

# Numerical Modelling and Prediction of Abandoned Mine Methane Recovery: Field Application at the Saar Coalfield, Germany

Sevket DURUCAN

Ji-Quan Shi, Anna KORRE

Minerals, Energy and Environmental Engineering Research Group  
Department of Earth Science and Engineering  
Royal School of Mines  
Imperial College London



# Outline

- ❑ Background on Imperial CBM simulator METSIM2
- ❑ Abandoned mines methane extraction in the Saar Coalfield
- ❑ Abandoned mine model development
- ❑ History matching of field production data (Hangard shaft)
- ❑ Production forecasts for two new boreholes
- ❑ Summary and conclusions

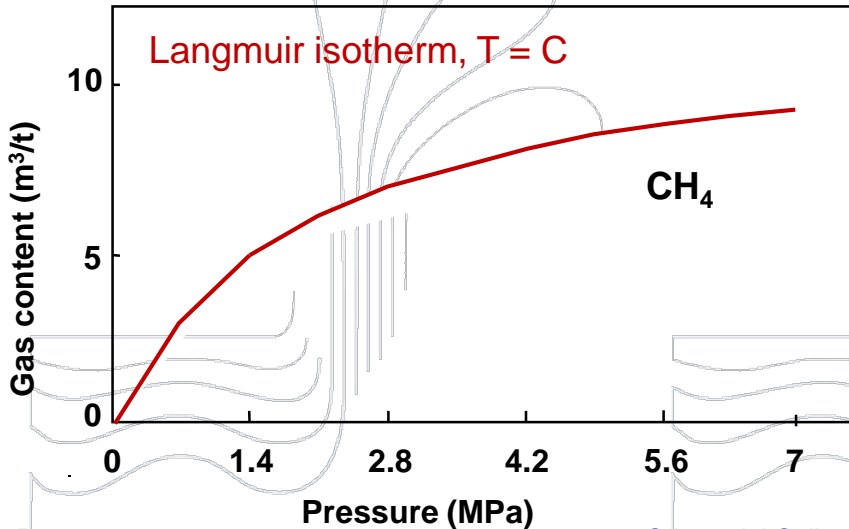


# Coal as a Reservoir Rock

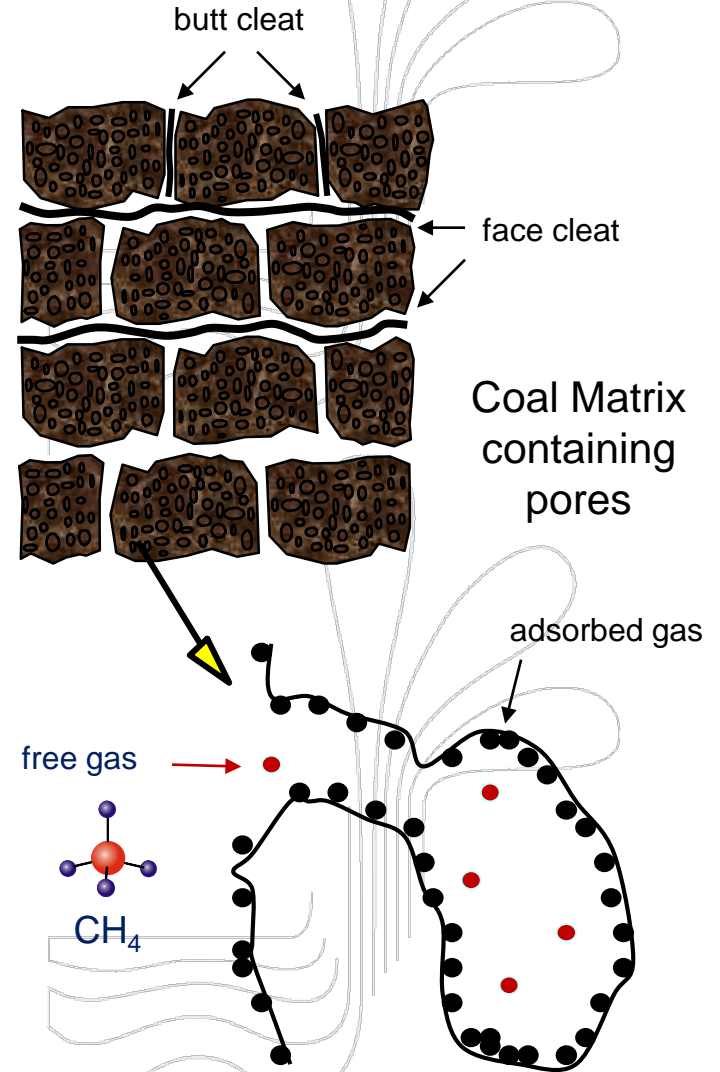
## Uniform and orthogonal fracture (CLEAT) structure



- Macropores > 50 nm
- Mesopores 2 – 50 nm
- Micropores < 2 nm
- Cleat system (2mm - 25 mm)
- Pore surface area 20 – 200 m<sup>2</sup>/gm



$$V = \frac{V_L p}{R_L + p}$$



# Imperial College In-House Coalbed Methane Simulator METSIM 2

**Permeability of coal is both Stress and Pore Pressure dependent**

$$k = k_0 e^{-3c_f (\sigma - \sigma_0)}$$

$$k = \frac{1}{12} \frac{b^3}{a}$$

$c_f$  – cleat volume compressibility

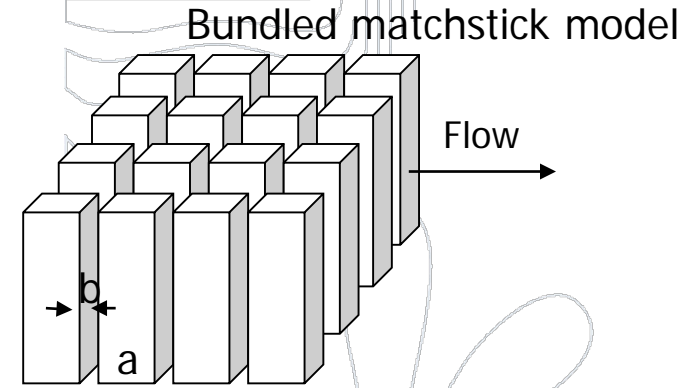
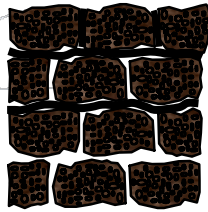
$\sigma - \sigma_0$  - changes in effective horizontal stress

$$\sigma - \sigma_0 = -\frac{\nu}{1-\nu} (p - p_0) + \frac{E\alpha_s (V - V_0)}{3(1-\nu)}$$

compaction term

shrinkage term

**Shi and Durucan Permeability Model**



(after Seidle et al., 1992)

