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This document was created in response to a Freedom of Information request made to CSIRO.

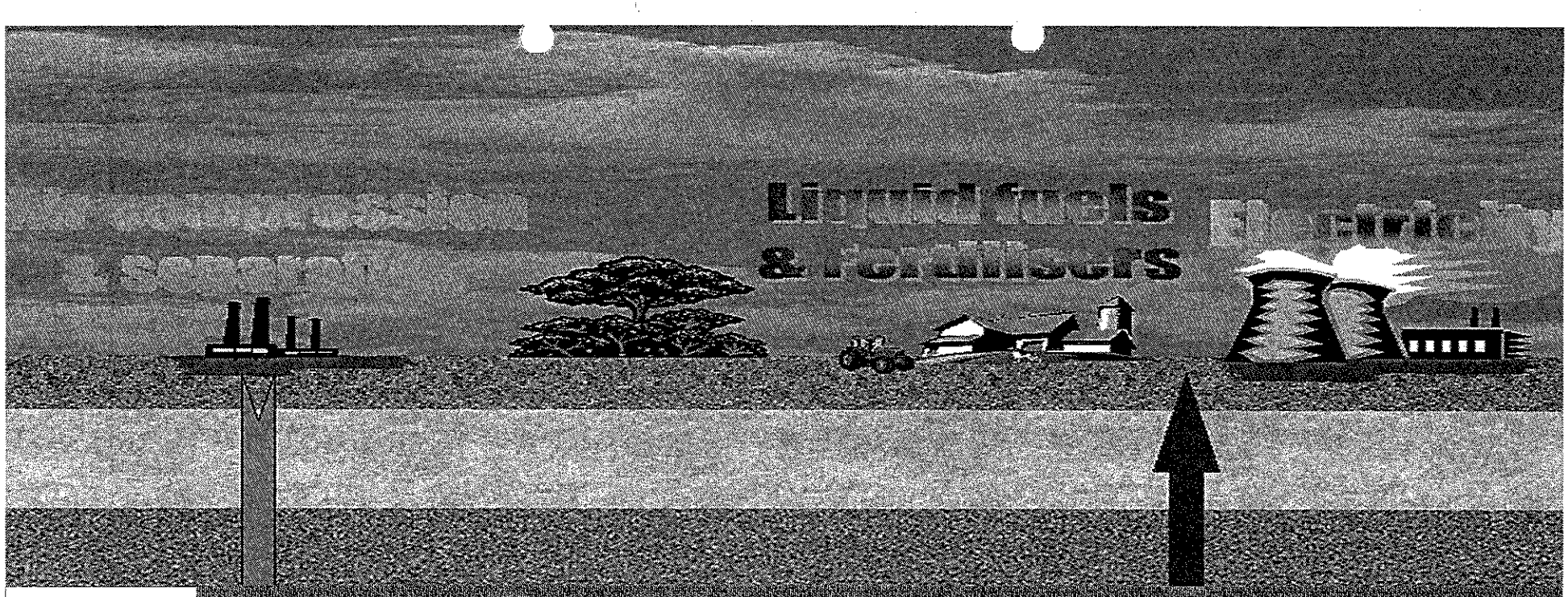
FOI Number: FOI2016/29

Date: 3 June 2016

Request: Any publications relating to "Underground Coal Gasification" which have been drafted by or released by the CSIRO or written by another entity which sourced resources or collaboration or input from the CSIRO.

Document(s): 7-8

For more information, please refer to CSIRO's FOI disclosure log at www.csiro.au/FOILog



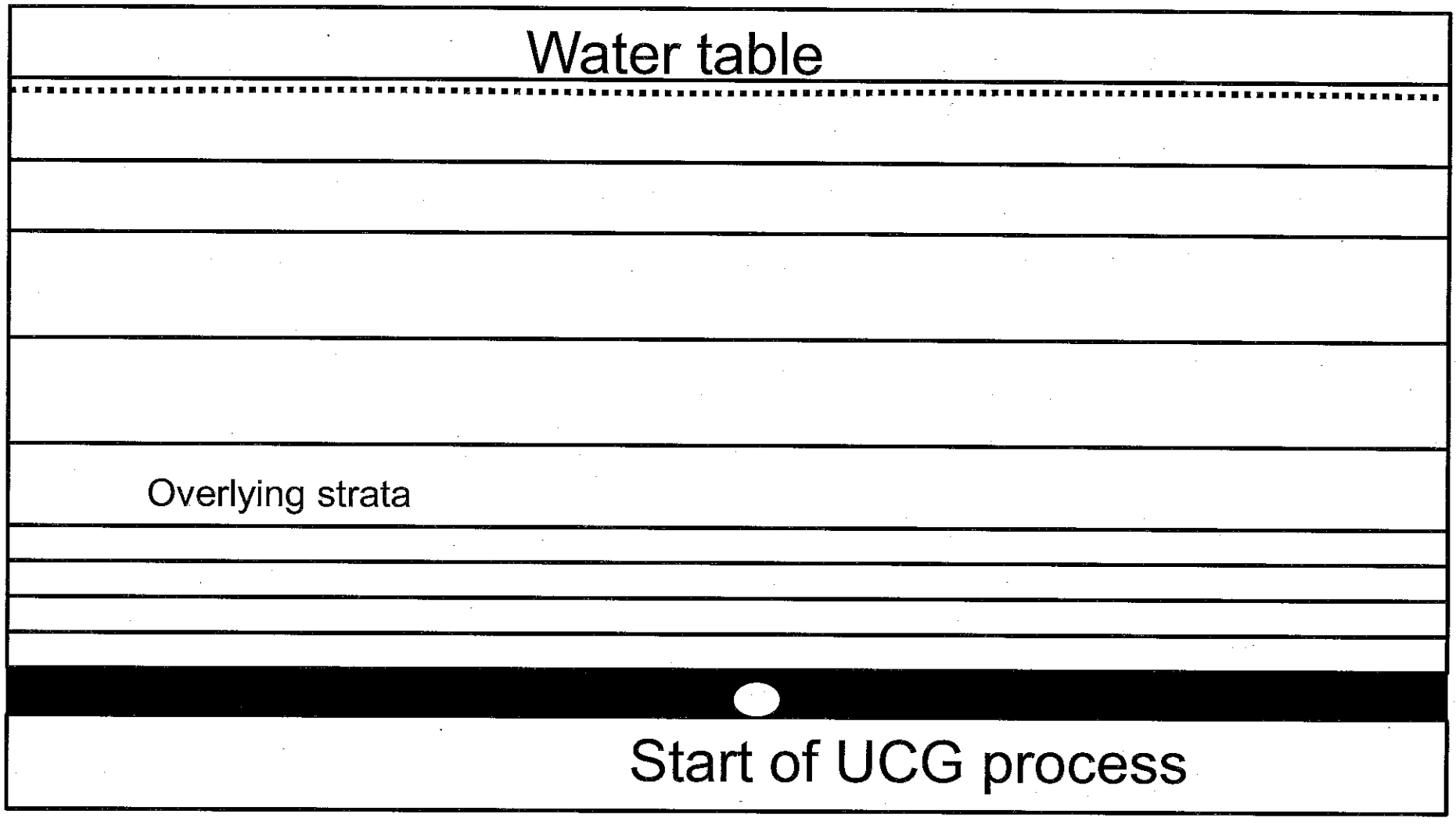
Underground coal gasification (UCG)

CSIRO

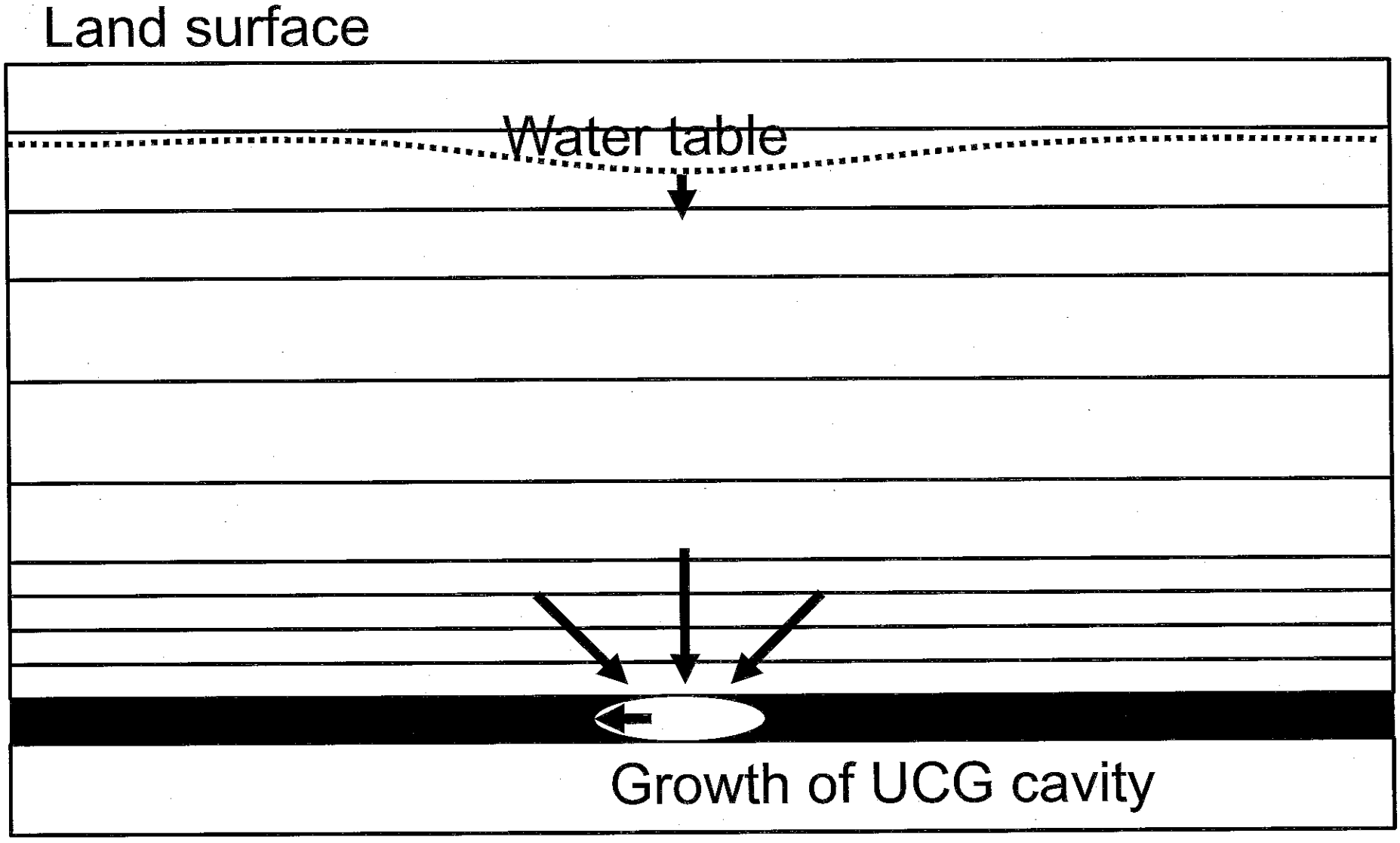
CONTENT

- UCG Process
- Historical notes
- Site distribution
- General performance
- Technology variants
- Important considerations
- Carbon Energy

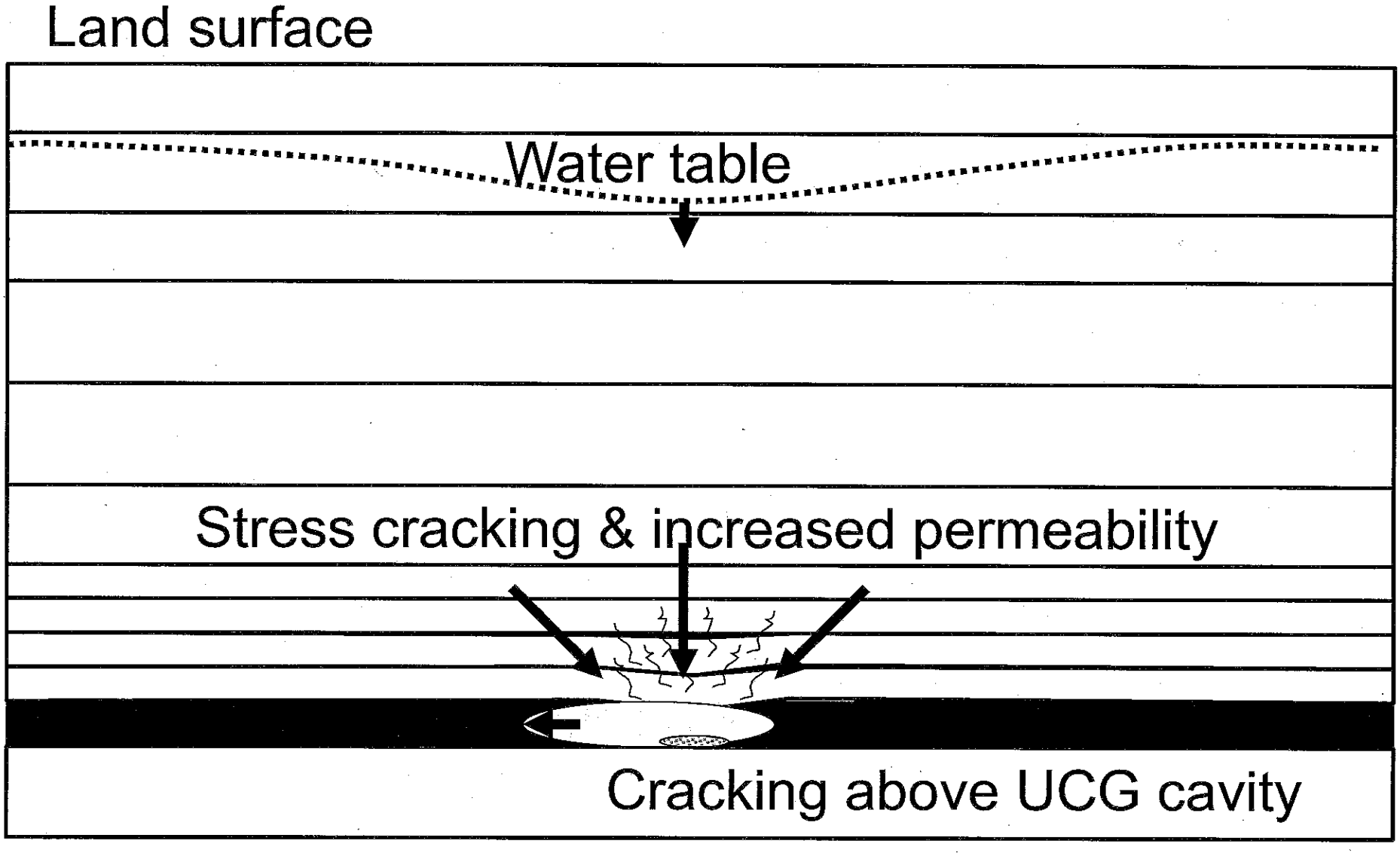
UCG Process - Start



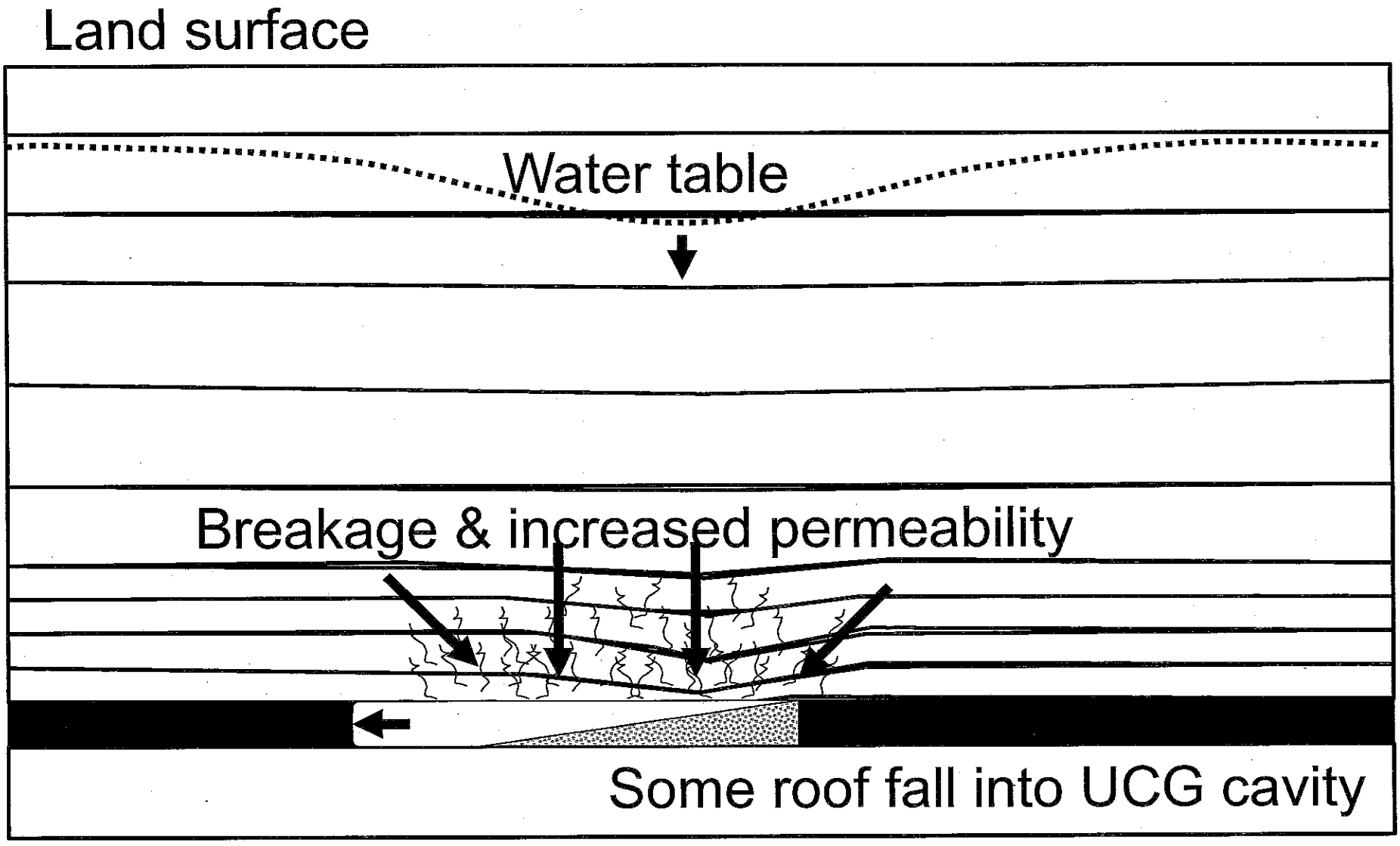
UCG Process - Growth



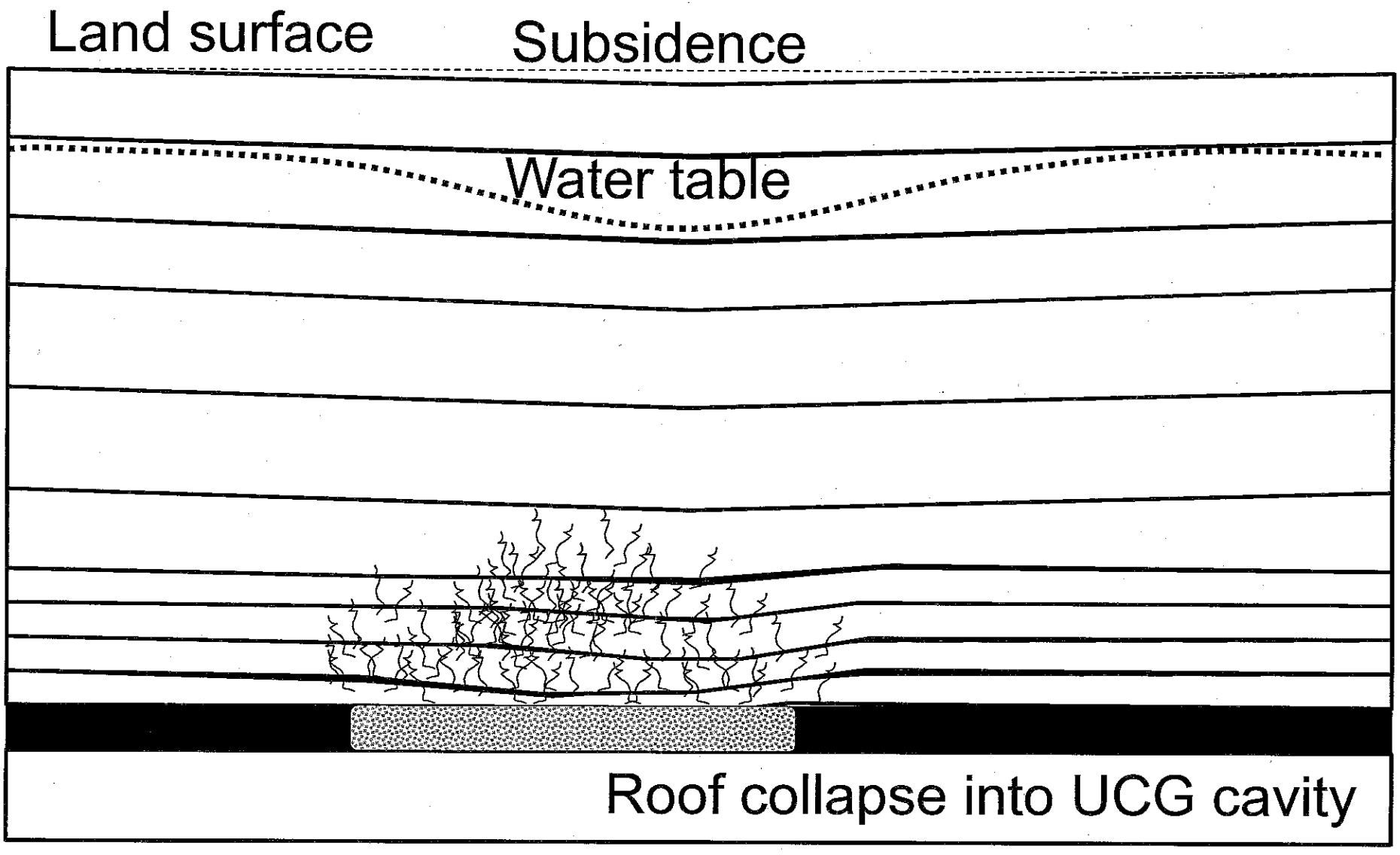
UCG Process - Cracking



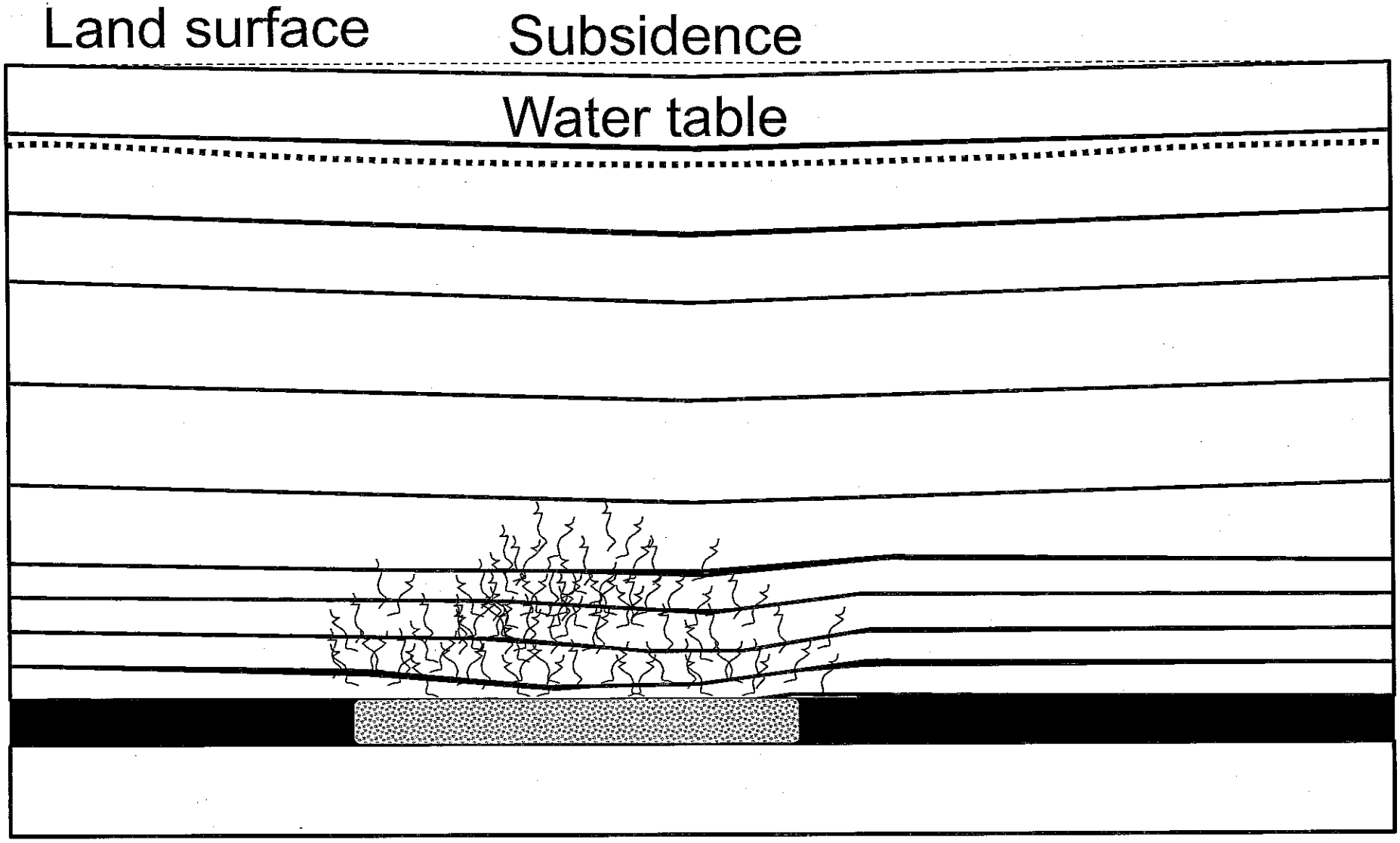
UCG Process - Breakage



UCG Process – Closure/Collapse



UCG Process - Recovery



Historical notes

- Underground coal gasification has been used in large-scale operations in countries of the former Soviet Union for over 40 years
- Numerous experimental trials have been performed in Soviet states, the USA, Western Europe and a number of other countries
- Over 15 million tonnes of coal have been gasified worldwide

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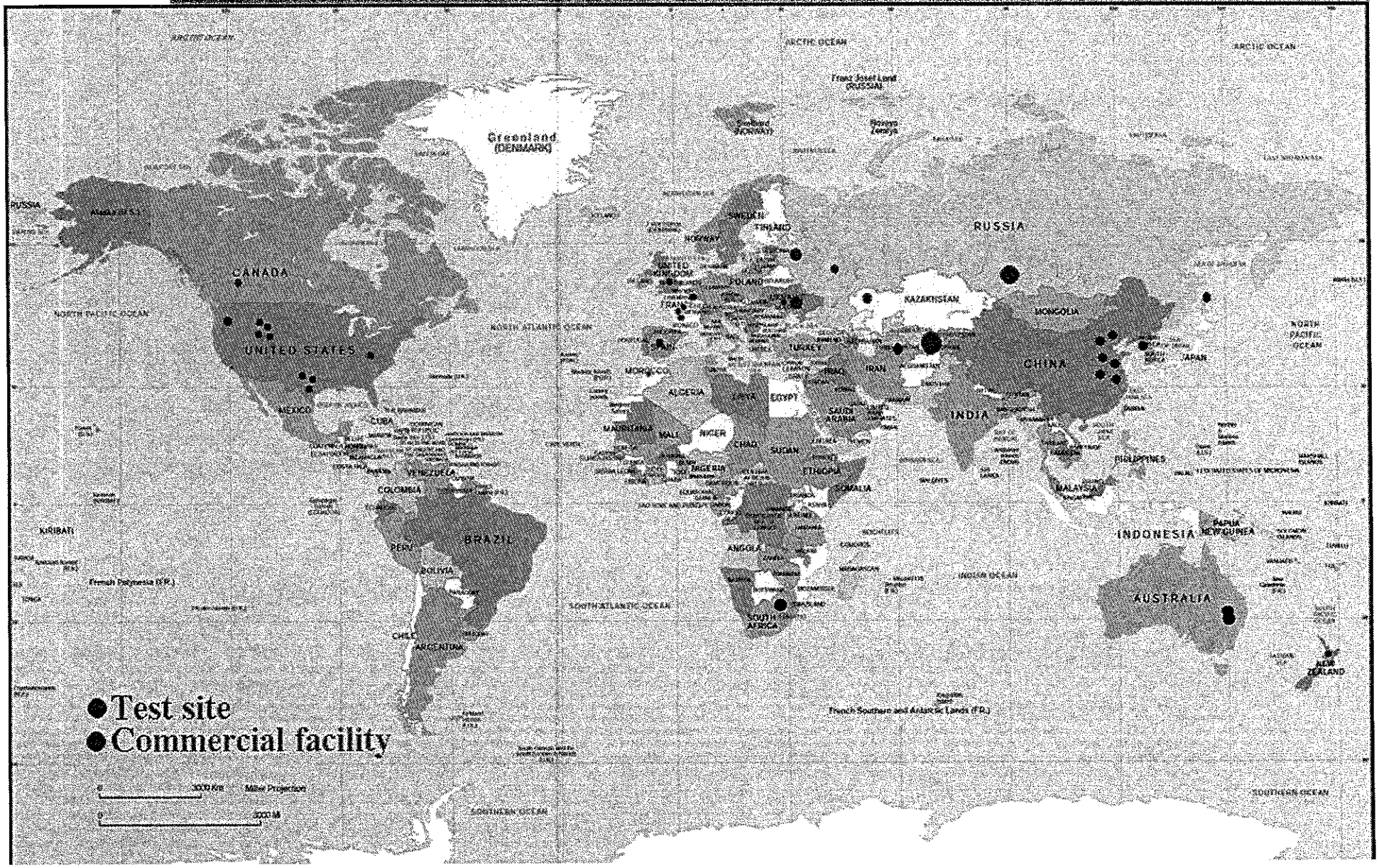
Site distribution



