

# Case Study: Long Term Abandoned Mine Methane Recovery Operation in the U.S.

案例研究：美国废弃矿井甲烷长期回收应用项目

*Sino-U.S. New Energy Sci-Tech Forum and  
Conference on Recovery and Utilization of  
Coalmine Methane, Jincheng, Shanxi, China*

中美新能源科技论坛暨煤矿气回收利用会议，中国，山西，晋城

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Presented by: 演示者：

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# Presentation Outline

## 演示概要

- Project Background 项目背景
- Field Operations 实地操作
- Project Performance 项目执行情况
- Estimating Reserves 预计储量
- Lesson's learned 经验教训

# Project Background

## 项目背景

- First started by Illinois Methane in 2002 and was shutdown for financial reasons in 2004

2002年由伊利诺伊甲烷公司发起，2004年因财政原因终止。

- DTE Methane Resources purchased from Illinois Methane in 2004, modified the facilities, and restarted the project in March 2005

2004年DTE甲烷资源公司从伊利诺伊甲烷公司购买该项目，并对设施进行了修缮，该项目于2005年3月重新启动。

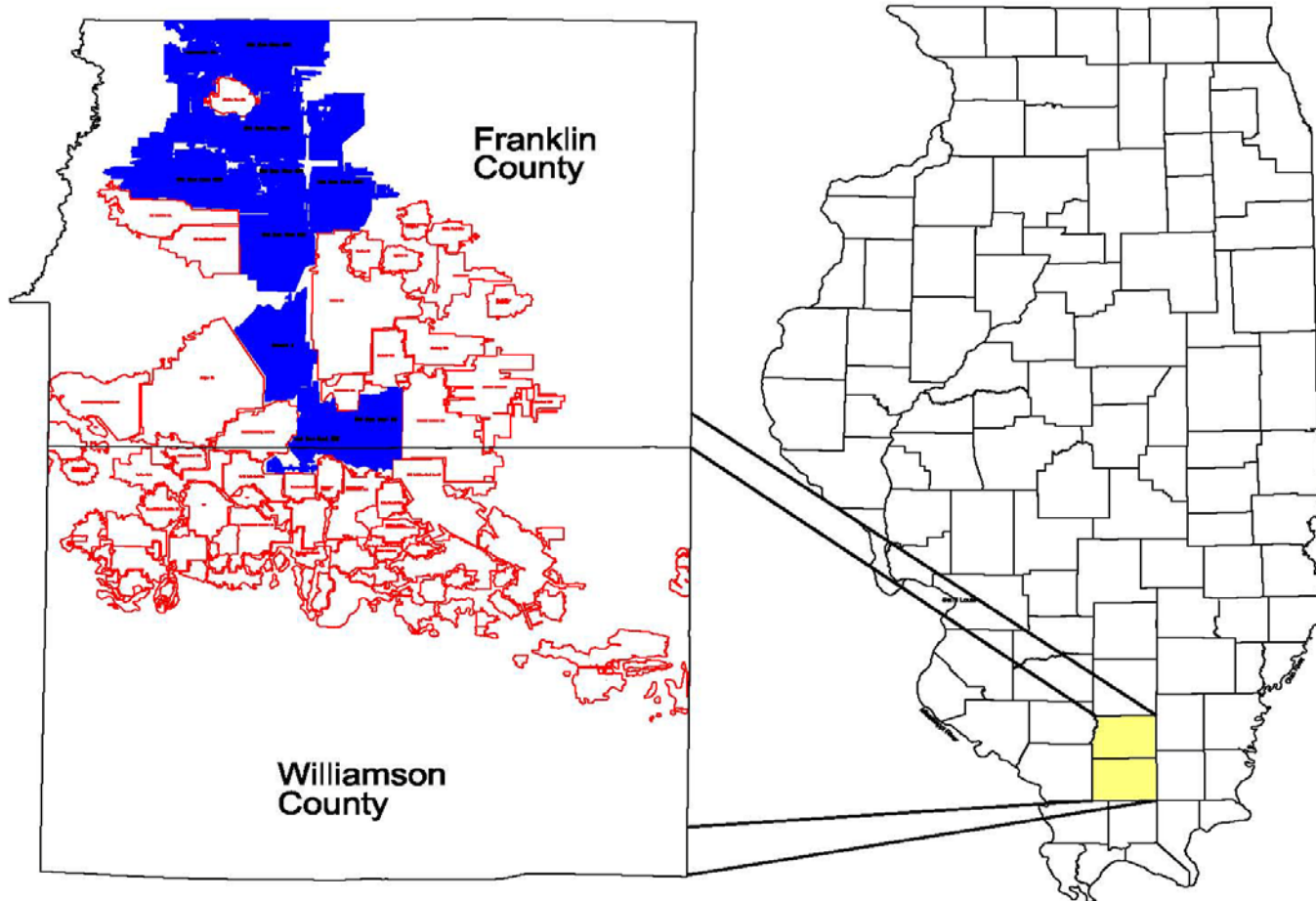
# Location of State of Illinois

伊利诺斯州所在地

