EUROPEAN CENTER FOR SCIENCE ARTS AND CULTURE (ECSAC) OF LOŠINJ

WORKSHOP ON STATUS AND FUTURE OF GEOTHERMAL ENERGY IN THE PERI-ADRIATIC AREA

VELI LOŠINJ CROATIA
25-27 AUGUST 2014

GEOTHERMAL RESERVOIR CHARACTERISATION AND MANAGEMENT

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GPC INSTRUMENTATION PROCESS (GPC IP)

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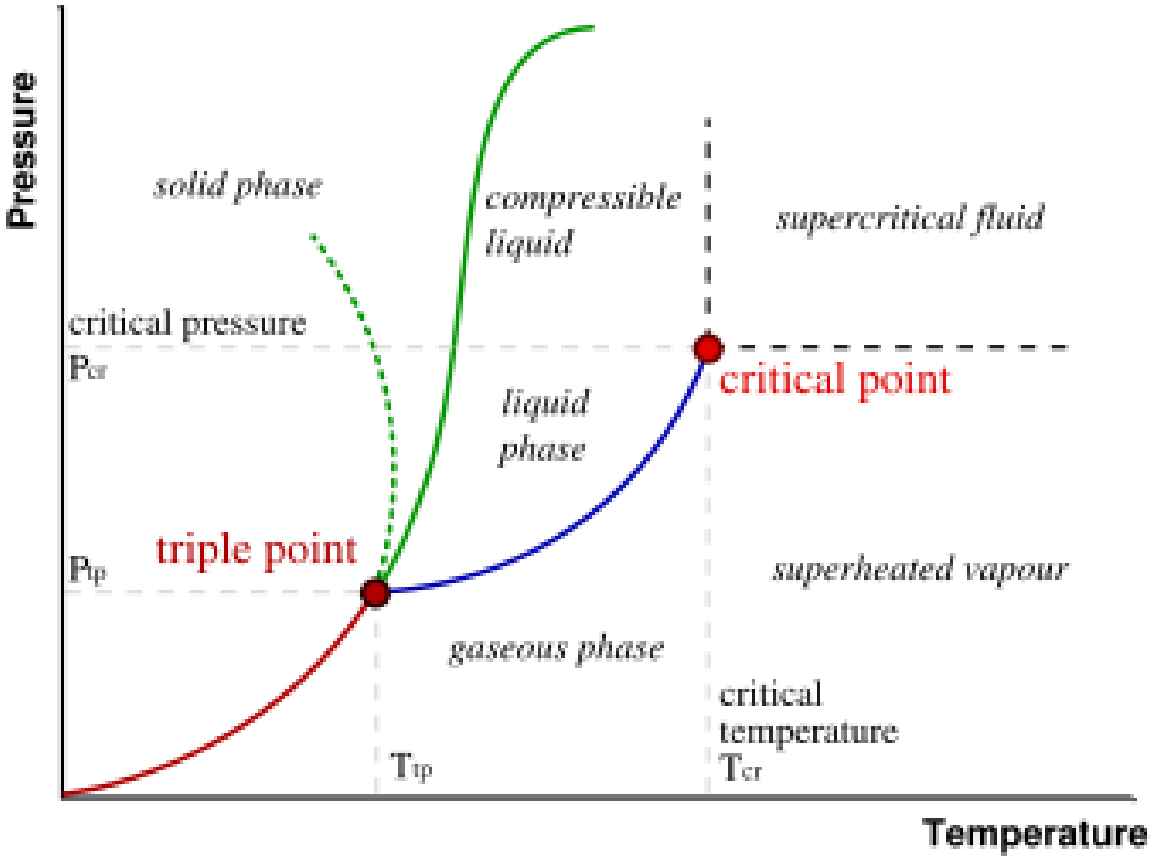
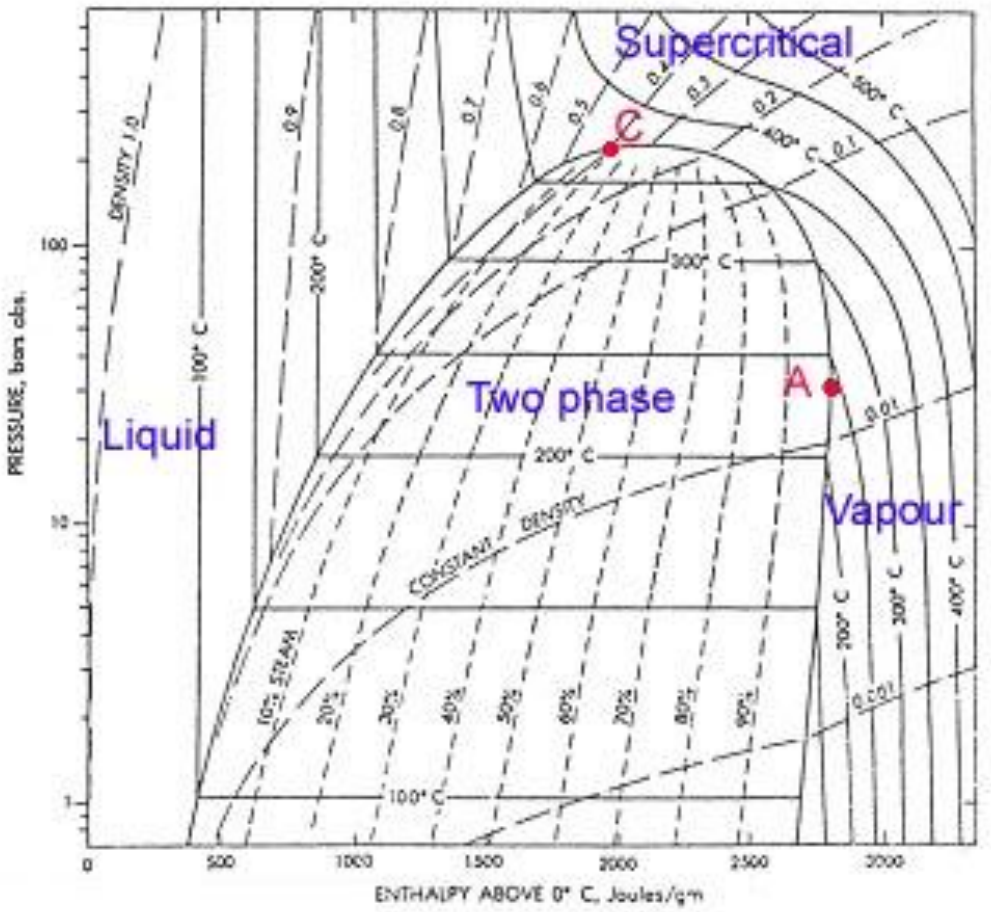
OUTLINE

- OUTLOOK
- CONCEPTUAL MODELLING
- EXPLORATION GEOPHYSICS
- STRUCTURAL GEOMODELLING
- RESERVOIR ASSESSMENT
- RESERVOIR SIMULATION
- SUSTAINABLE RESERVOIR/ RESOURCE MANAGEMENT

OUTLOOK
PURE WATER PHASE DIAGRAM

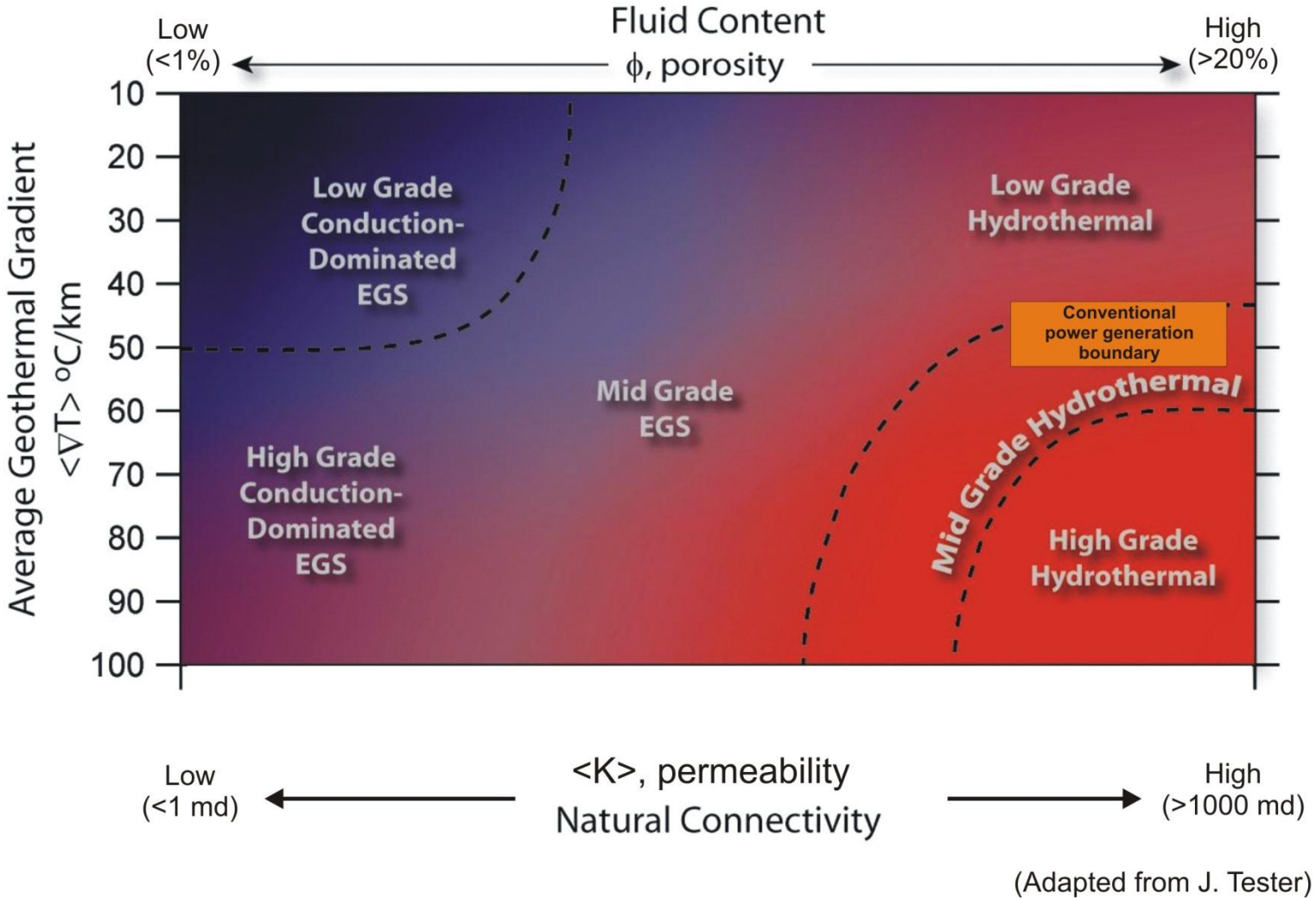


OUTLOOK
PRESSURE-ENTHALPY (MOLLIER) DIAGRAM FOR PURE WATER



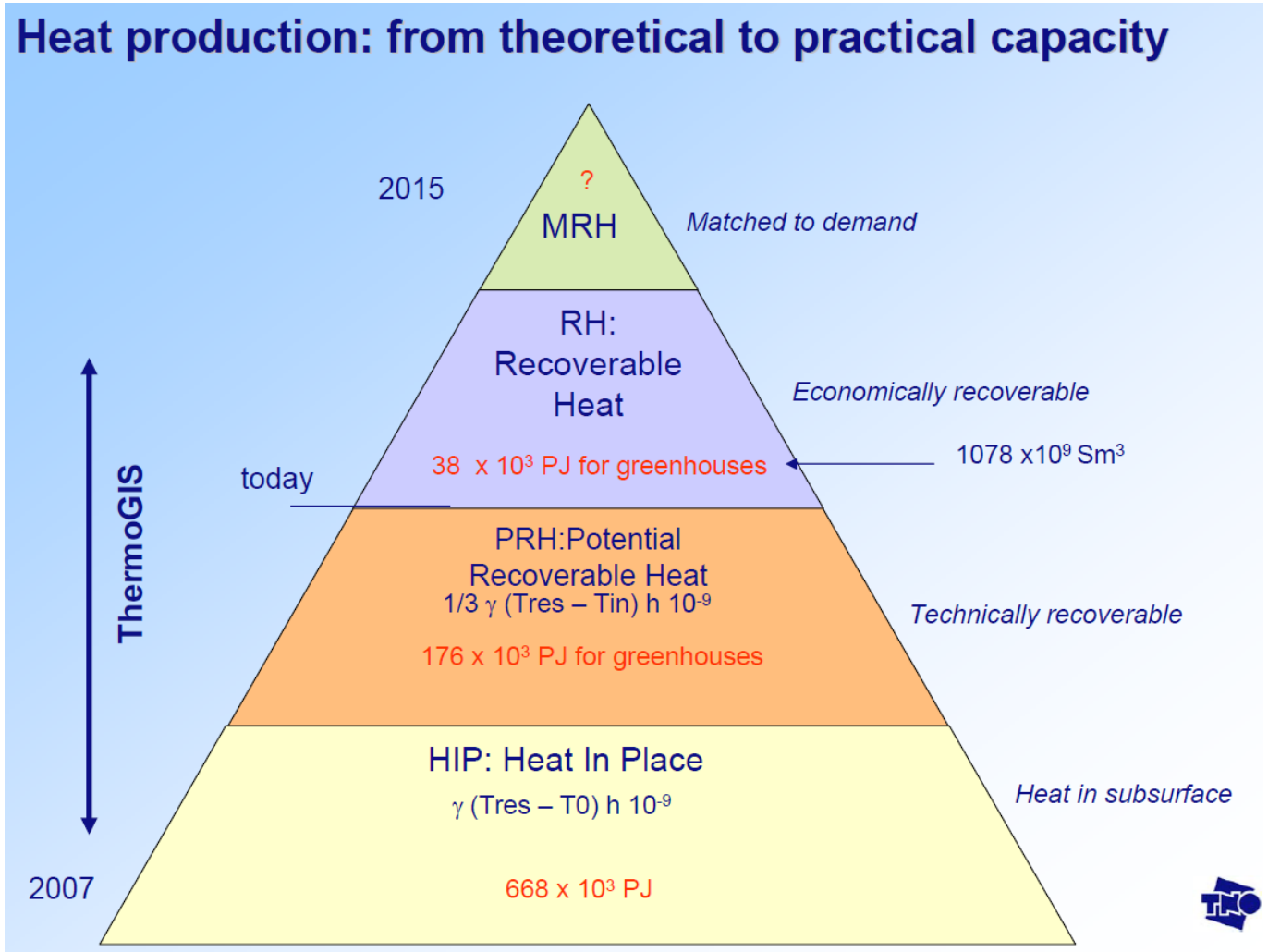
A: maximum enthalpy (2803 kJ/kg, 240 °C, 33.47 bar)
C: critical point (374.1 °C, 224 . 91 bar)

GEOTHERMAL CONTINUUM – THE EGS ISSUE



(Adapted from J. Tester)

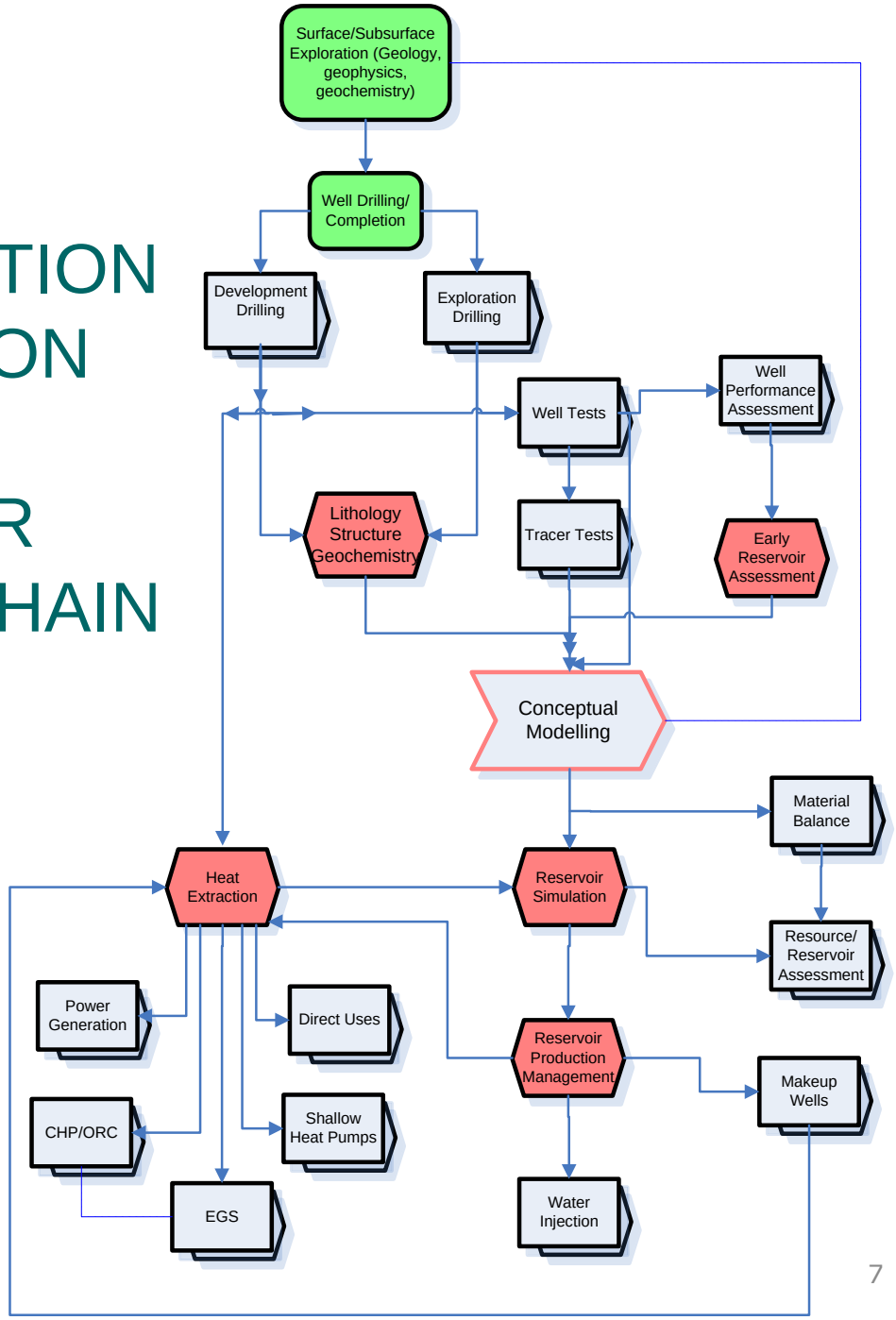
OUTLOOK
GEOTHERMAL RESOURCE & RESERVE ASSESSMENTS