General performance

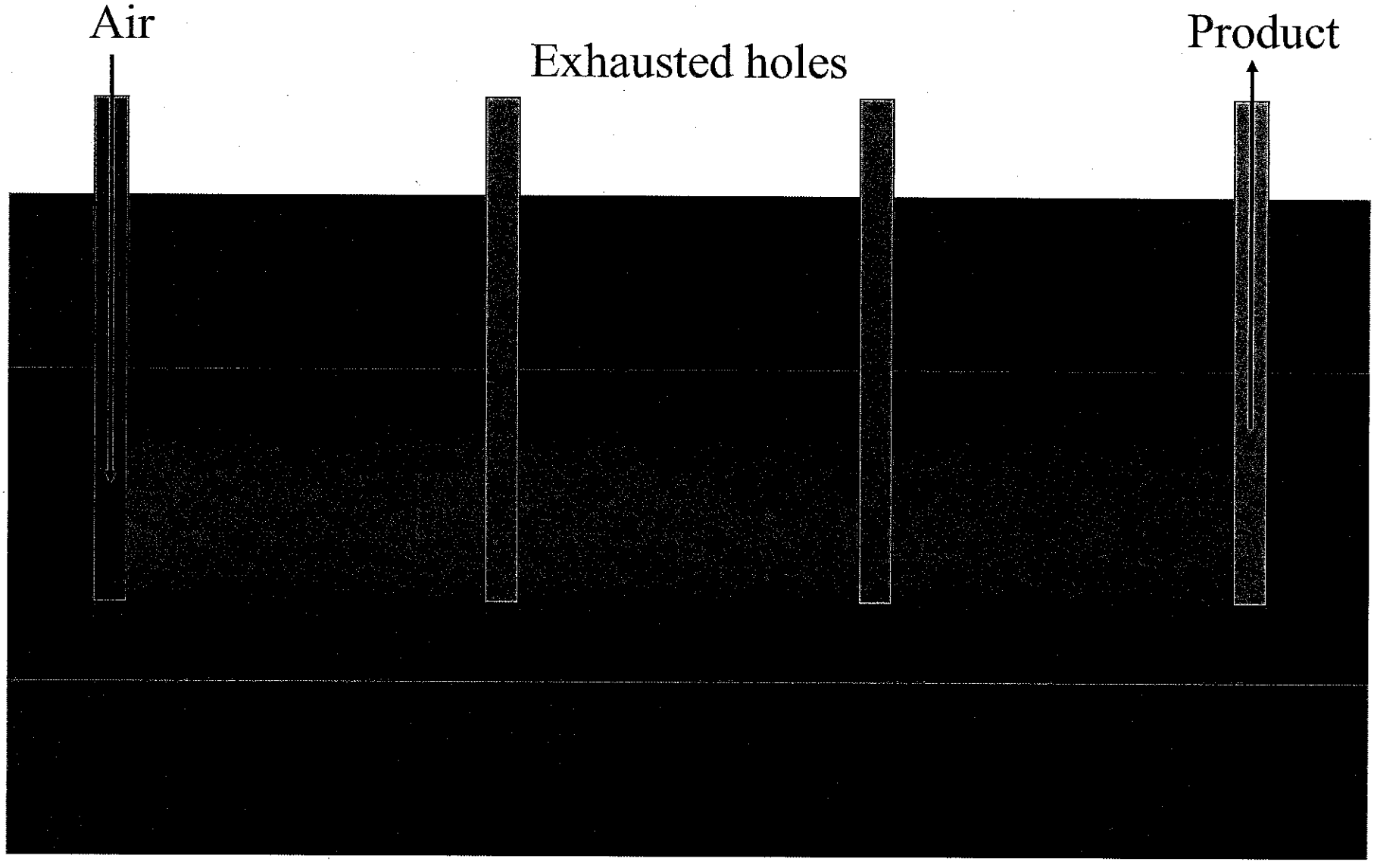
- Product gas quality can be similar to surface gasification on the basis of calorific value, but with higher methane and lower carbon monoxide content that is similar to fixed bed gasifiers
- Published coal recovery data is inaccurate but it is typically reported to be in the range of 70-90% of the affected coal seam
- Major influences on performance are the coal seam thickness, ash content of coal and the rate of water ingress

Technology variants

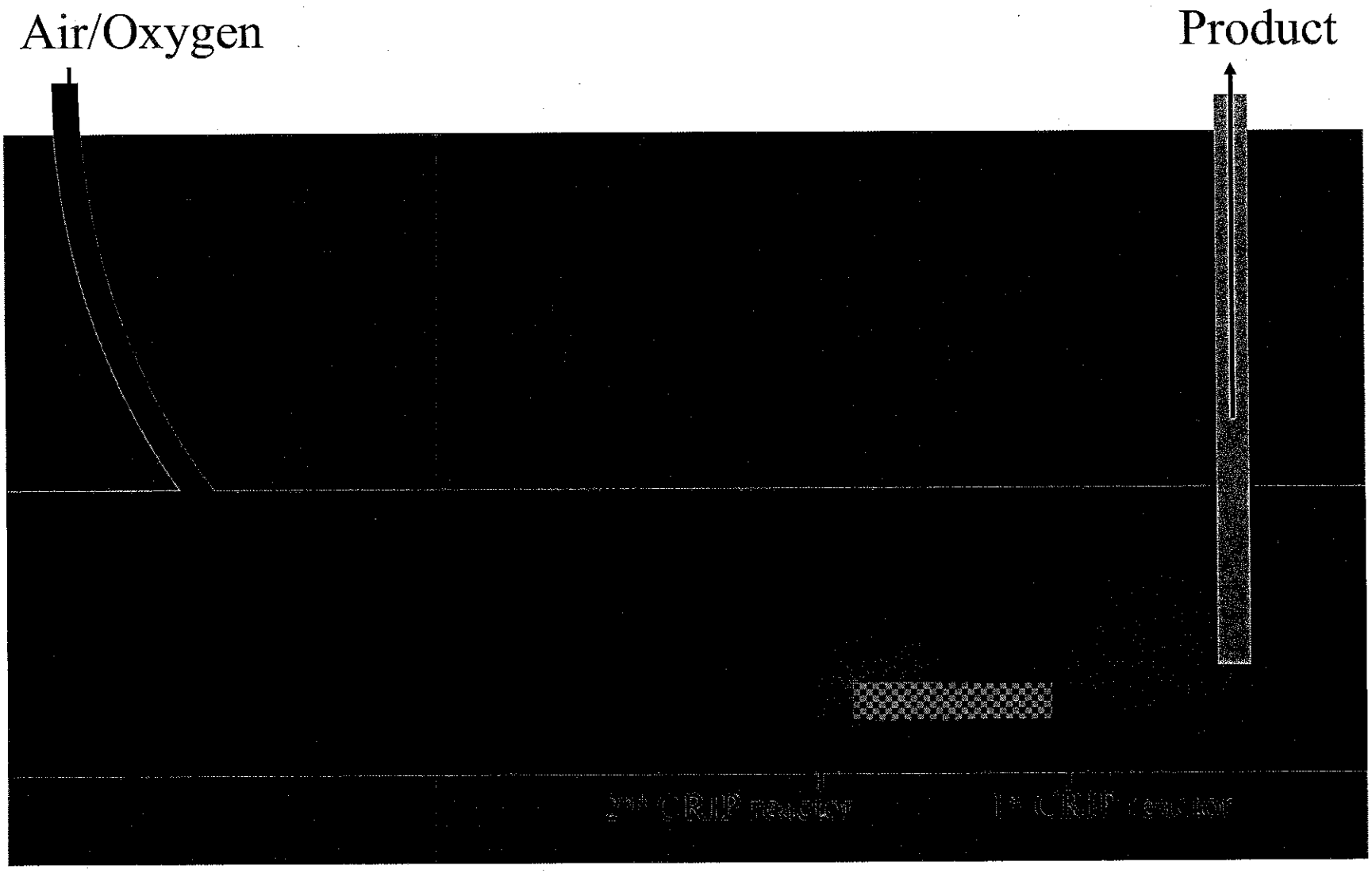
There are variations on the technology that may be applicable to specific sites:

- **Vertical Wells**
- **Controlled Retracting Injection Point**
- **Steeply Dipping Bed**
- **Parallel wells**
- **Tunnel**

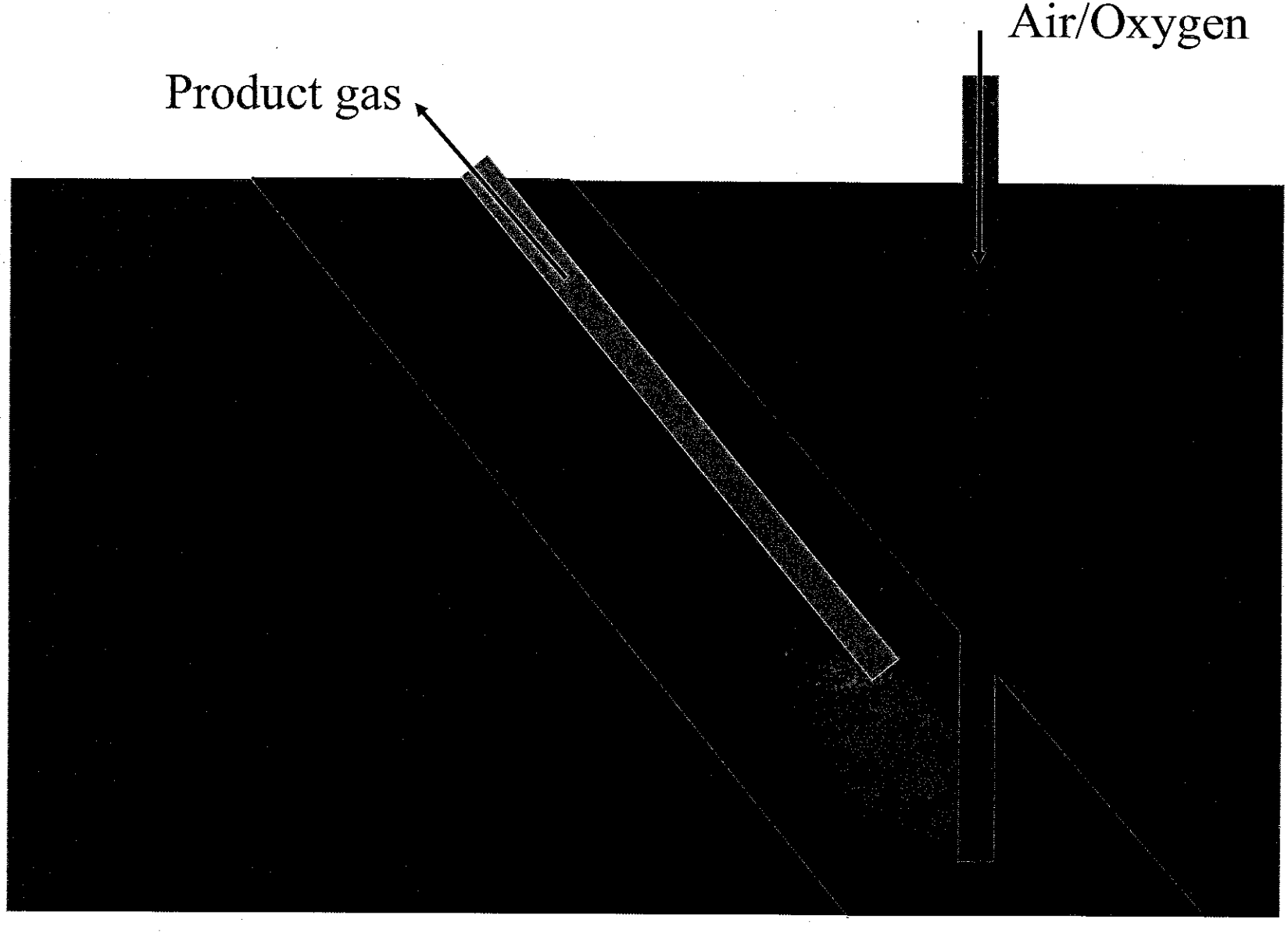
Vertical Wells (Various configurations used by Linc Energy/Ergo Exergy/Eskom)



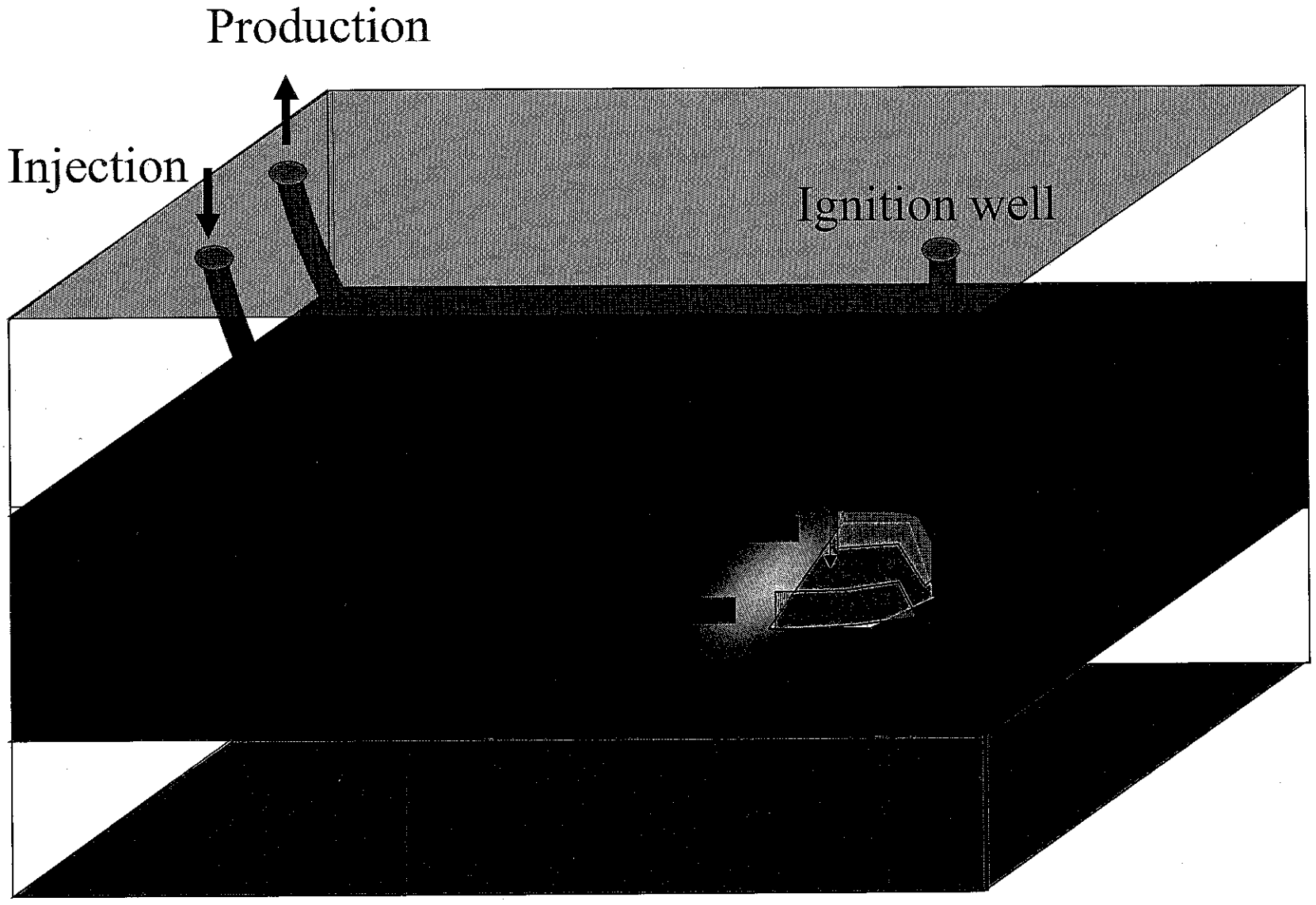
Controlled Retracting Injection Point (used for European trials and some in USA)



Steeply Dipping Bed (used by Carbon County UCG)



Parallel wells (Carbon Energy approach)



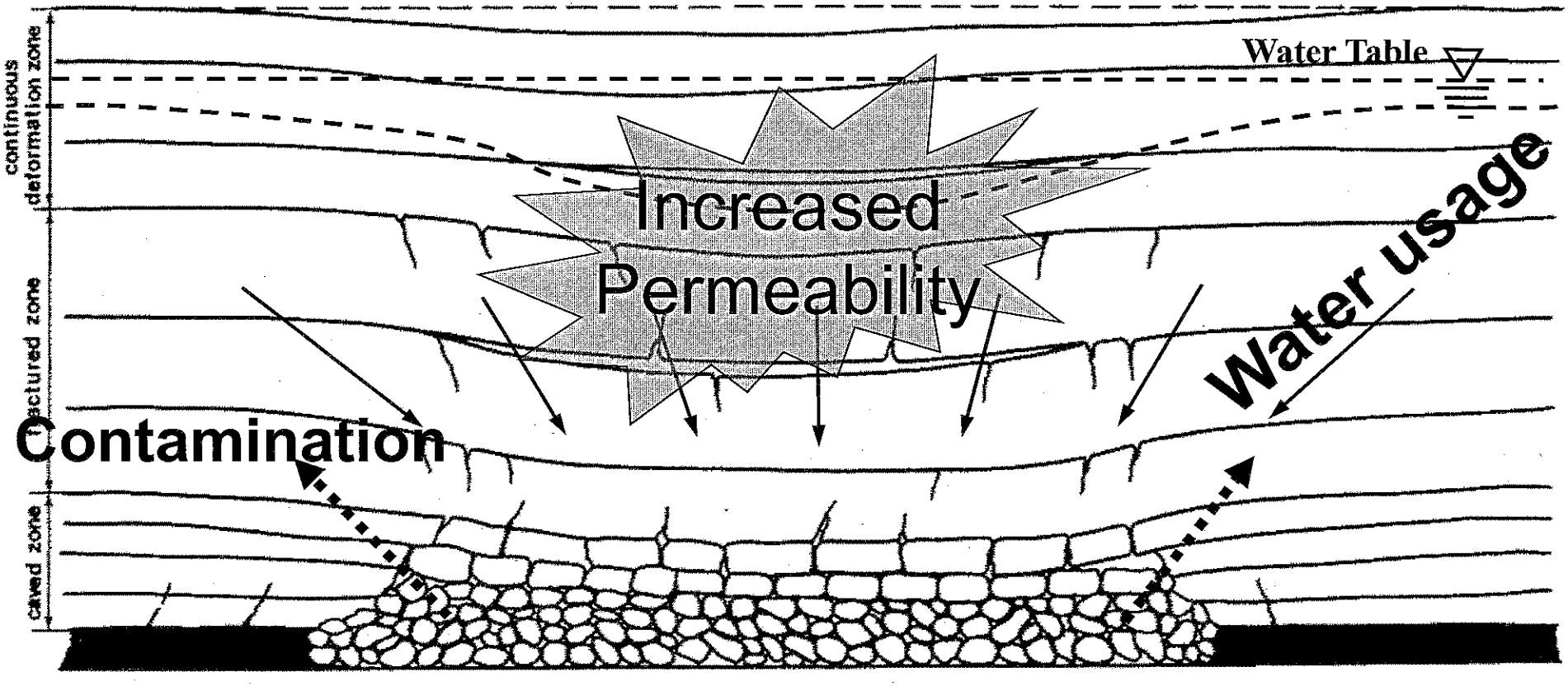
Tunnel
(Xinwen Mining has 6 for town gas supply)

Important considerations

- Environmental impacts
- Applications
- Site selection
- Potential problems
- Operating rules

Potential Environmental Impacts

Surface subsidence



Applications for the product gas

❖**The product gas can be used as a:**

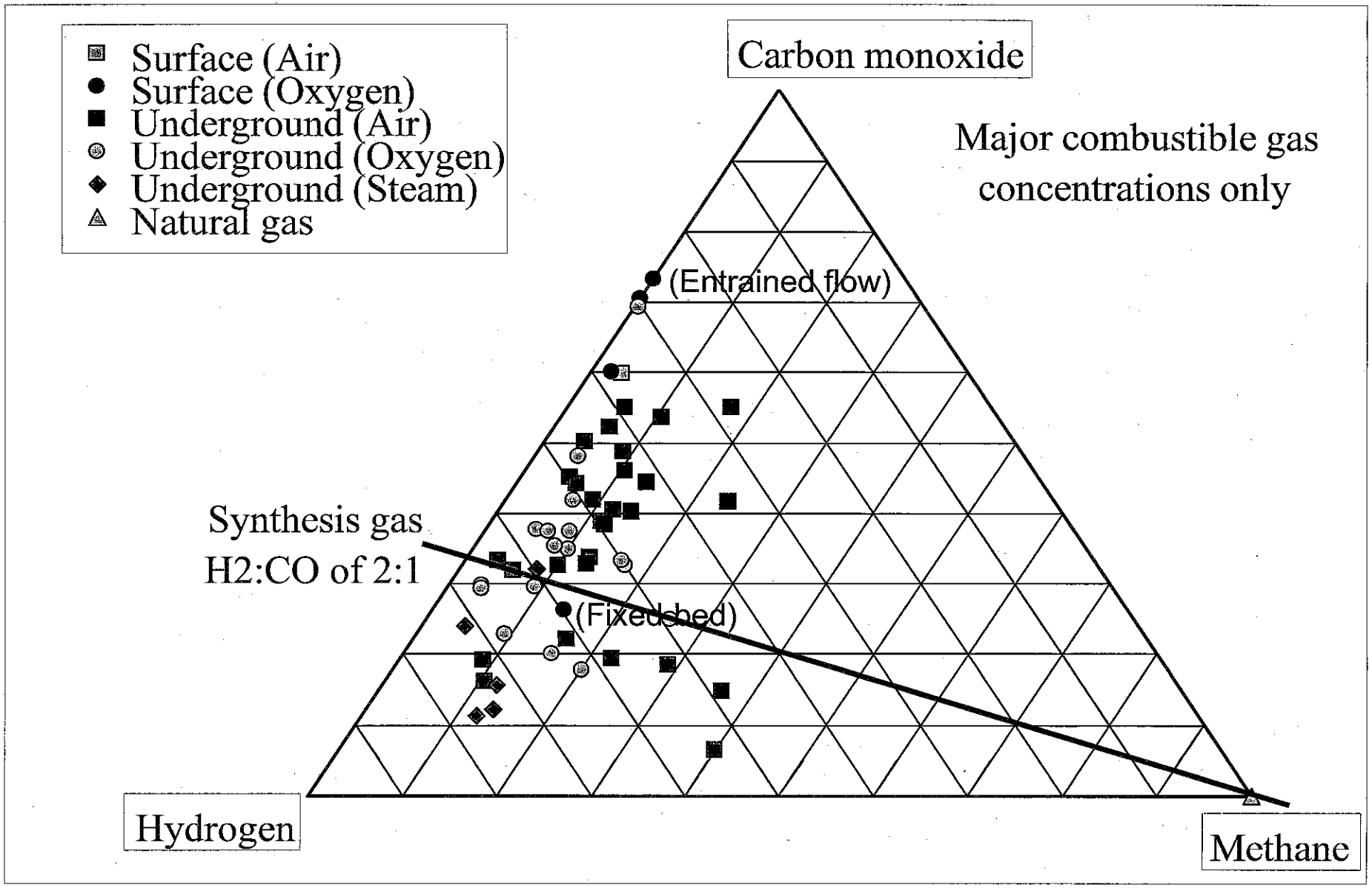
oFUEL eg.

- Low emission electricity production
- Steam production
- Domestic use as town gas

oSYNTHESIS FEEDSTOCK eg.

- Production of chemicals (eg. fertilisers)
- Synthesis of liquid fuels (Fischer-Tropsch)

Gas composition



Site selection

Desirable site characteristics

oThick coal seam

oMinimal geological discontinuities

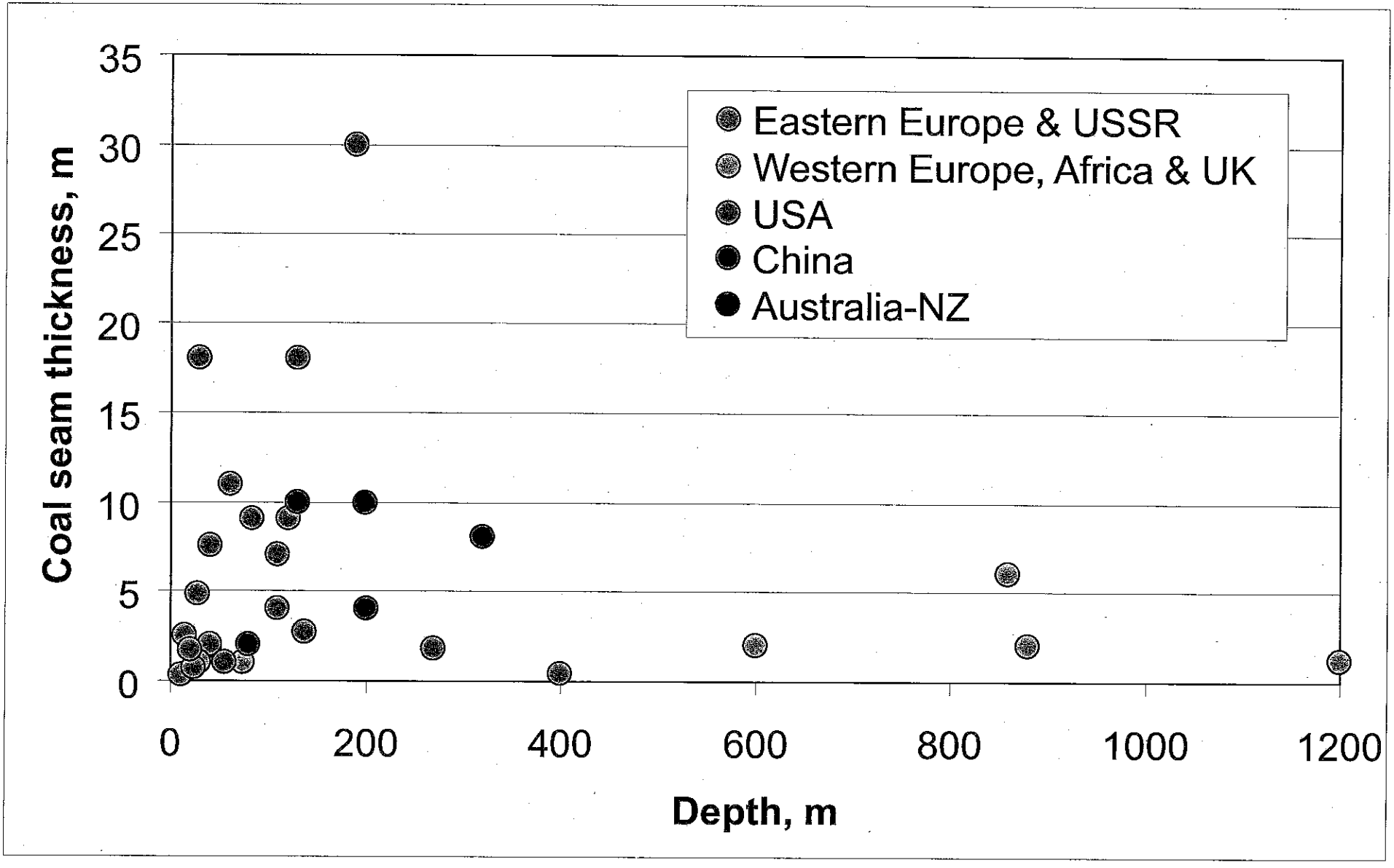
oNo good water aquifers

oMinimal surface development

(eg. buildings, roads, etc)

These provide the opportunity for a safe and efficient UCG operation

Site characteristics



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- Poor understanding of the site features, such as the coal seam layout and the overburden properties, can result in poor performance
- Drilling errors, roof collapse and flooding problems are generally related to site characterisation errors
- Aquifer contamination relates to selection of an unsuitable site and/or unsuitable operations

Operating rules

These are chiefly aimed at environmental protection, in brief:

- **Operating pressure must be maintained below the site hydrostatic head at all times**
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Carbon Energy

- CSIRO developed a suite of models for prediction of the operational and environmental performance of UCG sites and processes
- In July 2006, these were transferred to a spin-off company, now called Carbon Energy
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- Carbon Energy is currently conducting a 100 day demonstration of technology and has agreements relating to potential ammonia and methanol synthesis applications

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The End

Underground coal gasification (UCG)

David Harris
CSIRO Energy Technology
November 2008

Document 7a

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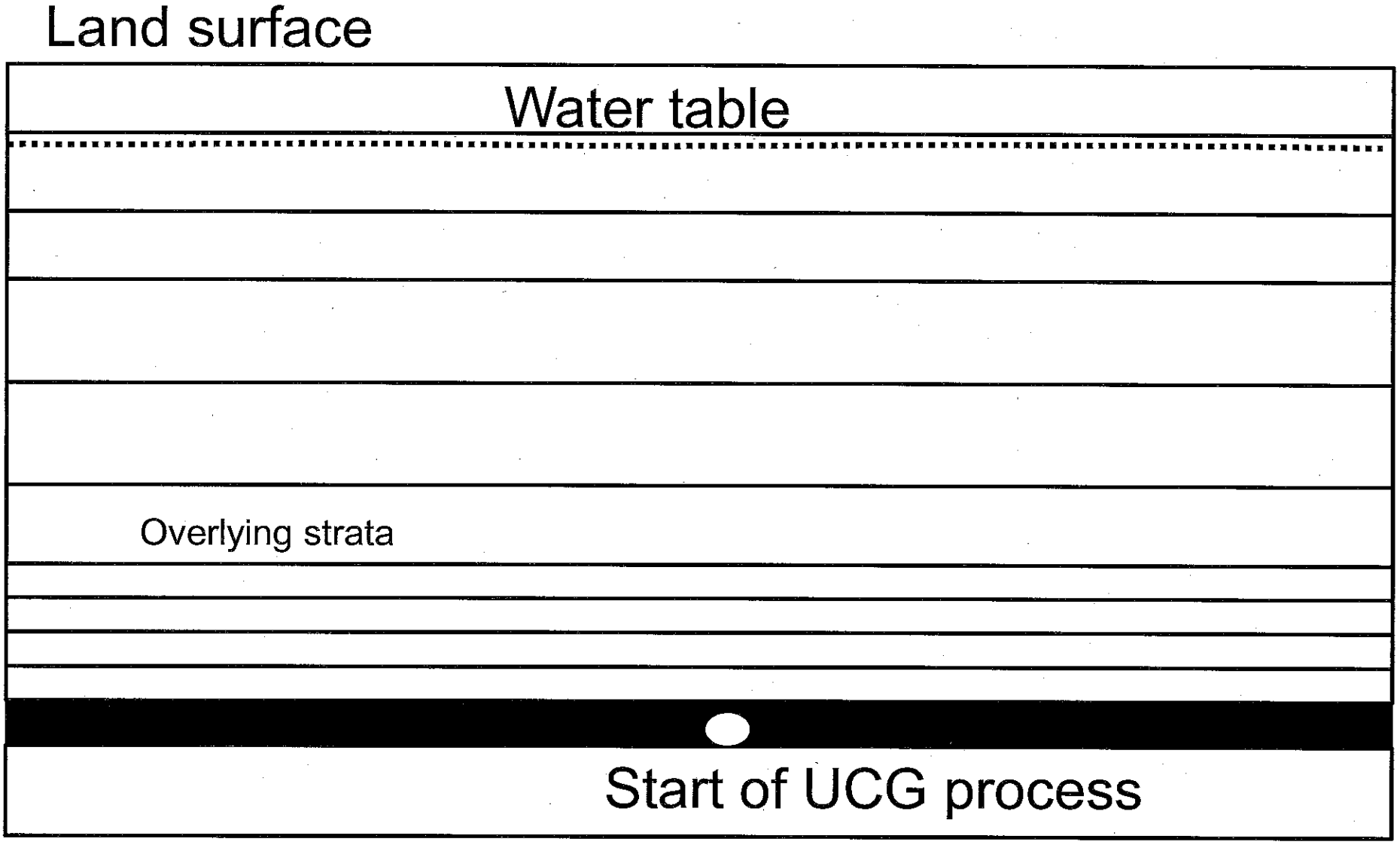

