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

Alison Ord

Centre for Exploration Targeting,
University of Western Australia

Approach

- Hydrothermal mineralising systems are open flow thermodynamic systems held away from thermodynamic equilibrium by the flow of heat, chemical species, fluids, and momentum.

热液成矿系统是一个开放的流动热力学系统，由于热流，化学反应，流体以及动力而远离热力学平衡

- These processes are coupled so that non-linear behaviour is expected.

这些过程是耦合的，所以有望呈现非线性特征

- In this first visit, I shall explore a systems approach to hydrothermal mineralising systems, providing computational examples of interacting processes at various scales.

介绍对热液成矿系统的系统研究方法，以及在不同尺度下的相互作用的计算实例

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

AN OVERVIEW OF MODELLING.

The Simulation of Geological Processes as a Guide to Exploring Scenarios.

地质过程模拟引导探索地质场景

The challenge for geologists is to develop robust models for the formation of high quality resources (large tonnage, high grade, and suitable metallurgical properties) that will impact significantly on global and local exploration strategies.

地质学家致力于开发一种形成高质量资源的稳健模型（储量大，高品位，利于冶炼），这些显著的影响全球和地区的勘探策略

It will be increasingly possible to formulate detailed models at the local, regional and lithospheric scale.

构建局部，区域，岩石圈尺度的精细模型愈发可能

This will drive a shift in perspective away from the traditional deposit-oriented and class-oriented approaches to ore deposit research towards understanding the basic and common processes that are involved in hydrothermal systems.

这将带来从传统的矿床导向，类型导向方法到了解热液系统的基础和普遍过程的转变

Arising from this systems, or holistic approach to ore deposit localisation, our goal is to develop a scenario testing methodology that enables the exploration team to test a range of hypotheses concerning an exploration model with the aim of decreasing the time and cost to discovery of significant mineral deposits.

我们的目标是建立一种基于场景测试的方法体系，能够对关于勘探模型的一系列假设进行验证，以减少发现大型矿床的时间和资金消耗

If one is to develop a quantitative, rather than qualitative approach to the modelling of hydrothermal ore processes then it is clear from the start that a number of difficulties arise from the uncertainties involved in precisely defining or understanding, at the time of mineralisation,

采取定量方法去对热液成矿过程进行模拟，一些难题应运而生，在成矿发生时

- the geometry and dimensions of the ore system,
  矿床系统的几何形状和尺寸
- the physical and chemical characteristics of the system, 矿床系统的物理和化学特征
- the geodynamic history, 地球动力学历史
- the processes responsible for fluid flow and
  流体流动过程
- the processes involved in transport and deposition of the metal species. 金属成分的运移和沉淀过程

We chose to adopt a scenario approach similar to that used by the Royal Dutch Shell Group of Companies over the past 40 years.

我们采用了一套场景方法，类似于

Royal Dutch Shell公司在过去的40年里采用的方法

Scenarios regarding the formation of hydrothermal ore deposits are plausible and challenging stories.

They may not necessarily be correct.

关于热液矿床形成的故事似乎合理且赋有挑战，但可能并不是必然正确

They are meant to offer several alternative stories that describe how a particular ore body formed.

可能具有几种故事去解释某种矿体的形成

Each story must be plausible,

that is, internally consistent with all available data, & also

challenging in that there is a deep dependence on the intuition & geological experience of the people developing the scenarios.

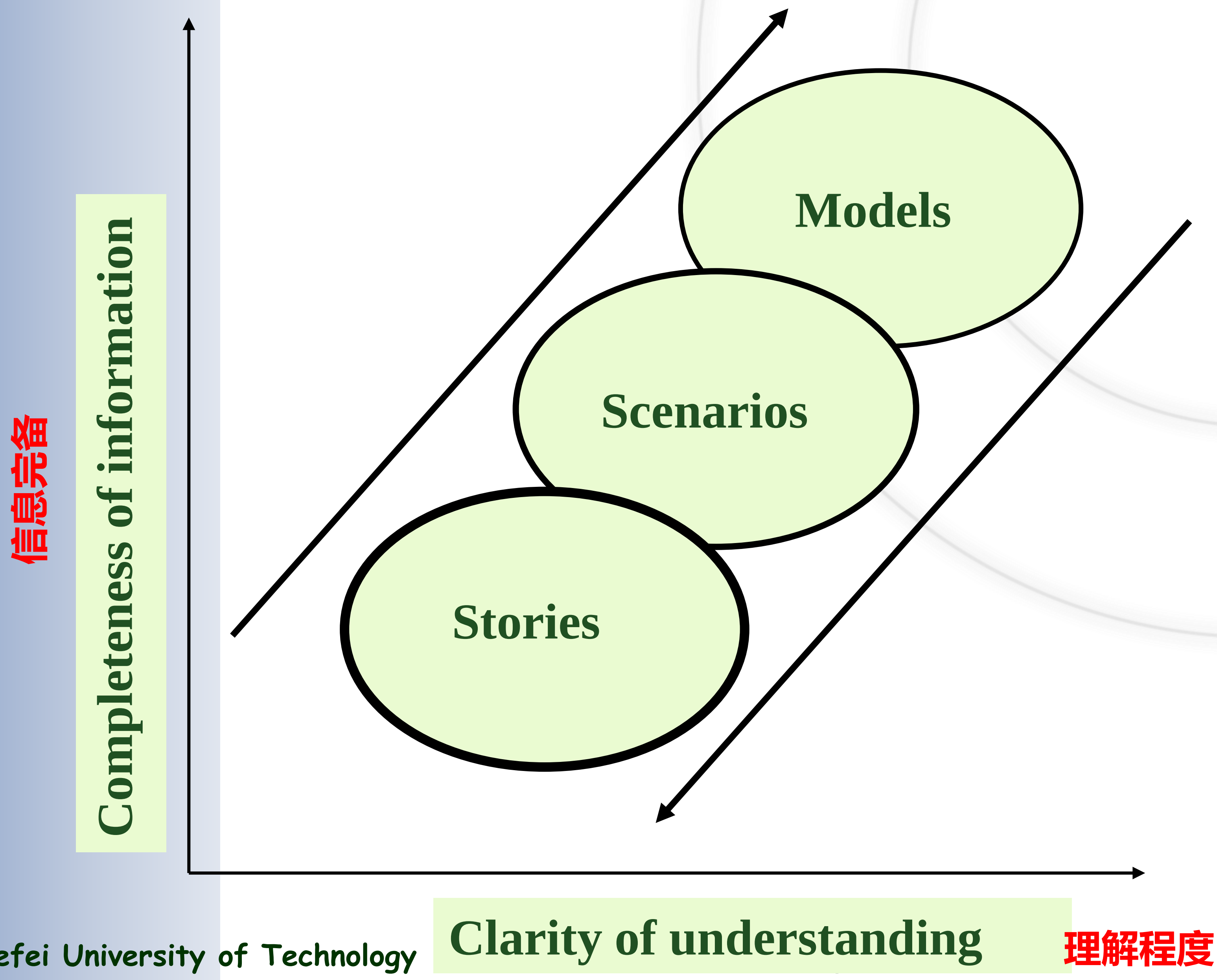
每一种故事都是可能的，也就是说，已知数据内在统一，这也挑战着于人们在构建场

景时具有的直觉的地质经验的深度依赖

The development of these scenarios by a team helps to create a common culture and language through which a rigorous series of exploration models may be developed and explored. They challenge the mental maps held by the team.

构建这样的场景，可以通过构建一系列勘探模型帮助创造一种通用的文化和语言。

Models, Scenarios, & Stories



MOST FEATURES IN MINERALISED ROCKS FORM THROUGH INTERACTIONS BETWEEN FOUR TYPES OF PROCESSES.

矿化岩石中四种过程相互作用的显著特点

1. Deformation. 变形
2. Heat. 热
3. Fluid Flow. 流体流动
4. Chemical Reactions. 化学反应

HENCE OUR APPROACH OVER THE PAST DECADE HAS BEEN TO ASSEMBLE COMPUTER CODES THAT ENABLE THE SIMULATION OF THESE FOUR PROCESSES,

我们的方法集合了相关计算机代码，能够对这四种过程进行模拟。

FIRST
AS SINGLE PROCESSES AND PROGRESSIVELY, AS COMPLETELY COUPLED PROCESSES.

首先是对单一过程进行模拟，之后渐进的对四种过程进行全耦合模拟。

The approach allows industry to have greater confidence in its exploration programs

可以充分相信这些方法并应用于实际勘探项目，

Geodynamic modelling of the Century Zinc mineralising system, Australia

澳大利亚“世纪”锌成矿系统地球动力学模型

Goals

- To identify criteria for another Century
  为寻找其他“世纪”矿床识别控矿要素
- To understand local Zn/Pb/Fe grade distributions
  理解局部 Zn/Pb/Fe 品位的分布
- To understand the zoned nature of the deposit
  理解矿床的分带特性

3 conclusions

- Fluid mixing produces high grade

流体混合形成高品位

- Structural architecture enables mixing

构造结构促进流体混合

- One must integrate data sets at all scales to reveal the controls of architecture on fluid mixing

整合所有尺度的数据，揭露控制流体混合的结构

Geodynamic modelling

- "Soft" conceptual models

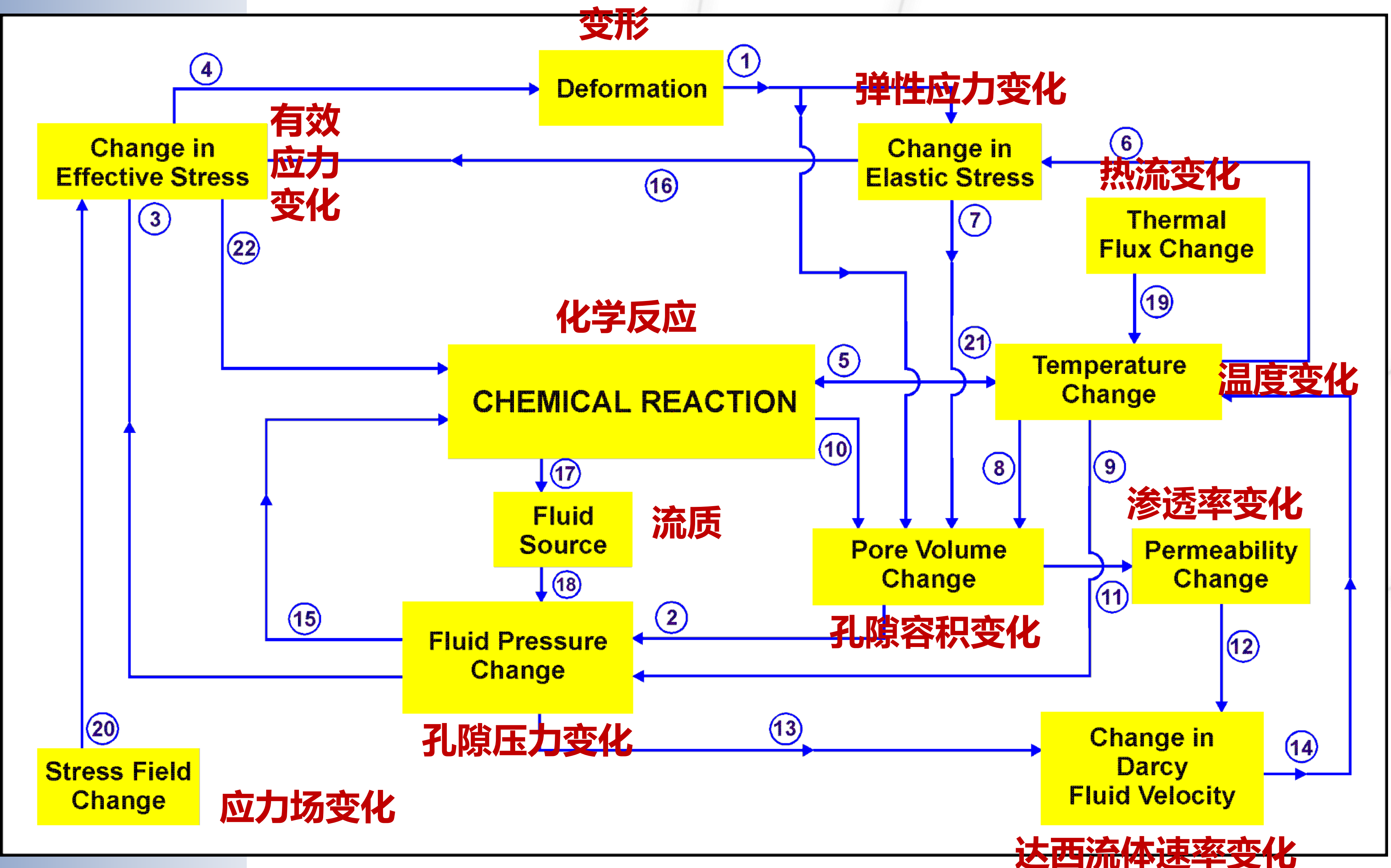
  - based on integration of geological , geochemical and geophysical data at all scales

  基于所有尺度下地质、地球化学及地球物理数据的整合

- "Hard" numerical models

  - provide quantitative evaluation of diverse exploration scenarios based on the "soft models"

  在软模型的基础下，提供对不同勘探场景的定量化评价


变形
Deformation
弹性应力变化
Change in Elastic Stress
有效应力变化
Change in Effective Stress
热流变化
Thermal Flux Change
化学反应
CHEMICAL REACTION
温度变化
Temperature Change
流质
Fluid Source
Pore Volume Change
孔隙容积变化
渗透率变化
Permeability Change
Fluid Pressure Change
孔隙压力变化
Change in Darcy Fluid Velocity
达西流体速率变化
Stress Field Change
应力场变化
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

5 Key Issues

- Architecture & Properties?

  结构 & 属性
- P-T-t histories?

  P-T-t 历史
- Nature of Fluid Reservoirs?

  流体储存的性质
- Mechanisms Responsible for Fluid Flow?

  流体流动机制
- Mechanisms for Metal Transport / Deposition?

  金属运移成矿机制

The Purpose

- To compare relative effects of varying
  - *Geometry of the system*
    系统的几何特征
  - *Initial and evolving material properties*
    初始和演变后的材料属性
  - *Burial and far-field stresses*
    埋深及原场应力
- Enables us to assess critical factors for
  - *Assessing and refining existing models*
    评价和改善已有模型
  - *Developing new testable models*
    构建新的可试验模型

Structural architecture to enable mixing

- What is the scale of the mineralising system?

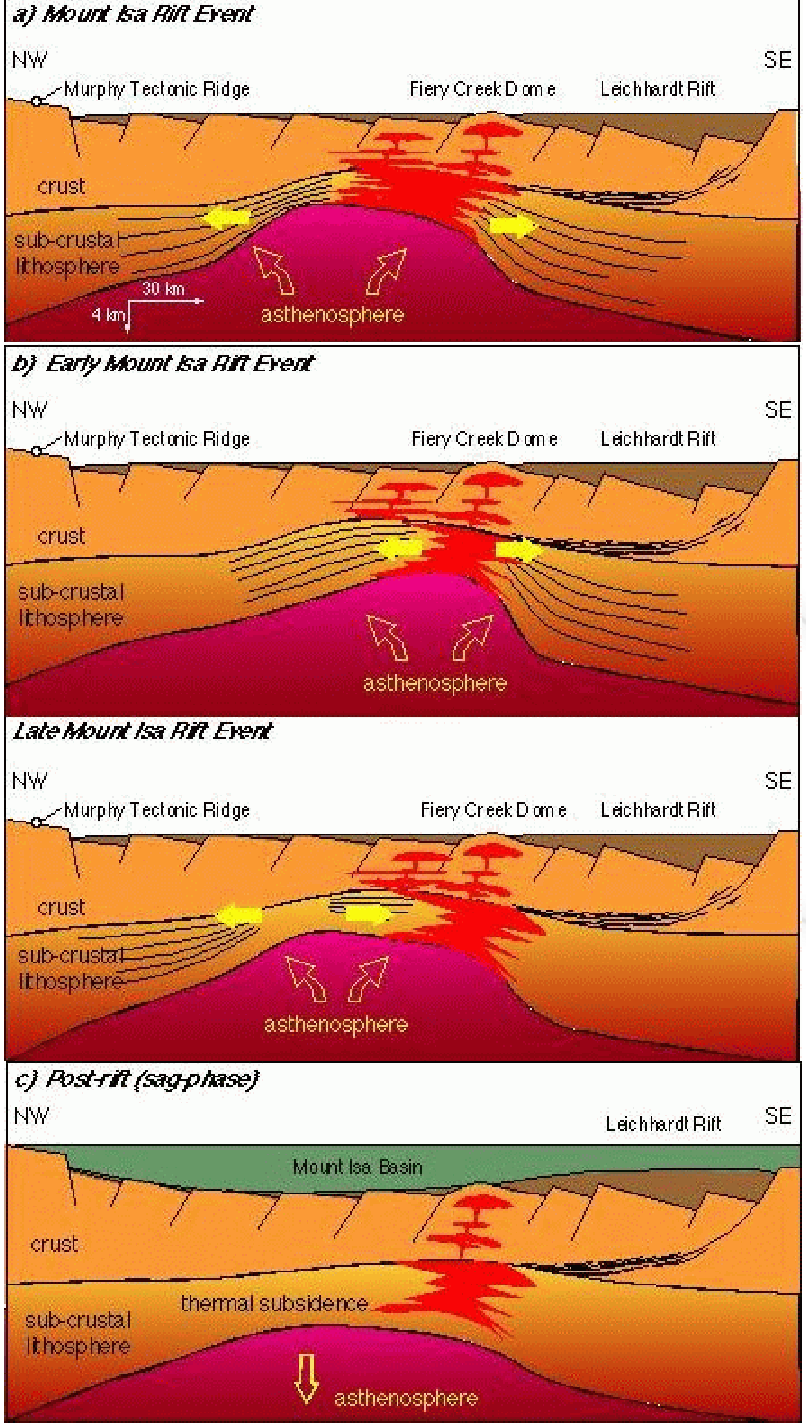
  成矿系统尺度是什么?

- What is the architecture of the system ?

  系统的结构是什么?

