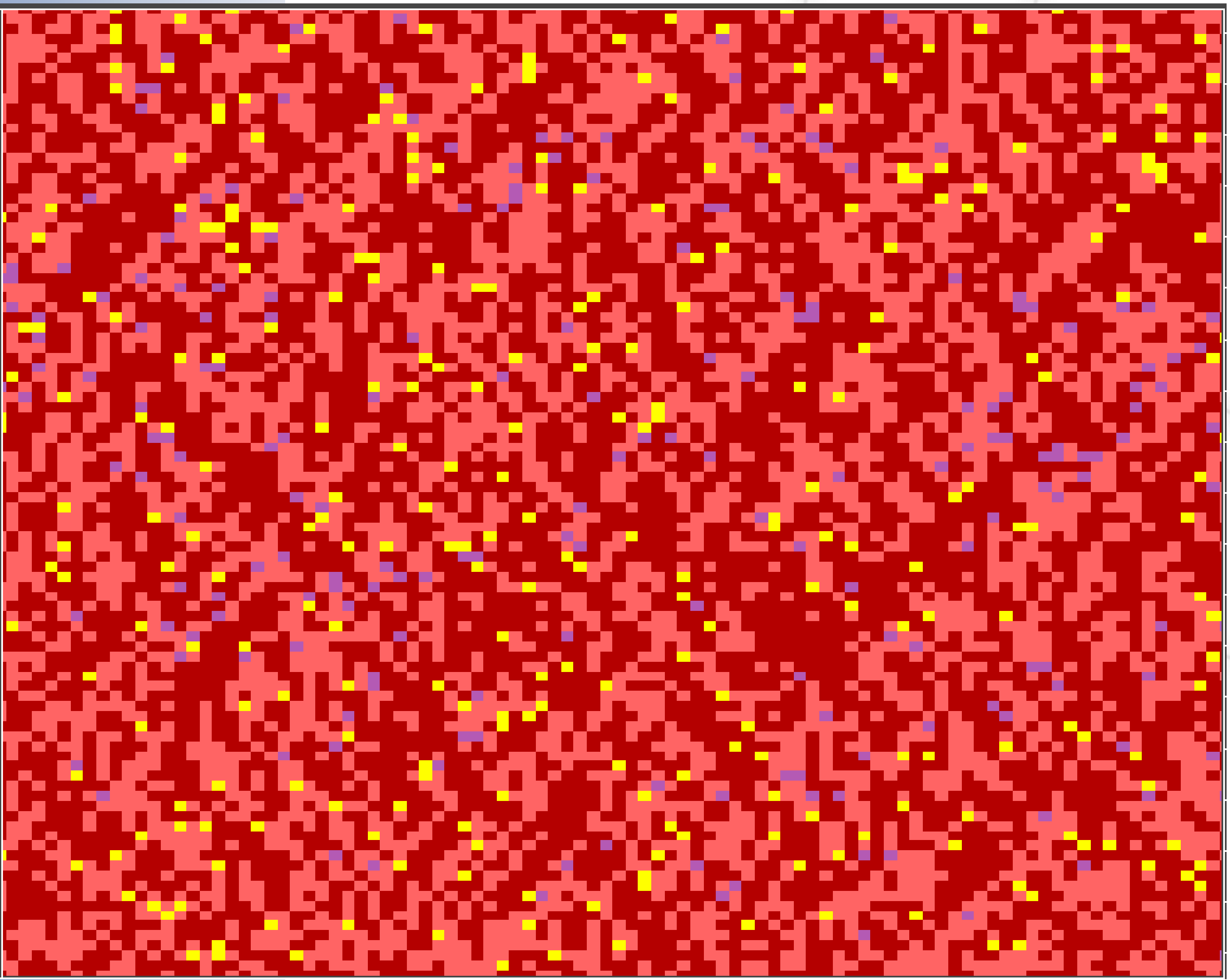


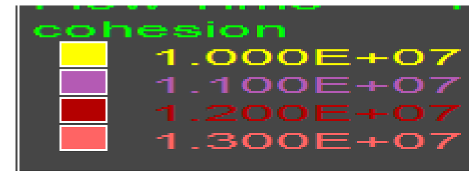


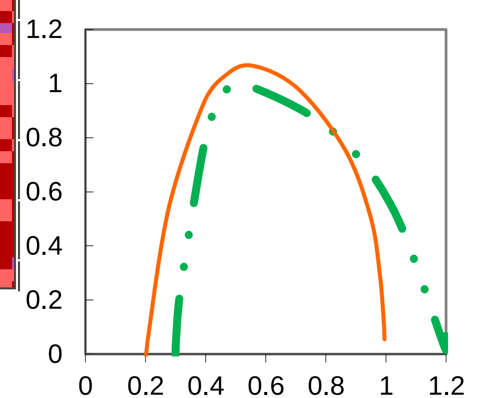


On yield, cohesion increases from 12MPa to 13MPa

屈服过程，内聚力从12MPa 增加至 13MPa

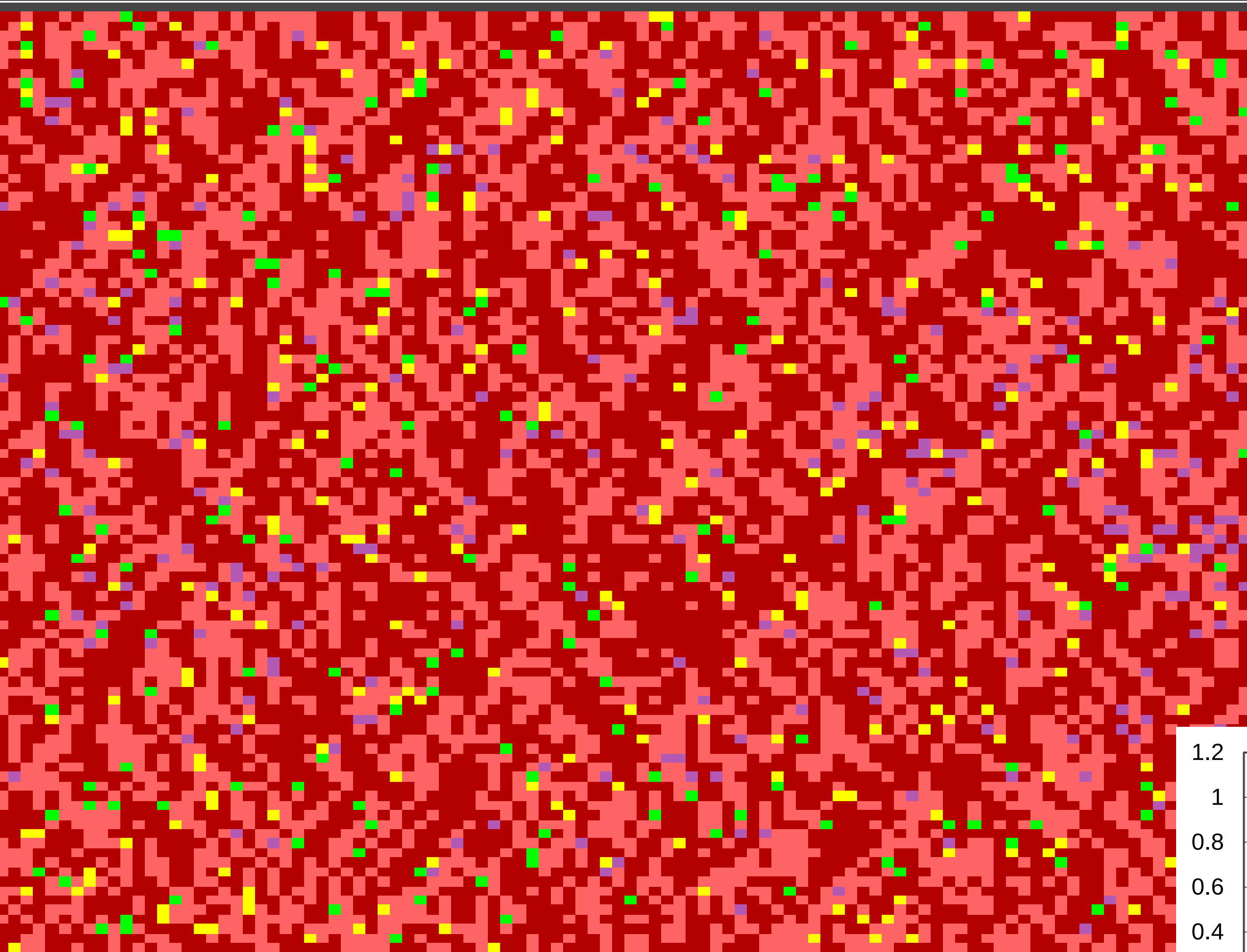


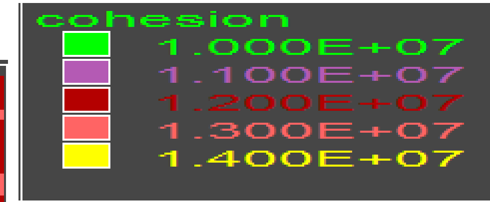


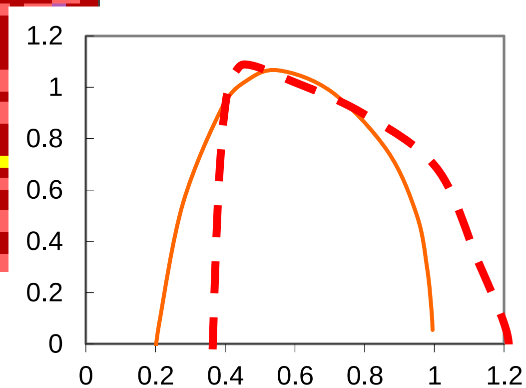


On yield, cohesion increases from 13MPa to 14MPa

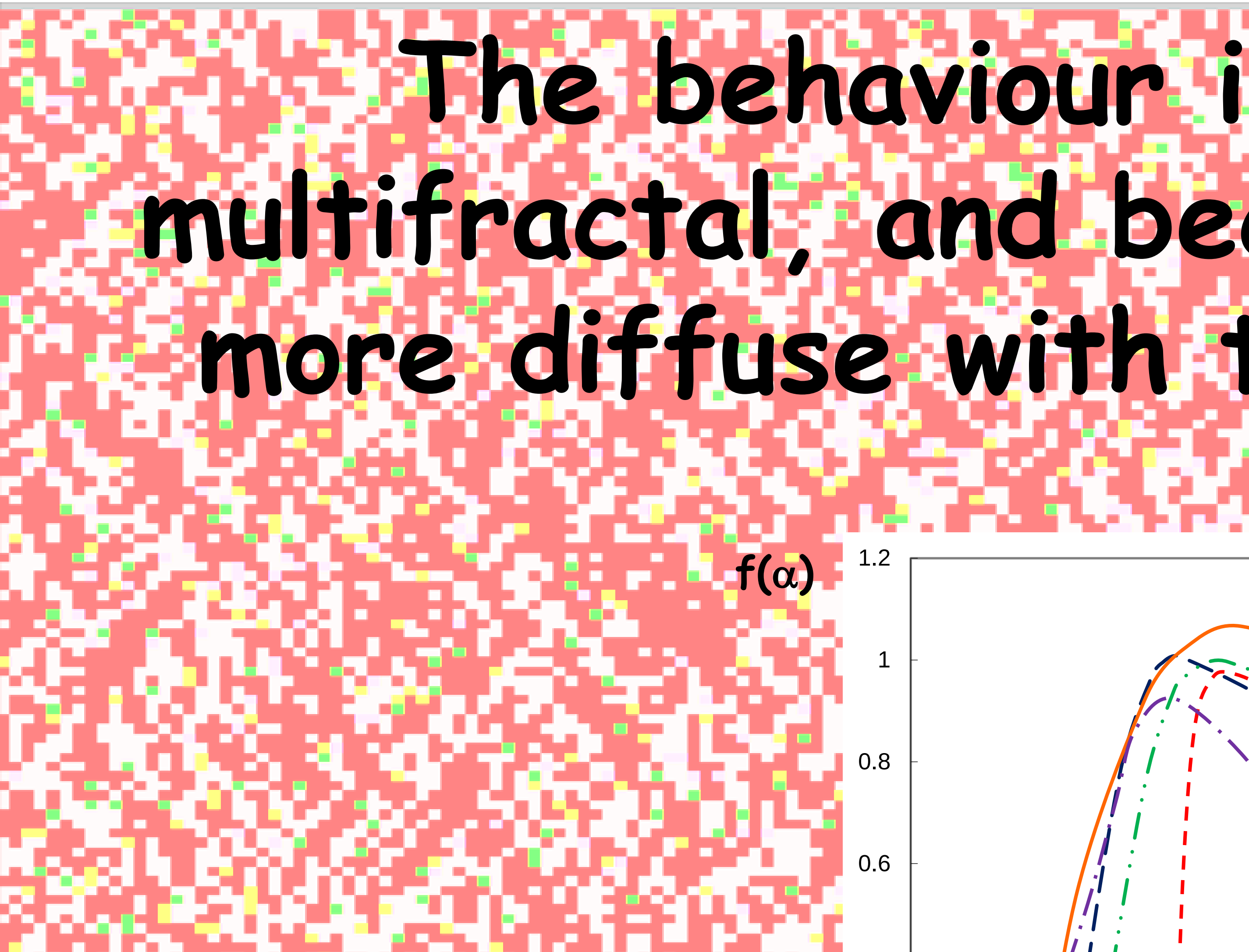
屈服过程，内聚力从13MPa 增加至 14MPa

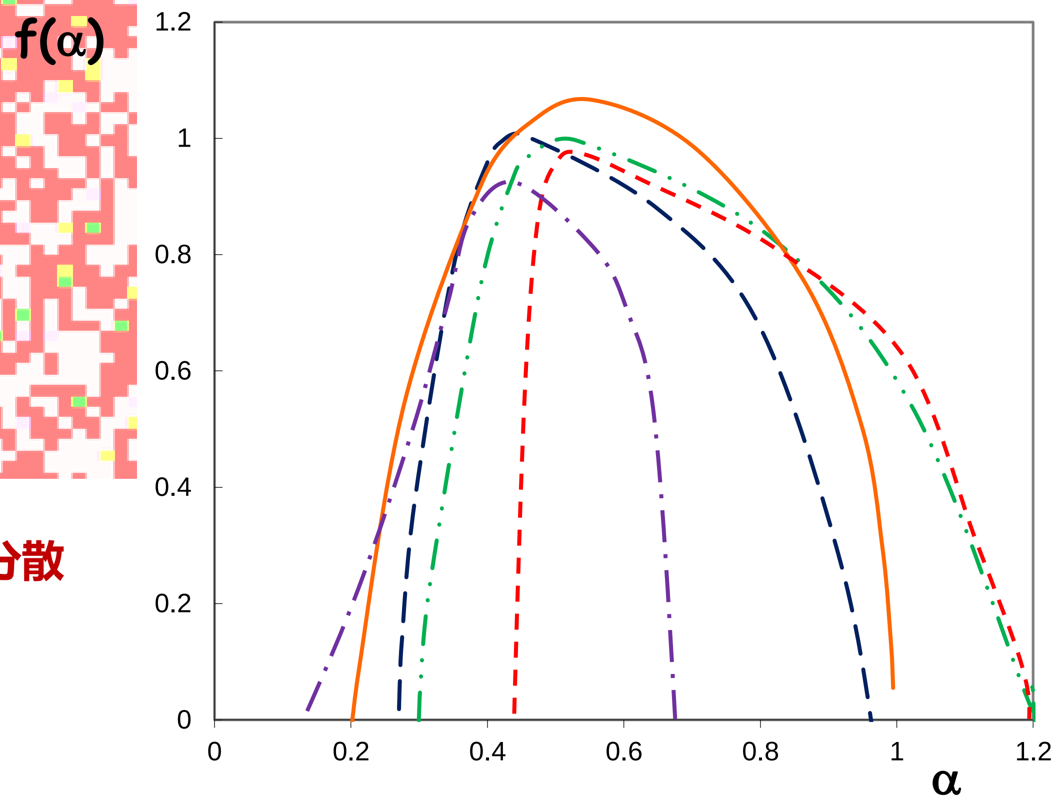




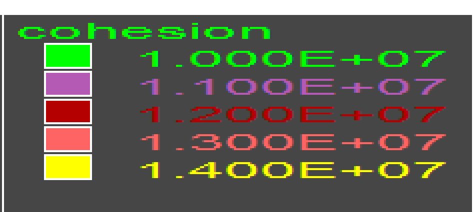


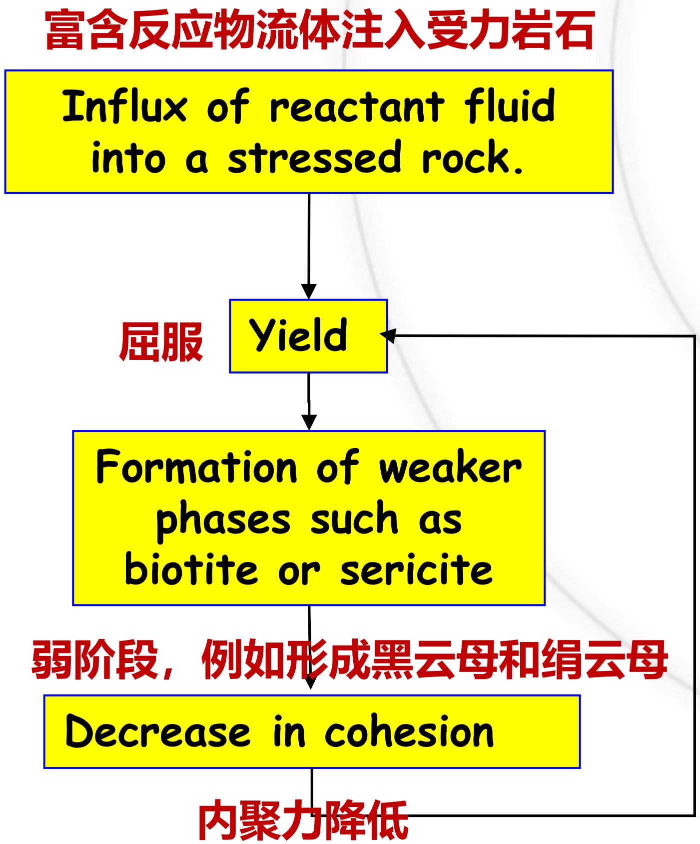
The behaviour is multifractal, and becomes more diffuse with time.