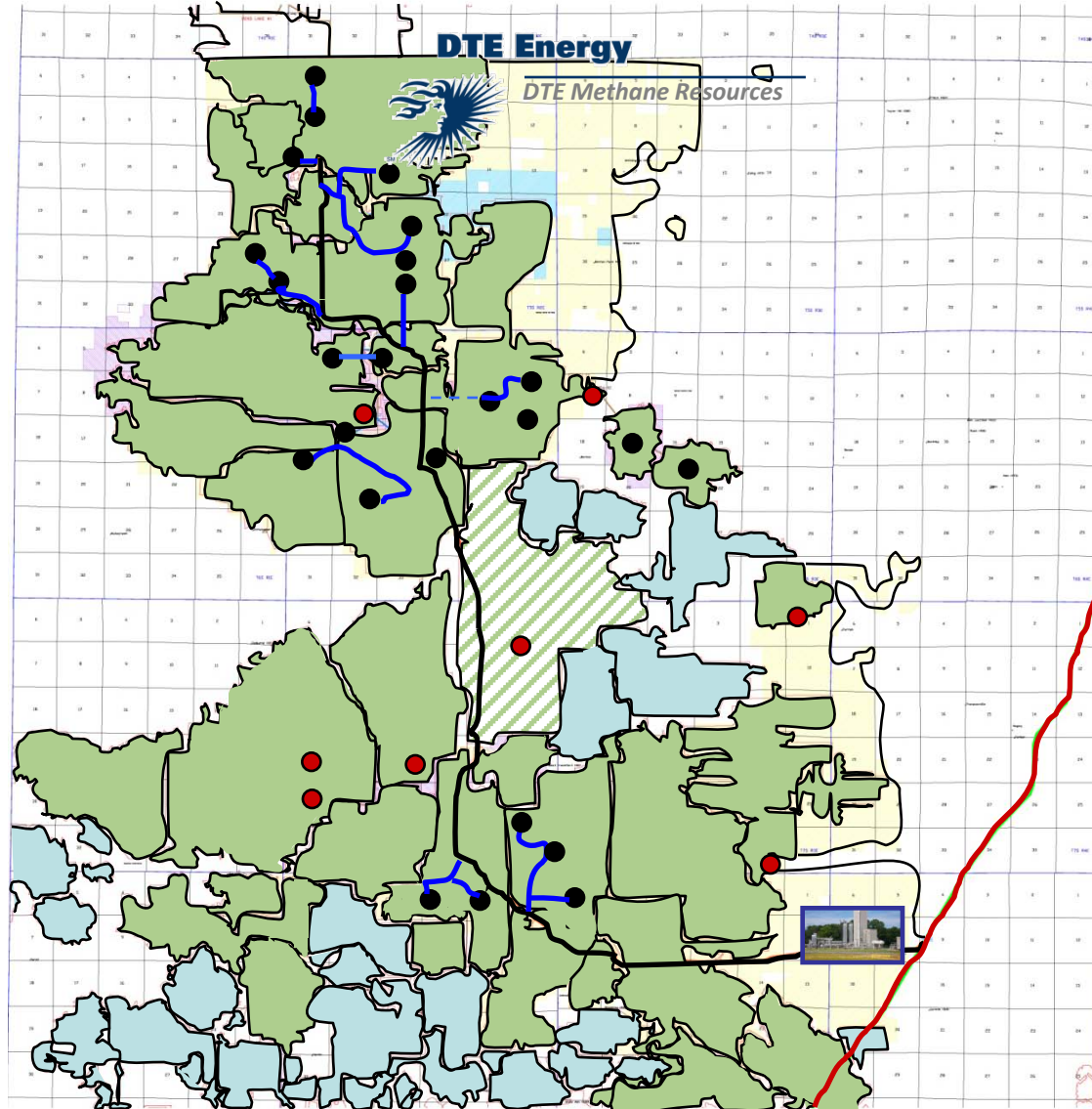
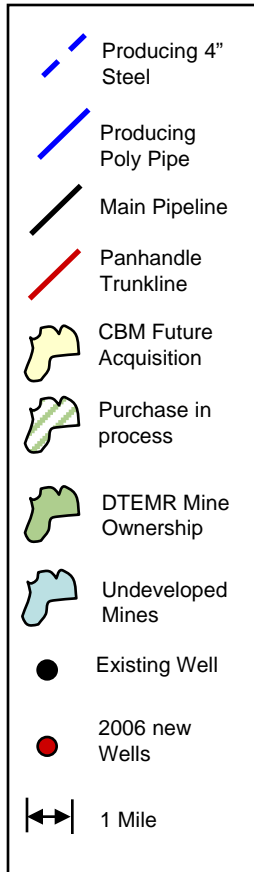


# Project Background

## 项目背景



83,000 acres  
8.3万英亩  
34 wells  
34口井



# Project Background

## 项目背景

- The Mines 矿井

- The mines in the project range in depth from approximately 100 to 200 meters.

该项目的矿井深度约为**100到200米**

- All project mines are shaft mines and most are tightly sealed from the atmosphere.

该项目的所有矿井都是通风井，而且大多都被严密封存，与外界气体隔绝。

- Mine abandonment dates range from 1926 to 1996.

矿山废弃日期从**1926年到1996年**。

# Project Background

## 项目背景

- The Mines **矿井**

- The average gas composition is 72% methane, 20% nitrogen and 8% carbon dioxide.

气体成分的平均构成为**72%**的甲烷，**20%**的氮气和**8%**的二氧化碳。

- The pressure in the mines prior to production ranged from 6.9 kpa to 106.2 kpa above atmospheric (1 psig to 15.4 psig) averaging 71.7 kpa (10.4 psig),

投入生产前矿井的压力范围为**6.9kpa**到**106.2kpa**（**1psig**到**15.4psig**），平均值为**71.7kpa** (**10.4psig**)

- The average mined coal seam thickness is 2.5 meters (8.3 feet)