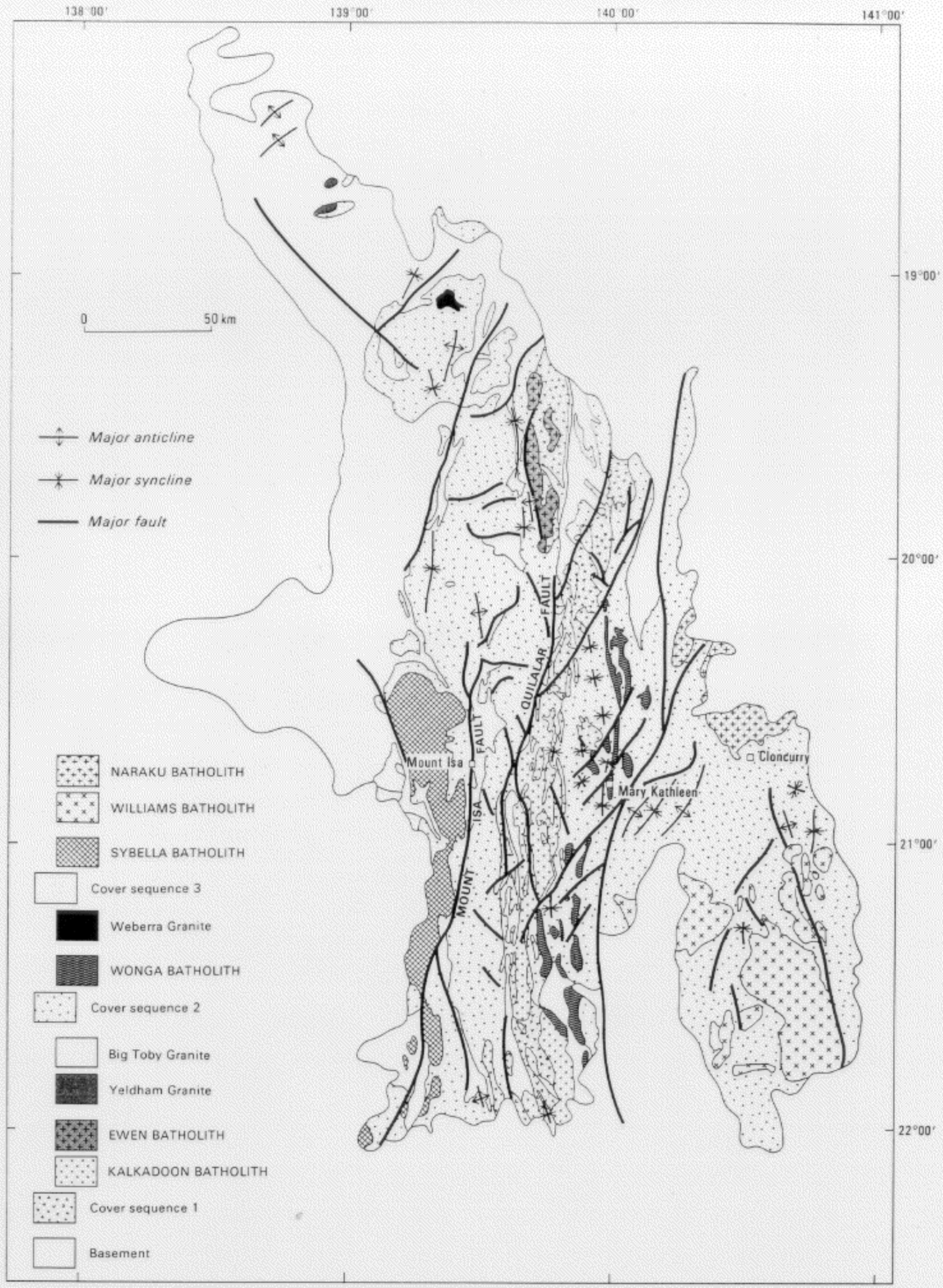
Tectonic scale

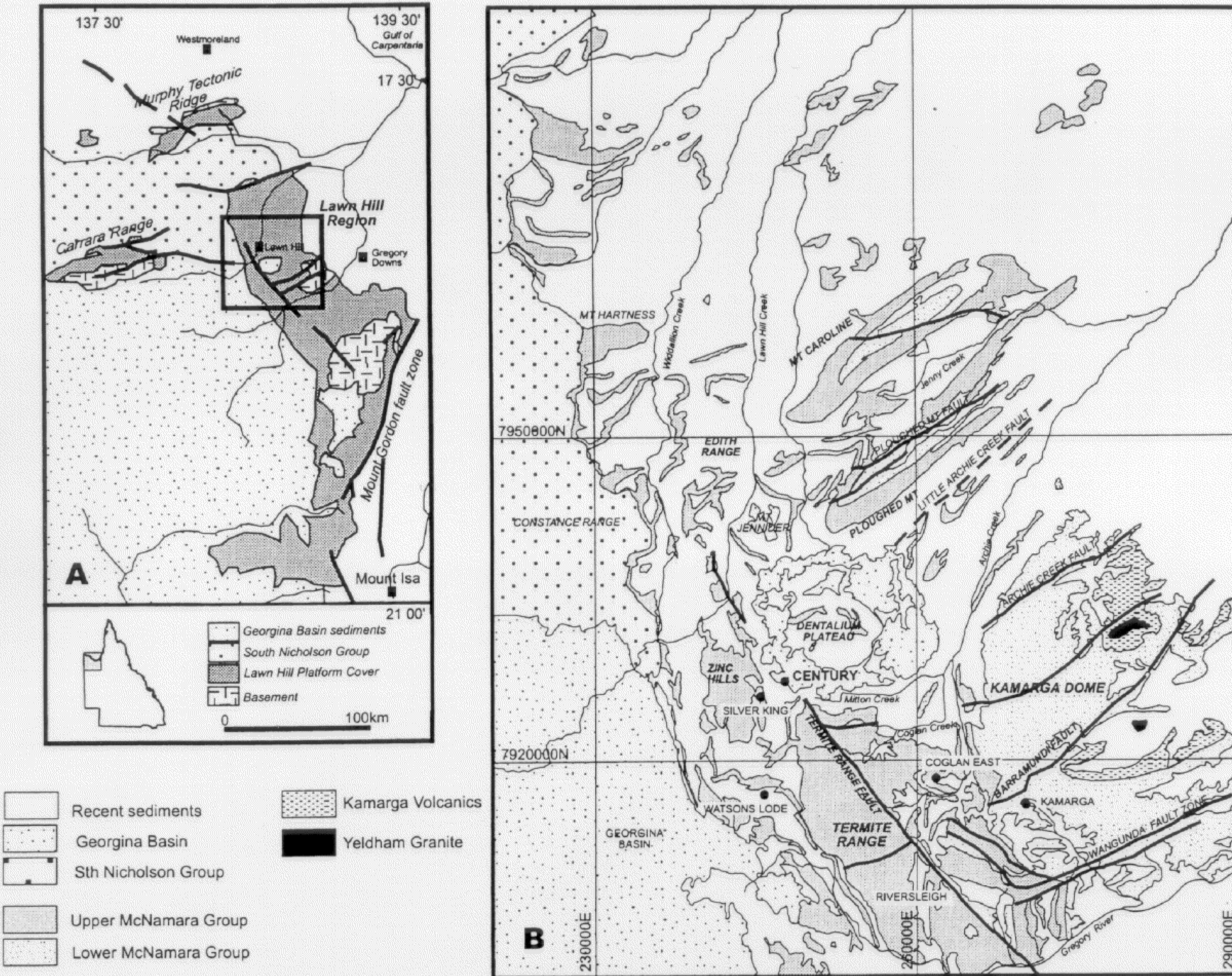
构造尺度



Regional scale

区域尺度





137 30'
139 30'
Gulf of Carpentaria
Westmoreland
17 30'
Murphy Tectonic Ridge
Lawn Hill Region
Carrara Range
Lawn Hill
Gregory Downs
Mount Gordon fault zone
A
Mount Isa
21 00'
Georgina Basin sediments
South Nicholson Group
Lawn Hill Platform Cover
Basement
0
100km
Recent sediments
Georgina Basin
Sth Nicholson Group
Upper McNamara Group
Lower McNamara Group
Kamarga Volcanics
Yeldham Granite
MT HARTNESS
Widdallion Creek
Lawn Hill Creek
MT CAROLINE
Jenny Creek
PLOUGHED MT FAULT
LITTLE ARCHIE CREEK FAULT
PLOUGHED MT
7950800N
EDITH RANGE
CONSTANCE RANGE
MT JENNIFER
Archie Creek
ARCHIE CREEK FAULT
DENTALIUM PLATEAU
ZINC HILLS
CENTURY
KAMARGA DOME
Silver King
Mitton Creek
Coglan Creek
TERMITE RANGE FAULT
BARRAMUNDI FAULT
7920000N
COGLAN EAST
KAMARGA
WATSONS LODE
TERMITE RANGE
WANGUNDA FAULT ZONE
GEORGINA BASIN
RIVERSLEIGH
Gregory River
B
230000E
260000E
290000E

Scale & Architecture

区域&结构

Synthesis by industry colleague supplied

- ***estimates for thickness and distribution of stratigraphic units***

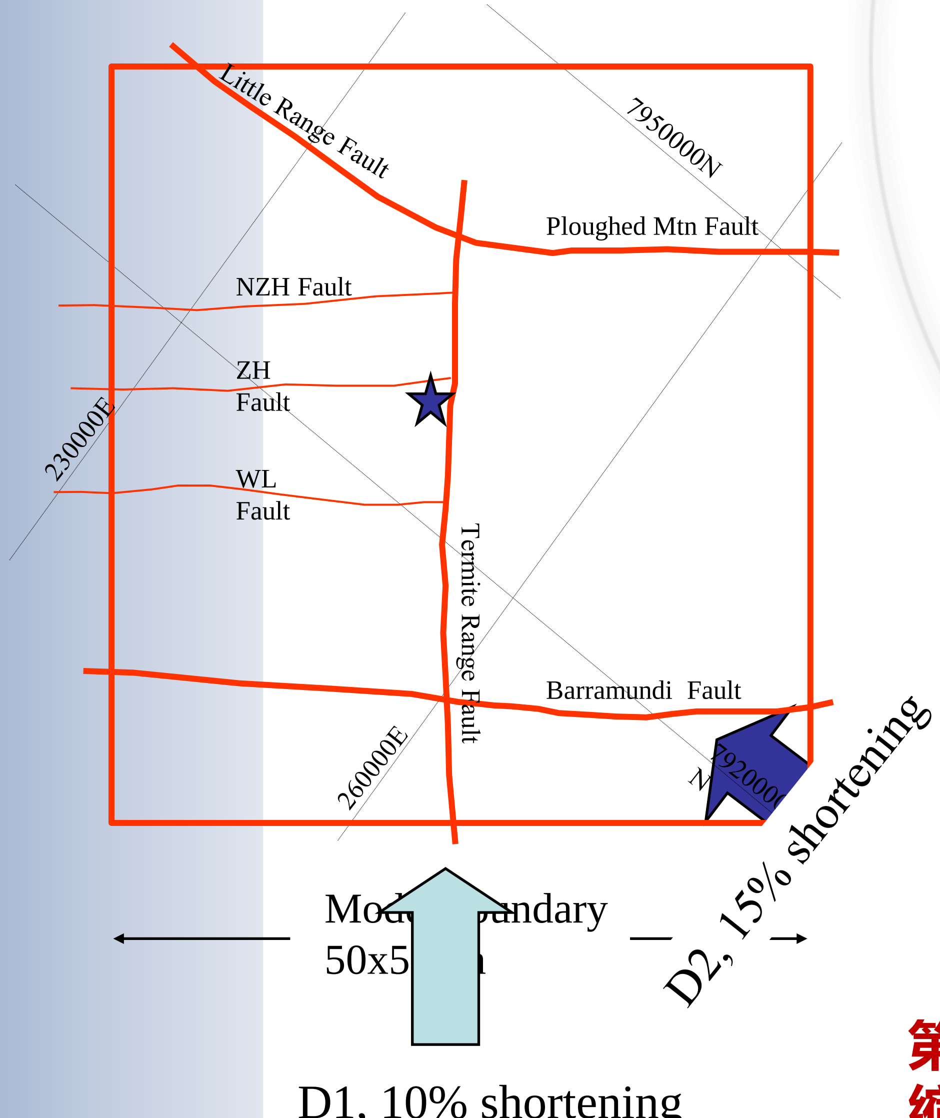
估算地层单元的厚度及分布

- ***suggestions for permeabilities of rock units at time of mineralisation***

提供在成矿期间岩石单元的渗透率

初始结构模型

Initial model architecture



Century Model Parameters

Initial shortening of 10% from SE to NW (I.e. bottom of model boundary to top of model boundary = D1 of Mt Isa Orogeny = main stage of Century mineralisation? Fluid pressure gradient from S of model (~???km hydrostatic head to provide fluid drive?)

第一阶段由SE至NW压缩10%（造山运动是否是世纪矿床成矿的主要阶段?流体压力梯度由南起始（？？km的水头能够提供流体运移）

Deformation (D2) to then shift progressively to SE-NW of model (if possible, otherwise will have to do as two events) to give a further 15% shortening. Maintain hydraulic gradient from S or E.

第二阶段，转变为模型的SE向NW压缩15%，流体压力梯度从S或者E起始

Graeme Broadbent, 1999

What are the basic elements of the architecture?

结构的基础要素是什么?

- Horizontal seals defined by impermeable shales.

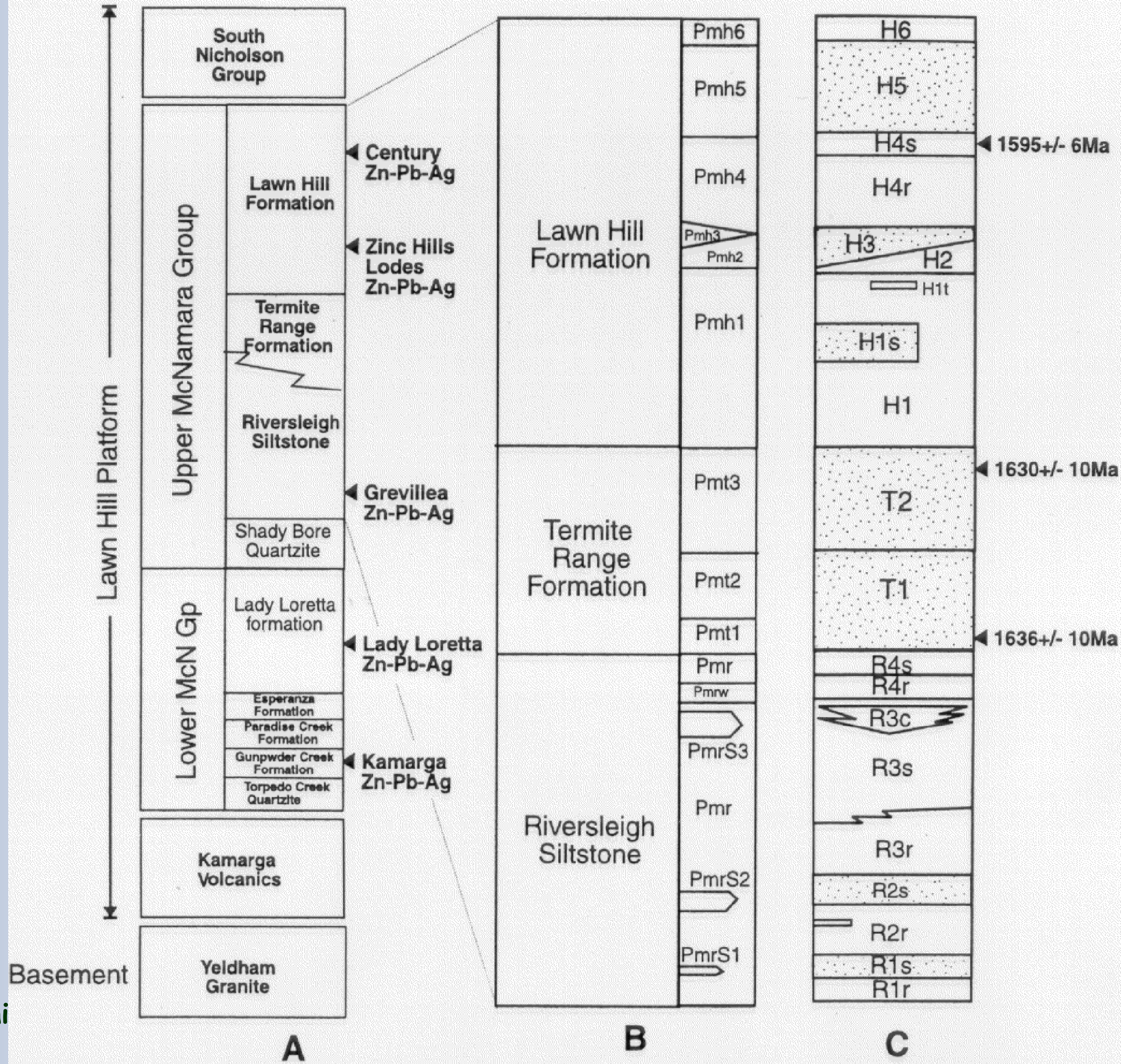
  不透水页岩实现水平封闭

- Faults such as the Termite Range Fault provide a conduit for fluids.

  断裂提供流体通道

- Permeable horizons such as the Termite Range Formation act as the high fluid flow systems.

  透水层可成为流体高流动系统


South Nicholson Group
Lawn Hill Platform
Upper McNamara Group
Lawn Hill Formation
Termite Range Formation
Riversleigh Siltstone
Shady Bore Quartzite
Lower McN Gp
Lady Loretta formation
Esperanza Formation
Paradise Creek Formation
Gunpwder Creek Formation
Torpedo Creek Quartzite
Kamarga Volcanics
Basement
Yeldham Granite
Century Zn-Pb-Ag
Zinc Hills Lodes Zn-Pb-Ag
Grevillea Zn-Pb-Ag
Lady Loretta Zn-Pb-Ag
Kamarga Zn-Pb-Ag
A
Lawn Hill Formation
Termite Range Formation
Riversleigh Siltstone
Pmh6
Pmh5
Pmh4
Pmh3
Pmh2
Pmh1
Pmt3
Pmt2
Pmt1
Pmr
Pmrw
PmrS3
Pmr
PmrS2
PmrS1
B
H6
H5
H4s
H4r
H3
H2
H1t
H1s
H1
T2
T1
R4s
R4r
R3c
R3s
R3r
R2s
R2r
R1s
R1r
1595+/- 6Ma
1630+/- 10Ma
1636+/- 10Ma
C

3D Century models

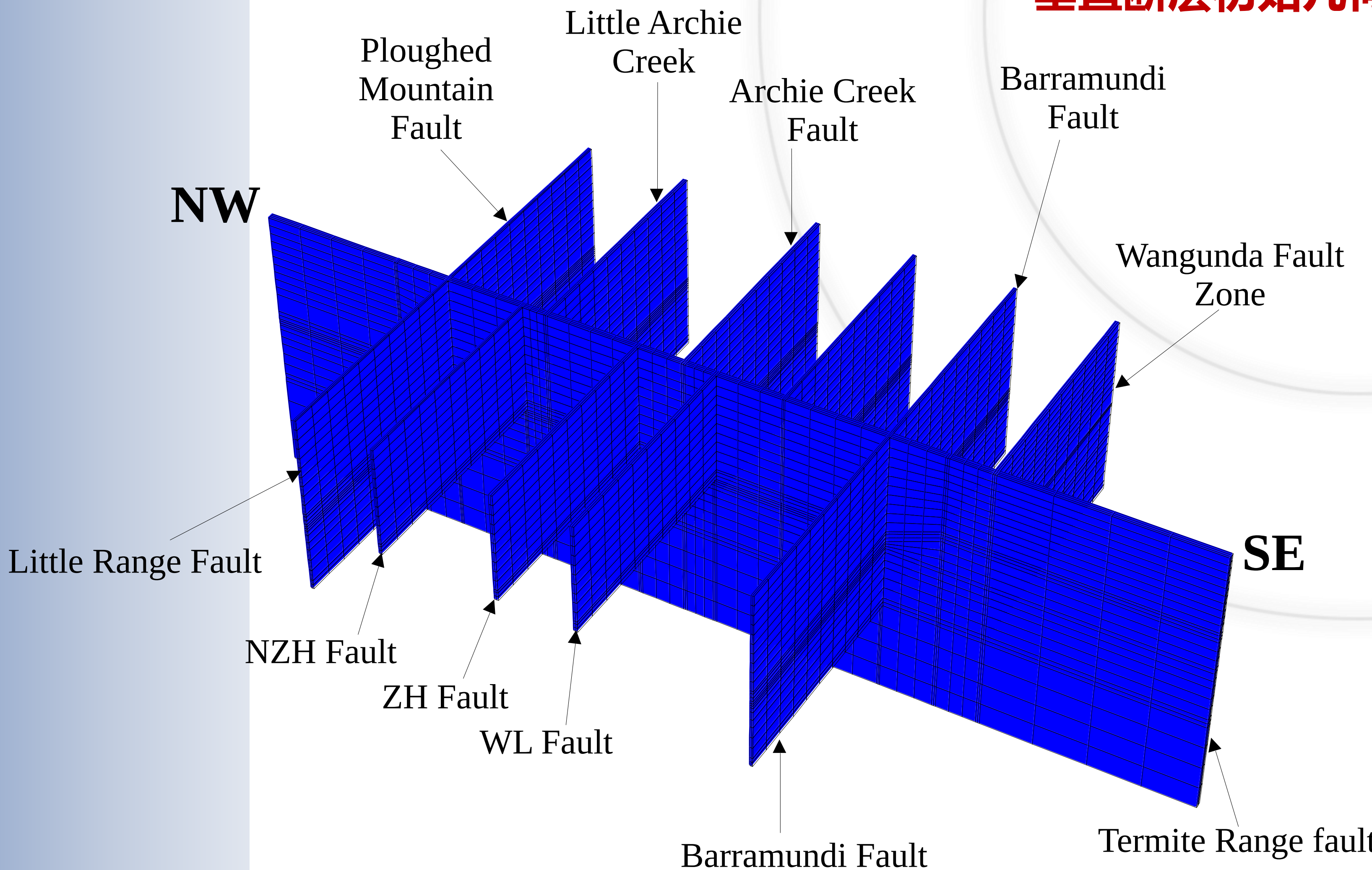
1. Variations in initial model geometry — 验证初始模型
   - *NE-trending faults are vertical* — 走向NE断层直立
   - *NE-trending faults inclined to SE* — 走向NE断层倾向SE

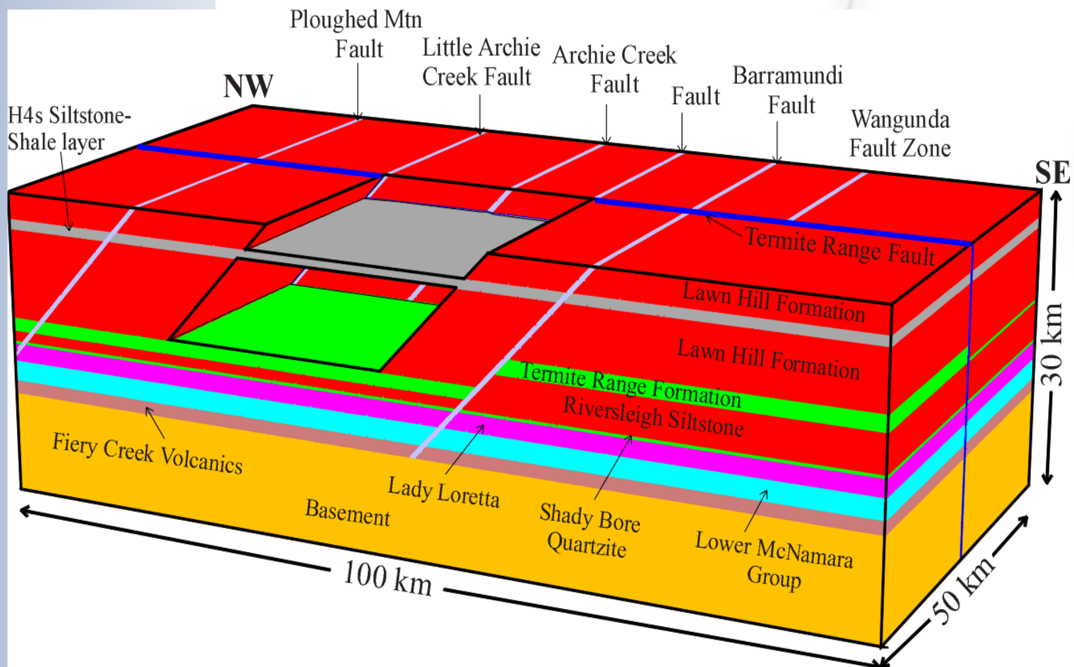
2. Variations in material properties — 验证材料属性
   - *Weak, intermediate and strong faults* — 断裂强度弱，中等，强
   - *Weak and competent shale layers* — 页岩层能干性

3. Variations in far-field stresses — 验证远端应力
   - *Maximum compression during D1 – NW-SE* — 最大挤压 D1 NW-SE
   - *Maximum compression during D2 – E-W* — 最大挤压 D2 E-W