具有多重分形行为特征，随着时间更加分散



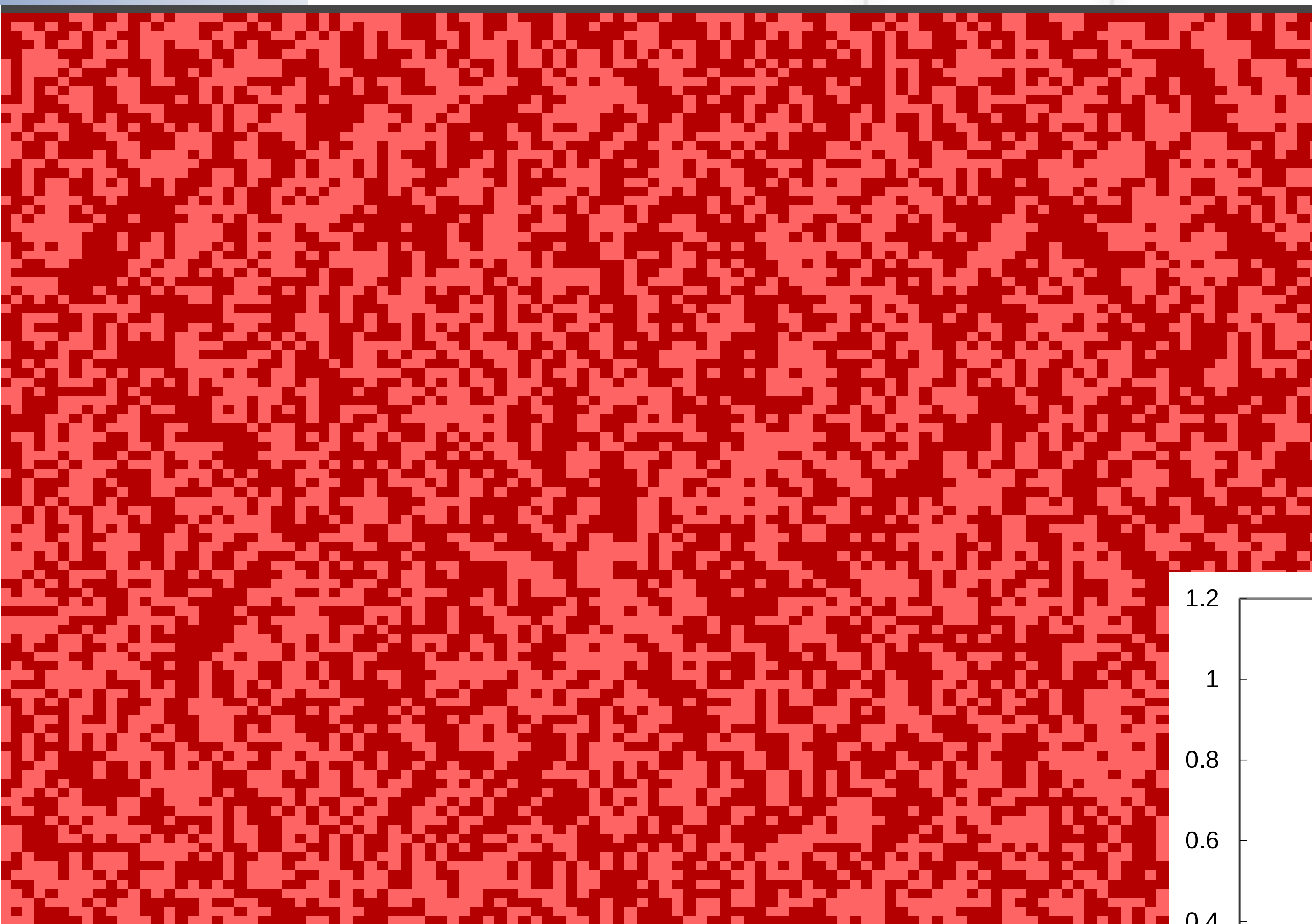


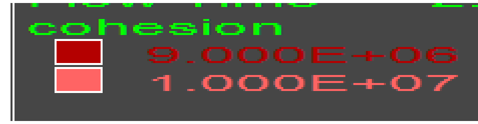
Cohesion softening

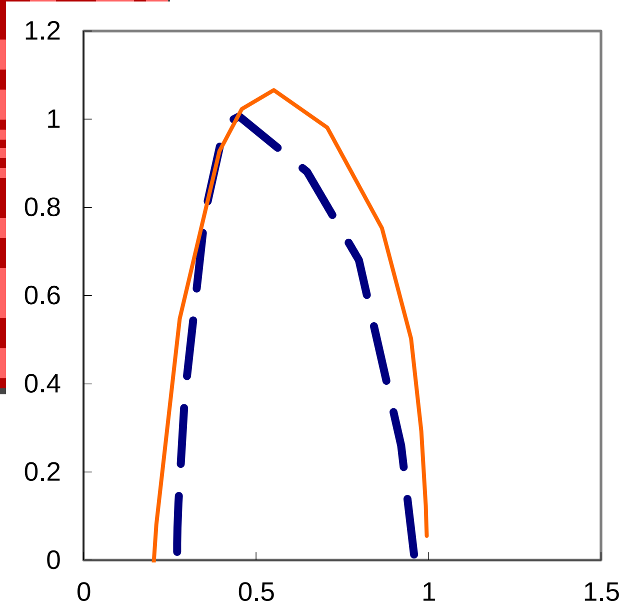
内聚力软化

On yield, cohesion decreases from 10MPa to 9MPa

屈服过程，内聚力从10MPa降低至 9MPa

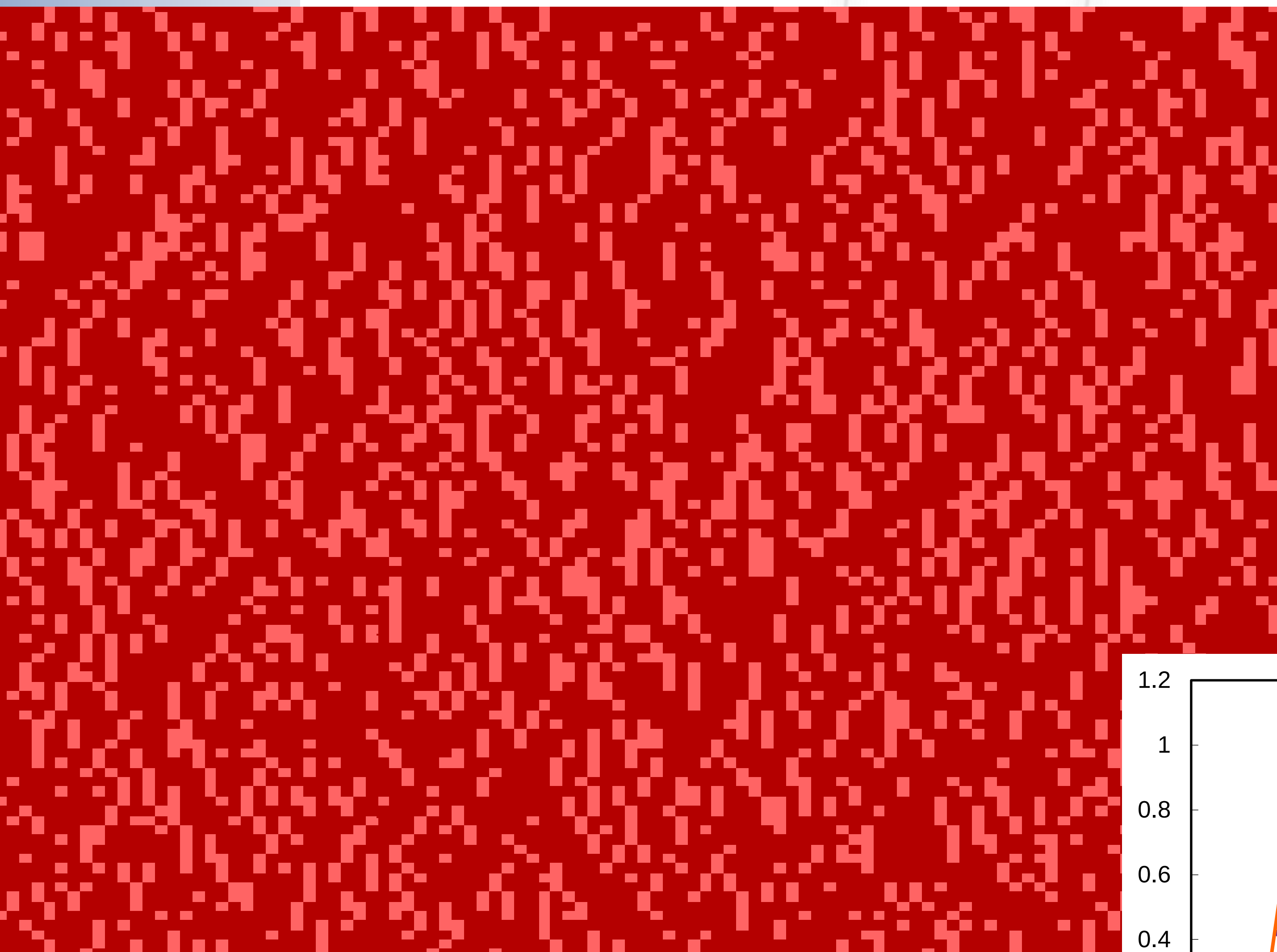


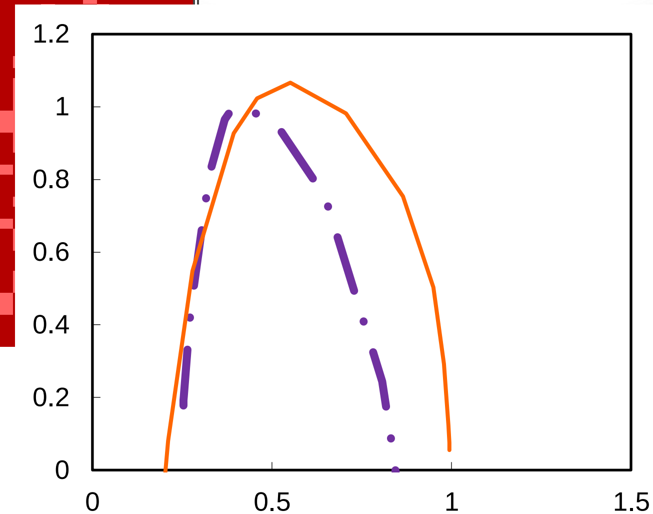




On yield, cohesion decreases from 9MPa to 8MPa

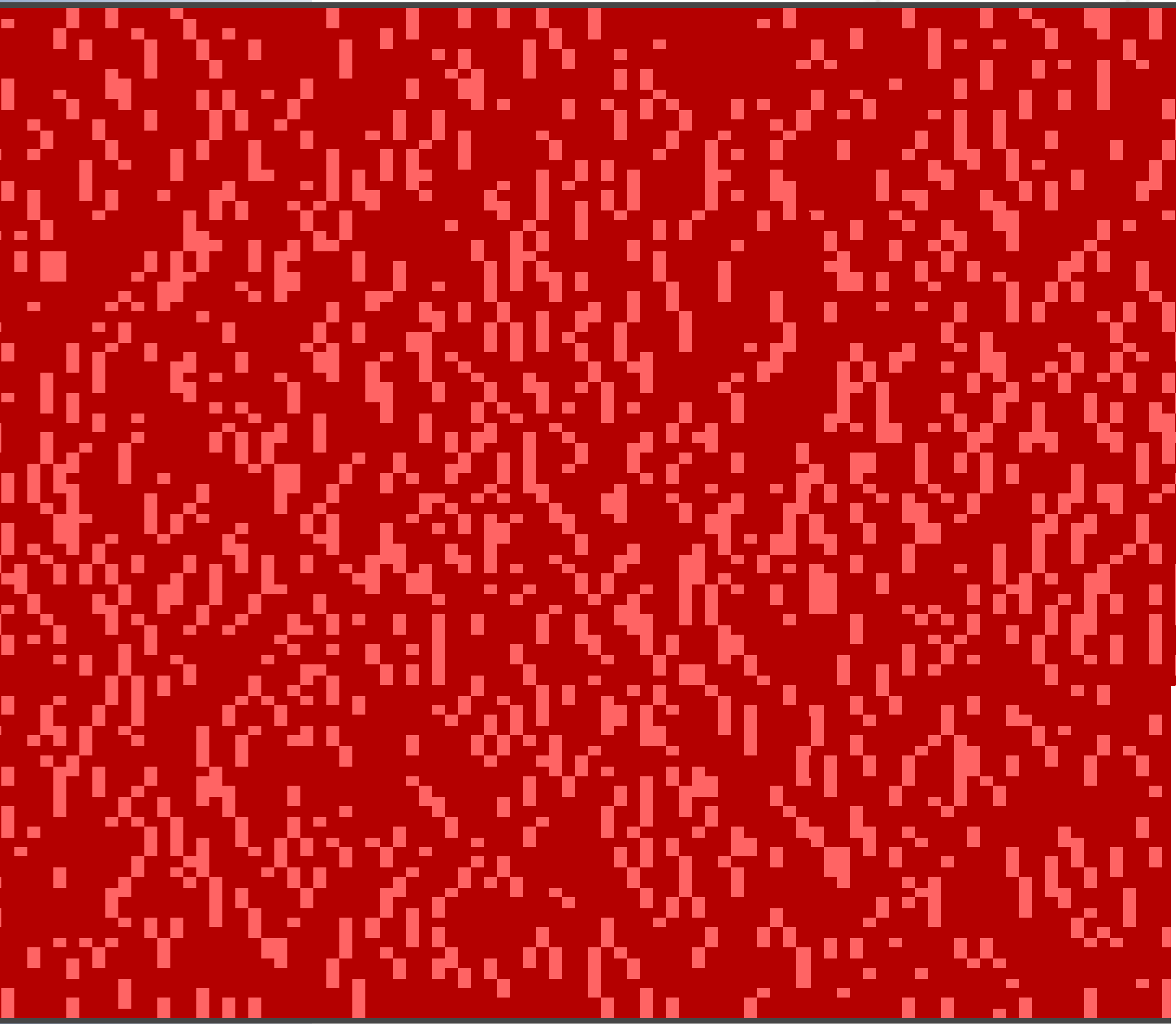
屈服过程，内聚力从9MPa降低至 8MPa

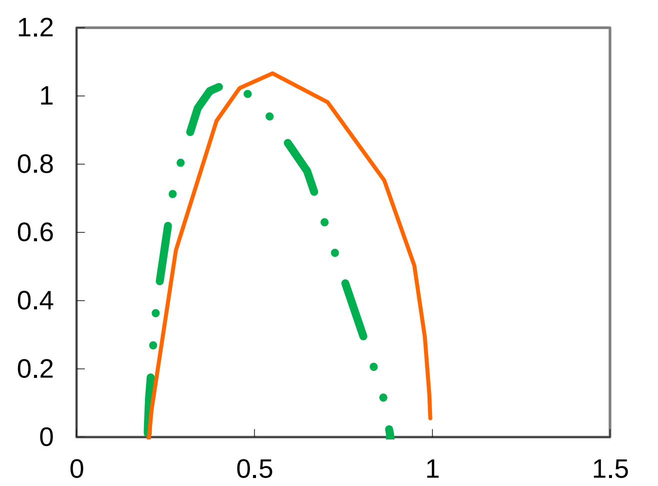