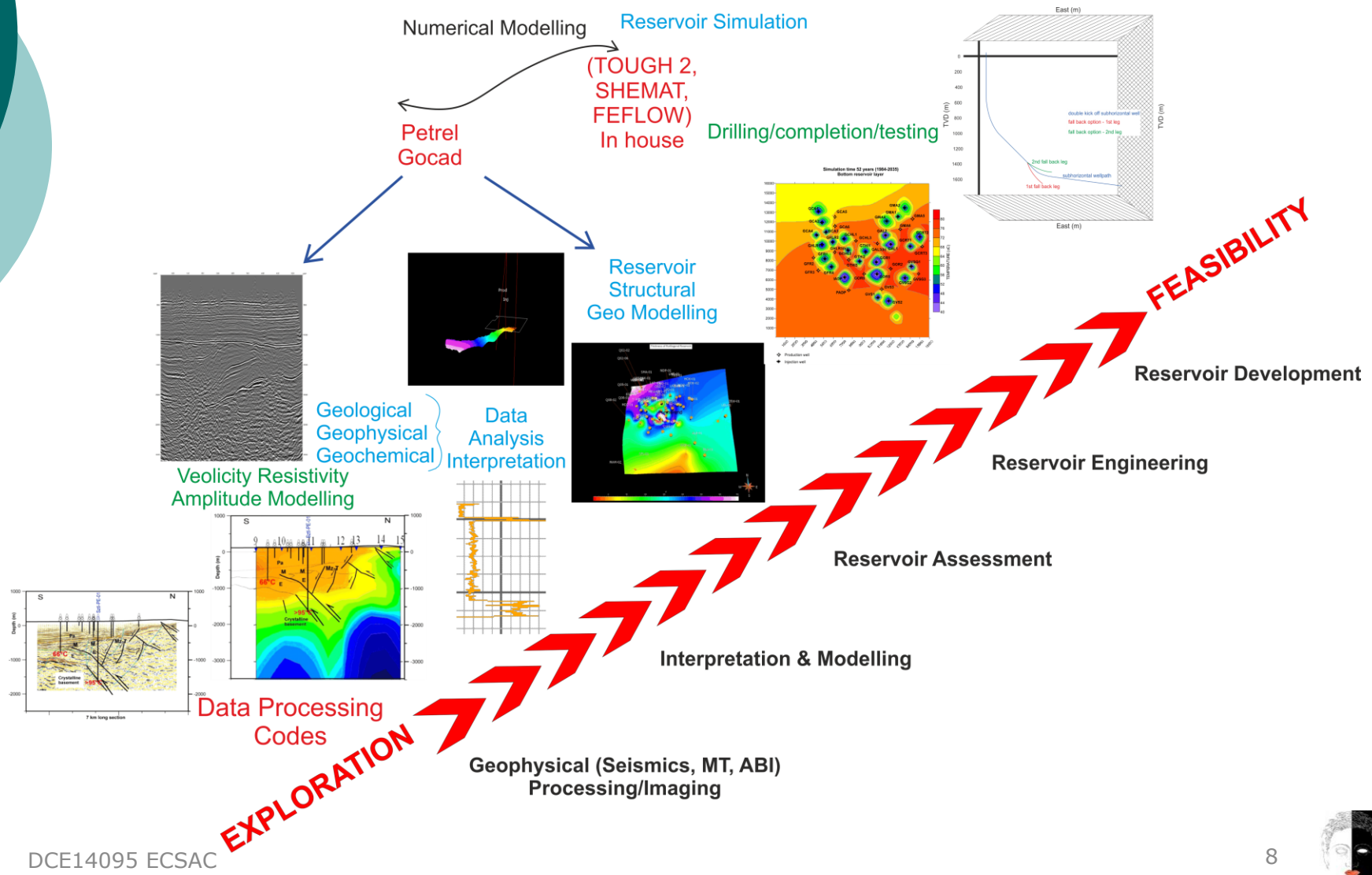
OUTLOOK

FROM EXPLORATION TO PRODUCTION

A RESERVOIR ENGINEERING CHAIN

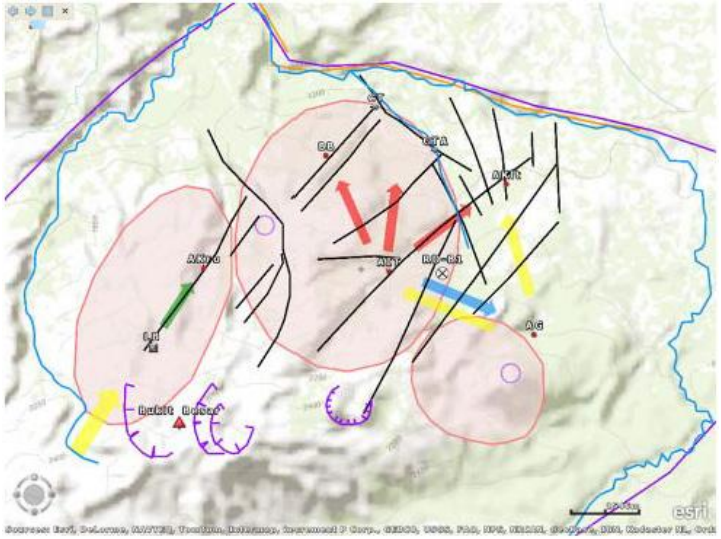


RESERVOIR ENGINEERING AN INTEGRATED APPROACH

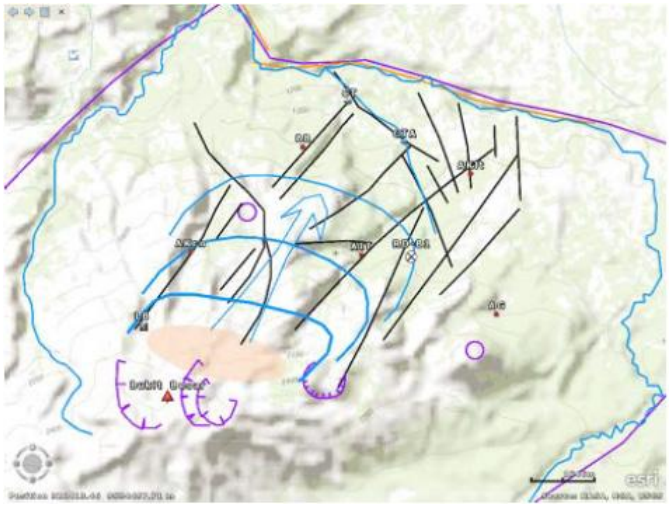


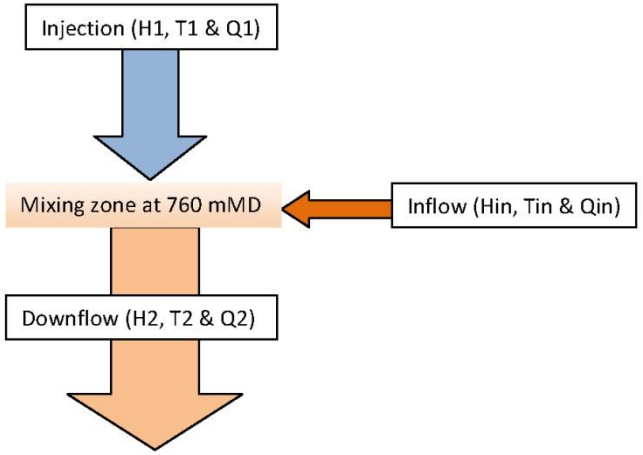
CONCEPTUAL MODEL
VOLCANO-TECTONIC ENVIRONMENT
INDONESIAN SUBDUCTION

Caldera setting



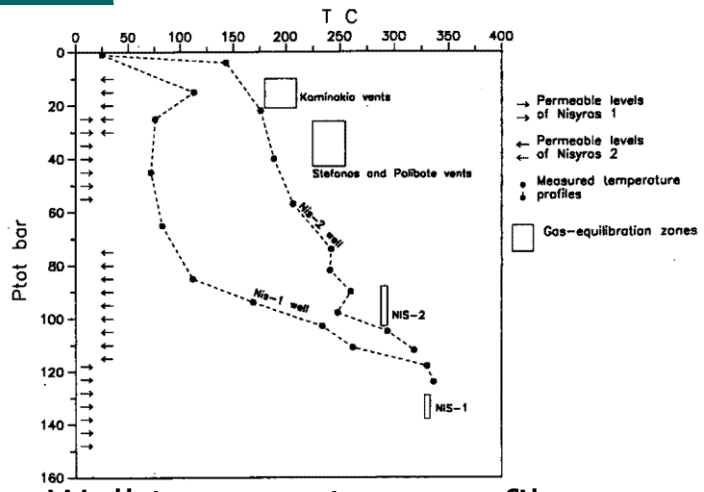
Fumaroles and faults intersections





Dual reservoir evidence

CONCEPTUAL MODELLING
EXPLORATION/DEVELOPMENT STATUS
NISYROS(DODECANESE)

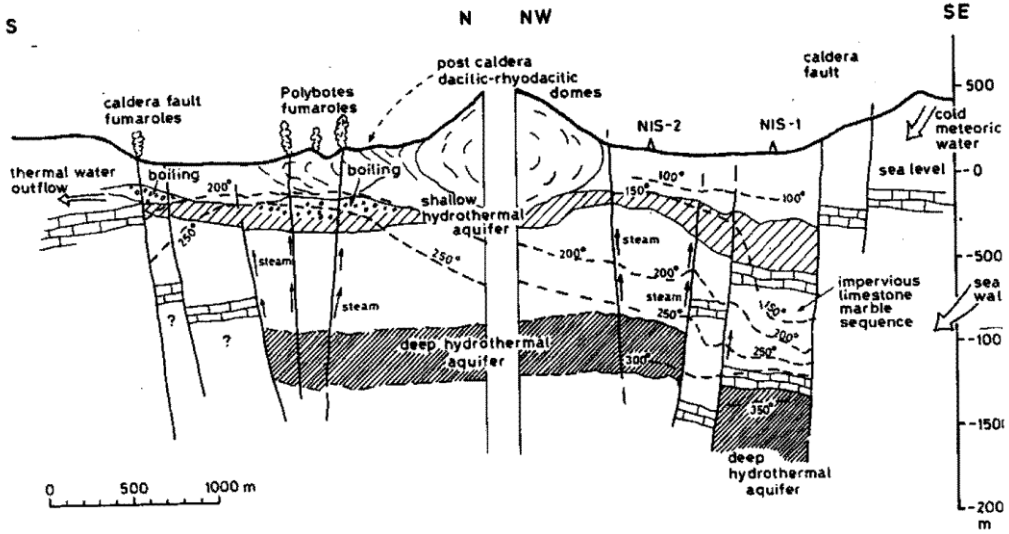


Well temperature profiles

Well Name	N-1	N-2
Year completed	1982	1983
Total depth (m)	1,816	1,547
Productive interval (s) (m)	360-695 1,420-1,816	1,000-1,547
BHT (°C)	350	350
WHT (°C)	n.a.	178
WHP (bars)	n.a.	7.6
Total flow (t/h)	13(*)	69
Steam water ration	0.8(*)	0.5
Specific enthalpy (kJ/kg)	2,350(*)	1,520
Non condensable gascontent (% wt)	n.a.	5
TDS (ppm)	150,000(*)	60,000

(*) superficial reservoir

Exploratory well summary sheet
- Total well deliverability=4MWe

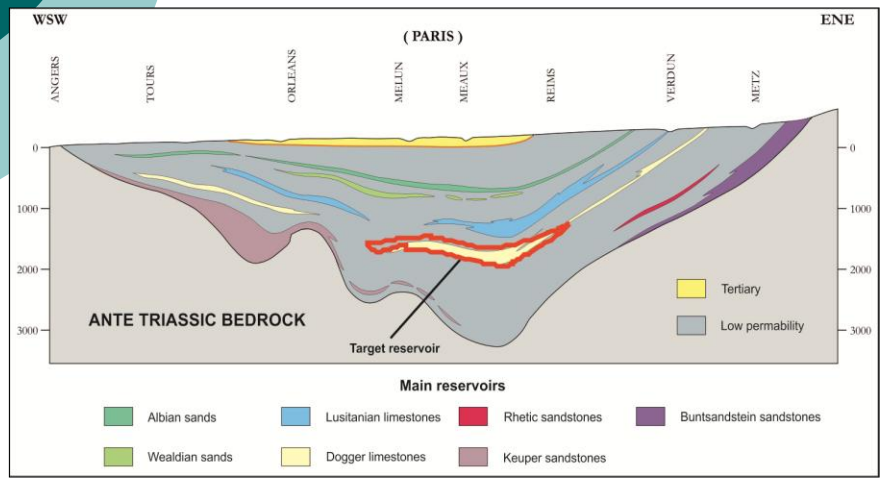


Hytrothermal conceptual model

CONCEPTUAL MODELLING
TWO CONTRASTED SEDIMENTARY ENVIRONMENTS

Paris Basin

Dogger limestones

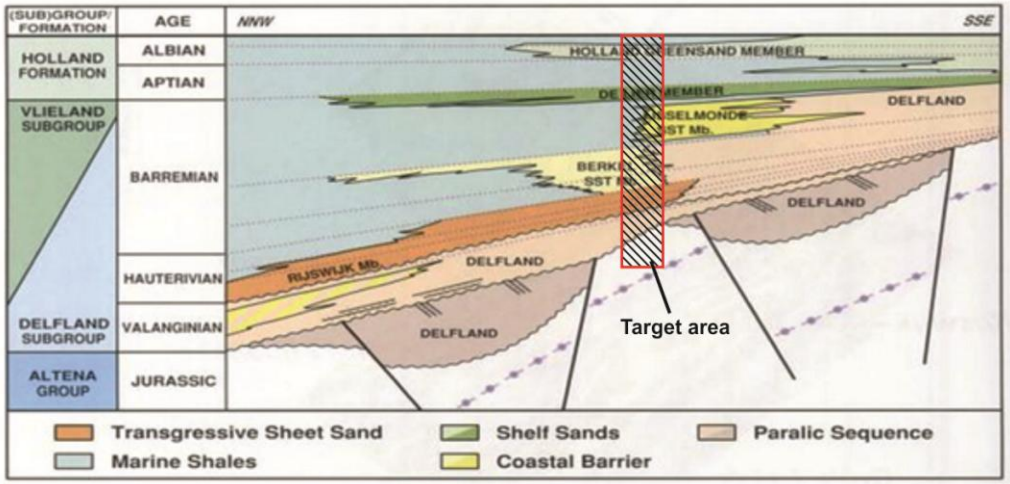


(modified from Ph Maget , 1983)

- Carbonate

West Netherland Basin

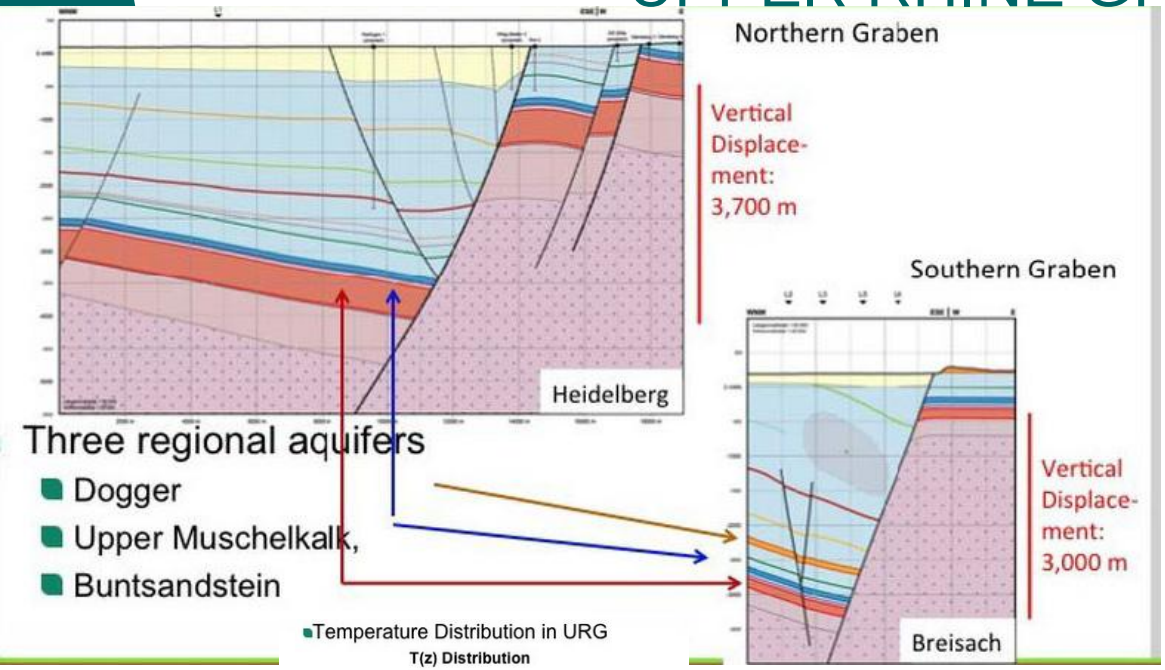
Rijswijk sandstones



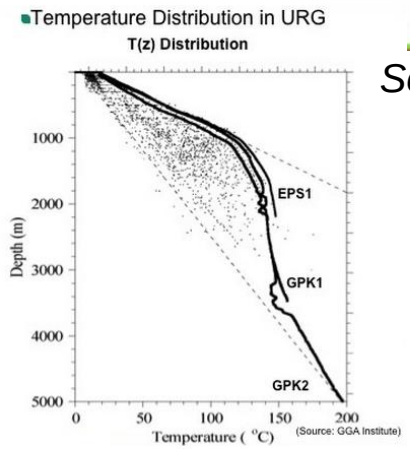
(Netherlands Organization for Applied Scientific Research, TNO)