Initial geometry of vertical faults

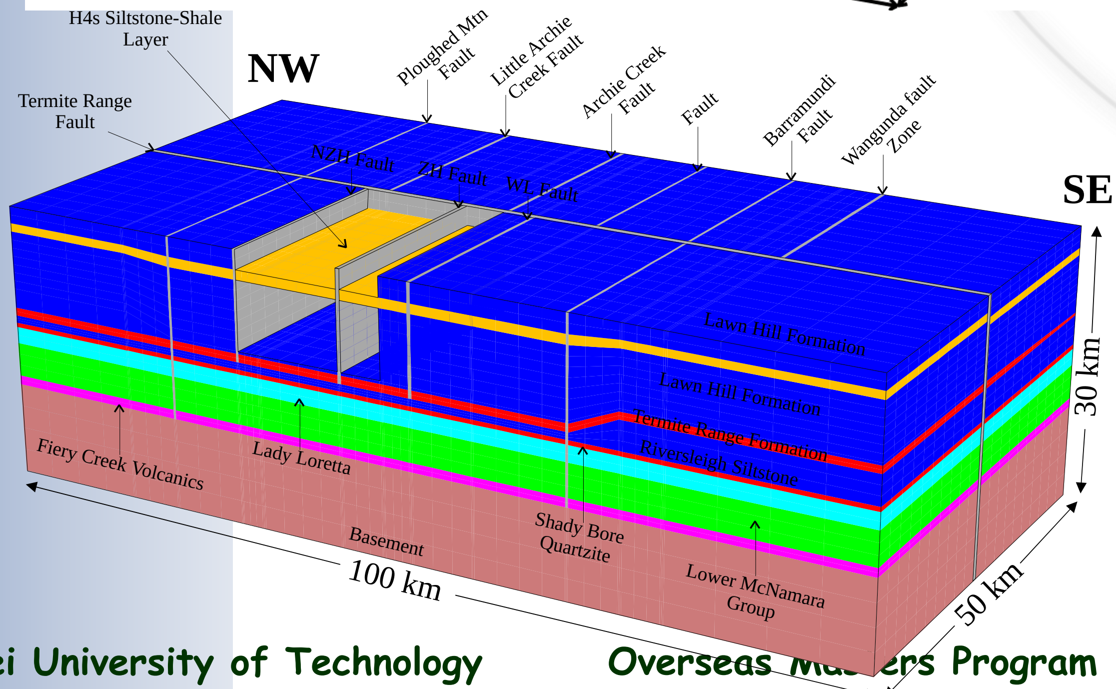
垂直断层初始几何模型





世纪矿床几何模型
&倾斜断层

Century model geometry with inclined faults



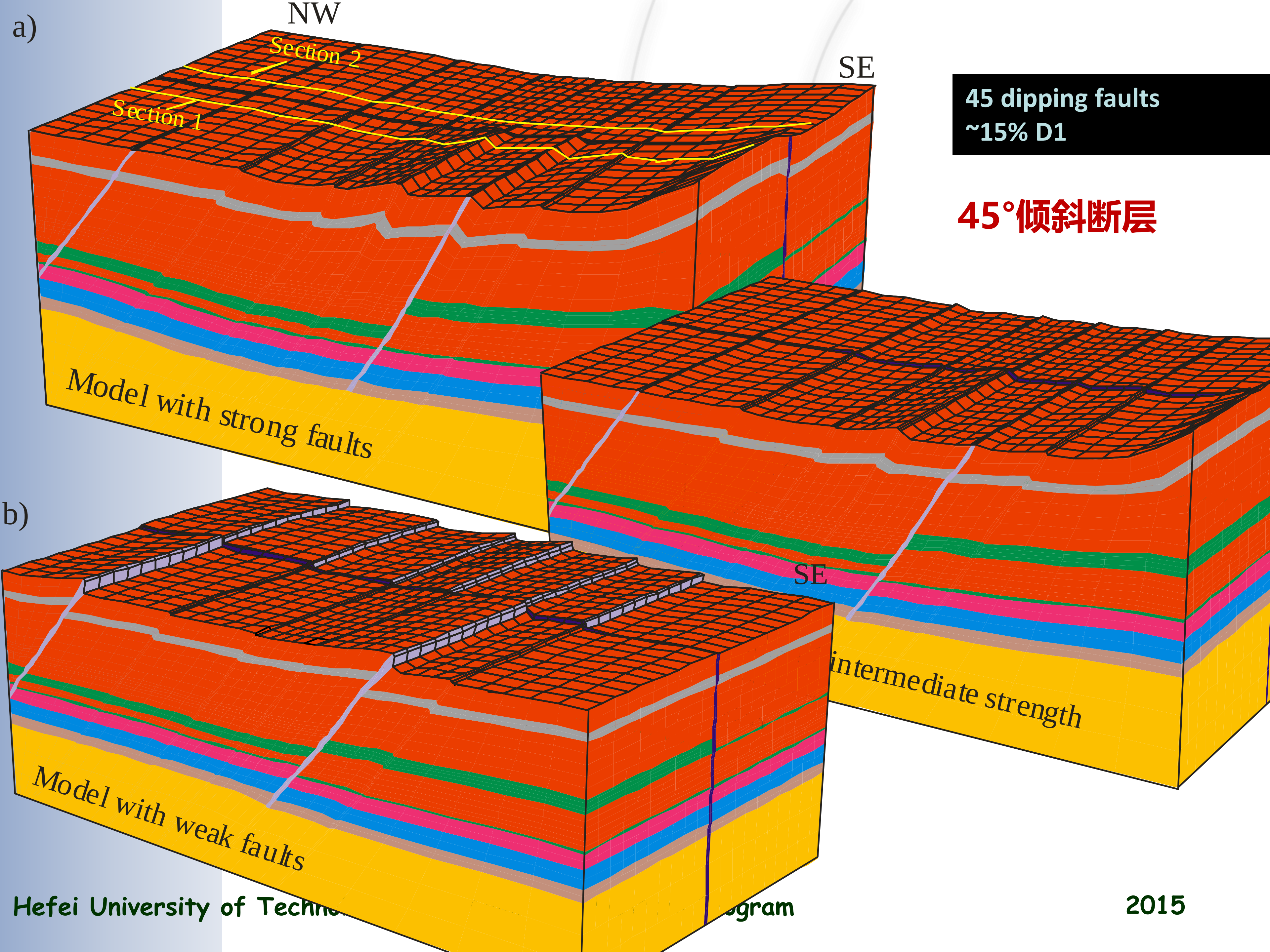
世纪矿床几何模型
&垂直断层

Century model geometry with vertical faults

Century Zn-Pb system – *inclined fault geometry*

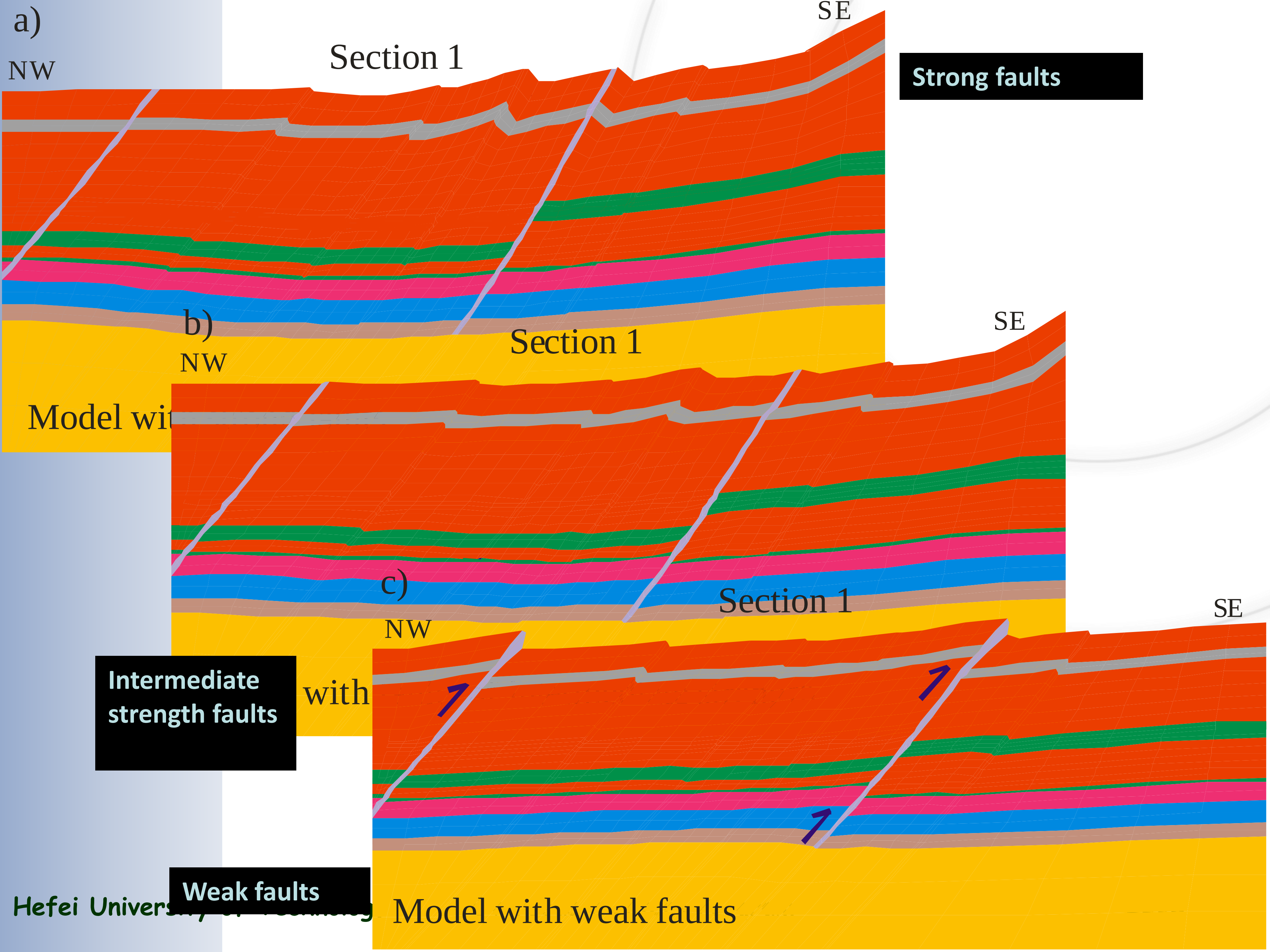
世纪Zn-Pb矿床-倾斜断层

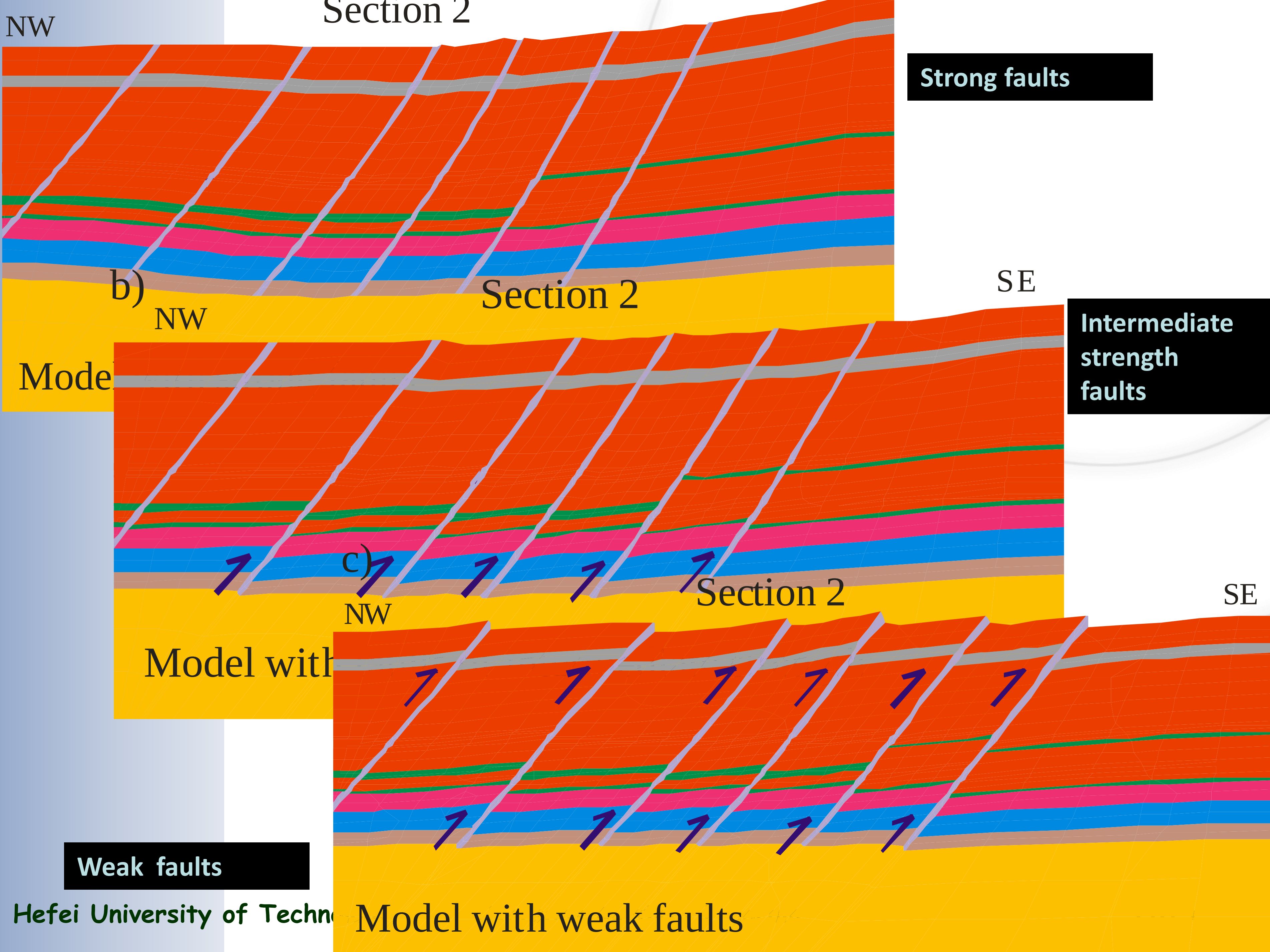
- Faults relatively strong 断裂强度较强
  - *Folding dominates* 褶皱主导
- Faults relatively weak 断裂强度较弱
  - *Faulting dominates* 断裂主导
- Faults of intermediate strength 断裂强度中等
  - *Combined folding and faulting* 断裂褶皱共同控制



45 dipping faults
~15% D1

45°倾斜断层


a)
NW
Section 1
SE
Strong faults
b)
NW
Section 1
SE
Intermediate strength faults
c)
NW
Section 1
SE
Weak faults
Model with weak faults


Section 2
NW
Strong faults
Mode
b)
Section 2
NW
SE
Intermediate strength faults
Model with
c)
Section 2
NW
SE
Weak faults
Model with weak faults

3. What drives fluid flow?

什么驱动流体流动?

Topography generated by the Isan Orogeny drives basinal fluid flow.

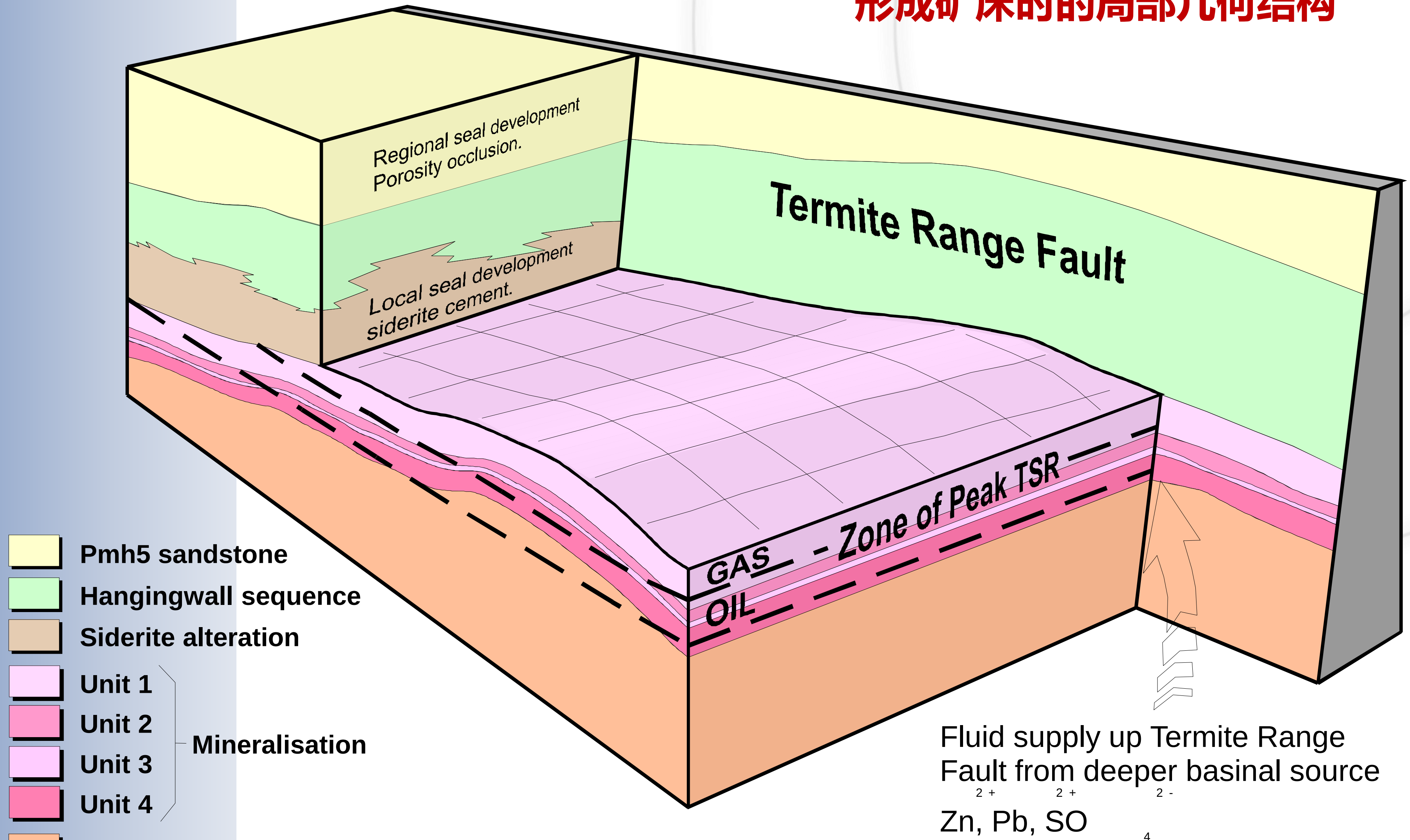
Isan 造山运动形成的地形起伏驱动盆地流体流动

Hydrofracture of H_2S, CH_4, CO_2 from carbon rich shales.

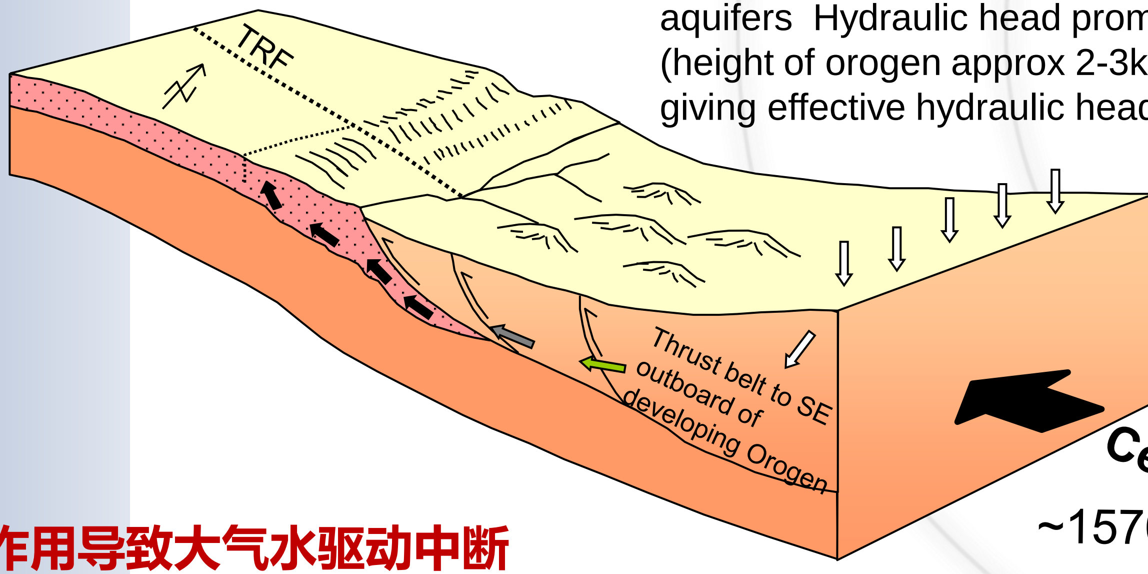
富C页岩中H_2S, CH_4, CO_2水力压裂

Local geometry during formation of the Century deposit.

形成矿床时的局部几何结构



Century fluid system supplied by "squeegying" of deep basin aquifers Hydraulic head promoted by meteoric water input (height of orogen approx 2-3km above Century position, giving effective hydraulic head of ~500m-1km?)