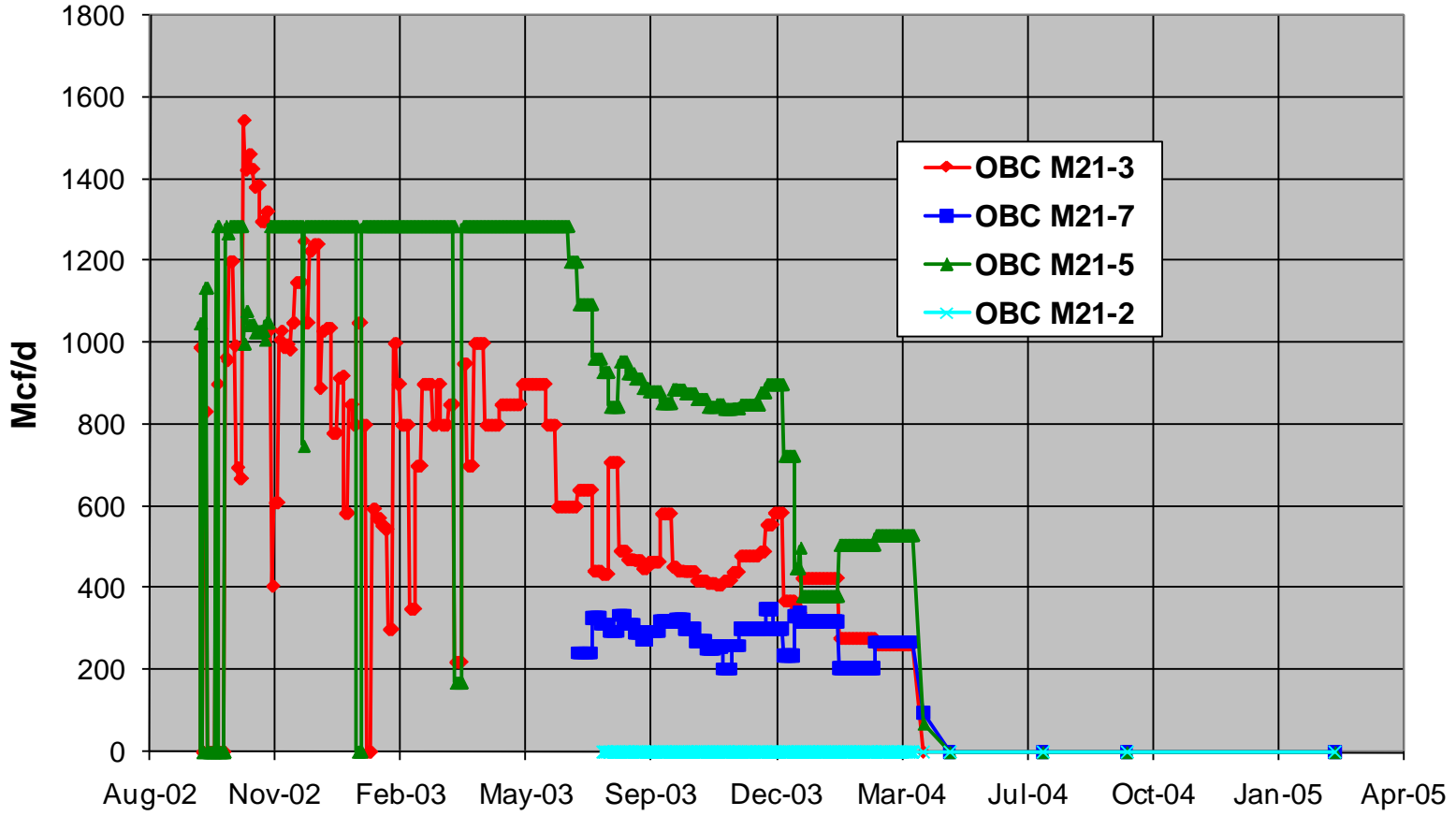
平均开采煤层厚度为**2.5米**（**8.3英尺**）

# Project Background

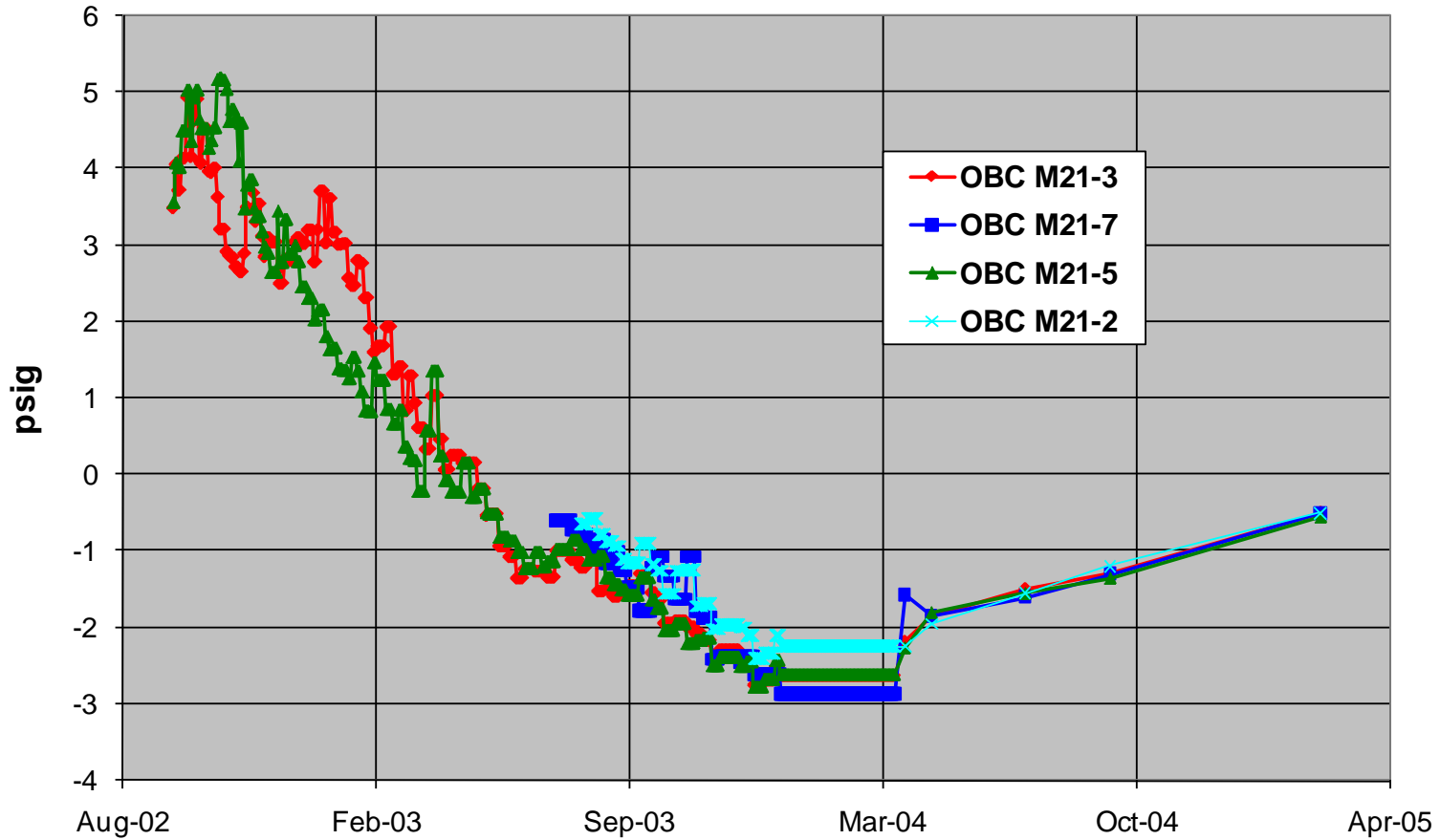
## 项目背景

- The Mines 矿井
  - The wells in each mine were found to be in pressure communication with each other  
每个矿的矿井之间的压力都是彼此相通的。
  - Some mines were found to be in pressure communication with each other  
一些矿与矿之间的压力也是彼此相通的。

## Production Rate for Wells in Old Ben #21



## Flowing Wellhead Pressure for Wells in Old Ben #21



# Project Background

## 项目背景

- Risks 风险

- Mines are water flooded. 煤矿被水淹。
- Low pressure (leakage or historical venting).

低压（泄漏或历史泄气）

- Well location (roof collapse or tight seals).

矿井位置（屋顶坍塌或密封太紧）

- Air inflow (gas quality issue).

空气流入（气体质量问题）

- Recharge rate of methane limits production rate.