$\alpha_s$  – shrinkage coefficient

$V$  – adsorbed gas volume

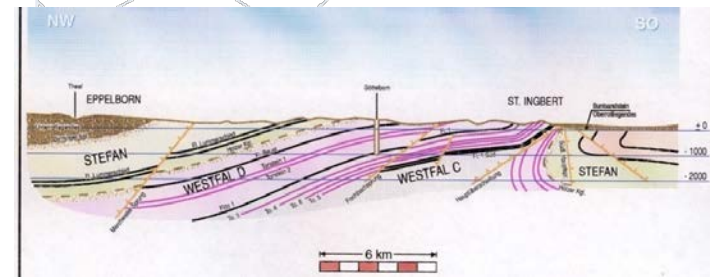
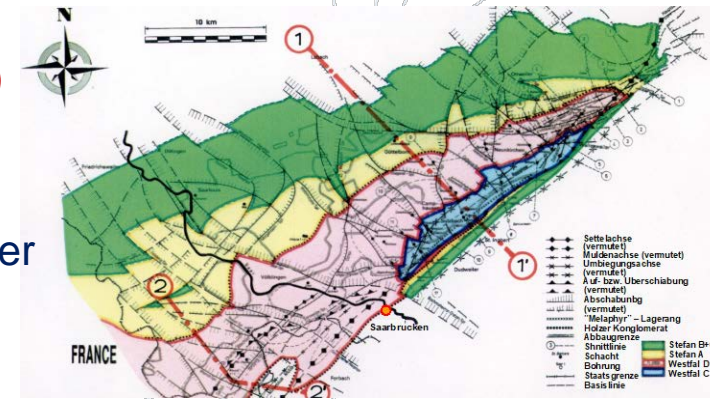
$E$  – Young's modulus

$\nu$  – Poisson's ratio

# Mining History in the Saar Basin

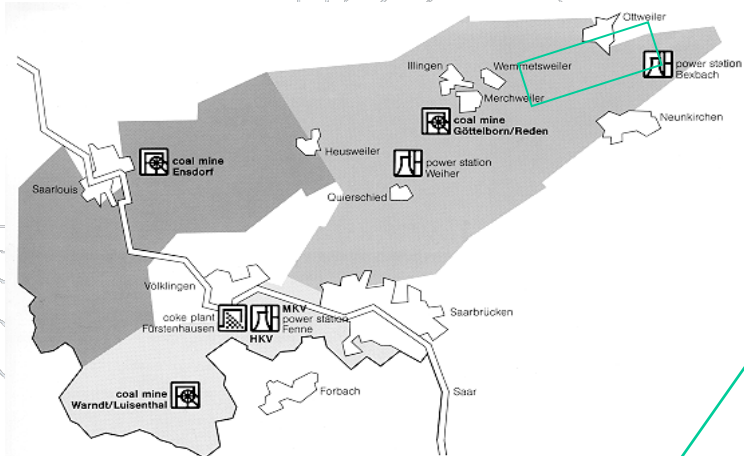
## Upper Carboniferous age (formed 350-285 Million years ago)

- 1816 Mining activities began
- 1879/82 Construction of shafts Frankenholz 1 and 2 and later Frankenholz 3, 4 and 5 (5=Hangard)
- 1903 Start of production
- 1908 Known CH<sub>4</sub> gas explosions in Saarland workings
- 1930 2.822 workers produced 484.228 tons coal
- 1941 Greatest explosion and subsequent mine closure
- 1946 Reopening of Frankenholz colliery
- 1954 Opening of St. Barbara colliery
- 1960 Connection of St. Barbara and Frankenholz mines and upcast ventilation from the Hangard shaft
- 1984 Filling of Hangard shaft (= Frankenholz 5)
- 1992 Filling of Anna shafts 1 and 2, later known as Kohlwald

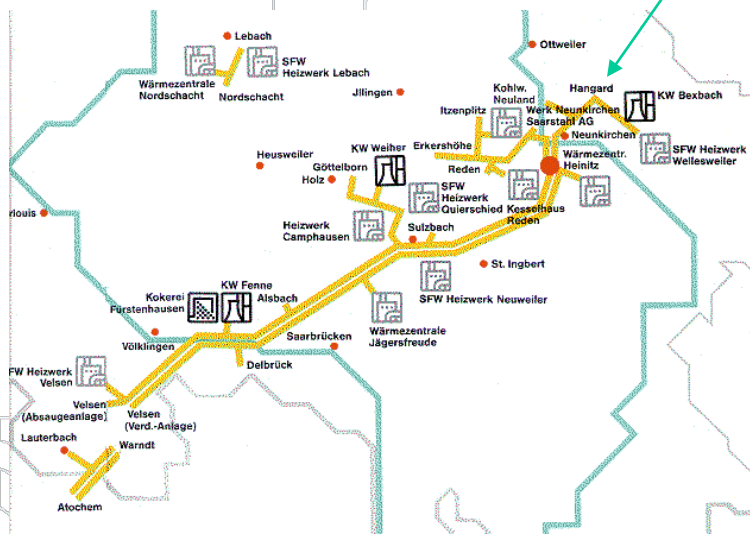


**Frankenholz Colliery is known as one of the most gassy mines in Europe**

# Saar Coalfield: Operating mine methane drainage and AMM



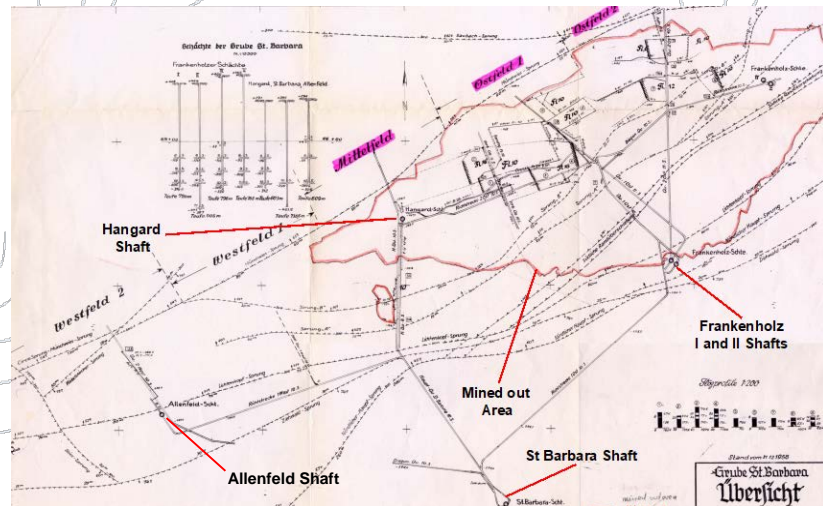
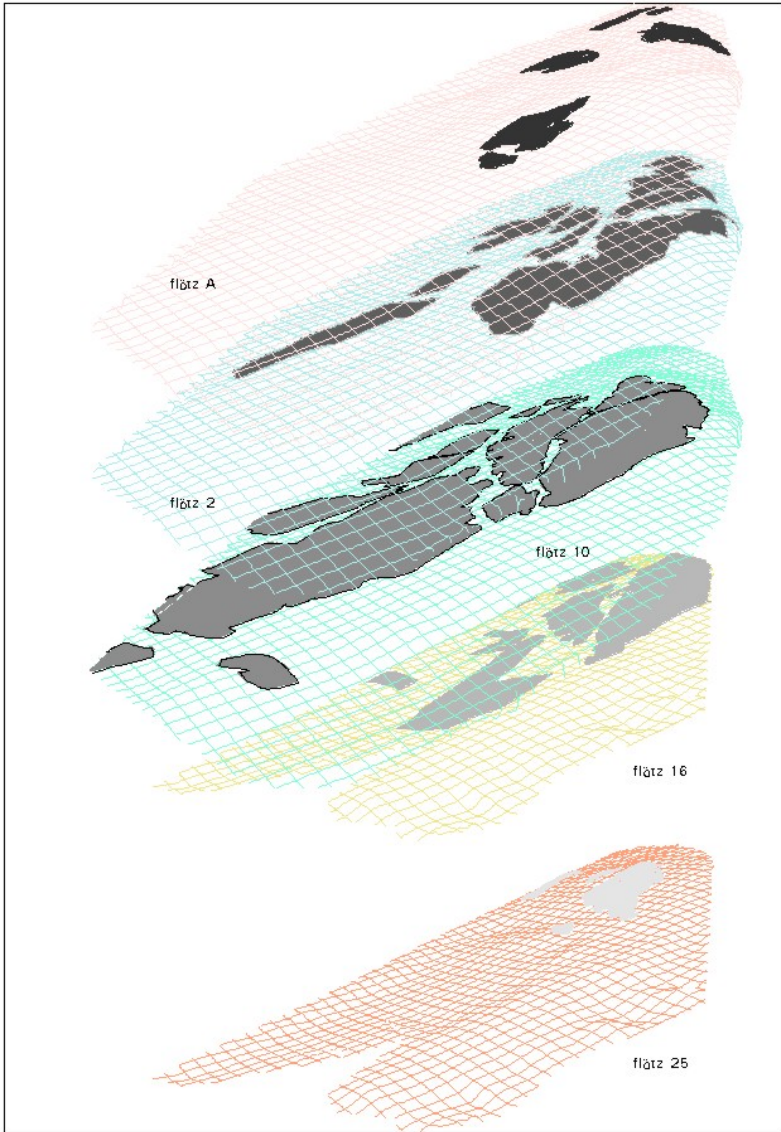
Mine	Volume flow rate per day	Methane Concentration
<b>Hangard</b>	<b>40,000 m<sup>3</sup></b>	<b>73,0 %</b>
Kohlwald	75,000 m <sup>3</sup>	52,8 %
Sinnerthal	24,000 m <sup>3</sup>	35,4 %
Reden	50,000 m <sup>3</sup>	34,5 %
Itzenplitz	102,000 m <sup>3</sup>	42,0 %
Erkershöhe	71,000 m <sup>3</sup>	30,8 %
Camphausen	125,000 m <sup>3</sup>	37,3 %
Götteleborn	75,000 m <sup>3</sup>	29,1 %
Alsbach	127,000 m <sup>3</sup>	34,6 %
Delbrück	174,000 m <sup>3</sup>	50,0 %
Velsen	130,000 m <sup>3</sup>	43,6 %
Warndt	195,000 m <sup>3</sup>	49,2 %
Nordschacht	18,000 m <sup>3</sup>	32,9 %