On yield, cohesion decreases from 8MPa to 7MPa

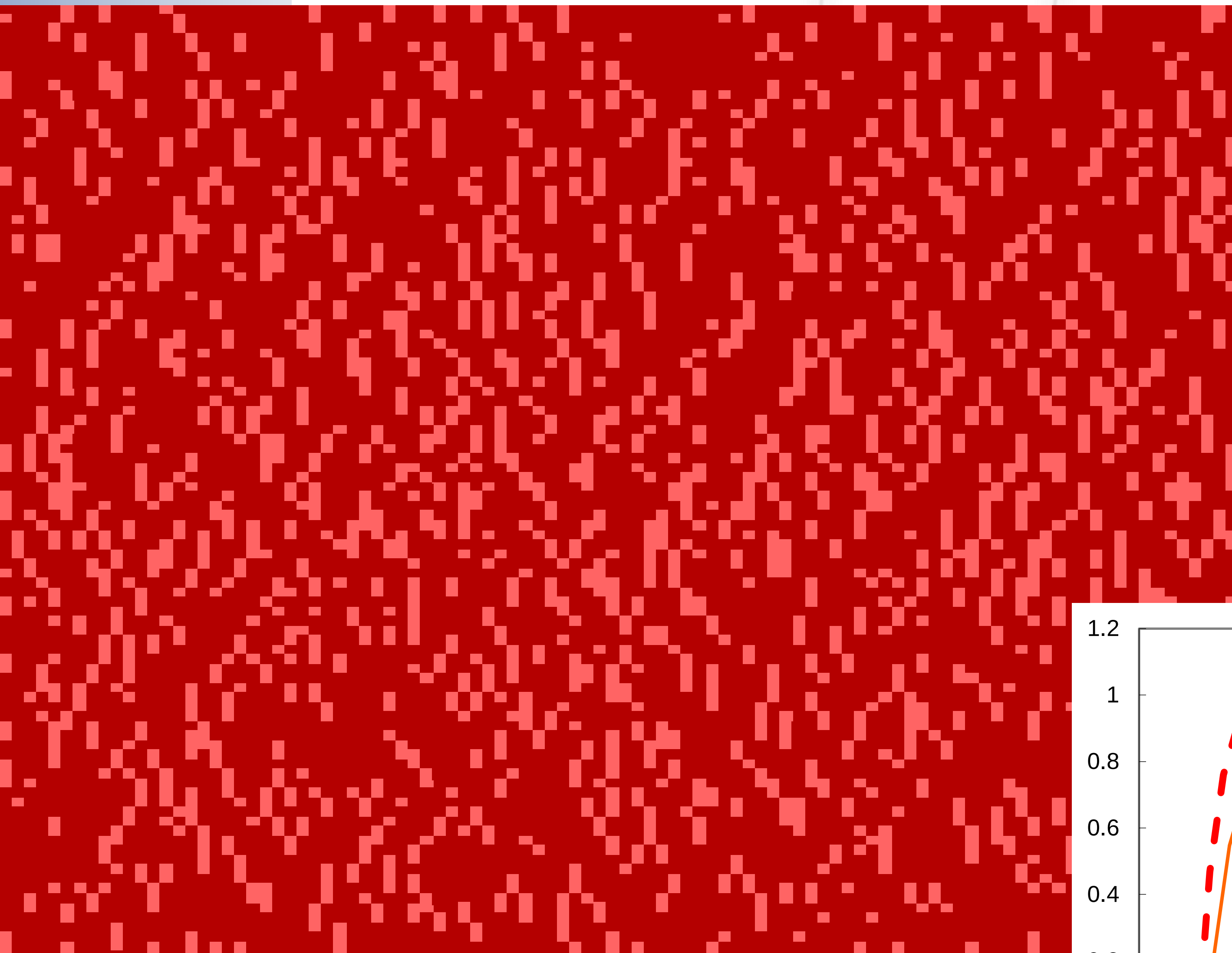
屈服过程，内聚力从8MPa降低至 7MPa

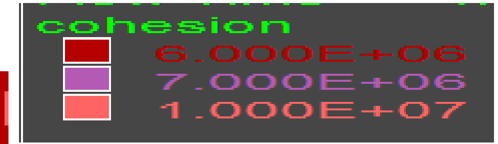


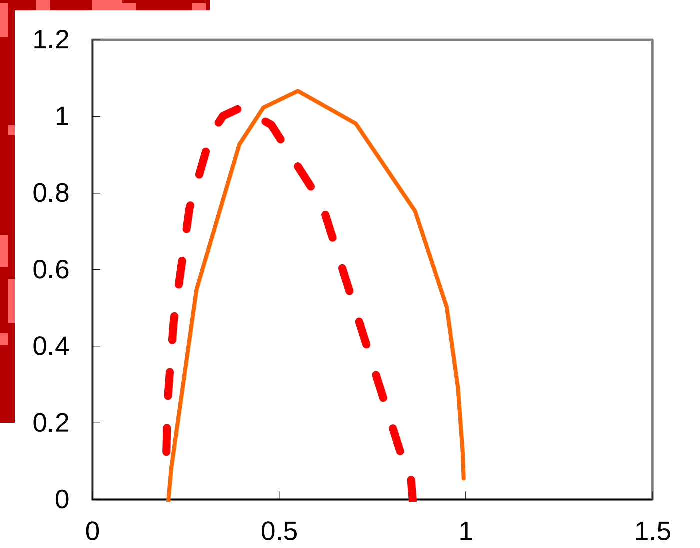


On yield, cohesion decreases from 7MPa to 6MPa

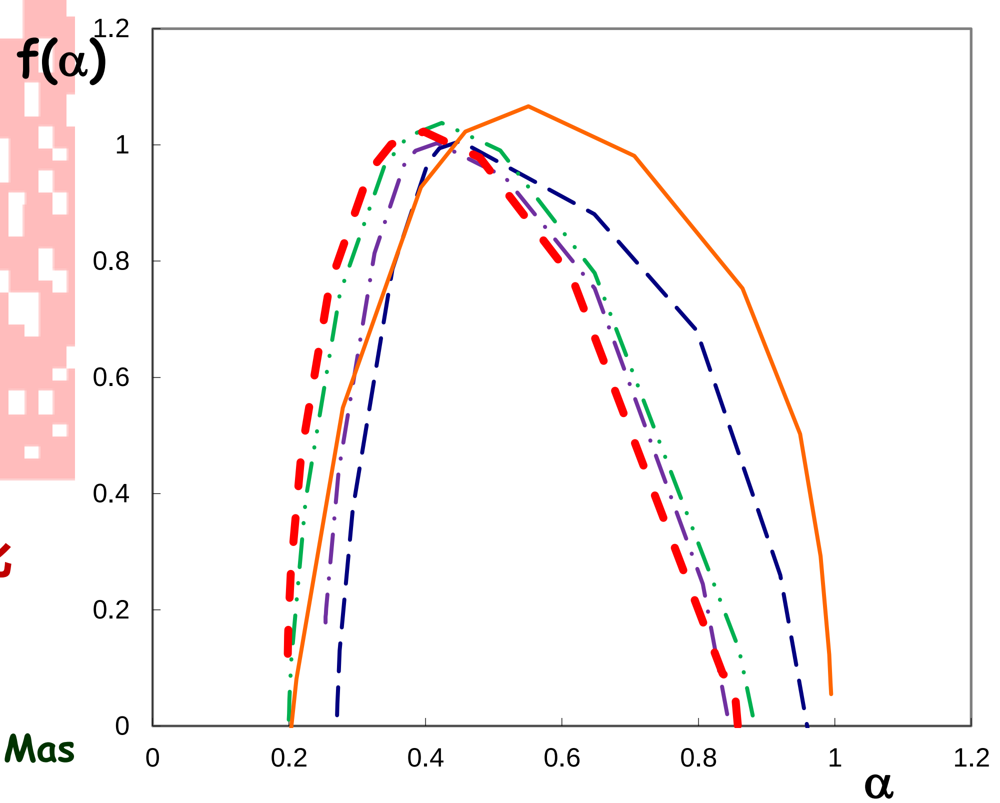
屈服过程，内聚力从7MPa降低至 6MPa



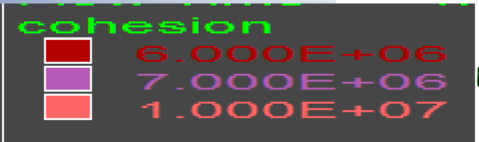


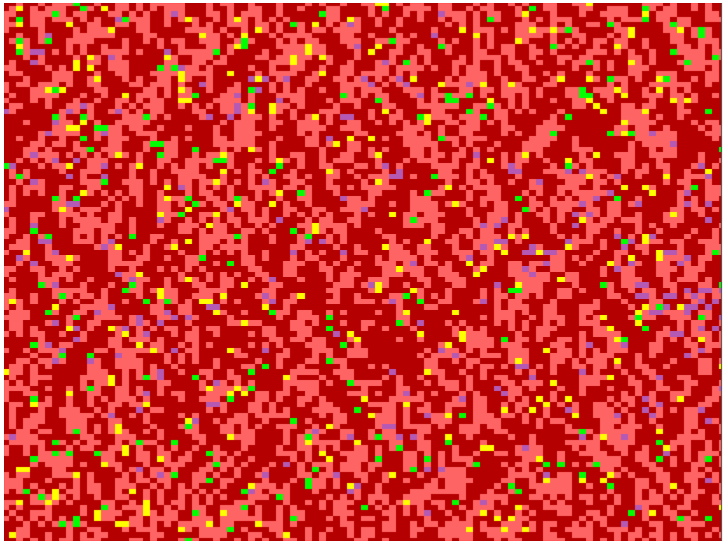


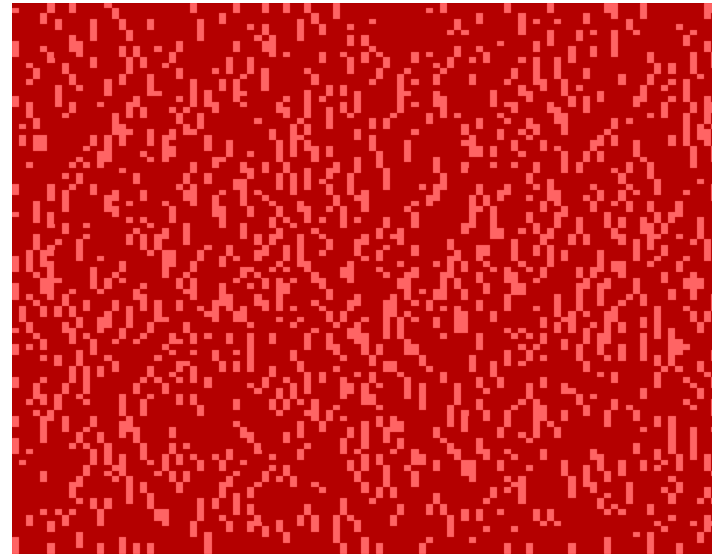
The behaviour is multifractal, and becomes more localised with time.