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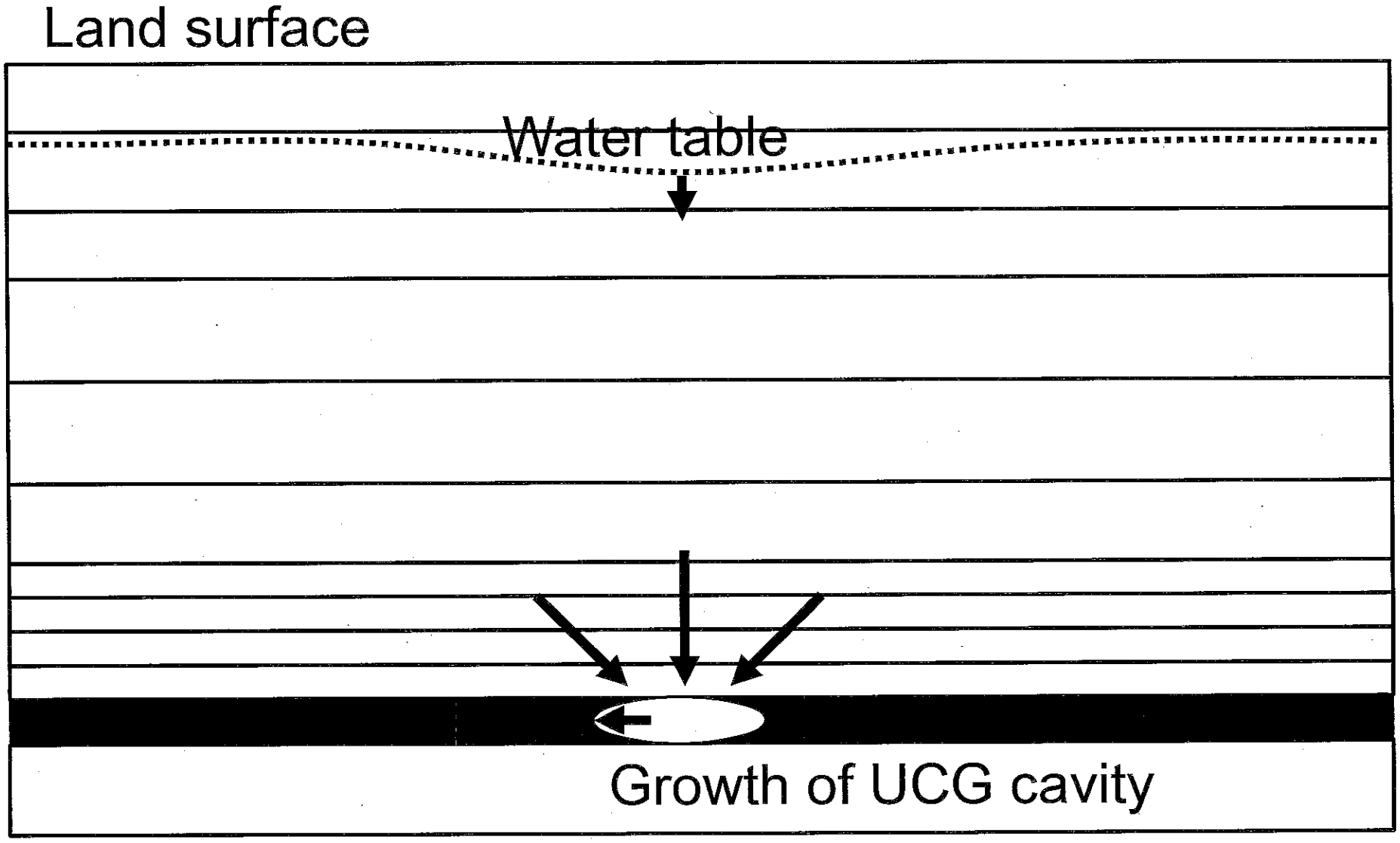

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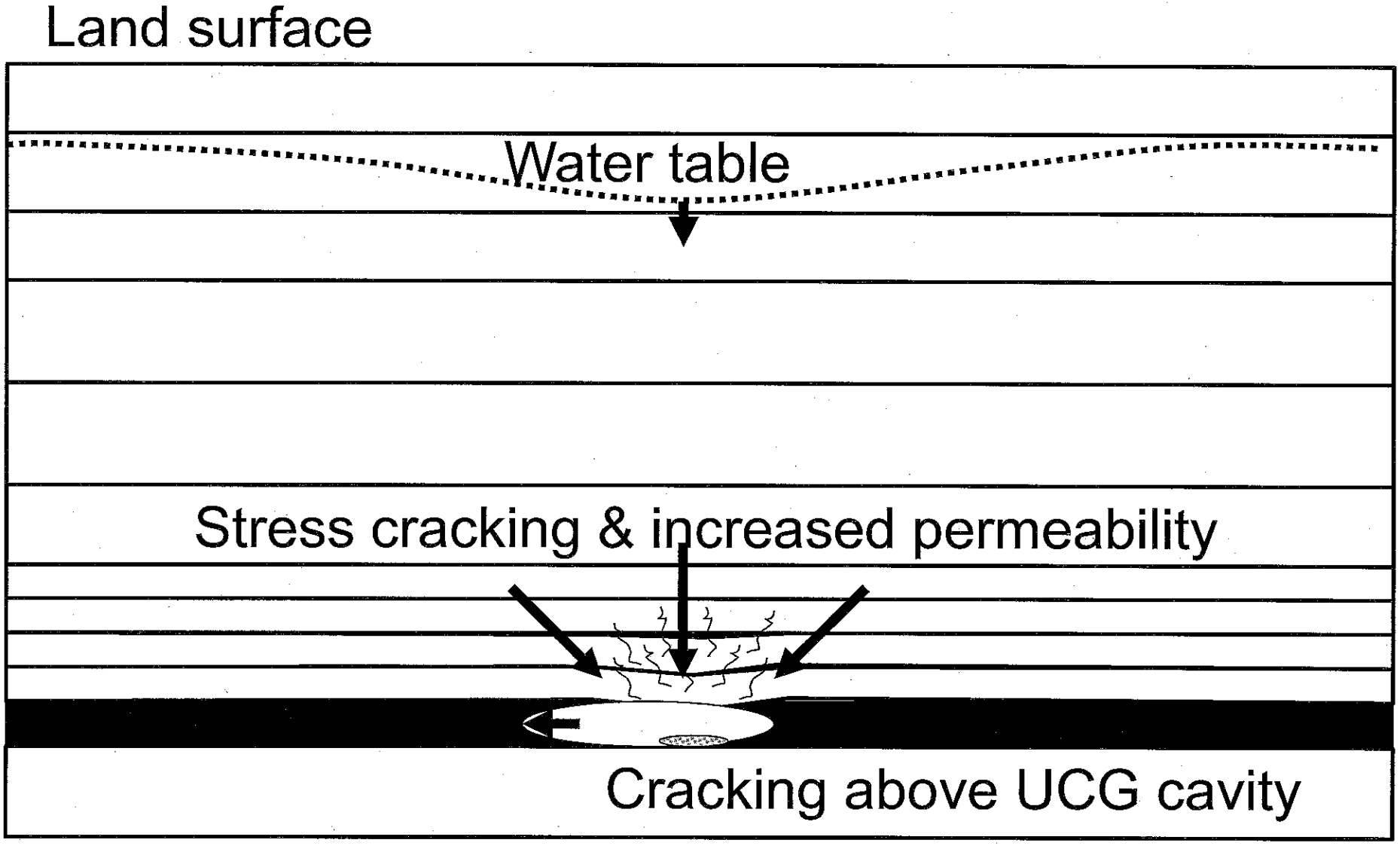

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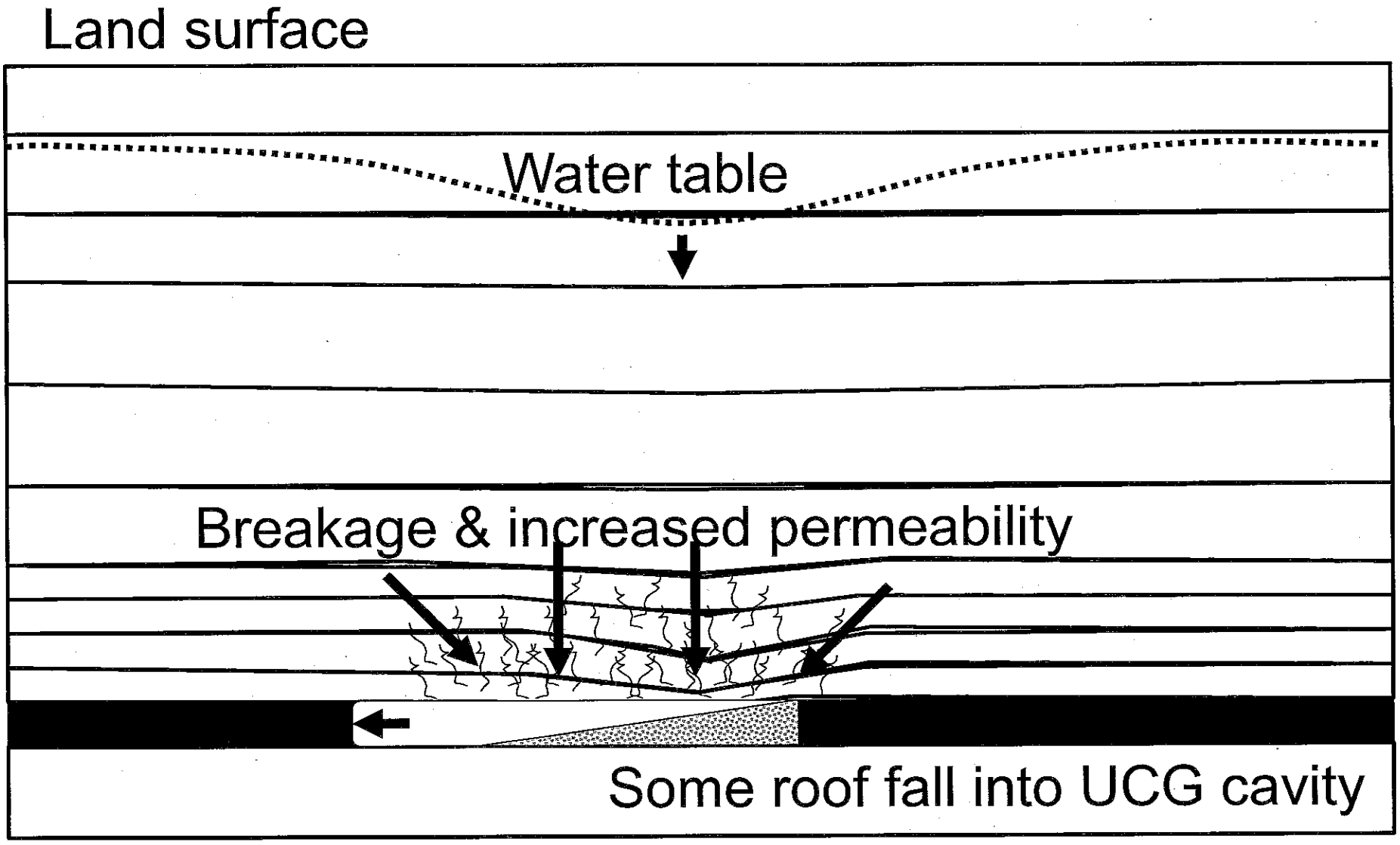

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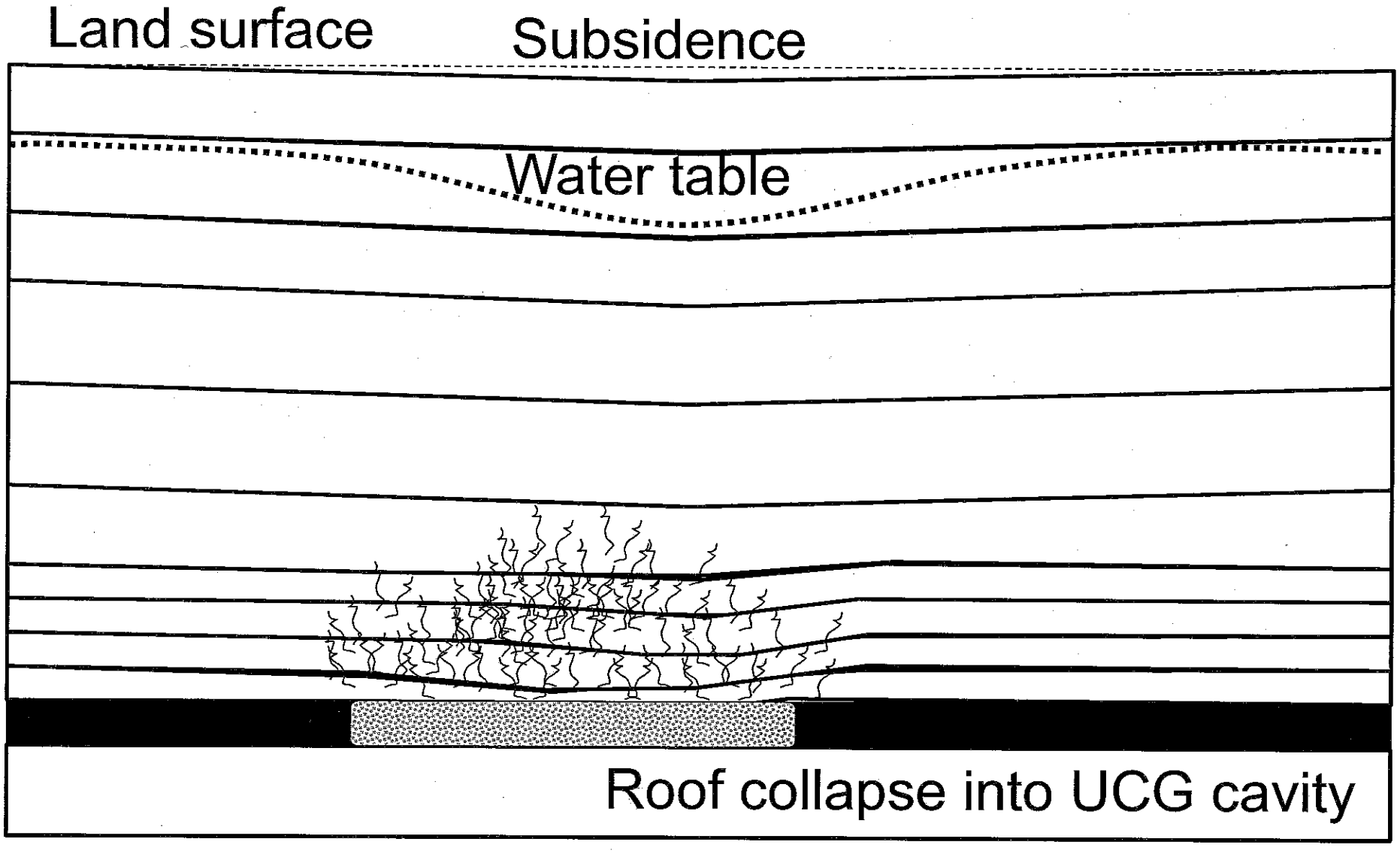

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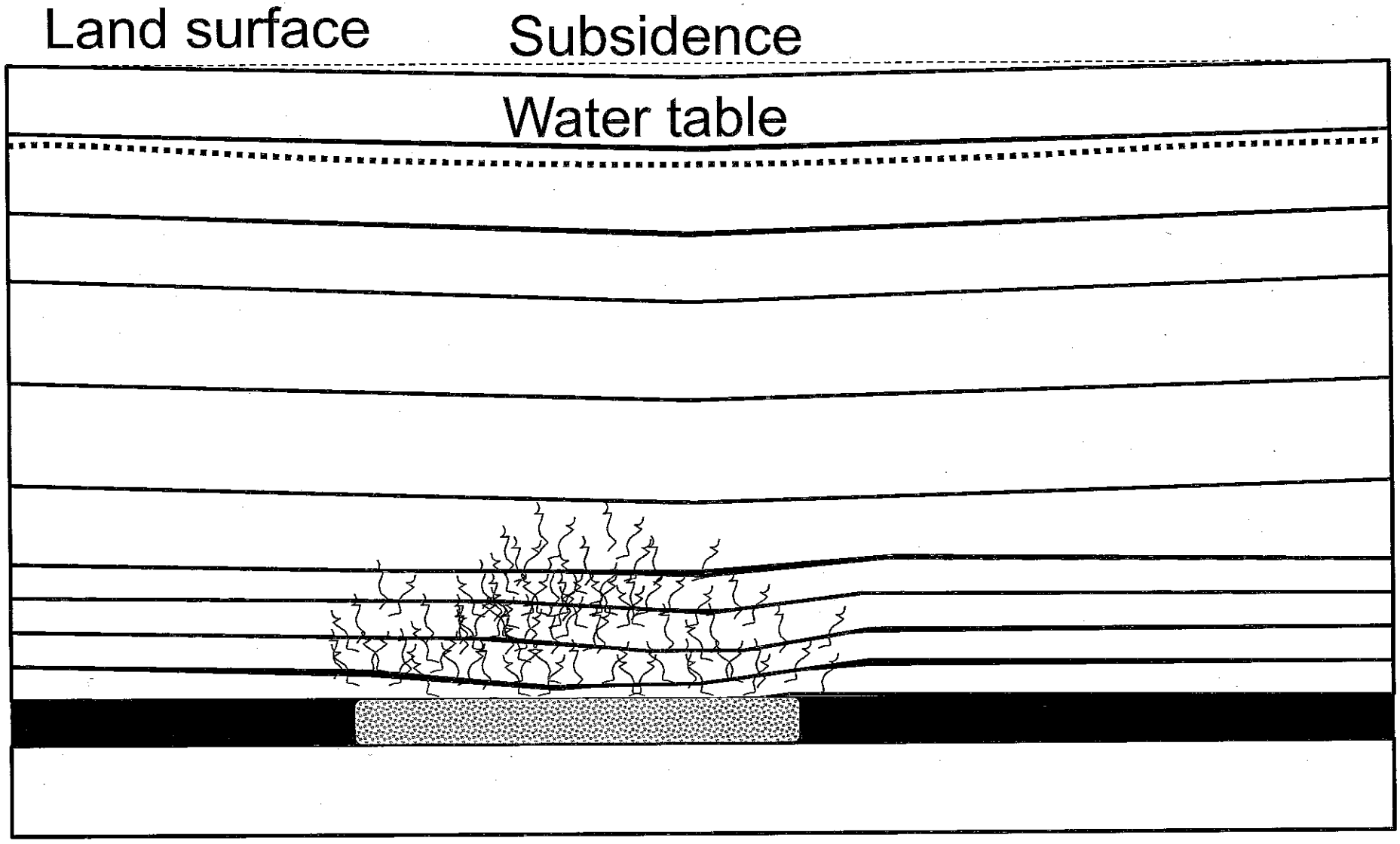

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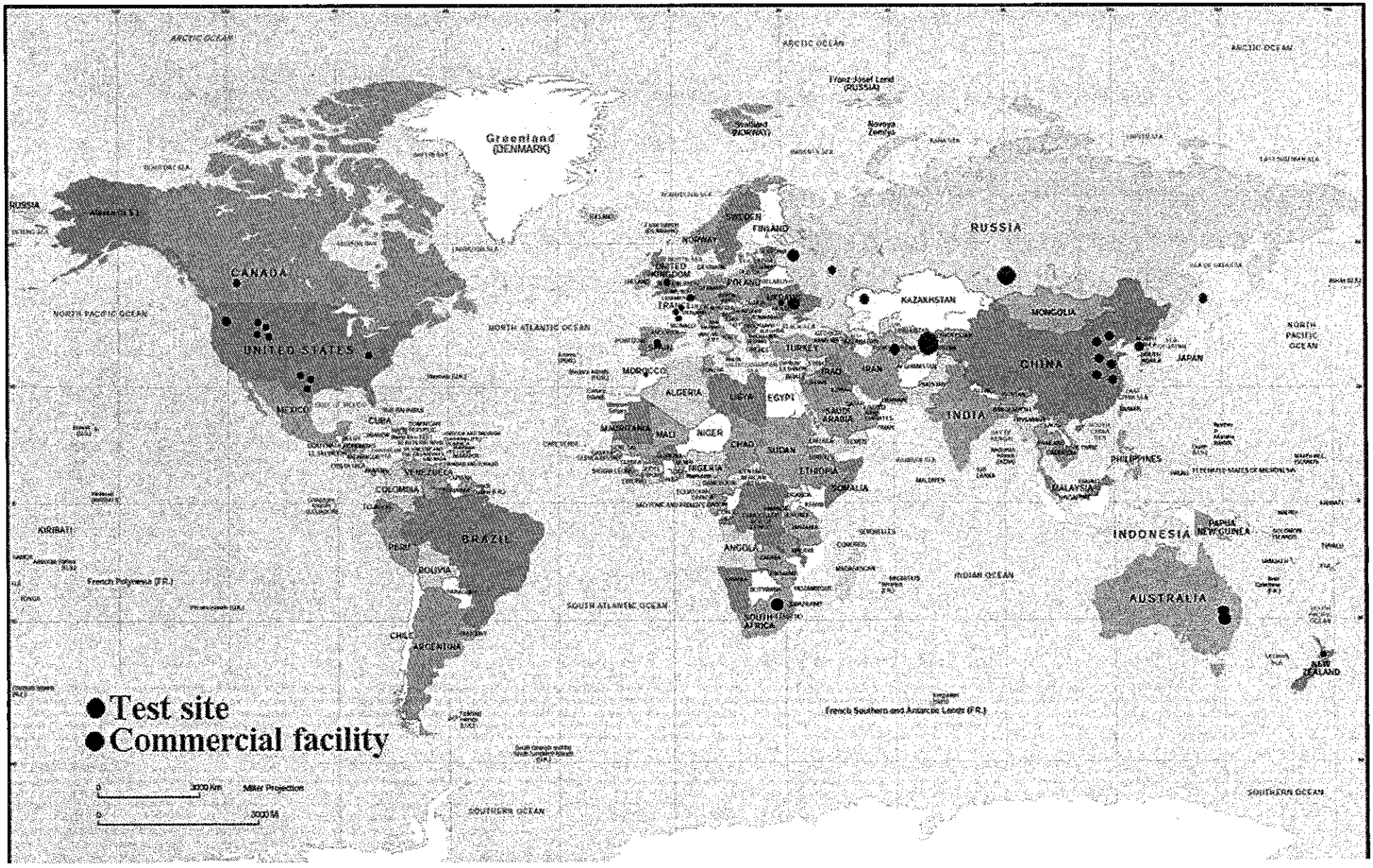

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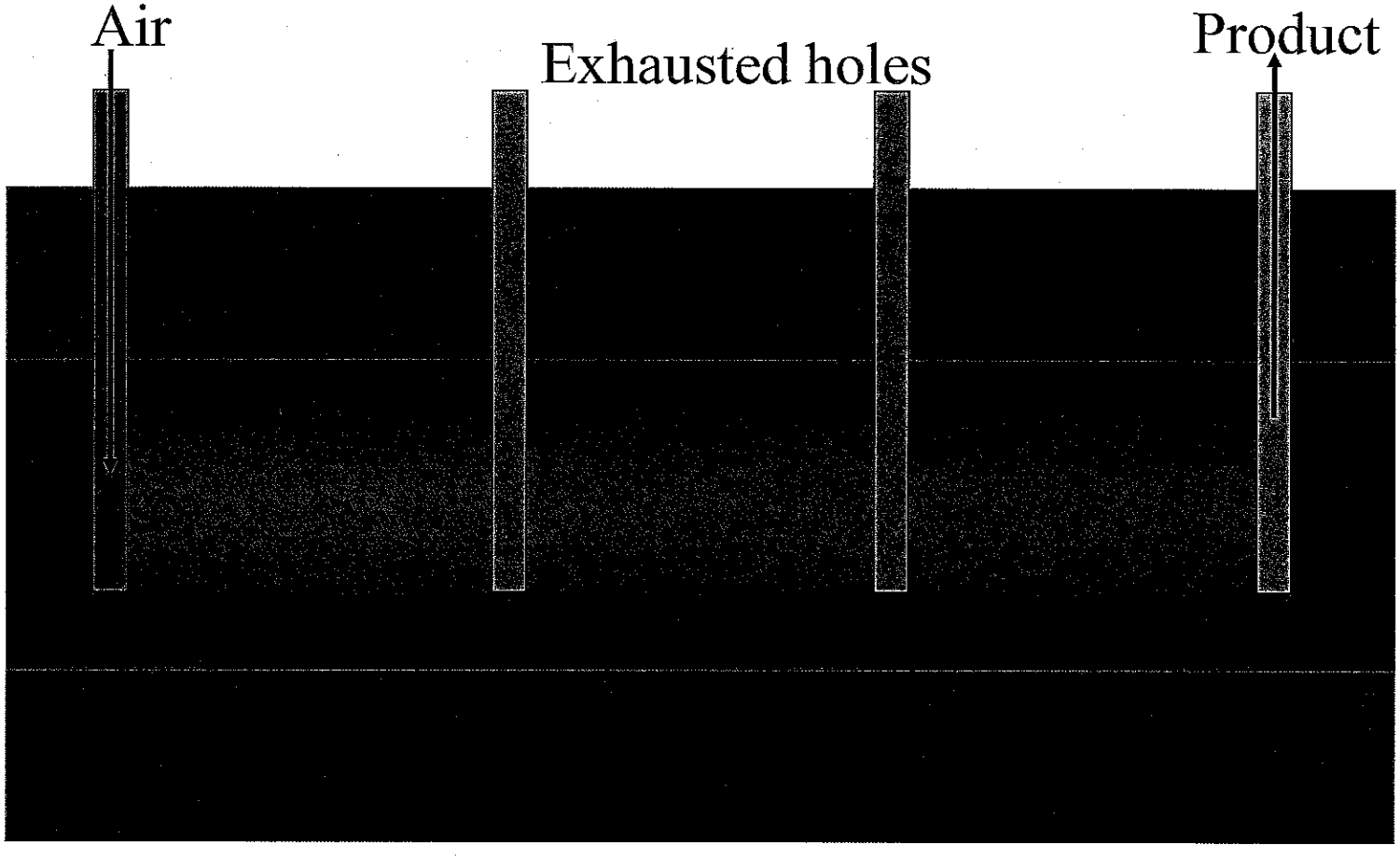

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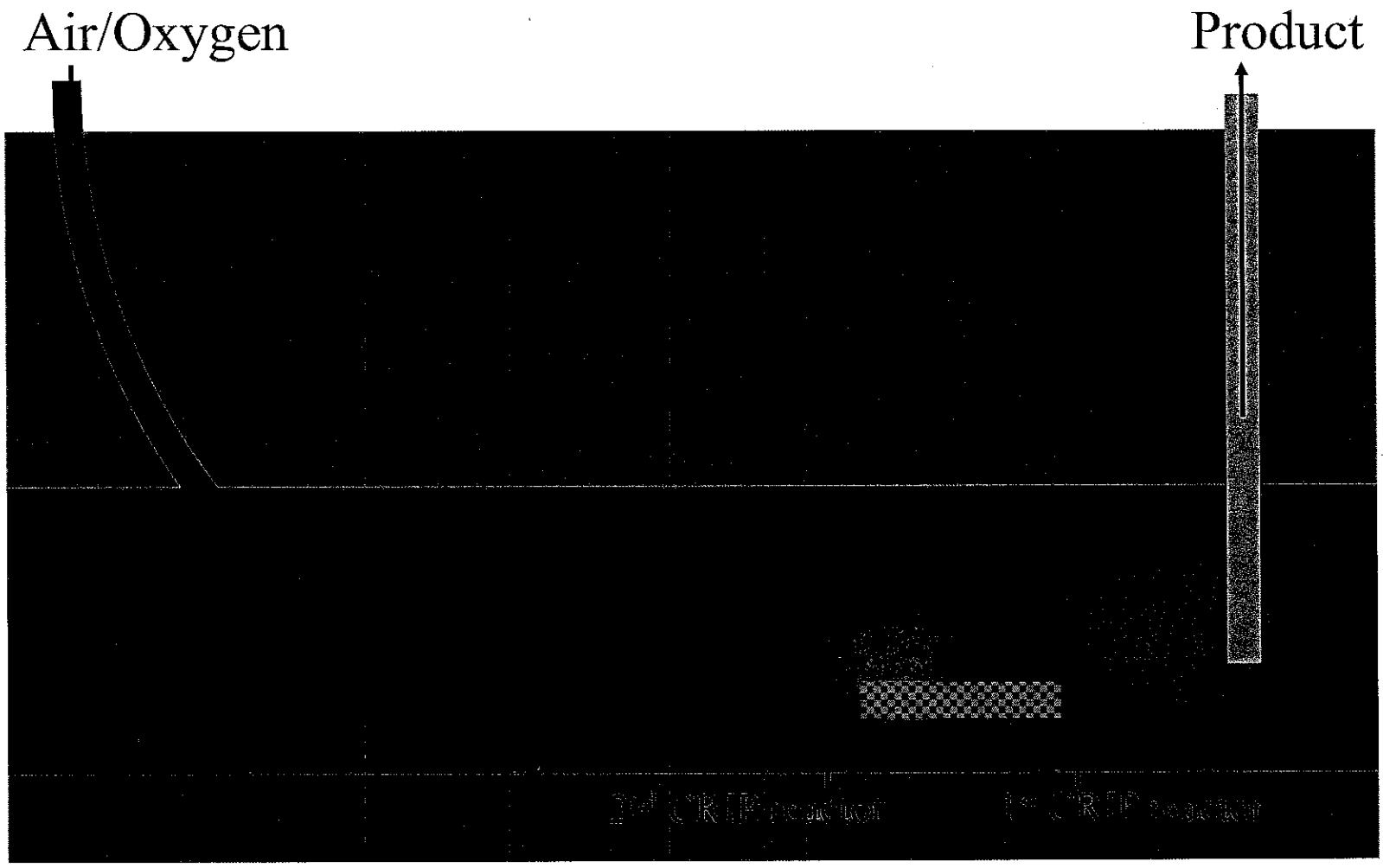