Until 2002 DSK produced mine gas from 13 shafts, with methane concentrations in the produced gas varying from 30 to 90%.

In 2003 the gas production activities have been transferred to a regional energy producer, STEAG Saar Energie AG (now STEAG New Energies GmbH).

# Frankenholz – St. Barbara Mining Complex



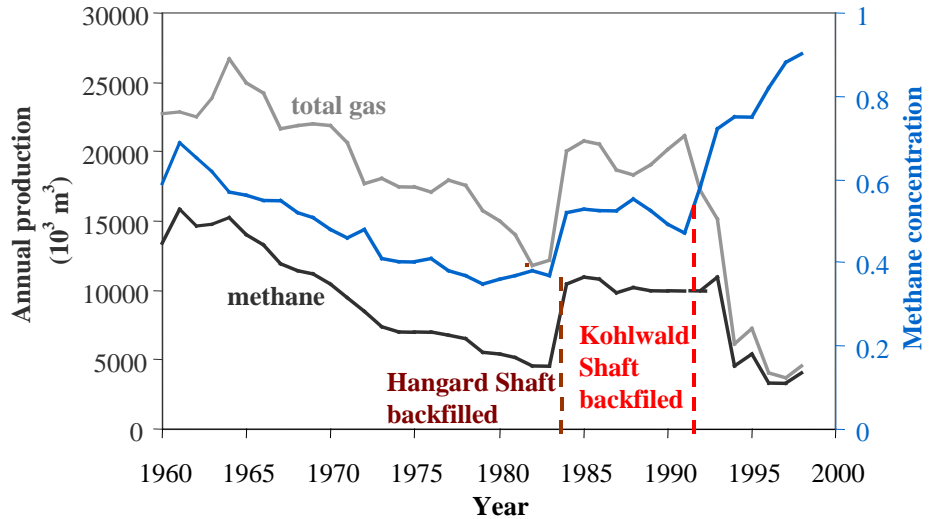
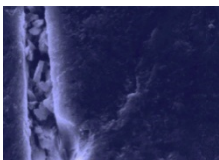
Up to 32 seams of varying thickness between 0.3 – 3 m in the Frankenholz - St. Barbara mining complex, dipping in Northwest direction.

Between levels 1 and 11 (- 470 m), where the water level was before filling of the Hangard shaft in 1984, the total thickness of coal is calculated as 40 metres in 430 metres of coal measures strata.

The water level in the mining complex rose from level 11 (- 470 m) to between levels 9 and 10 (- 244 m) by 1984 and has remained at the same level since

From 1833 to 1959, Frankenholz and St. Barbara Collieries jointly mined a total coal surface area of 4.5 km<sup>2</sup>

# Historical Gas Production from the Hangard Shaft



Gas extraction from the Hangard shaft reached over 26 million m<sup>3</sup> per annum with a methane concentration of over 57% in the first few years of production.

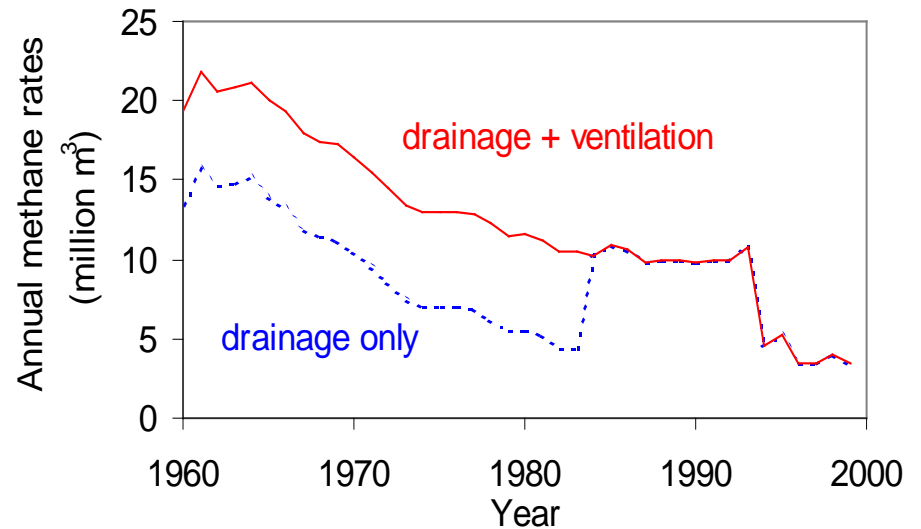
The back-filling of Hangard Shaft in 1984 resulted in an immediate recovery in both the gas rates and methane concentration, reaching approximately 20 million m<sup>3</sup> per annum and 55% respectively.

The produced gas quality was further boosted to a high of 90% methane following the filling of the Kohlwald Shaft in 1992.

Hangard has vented an average of 6 million m<sup>3</sup> of methane per annum between 1981 and 1984.