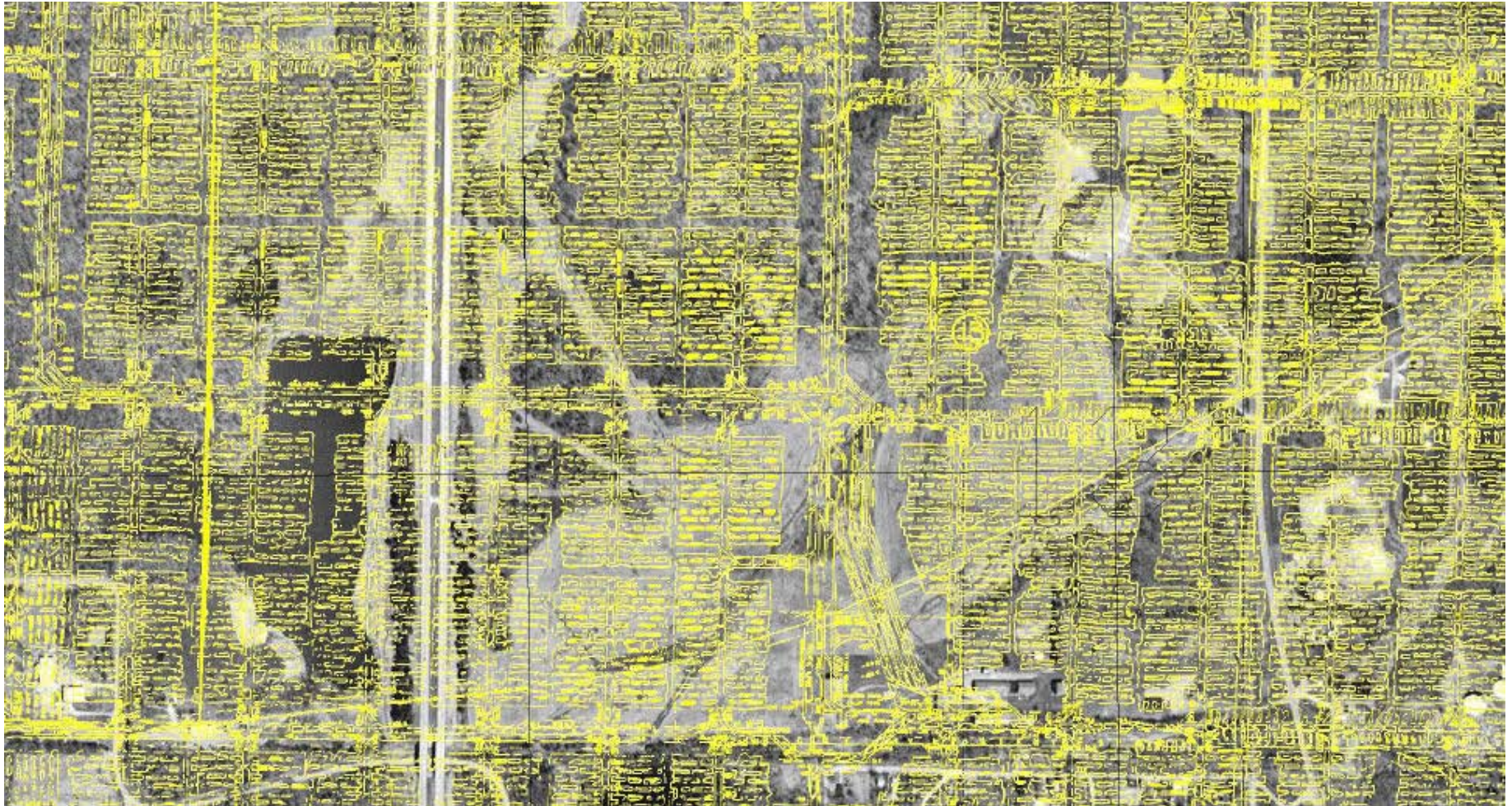
甲烷补给率限制生产速度

- Drilling into coal pillars.

钻探煤柱

# Photo Overlay on Mine Map

矿区覆盖图片



# Operations: Wells

## 矿井操作

- Metering runs consist of either venturi tubes or orifice runs  
测量包括文丘里管或孔口运行
- Meters are read monthly 每月都会进行测量
- Quarterly calibration checks 每季度都会进行校准检查
- Quarterly gas sampling 每季度都会进行气体采样
- Well headers to field stations are HDPE 井外部场站的填充物是高密度聚乙烯

# Operations: Wells

## 矿井操作

- Drilled using truck-mounted rigs commonly used for coring of coal exploration wells

使用常用的勘探煤矿的车载钻机进行钻孔

- Blowout preventers are necessary 放喷装置十分必要

- Casing program 套管程序

- 8-5/8 inch (219 mm) surface casing

**8-5/8英寸 ( 219毫米) 表面套管**

- 5-1/2 inch (140 mm) production casing cemented to surface

**5-1/2英寸 ( 140毫米) 水泥硬化地面生产套管**

- Case to within 50 feet (15.2 m) of mine void

只可深入到**50英尺 ( 15.2米) 的矿井处**

- Drill into mine with a 4-3/4 inch (121 mm) bit

用**4-3/4英寸 ( 121毫米) 的钻机钻进矿井**

## Operations: Field Compressor Stations 野外压缩站操作

- Wells connected to individual field stations via HDPE pipelines  
矿井通过高密度聚乙烯管道连接到单个野外压缩站
- Standard infrastructure at each field station includes suction scrubber, compressor-gas engine skid, discharge scrubber, and metering  
每个压缩站的标准基础设施包括吸入式洗涤器，压缩机--防滑气体发动机，卸货洗涤器和计量器
- Compression equipment comprises oil-flooded rotary screw compressors driven by gas engines operating on coal mine methane  
压缩设备包括甲烷燃气发动机驱动的石油淹没式旋转螺杆压缩机

# Operations: Field Compressor Stations

## 野外压缩站操作

- Gas compression capacities vary from 100 Mscf/d (2832 m<sup>3</sup>/d) to 1700 Mscf/d (48140 m<sup>3</sup>/d)  
气体压缩能力从**100 Mscf / d** ( **2832**立方米/ d ) 到**1700Mscf / d** ( **48140m<sup>3</sup>/ d** ) 不等
- 40 to 400 BHP (29.8 to 298 kW); six stations total  
**40至400BHP** ( **29.8至298**千瓦) ;共**6**个站点
- Nominal design compressor operating range is -3 psig (80 kPa) intake up to 170 (1274 kPa) psig discharge pressures  
通常压缩机工作范围是**-3 psig** ( **80**千帕) , 摄入量可达**170** ( **1274**千帕) **psig**排放压力
- Two full-time field operators 两个全职野外操作者
- Gas accumulator bottles are installed to obtain a weighted average gas composition  
安装集气瓶以保持加权平均气体成分

## Operations: Gathering Pipeline 集输管道操作

- Twenty-nine (29) miles (47 km) of 8-inch (203 mm) diameter carbon steel, internally coated pipeline  
**29英里（47公里）的直径为8英寸（203毫米）的有内壁涂层的碳钢管道**
- Maximum operating pressure of 720 psig (5067 kPa)  
**最大操作压力为720psig(5067kpa)**
- Capacity up to 14000 Mscf/d (396443 m<sup>3</sup>/d)  
**容量达到14000Mscf/d(396443 m<sup>3</sup>/d)**
- Typical operating pressures range from 130 to 140 psig (998 to 1067 kPa) at the beginning of the pipeline to about 90 psig (722 kPa) at the processing plant  
**典型的操作压力范围从刚开始的130到140 psig（998至1067千帕）到加工中的约90 psig（722千帕）**
- Quarterly Batch inhibition schedule for corrosion protection  
**拟定季度批次时间表以用于腐蚀保护**