行为具有多重分形特征，随着时间越发局部化

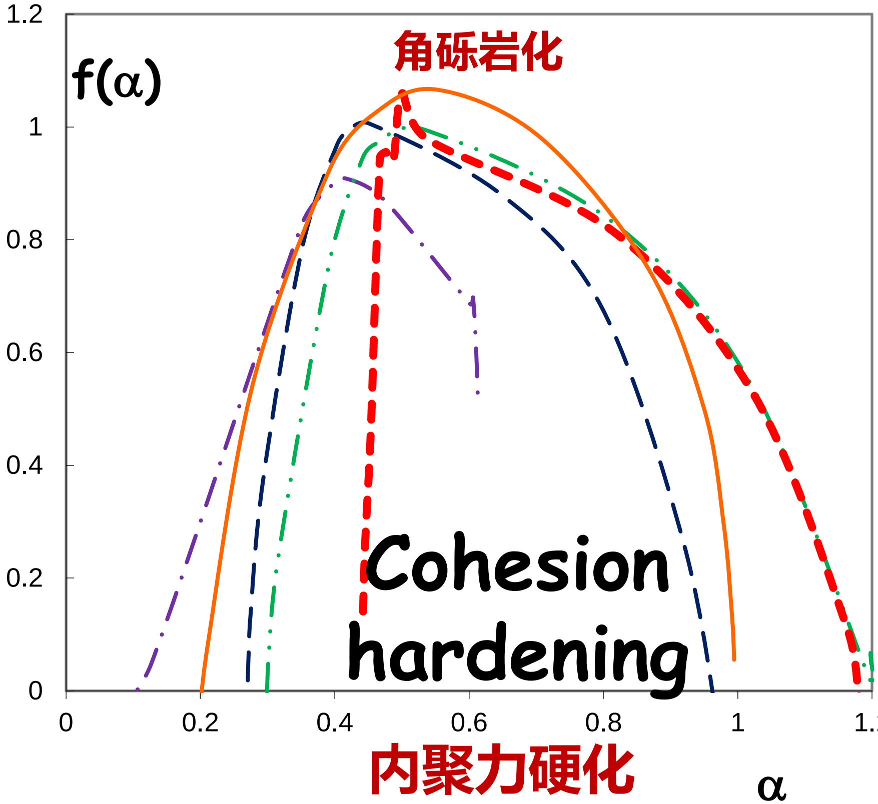


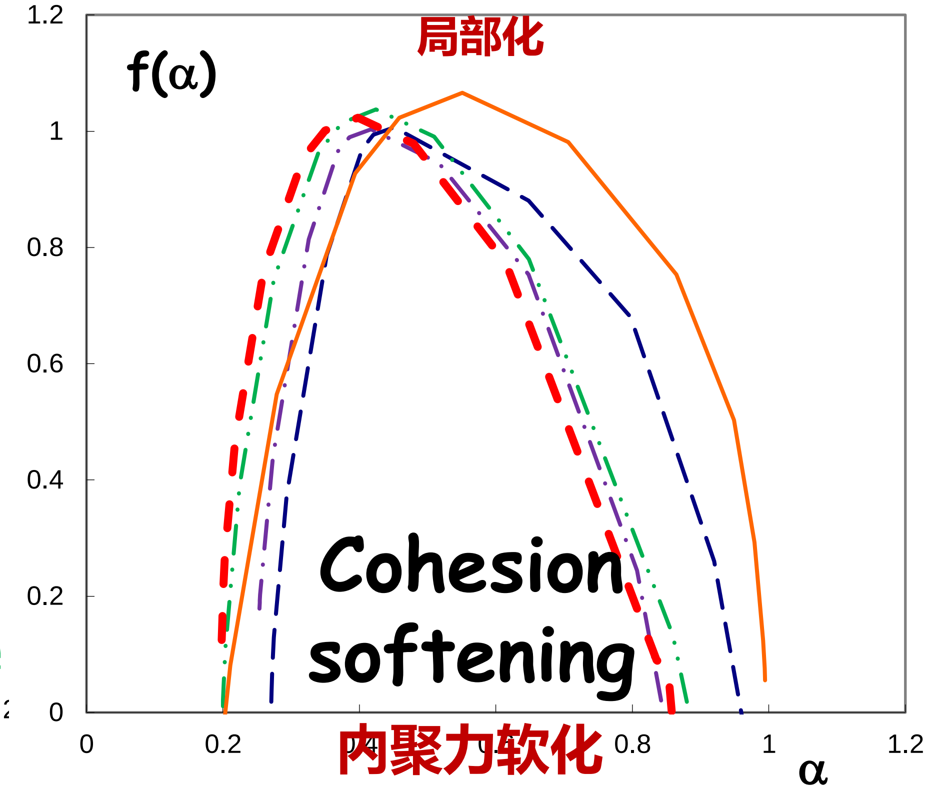


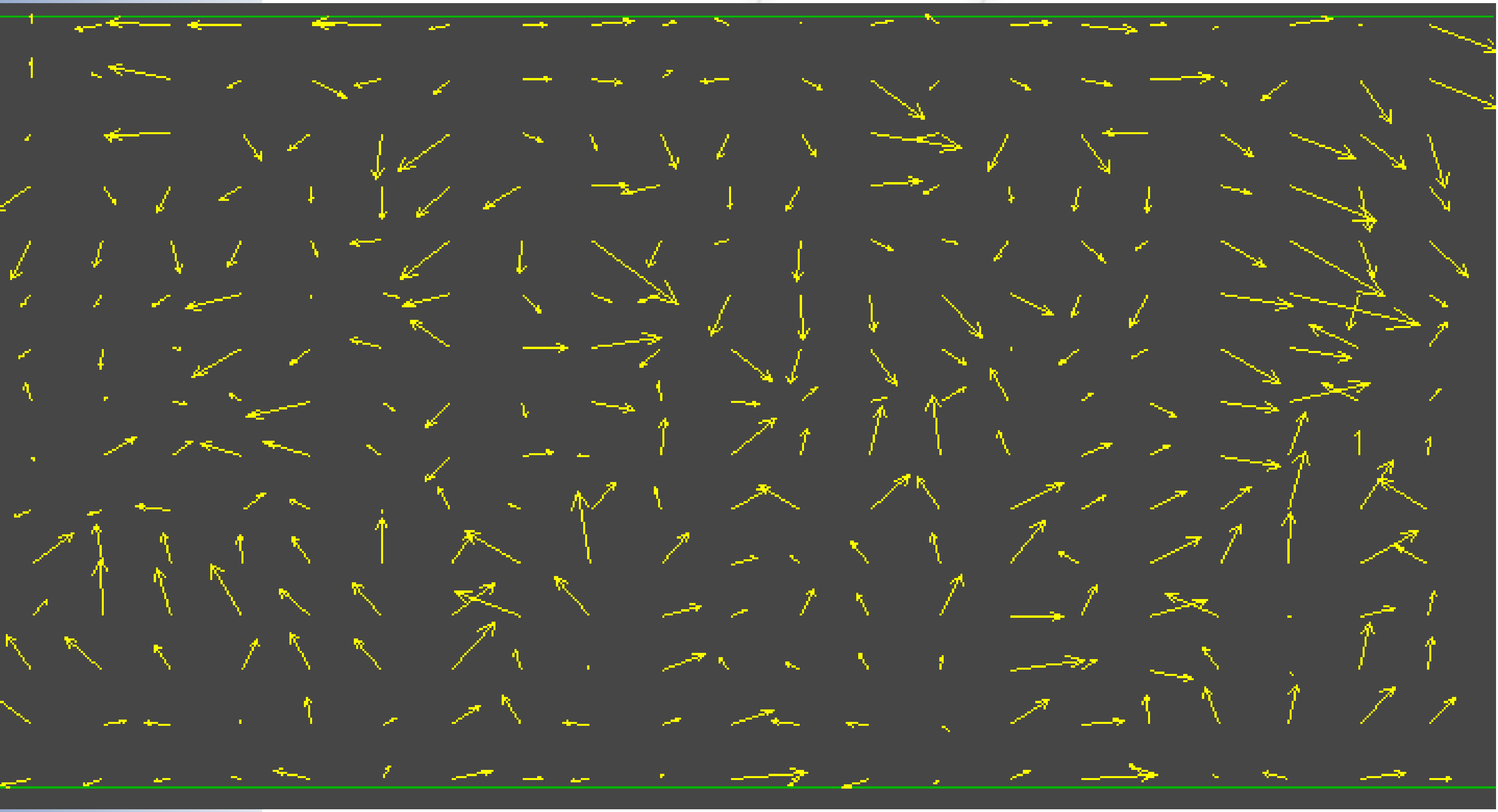


Brecciation

Localisation







Instantaneous fluid flow vectors showing the opportunities for fluid mixing, & therefore chemical reaction, within at least one of these scenarios.

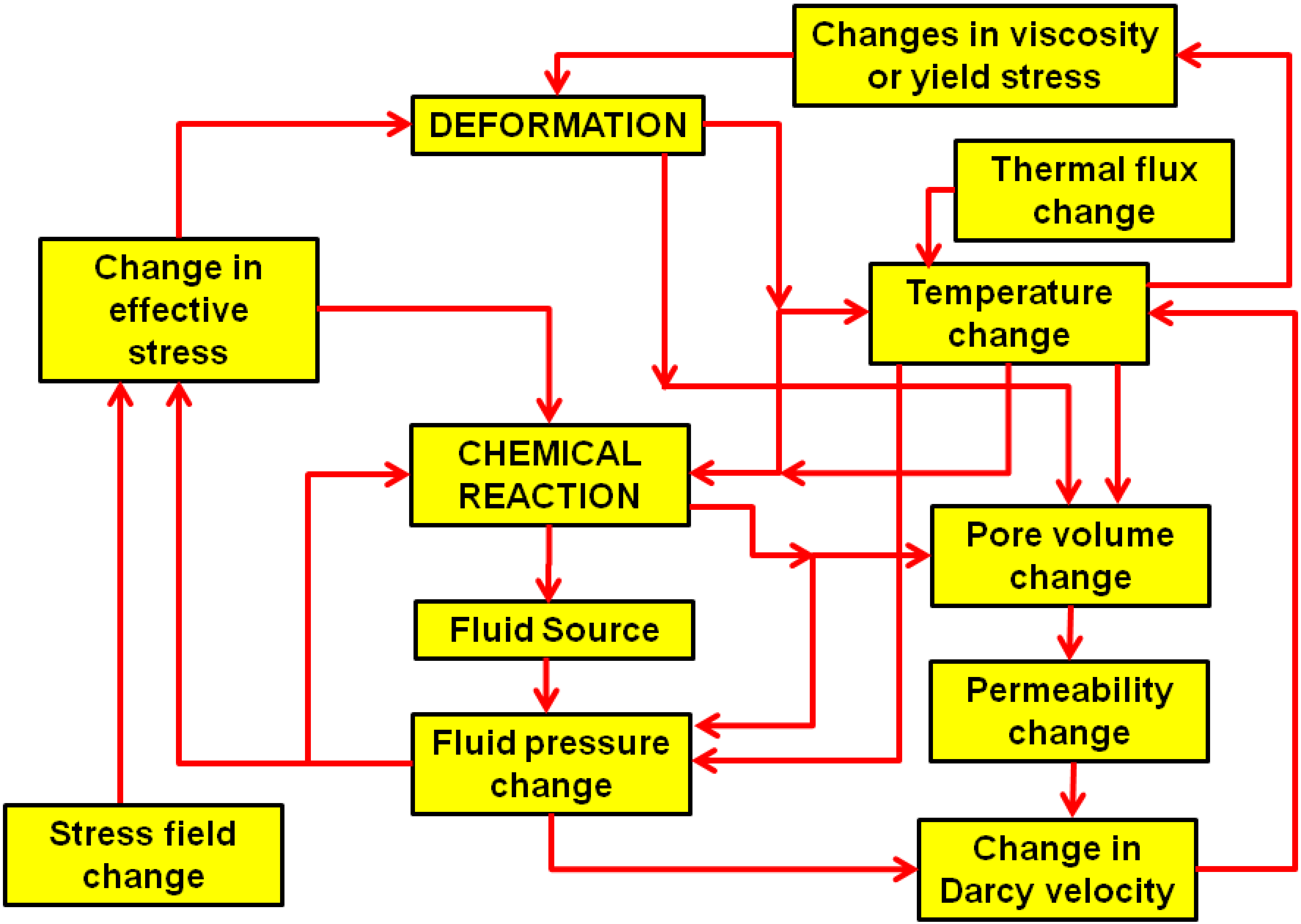
瞬时流体矢量表示流体混合存在机会& 因此至少一个场景讲存在化学反应

This is a reasonable first step towards modelling brecciation behaviour.

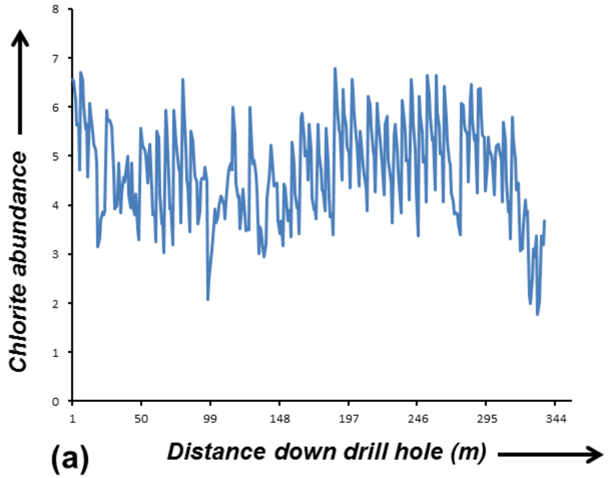
这是构建角砾岩化模型合理的第一步

Does cohesion softening promote the development of mineralising systems while cohesion hardening results in barren systems?

内聚力软化促使成矿系统进一步发展，而内聚力硬化会导致系统贫化?

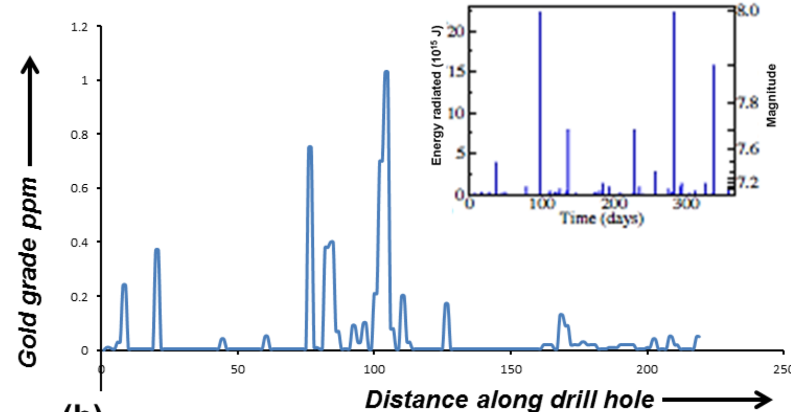

Changes in viscosity or yield stress
DEFORMATION
Thermal flux change
Change in effective stress
Temperature change
CHEMICAL REACTION
Pore volume change
Fluid Source
Permeability change
Fluid pressure change
Stress field change
Change in Darcy velocity

Data sets from hydrothermal systems.



(a)

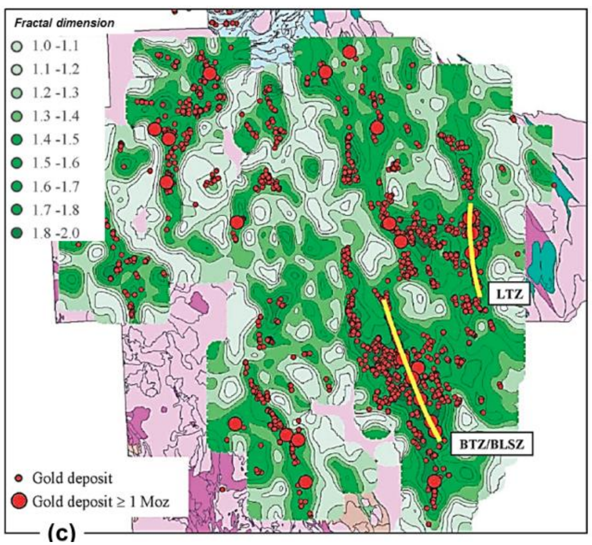
Chlorite abundance along a drill hole measured by infra-red reflectance methods. Salt Creek gold deposit, Western Australia.