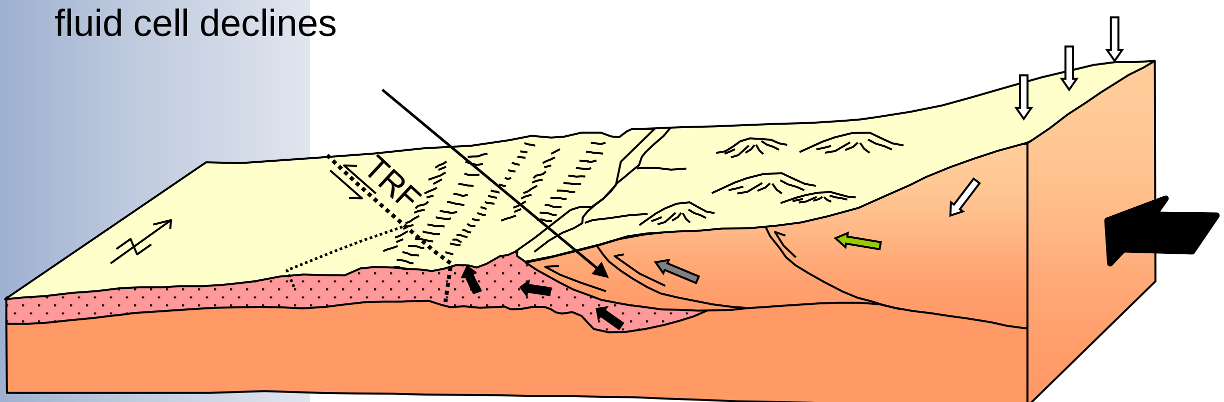


流体系统受到盆地深部含水层的补充，水头促进大气水的输入

Century "D1" SE-NW
~1570Ma

构造作用导致大气水驱动中断

Meteoric water drive interrupted by structuring, Century fluid cell declines

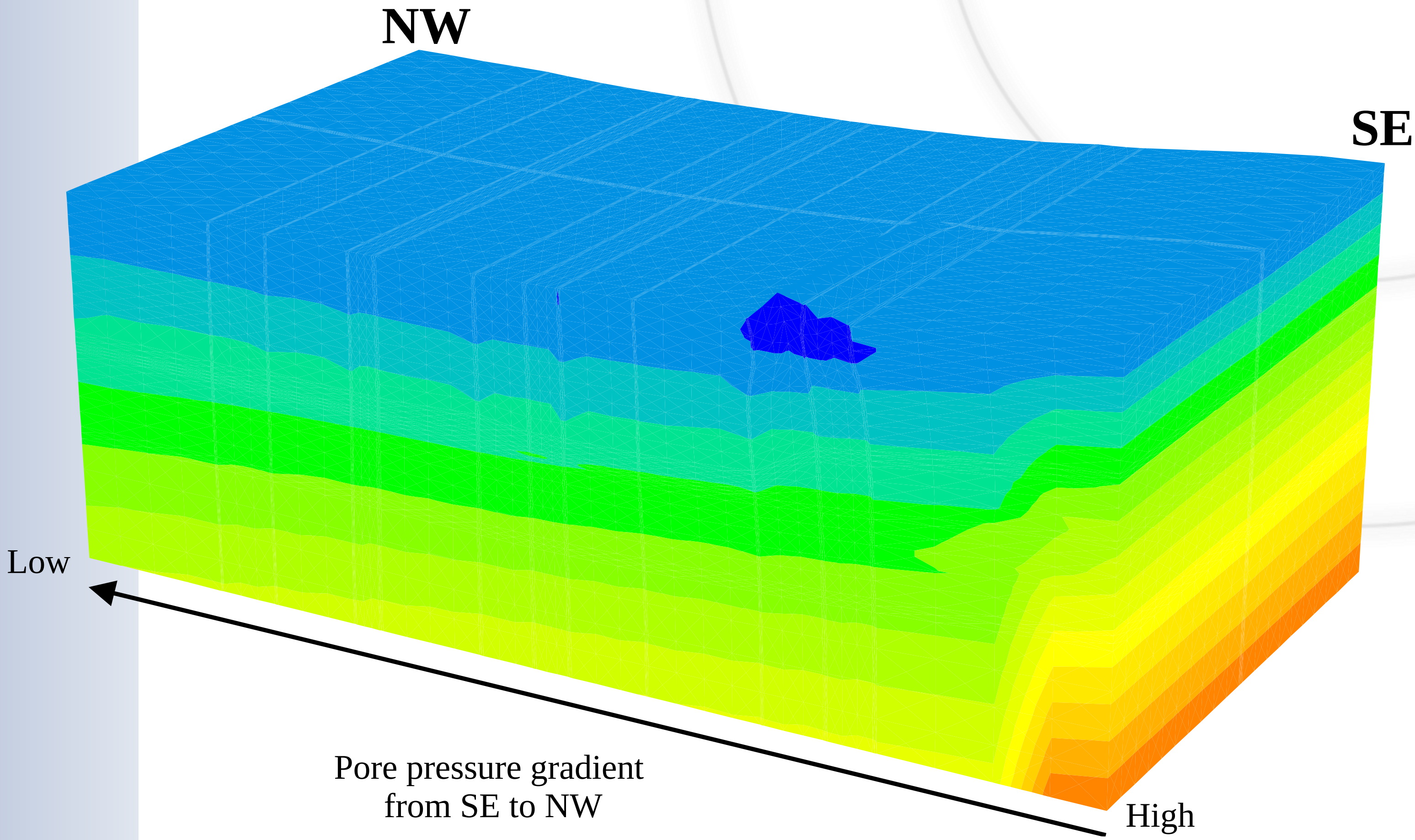


Century "D2" E-W
~1550Ma

Inspired by Oliver (1986) and Garven & Freeze (1984)

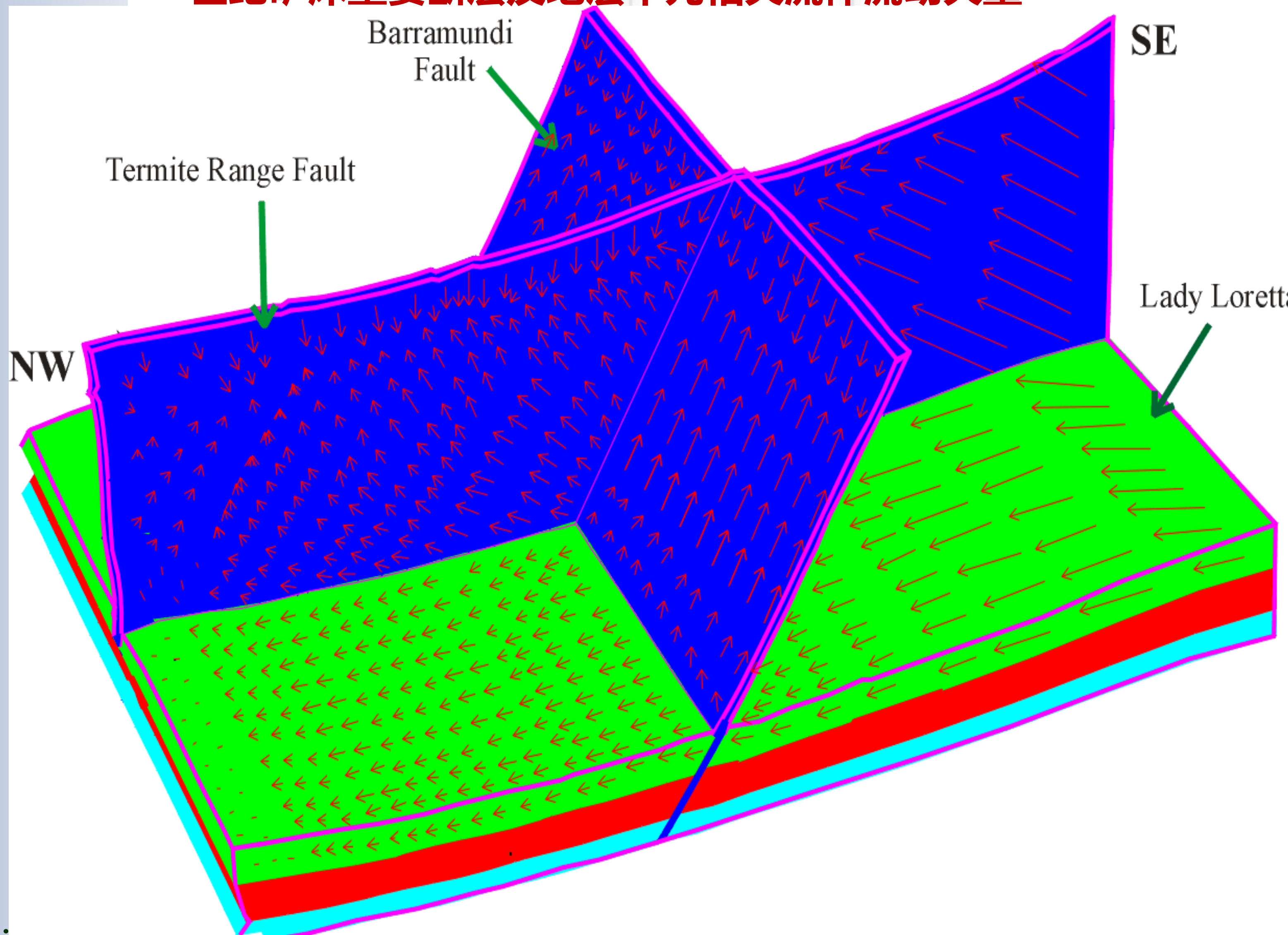
Decrease in pore pressure gradient from the SE to the NW. This enhances lateral fluid flow through the model from SE to the NW.

从SE到NW，孔隙压力梯度逐渐减小。说明流体流动方向为SE-NW。



Fluid flow vectors associated with critical faults and stratigraphic units in the Century system

世纪矿床重要断层及地层单元相关流体流动矢量

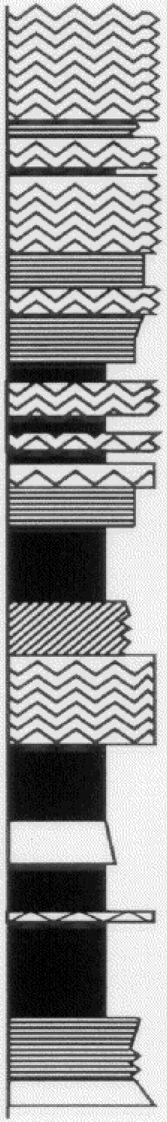


What drives fluid flow?

什么驱动流体流动?

- Hydrofracture of H_2S, CH_4, CO_2 from carbon rich shales.

富C页岩中水力压裂的H_2S, CH_4, CO_2

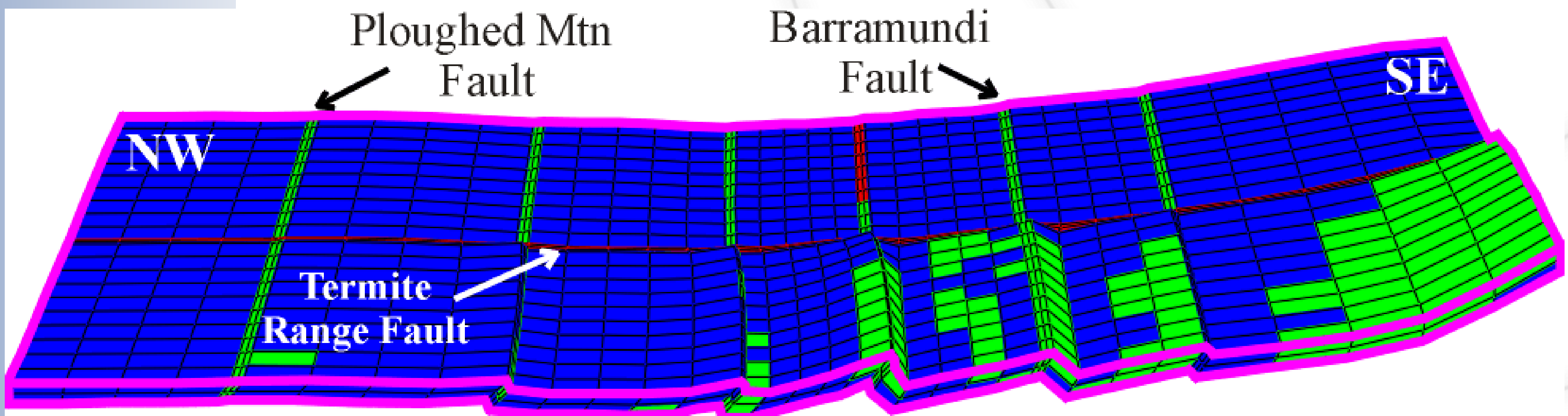


Hanging-wall Sequence	Unit	Sub-Unit
Interbedded styolitic sideritic siltstone & black sulfidic shale	1	1.1 & 1.2
Thin banded sulfidic black shale Zn-Pb-Ag	2	2
Interbanded black shale/sideritic silstone	3	3.1
Stylolitic sideritic siltstone		3.2
Thin banded sulfidic black shale Zn-Pb-Ag	4	4.1
Massive black mudstone		4.2
Thin banded sulfidic black shale Zn		4.3
		4.4
Thin banded sulfidic black shale Zn		4.5
Sulfidic black shale (pyritic) Py-Zn		4.6

Footwall Sequence

Hydrofracture with folding

褶皱与水力压裂

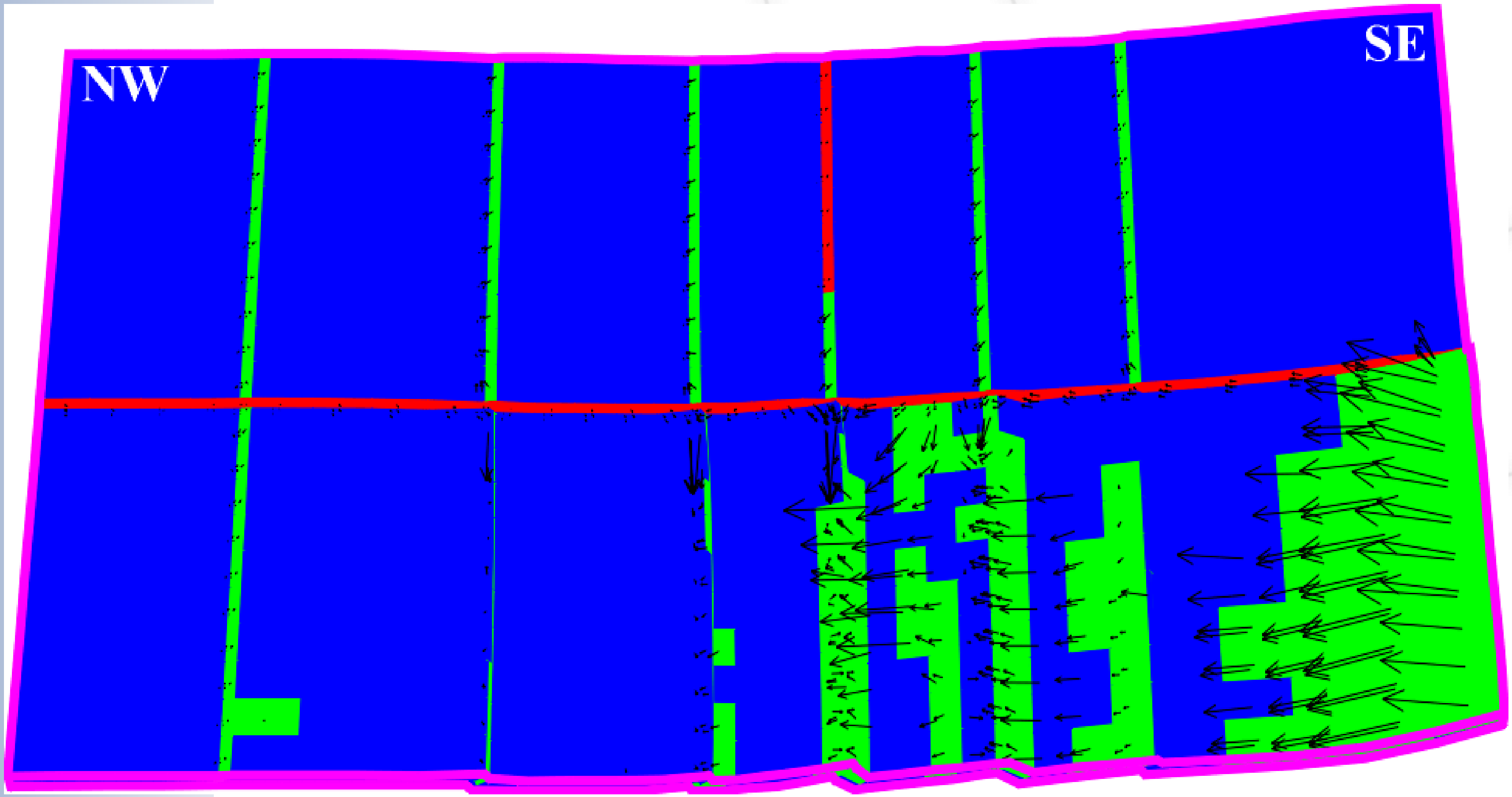


Provides higher permeability dilational sites for focussing the fluids

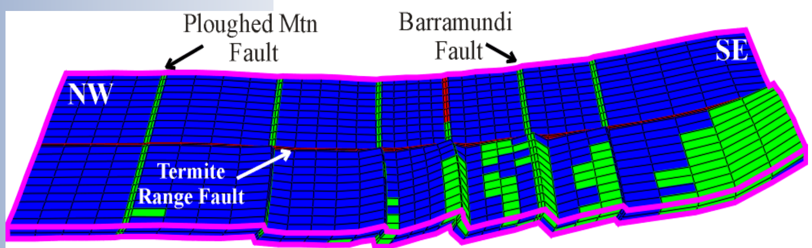
提供高渗透率膨胀区域，有利于流体的聚集

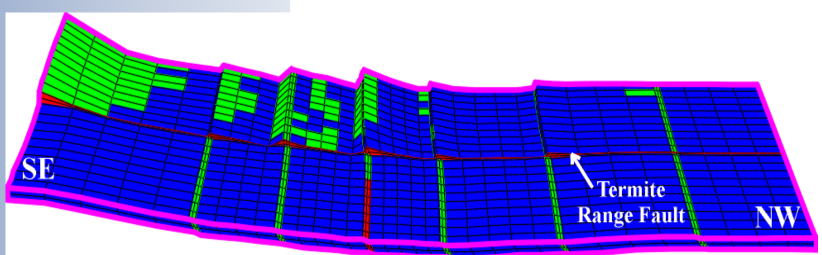
Hydrofracture with folding and fluid flow