## Operations: Gas Processing Plant 气体处理厂操作

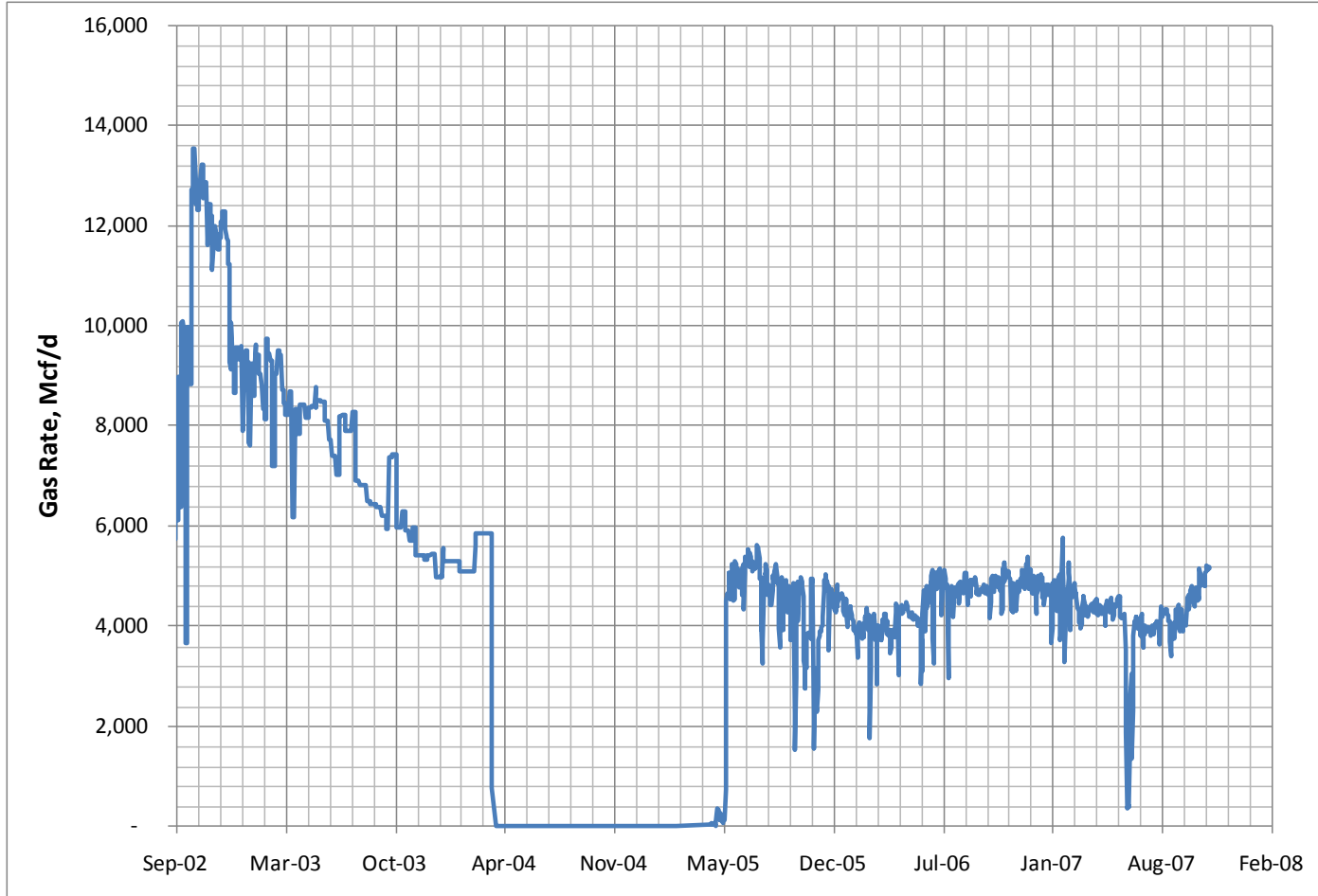
- Inlet Gas Quality 进气质量
  - Methane: 74% 甲烷**75%**
  - Nitrogen: 18% 氮**18%**
  - Carbon Dioxide: 8% 二氧化碳**8%**
  - Oxygen: 0.1% 氧气**0.1%**
  - Hydrogen Sulfide: Trace to 5 ppm 硫化氢: 微量 至**5ppm**
  - Heating Value (HHV): 750 Btu/scf (28 MJ/m<sup>3</sup>)  
高热值: **750Btu/scf(28MJ/m<sup>3</sup>)**

## Operations: Gas Processing Plant 气体加工厂操作

- Inlet Gas Volumes 进气容积  
Design: 12500 Mscf/d (353957 m<sup>3</sup>/d)  
设计: **12500 Mscf/d (353957 m<sup>3</sup>/d)**  
Current Rates: 4000 to 6000 Mscf/d (113270 to 169904 m<sup>3</sup>/d)  
目前费率计算: **4000 to 6000 Mscf/d (113270 to 169904 m<sup>3</sup>/d)**
- Plant Design & Construction: 工厂设计与施工  
BCCK Engineering (Midland, TX) **BCCK**工程公司 (米德兰, 美国得克萨斯)
- Four full-time Operators (24/7 coverage) 四名全职工人 ( **24 / 7**覆盖率)
- One full-time Facility Manager 一名全职设备经理

