CO_2 Sub-Surface Risk Management & Mitigation

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Schlumberger Integrated Project Management

CO2 Capture and Sequestration (CCS) in Future International R & D Programmes

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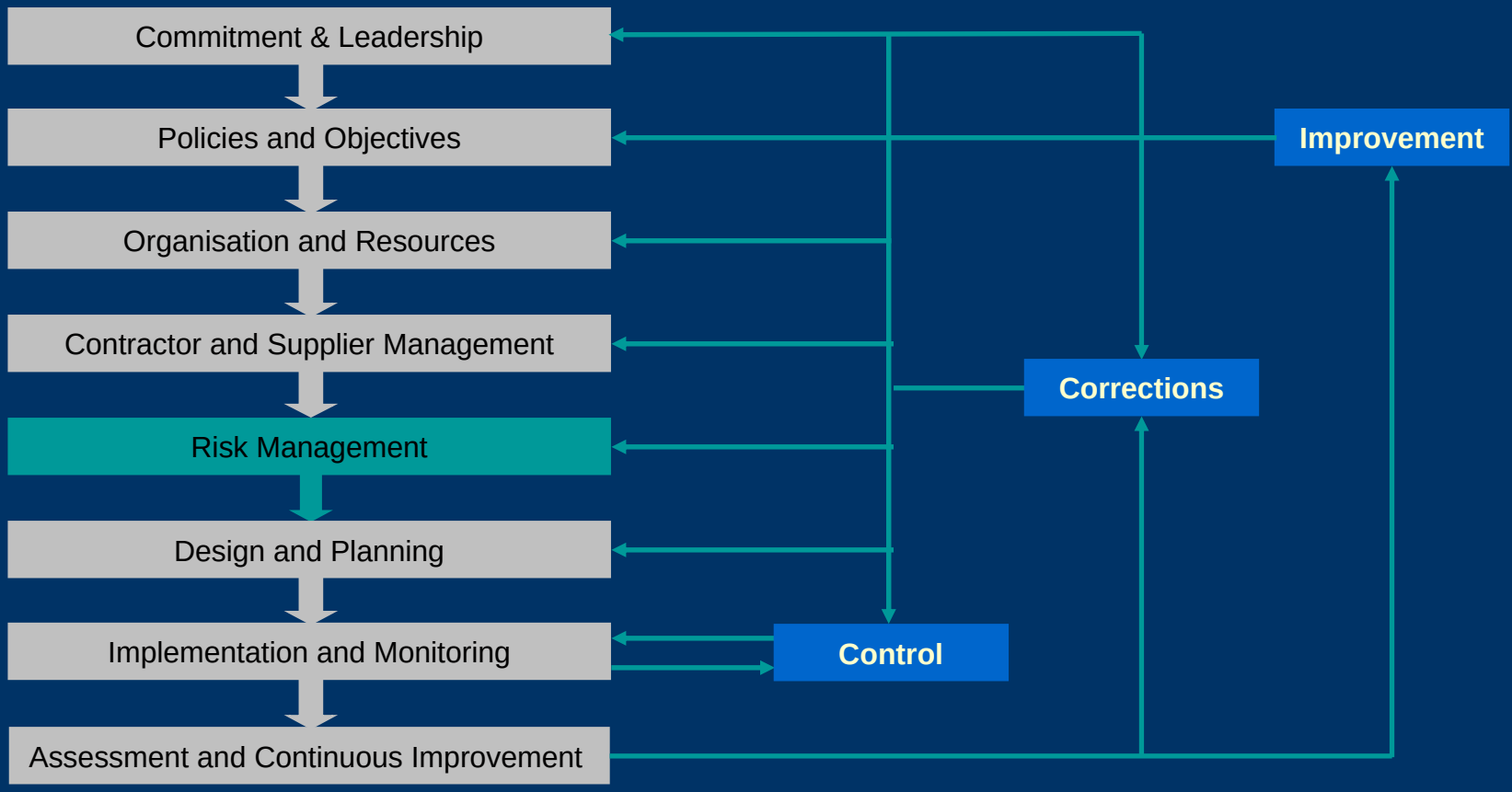
Schlumberger Involvement in CO_2 Capture & Storage