- Clastic

CONCEPTUAL MODELLING
CONTINENTAL RIFT ACTIVE TECTONICS
UPPER RHINE GRABEN

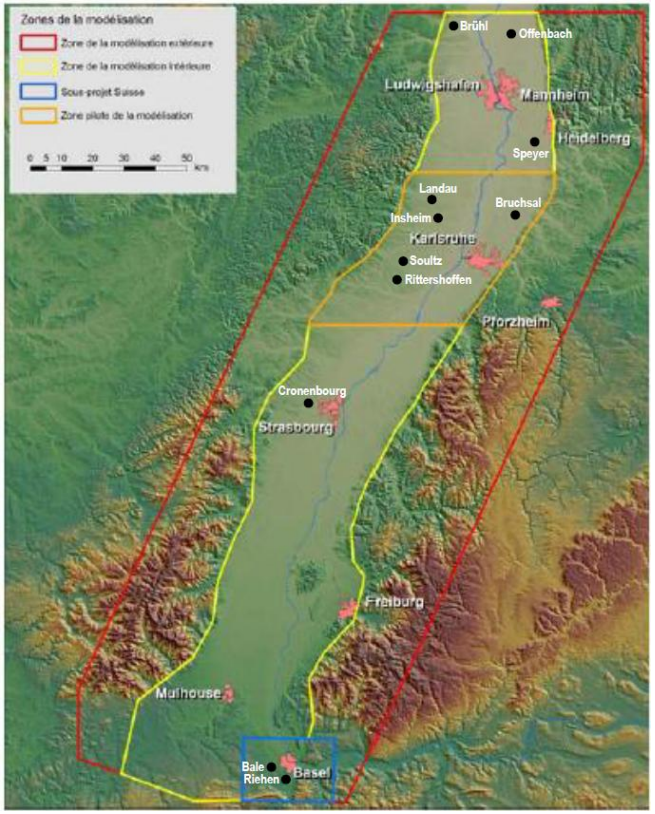


Source: Thomas KOHL, 2014



Source: CGA institute

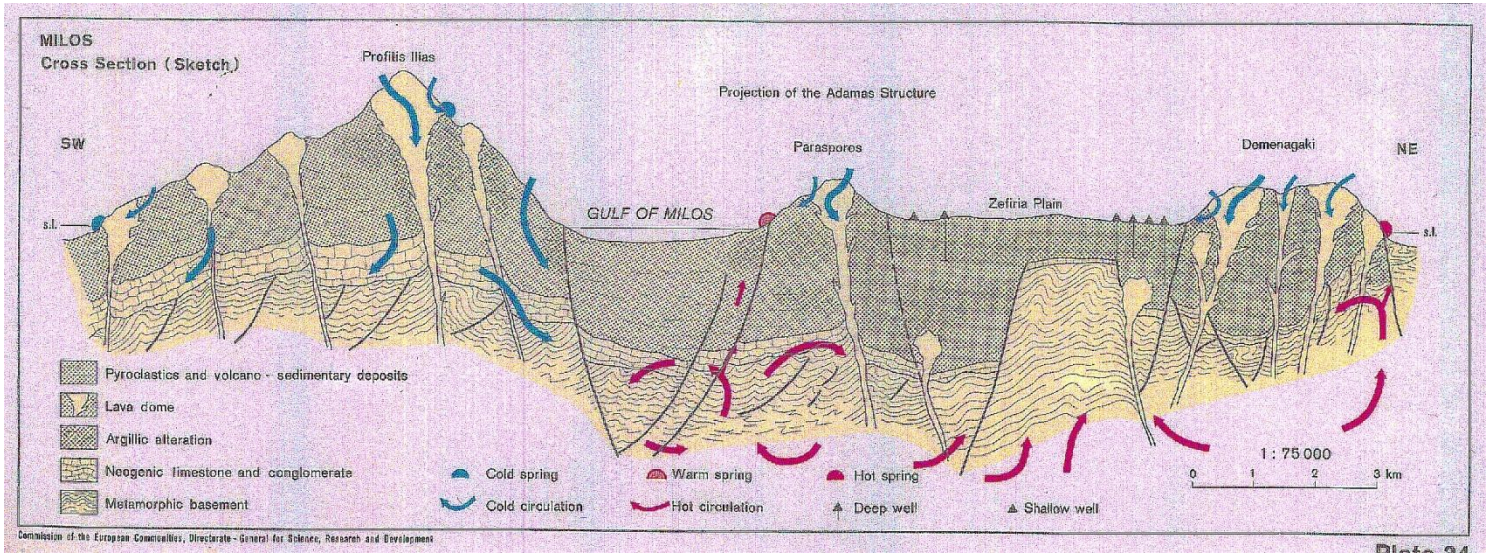
Deep Drilling locations



EXPLORATION/DEVELOPMENT STATUS
MILOS (CYCLADES)

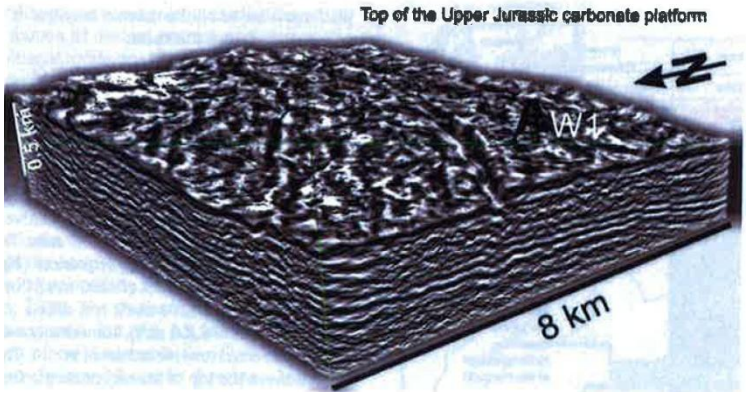
Well name	MZ1	MA1	MI-1	MI-2	MI-3
Year completed	1975	1976	1981	1981	1982
Total depth (m)	1100	1165	1100	1380	1000
Productive interval (m)	810-1100	750-1165	900-1100	940-1380	900-1000
BHT (°C)	300	250	323	282	300
BHP (MPa)	n.a.	n.a.	11.7	11.9	n.a.
WHP (MPa)	0.6	0.74	1.2	1.2	n.a.
Total flow (t/h)	22	51	120	50	125
Steam / water ratio (1 MPa)	0.64	0.22	0.35	0.71	0.42
Specific enthalpy (kJ/kg)	2010	1170	1460	2200	1600
TDS (ppm)	> 100,000	> 100,000	120,000	140,000	130,000

Milos exploratory/step out well summary sheet

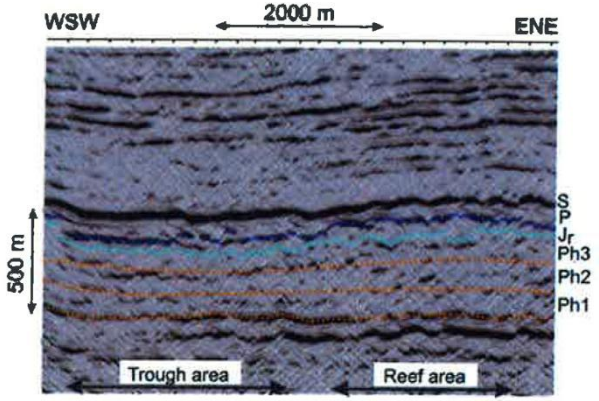


SW-NE cross section of Milos geothermics

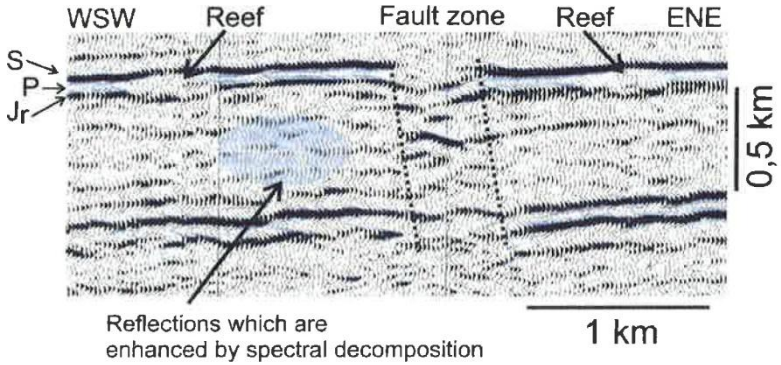
EXPLORATION
SOUTHERN GERMANY MOLASSE BASIN. MALM RESERVOIR. SEISMIC ATTRIBUTES



Upper Jurassic morphology from 3D seismic survey



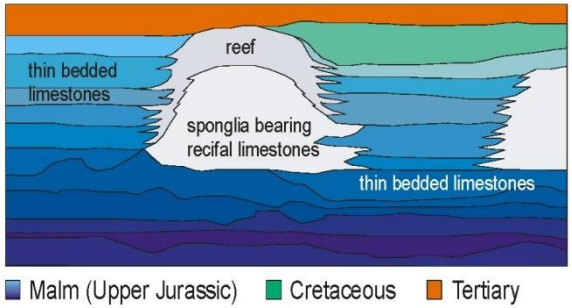
Migrated seismic depth section



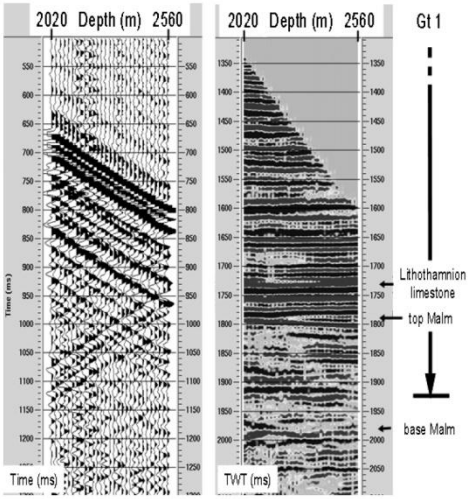
Fault graben structure evidenced by migrated depthsection

Source: H. Von Hartmann et al, 2012

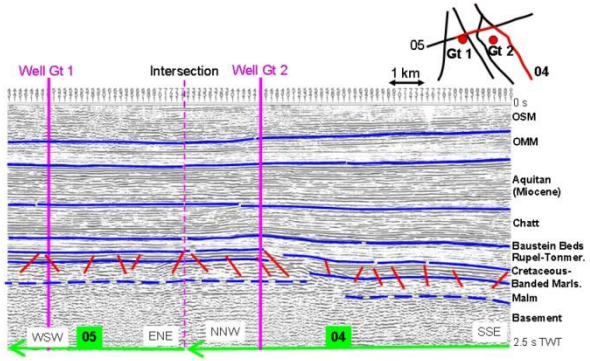
EXPLORATION
SOUTHERN GERMANY MOLASSE BASIN
SEISMIC (RE)PROCESSING



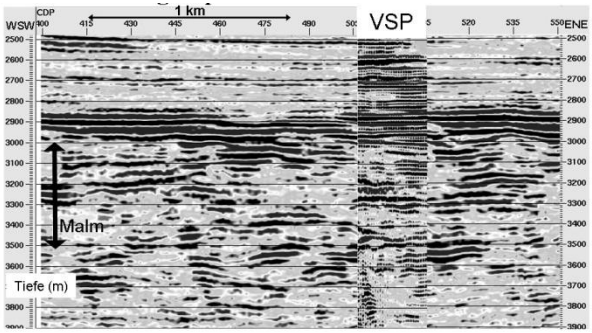
MALM Reef facies



VSP (raw, processed) on well GT1 (Geophone depth # 2000-2500 m) offset (#4000 m)

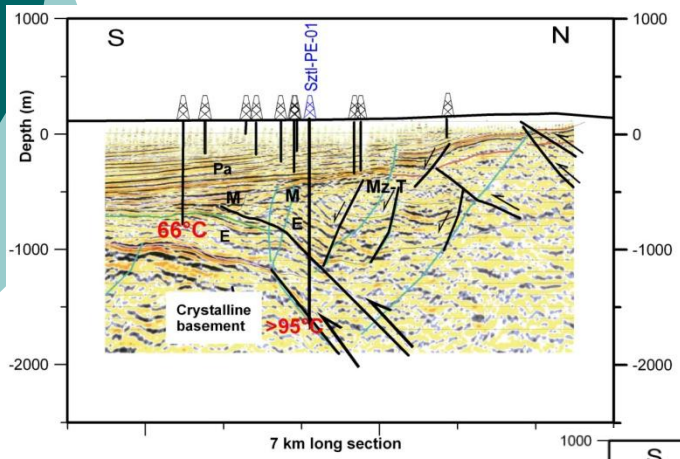


Reprocessed 2D seismic line location of wells GT1 & GT2

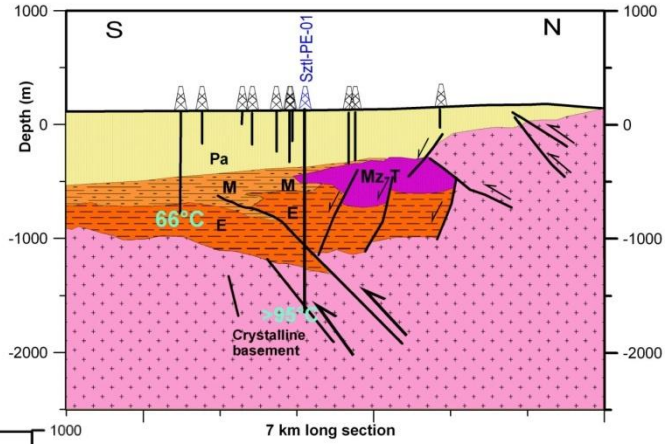


Zero offset and reprocessed 2D line match

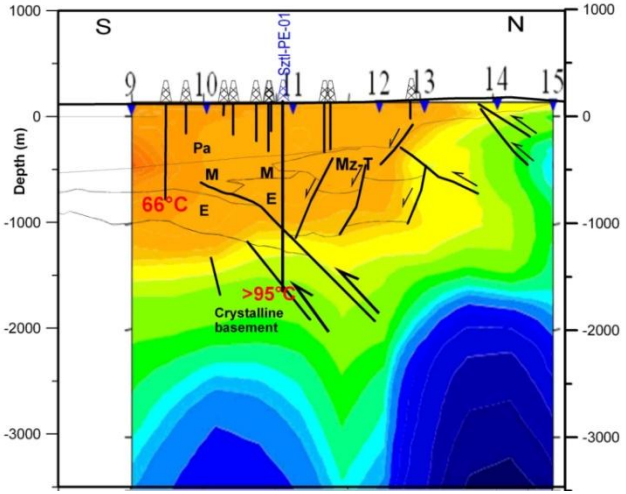
EXPLORATION
PANNONIAN BASIN
COMBINED WELL GEOLOGY/SEISMIC (2D PROFILES, VSP)/MT PROCESSING