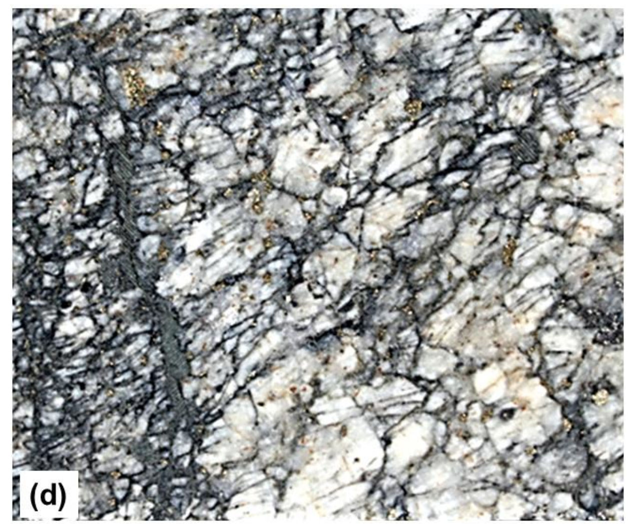
(b)

Gold abundance along a drill hole measured by assay. Salt Creek gold deposit, Western Australia. Inset: energy release sequence for earthquakes in California, 1995.

Map of "complexity" in part of the Yilgarn craton of Western Australia. The figure is a contoured map of fractal dimension (determined by box counting) of mapped structures with gold occurrences superimposed.



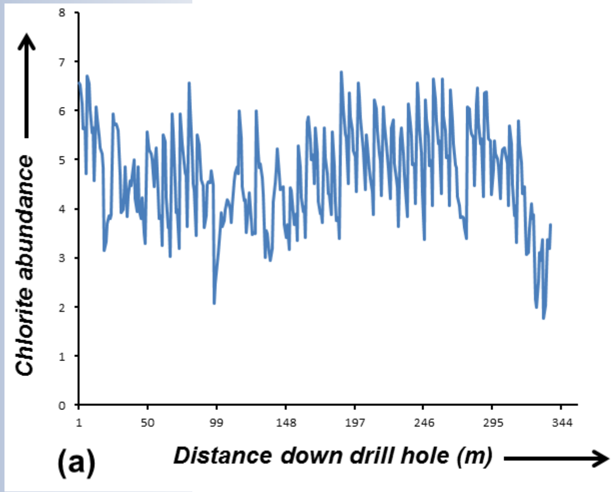
(c)

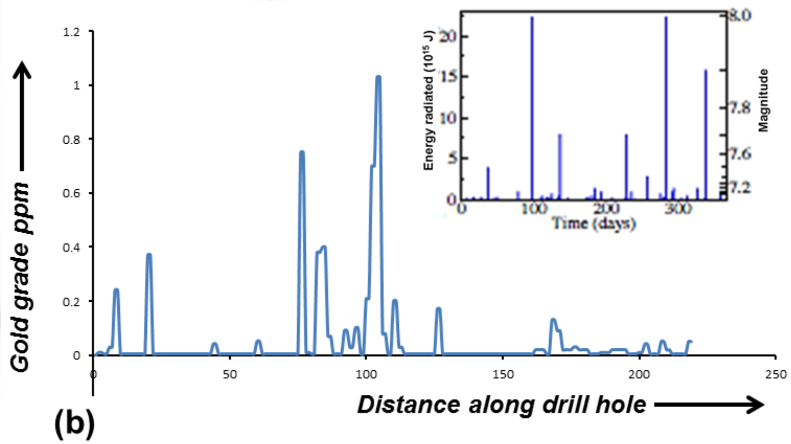


Yellow lines show locations of the Bardoc Tectonic Zone and Boulder – Lefroy Shear Zone (BTZ/BLSZ) in the Kalgoorlie Terrane and the Laverton Tectonic Zone (LTZ). After Hodkiewicz et al. (2005).

Image of fractures in a breccia from the Tropicana gold deposit in Western Australia. Bright golden specs are gold bearing arseno-pyrite grains. Scale: Image is 1.5 cm across base.

Data sets from hydrothermal systems.

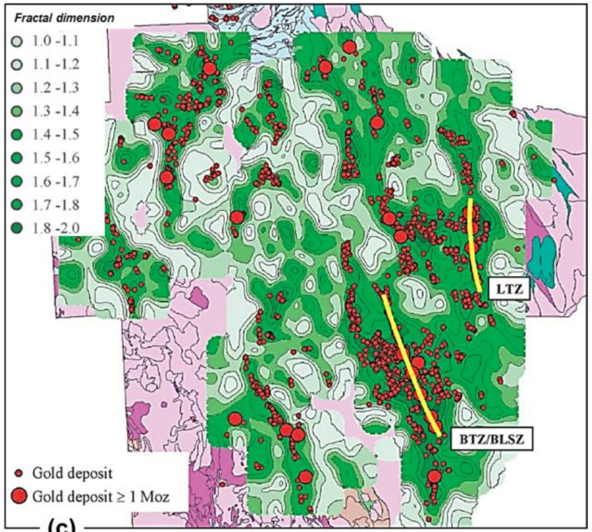




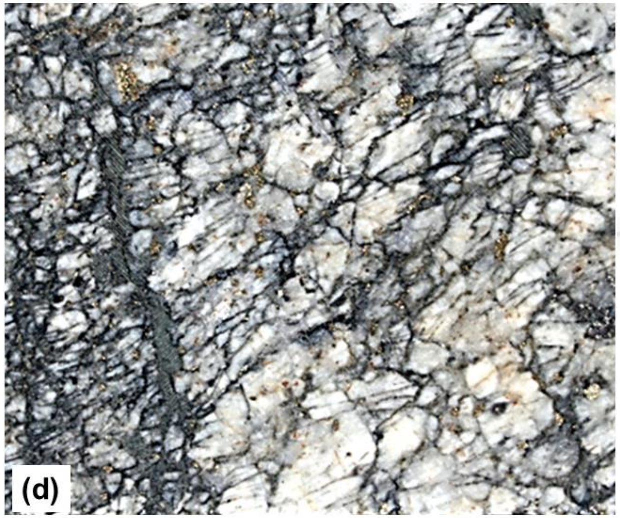
沿着一个钻孔，用红外线反射率方法测量绿泥石丰度。盐河金矿，西澳大利亚州。

沿法测定钻孔黄金丰度。盐河金矿，西澳大利亚州。插图：在加利福尼亚州，1995年地震能量释放序列。

地图的"复杂性"，澳大利亚西部的伊尔干克拉通的一部分。下图是黄金映射的结构叠加出现分形维数（由框计算确定）的轮廓图。



黄线显示Bardoc构造带和巨石的位置 - 勒弗罗伊剪切带（BTZ/ BLSZ）在卡尔古利地体和拉弗顿构造带（LTZ）。根据Hodkiewicz等。（2005）。



康纳金矿位于西澳大利亚，一个角砾岩的影像。明亮的金色是含金砷黄铁矿颗粒。

The questions are:

- Are these systems chaotic?
- Are the transitions seen in these systems continuous or abrupt?
- Does the system reach criticality?
- And if so, does such criticality represent Self-Organised Criticality (SOC)?
- Are the states we see non-equilibrium stationary states?

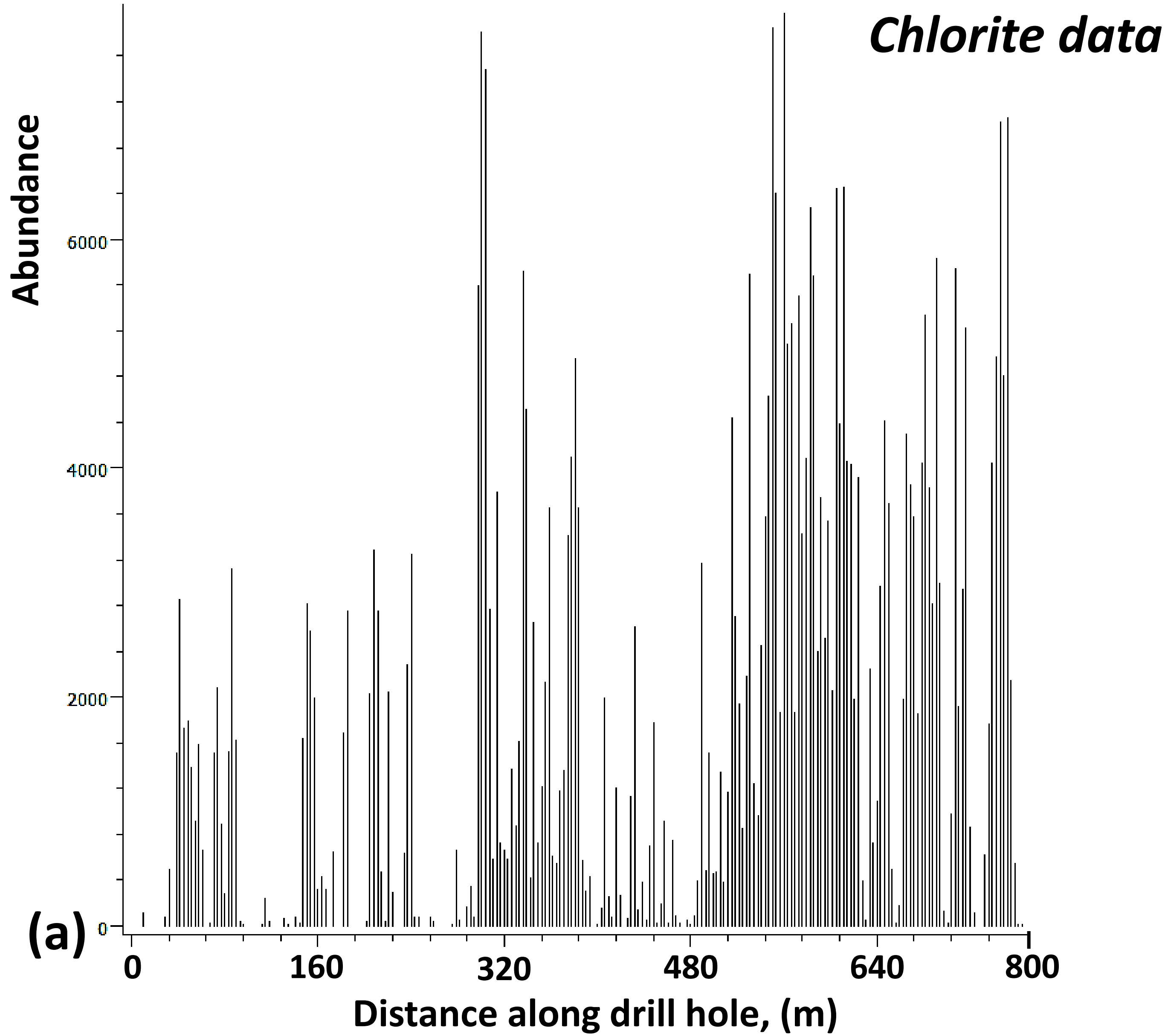
问题:

- 难道这些系统是混乱态?
- 这些系统连续或存在急剧的过渡?
- **系**统是否达到临界状态?
- **如果是**这样，那么这样的关键性代表自有组织临界（**SOC**）？
- 难道我们看到时非平衡态的状态?

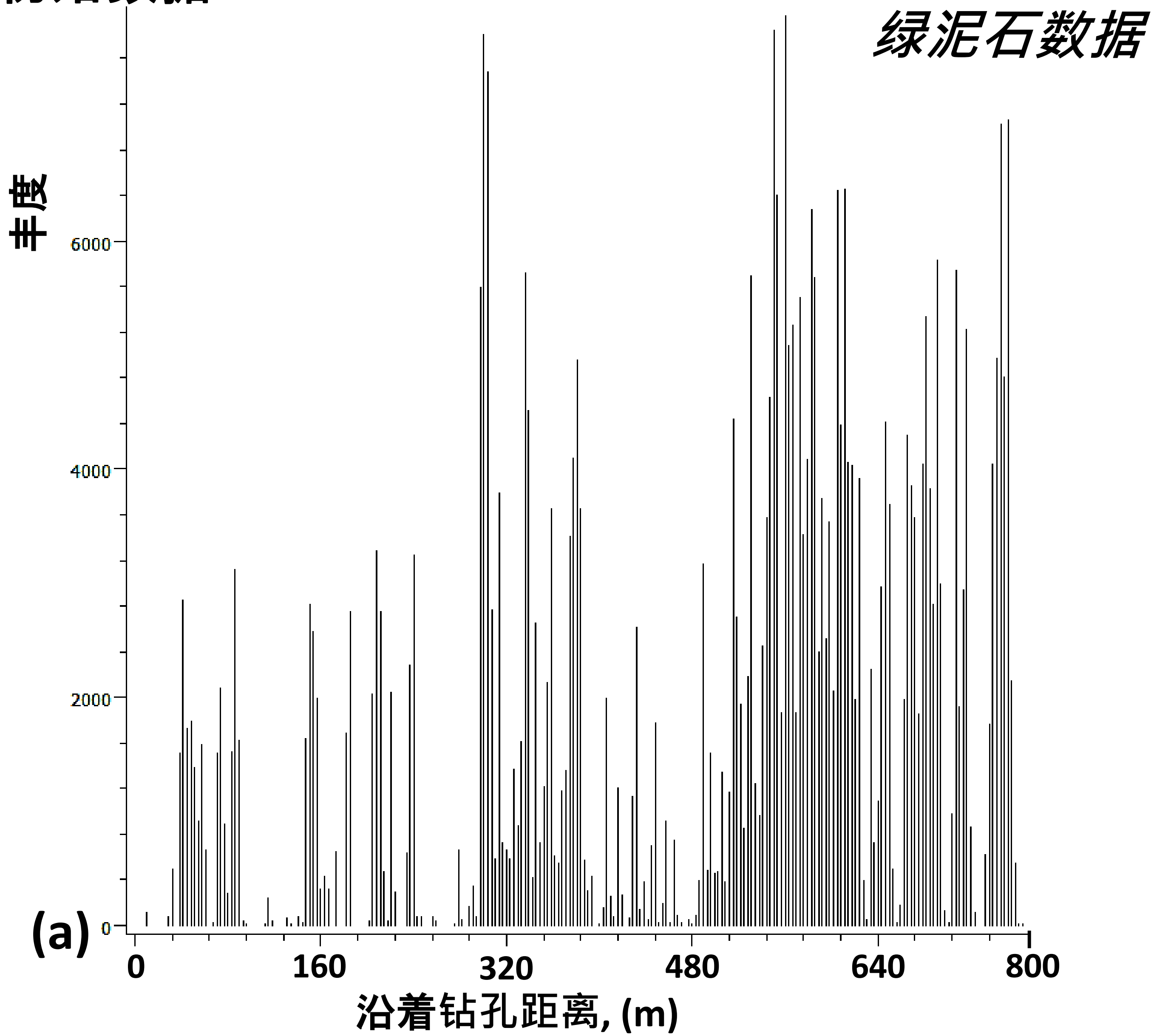
Characteristics of a chaotic system
一个混沌系统的特点