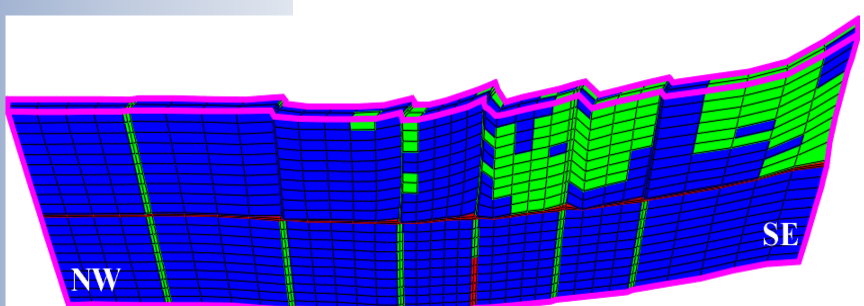
褶皱、流体流动与水力压裂

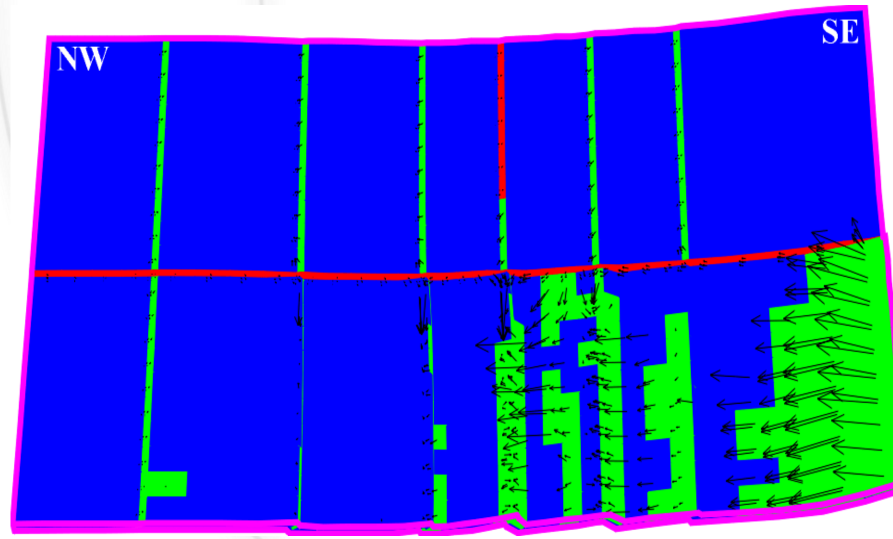


Hydrofracturing within Layer H4s of Lawn Hill Formation









Green represents hydrofracturing due to tensile failure

由于水力压裂导致的张性破坏

This enhances permeability and therefore promotes fluid flow

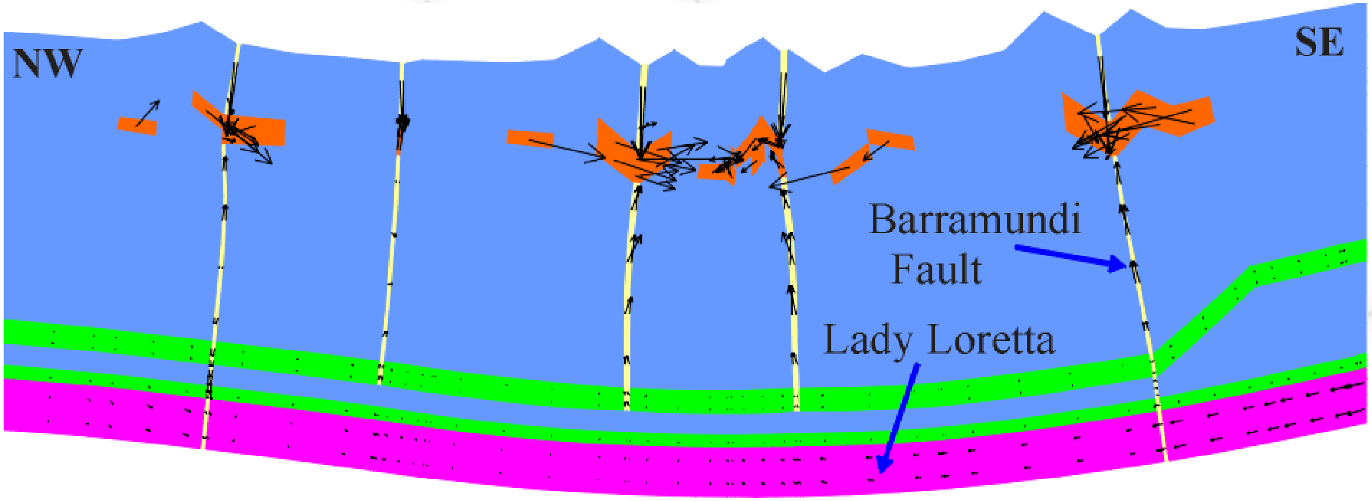
水力压裂模式

Hydrofracturing patterns

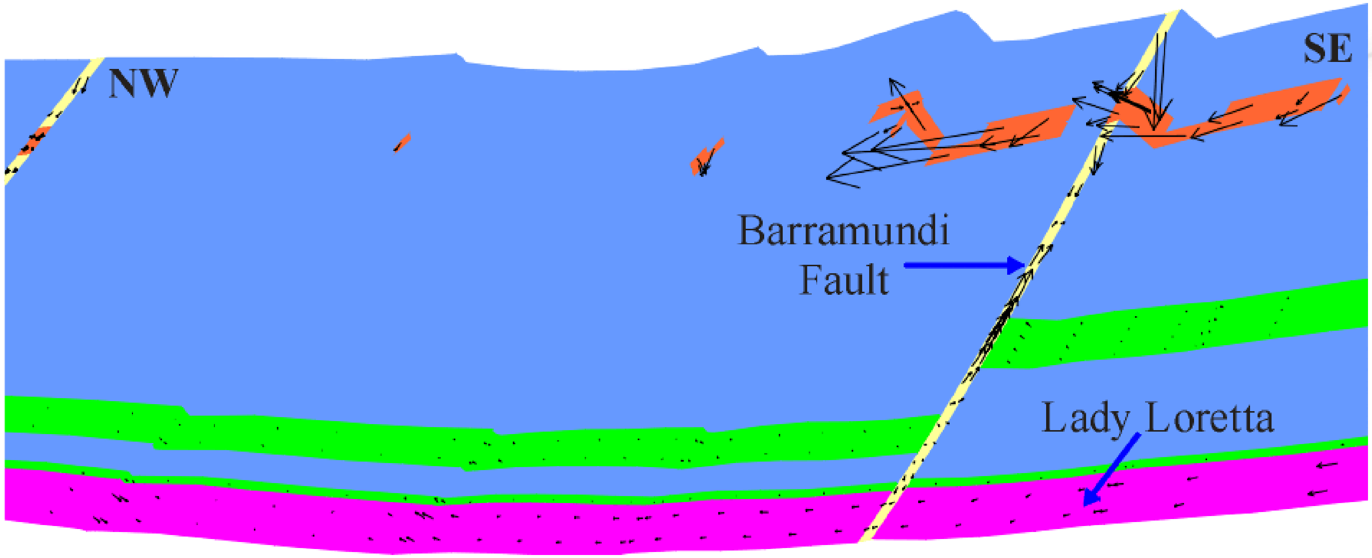
Instantaneous Darcy flow vectors

NW-SE sections, SW of Termite Range Fault

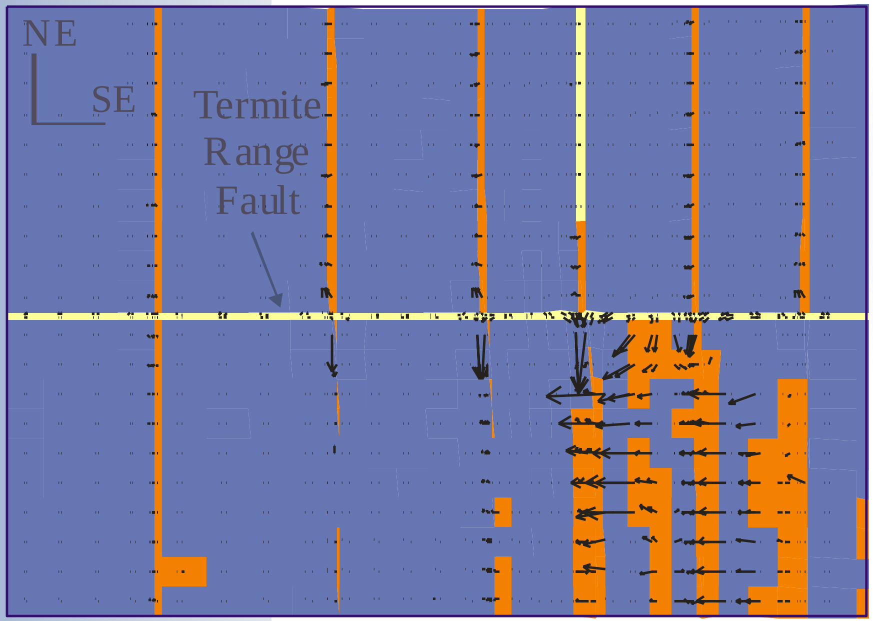
vertical strong faults Max. rate 7.0 x 10^{-7} m s^{-1}

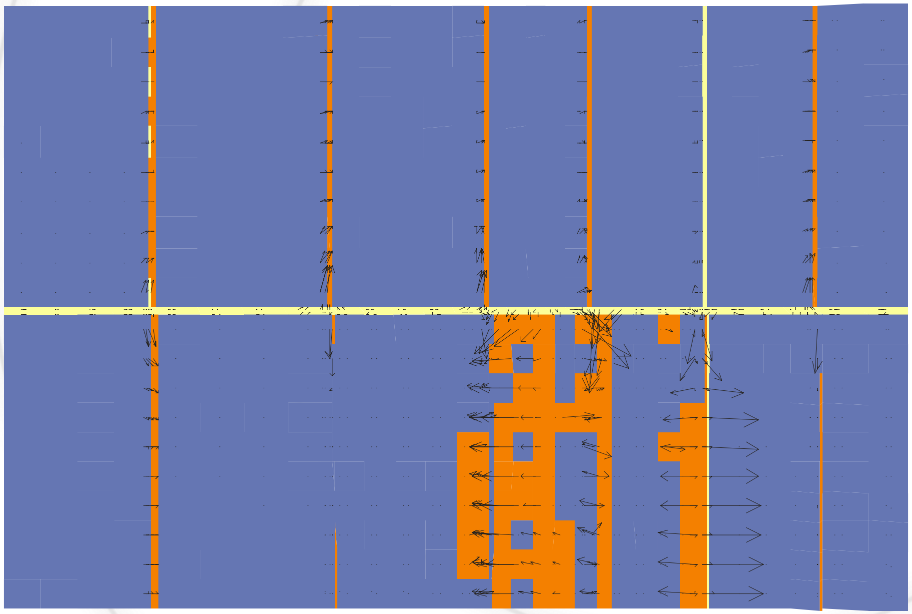


45^{o} dipping strong faults Max. rate 5.0 x 10^{-7} m s^{-1}

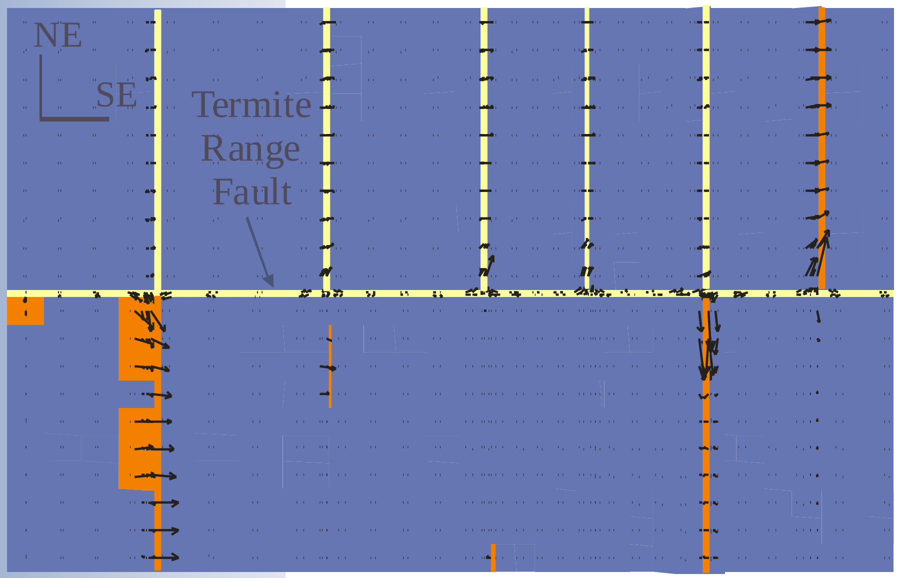


b)





b)



45 dipping faults - 15% D1

Top left) strong faults
Max. rate: 6.7×10^{-7} m s^{-1}

Top right) intermediate strength faults
Max. rate: 7.3×10^{-7} m s^{-1}

Bottom left) weak faults
Max. rate: 5.0×10^{-7} m s^{-1}

4. What are the reservoirs for the various fluids?

- Pb, Zn in basinal brines. Sulphate in basinal brines.

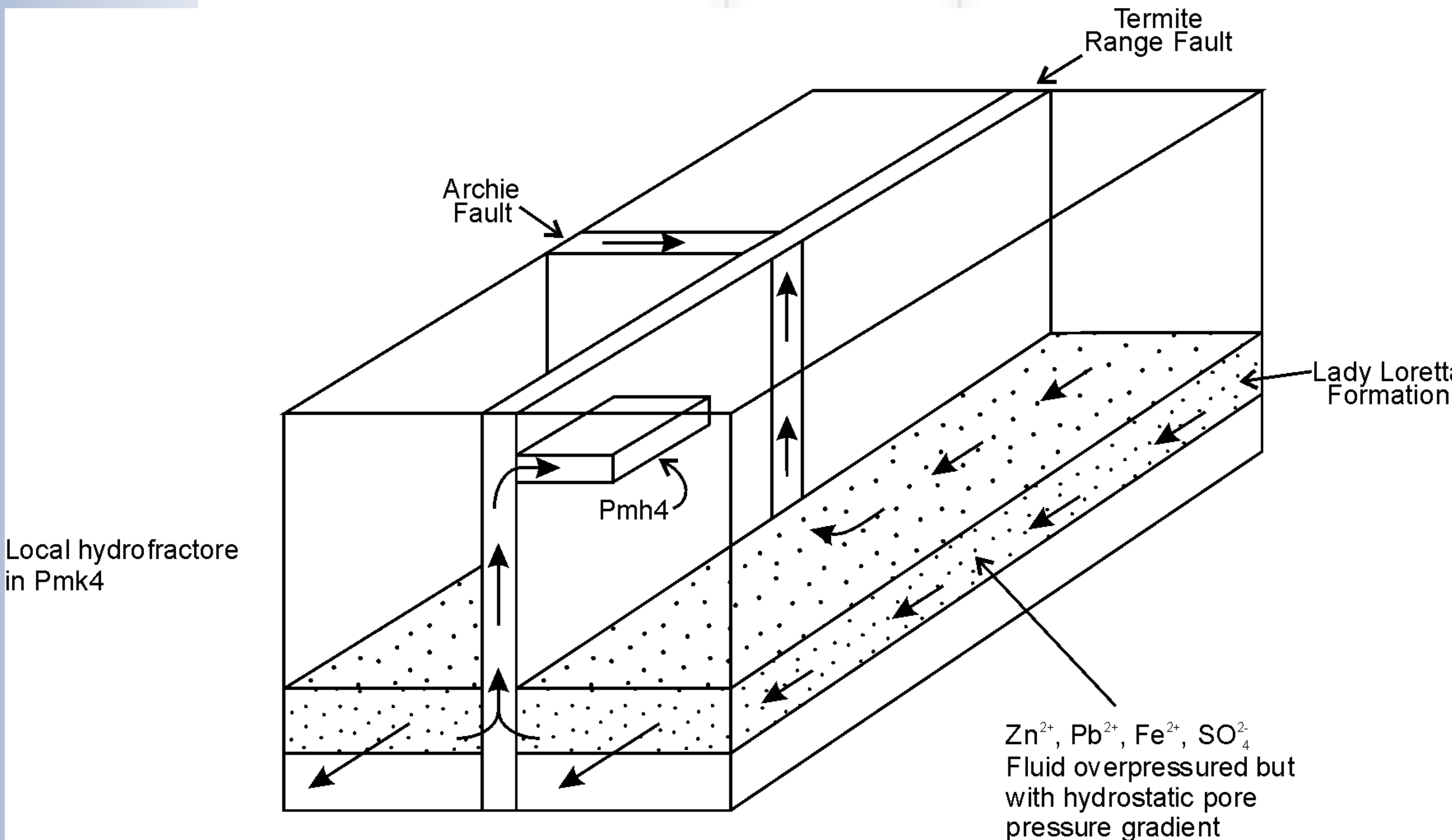
  Pb, Zn 在盆地卤水中. 碳酸盐在盆地卤水中。

- CH_4, CO_2 and particularly H_2S, derived from local black shales as they enter the “oil-window”, ie., 80 - 150 deg C.