Re-interpreted seismic section

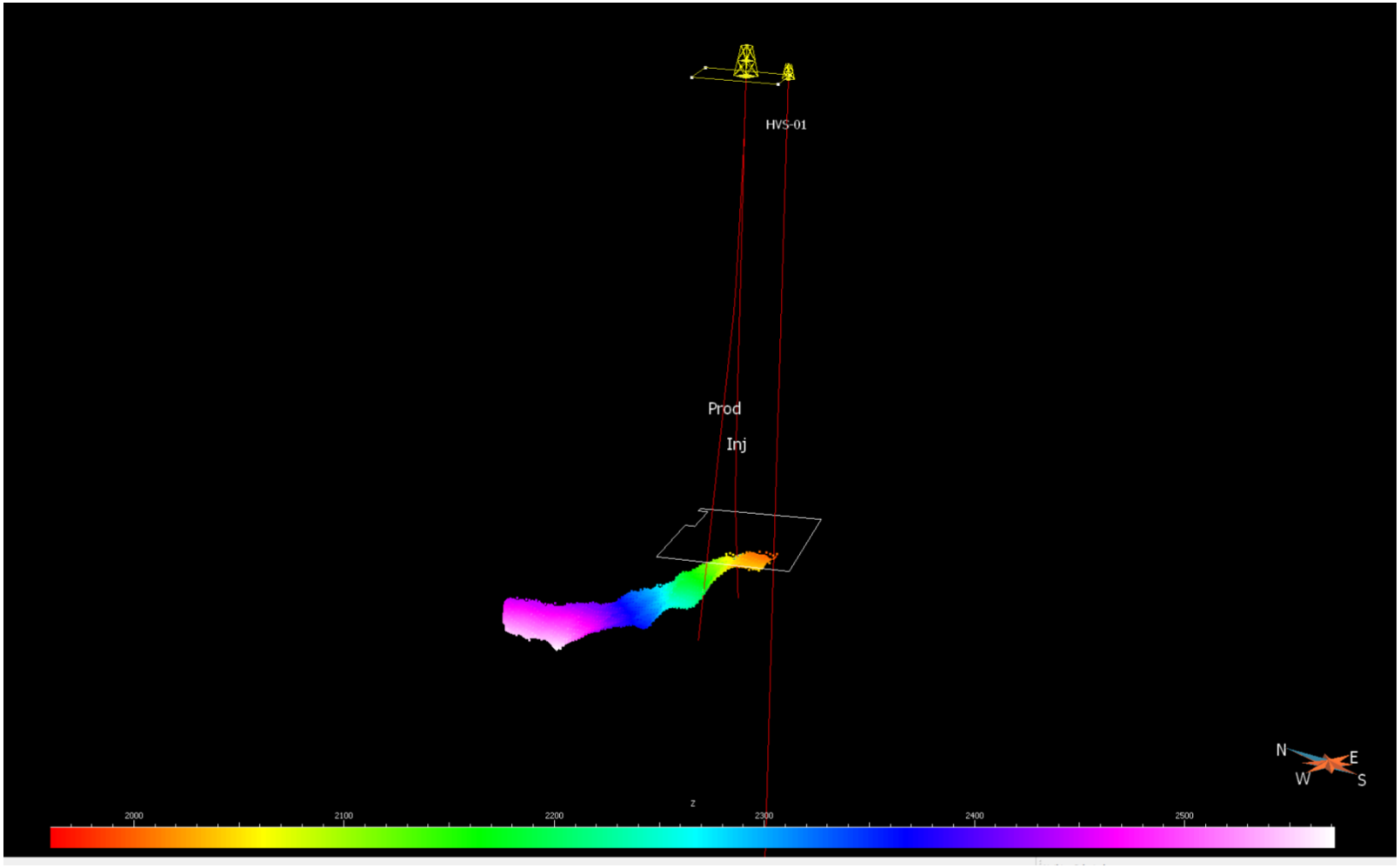


Geological cross section and AMT/MT inversion data



Source: Tulinius et al, 2010

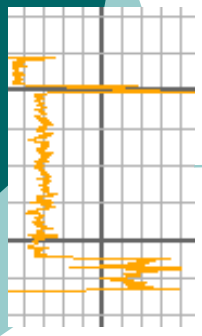
3D STRUCTURAL MODELLING
PERMO TRIASTIC RESERVOIR

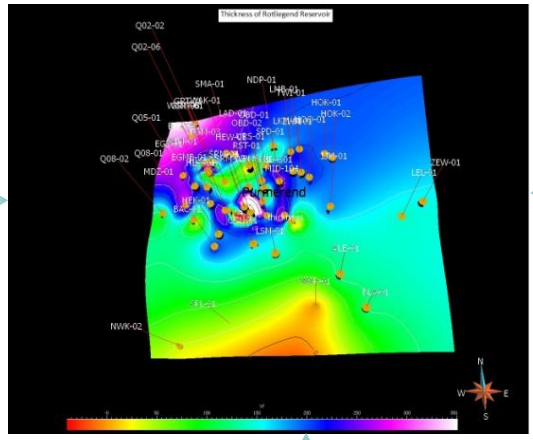


3D STRUCTURAL GEOMODELLING

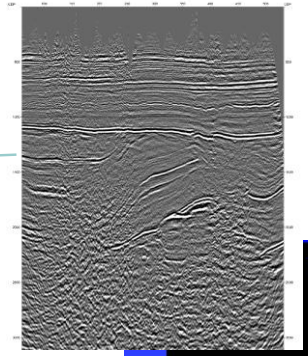
3D REGIONAL GEOLOGICAL MODEL

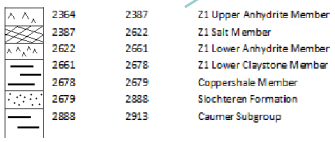
Borehole data:
logs and lithostratigraphic columns





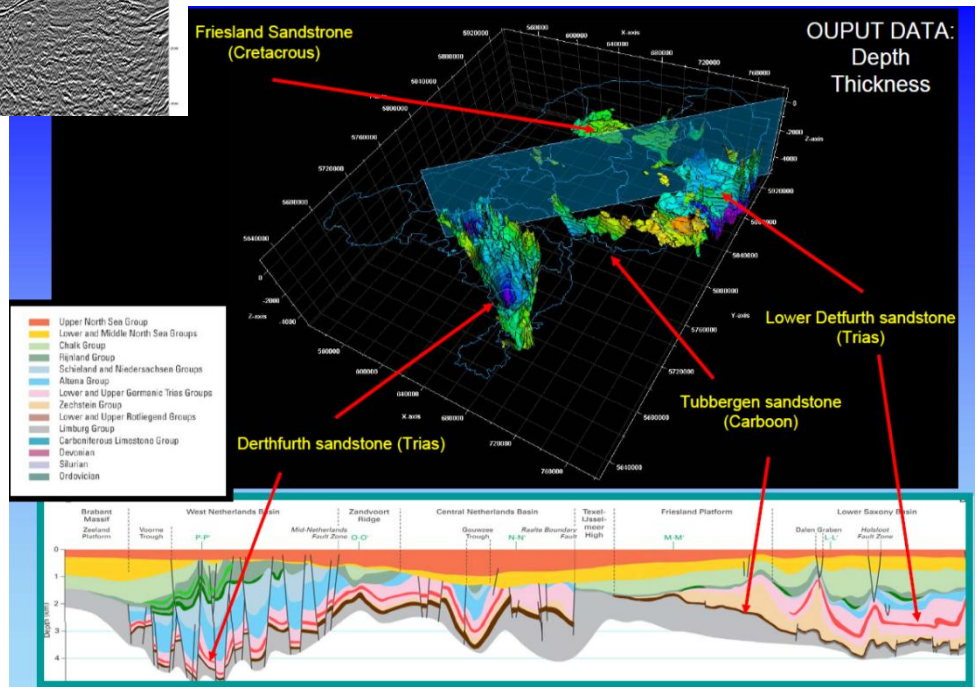
Seismic data





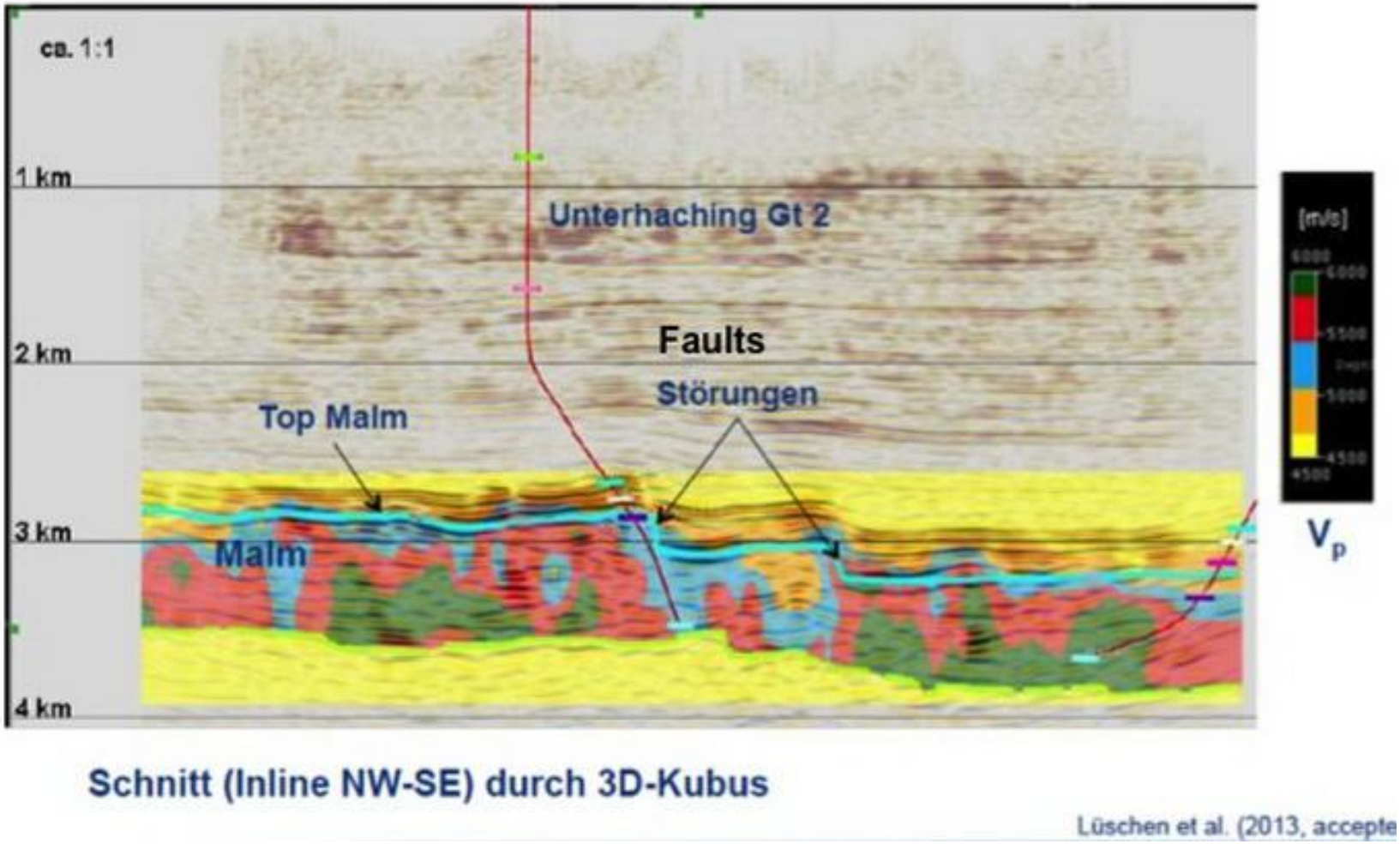
Interpolated data extracted from existing databases and geological atlases

SOUTHERN NETHERLAND CLASTICS



Source: TNO

MOLASSE BASIN. MALM RESERVOIR 3D SEISMIC PROCESSING. RESERVOIR TARGETING

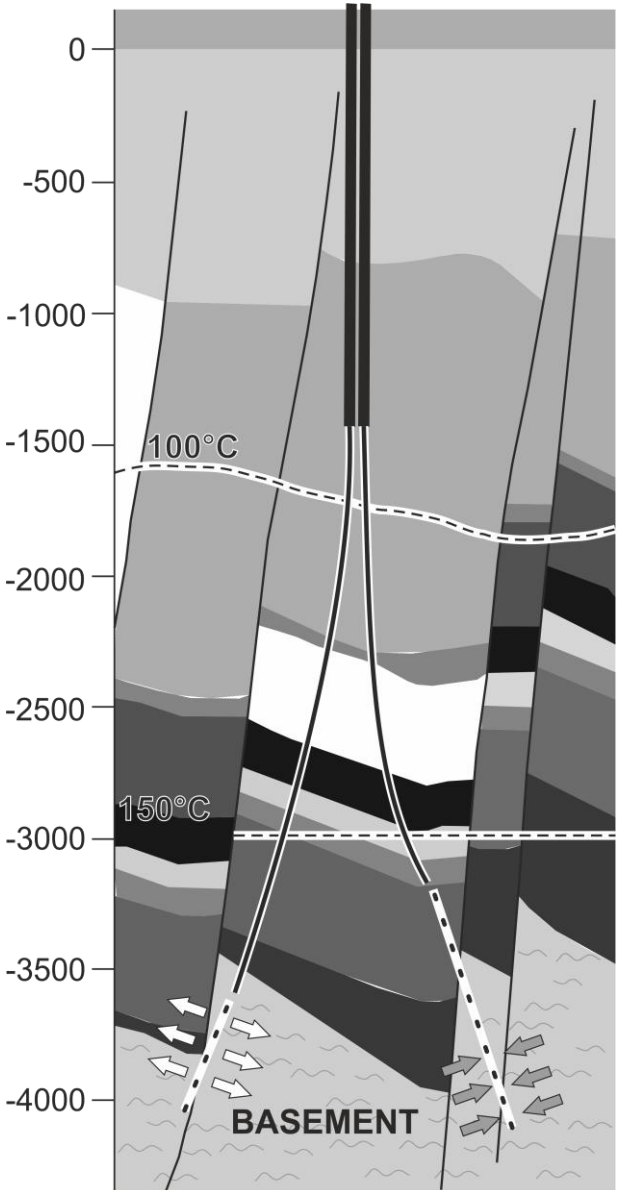


Source: Knapek, D-GEO-DAYS, PARIS 2014

RESERVOIR ASSESSMENT

WELL TARGETING

FAULT BLOCK STRUCTUAL SETTING



Source: Dernières Nouvelles d'Alsace (DNA, 2013) adapted from FONROCHE interview

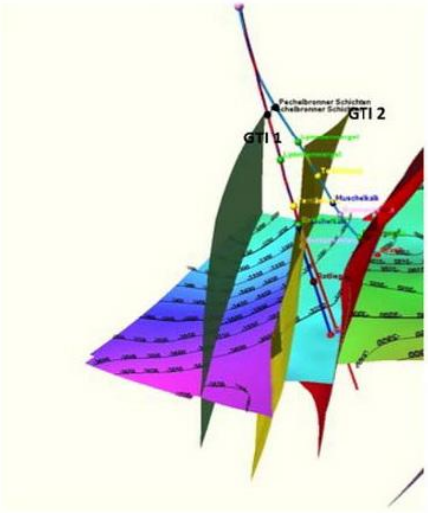
RESERVOIR ASSESSMENT
WELL TARGETING
MULTI HORIZON CONCEPT

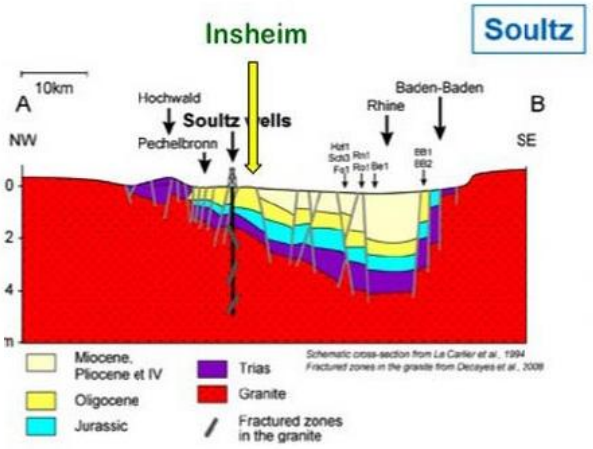
„Multi-Horizon Concept“

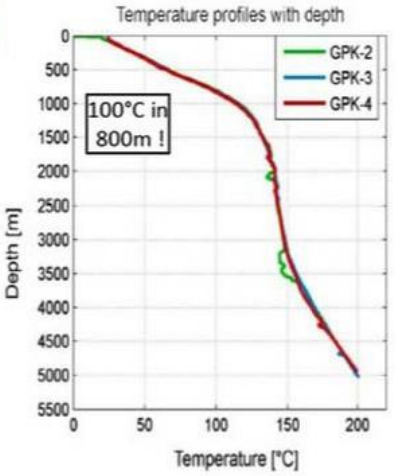
Well GTI 1
Start: 03.06.2008
End: 12.09.2008
Depth: **3654 m**