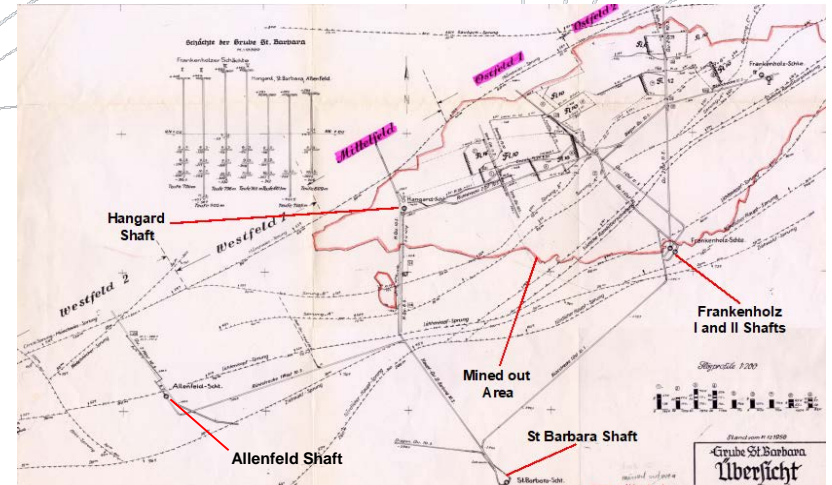
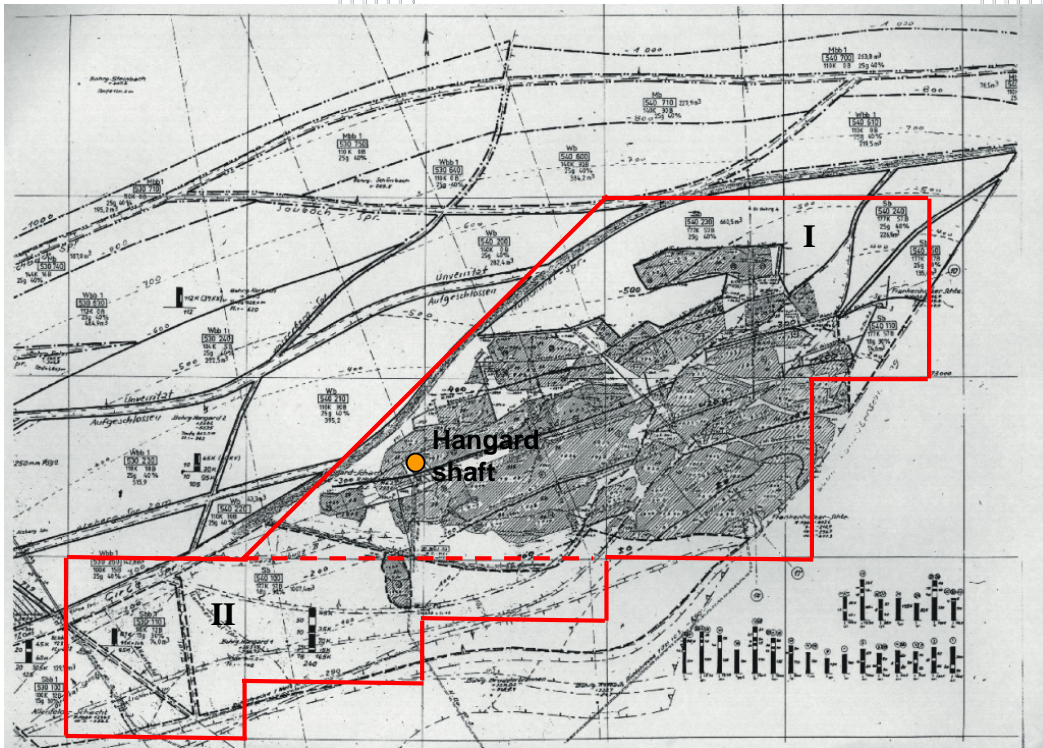
After the filling of Hangard shaft in 1984 the free methane gas in the mine air was also recovered.

Assuming that an average volume of 6 million m<sup>3</sup> methane was lost through ventilation in the period from 1960 to 1984, the total methane flow rates at the Hangard shaft were plotted.





# Abandoned Mine Reservoir Model Development



An areal model with a uniform thickness of 40 m (the net thickness of all the seams down to - 470 m) was built.

A uniform grid of 710 active gridblocks (100m x 100m) used.

5.0 million m<sup>2</sup> in the Northeast region (I) and 2.1 million m<sup>2</sup> in the Southwest region (II) yielding a net coal volume of 7.1 m<sup>2</sup> x 40 m = 284 million m<sup>3</sup>.

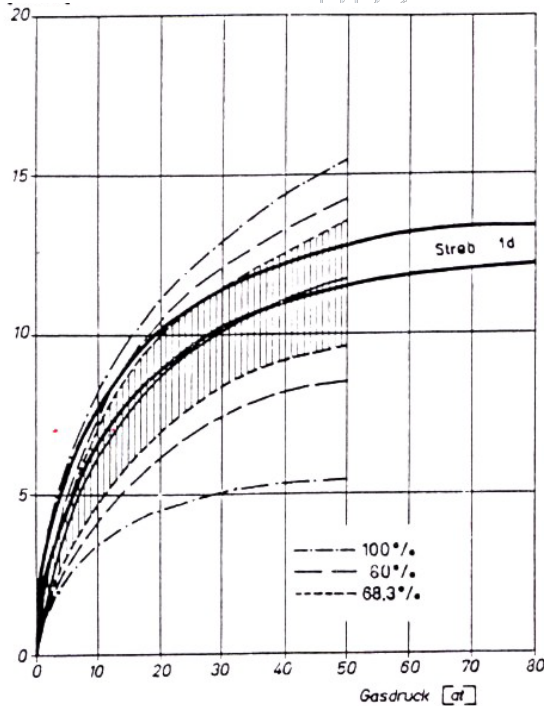
# In situ Gas Content and Initial Gas-in-place

## In situ gas content estimates at Frankenholz – St. Barbara Mining Complex

**Düpre and Barth [1980]** 2,700 million m<sup>3</sup> of methane in situ in virgin conditions and 15m<sup>3</sup>/tonne for the Frankenholz – St Barbara mining area

**Kneuper and Muller [1971]** 10.77 m<sup>3</sup>/tonne for the coal seams in the Saar coalfield.

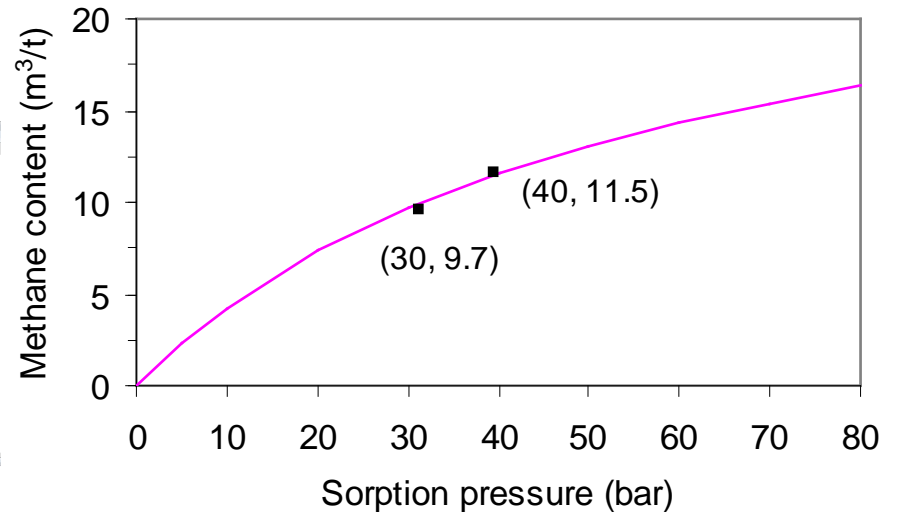
**Hebel [1999]** approximately 4,000 million m<sup>3</sup> gas in situ between levels 1 and 11 in the area defined as regions I and II in the areal model  
10.8 m<sup>3</sup>/t