- **Multifractal**
  多重分形
- **Long Range Order**
  长程有序

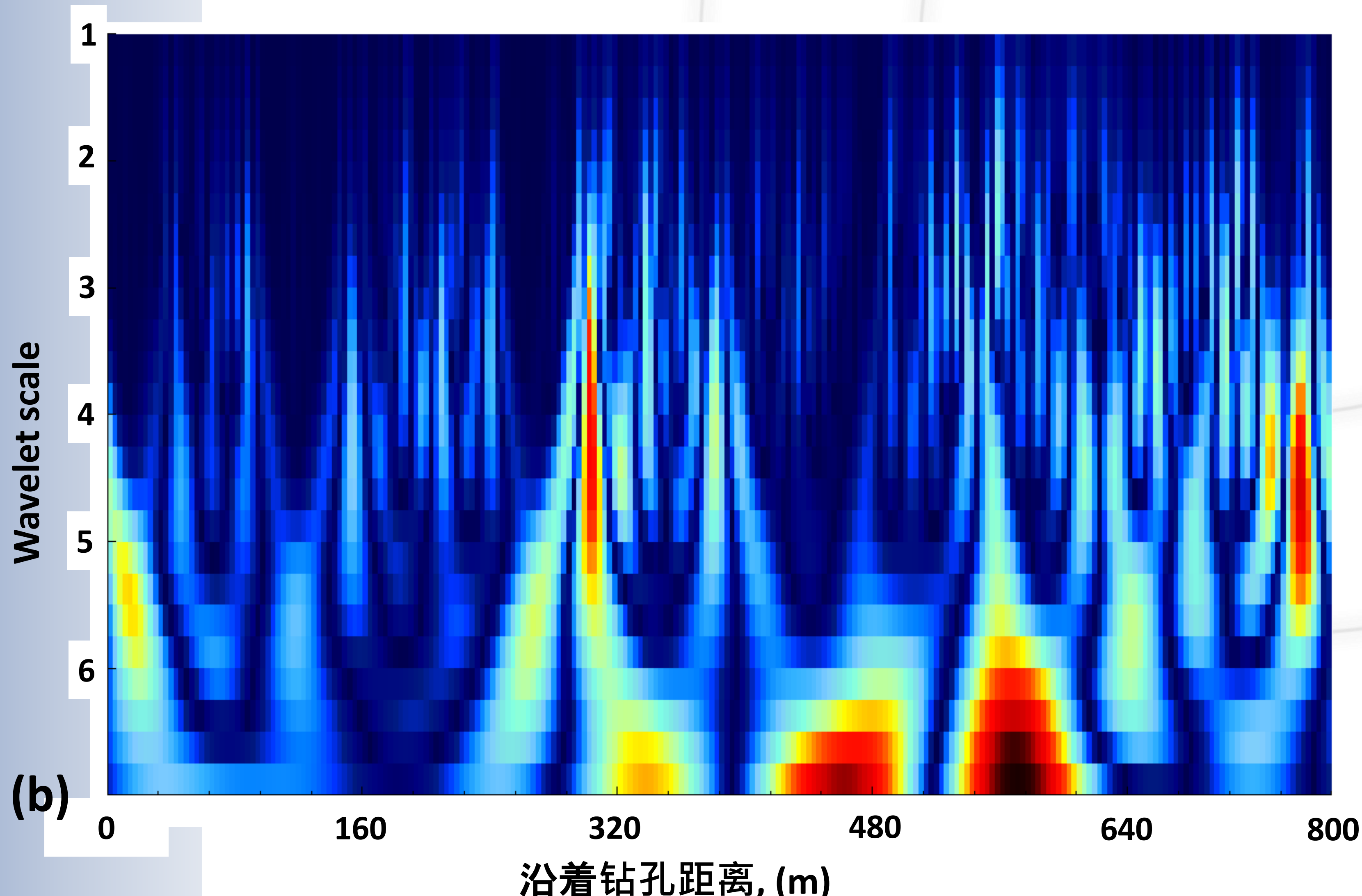
INITIAL DATA



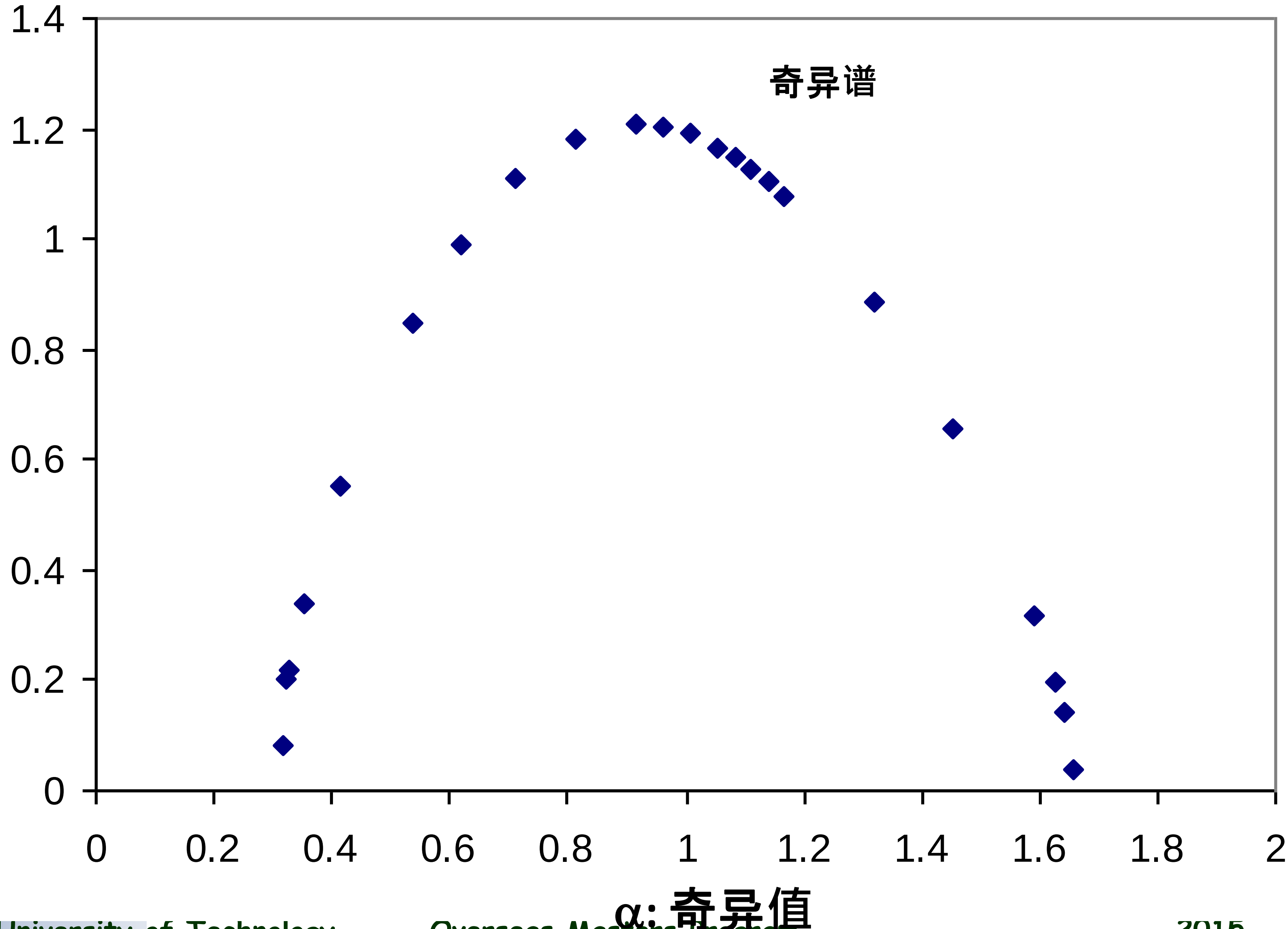
初始数据



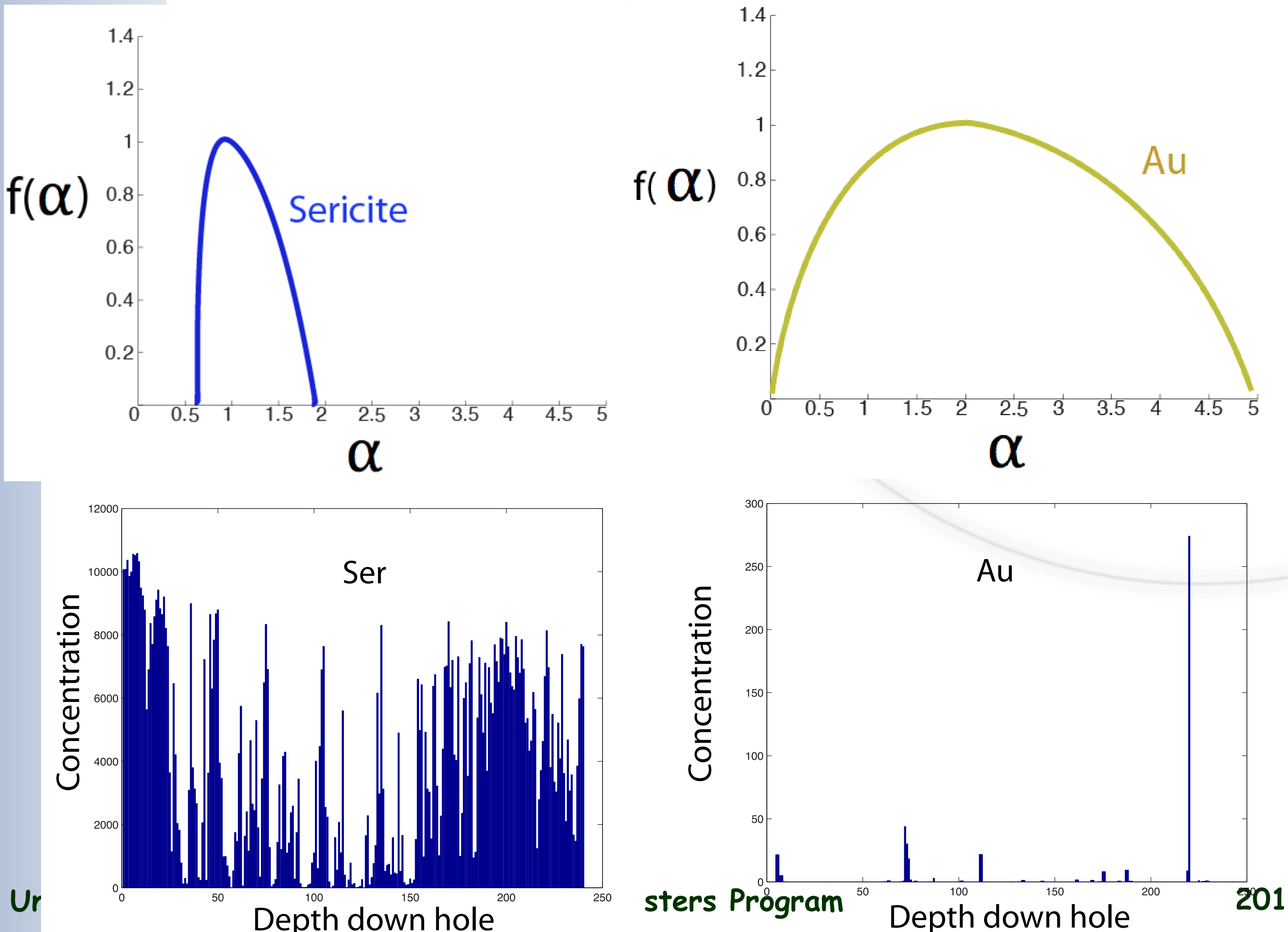
小波变换



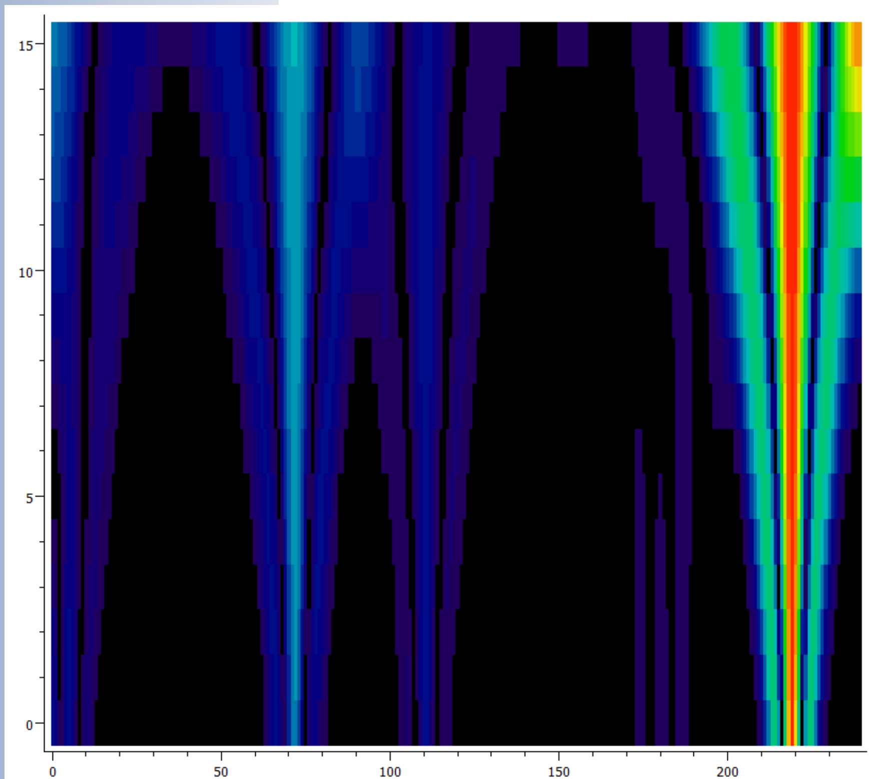
$f(\alpha)$: 局部分形维数



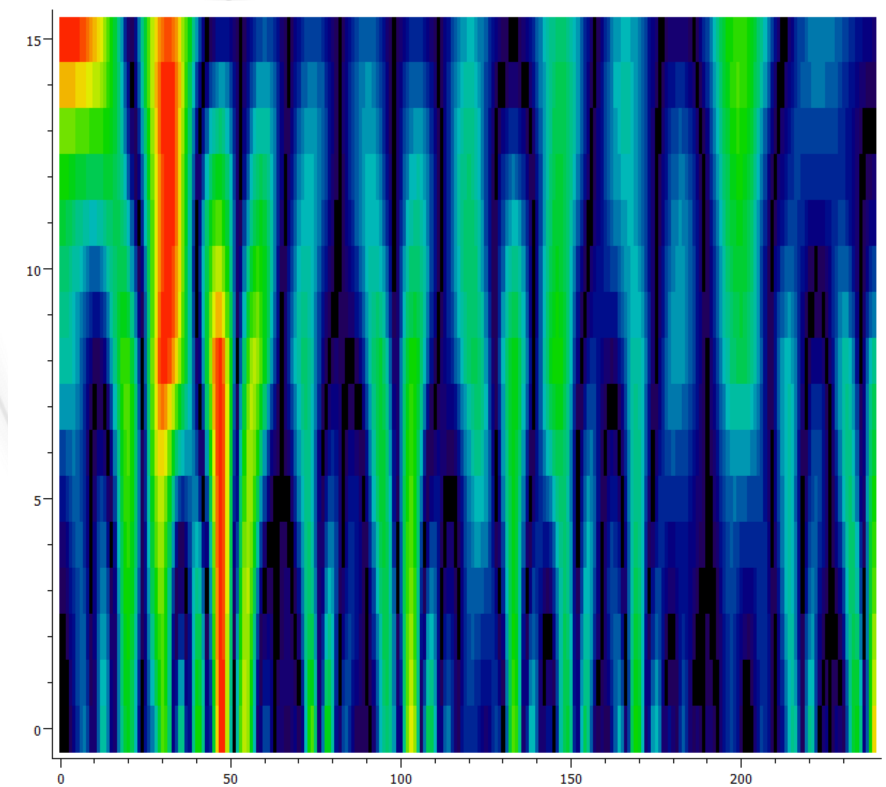
解释多重分形特征的变化……



体现在小波尺度图...