Well GTI 2
Start: 28.01.2009
End: 20.04.2009
Depth: **3846 m**

Target Formations:
Limestone,
Buntsandstone,
Perm,
Granite

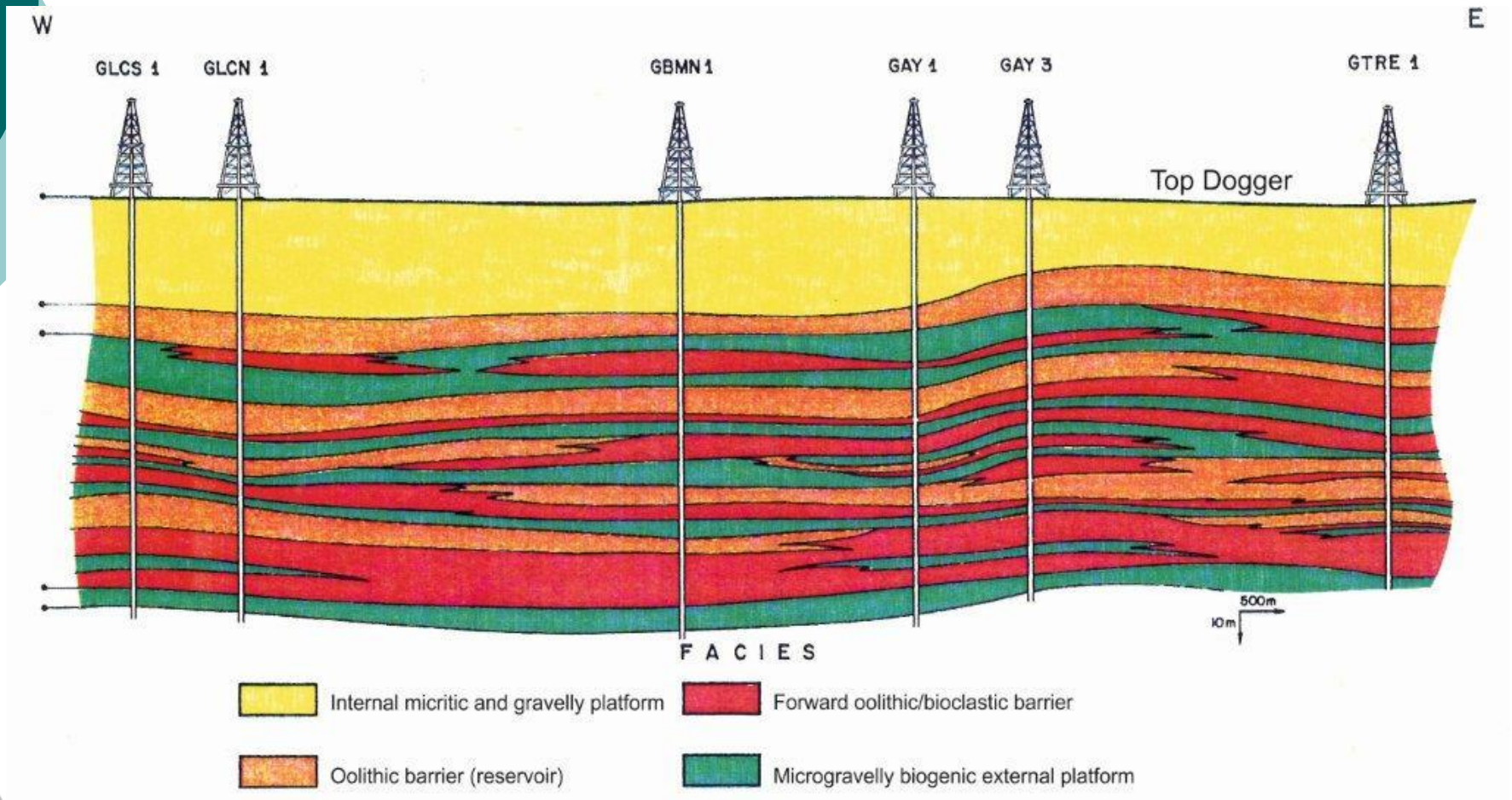






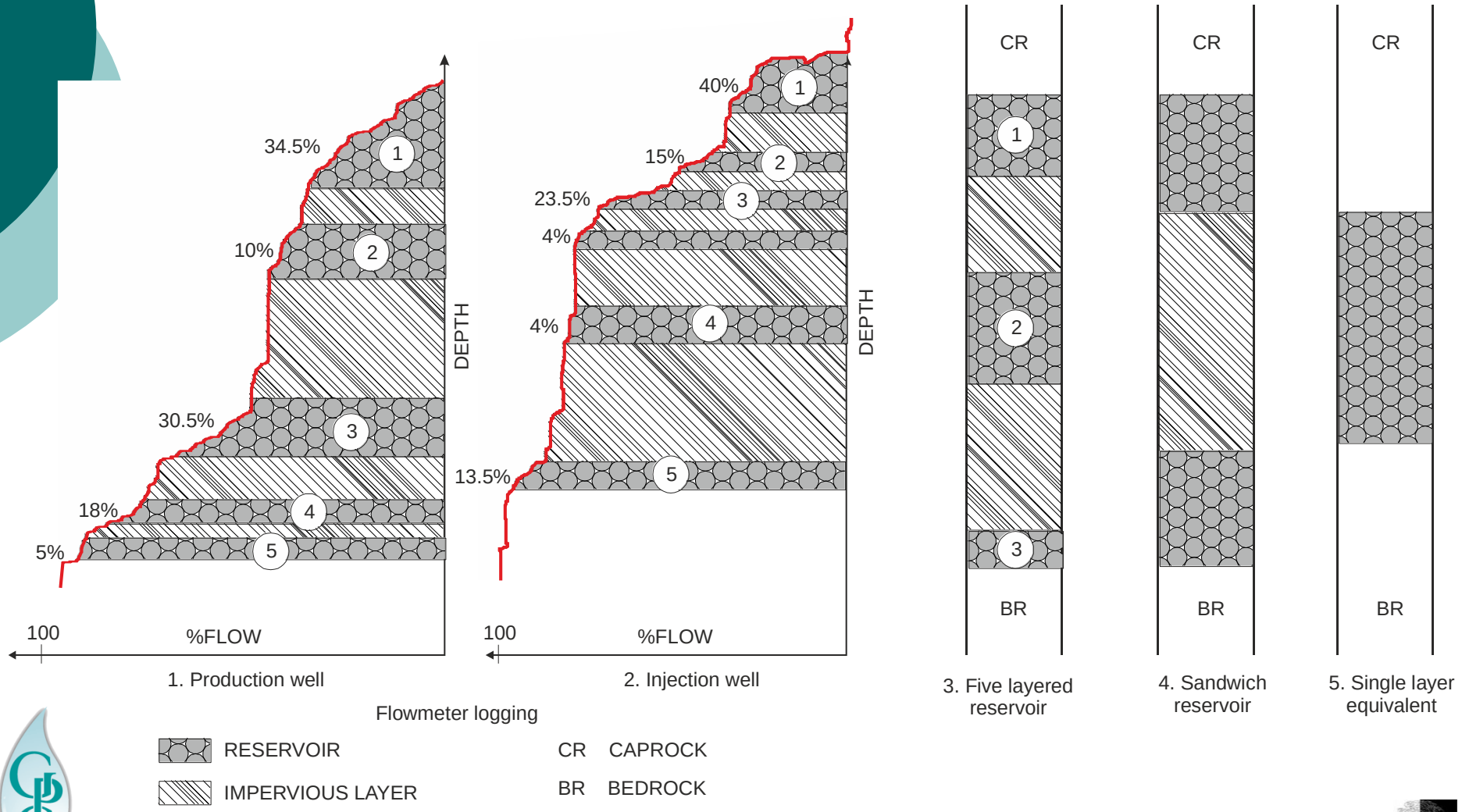
Source: BESTEC

RESERVOIR ASSESSMENT
MULTILAYERED RESERVOIR
TENTATIVE FACIES CORRELATIONS



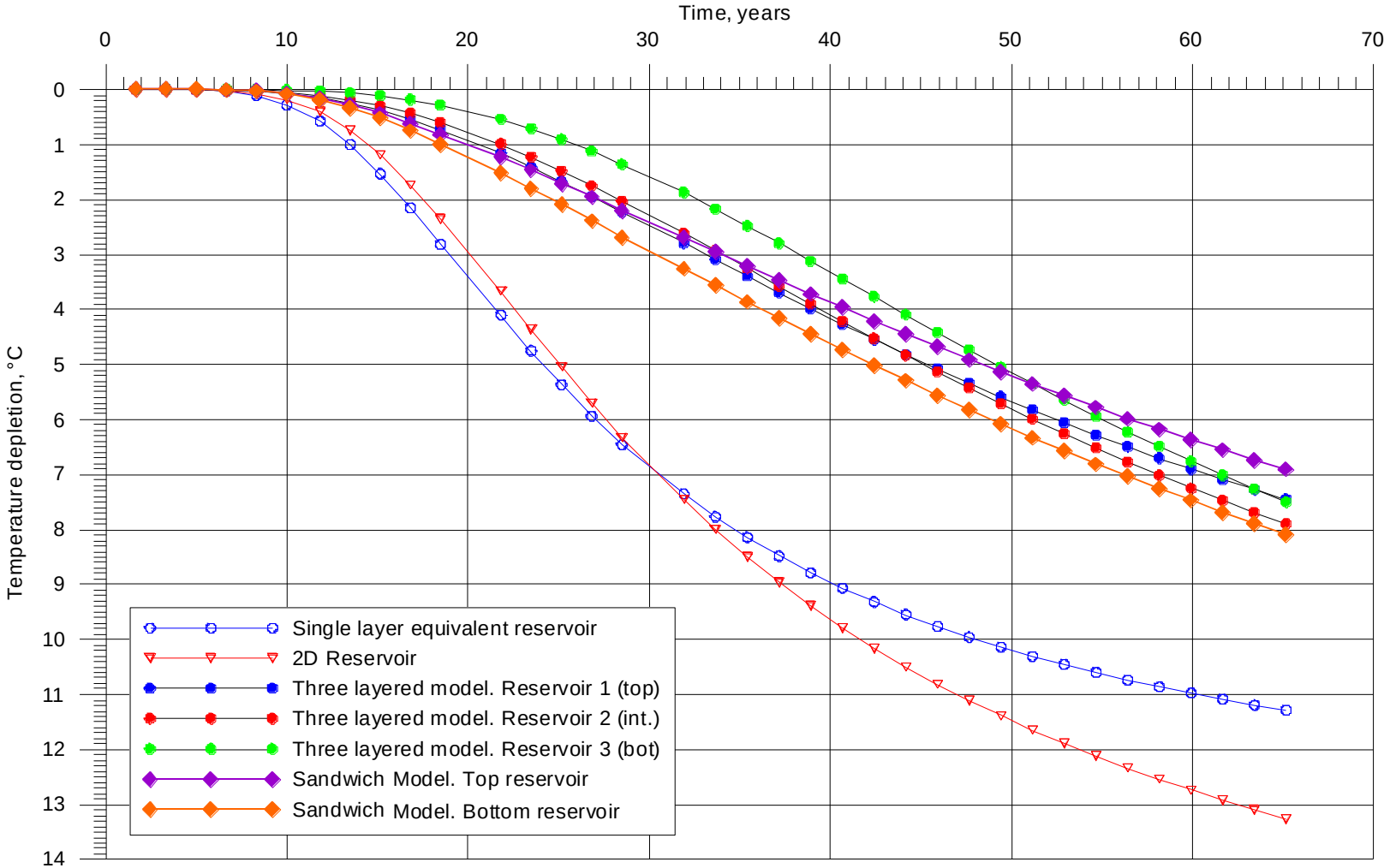
Source: Rojas et al

RESERVOIR ASSESSMENT
LAYERING IMPACT. CANDIDATE RESERVOIR STRUCTURES

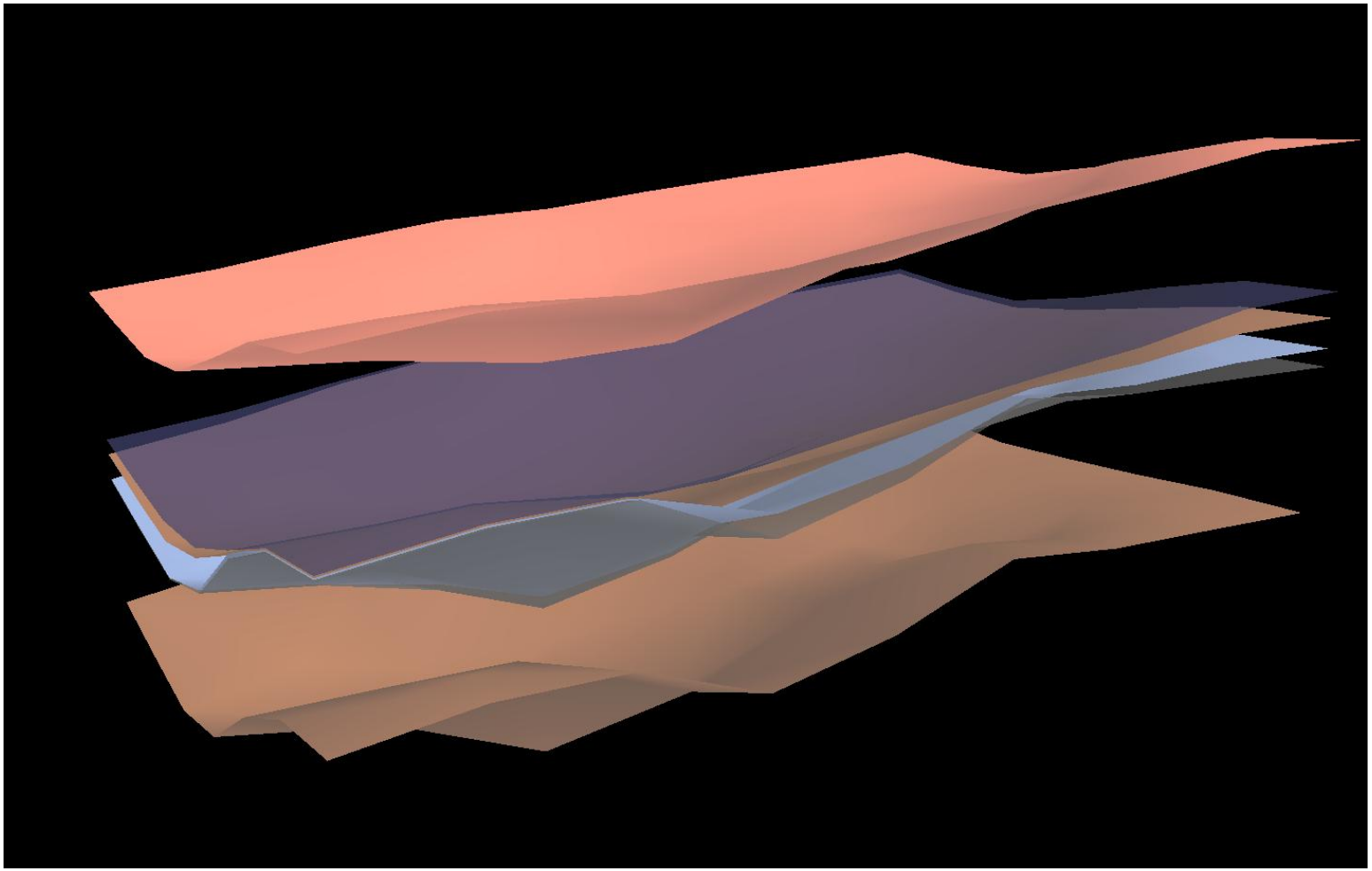


RESERVOIR ASSESSMENT

LAYERING IMPACT. CANDIDATE RESERVOIR STRUCTURES. PRODUCTION WELL COOLING KINETICS

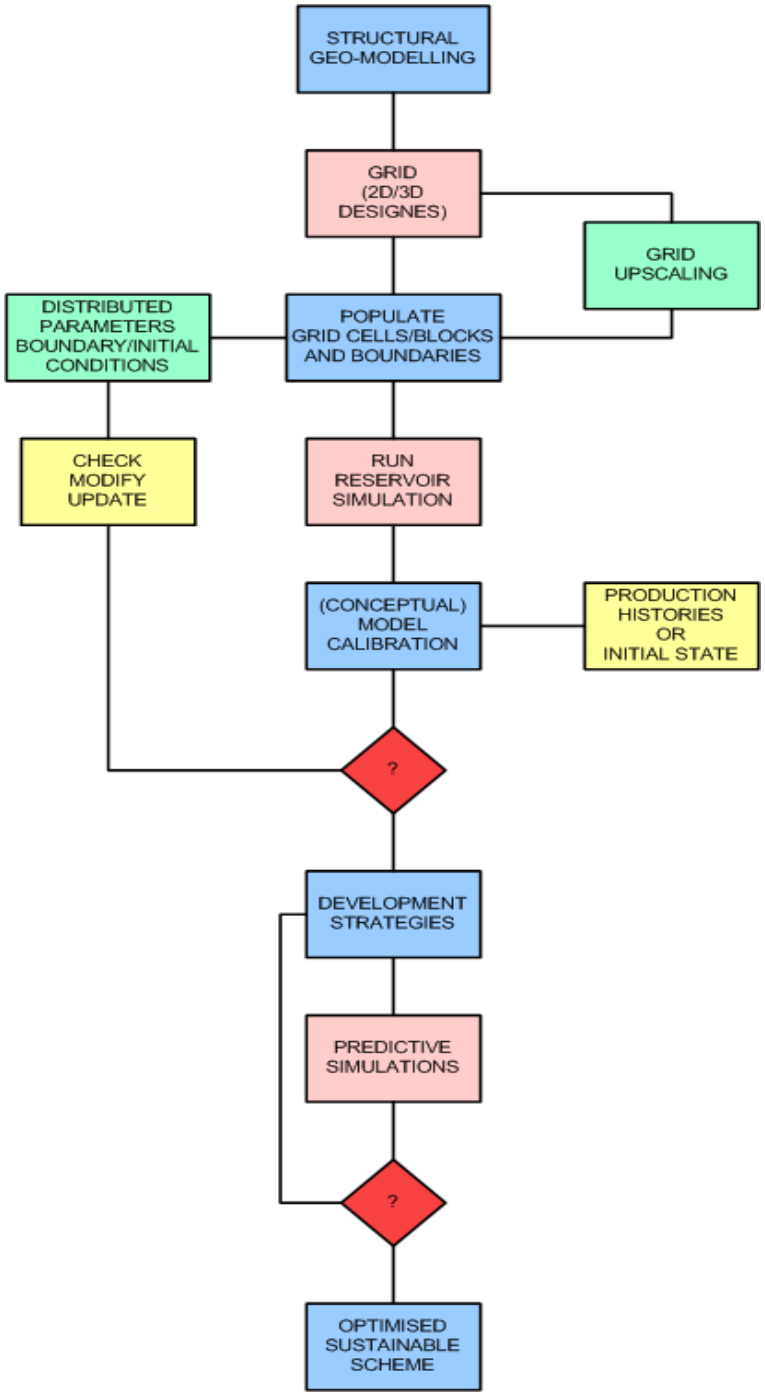


RESERVOIR ASSESSMENT
STRUCTURAL GEOMODELLING