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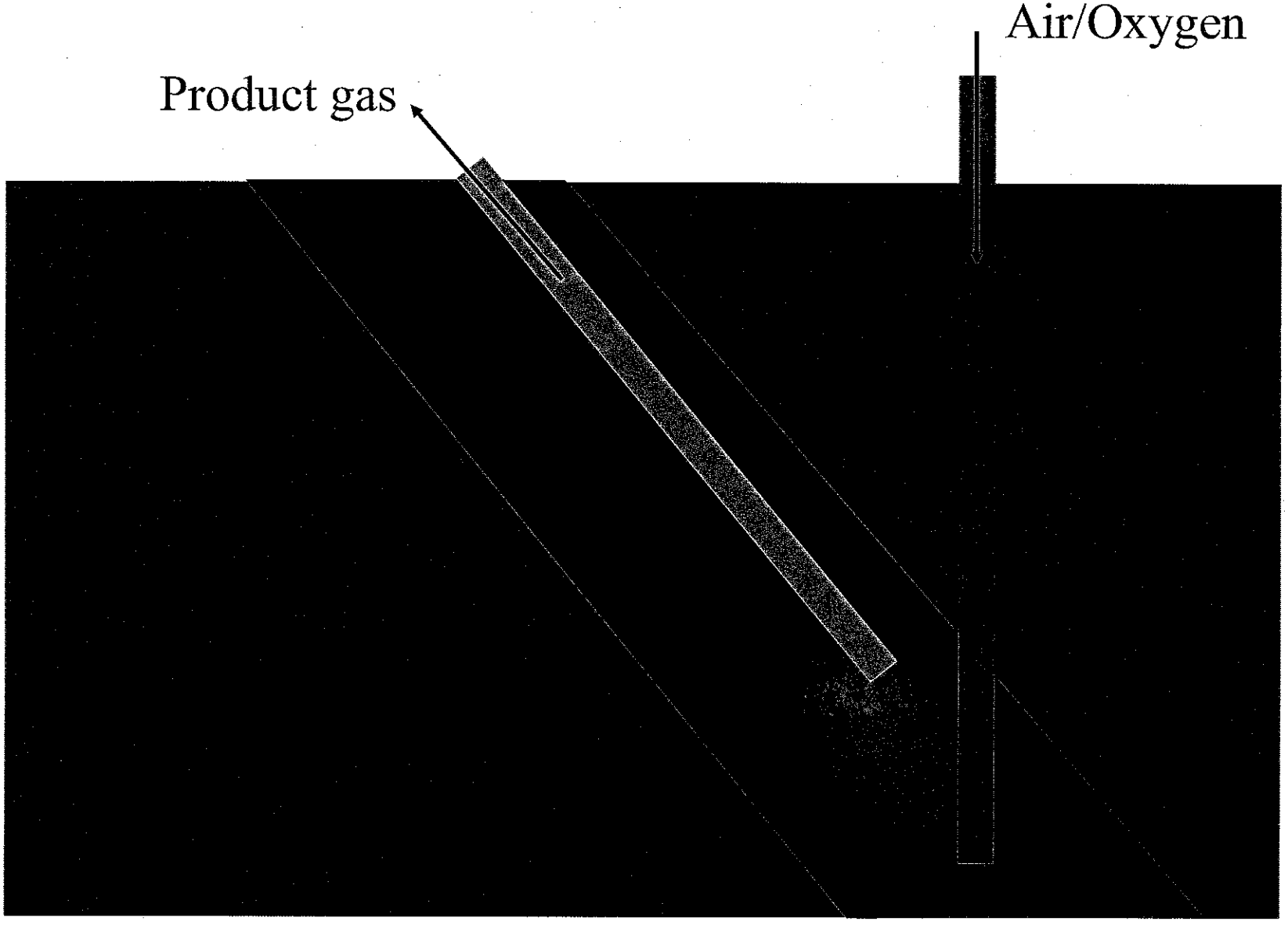

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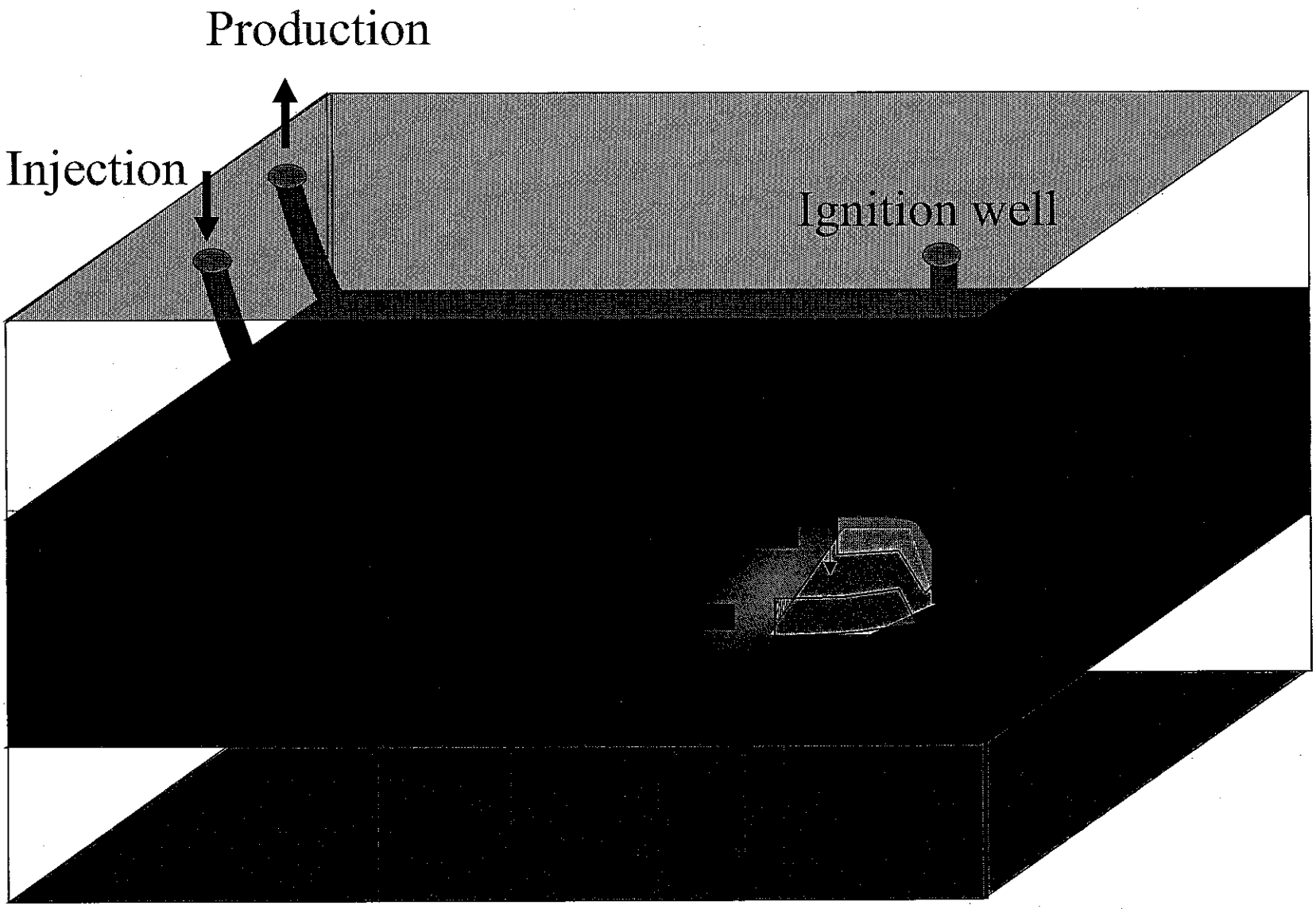

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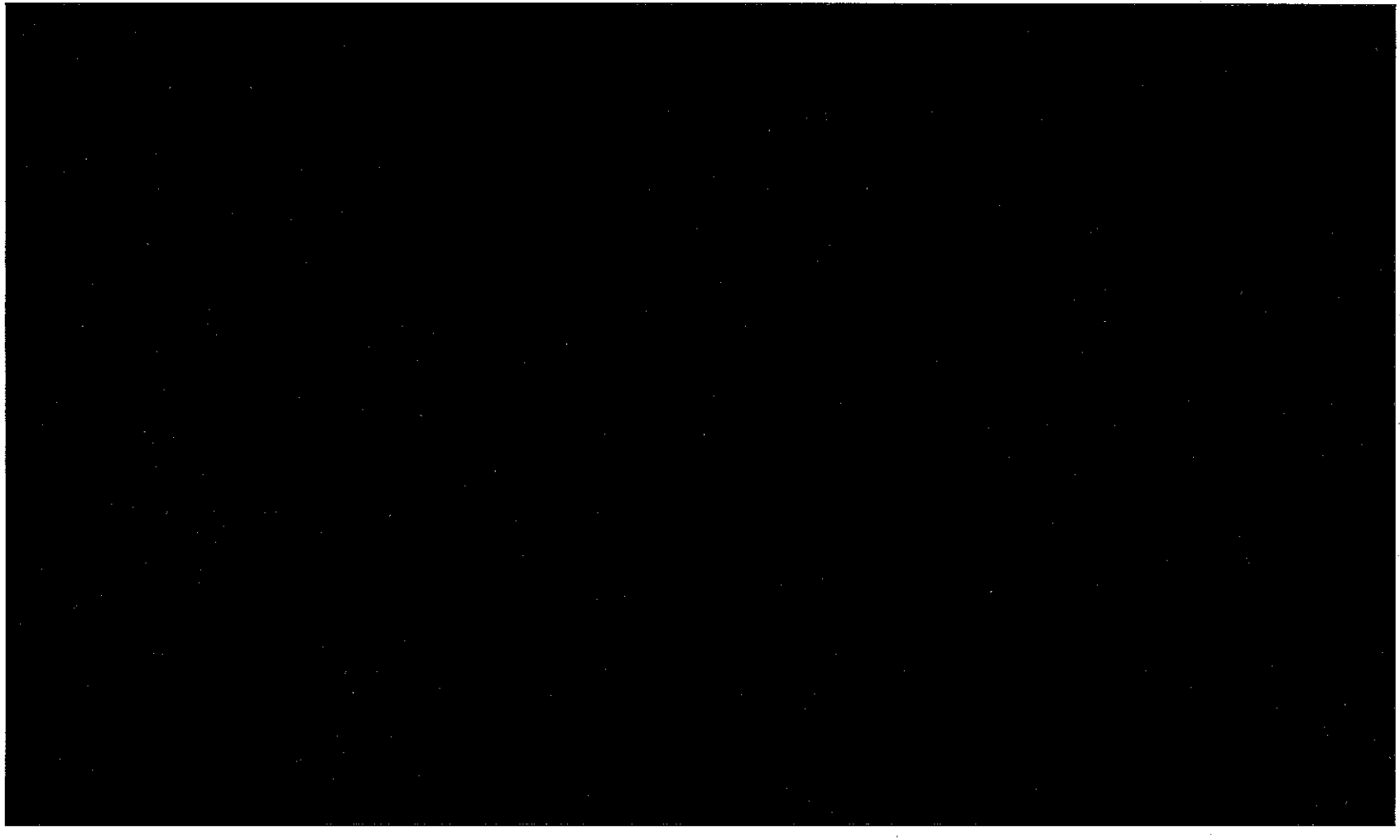

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- **Applications**
- **Site selection**
- **Potential problems**
- **Operating rules**

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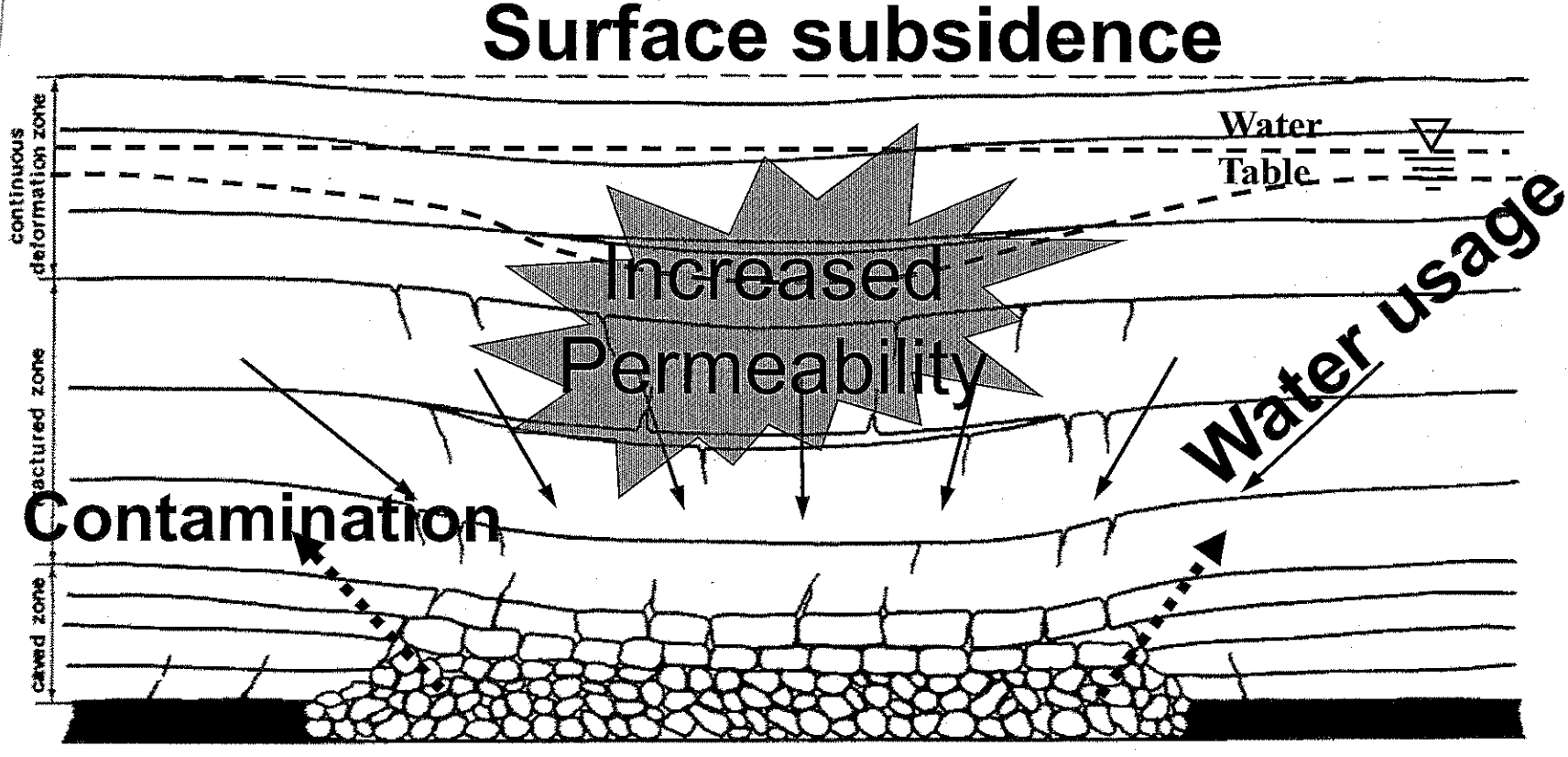

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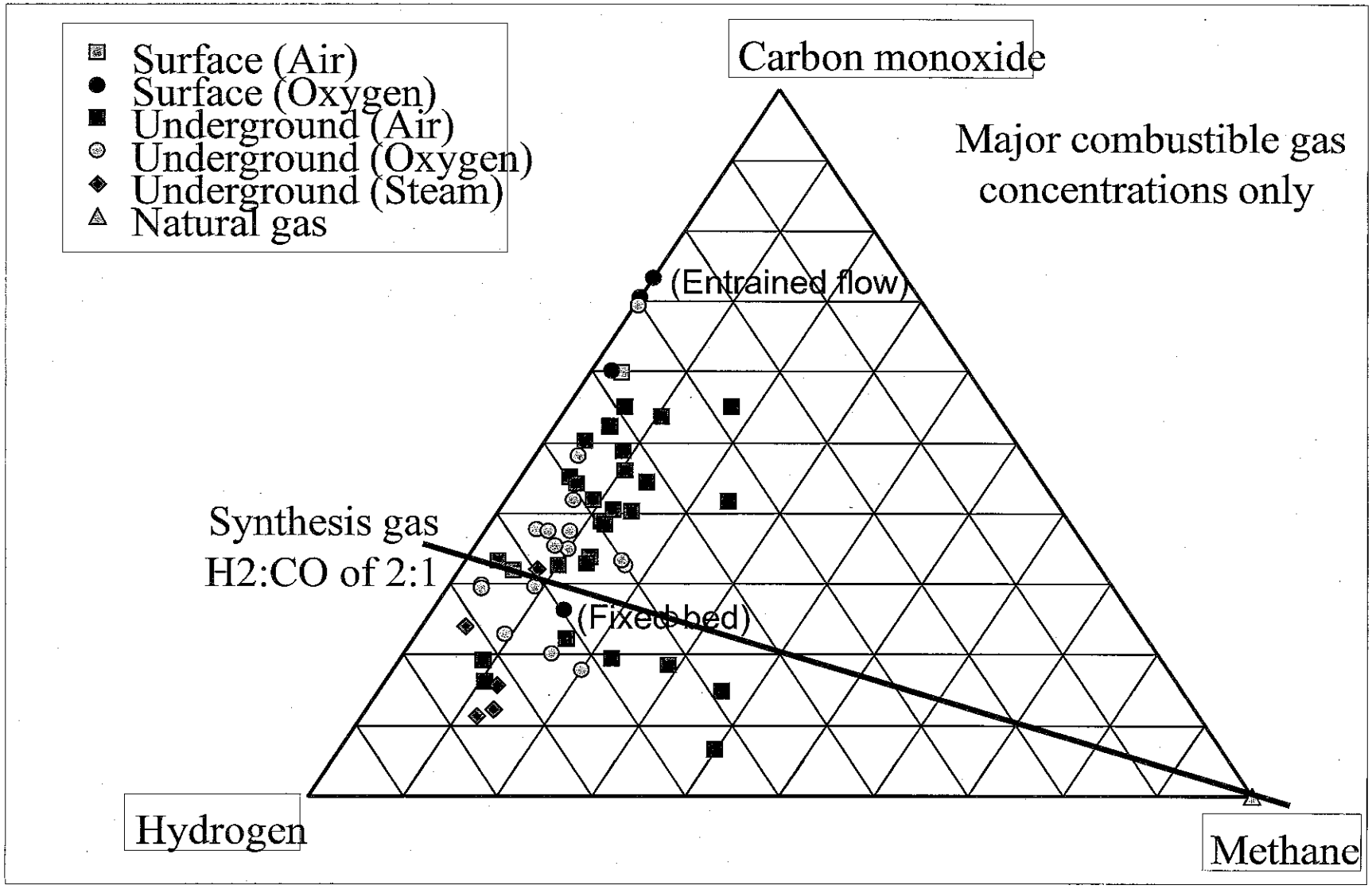
Gas composition



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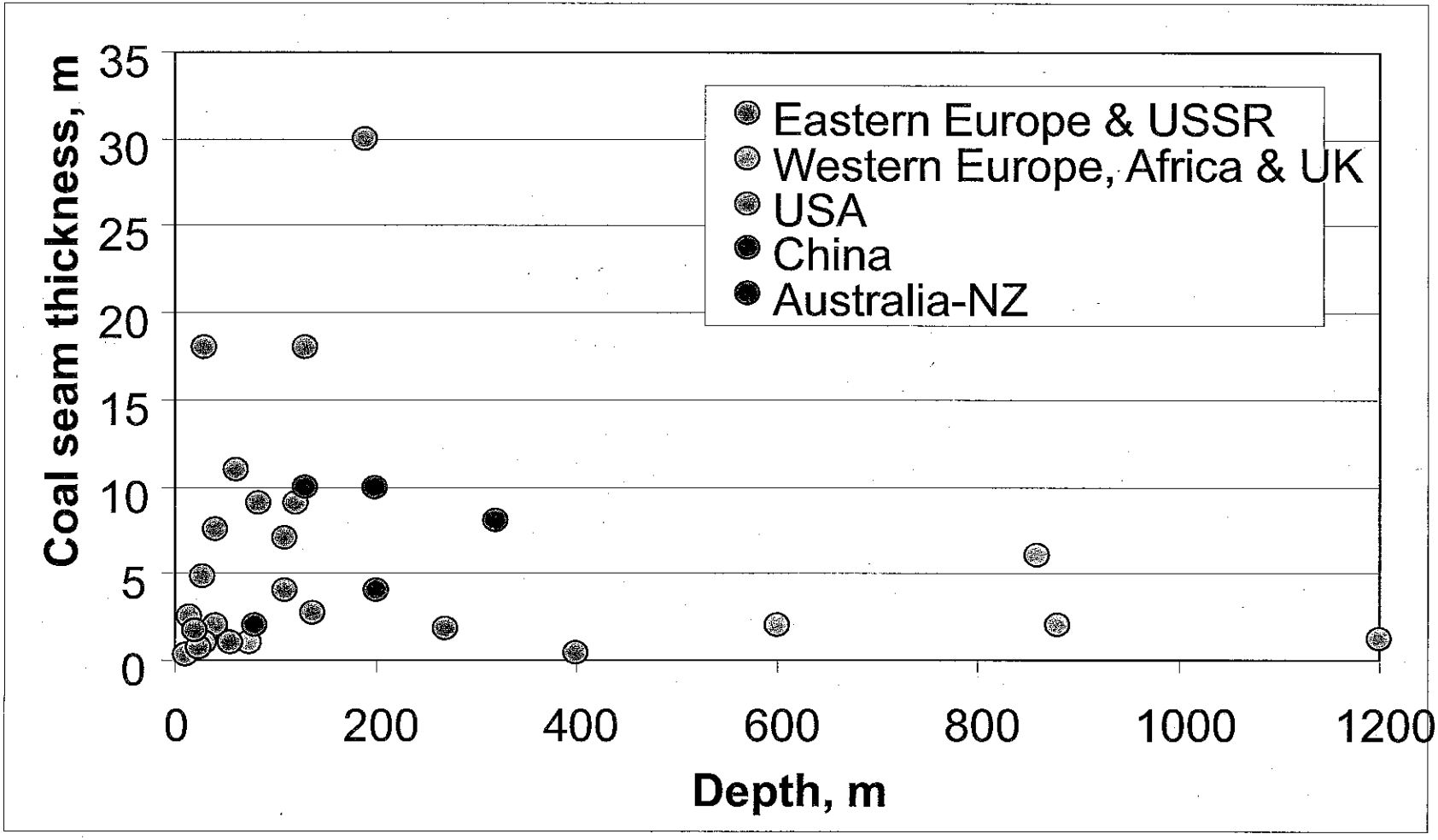
Site characteristics



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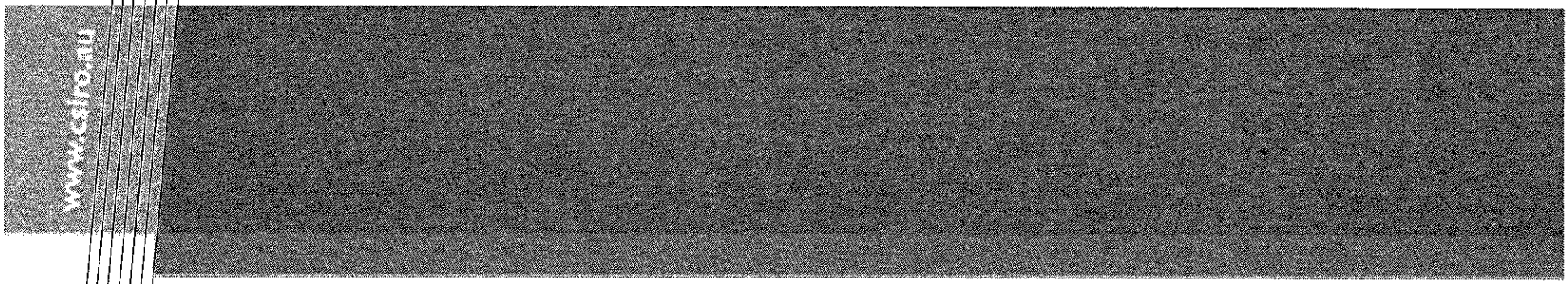
CSIRO Energy Technology
Dr Andrew Beath
Senior Research Scientist
Newcastle Energy Centre

Phone: +61 (2) 4960 6137
Email: Andrew.Beath@csiro.au
Web: www.csiro.au/science/energy



Contact Us
Phone: 1300 363 400 or +61 3 9545 2176
Email: enquiries@csiro.au Web: www.csiro.au

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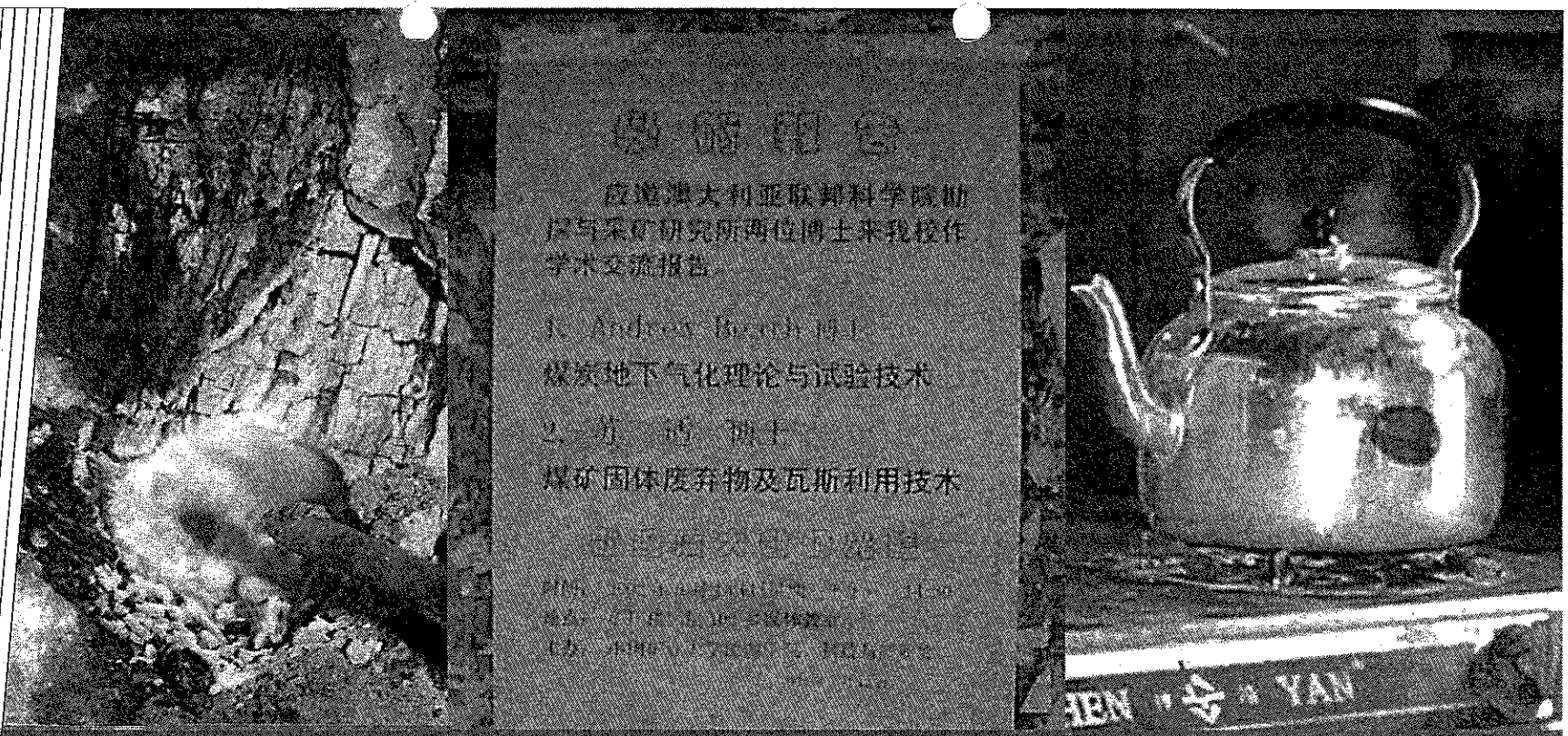

Underground Coal Gasification: Technical Challenges

Andrew Beath
CSIRO Energy Technology
5th May 2009

www.csiro.au

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Document 8

Who am I?

- Chemical Engineer with a background in mathematical modelling of reaction processes
- Past employment: R&D roles in Pacific Power and the Sugar Research Institute
- Joined CSIRO in 1999: Post-Doc modelling of Underground Coal Gasification project with CSIRO Exploration & Mining
- Joined Energy Technology in 2007 to work on Coal-to-Liquids research

What is Coal Gasification?