15
10
5
0
0
50
100
150
200



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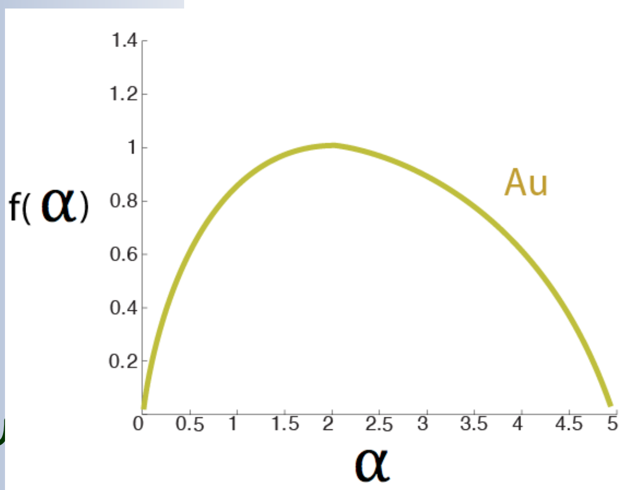
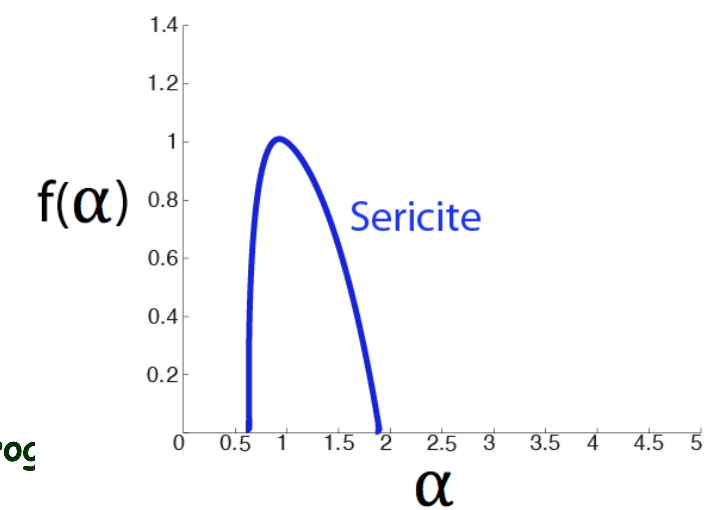
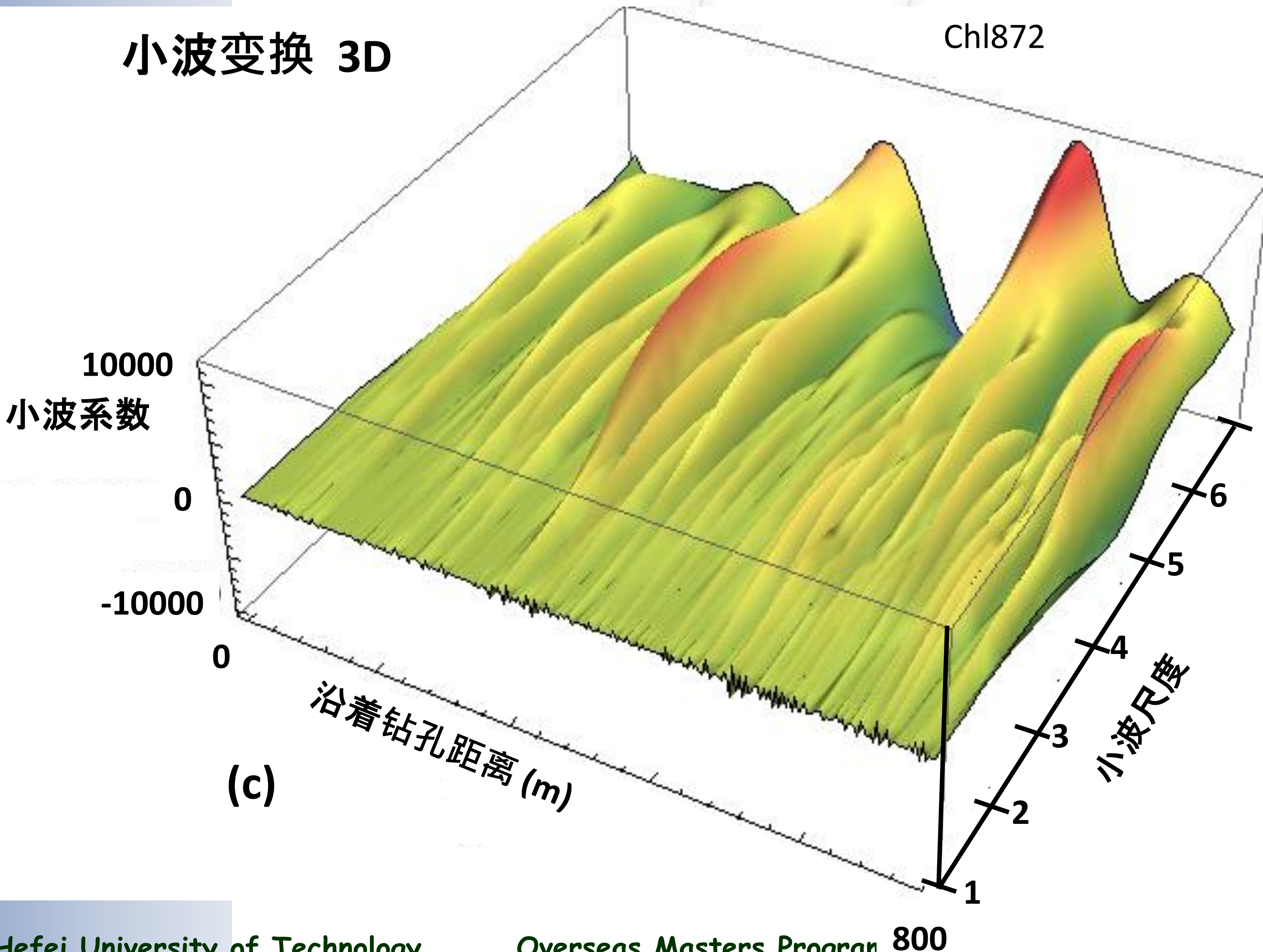