GOCAD 3D VIEW OF THE SANDWICH RESERVOIR EQUIVALENCE



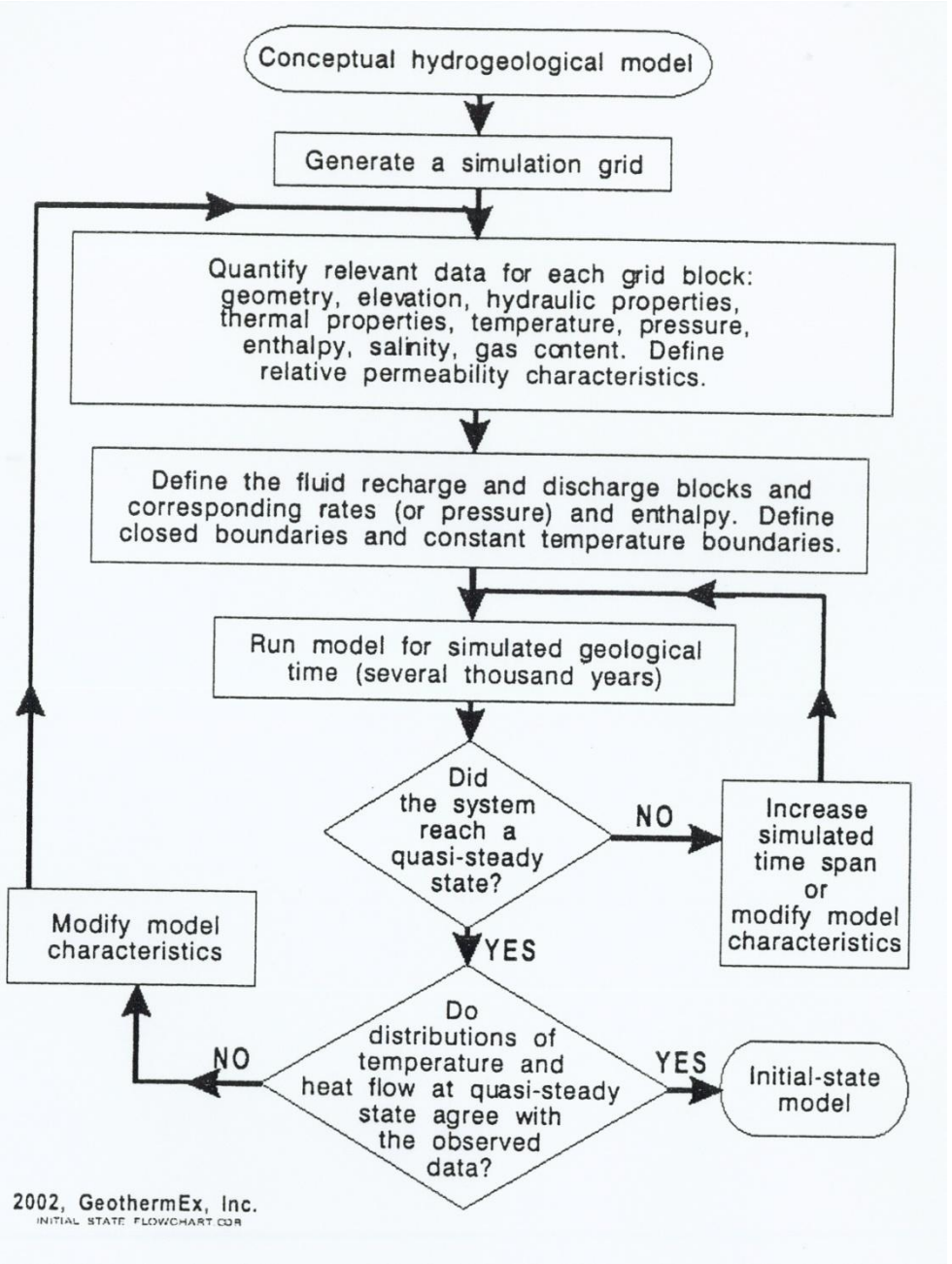
RESERVOIR SIMULATION

MODELLING/ SIMULATION CHAIN



RESERVOIR SIMULATION

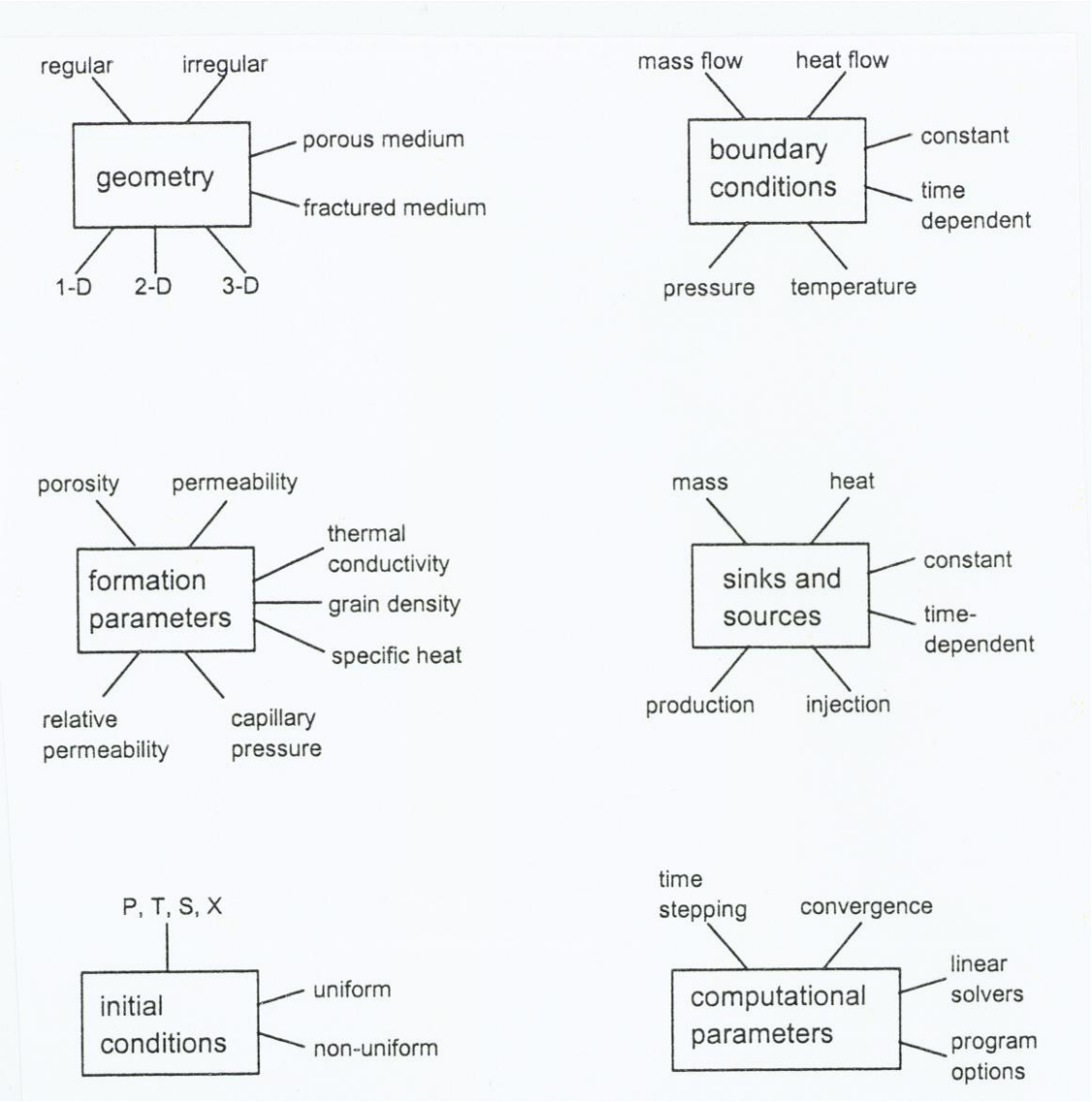
NATURAL STATE MODELLING FLOWCHART



Source: Sanyal, 2002

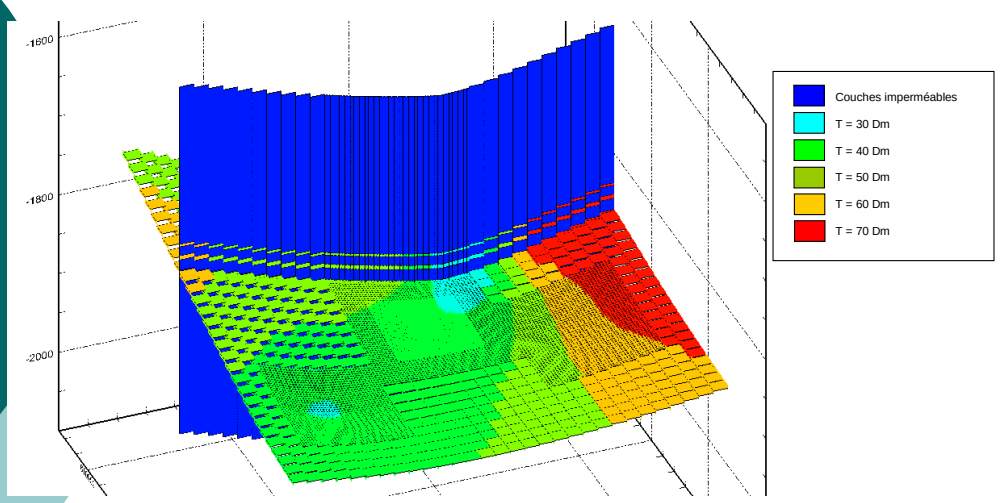
RESERVOIR SIMULATION

SIMULATION INPUT DATA GROUP

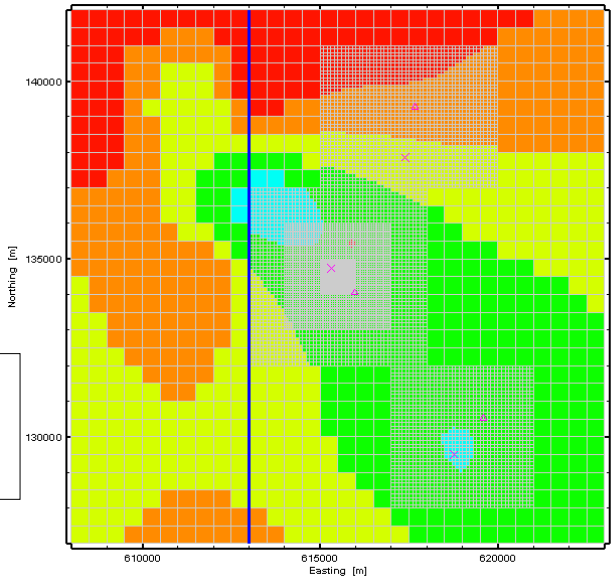


Source: Pruess, 2002

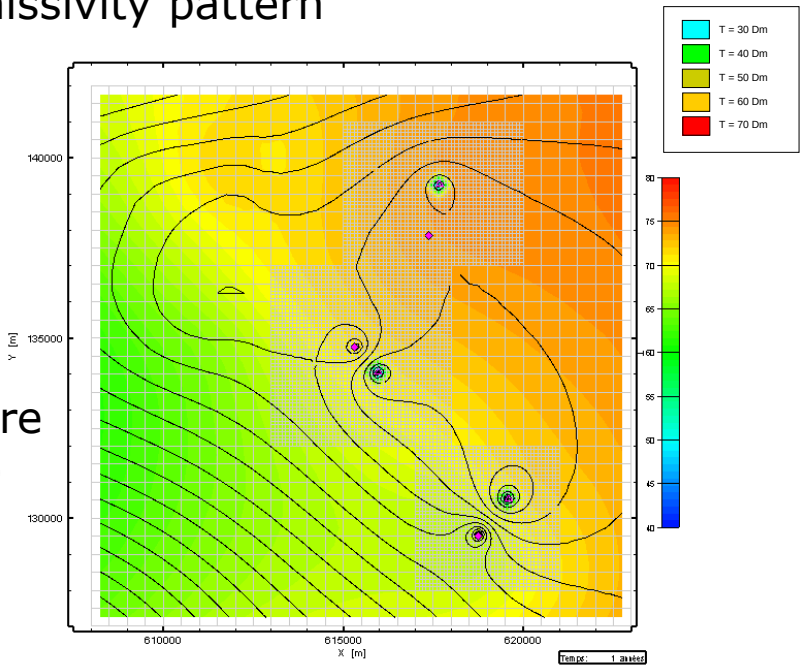
RESERVOIR SIMULATION



3D Transmissivity pattern

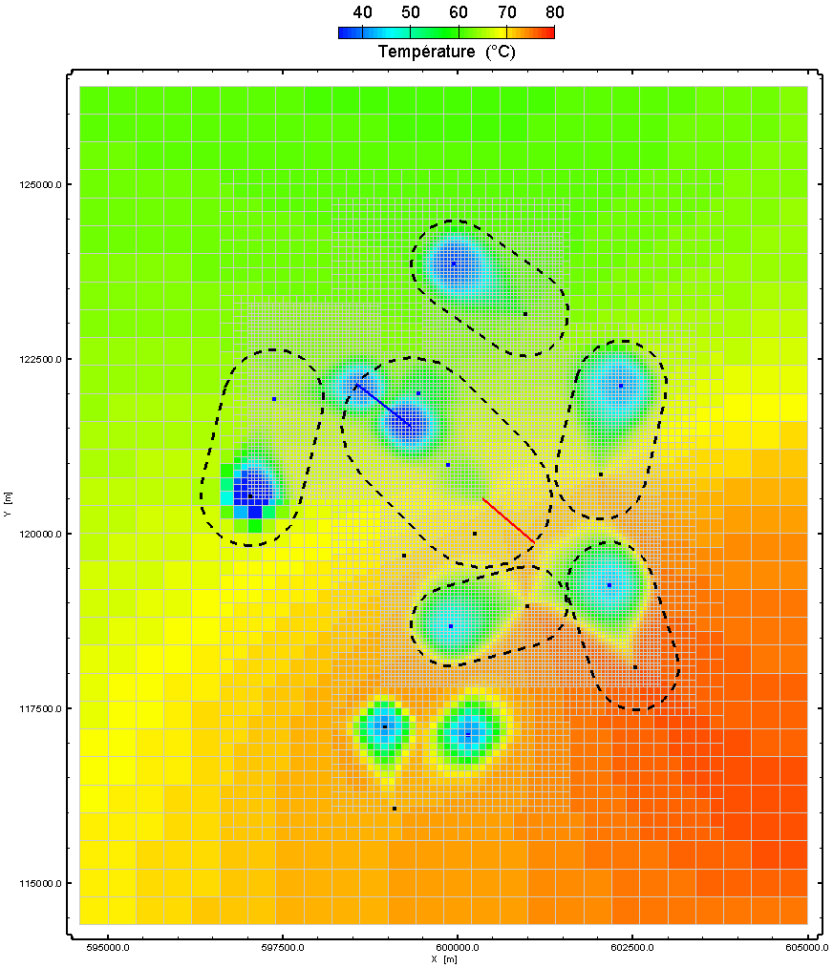


Horizontal Gridding
Transmissivity distribution

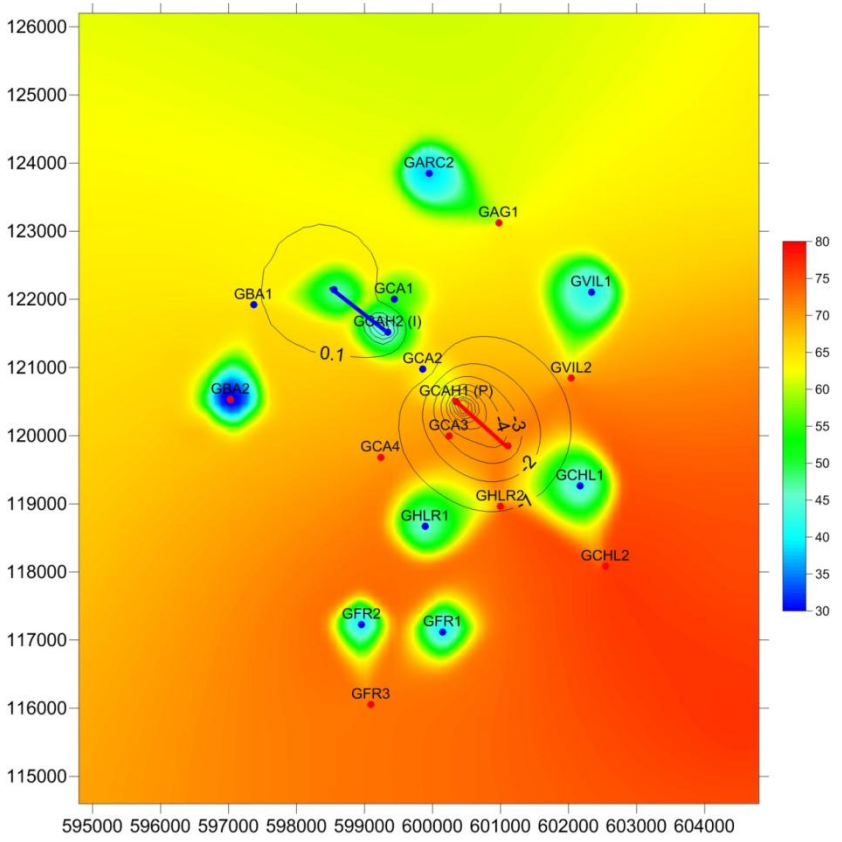


Computed pressure/temperature field (refined grid)