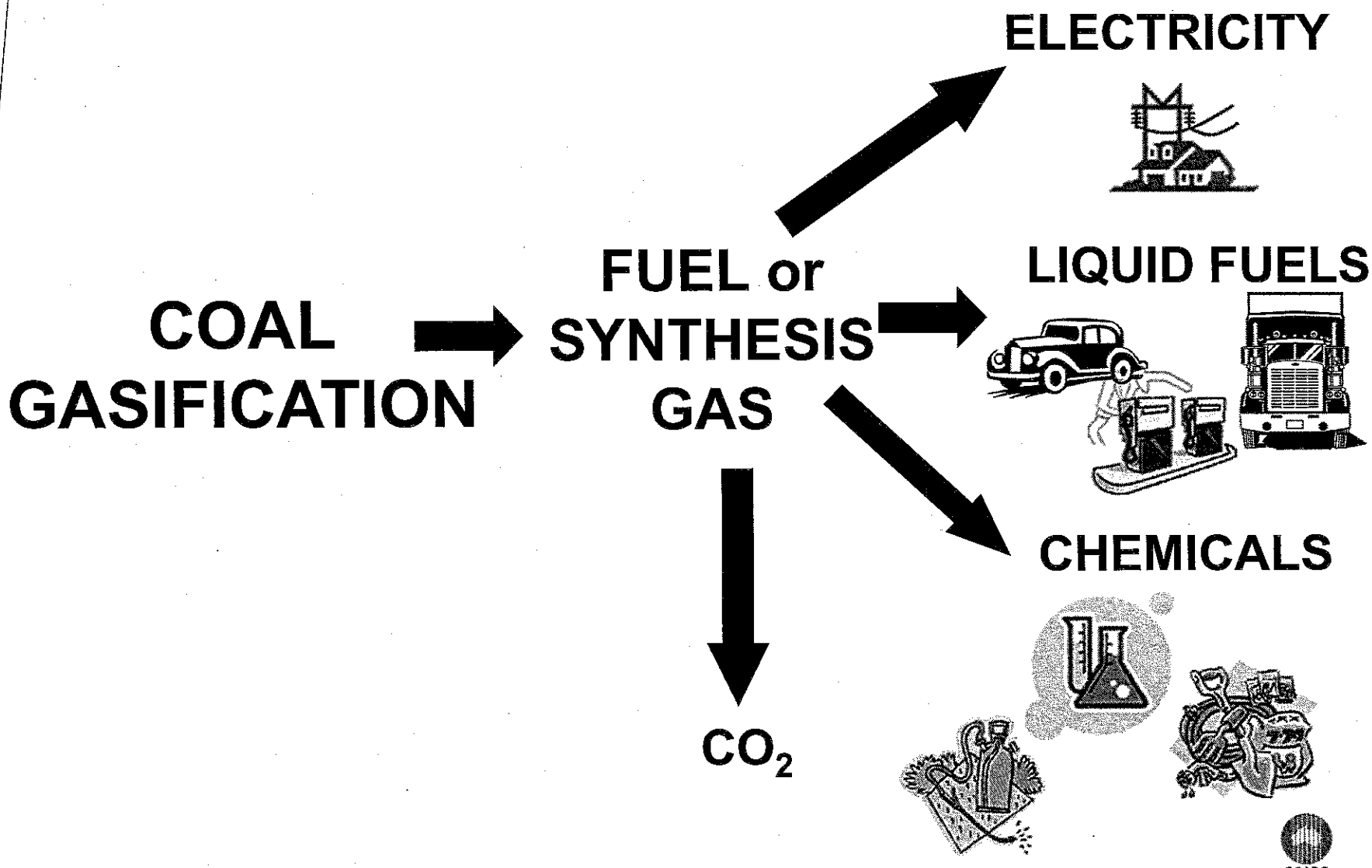
Coal, Water, & Oxygen

Reaction

Heat, Char, Gas, & Tar

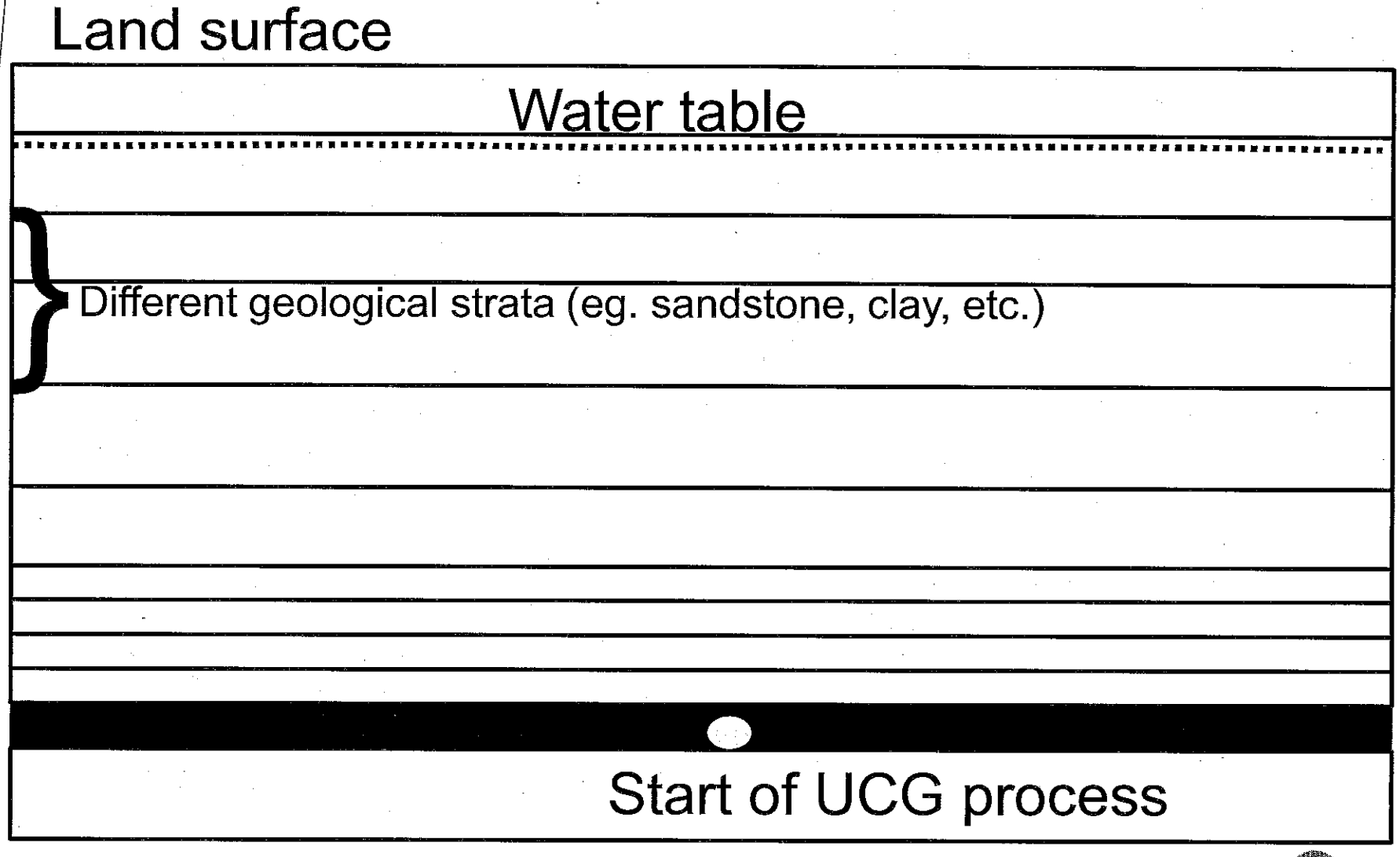
The key product is fuel or synthesis gas that contains carbon monoxide, hydrogen and methane, plus carbon dioxide and water

What can the product be used for?



Stages of UCG

1.Start



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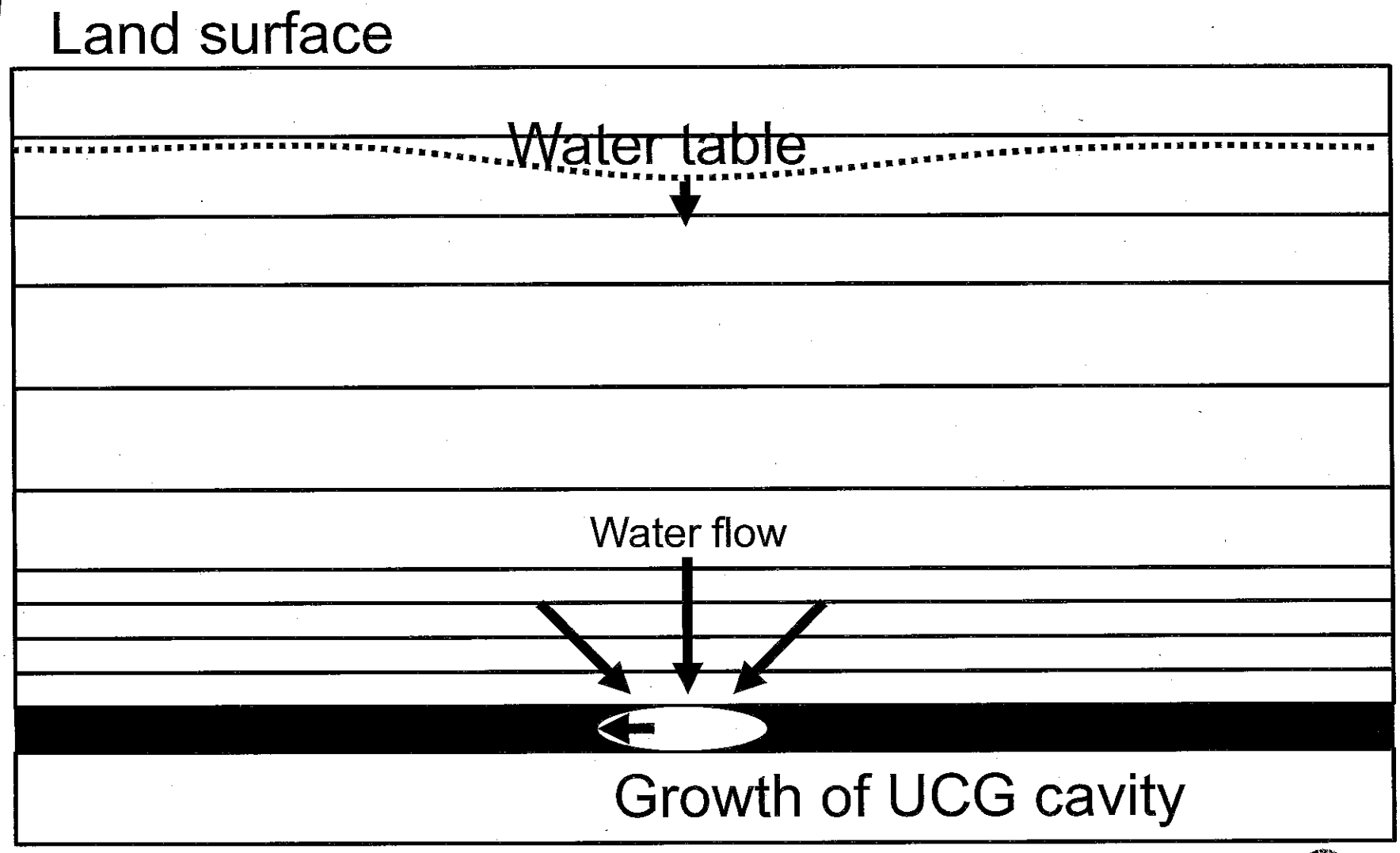
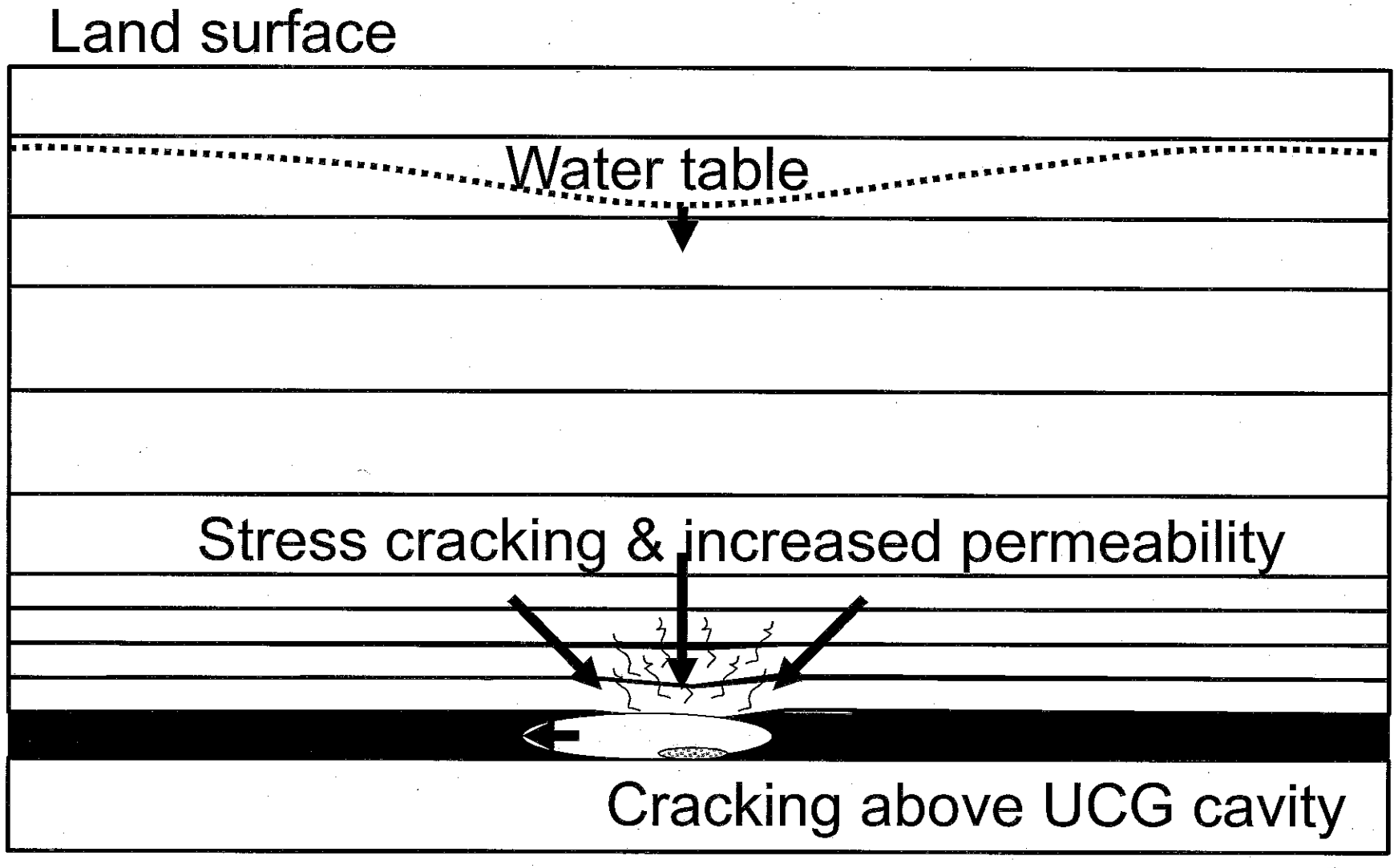
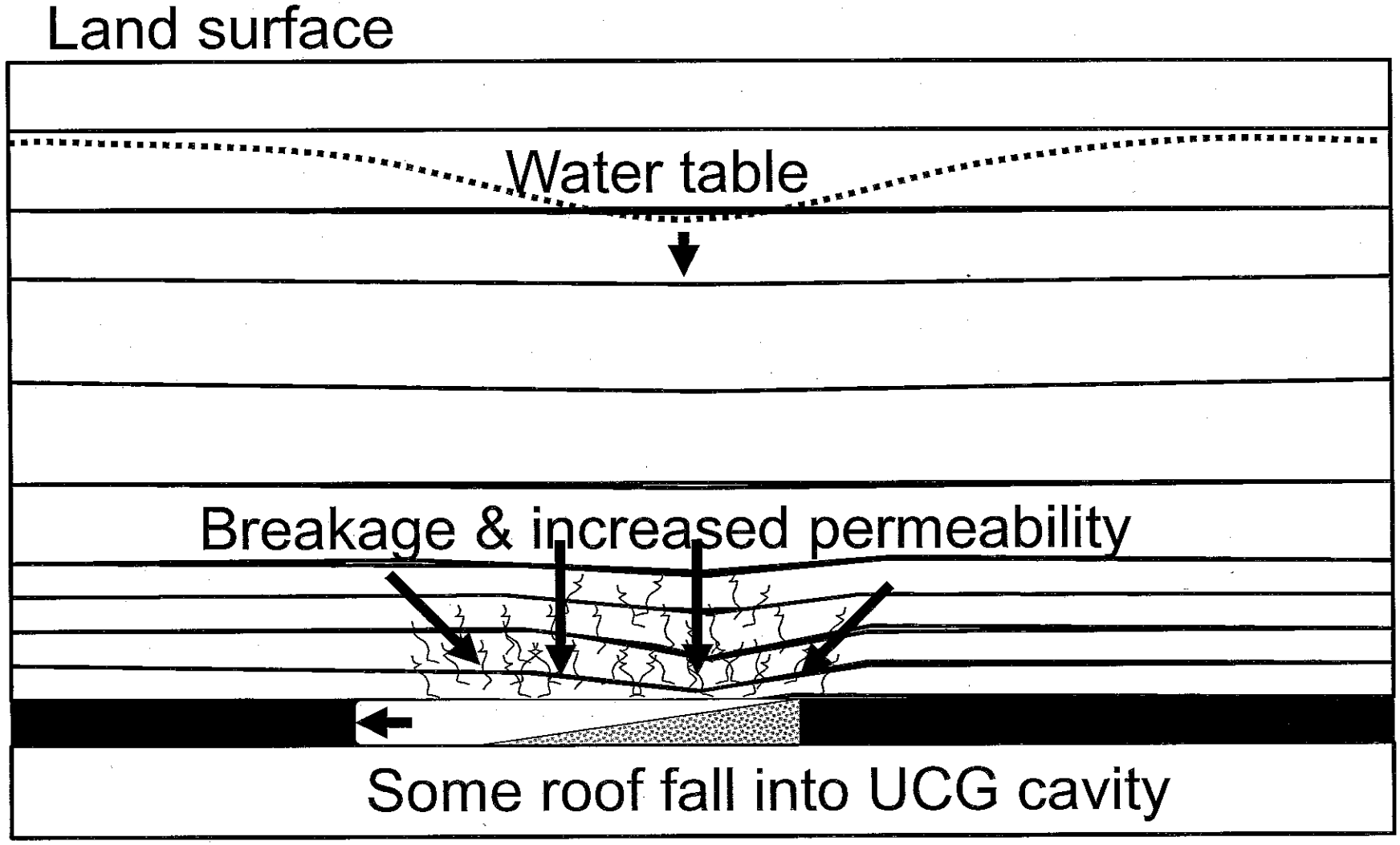
2. Growth



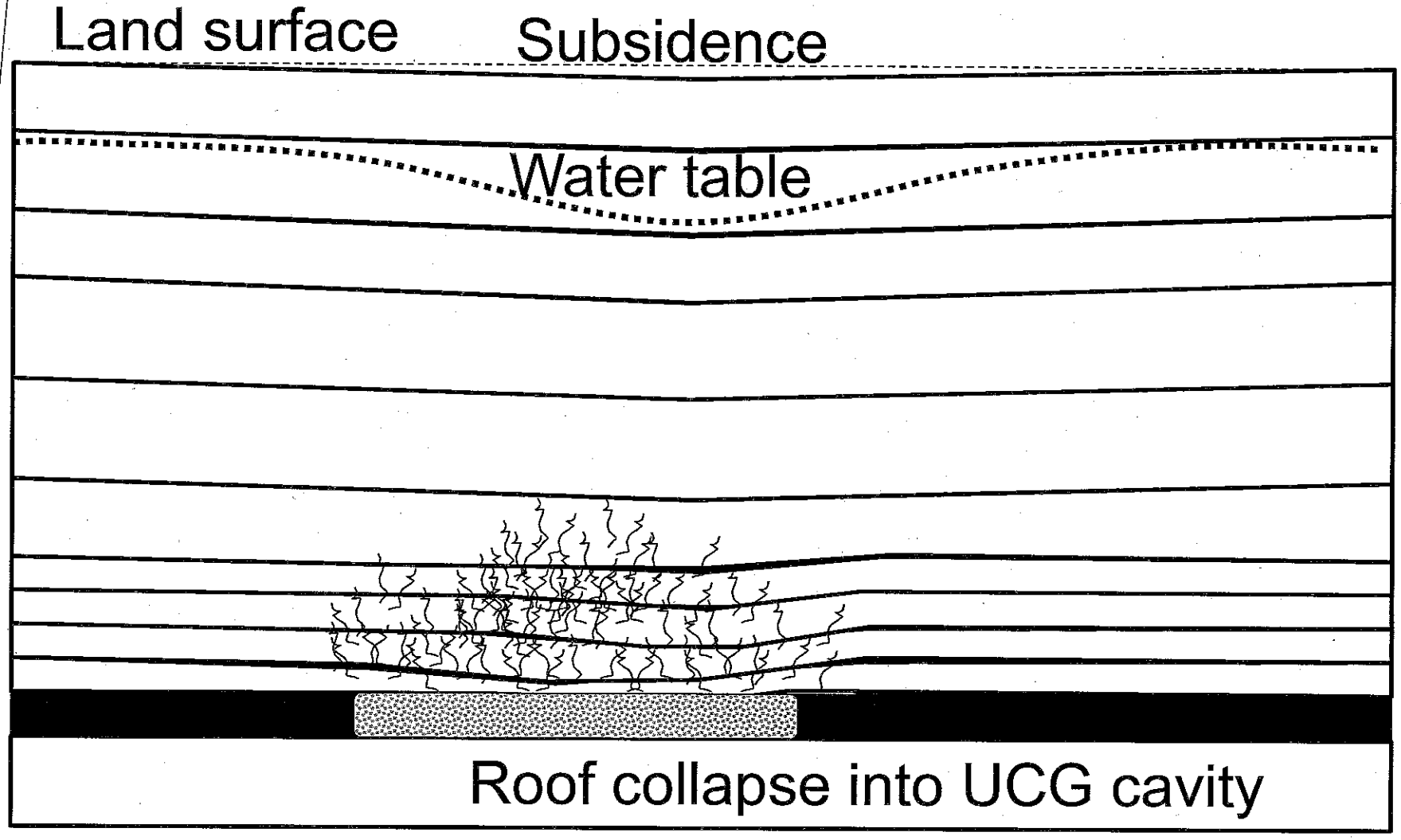
3. Cracking


Land surface
Water table
Stress cracking & increased permeability
Cracking above UCG cavity

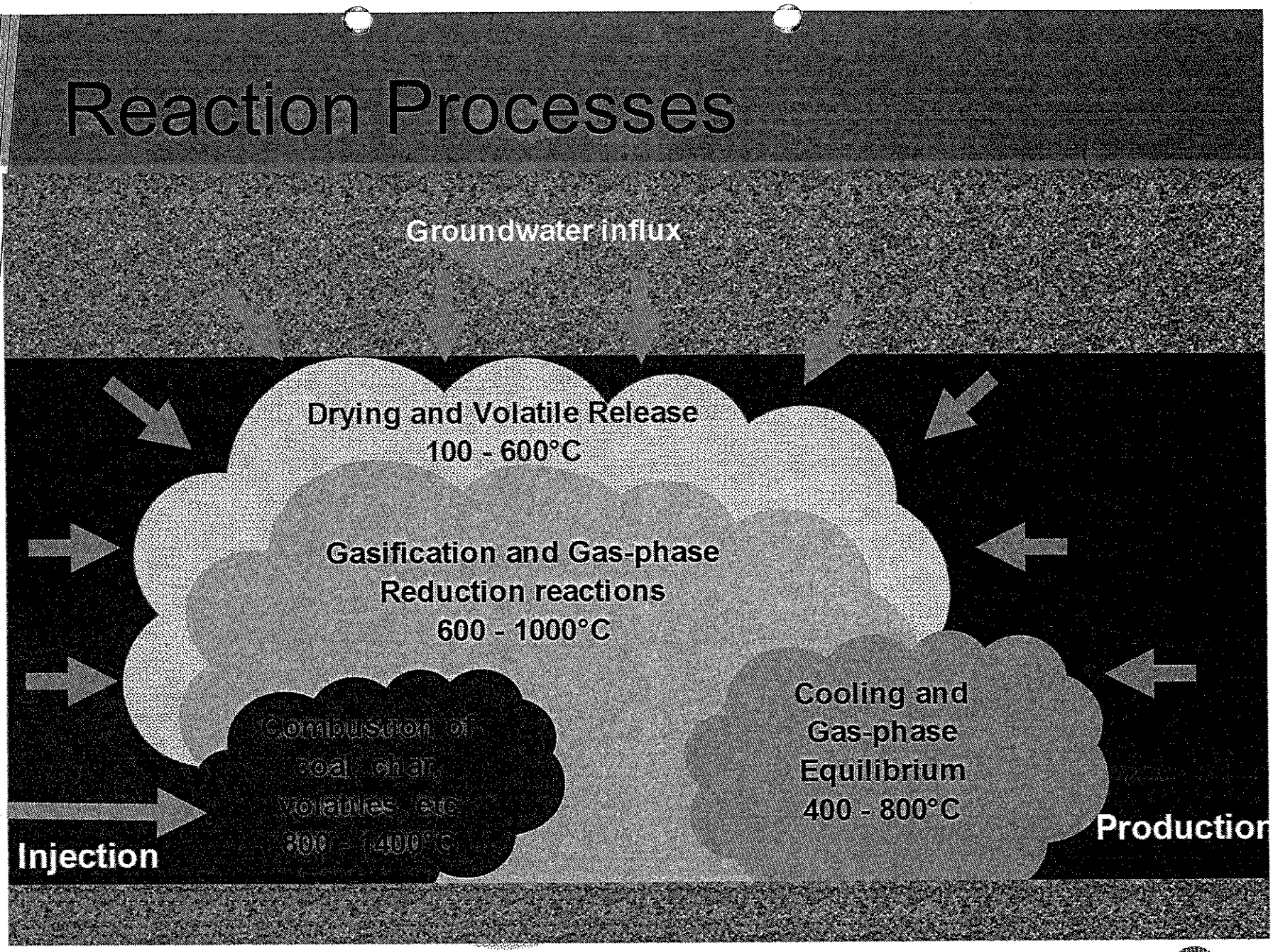
4. Breakage


Land surface
Water table
Breakage & increased permeability
Some roof fall into UCG cavity

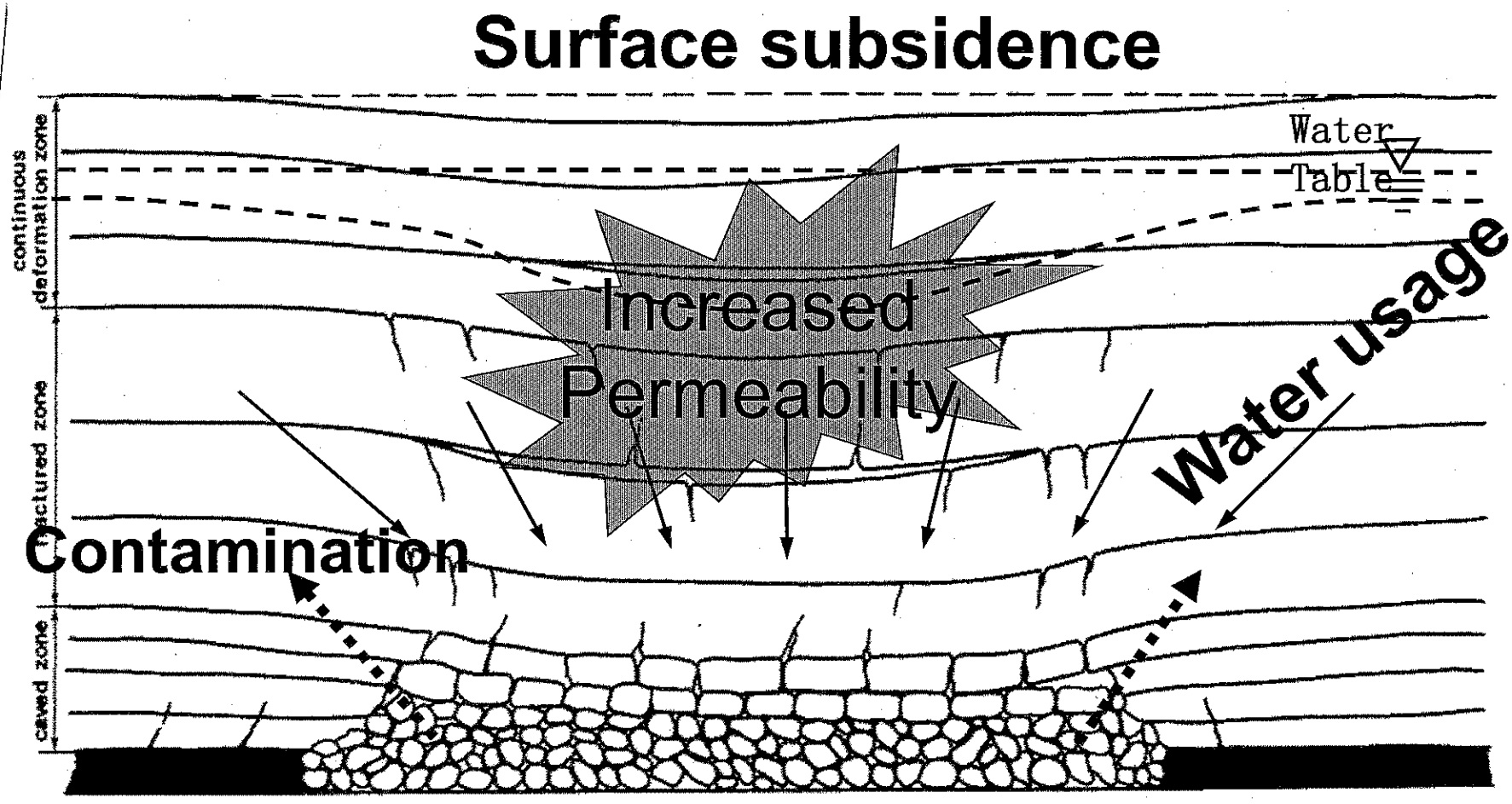
5. Closure/Collapse



Reaction Processes



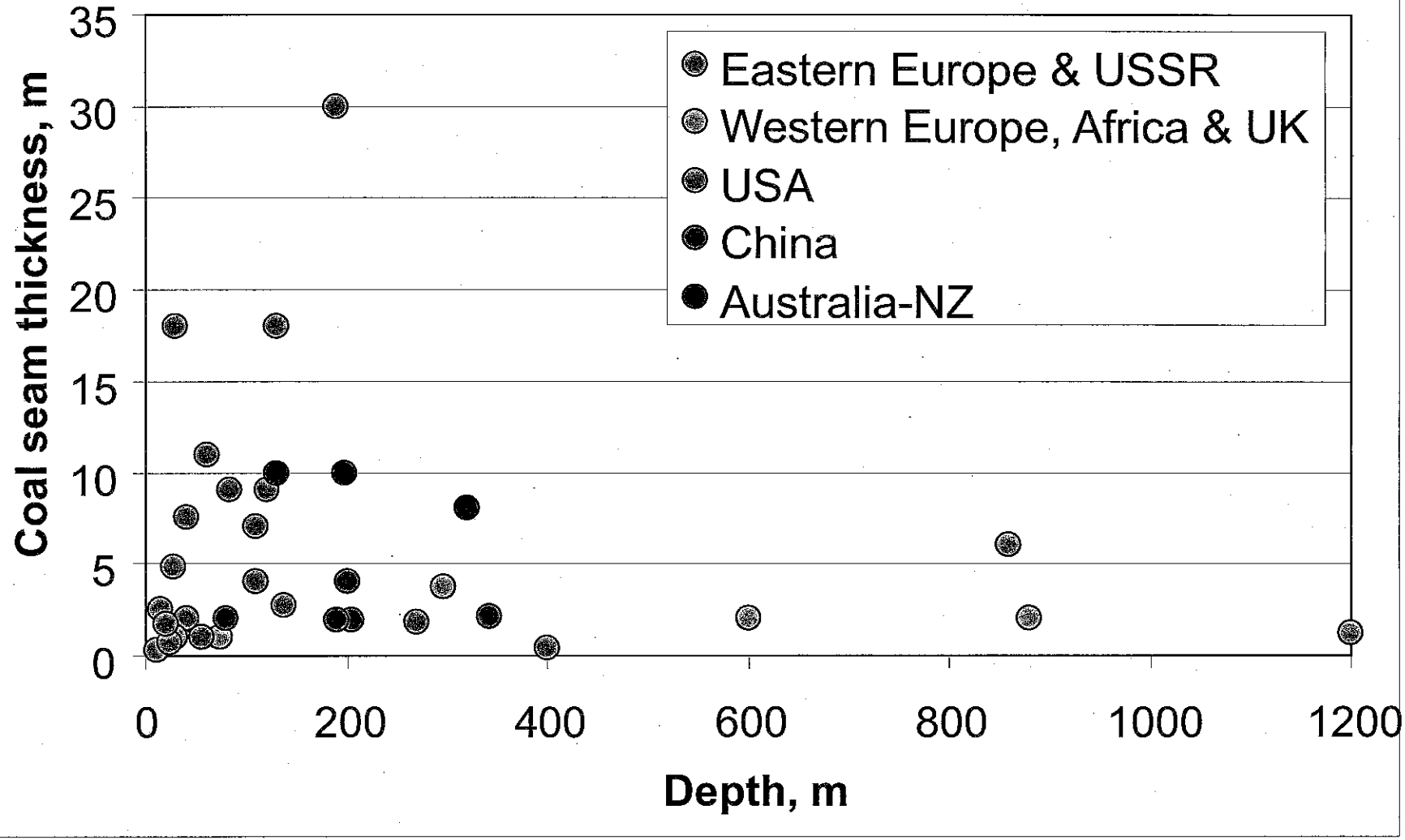
What happens at the UCG site?



What makes a good UCG site?