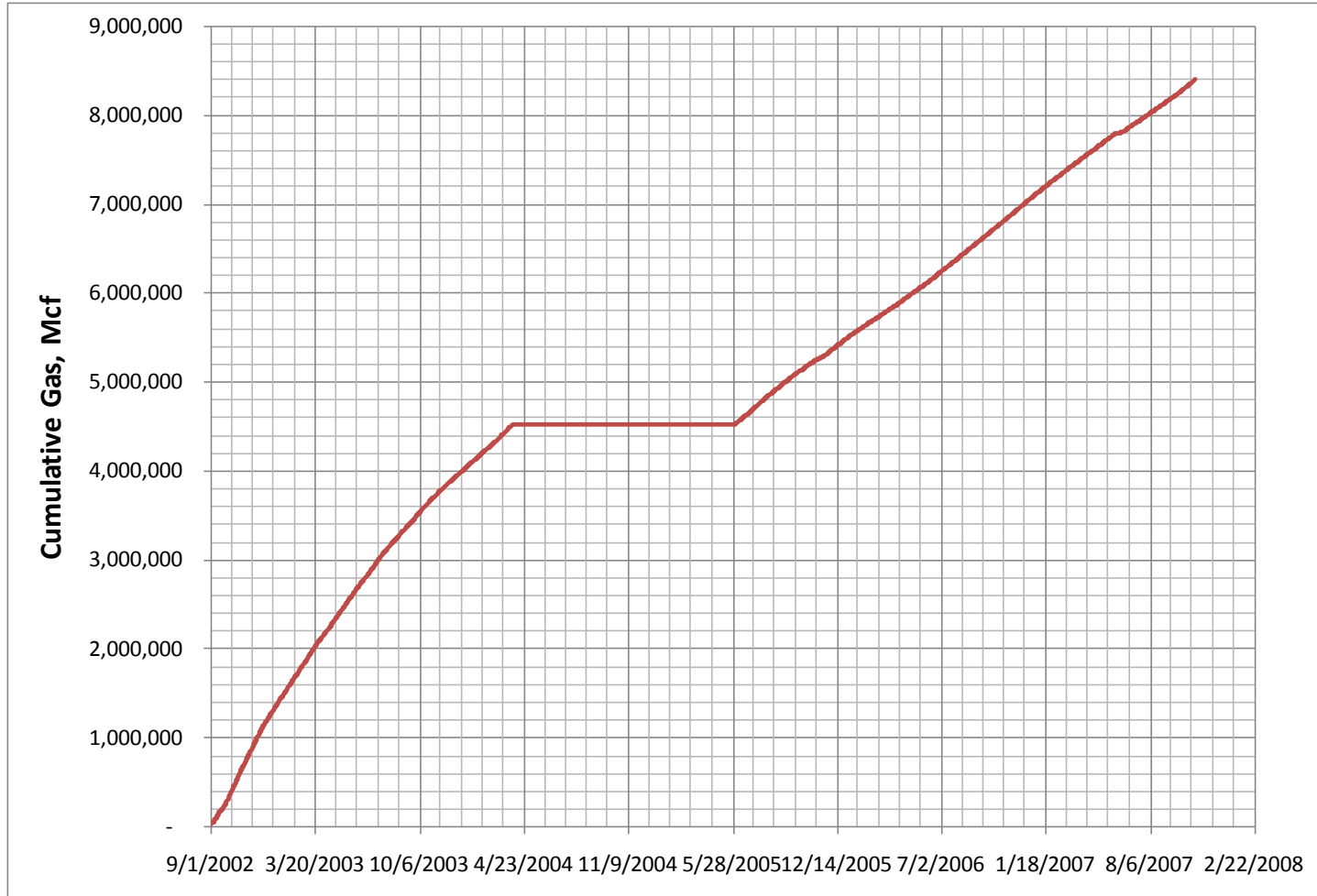
# Project Performance

## 项目执行情况



# Project Performance

## 项目执行情况



# Estimating Reserves

## 预计储量

- Build a conceptual numerical model for Computational Fluid Dynamics simulation for each mine.  
为每个矿井建立一个概念数值模型以模拟计算流体动力学。
- Each model is based on:每个模式的基础是:
  - Known information 已知信息
  - Estimated information 估算信息

# Known Information

## 已知信息

- Pressure in the void area 空隙面积压力
- Mine size 矿井规模
- Gas production and pressure history

气体生产和压力历史

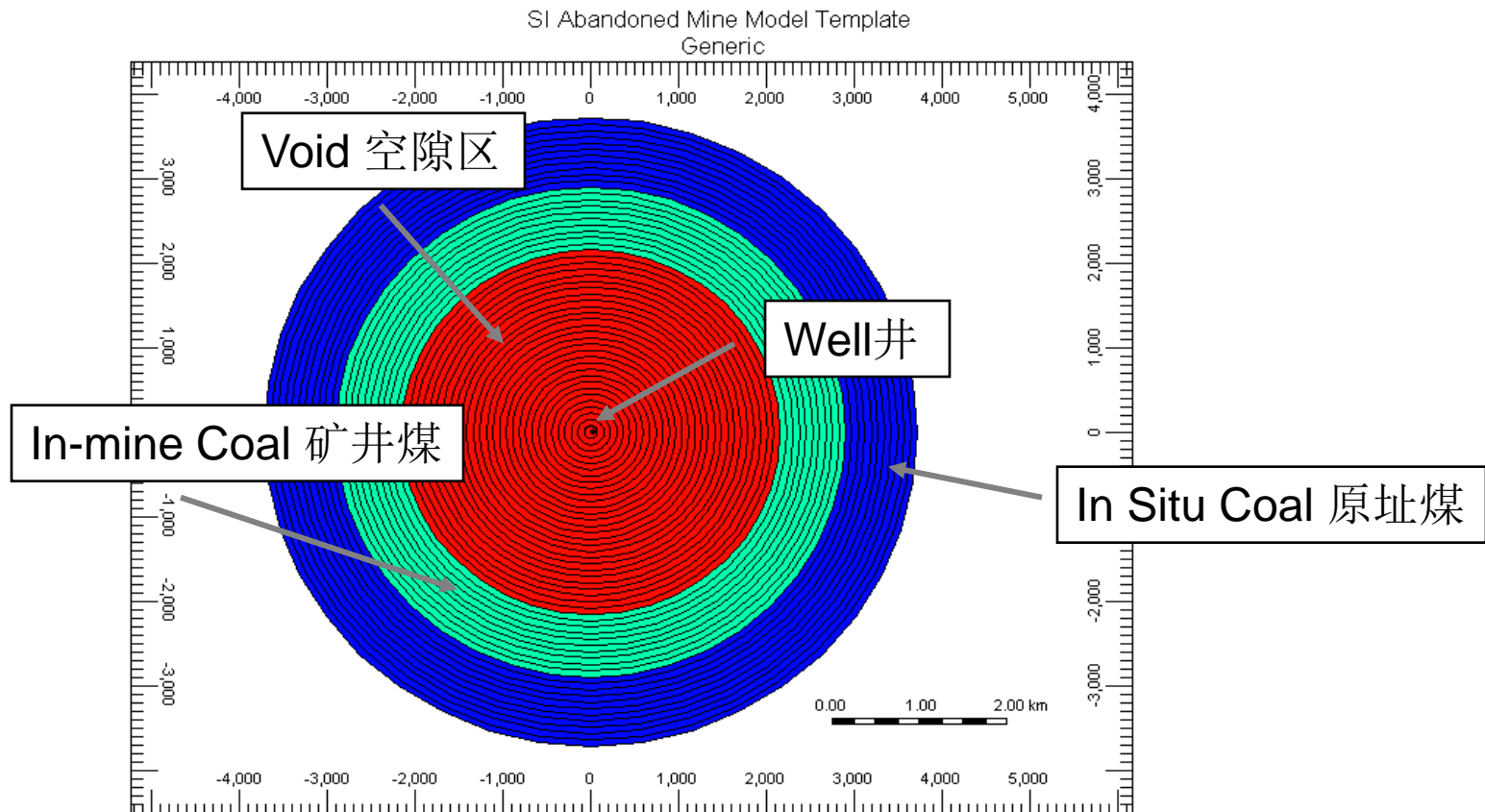
# Estimated information

## 估算信息

- Volume of coal in contact with void based on stratigraphic column  
根据地层柱得知接触空隙面积的煤炭量
- Permeability of coal and void 煤的渗透性和空隙面积
- Adsorption isotherm 吸附等温线
- Sorption time 吸附时间
- Initial assumption that the mine is not flooded 最初假设矿井未被淹没