f(α)
Au
α

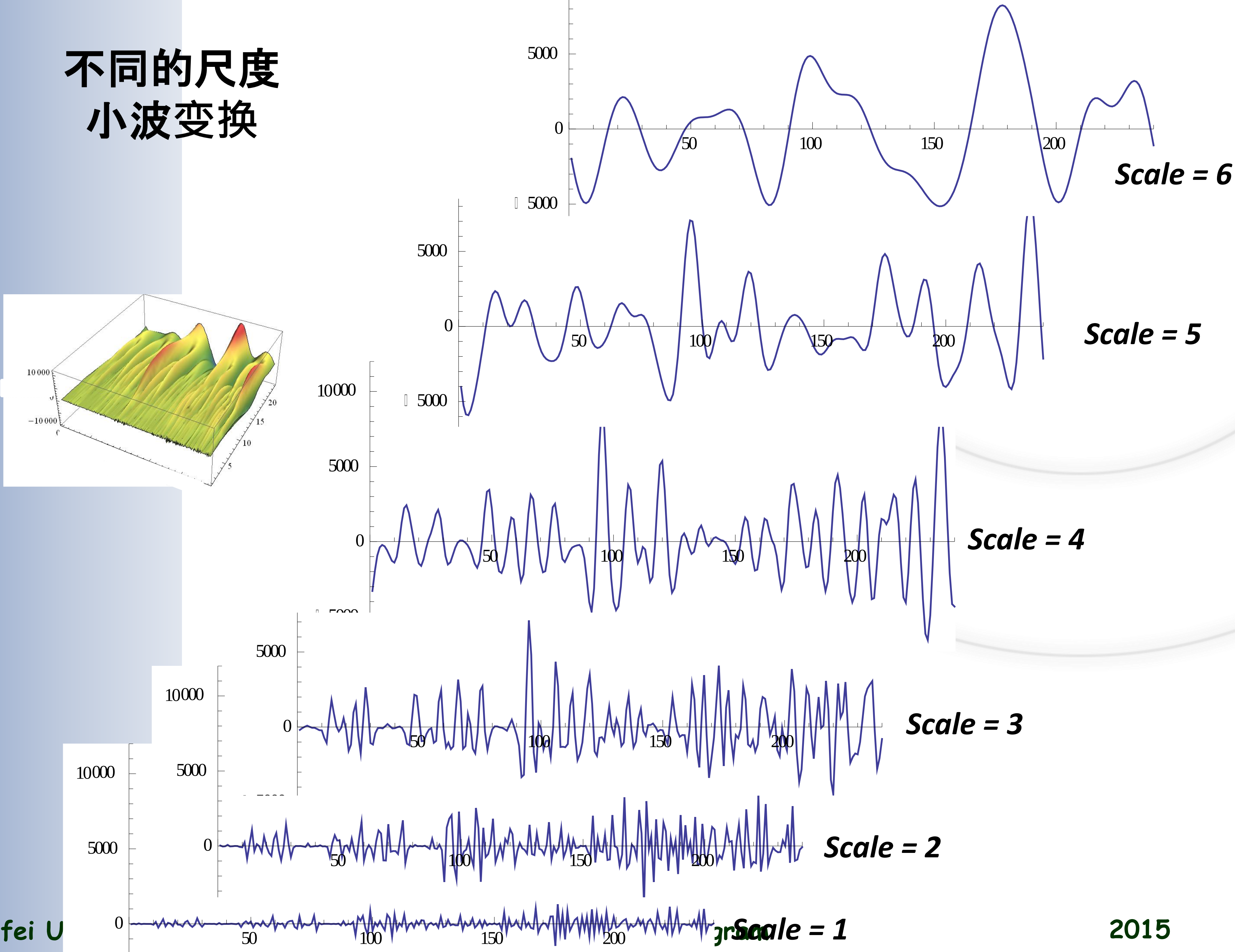


f(α)
Sericite
α

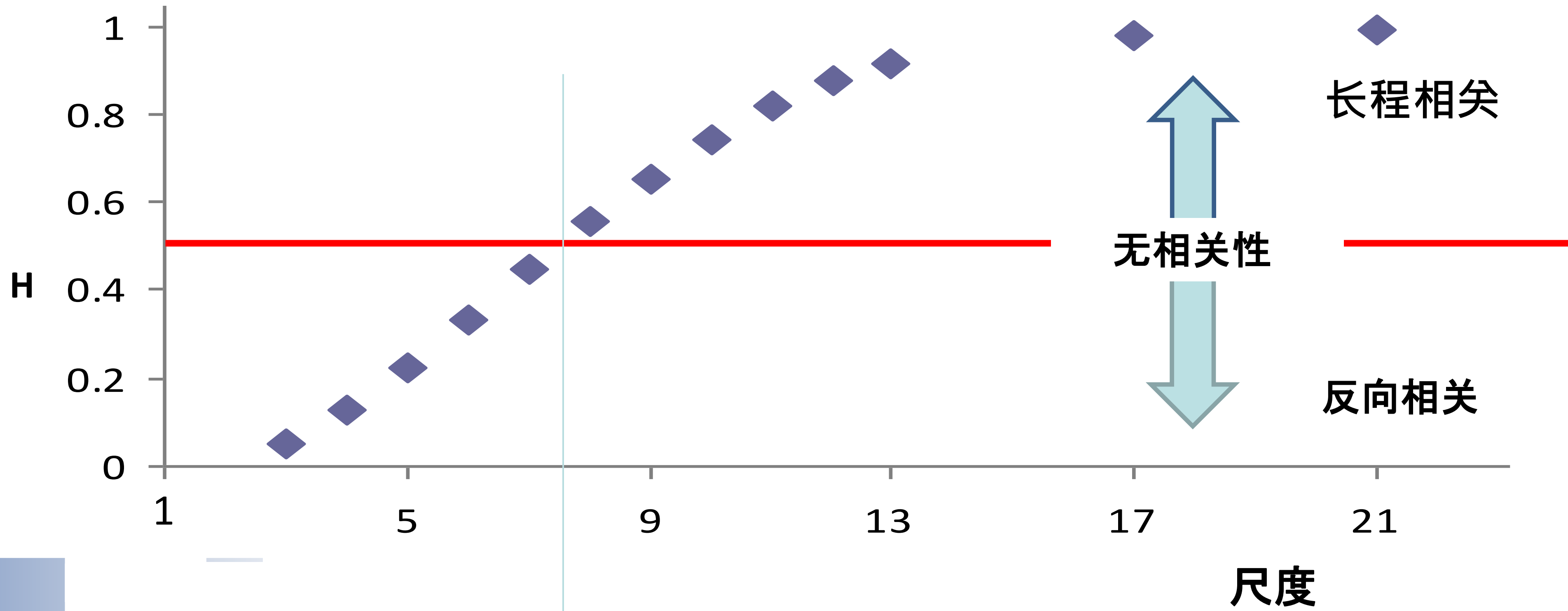
小波变换 3D



不同的尺度小波变换

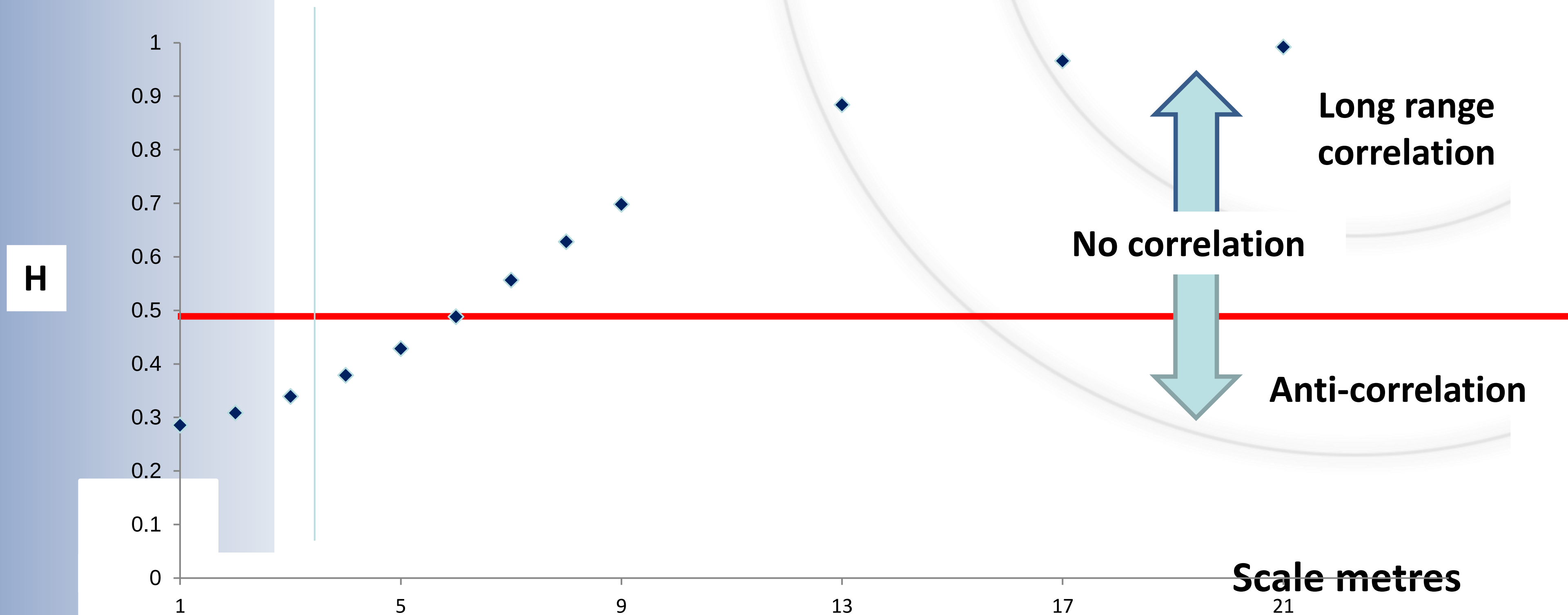


Hurst指数：0.54
Hurst指数：Wiesenhofer_1

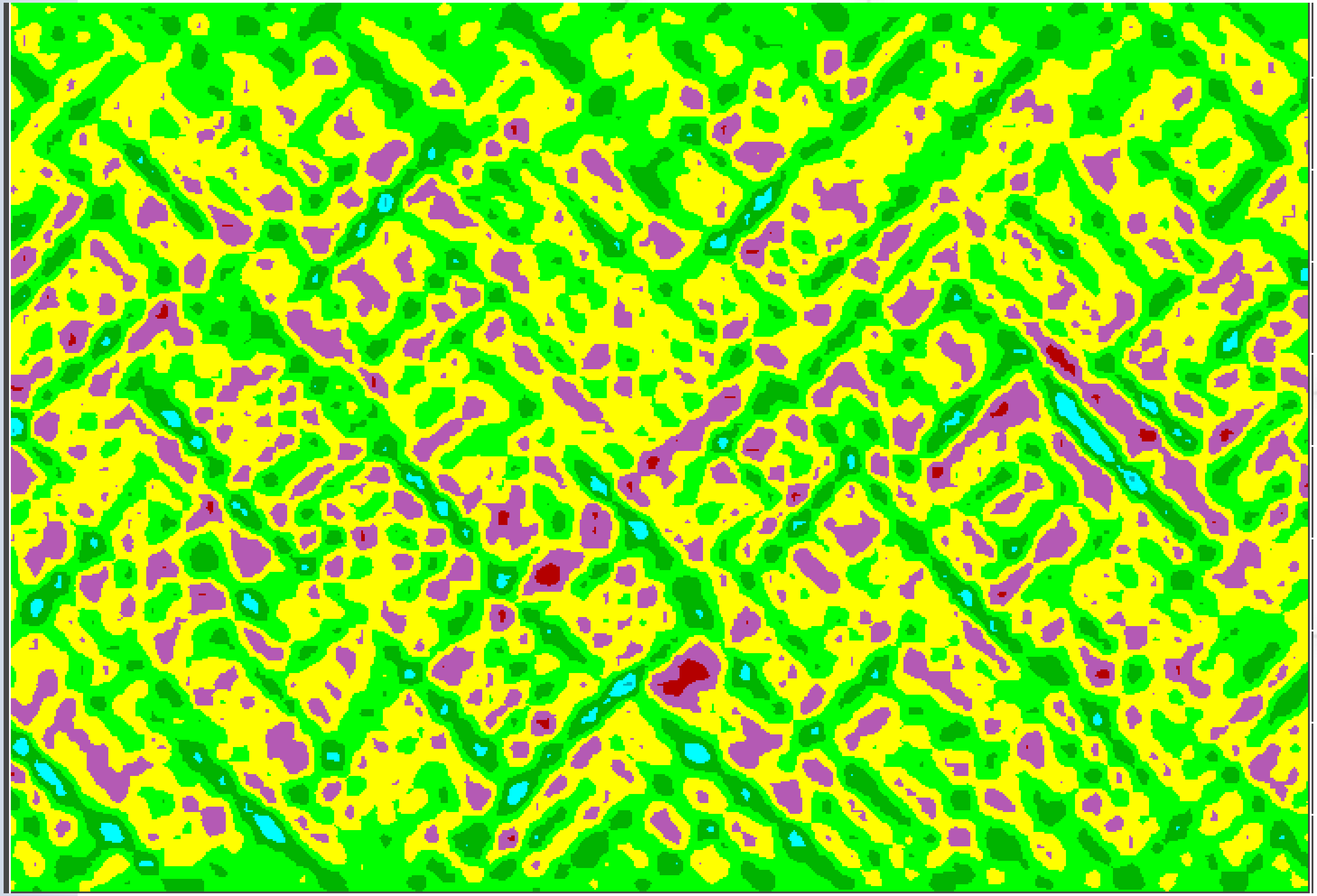


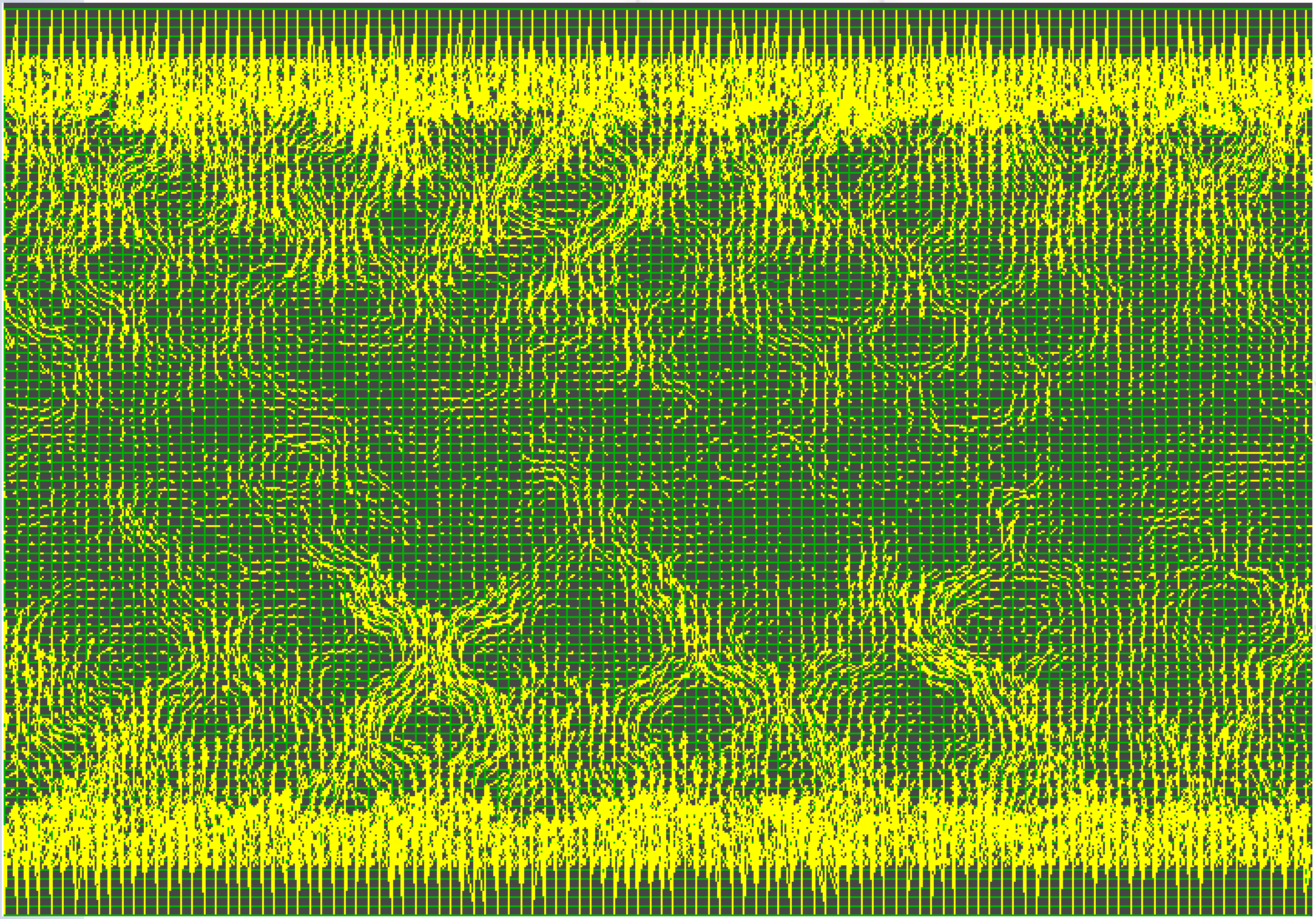
长程相关性在7.5km及以上

Hurst 指数： 0.64
Hurst 指数：
go45_16_1_ssi_51



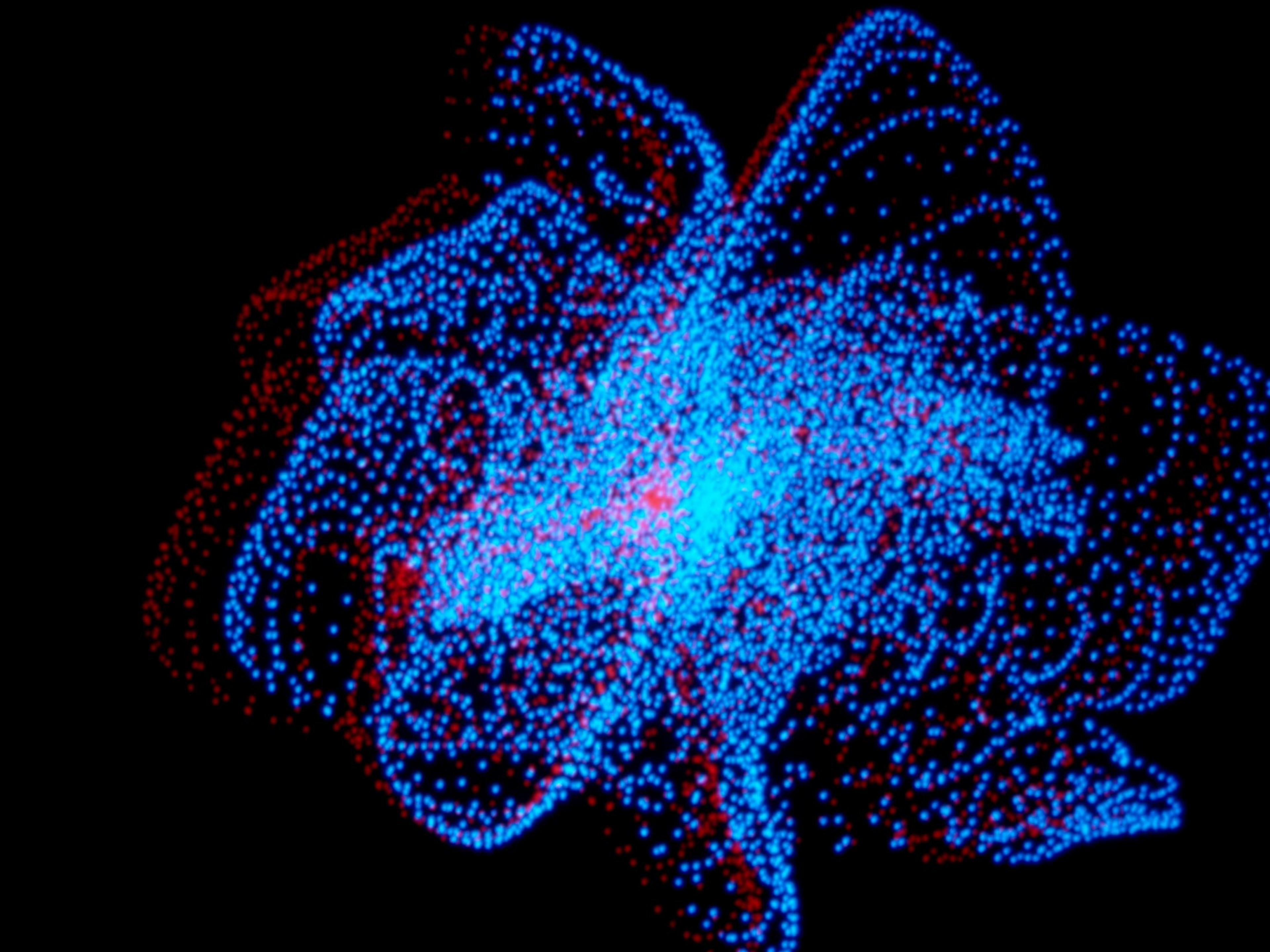
长程相关性在6m及以上





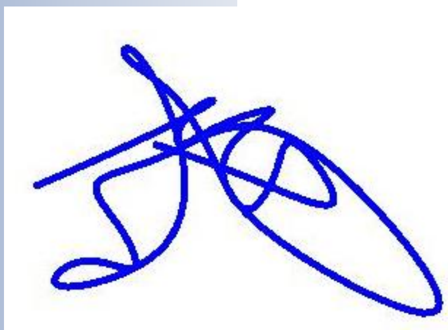
讨论

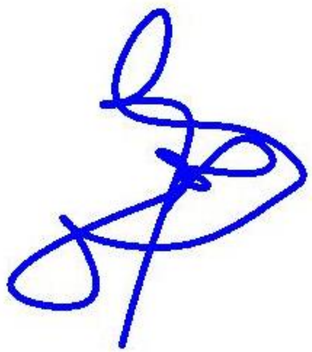
- 为了使系统保持开放的流控制系统，流量路径必须不断调整矿物反应的堵塞和（或）开放渗透率
- 长程关联演化的需要。
- 对比SOC，这些相关规则，必须不断重新审视。

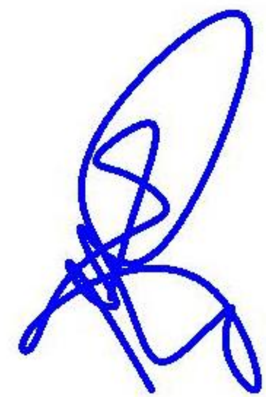


- **因此，** 热液矿物系统显示非线性动力系统的两个特点
- **多重分形几何**
- 长程关联与短程截止

- **由于**这些功能都保留下来，机制必须已经完善，不断重温定义这些几何特征。







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