- Coal seam continuity
- Thick coal seams
- Moderate water influx
- Strong overburden with low permeability
- Coal permeability sufficient to allow the required gas flow

Characteristics of trial site around the world

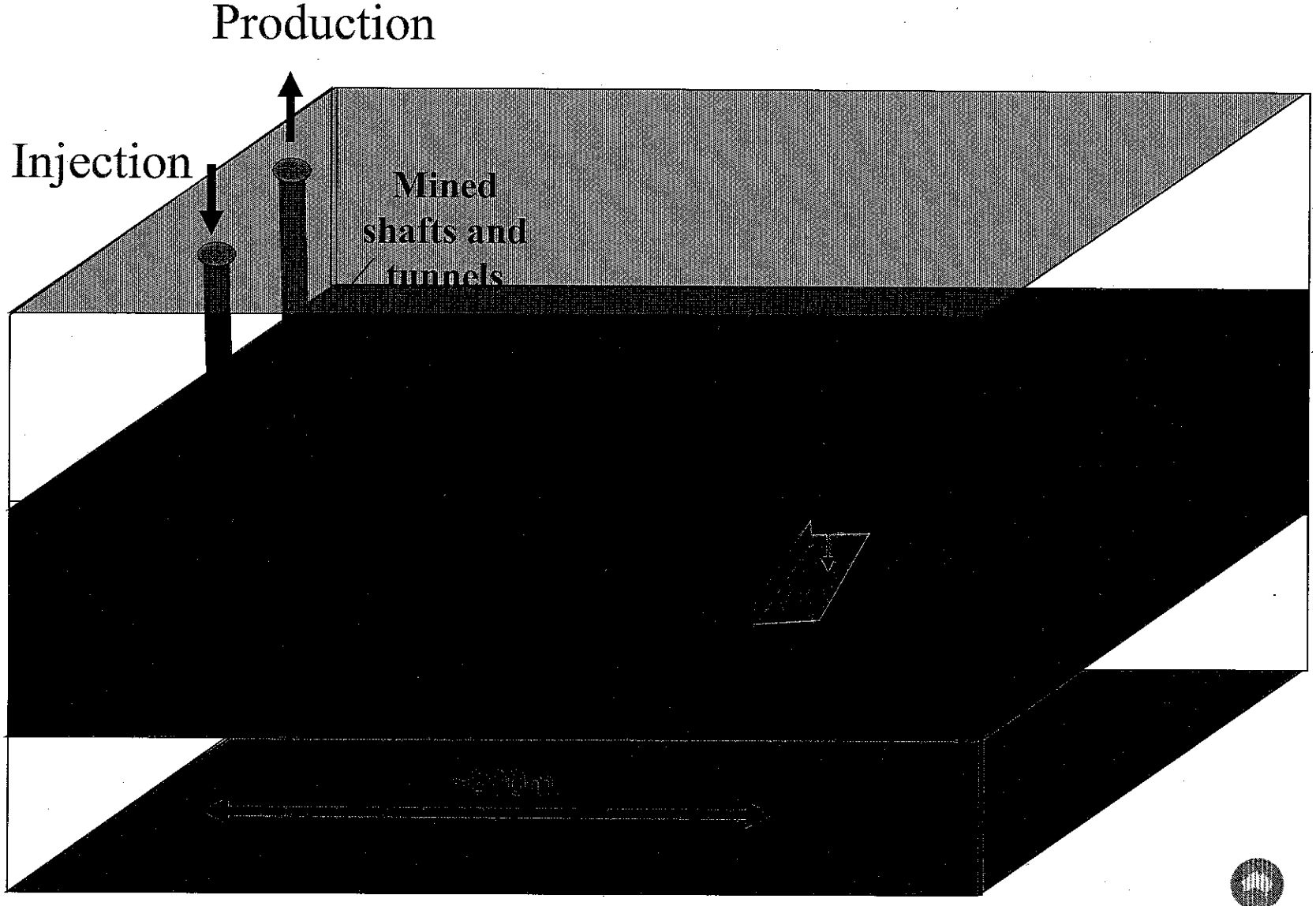


Constructing the Gasifier

Different UCG techniques:

- Chamber
- Vertical Wells
- SDB (Steeply Dipping Bed)
- CRIP (Controlled Retracting Injection Point)
- Parallel Well CRIP

Chamber



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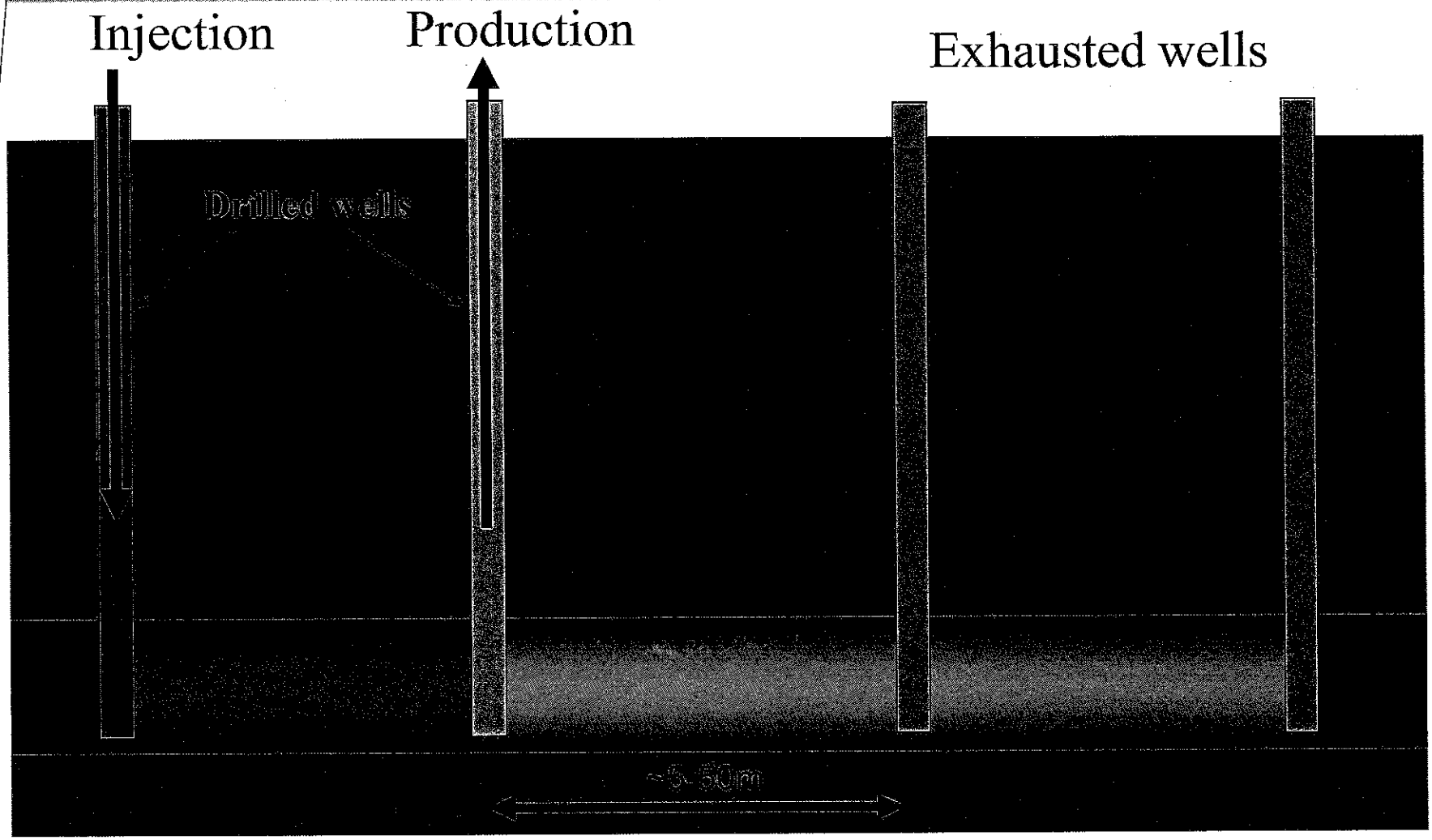
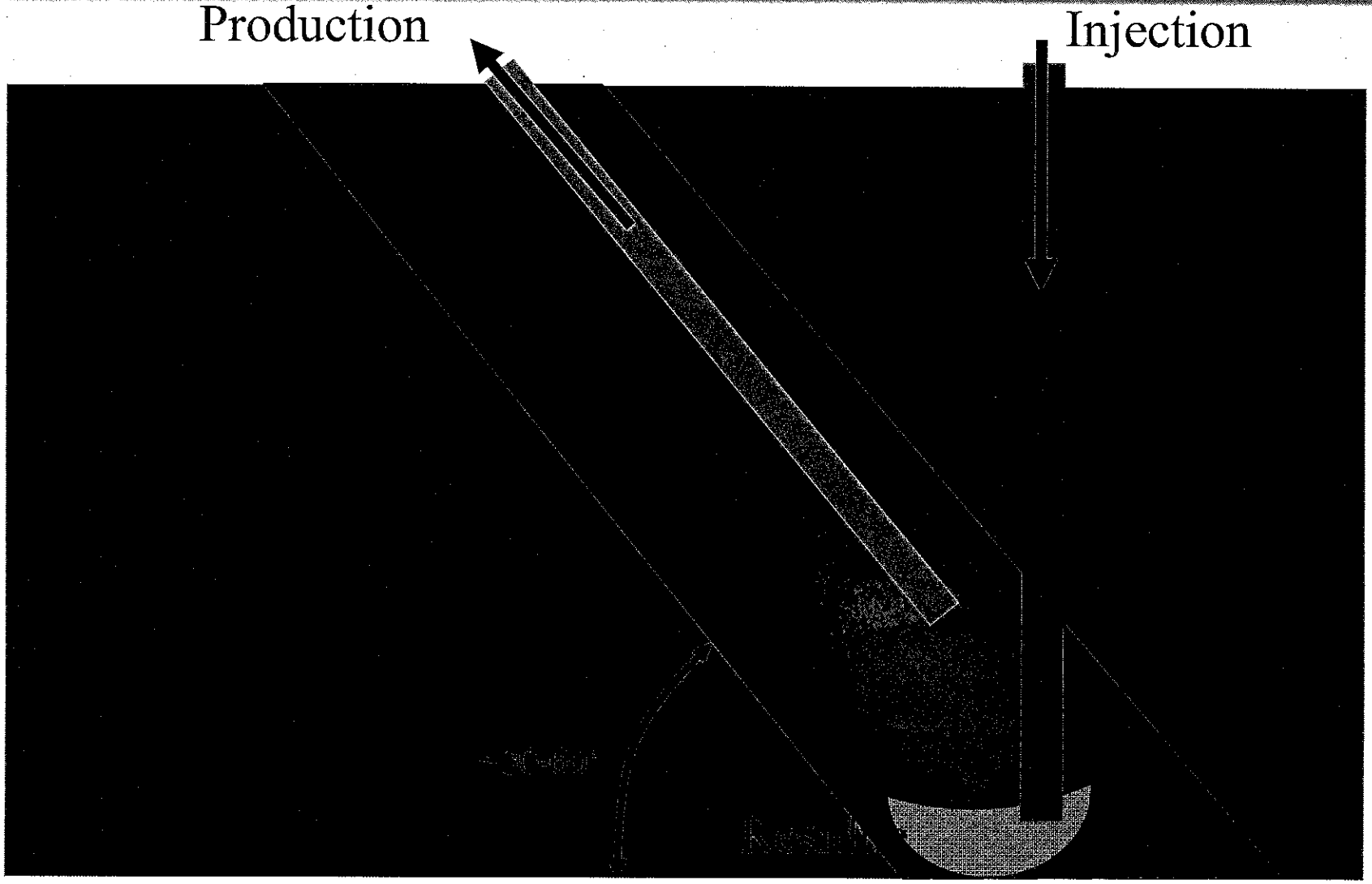
Vertical Wells

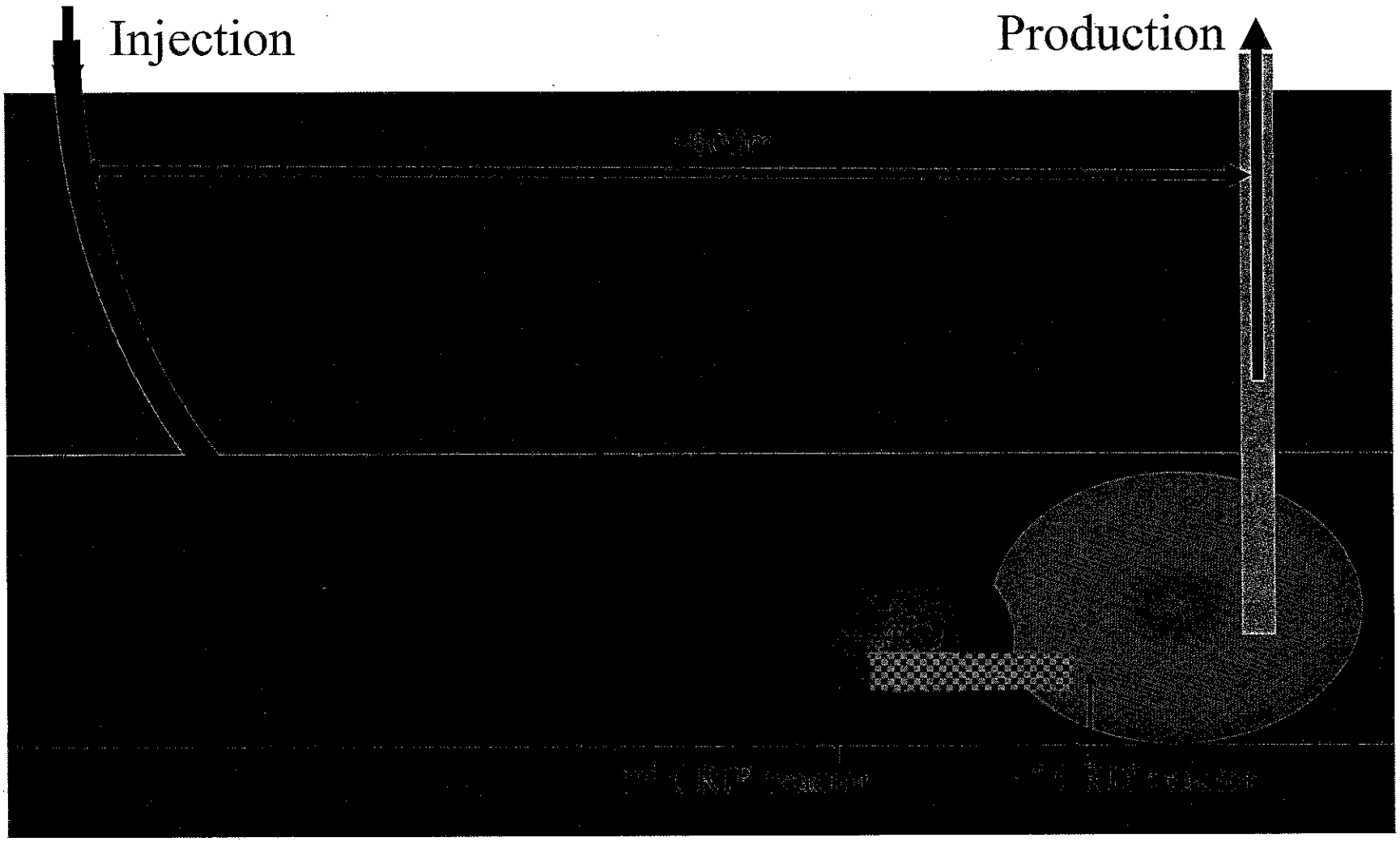


Linking of wells can be through natural or artificially enhanced coal permeability or drilling

SDB (Steeply Dipping Bed)



CRIP (Controlled Retracting Injection Point)



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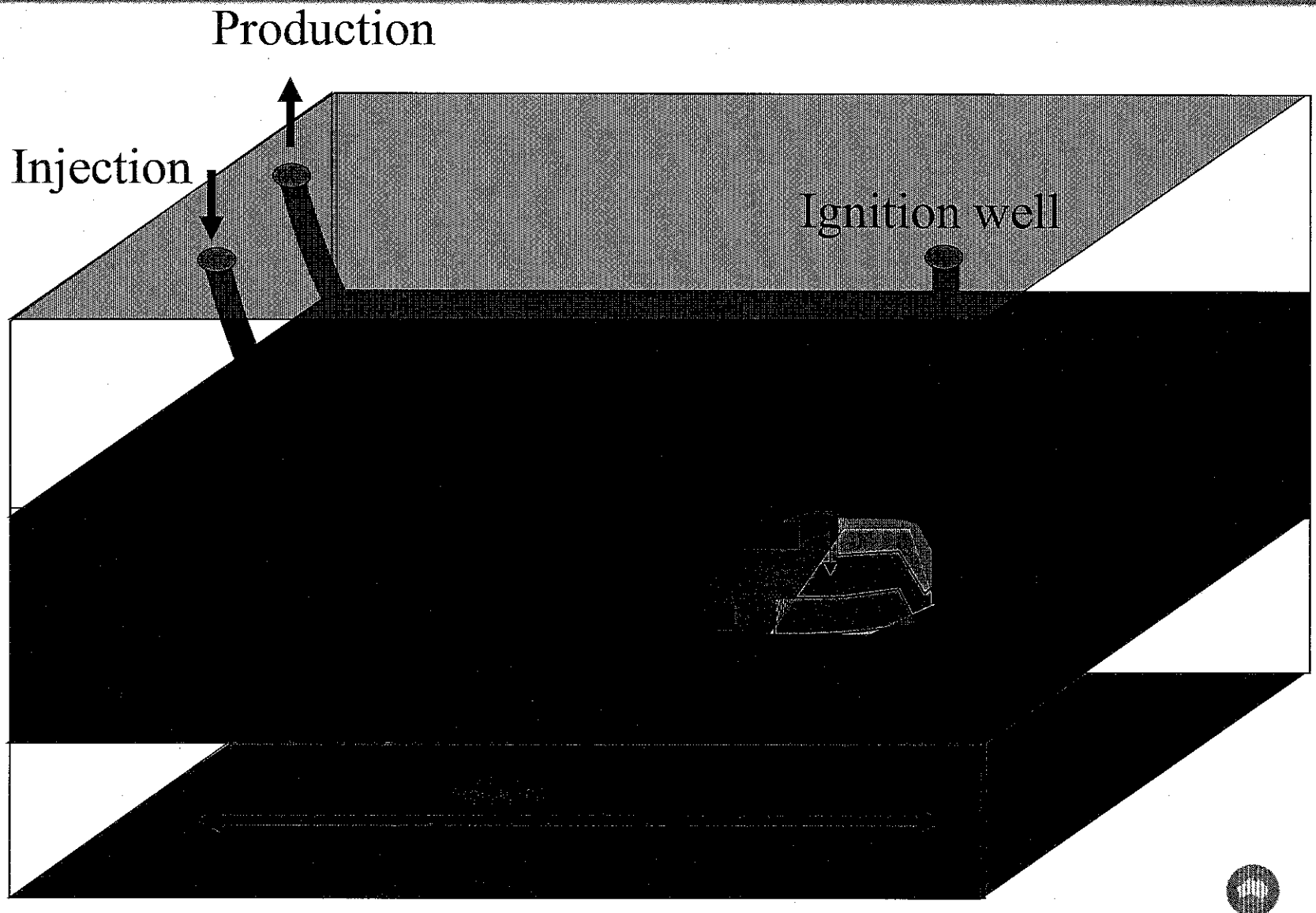
Parallel Well CRIP



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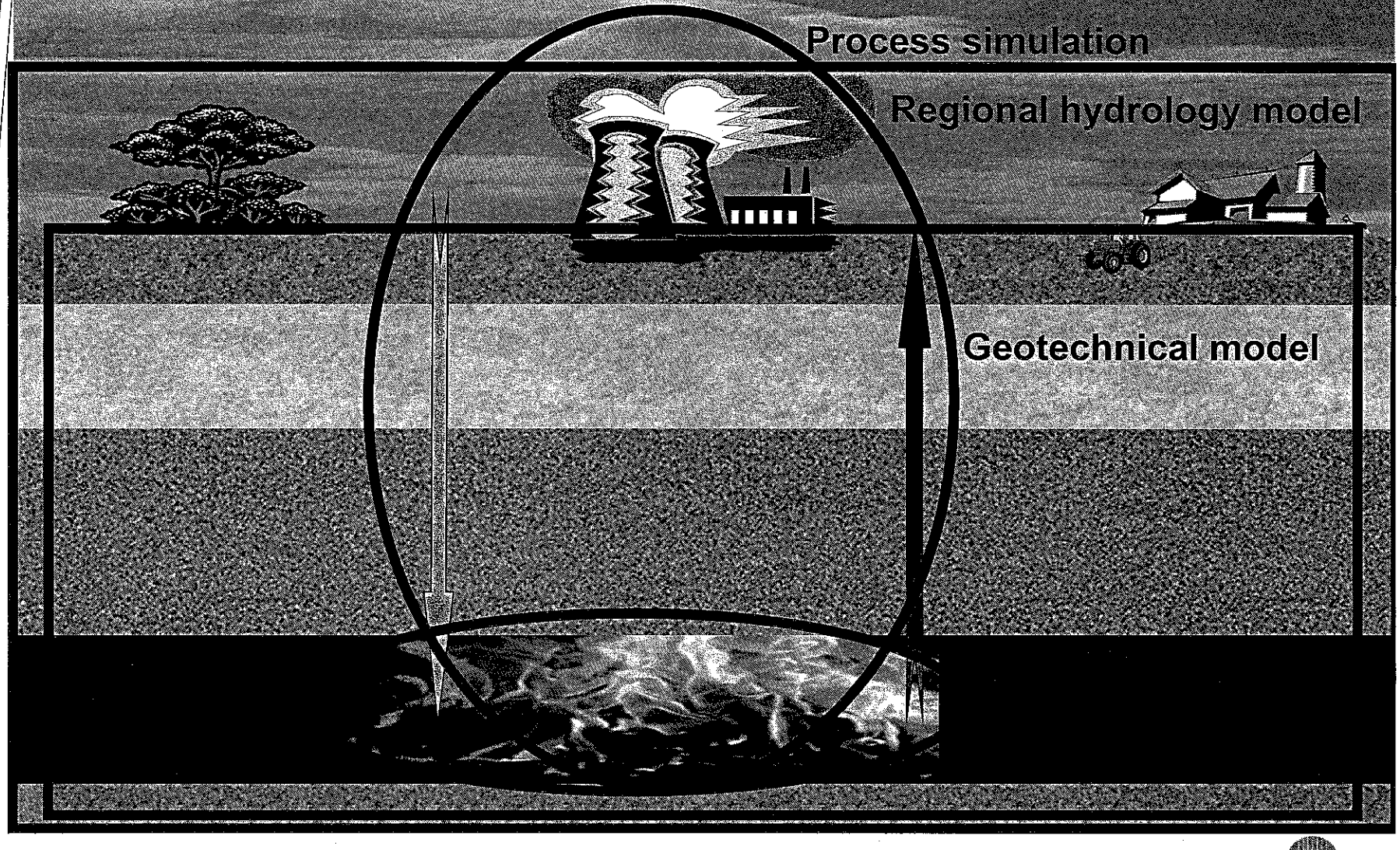
CSIRO Project

Developing models to predict the performance for specific site & design combinations.

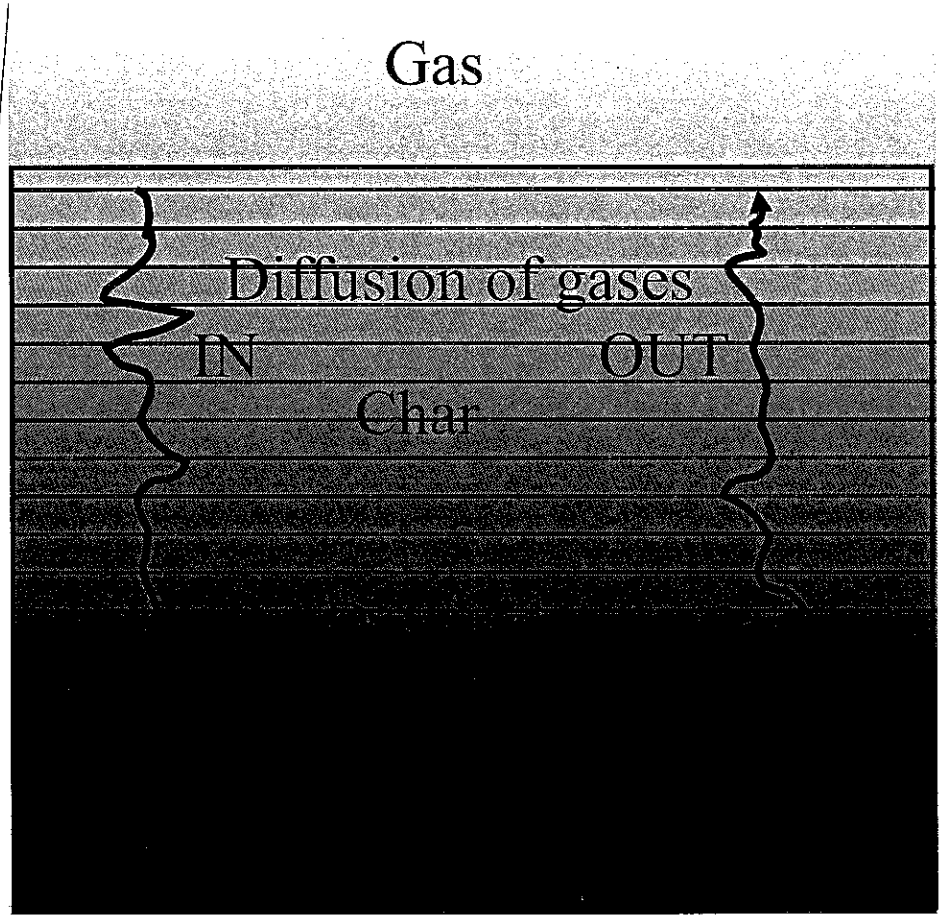
1. Demonstrate an understanding of UCG behaviour
2. Improve design, implementation and control
3. Evaluate suitability for different product gas uses

Later extended to encompass ***geological, geotechnical & environmental*** modelling that could provide better justification for site selection (+ additional risk analysis & societal attitude studies)

CSIRO Modelling IP
(transferred to Carbon Energy in 2006)



Coal Model



Coal Model represent a lump coal reacting with a hot gas

Included in the model are:

- Reactions
- Gas diffusion
- Water flow
- Drying
- Heat transfer
- Coal structural changes

Output is chiefly used in the cavity model.

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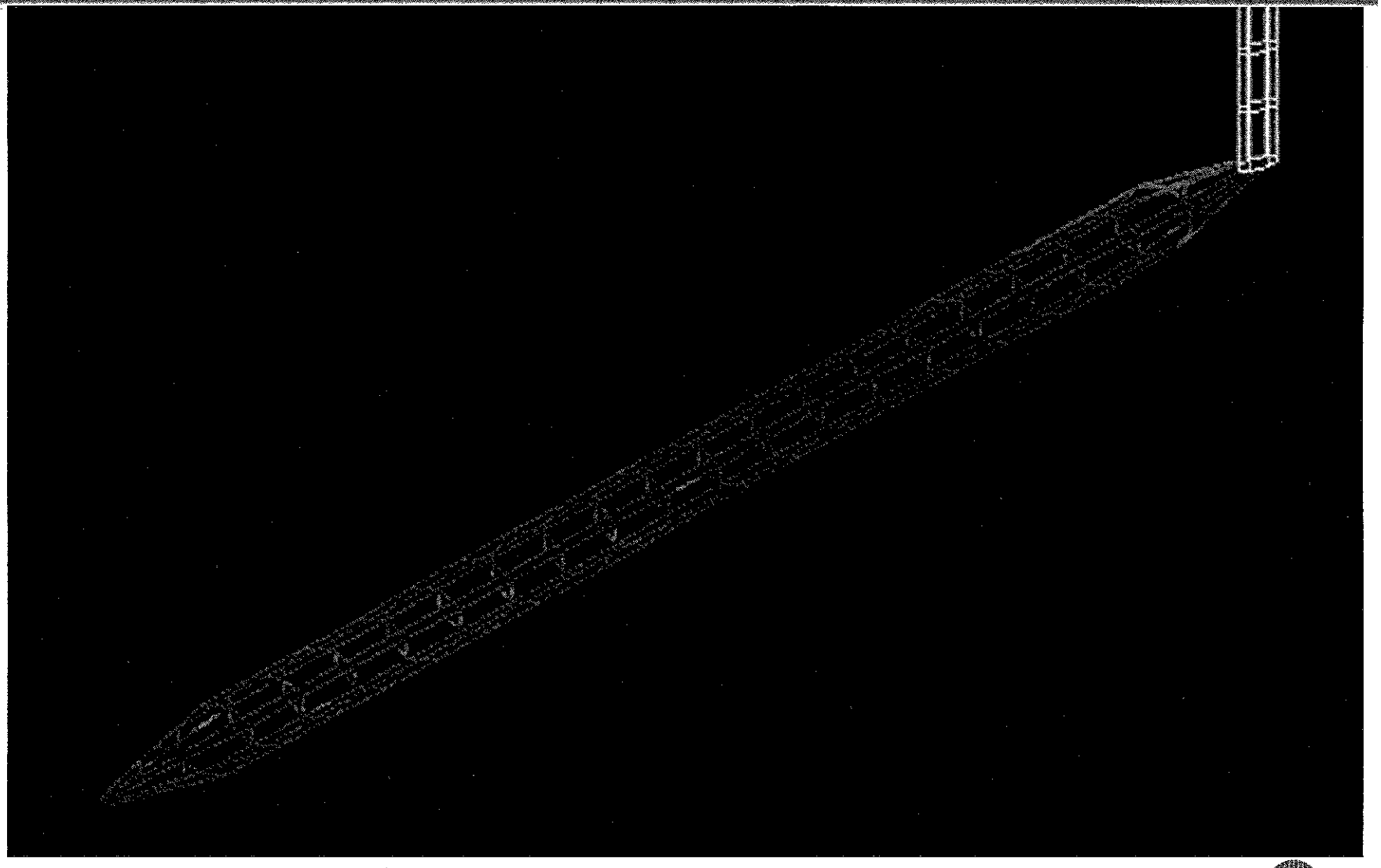
Cavity model operation