RESERVOIR SIMULATION
SUSTAINEBLE MANAGEMENT SCENARIOS



Pressure and temperature field
Year 2045
Wells (450 m^3/hr)



Interferences with
neighbouring doublets

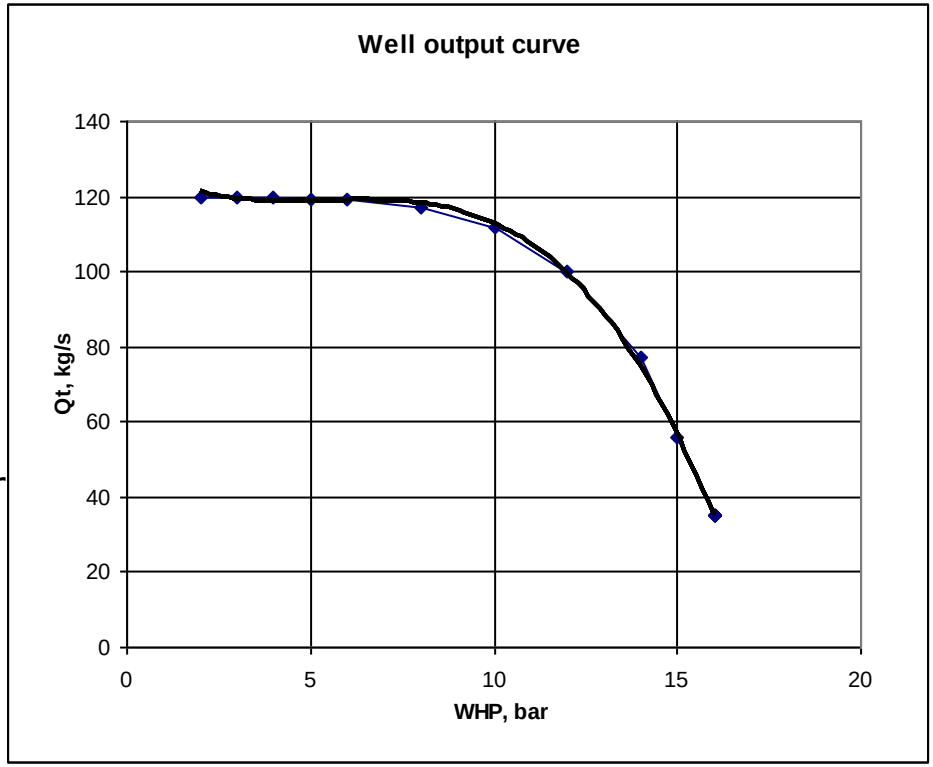
RESERVOIR DEVELOPMENT
RISK ANALYSIS
THE HIGH ENTHALPY CASE
MINING RISK ASSESSMENT. GEOPOWER

Well power output

- Formation temperature: 250°C
- Cold source (condenser) temperature: 50°C
- Condenser pressure: 0,120 bar
- Separator pressure (single stage flash): 10 bar
- Separator temp. (single stage flash): 180°C
- Mass flowrate @ 10 bar: 110 kg/s
- Power output @ 10 bar turbine inlet: #10MWe

Full success: 10 MWe

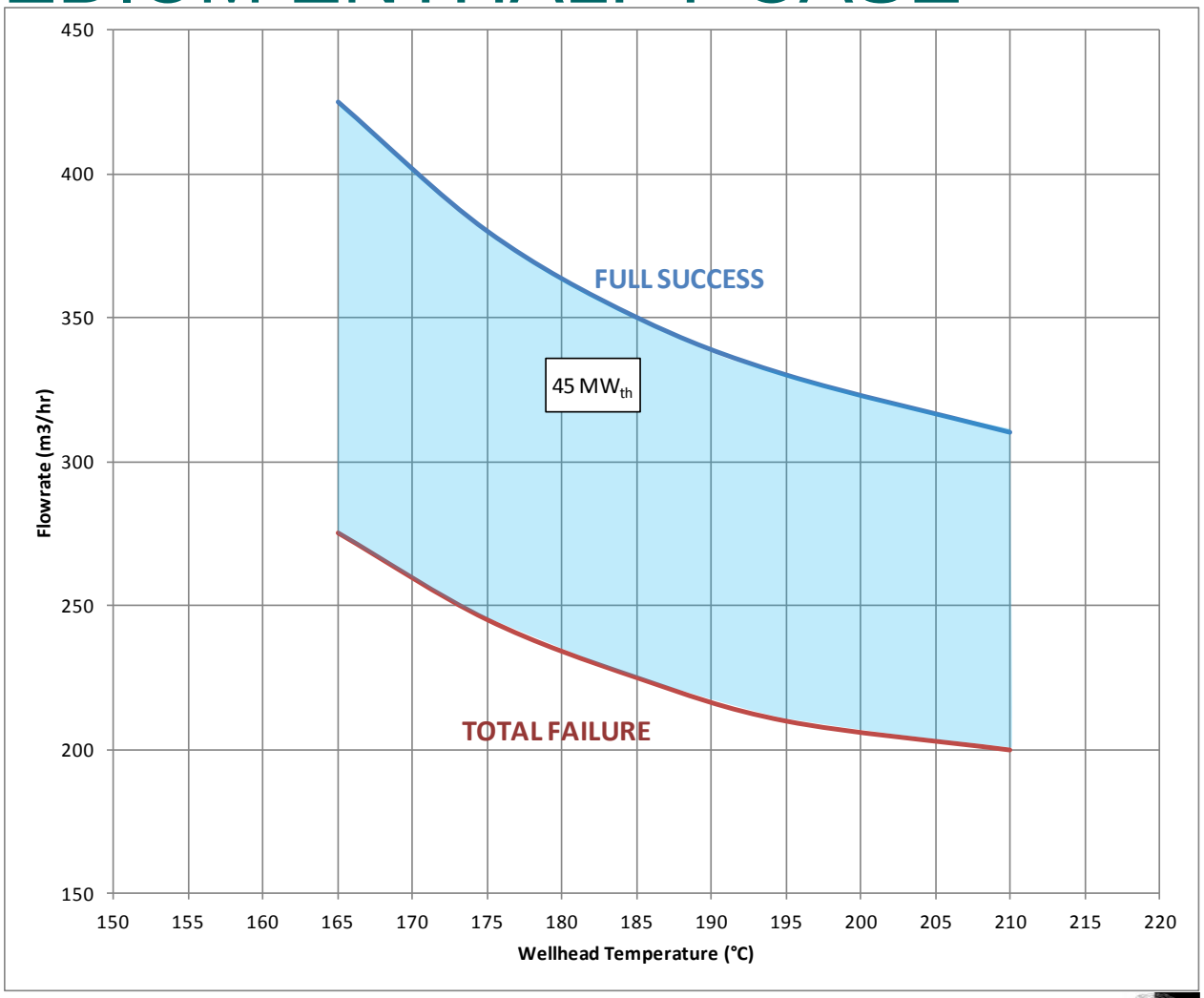
Total failure: 5 MWe



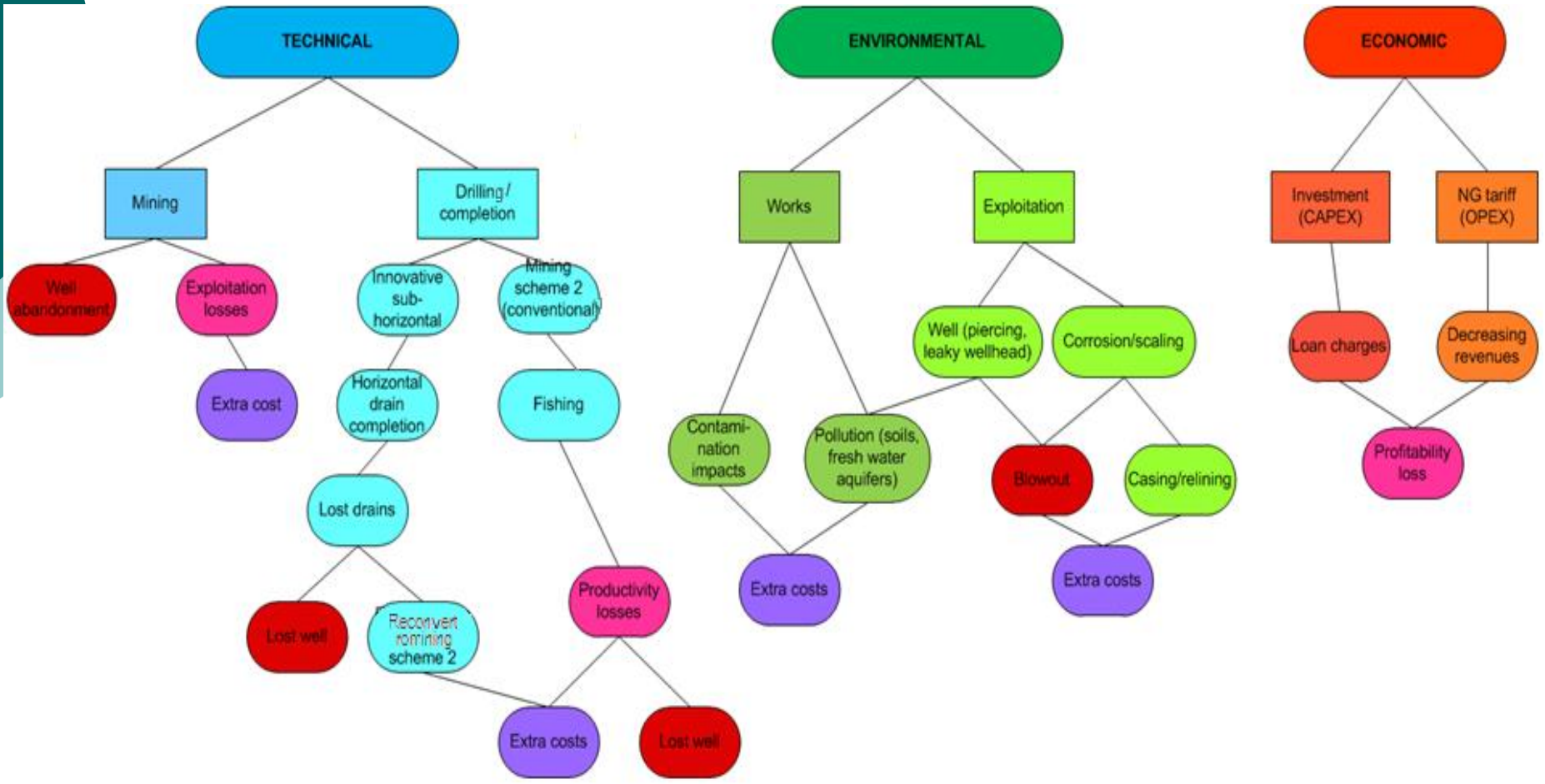
Well delivery curve

RESERVOIR DEVELOPMENT RISK ANALYSIS THE MEDIUM ENTHALPY CASE

MINING RISK
SUCCESS VS FAILURE CRITERIA (CHP PROJECT)

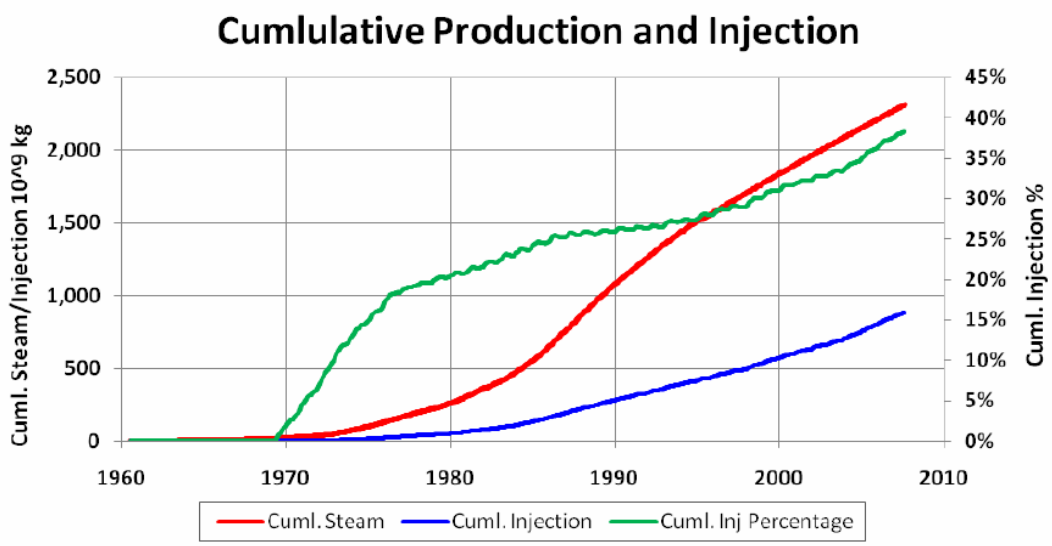


RESERVOIR DEVELOPMENT
RISK TREE OF A TYPICAL GDH SYSTEM

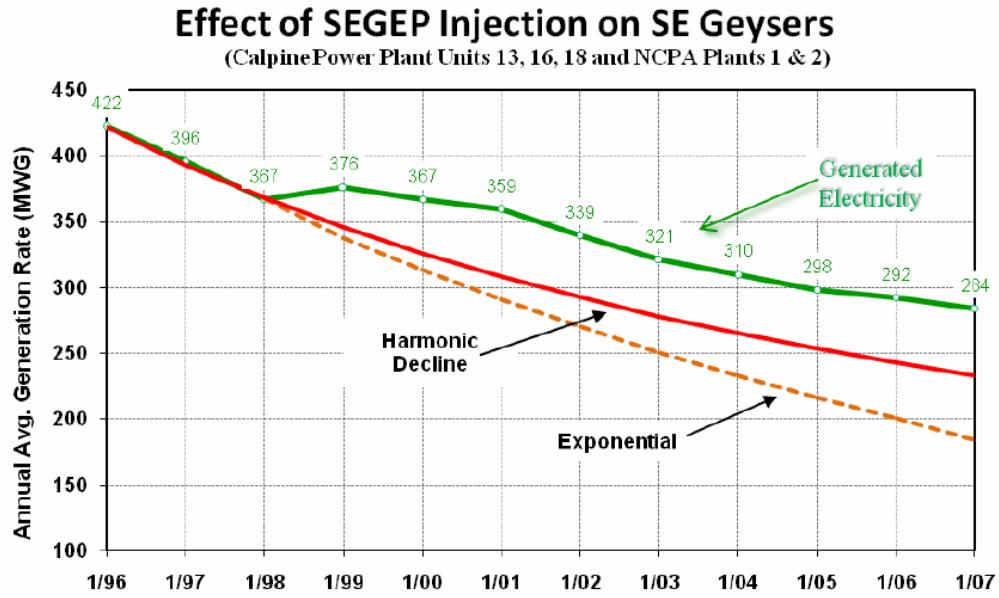


SUSTAINABILITY WATER INJECTION

- The Geysers field



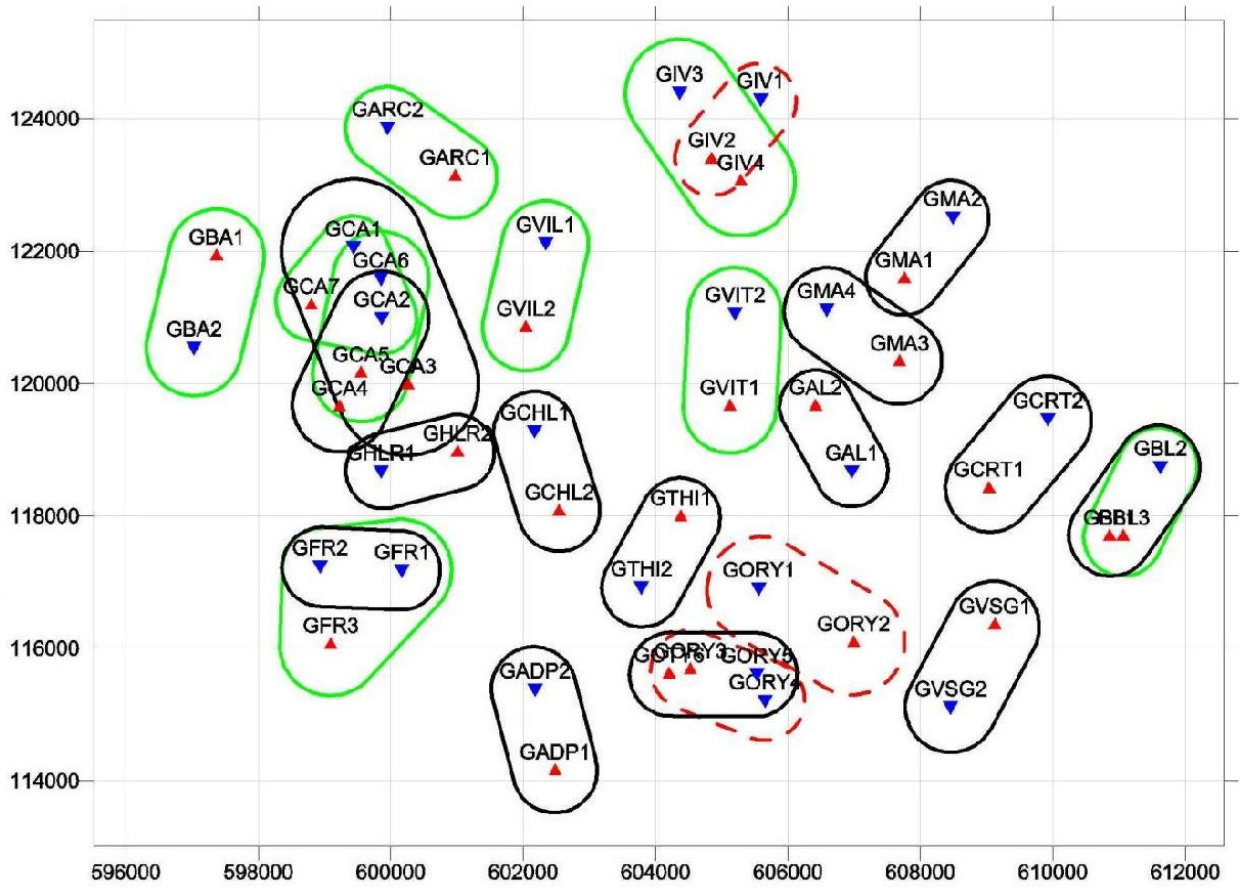
Cumulative Production and Injection
(Division of Oil, Gas, and Geothermal Resources)



Effect of SEGEP Injection on SE Geysers [Calpine and NCPA].