# Areal View of a Conceptual Abandoned Mine Model

## 概念性废弃矿井模型的横切面视图



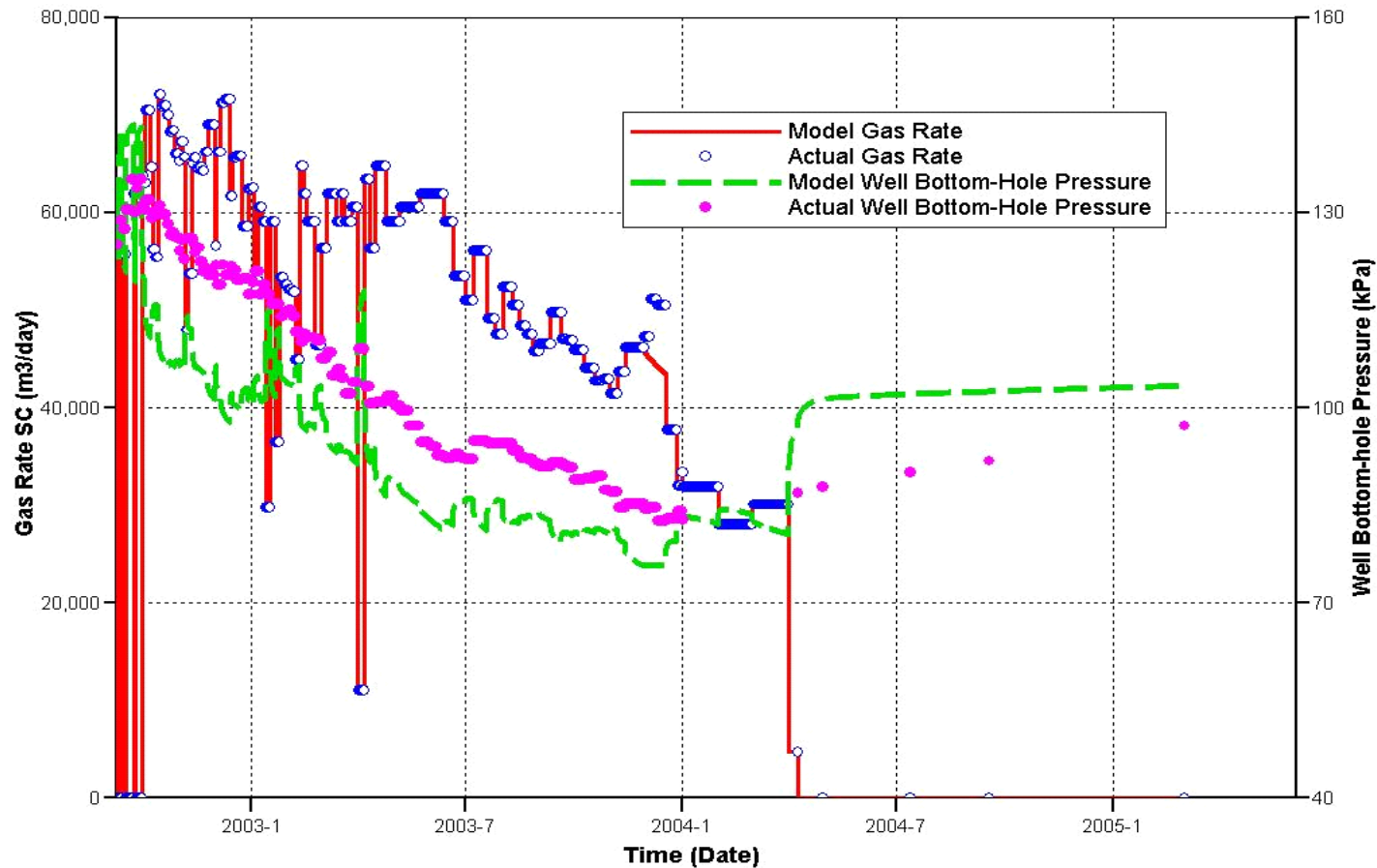
# Estimating Reserves

## 估算储量

- Model calibration 模型校准
  - The model's gas production rate is forced to match actual data.  
该模型的天然气产率应与实际数据相匹配。
  - Flowing wellhead pressure is predicted by the model  
流动井口压力通过模型预测
  - The model's permeability and volume parameters are modified within limits to match measured wellhead pressure data  
该模型的渗透率和体积参数在一定范围内进行修正，以符合测量的井口压力数据