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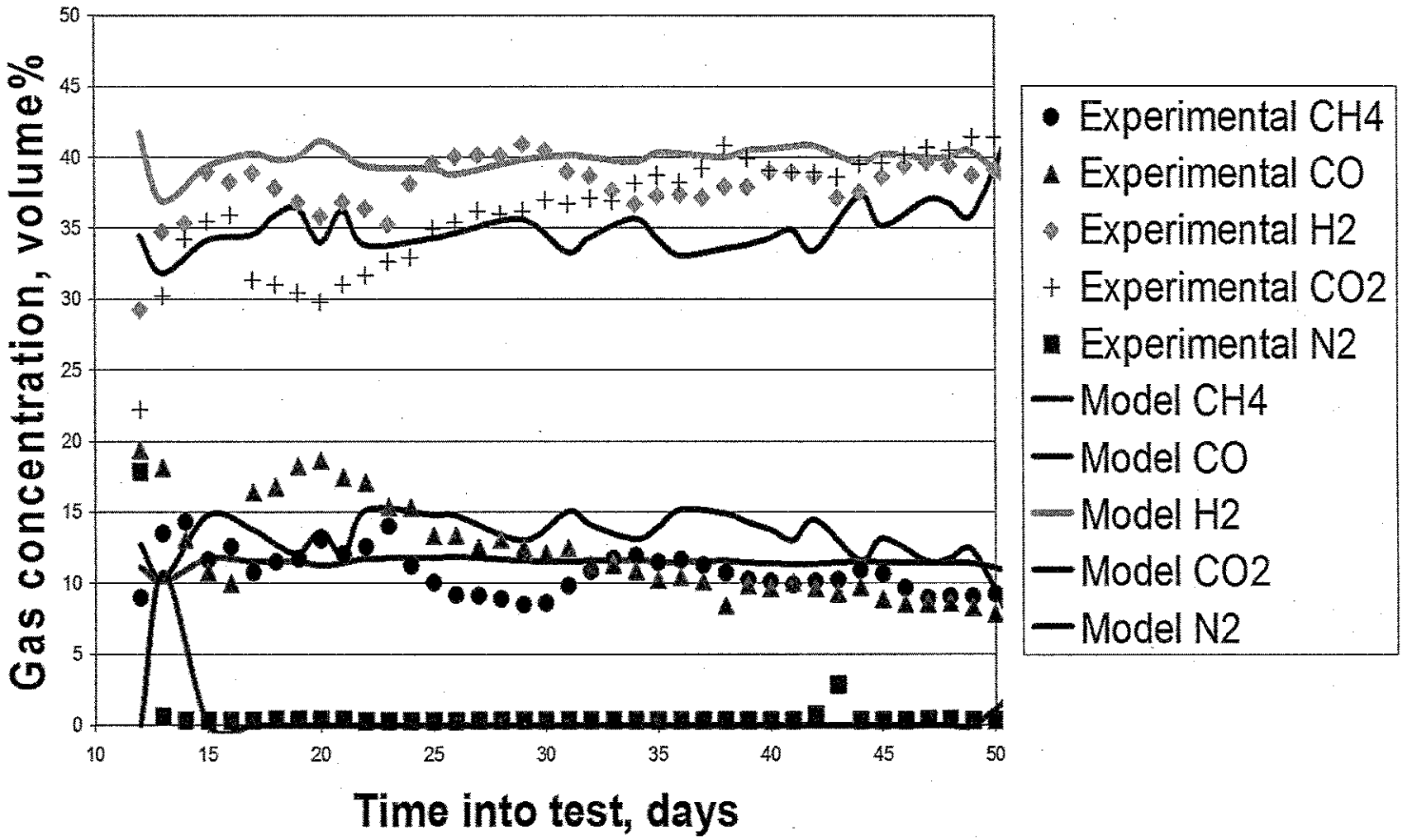
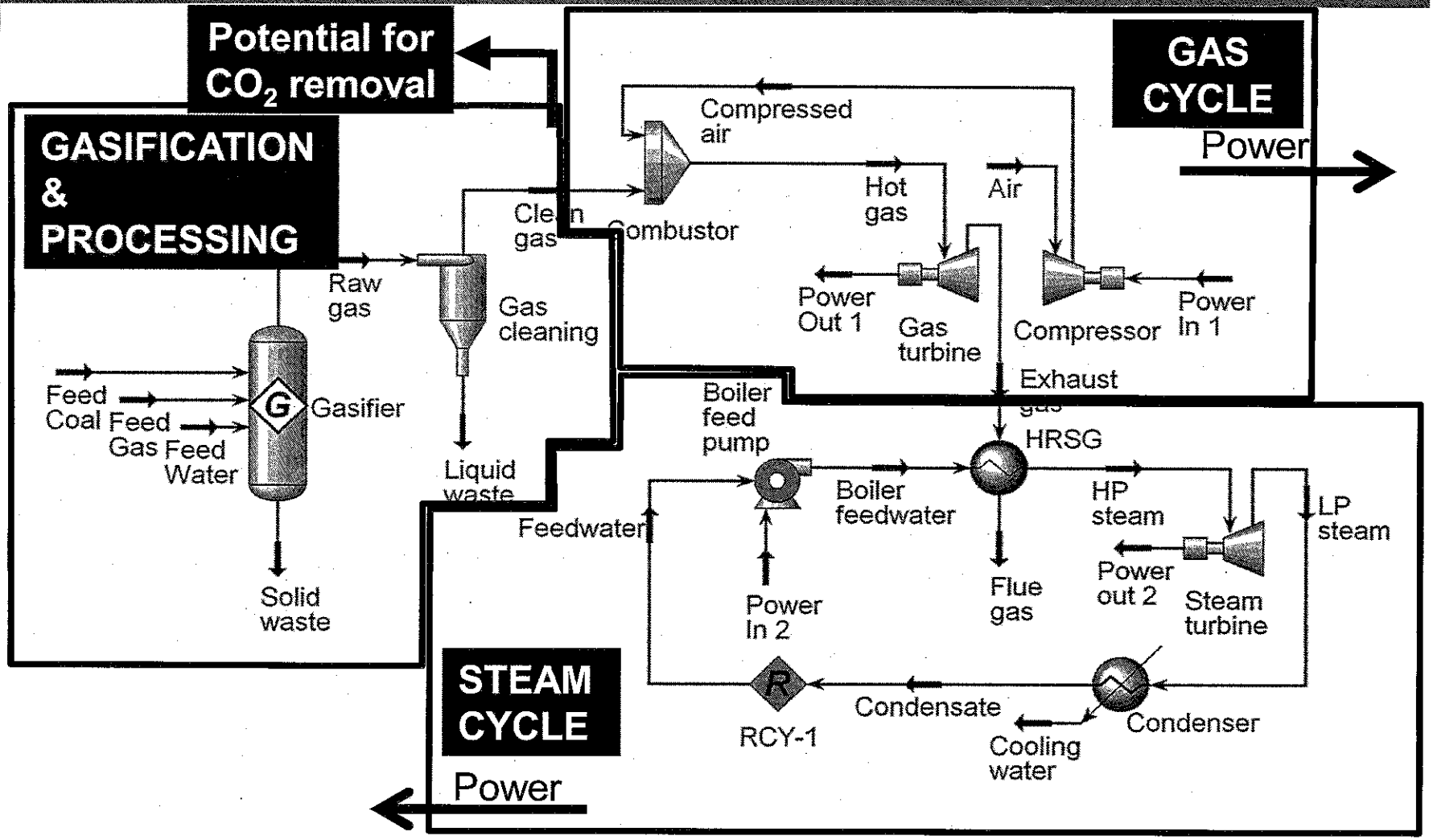
CASE STUDY: Rocky Mountain 1 trial (1987-88)

Oxygen-blown, Knife Edge CRIP



Well-controlled and characterised sites are predictable

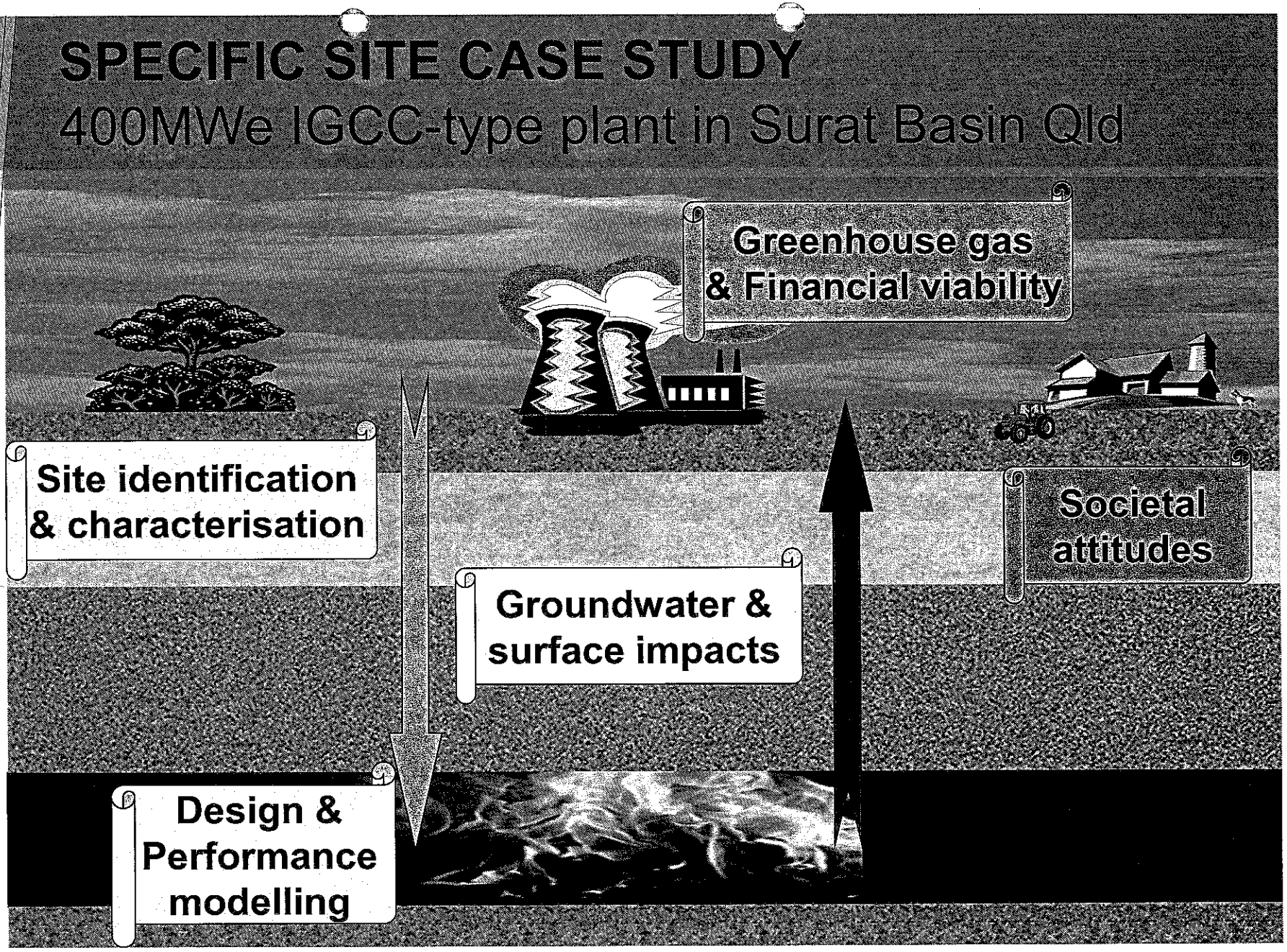
Process Simulation
- Combined cycle electricity generation



Note: Simplified for presentation the real simulation involves 50+ unit processes

SPECIFIC SITE CASE STUDY

400MWe IGCC-type plant in Surat Basin Qld



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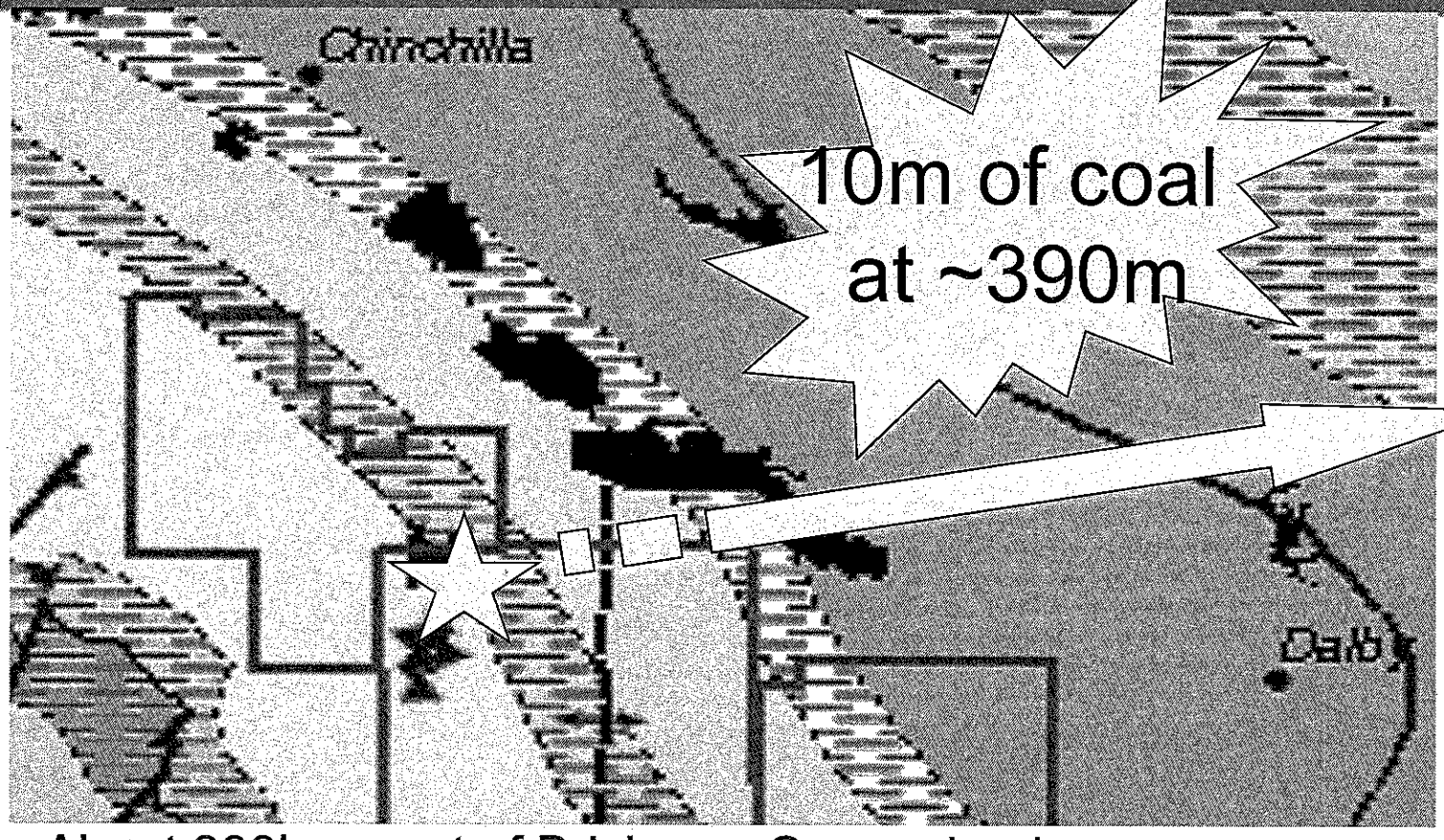
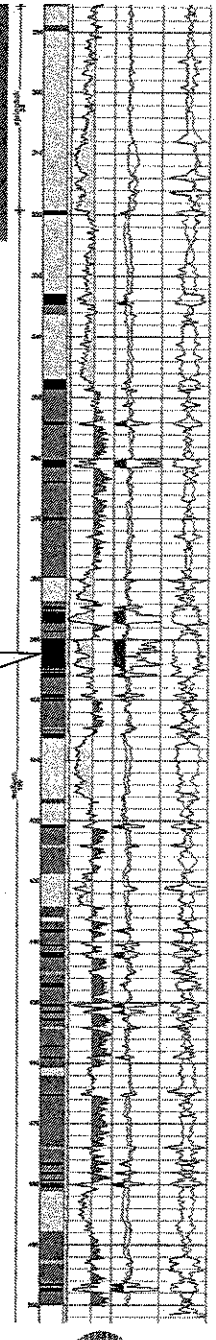
The Surat Basin Site





- About 300km west of Brisbane, Queensland.
- Coal outcrops are surface mined; no underground coal mining due to high ash content.

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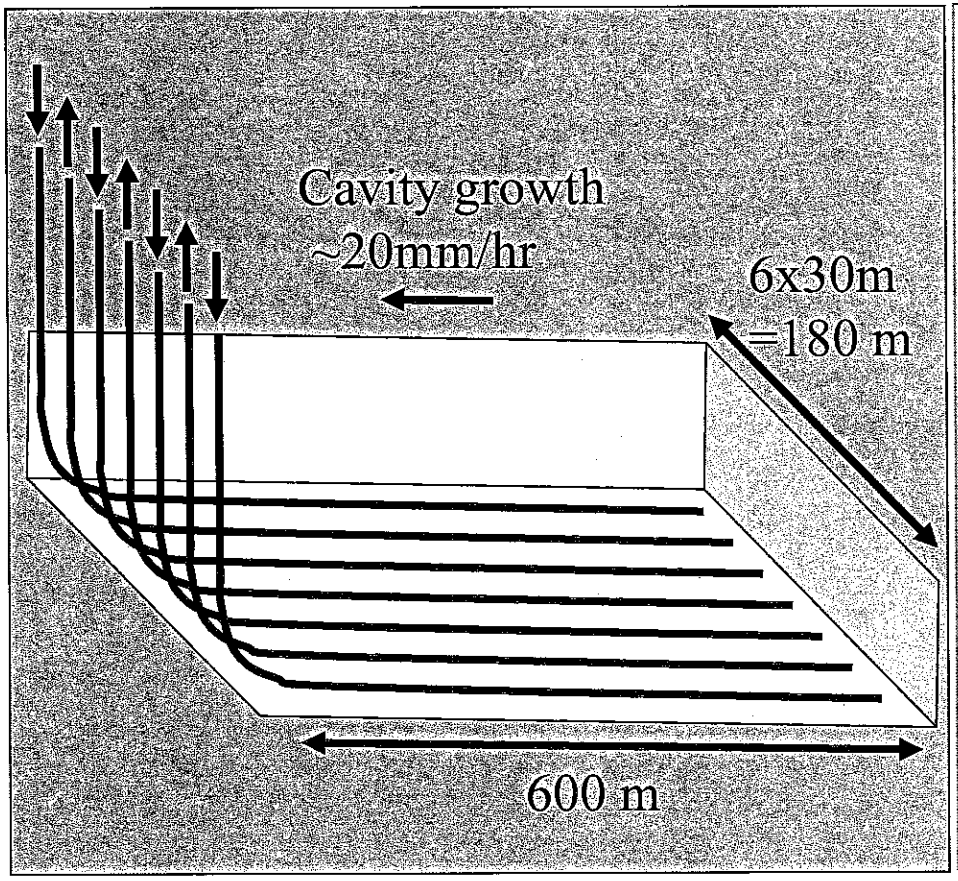
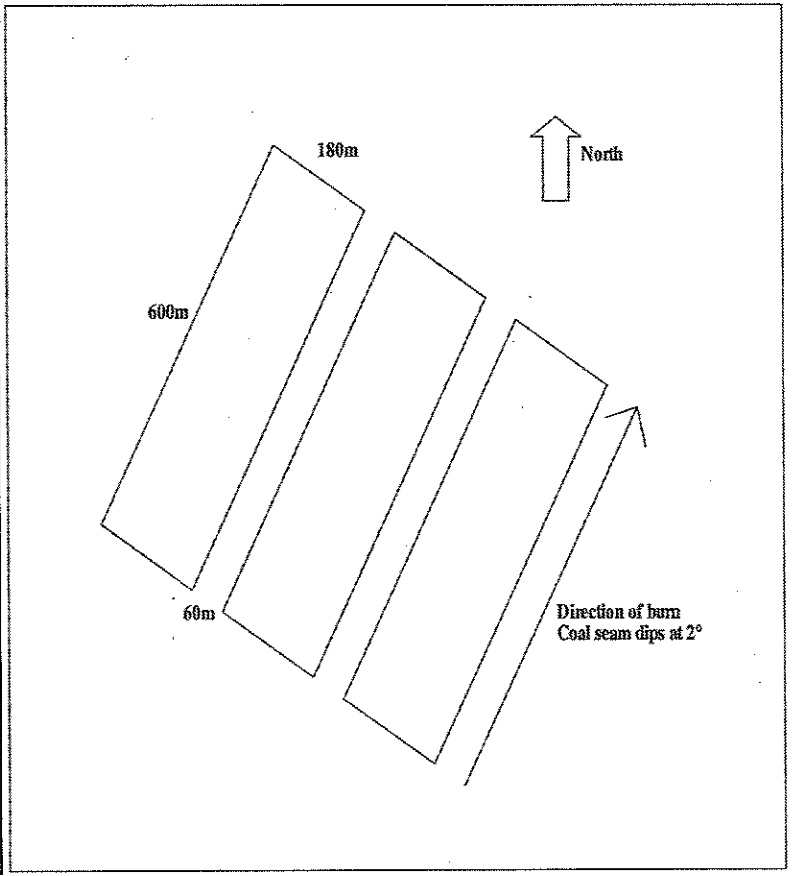
UCG design - Parallel Well CRIP



Module design



3 Modules for 400MWe
(Module life 2.3 years)

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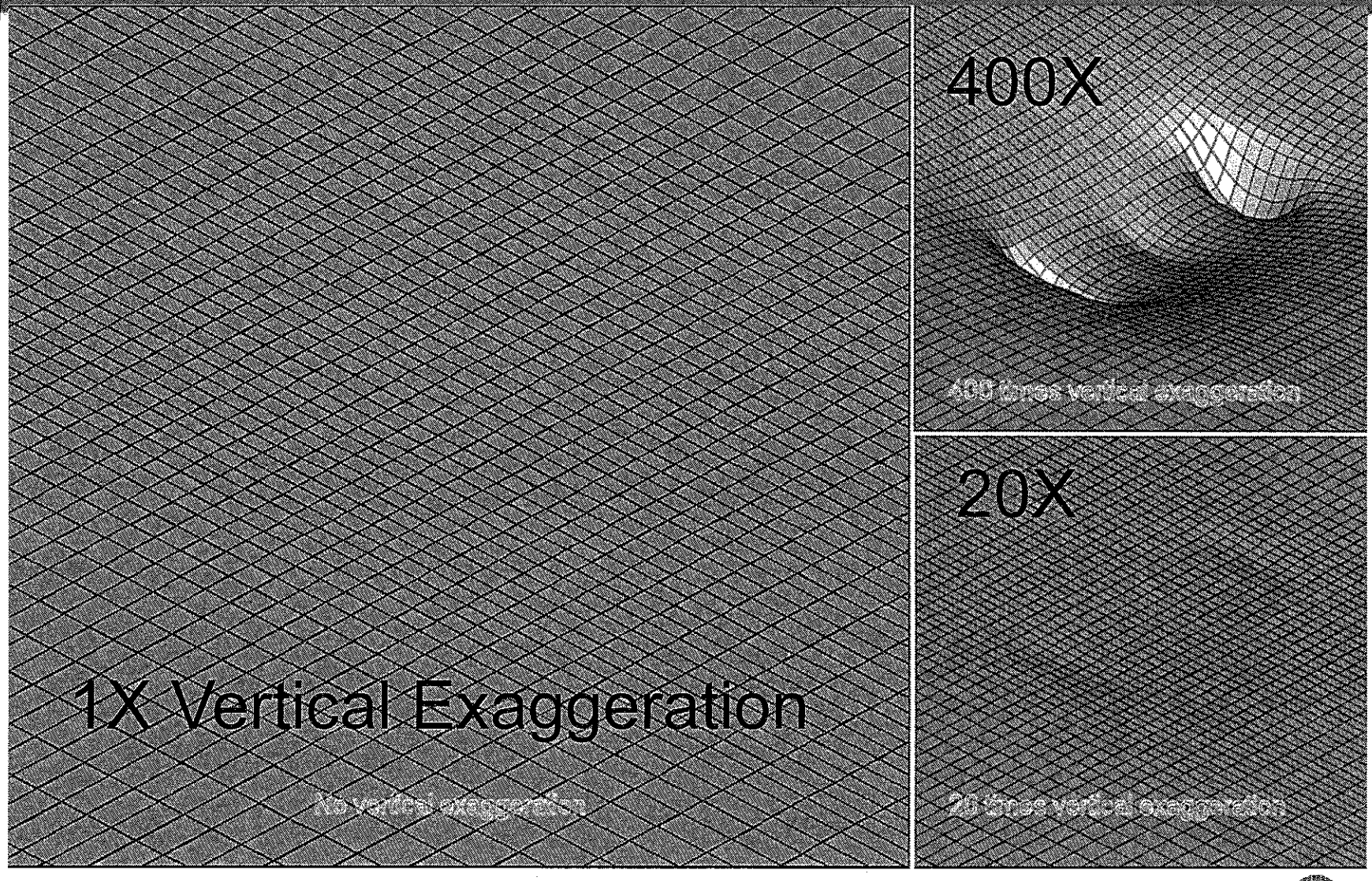
Subsidence



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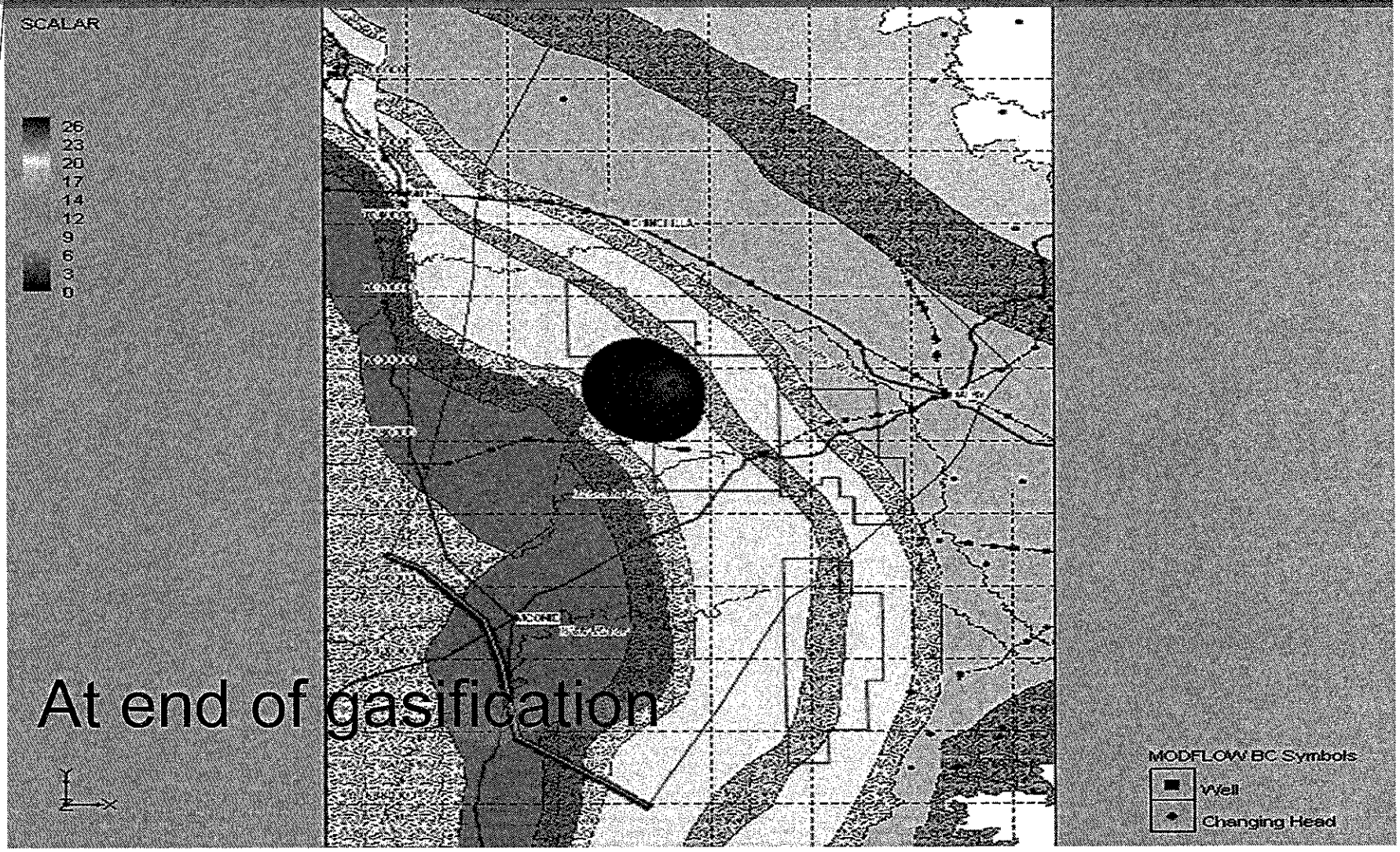
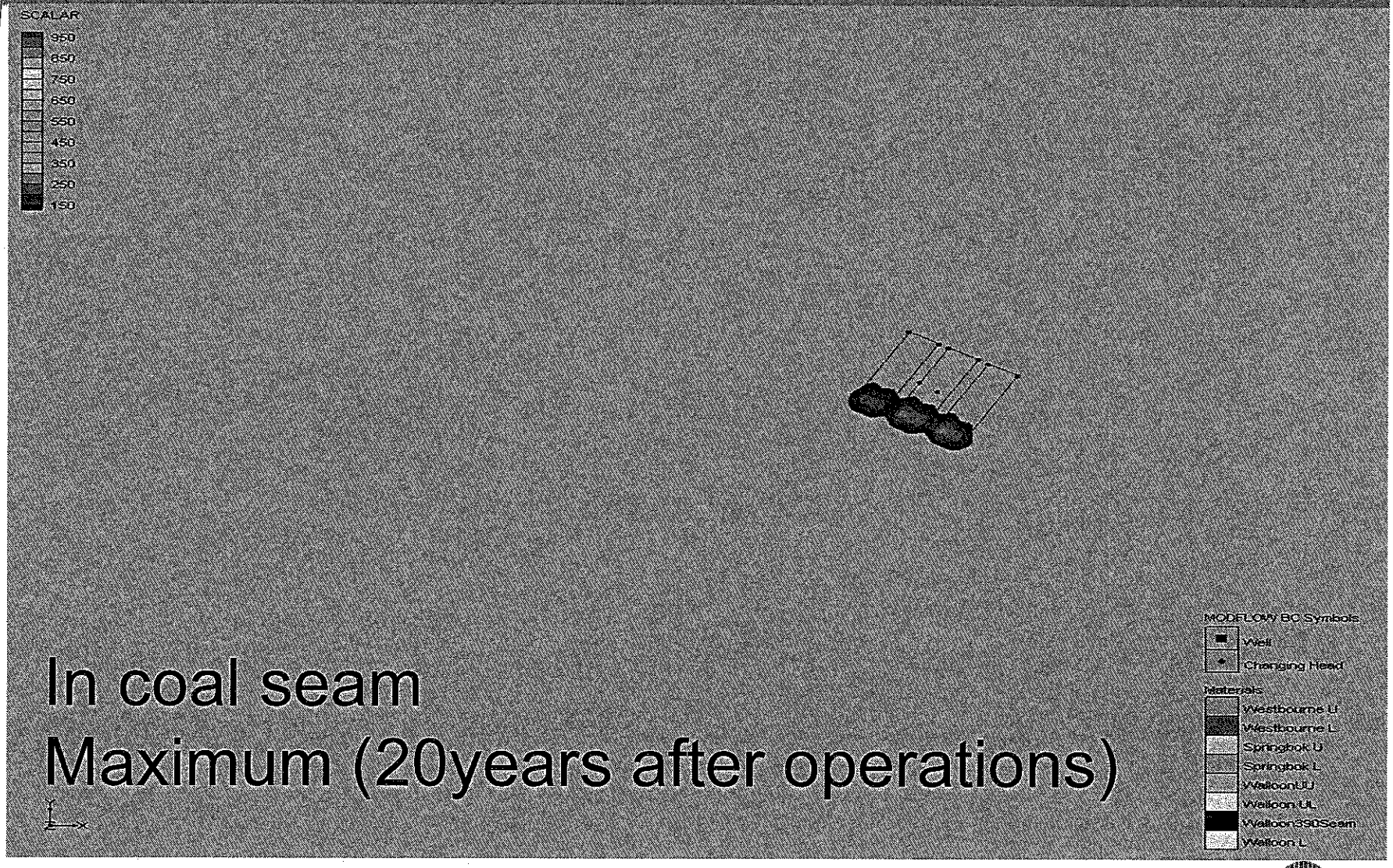
Groundwater changes