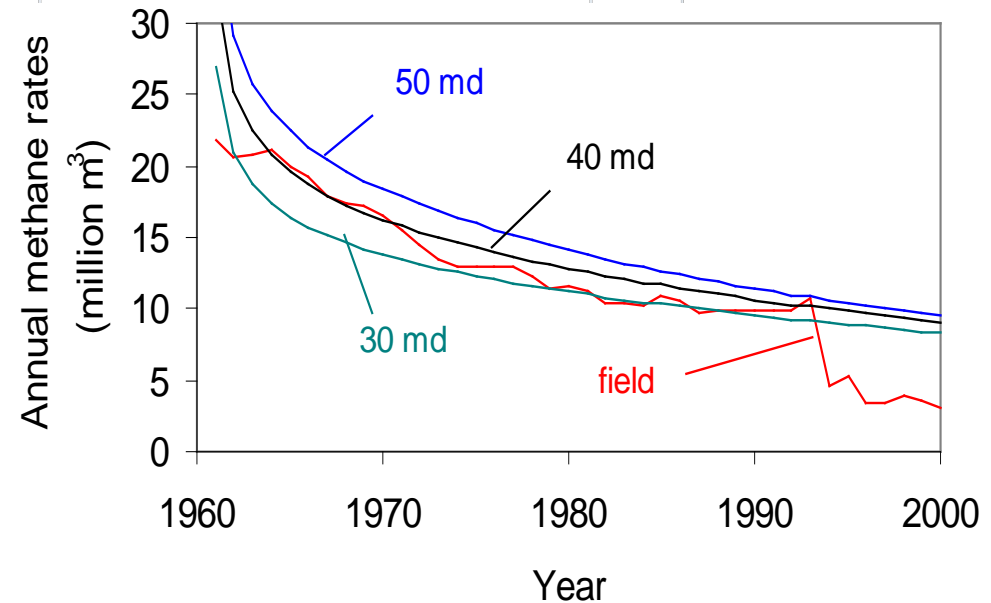
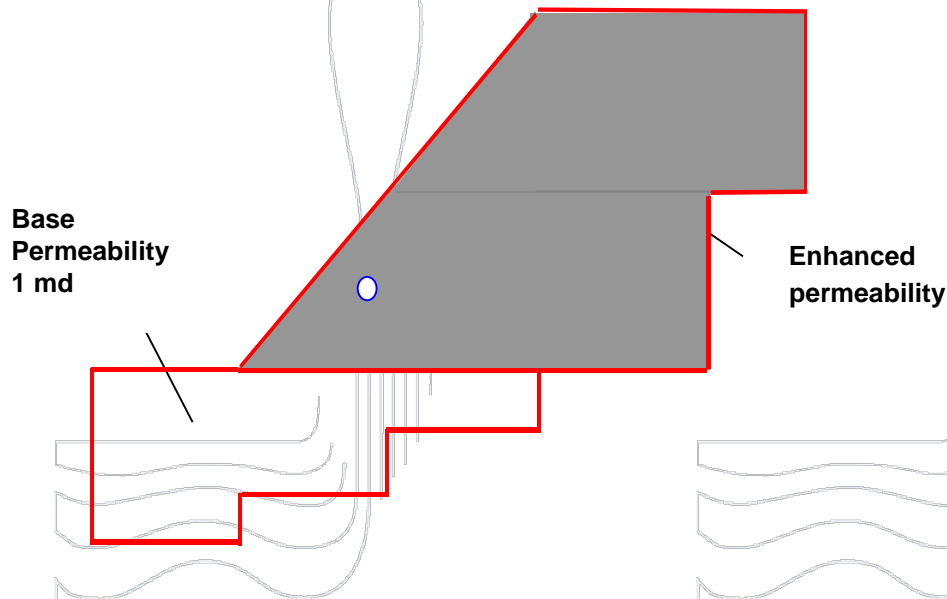
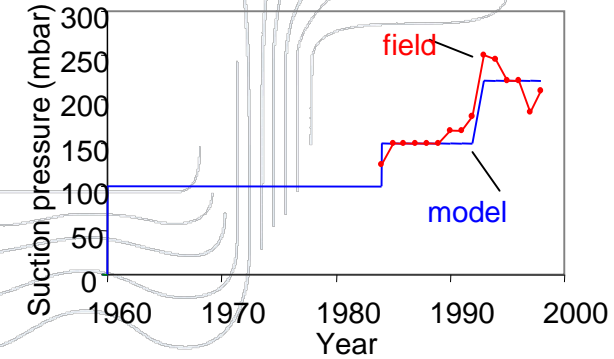
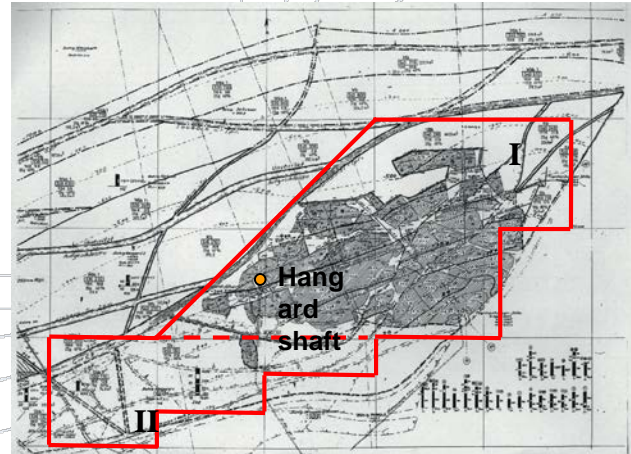
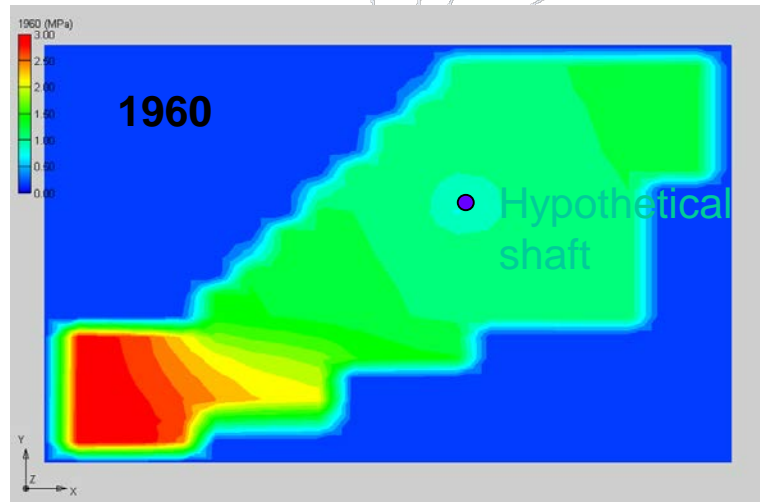
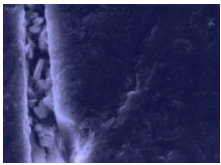
Initial gas content: Zone I = 11.5 m<sup>3</sup>/t  
Zone II = 9.7 m<sup>3</sup>/t