SUSTAINABILITY
GDH DOUBLET/TRIPLET COMPATIBILITIES
PARIS SOUTH
EXISTING AND PROJECTED GDH STATUS

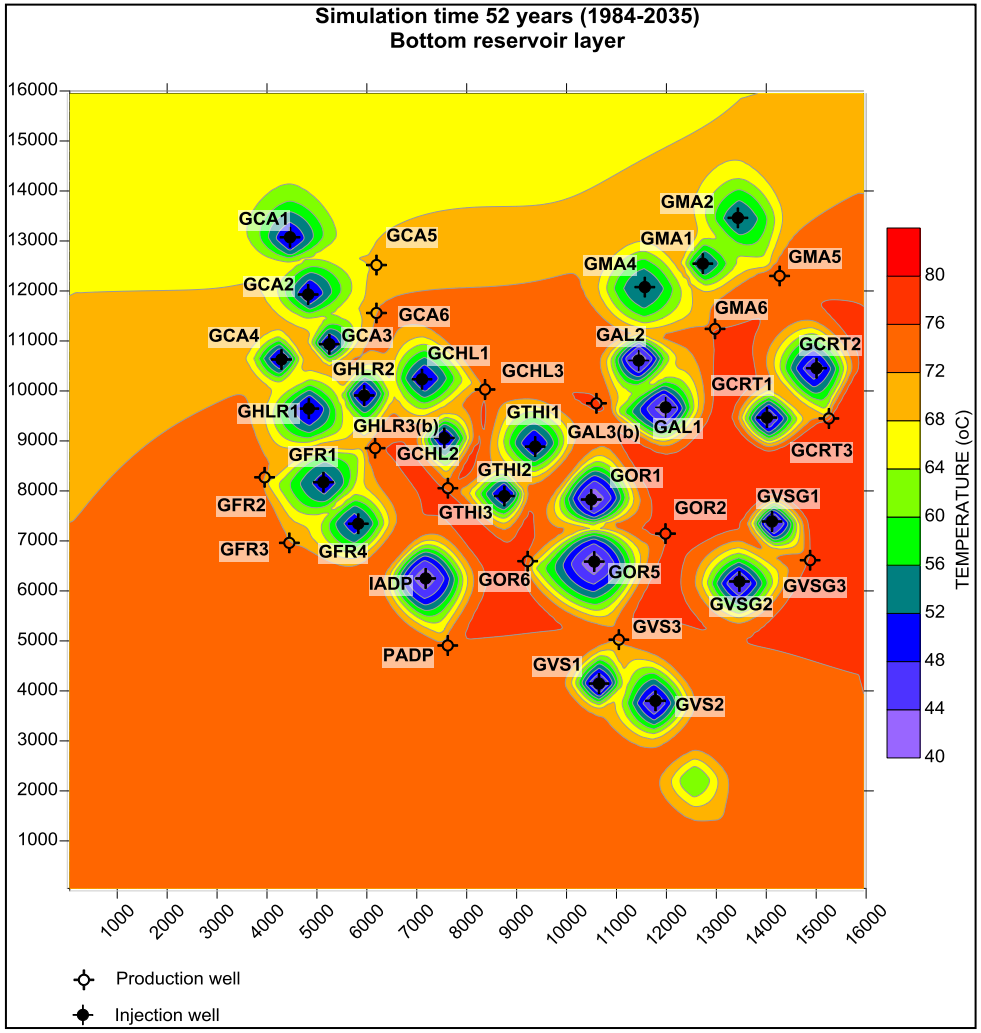
- 3 abandoned doublets
- 14 serviced doublets
- 6 new doublets
- 3 triplet rehabilitated doublets



Source : BRGM

SUSTAINABILITY

MULTI-DOUBLET EXPLOITATION (1984-2035)
PARIS SOUTH. YEAR 2035

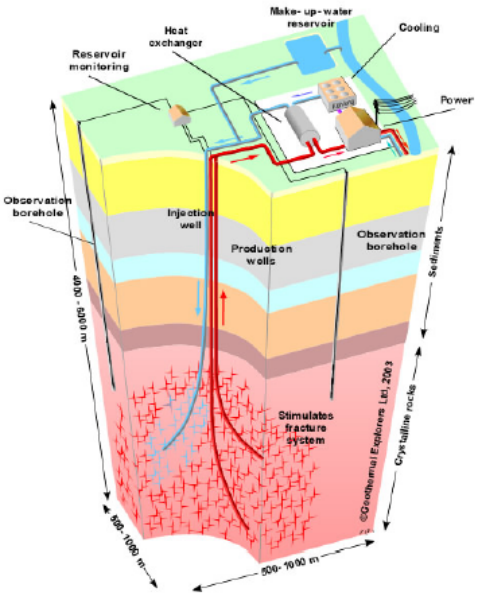


Source : Maria PAPACHRISTOU

HYDRO/THERMO/GEOCHANICAL MODELLING EGS ENVIRONMENTS

PROCESSES INVOLVED

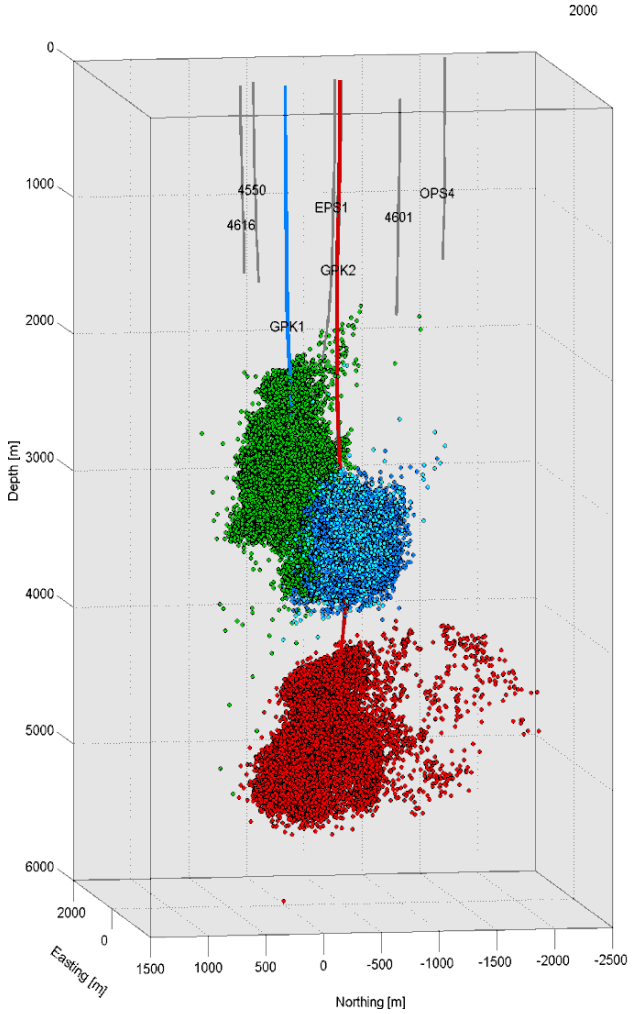
- Essentially fractured medium, Darcy flow; non-Darcy flow at high fluid velocities in fractures
- Hydraulic coupling: advection
- Thermal coupling: buoyancy, density, viscosity
- Mechanical processes play an important role in reservoir development and assessment
  - Fracture mechanics
    - Shear fracturing $\tau = c + \tan(\Phi) \cdot \sigma_n$
    - Tensile fracturing $P_f > S + \sigma_{\min}$ $P_f > S + \sigma_{\min} + \alpha \cdot P_p$
  - Matrix elasticity
    - Poroelasticity
    - Thermoelasiticity
- Injected fluid and formation fluids are different; biphasic flow or multicomponent transport
- Geochemistry also play an important role in reservoir characteristics



Source: Kohl, 2007

INDUCED SEISMICITY
POST FRACTURING MAPPED EVENTS

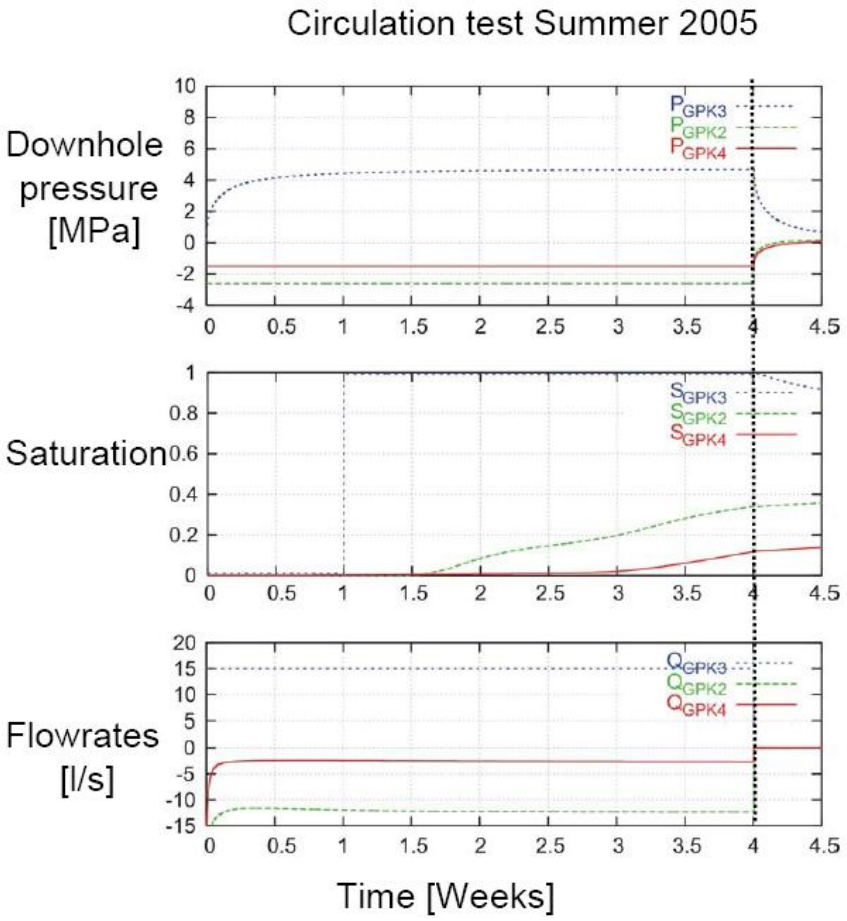
Field Monitored

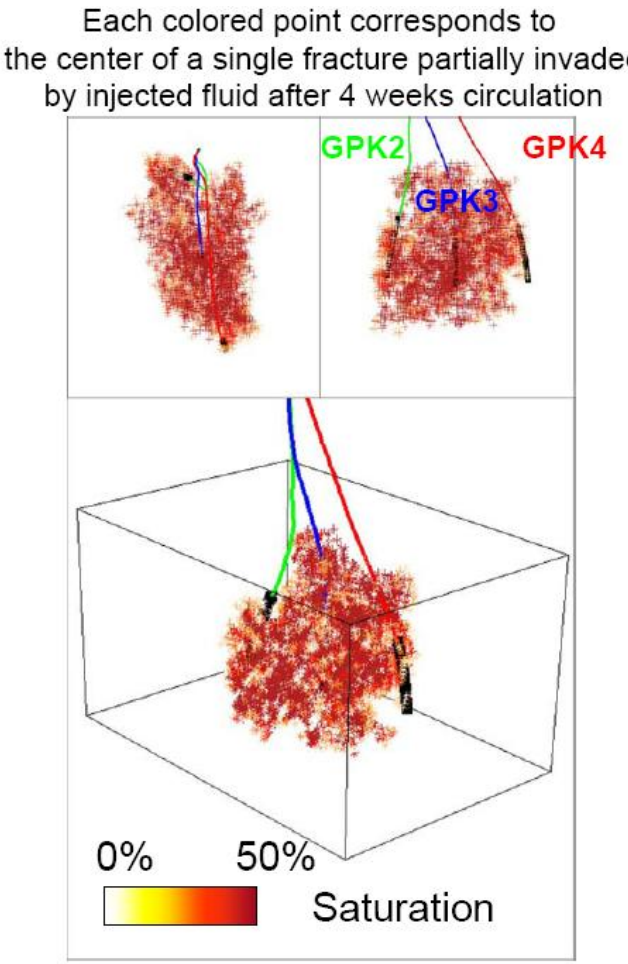


Source: Baria et al, 2007

EGS
INDUCED SEISMICITY
COMPUTED POST FRACTURING SEISMIC EVENTS

Computer Generated





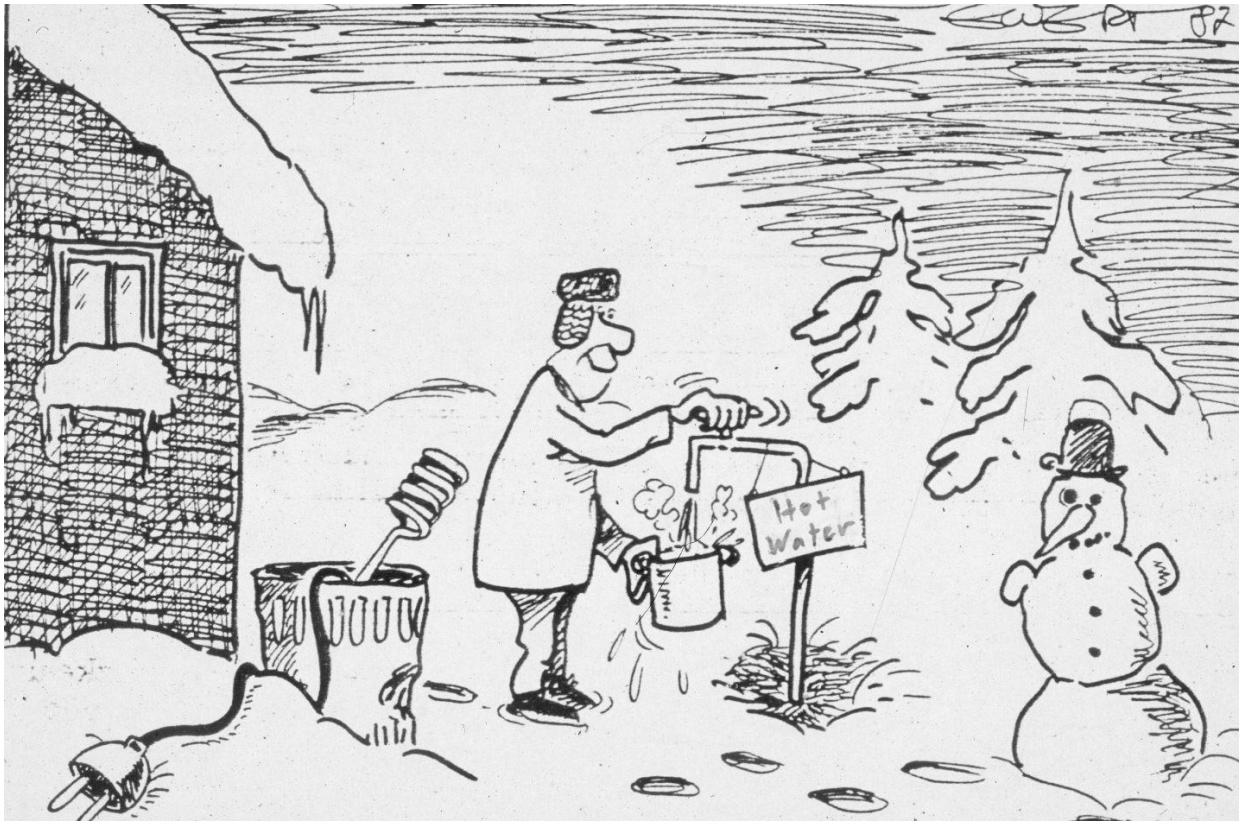
Source: Kohl, 2007

INDUCED SEISMICITY

- EGS undertakings hosted in seismically active tectonic environments
- A fatal issue during the build-up of any EGS reservoir
- A major contributor to fracture mapping and stimulated bulk-rock volume estimates
- A sensitive social acceptance issue: triggering of M=2.9 (Soultz) and 3.4 (Basel) seismic events leading to pressure mitigation (Soultz), flowrate limitations (Landau) and project abandonment (Basel)
- Requirements
  - Remote well sites
  - Thorough microseismic monitoring protocols
  - Soft rock stimulation procedures
  - Low injection pressures (multipath well trajectories)
  - Interactive communication with the public

GEOTHERMAL ENERGY:

RENEWABLE-SUSTAINABLE-PROVEN-ACHIEVABLE-REALISTIC



THANK YOU! MERCI!

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