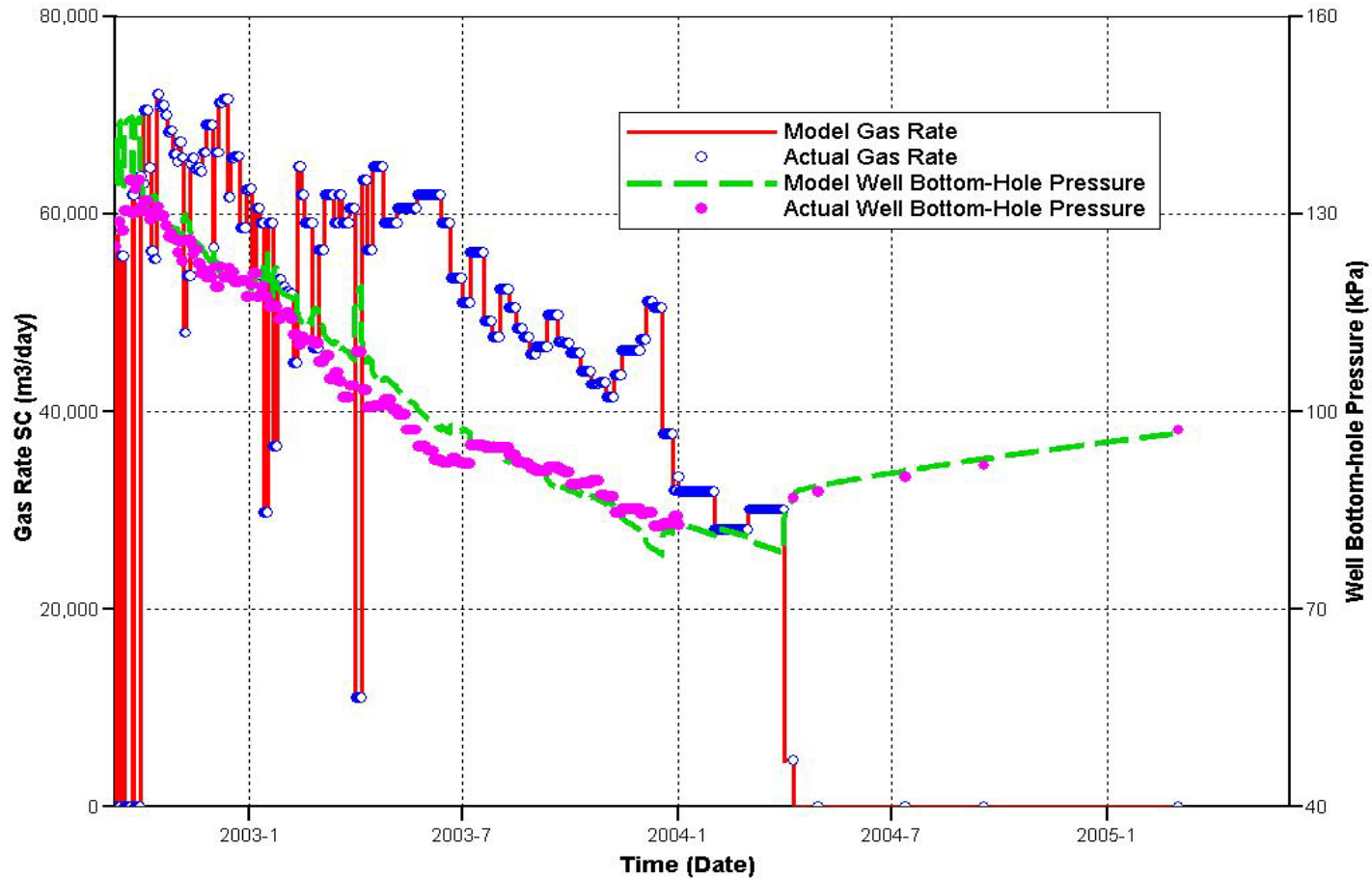
# Initial Pressure Match 初始压力匹配

SI Abandoned Mine Model Template  
Mine 21



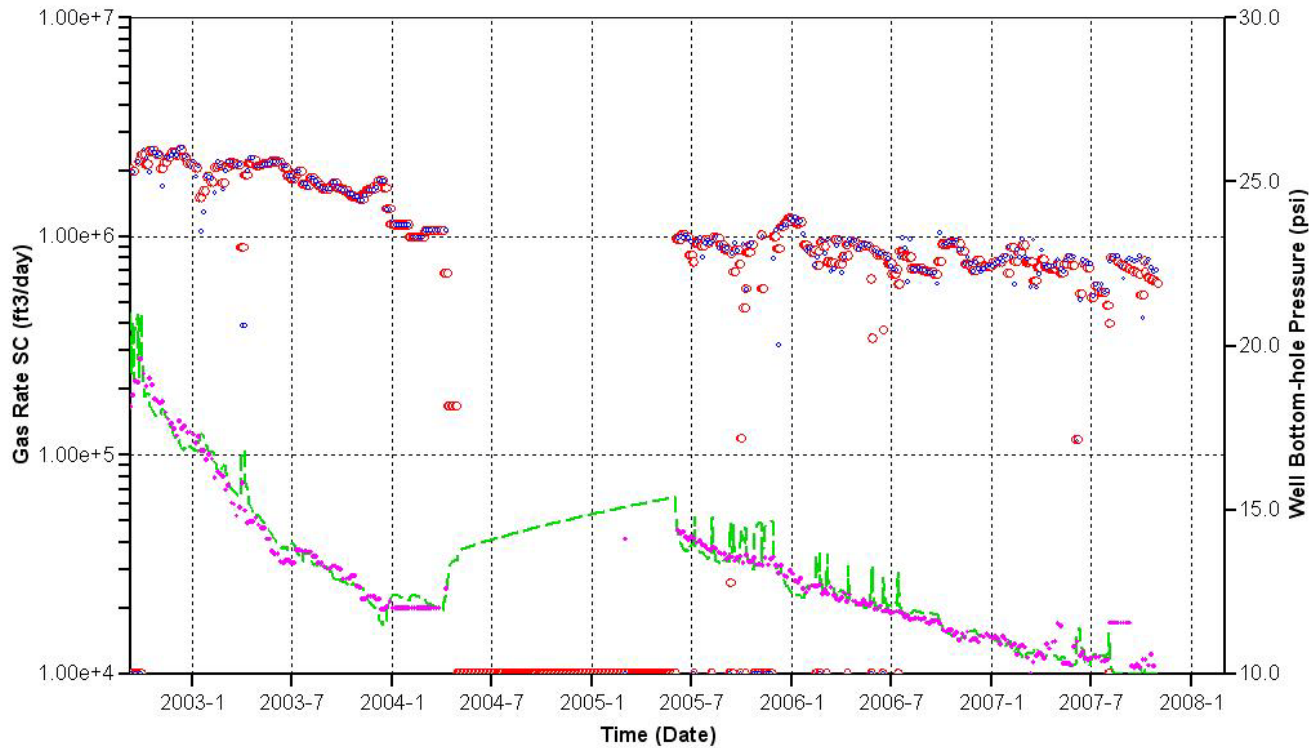
# Final Pressure Match 最终压力匹配

SI Abandoned Mine Model Template  
Mine 21



# History Match After 5 Years 5年后的历史匹配

SI Abandoned Mine Model Template  
Old\_Ben\_21



- Gas Rate SC OBC\_21 11-07.irf
- Gas Rate SC OBC\_21-rate 11-07.fhf
- Well Bottom-hole Pressure OBC\_21 11-07.irf
- Well Bottom-hole Pressure OBC\_21-rate 11-07p.fhf

Expected Ultimate Recovery, 预计最终采收率

Mine 井	Mcf	Million m <sup>3</sup> <sub>百</sub> 万立方米
OBC #8	940,982	26.6
OBC #14	2,436,243	69.0
OBC #15	378,499	10.7
OBC #19	217,552	6.2
OBC #21	2,490,489	70.5
OBC #22	1,340,187	38.0
OBC #24	2,356,221	66.7
OBC #26	3,605,208	102.1
Orient #1	741,098	21.0
OBC #25	485,592	13.8
OBC #27	140,854	4.0
	<b>15 132 926</b>	<b>429</b>

## Lessons Learned经验教训

- Adequate resource evaluation is essential to avoid over-sizing facilities  
为避免设施过大，充足的资源评估是必不可少的
- All gas processing technologies should be considered  
所有气体处理技术都应该考虑在内
- Monitoring production volumes, wellhead pressures and gas composition is essential for reserves analysis
- 监测生产量、井口压力和气体成分对于储量分析来说是必不可少的

# Lessons Learned

## 经验教训

- Reservoir models need to be updated periodically to adequately account for long-term recharge rates  
水库模型需要定期更新，以充分考虑长期补给率
- Well location selection requires detailed evaluation of mine maps  
矿井选址需要对矿井地图进行详尽评估
- Performance risk based on flooding and/or compartmentalization needs to be taken into account  
必须考虑到基于洪灾和/或条块分割需要所引起的行为风险。

# Thank you 谢谢

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# Definitions and Conversions

## 定义与转换

- kPa: kilo Pascal  
**kpa:**千帕
- psig: pounds per square inch gauge  
**psig:**磅每平方英寸
- Mscf/d: thousand standard cubic feet per day  
**Mscf/d:**千标准立方英尺每天
- BHP: break horsepower 马力
- kW: kilowatts 千瓦
- BTU: British thermal unit 英国热量单位
- scf: standard cubic foot 标准立方英尺
- ppm: parts per million 百万分之一
- 1 psi = 6.9 kPa
- 1 acre = 0.4047 hectare
- 1 Mscf = 28.3 m<sup>3</sup>