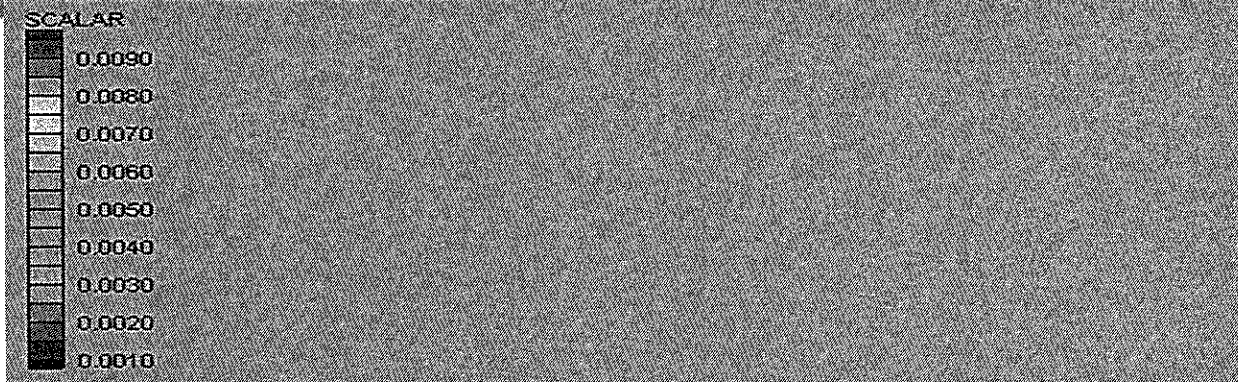
At end of gasification

Salt contamination



In coal seam
Maximum (20years after operations)

Benzene contamination



Springbok sandstone
100 years after operation
Constant release - no reaction or adsorption

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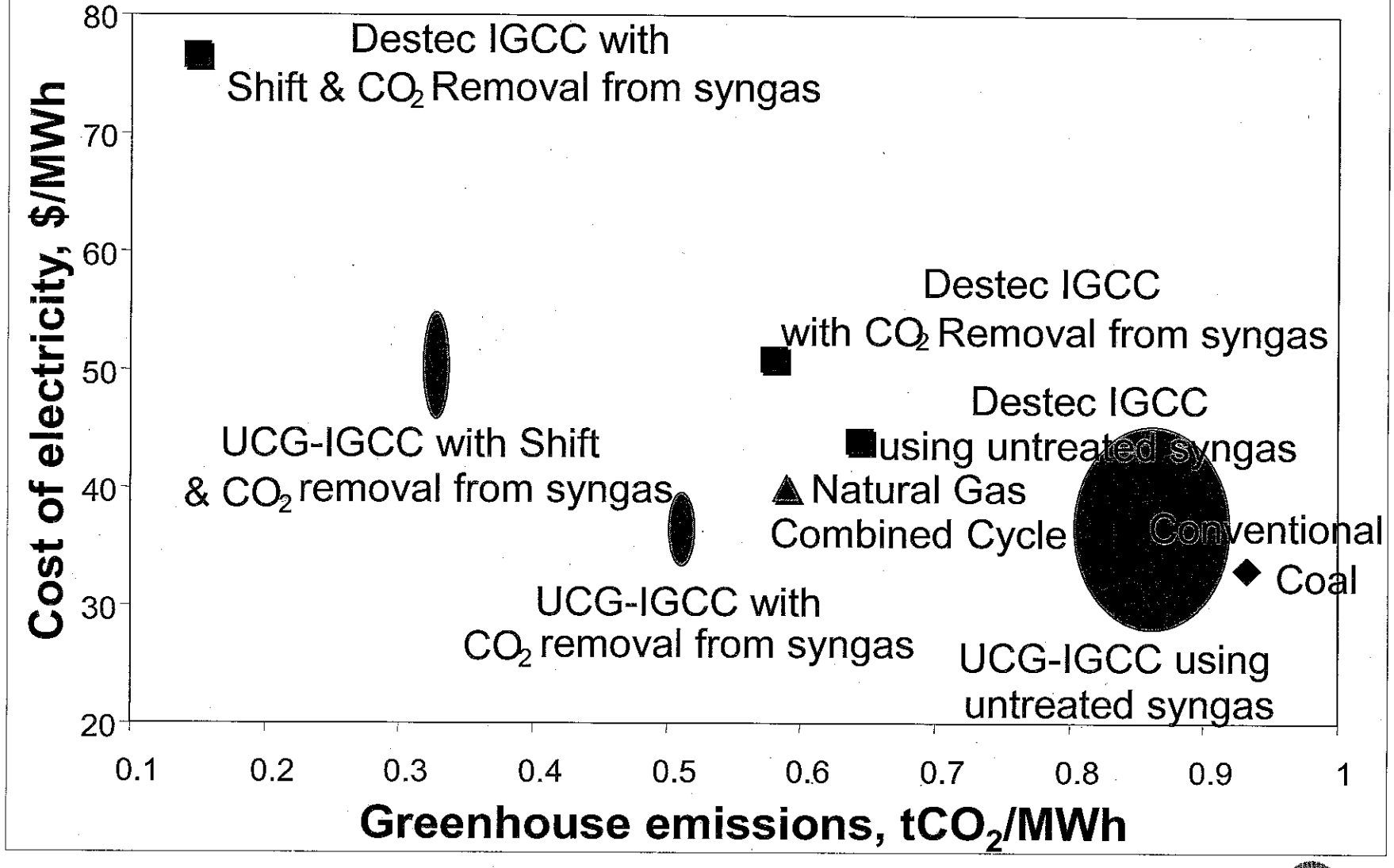
GHG Emissions and Cost Comparison



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General Findings

- Each site is unique
  - all modelling must be repeated for the specific size of the plant at the actual site
- UCG plants can be engineered to be environmentally sound & operationally efficient
- Experimental demonstration was too expensive
  - commercial partner sought and a spin-off created (Carbon Energy)

Current Situation

Australia

- ***Carbon Energy***: performed 100d demonstration and have agreements aimed at ammonia, methanol & electricity in Qld and WA.
- ***Linc Energy***: UCG-supplied small Fischer-Tropsch plant operating & plans for 100,000bbl/day in SA and 20,000bbl/day in Qld.
- ***Cougar Energy, Energie Future, Liberty Resources, Waratah Coal, Westralian Gas & Power, Metallica Minerals (MetroCoal) & Central Petroleum*** have expressed interest in UCG developments.

Worldwide

- ***Yerostigaz (Uzbekistan):*** operated a site since 1965.
- ***Eskom & Sasol (South Africa):*** pilot plant and have submitted EIS for their proposed sites.
- ***Solid Energy (NZ), GasTech (USA), Swan Hills Synfuels (Canada), BCG Energy (UK), HUGE (Poland)*** plus others have developments proposed.

Future Challenges of UCG

Our commercial spin-off, **Carbon Energy**, has performed a successful demonstration based on the CSIRO project. While we continue to support their activities, the future success of UCG appears to be more linked to commercial and government support

Longer term important challenges:

- efficient installation of instrumentation for large sites
- maintaining consistent operation without environmental problems

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Thank you

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Major Concerns/Past Problems

UCG has the typical coal utilisation concerns of gaseous emissions, such as Greenhouse emissions, but some more novel problems as well.

Problems that have occurred at past sites are:

- Extreme subsidence
- Groundwater depletion
- Groundwater contamination
- Construction/Geological Interpretation errors
- Poor process control

Some examples of these follow…

Extreme Subsidence
Hoe Creek #3 Trial (USA, 1979)

- **Total of 11m of coal at 39-55m depth**

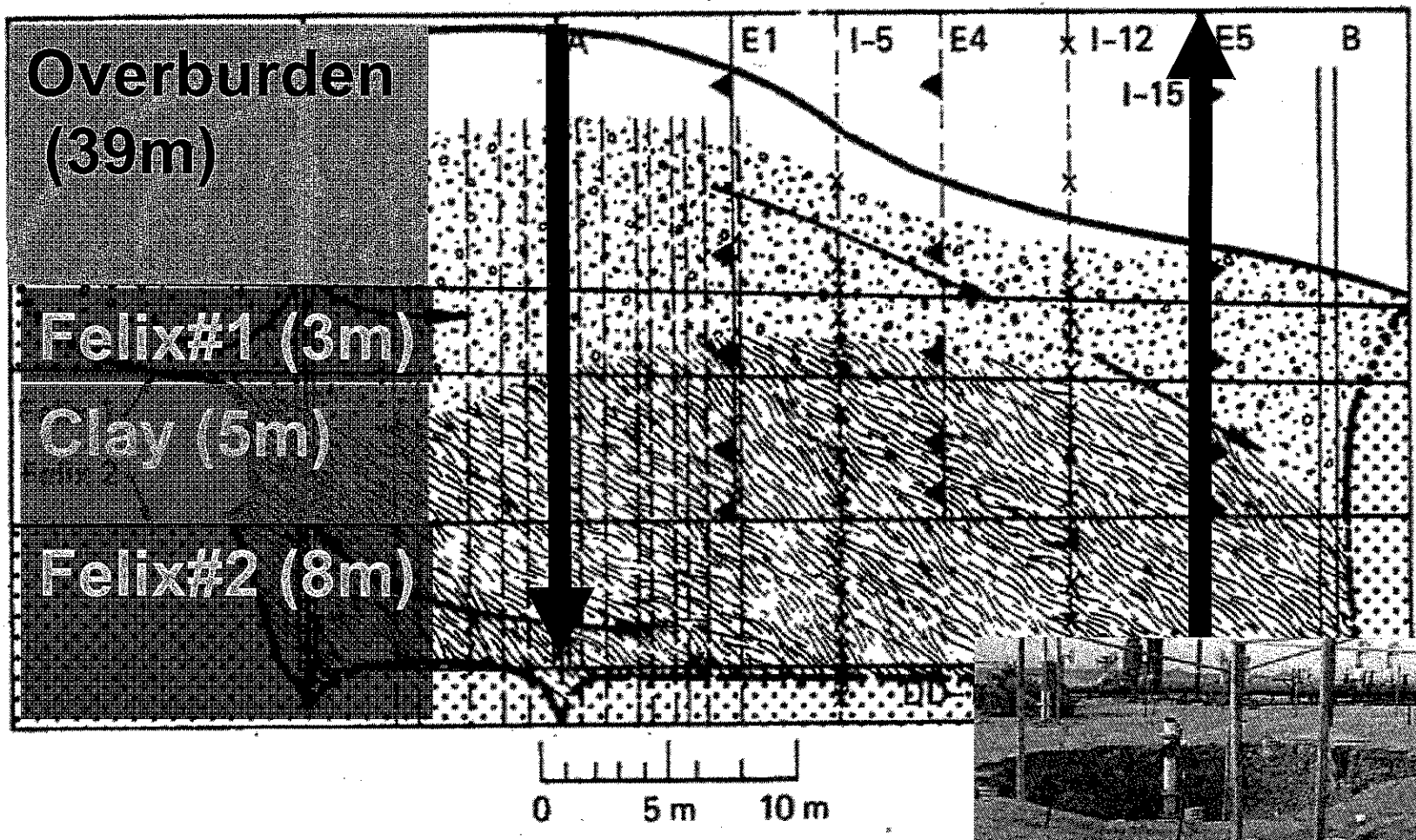
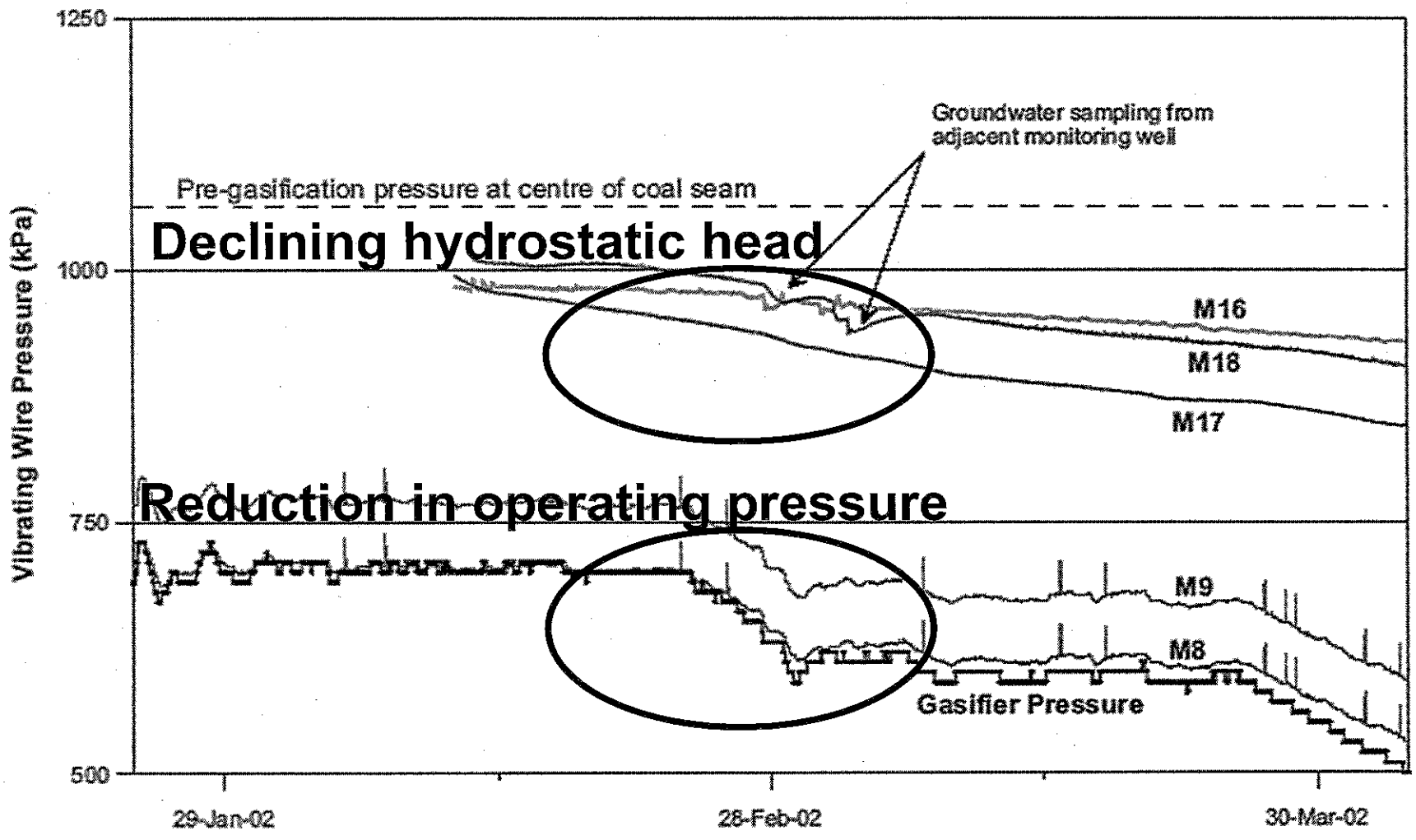


Photo courtesy of Wyoming DEQ

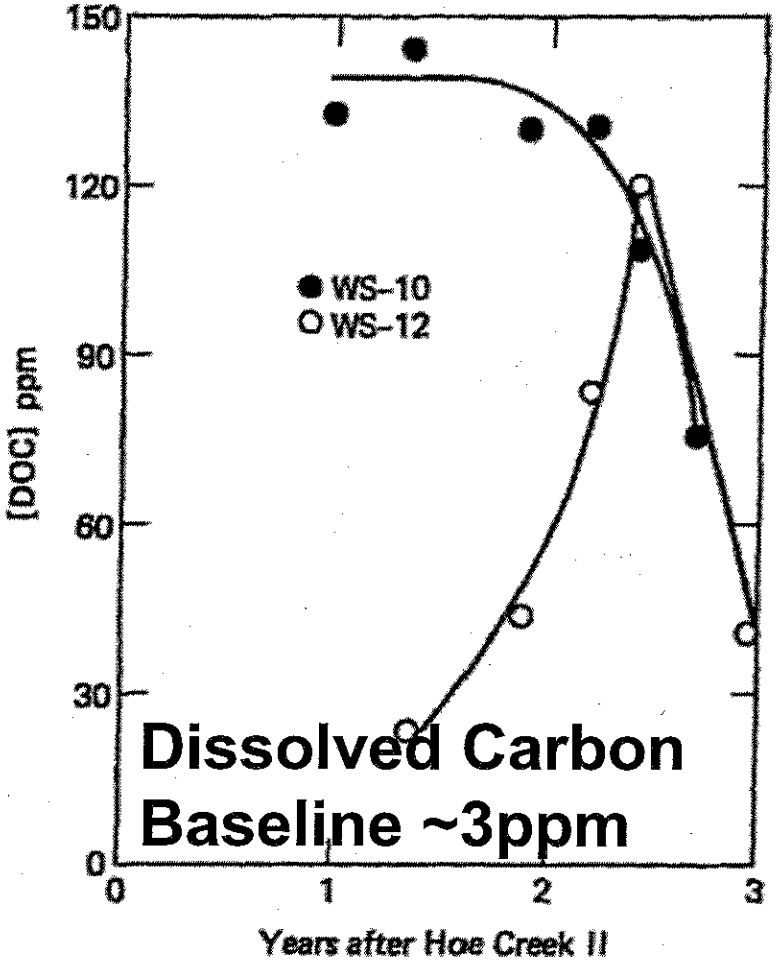
Groundwater Depletion
Linc Energy – Chinchilla (1999+)

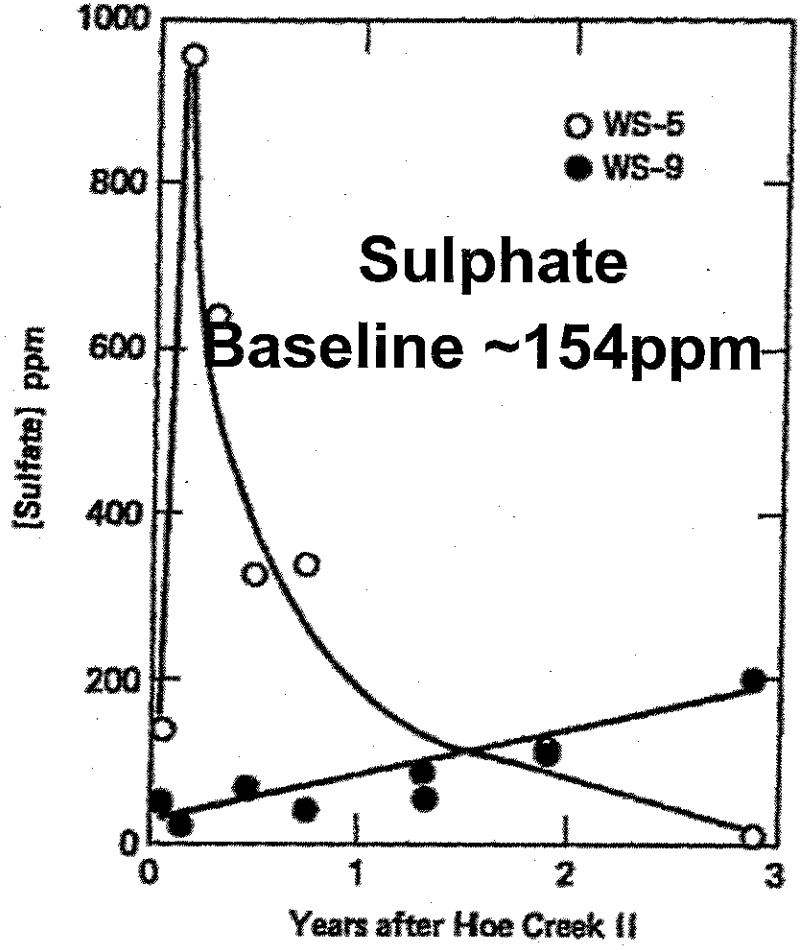


Source: Blinderman & Fidler, Water in Mining 2003

Groundwater Contamination
Hoe Creek II (USA, 1977)

- **Hoe Creek II ran at a 300kPa operating pressure**
- **The hydrostatic head dropped to essentially zero**





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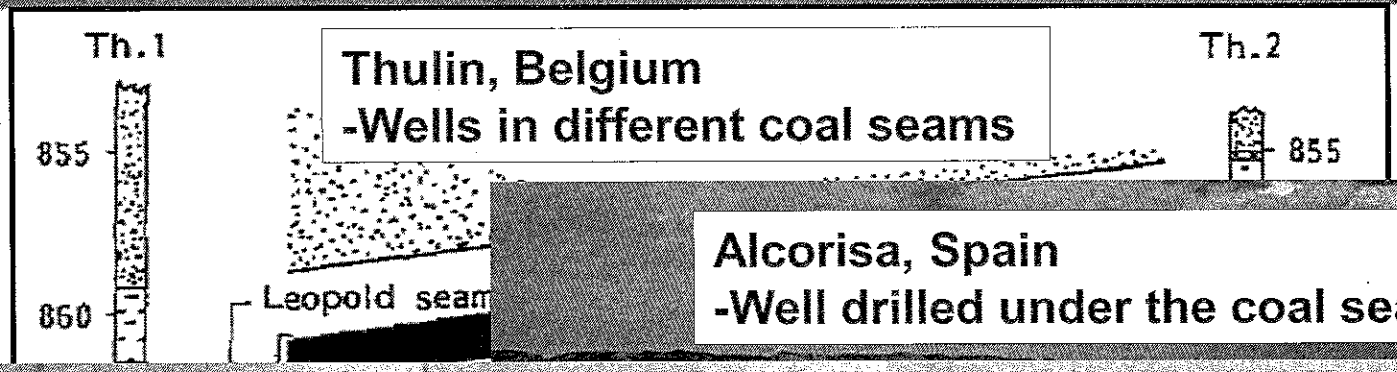
Construction/Geology Interpretation Errors



Thulin, Belgium
-Wells in different coal seams

Alcorisa, Spain
-Well drilled under the coal seam

Carbon County, USA
-Wells probably not in same coal seam

Rocky Mountain 1, USA
-Undefined fault leaked gas between two reactors

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Poor Process Control

Most sites have had gas quality decline with the length of operation, some including oxygen contamination of the product gas.

Variability in the hydrostatic head results in operating pressure changes, which could be significant to any process using the product gas.

This is a very broad issue that needs to be addressed through careful site design and operation.

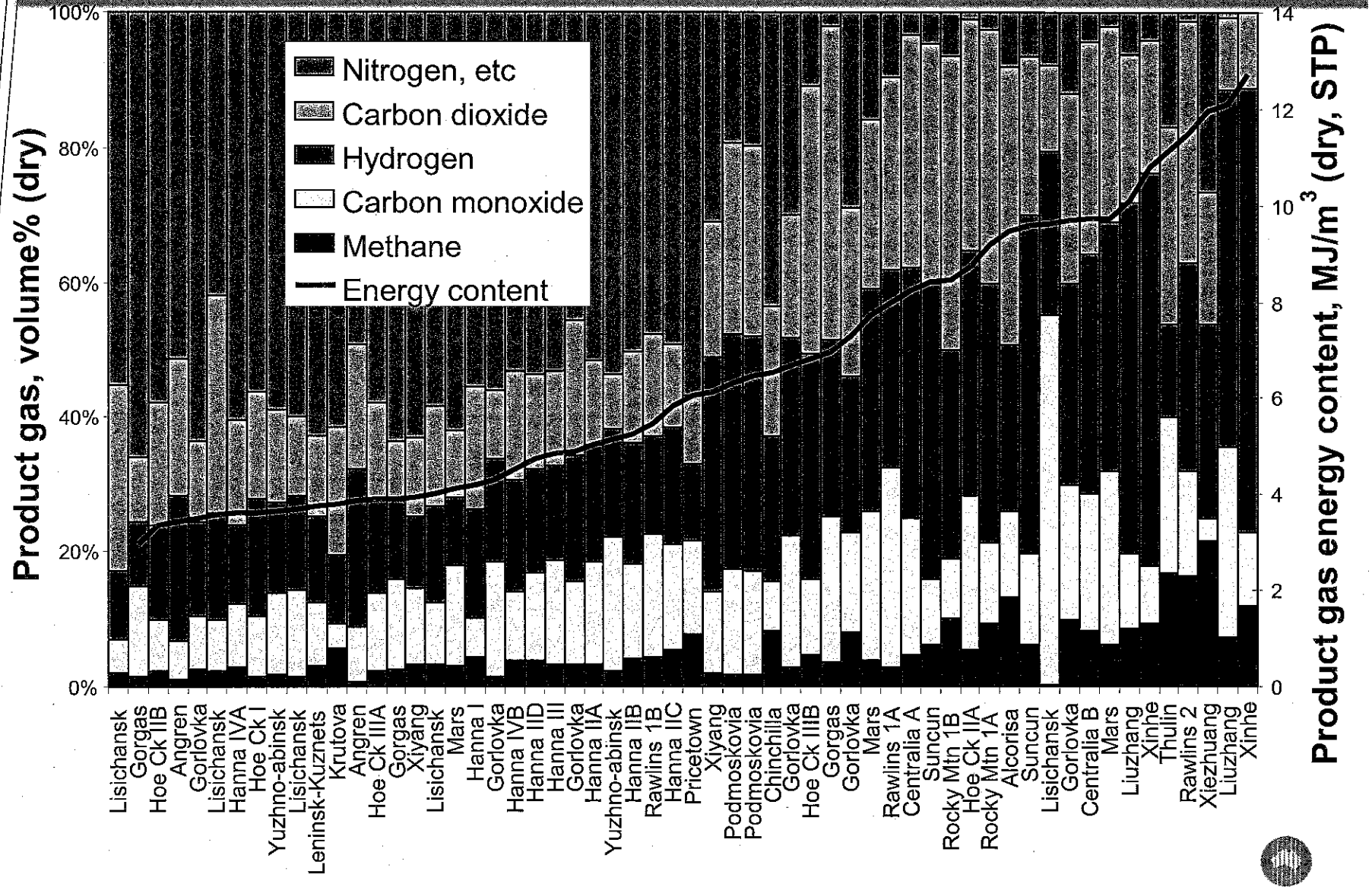
Summarising the Problems

The bulk of the problems arise from:

- Mechanical failures;
- Cheap geological evaluation;
- Poor site selection; &
- Inappropriate operating conditions.

Largely, these can be addressed through improved project planning but the past failures have introduced uncertainty about the technology that could be addressed by establishing guidelines and a better scientific understanding of the processes involved.

Variability in Performance



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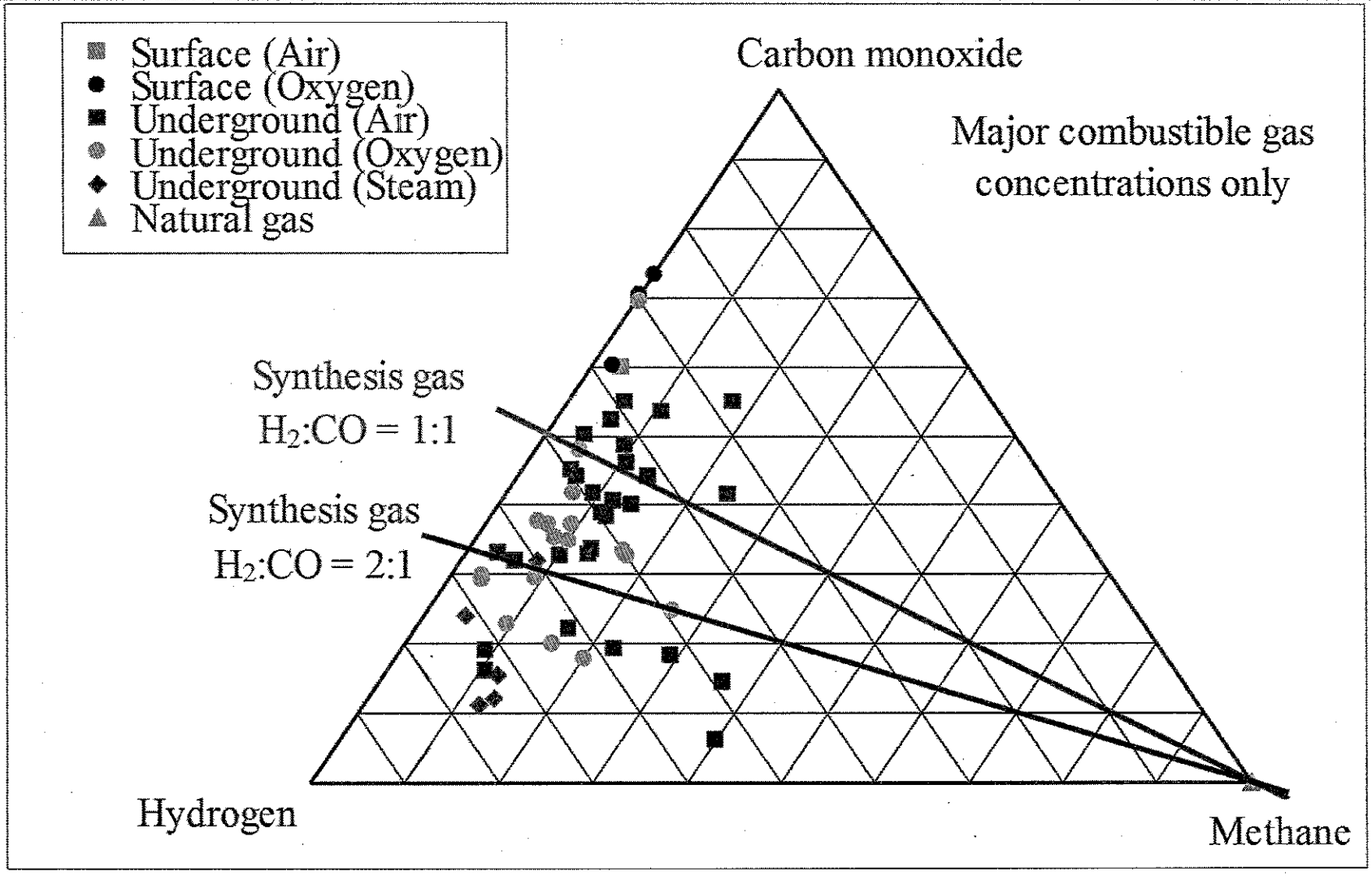
Another way of looking at it...



Performance is site sensitive, but some control is possible

Societal Attitude Survey

Issues raised by members of the public from the region after a discussion of the potential for UCG in the region

Benefits of UCG	Prospective concerns
•Better way of coal utilisation •Economic benefits •Environmentally beneficial •Benefits to regional community	•Safety •Environmental impact •Cost •Reliability of information •Better alternatives •Lack of trust in politicians, scientists & business