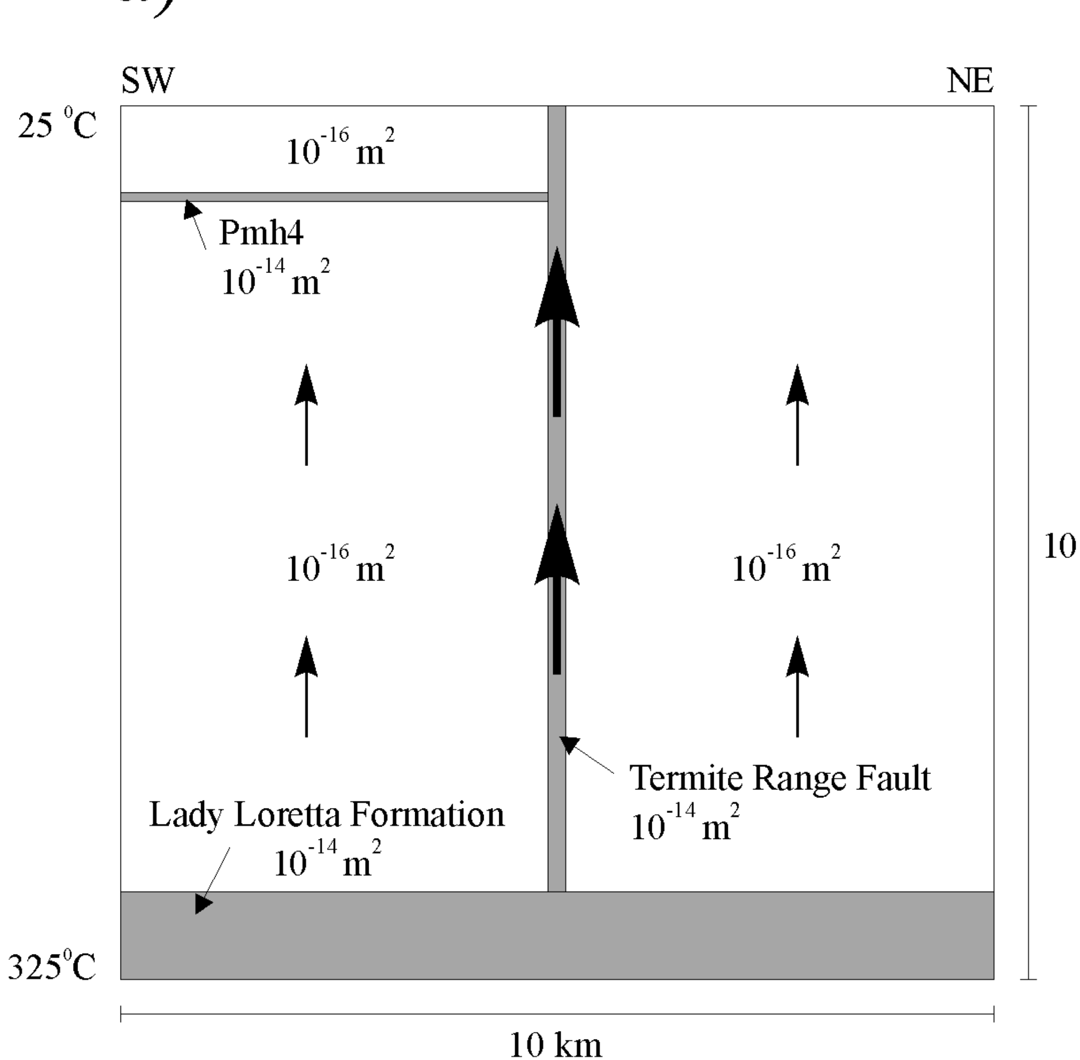
  CH_4, CO_2，尤其是H_2S来源于局部黑色页岩。

耦合流体流动-热模拟

COUPLED FLUID FLOW THERMAL MODELLING

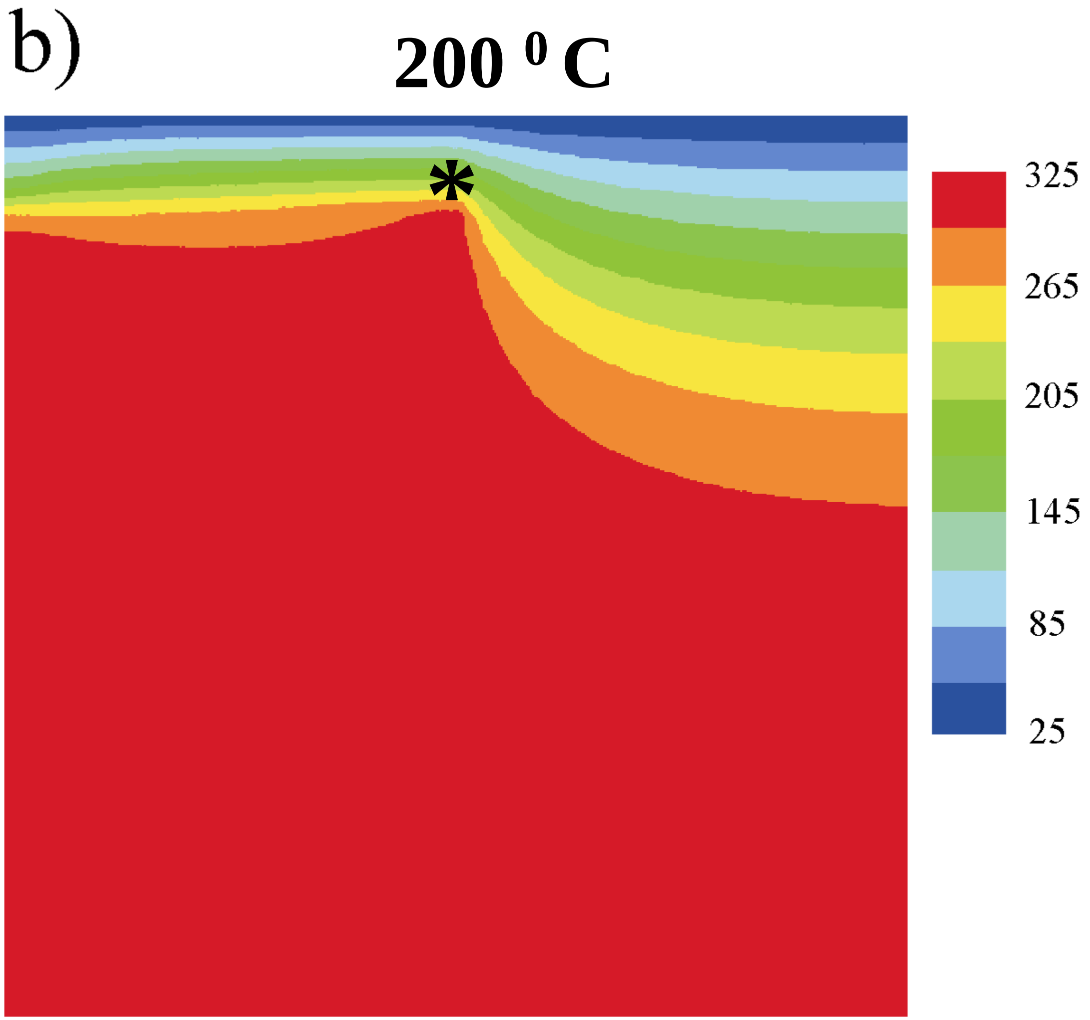


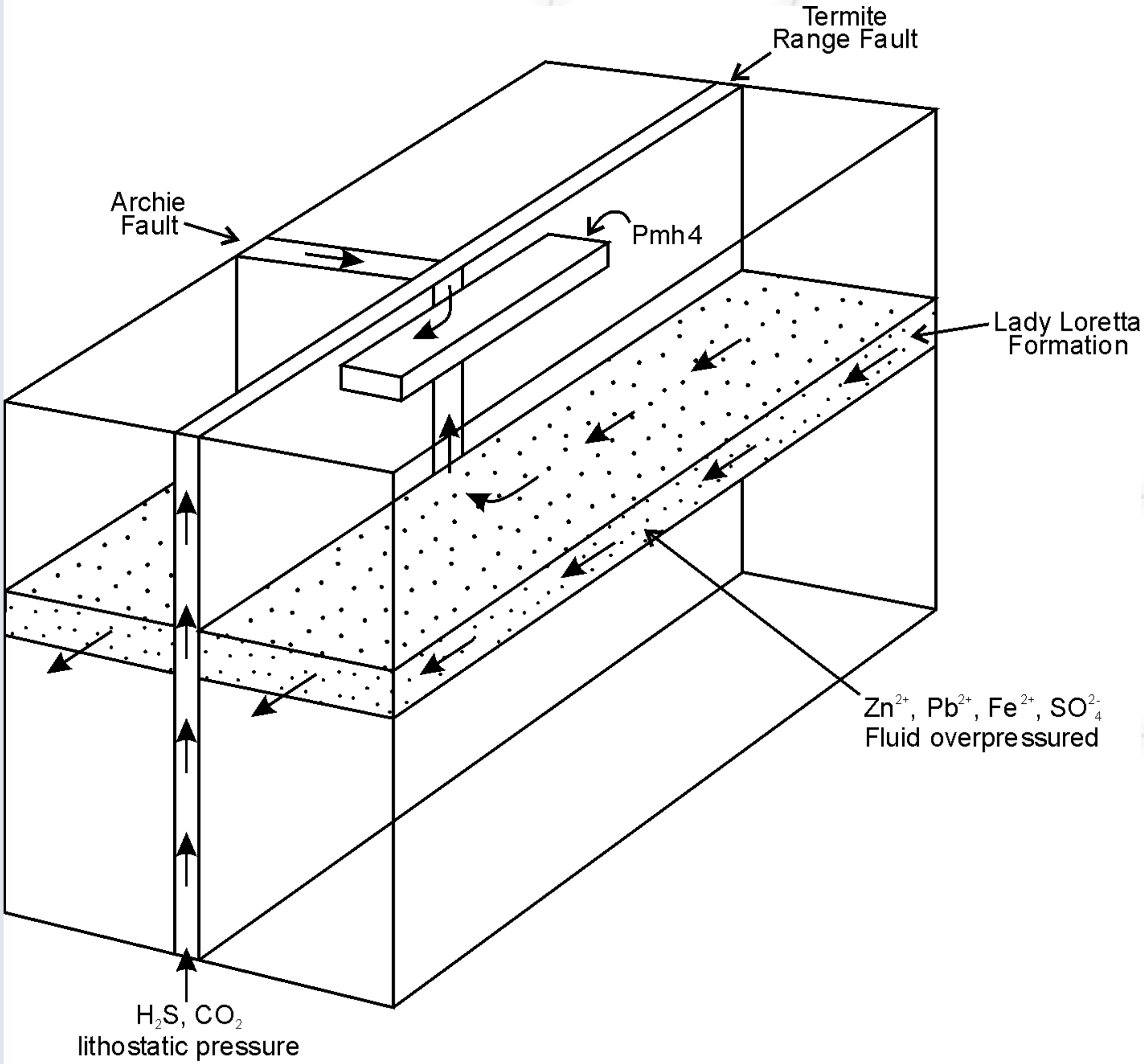
在静水孔隙压力梯度下流体超压



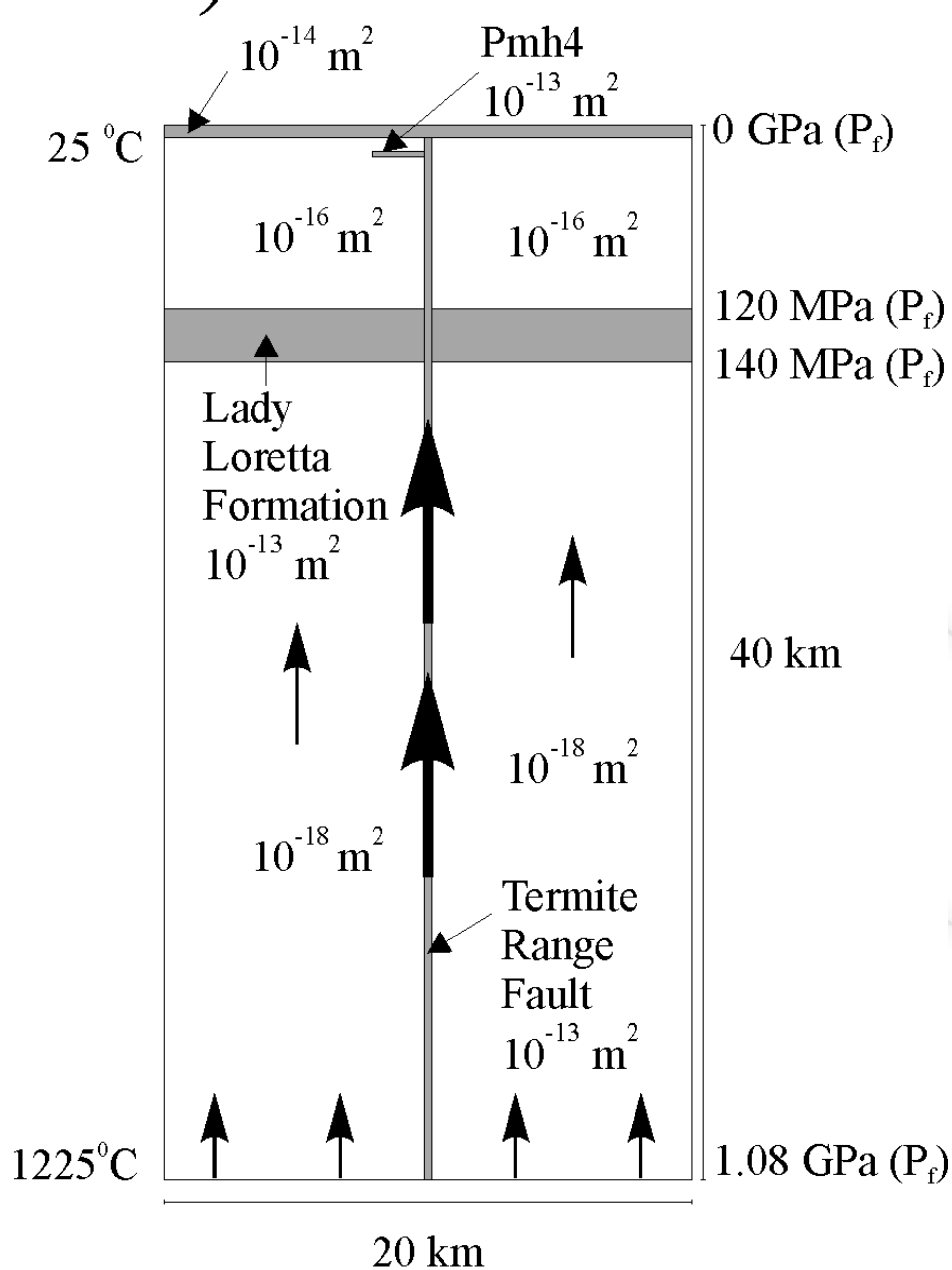
Overpressured fluid in Lady Loretta formation flows up the Termite Range Fault driven by hydraulic head imposed by Isan highlands to the SE.

受水头驱动的Lady Loretta组超压流体沿着Termite Range断层向上流动

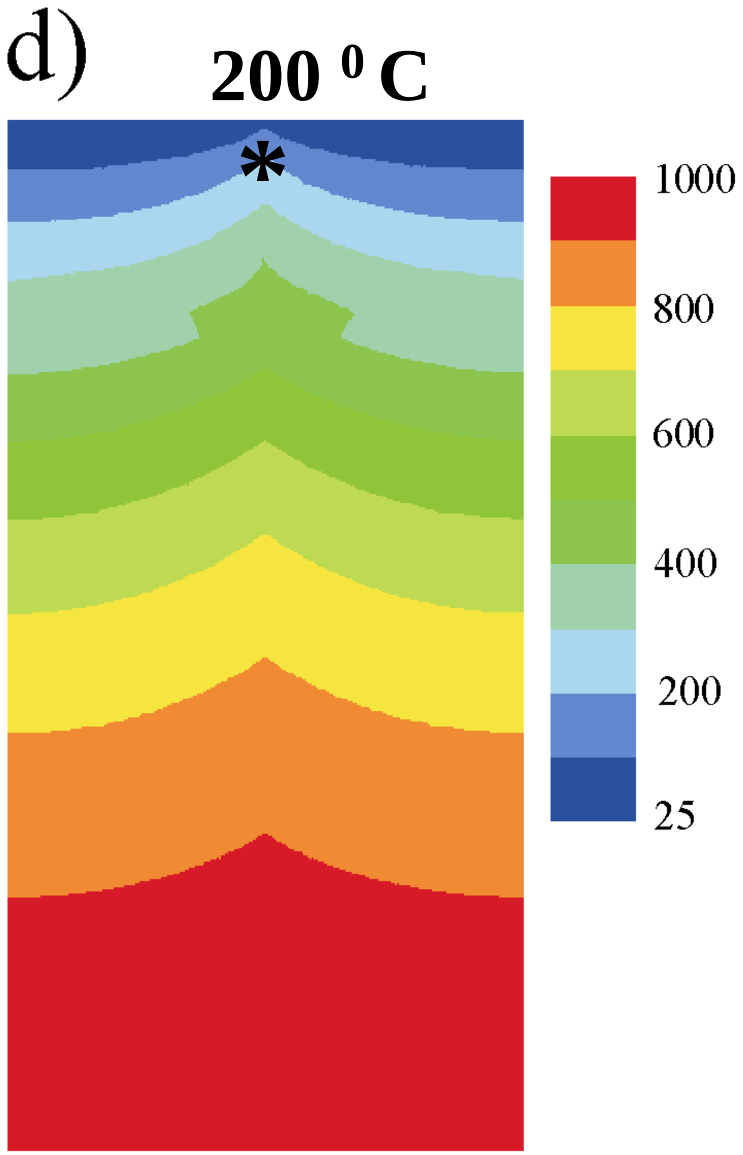

b)
200 0 C
325
265
205
145
85
25


Termite
Range Fault
Archie
Fault
Pmh4
Lady Loretta
Formation
Zn^{2+}, Pb^{2+}, Fe^{2+}, SO_4^{2-}
Fluid overpressured
H_2S, CO_2
lithostatic pressure

Fluids at lithostatic pressure injected into base of 40 km crust



静岩压力下的流体注入地壳40km处


d)
200 ⁰C
*
1000
800
600
400
200
25

耦合流体流动的化学模拟

COUPLED FLUID FLOW CHEMICAL MODELLING

Broadbent Model

$$CH_4 + SO^{2-}{}_4 \longrightarrow H_2S + HCO_3^- + OH^-$$

$$SiO_2 + OH^- + H_2O \longleftrightarrow H_3SiO_4^-$$

(after Dove & Rimstidt, 1994)

$$HCO_3^- + Me^{2+} \longrightarrow MeCO_3 + H^+$$

$$H_2S + Me^{2+} \longrightarrow MeS + 2H^+$$

Unfortunately, the reaction

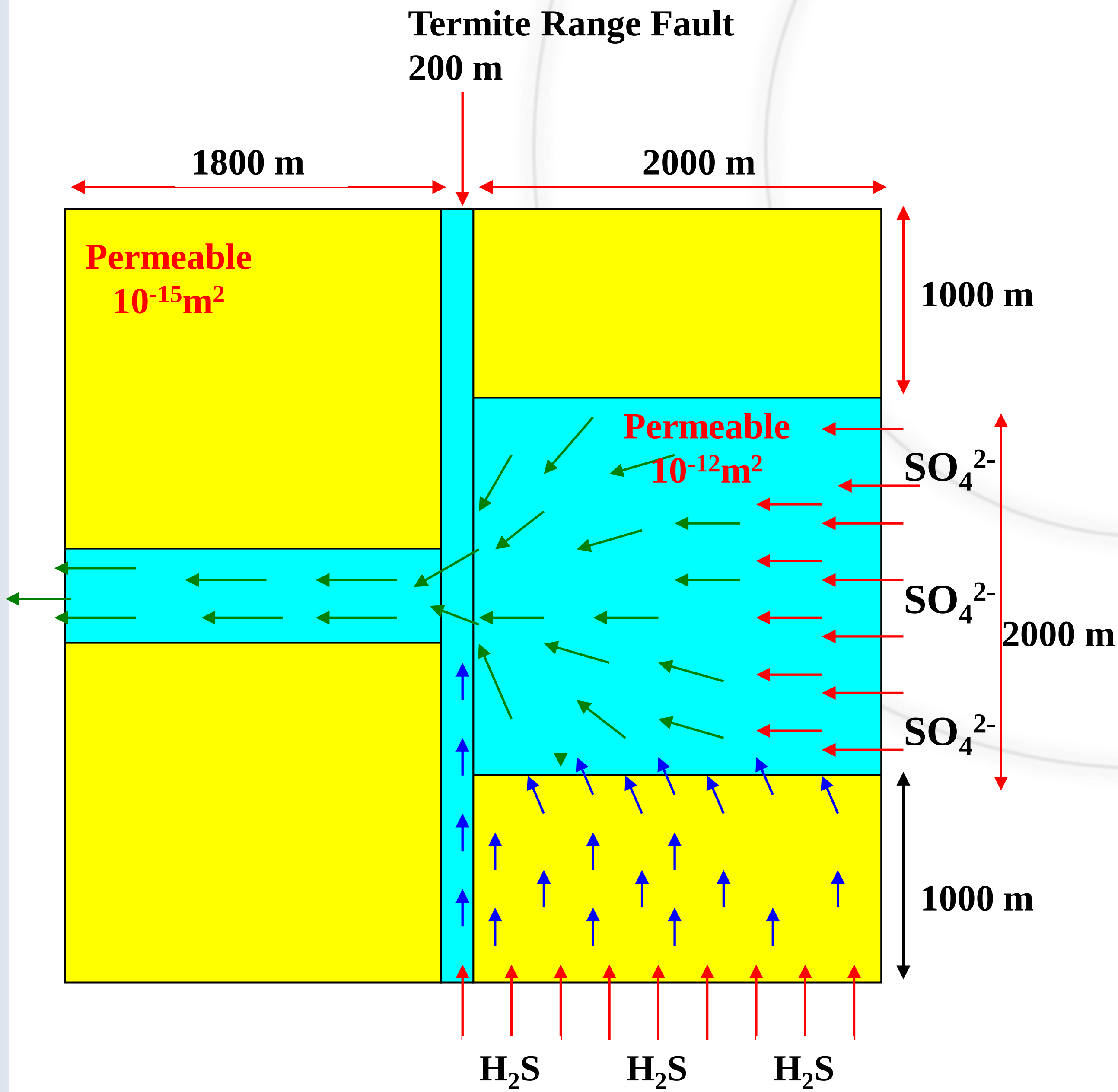
$$CH_4 + SO^{2-}_4 \longrightarrow H_2S + HCO_3^- + OH$$

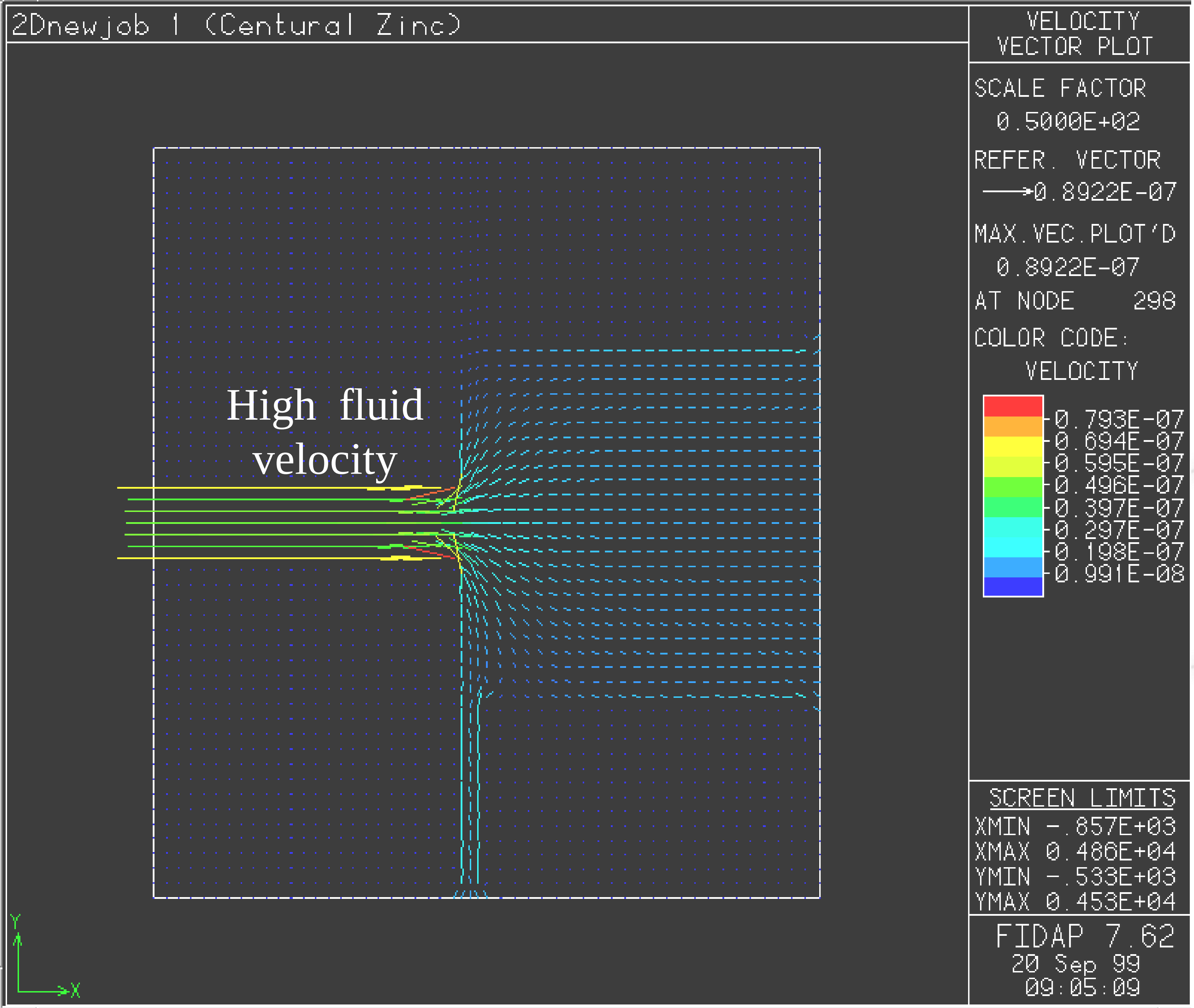
has never been observed experimentally at low temperatures.

We propose

$$H_2S + 2O_2 \longrightarrow 2H^+ + SO^{2-}_4$$

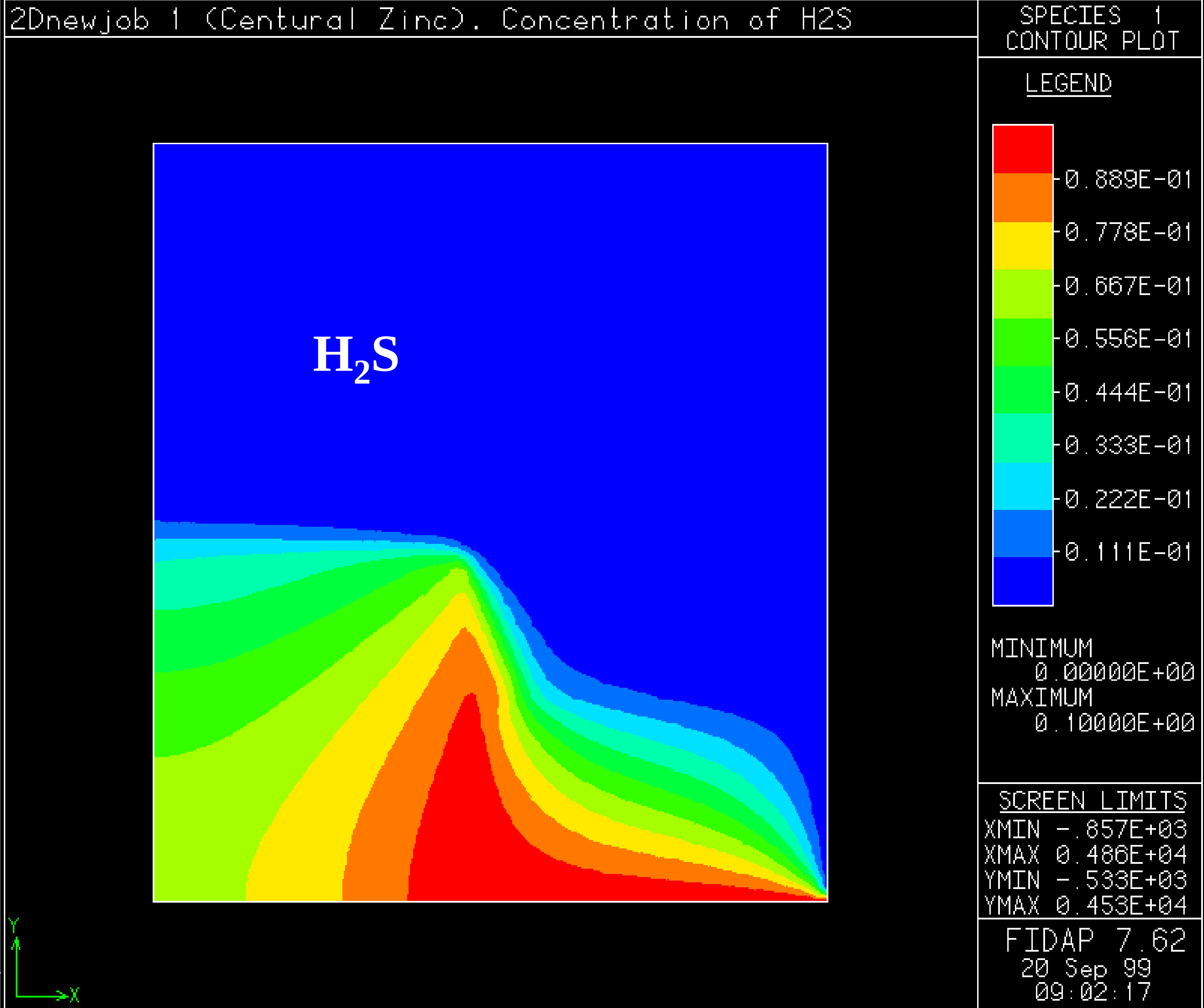
as the important reaction that controls pH.