Total initial methane in-place = 4,000 million m<sup>3</sup>

Residual methane after abandonment = 1.800 million m<sup>3</sup>

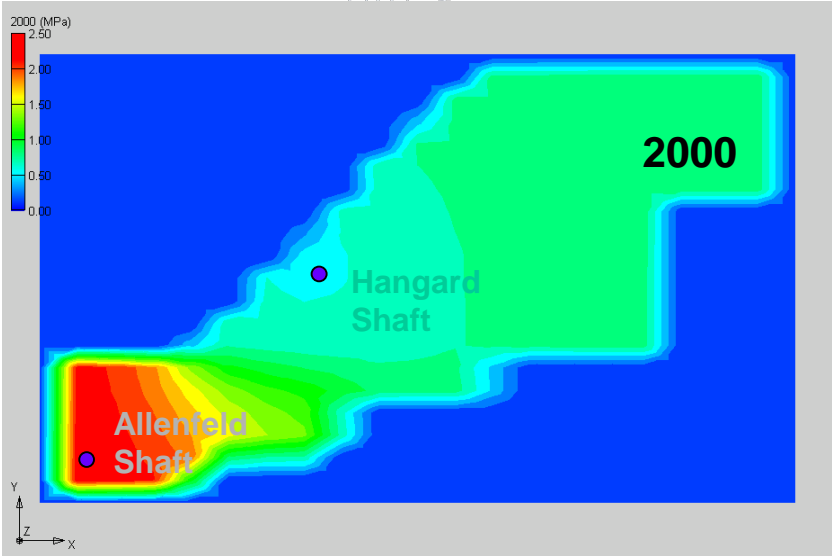


# History Matching of Field Data at Hangard Shaft

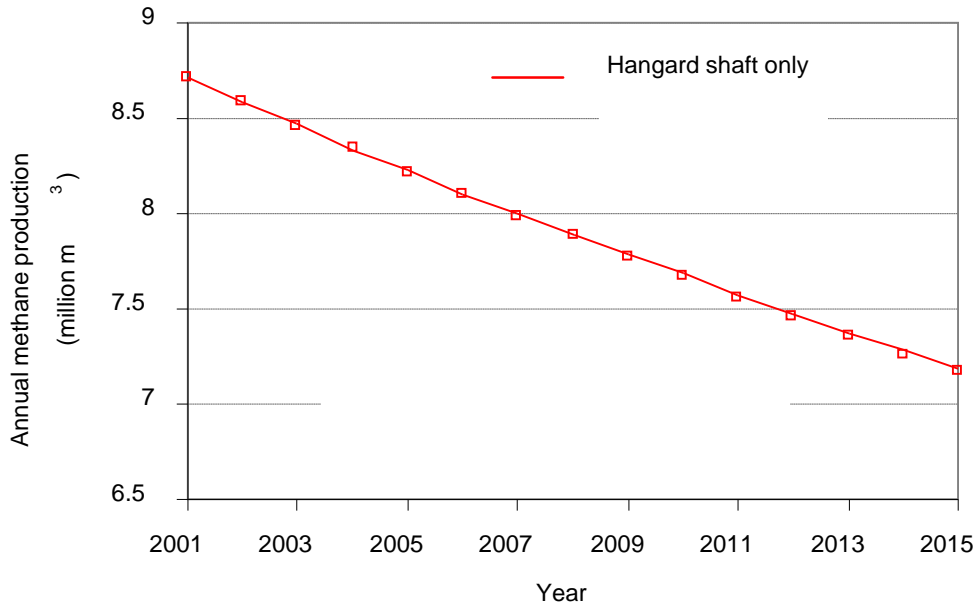


# Methane Production Predictions

## Frankenholz – St. Barbara Complex

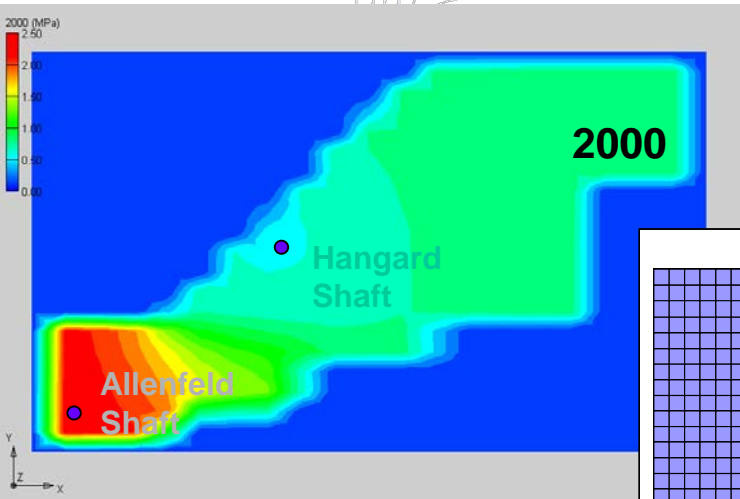


Methane pressure distribution with production from Hangard shaft only

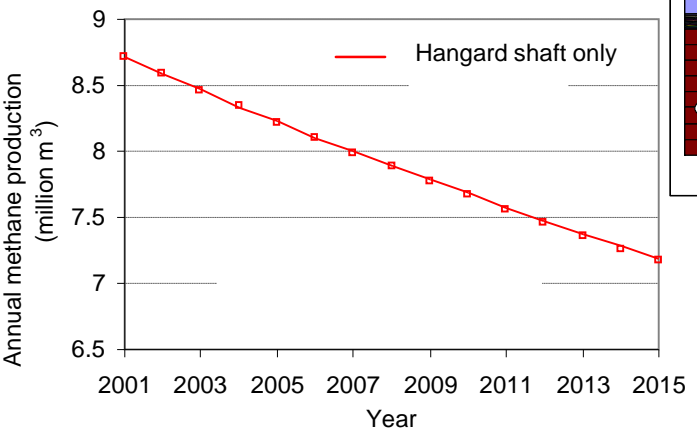
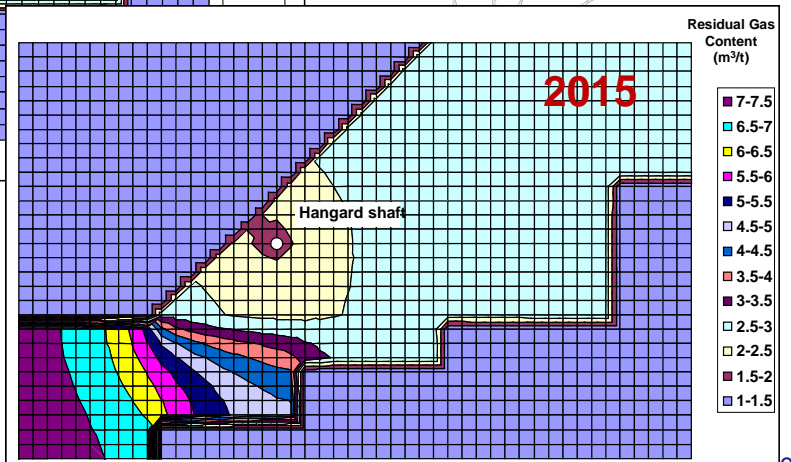
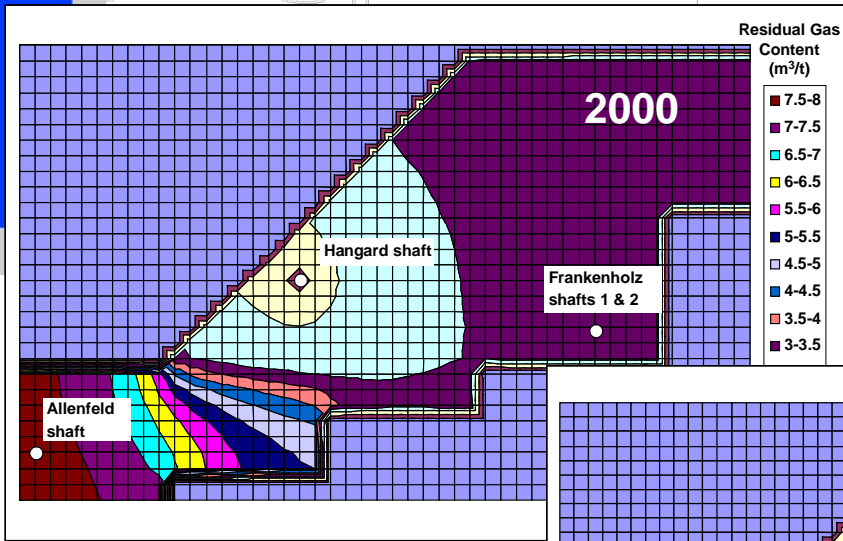