Termite Range Fault
200 m
1800 m
2000 m
Permeable
$10^{-15}m^2$
1000 m
Permeable
$10^{-12}m^2$
SO_4^{2-}
SO_4^{2-}
SO_4^{2-}
2000 m
1000 m
H_2S
H_2S
H_2S



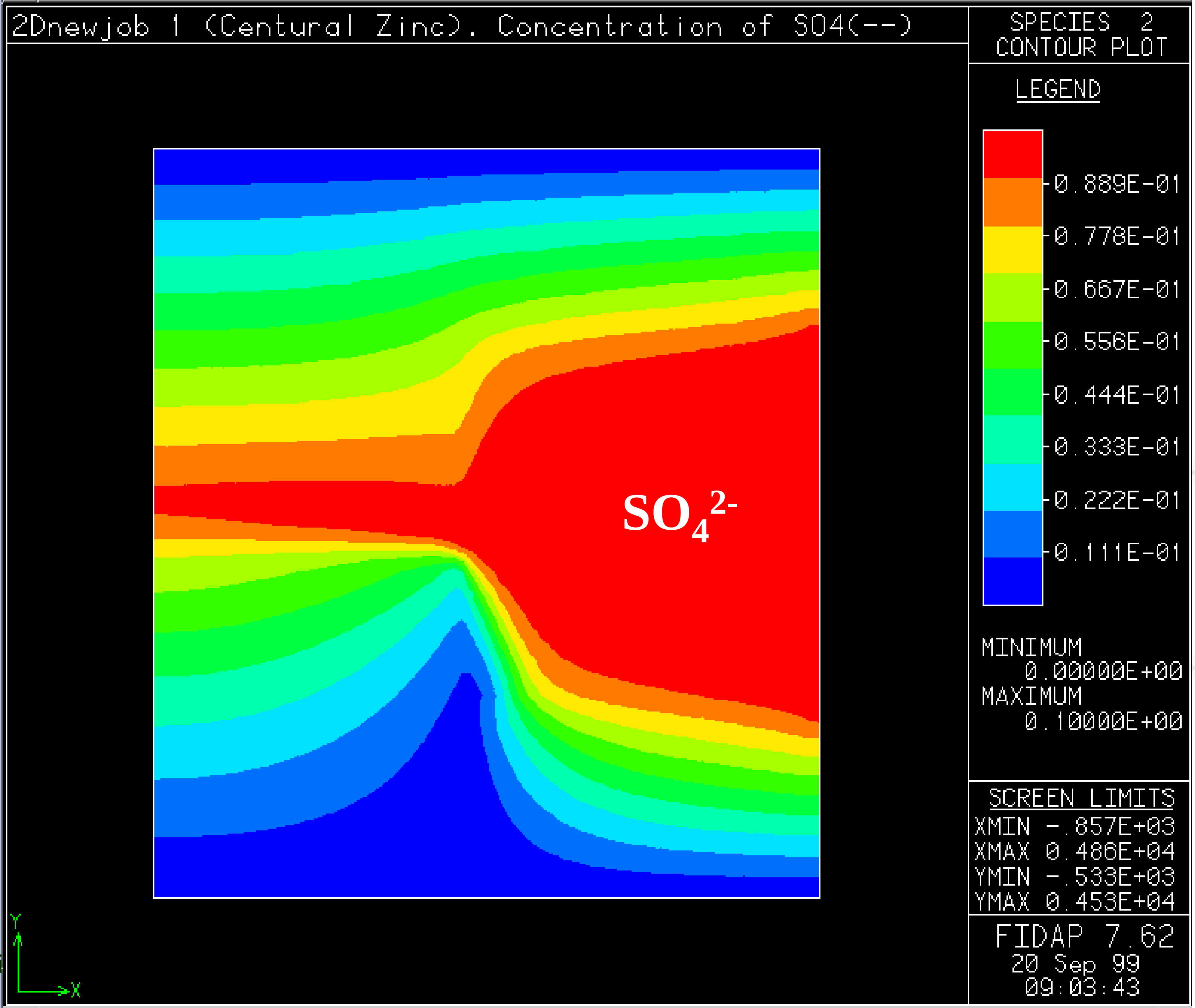
2Dnewjob 1 (Centural Zinc)
VELOCITY
VECTOR PLOT
SCALE FACTOR
0.5000E+02
REFER. VECTOR
0.8922E-07
MAX.VEC.PLOT'D
0.8922E-07
AT NODE 298
COLOR CODE:
VELOCITY
0.793E-07
0.694E-07
0.595E-07
0.496E-07
0.397E-07
0.297E-07
0.198E-07
0.991E-08
SCREEN LIMITS
XMIN -.857E+03
XMAX 0.486E+04
YMIN -.533E+03
YMAX 0.453E+04
FIDAP 7.62
20 Sep 99
09:05:09
High fluid
velocity
Y
X

Hefei

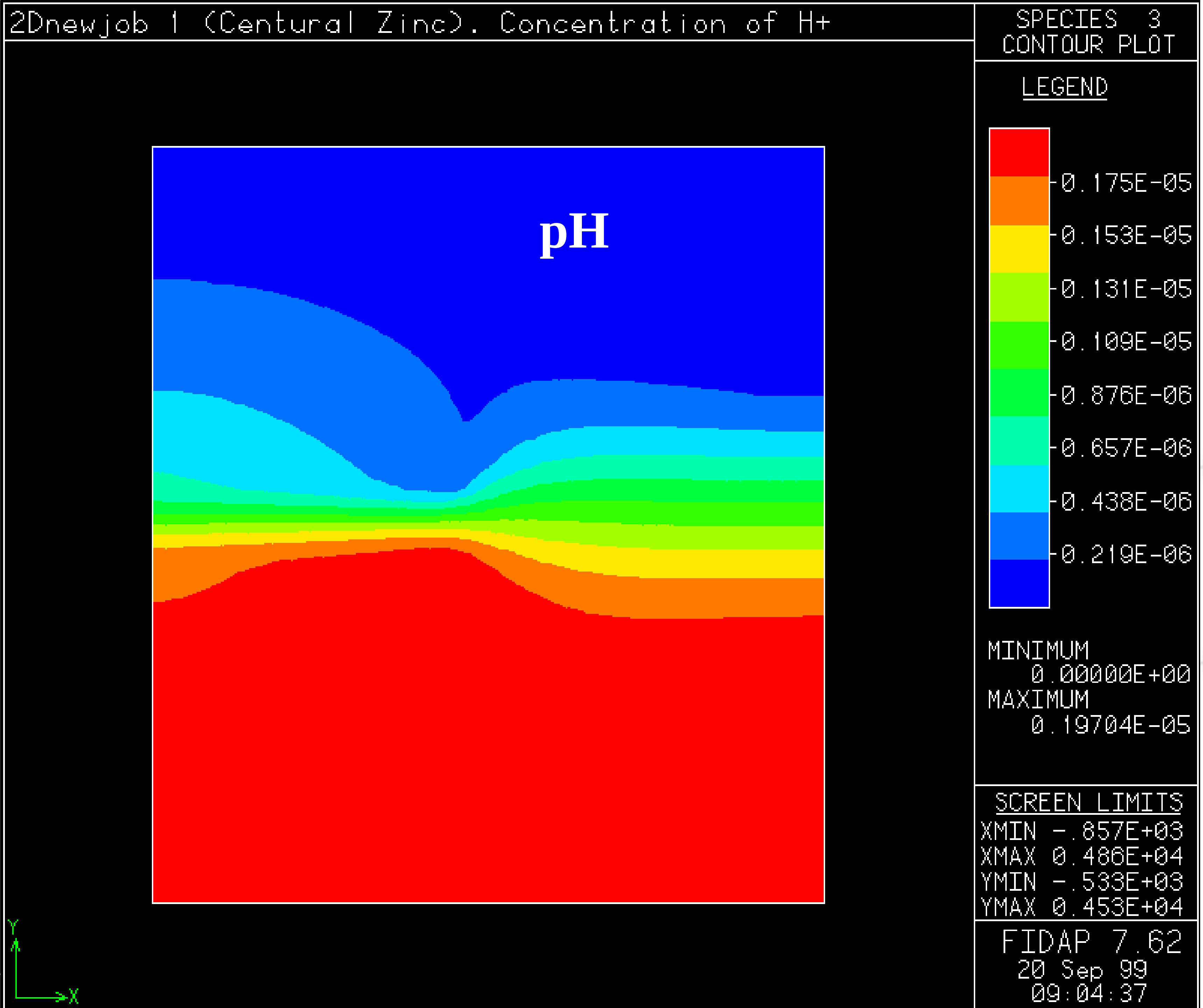


2Dnewjob 1 (Centural Zinc). Concentration of H2S
SPECIES 1
CONTOUR PLOT
LEGEND
0.889E-01
0.778E-01
0.667E-01
0.556E-01
0.444E-01
0.333E-01
0.222E-01
0.111E-01
MINIMUM
0.00000E+00
MAXIMUM
0.10000E+00
SCREEN LIMITS
XMIN -.857E+03
XMAX 0.486E+04
YMIN -.533E+03
YMAX 0.453E+04
FIDAP 7.62
20 Sep 99
09:02:17
H2S
Y
X

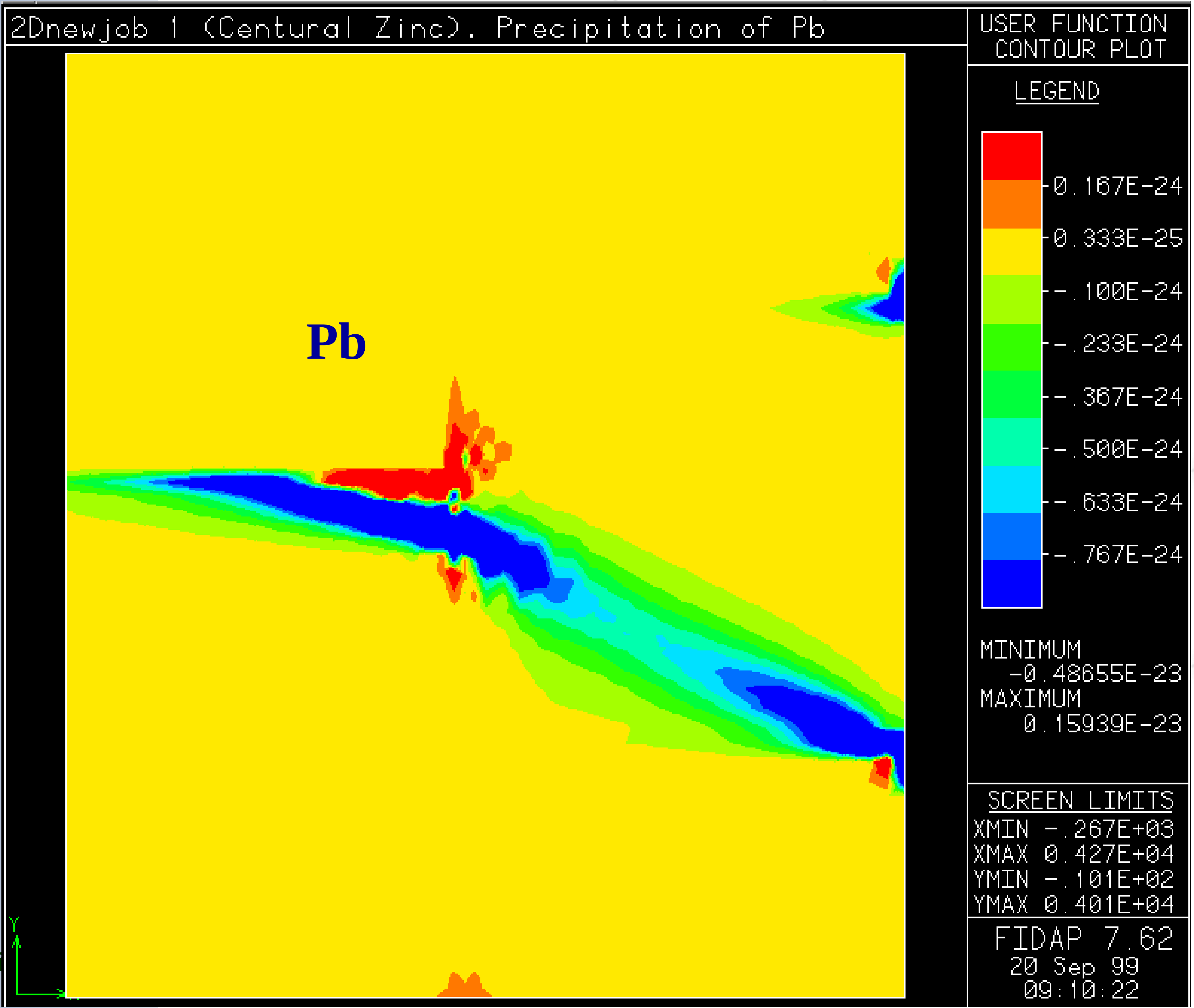
Hefe


2Dnewjob 1 (Centural Zinc). Concentration of SO4(--)
SPECIES 2
CONTOUR PLOT
LEGEND
0.889E-01
0.778E-01
0.667E-01
0.556E-01
0.444E-01
0.333E-01
0.222E-01
0.111E-01
MINIMUM
0.00000E+00
MAXIMUM
0.10000E+00
SCREEN LIMITS
XMIN -.857E+03
XMAX 0.486E+04
YMIN -.533E+03
YMAX 0.453E+04
FIDAP 7.62
20 Sep 99
09:03:43
Y
X
SO_4^{2-}

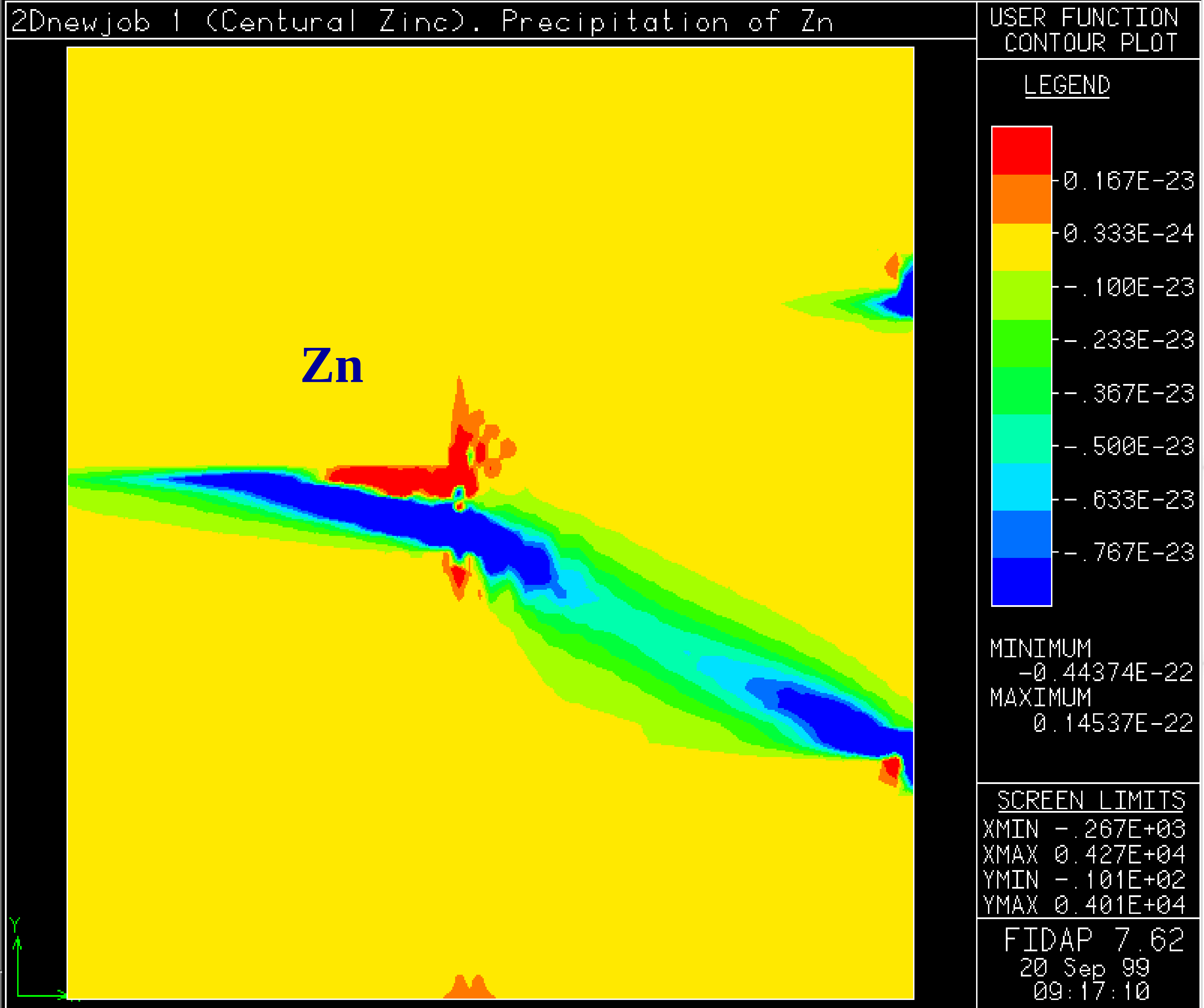
Hefei


2Dnewjob 1 (Centural Zinc). Concentration of H+
SPECIES 3
CONTOUR PLOT
LEGEND
0.175E-05
0.153E-05
0.131E-05
0.109E-05
0.876E-06
0.657E-06
0.438E-06
0.219E-06
MINIMUM
0.00000E+00
MAXIMUM
0.19704E-05
SCREEN LIMITS
XMIN -.857E+03
XMAX 0.486E+04
YMIN -.533E+03
YMAX 0.453E+04
FIDAP 7.62
20 Sep 99
09:04:37
pH
Y
X

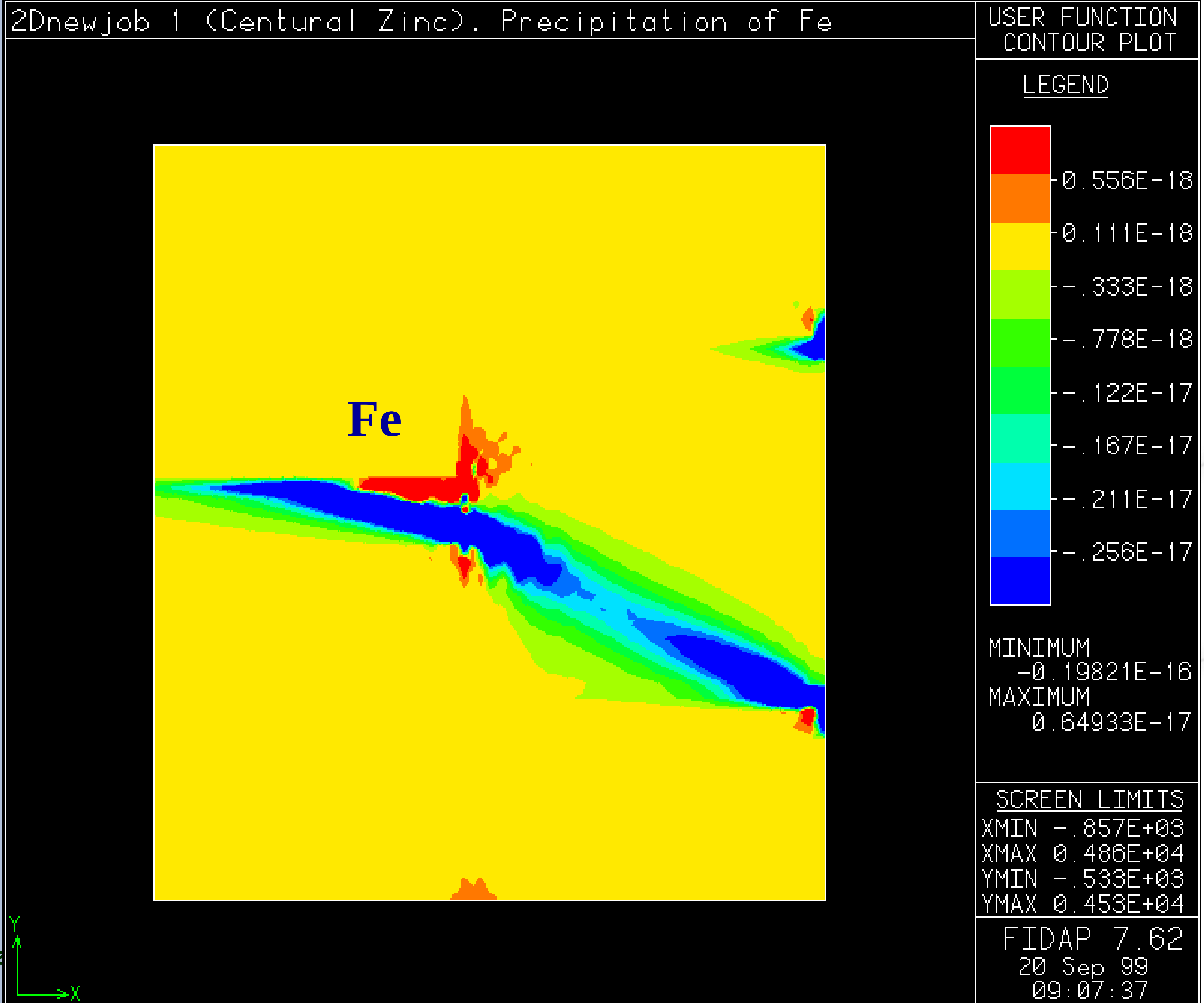
Hefe


2Dnewjob 1 (Centural Zinc). Precipitation of Pb
Pb
USER FUNCTION CONTOUR PLOT
LEGEND
0.167E-24
0.333E-25
-.100E-24
-.233E-24
-.367E-24
-.500E-24
-.633E-24
-.767E-24
MINIMUM -0.48655E-23
MAXIMUM 0.15939E-23
SCREEN LIMITS
XMIN -.267E+03
XMAX 0.427E+04
YMIN -.101E+02
YMAX 0.401E+04
FIDAP 7.62
20 Sep 99
09:10:22
Y