# Methane Production Predictions

## Frankenholz – St. Barbara Complex

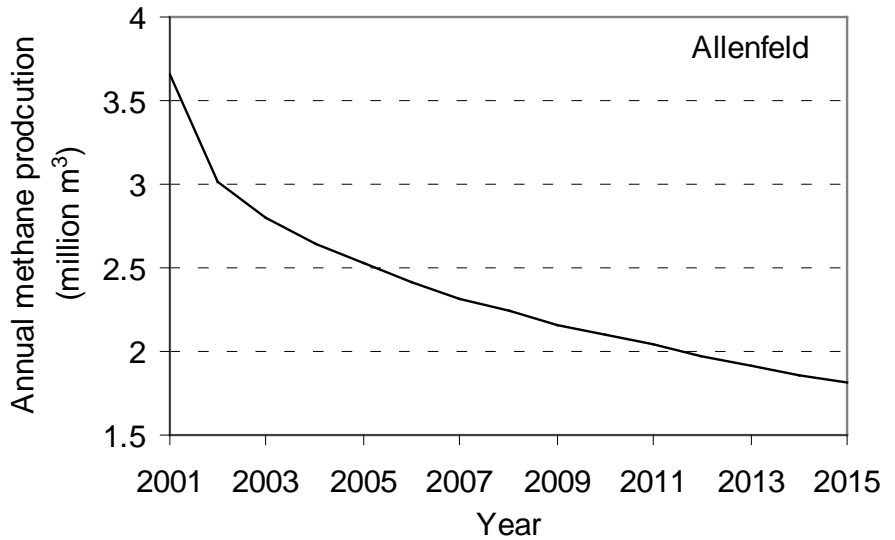


Residual methane contents with production from Hangard shaft only



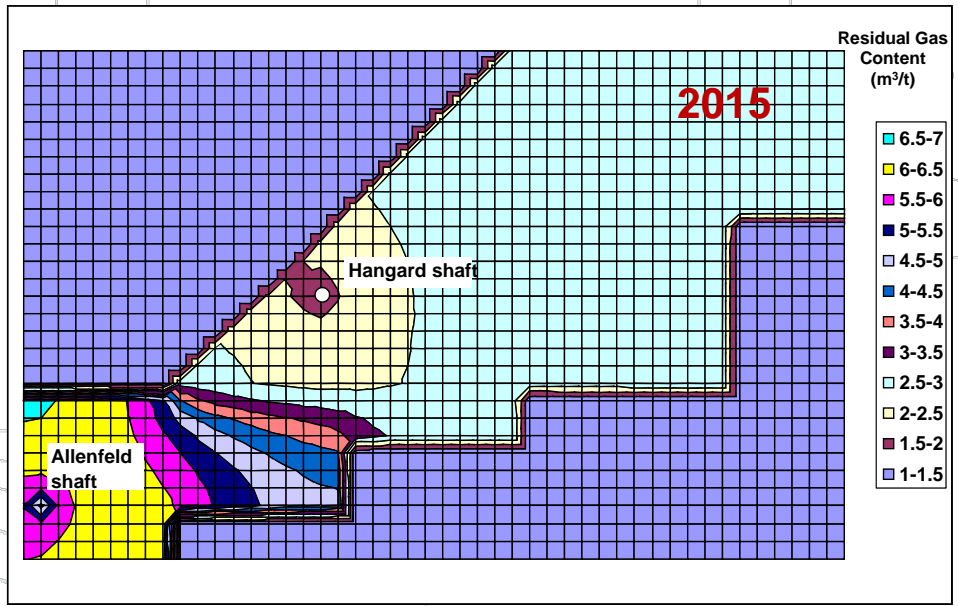
# Methane Production Predictions

## Methane Production Forecast from the Allenfeld Shaft



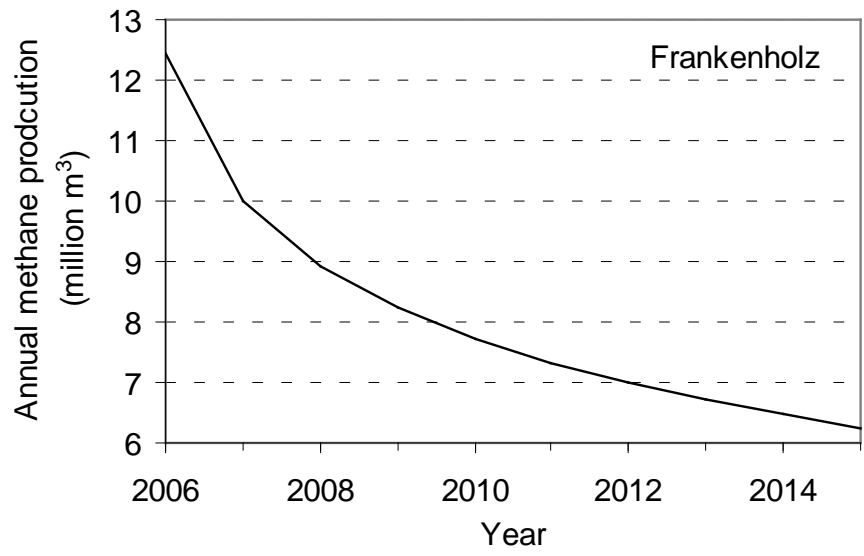
Allenfeld shaft was seen to be emitting  $5\text{m}^3/\text{min}$  (2.6 million  $\text{m}^3$  per annum)  $\text{CH}_4$