Hefei

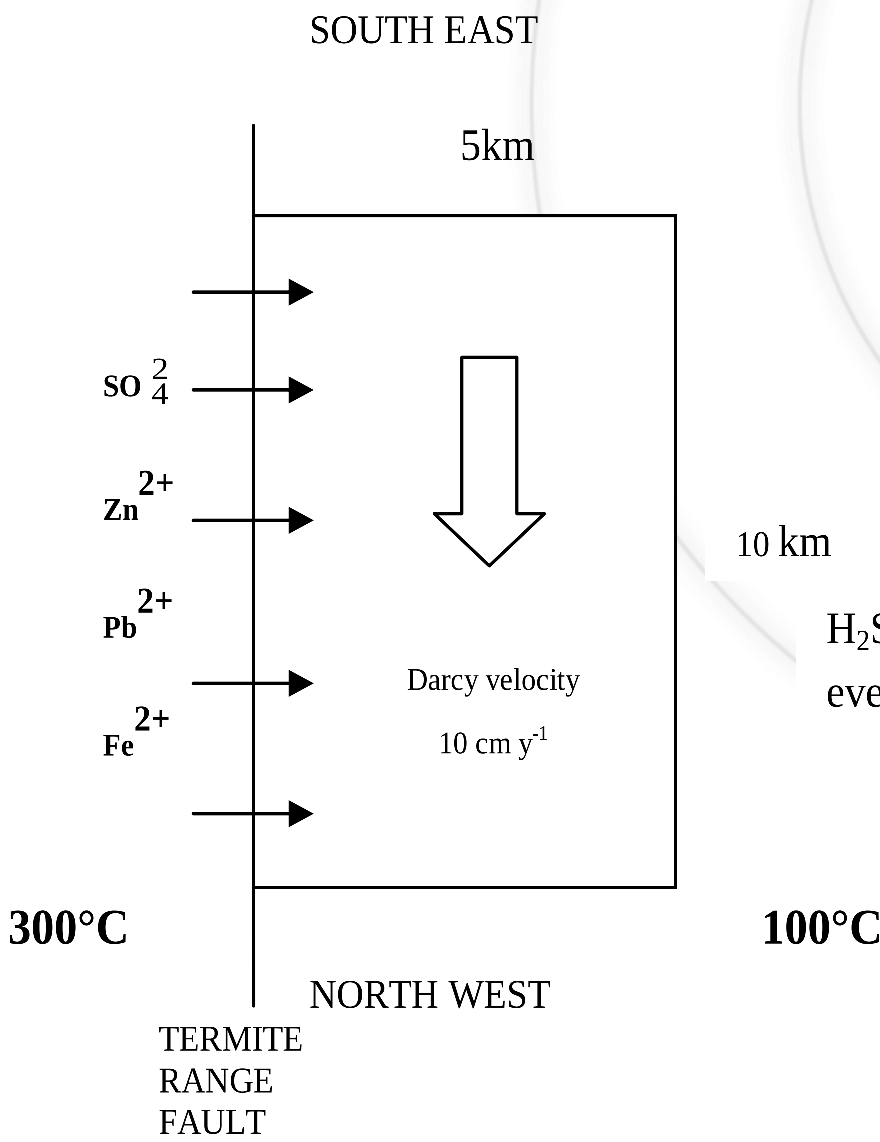

2Dnewjob 1 (Centural Zinc). Precipitation of Zn
USER FUNCTION
CONTOUR PLOT
LEGEND
0.167E-23
0.333E-24
-.100E-23
-.233E-23
-.367E-23
-.500E-23
-.633E-23
-.767E-23
MINIMUM
-0.44374E-22
MAXIMUM
0.14537E-22
SCREEN LIMITS
XMIN -.267E+03
XMAX 0.427E+04
YMIN -.101E+02
YMAX 0.401E+04
FIDAP 7.62
20 Sep 99
09:17:10
Zn
Y

Hefe

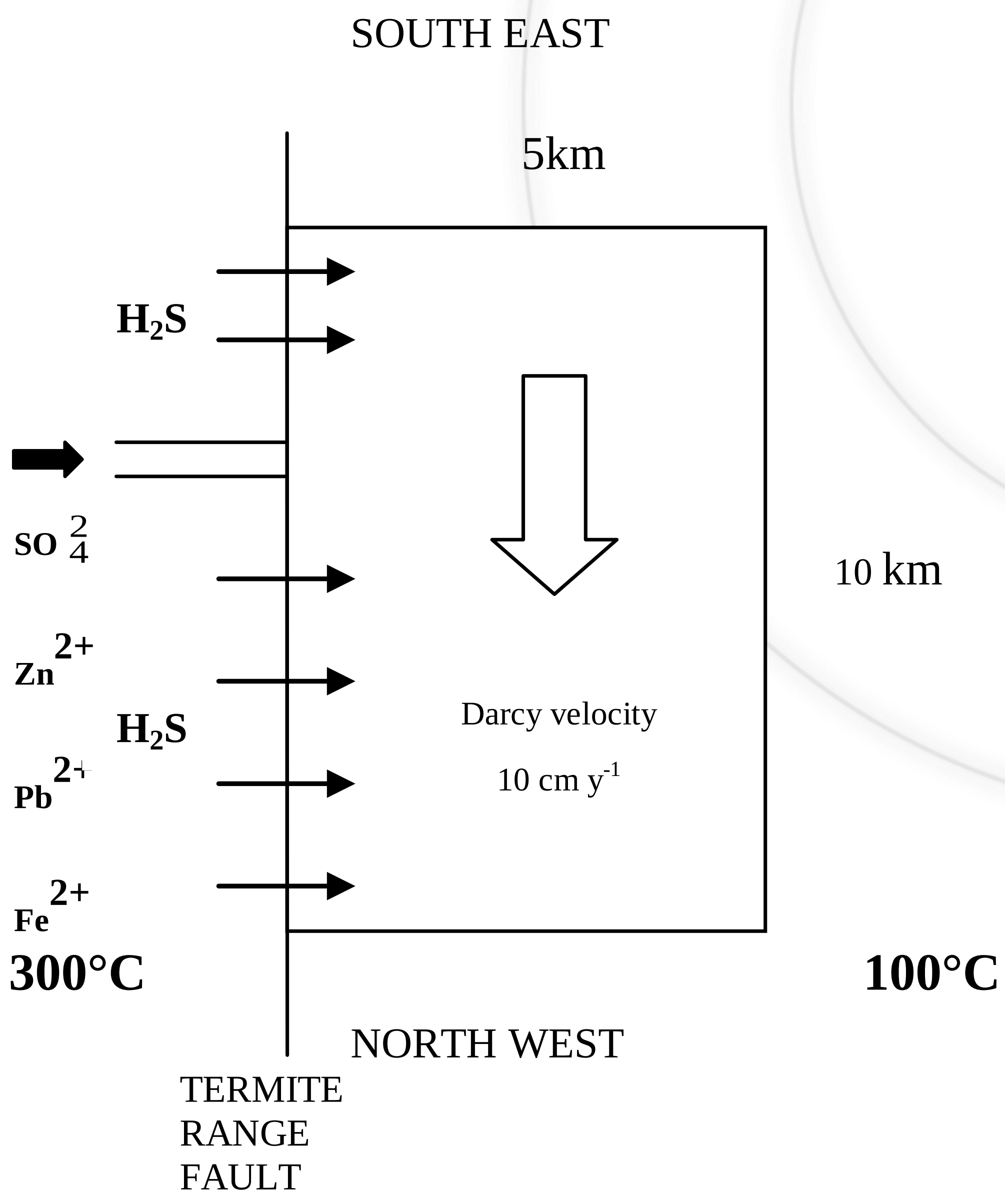

2Dnewjob 1 (Centural Zinc). Precipitation of Fe
USER FUNCTION CONTOUR PLOT
LEGEND
0.556E-18
0.111E-18
-.333E-18
-.778E-18
-.122E-17
-.167E-17
-.211E-17
-.256E-17
MINIMUM -0.19821E-16
MAXIMUM 0.64933E-17
Fe
SCREEN LIMITS
XMIN -.857E+03
XMAX 0.486E+04
YMIN -.533E+03
YMAX 0.453E+04
FIDAP 7.62
20 Sep 99
09:07:37
Y
X

Hefe

No ore body generated

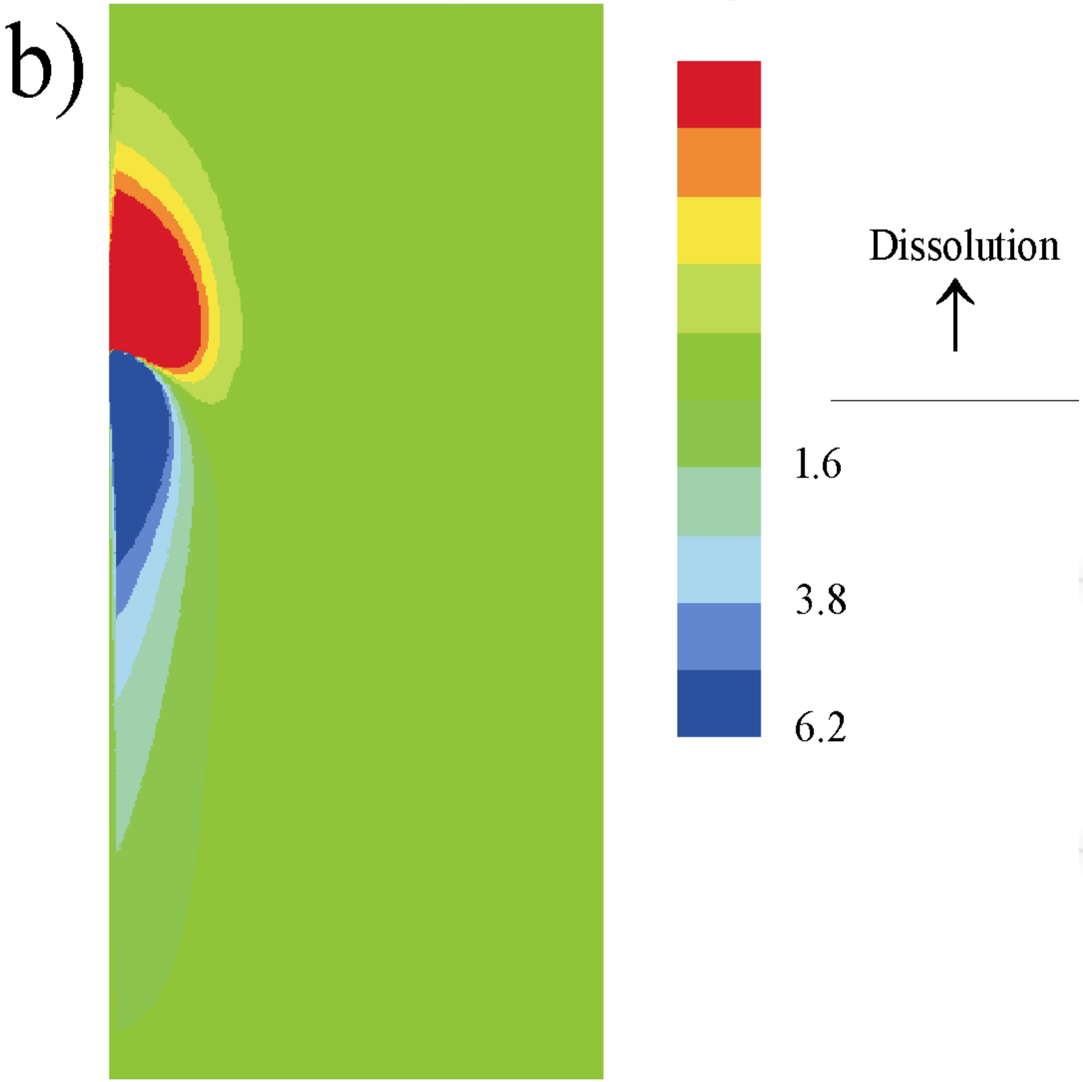


H_2S uniform everywhere


SOUTH EAST
5km
H_2S
SO_4^{2}
Zn^{2+}
H_2S
Pb^{2+}
Fe^{2+}
10 km
Darcy velocity
10 cm y^{-1}
300°C
100°C
NORTH WEST
TERMITE
RANGE
FAULT

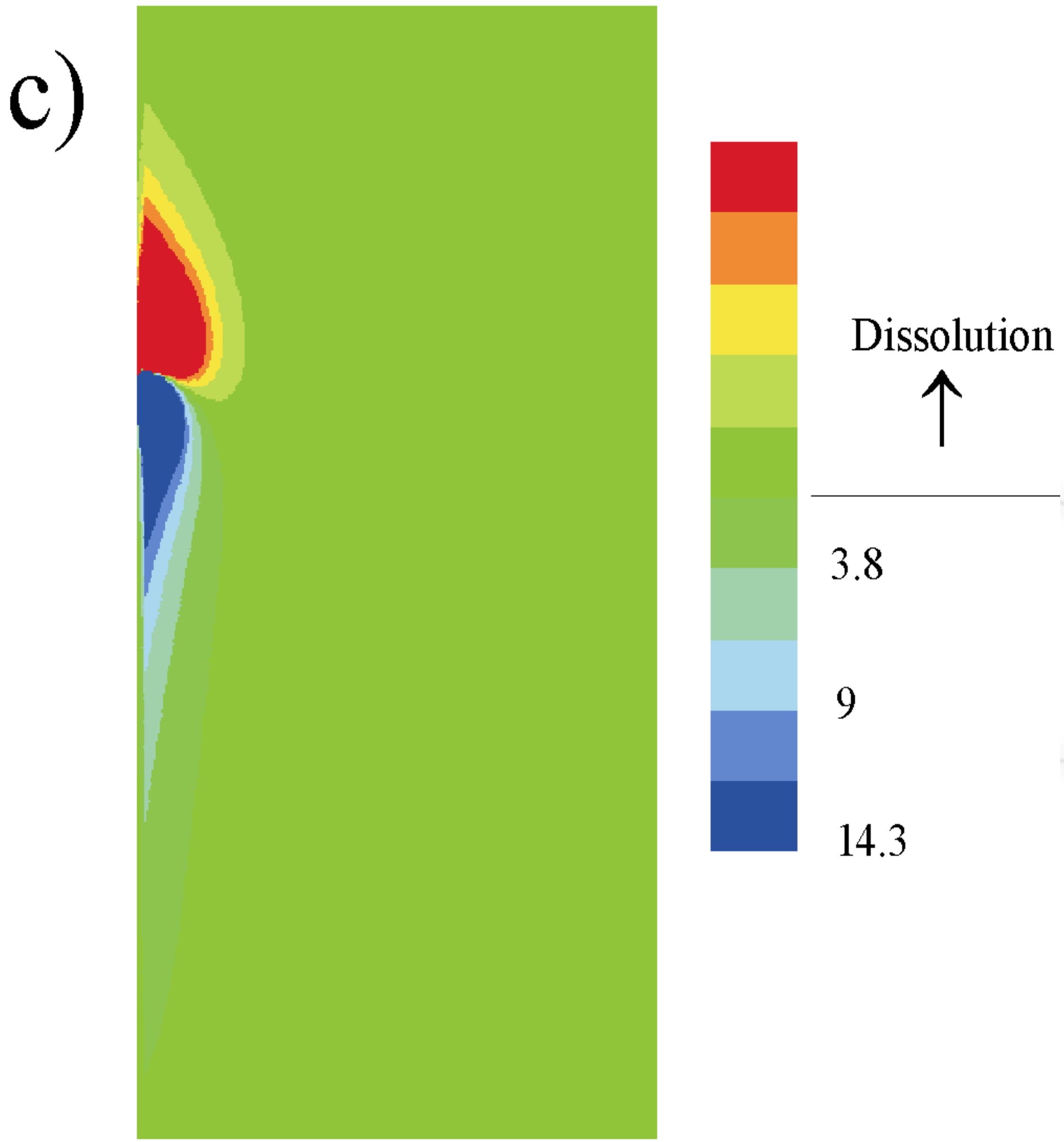
Sphalerite

闪锌矿



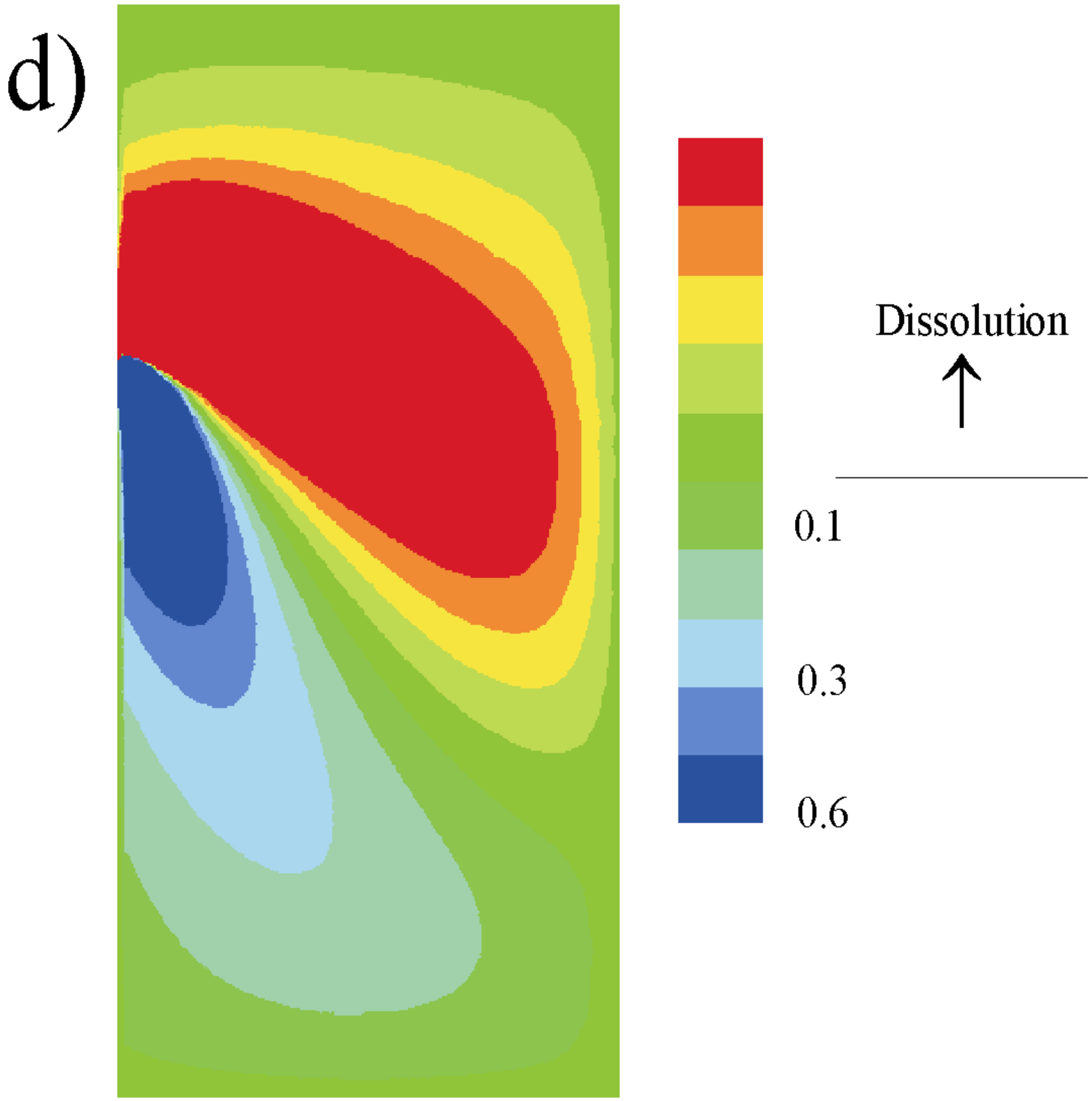
Galena

方铅矿



Pyrite

黄铁矿



Conclusions

- Models predict that Century is a zinc ore body with minor lead.
  模型预测，世纪矿床是一个贫铅的锌矿床
- Metal grades could develop in 2 to 3 MY
  金属来源于2到3百万年
- Models predict that pyrite, not pyrrhotite, is the iron sulphide.
  模型预测生成的铁硫化物是黄铁矿而不是雌黄铁矿
- Models explain shape of ore body and cross cutting relationship.
  模型解释了矿体的形状及穿插关系
- We have not yet added carbonates to investigate siderite distribution.
  尚未加入碳酸盐讨论的分布

Conclusions

- Topography generated by the Isan Orogeny drives basinal fluid flow.

  Isan造山时间产生的地形起伏驱动盆地内流体运动

- Horizontal seals defined by impermeable shales.

  不具渗透性的页岩提供了水平的封闭环境

- Hydrofracture of H_2S, CH_4, CO_2 may occur from carbon rich shales.

  水力压裂的H_2S, CH_4, CO_2可能发生自从富C页岩

Conclusions

- Faults such as the Termite Range Fault provide a conduit for fluids.

  断层提供了热液通道
- Permeable horizons act as the high fluid flow systems.

  具有渗透性的岩层为高流体流动系统
- D2 closes the system off.

  D2使成矿系统的关闭

3 Conclusions

- Fluid mixing produces high grade

  流体混合形成高的品位

- Structural architecture enables mixing

  构造结构促使流体混合

- One must integrate data sets at all scales to reveal the controls of architecture on fluid mixing

  需要在多尺度下整合数据，揭露流体混合的结构控制因素

A. Ord, B. E. Hobbs, Y. Zhang, G. C. Broadbent, M. Brown, G. Willettes, P. Sorjonen-Ward, J. L. Walshe, C. Zhao. 2002. Geodynamic modelling of the Century deposit, Mt Isa Province, Queensland. Australian Journal of Earth Sciences 49, 1011-1039.

Collaborators

Bruce Hobbs The University of Western Australia; CSIRO
Chongbin Zhao Central South University, Changsha
Mark Munro The University of Western Australia
Weronika Gorczyk The University of Western Australia
Chris Gonzalez The University of Western Australia
Qiangqiang Liu – Leo The University of Western Australia
Martin Paesold The University of Western Australia
Dan Lester Royal Melbourne Institute of Technology
Robert Niven University of New South Wales
Jorn Kruhl Ludwig-Maximilians University, Munich

Thank you

The University of Western Australia

Centre for EXPLORATION TARGETING

Australian Government
Australian Research Council

FIRST QUANTUM MINERALS LTD.

GROUP OF EIGHT AUSTRALIA

DAAD

Geological Survey Western Australia

silverlake RESOURCES

TUM
TECHNISCHE UNIVERSITÄT MÜNCHEN

SIGILL. UNIVERSITAT. LUDOVICO. MAXIM.

SOUTH AUSTRALIA

Government of South Australia
Department of State Development

ANGLOGOLD ASHANTI

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

CSIRO

mriwa
Minerals Research Institute of Western Australia