Residual methane contents with production from both Hangard and Allenfeld shafts



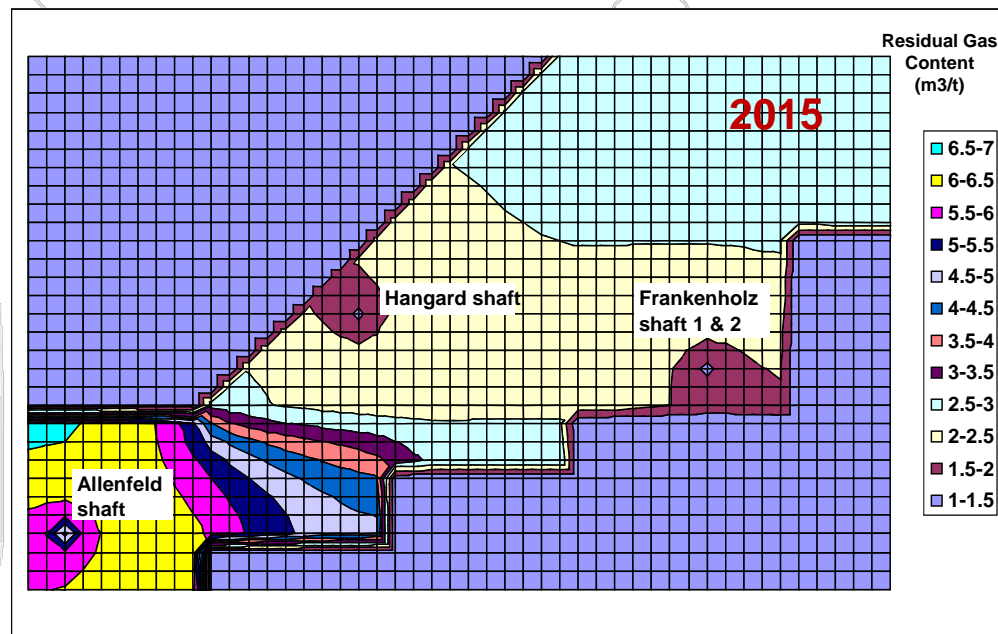
# Methane Production Predictions

## Methane Production Forecast from the Frankenholz Shaft



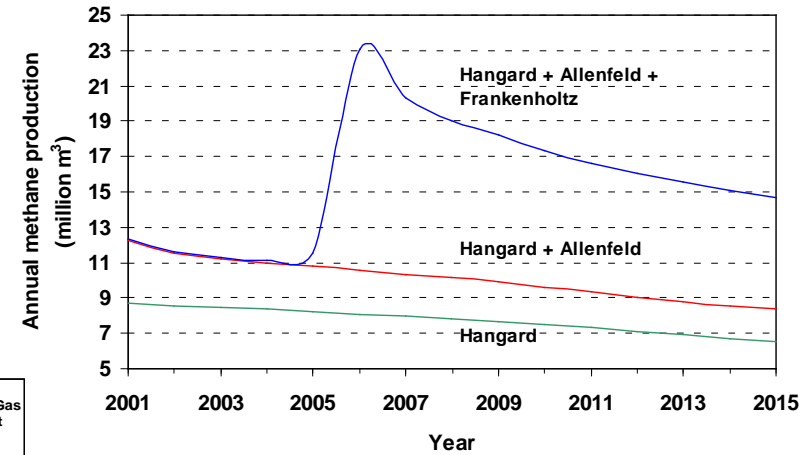
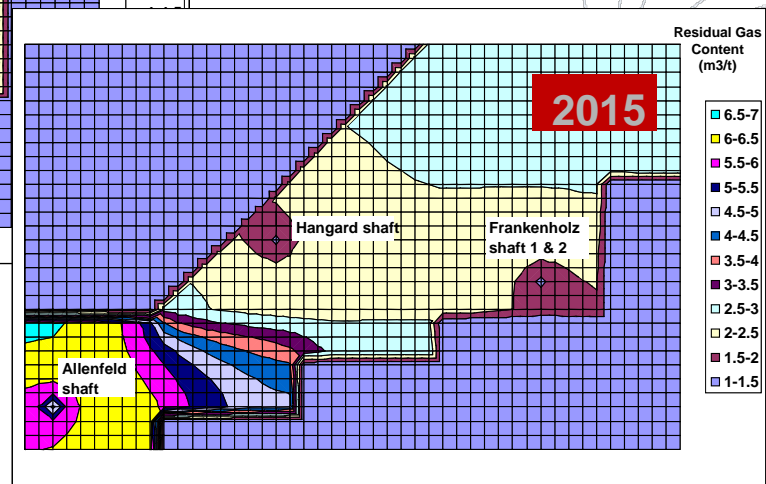
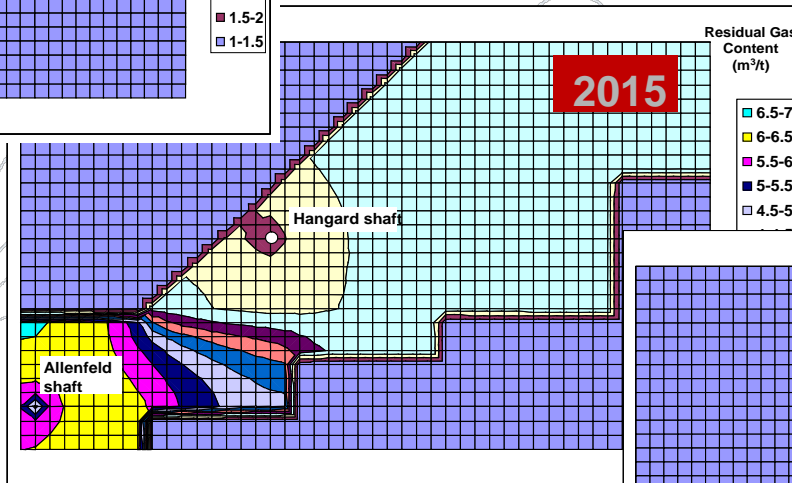
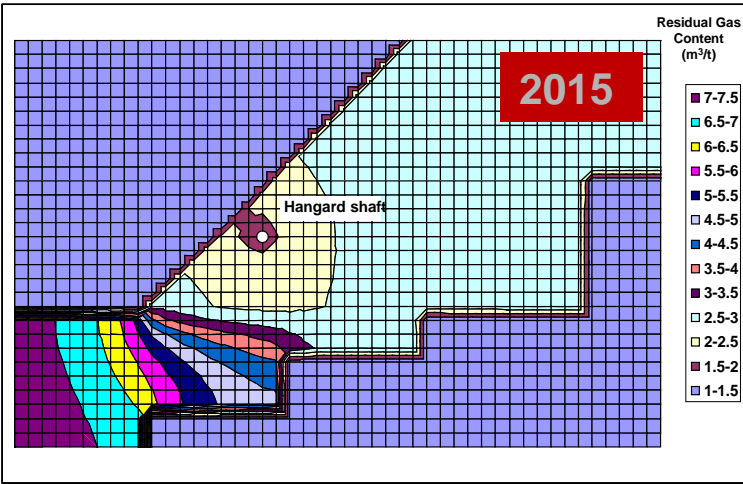
Predicted annual methane production at Frankenholz

Residual methane contents with production from Hangard, Allenfeld and Frankenholz shafts



# Methane Production Predictions

## Methane Production Forecast from the Frankenholz – St. Barbara Complex 3 Shafts Producing Simultaneously



Predicted annual methane production for the 3 shafts





# Conclusions

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- ❑ A general gas-water two-phase CBM simulator METSIM2 has been modified to simulate methane extraction from abandoned coal mines
- ❑ Reservoir characterisation was carried out and abandoned mine models were developed for an abandoned coal mine complex in the Saar coalfield of Germany
- ❑ A methodology for reservoir characterisation of abandoned mines has been formulated
- ❑ An areal model to represent the lumped effect of all coal seams that contribute to methane production was developed and used in the predictions
- ❑ Predictions carried out at Imperial College involved the assessment of potential gas production from additional boreholes at the Allenfeld and Frankenholz sectors for the future.



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Imperial College  
London



Sevket Durucan [s.durucan@imperial.ac.uk](mailto:s.durucan@imperial.ac.uk)