- Provision of:
  - Geological & Geophysical Solutions
  - Reservoir Simulation & Production Optimization
  - Wellbore & Reservoir Monitoring
  - Wellbore Construction, Isolation & Completion
  - Information & Knowledge Management Solutions
  - Real-time Automation: Production & Injection Management
  - Project Management
- Involved in almost all anthropogenic CO2 projects

Sub-Surface Management for CO_2

- Evaluation of Potential Storage Sites
- Uncertainty Assessment & Value of Information Analysis
- Static Model(s) and Prediction from Dynamic Simulation (ranges of outcomes)
- Integrated Well Construction & Formation Evaluation
- Sub-surface Monitoring (near wellbore and across wellbores)
- Resulting Actions:
  - Maintenance, Remediation
  - Update of Static & Dynamic Simulation

Quality & Risk Management Process



Qualitative Risk Prevention & Mitigation Matrix

-25 to -20	**BLACK**	NON-OPERABLE:	Evacuate the zone and or area/country
-16 to -10	**RED**	INTOLERABLE:	Do not take this risk
-9 to -5	**YELLOW**	UNDESIRABLE:	Demonstrate ALARP before proceeding
-4 to -2	**GREEN**	ACCEPTABLE:	Proceed carefully, with continuous improvement
-1	**BLUE**	NEGLIGIBLE:	Safe to proceed

MITIGATION

Control Measures

PREVENTION

LIKELIHOOD

SEVERITY

		Improbable 1	Unlikely 2	Possible 3	Likely 4	Probable 5
Light	-1	-1 1L	-2 2L	-3 3L	-4 4L	-5 5L
Serious	-2	-2 1S	-4 1S	-6 3S	-8 4S	-10 5S
Major	-3	-3 1M	-6 2M	-9 3M	-12 4M	-15 5M
Catastrophic	-4	-4 1C	-8 2C	-12 3C	-16 4C	-20 5C
Multi-Catastrophic	-5	-5 1MC	-10 2MC	-15 3MC	-20 4MC	-25 5MC

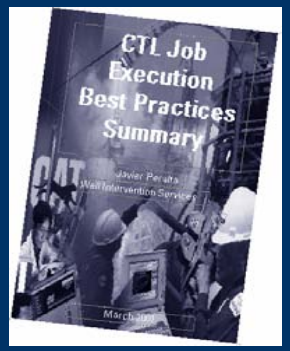
White arrow indicates decreasing risk

Integration of QHSE-MS, Technology and Knowledge Management for Risk Management

Total Risk Control

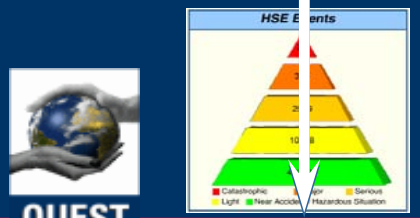
Data Reports

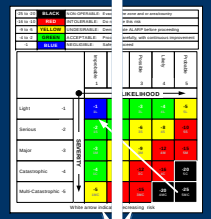
Proactive Hazard/Risk Assessment



Best Practices

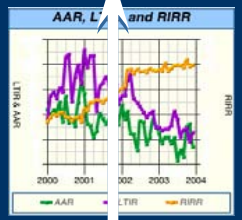
Wisdom





QUEST

InTouchSupport.com



Project Knowledge Hub

Acquisition, Trends, Categories…

Critical Technology Assessment

Knowledge Management

Knowledge Management

Quality Management for CO_2 Field Management

West Texas

- CO2 andWaterflood - Oil Production
- Oil = 6,000 BOPD, Gas = 10 MMCFD, Water = 132,000 BWPD
- >500 oil/gas producers & >400 water/CO2 injectors.
- Provision of:

  Contract Management, Operations, Maintenance, Engineering, and QHS&E. Operate CO2 compression for recycle. Reduced Operating Costs by 23%.
- Reduced Decline from 36% to 0% for 6 Months; Decline Resumed at 12%
- Reduced Field Spills by 66% In 10 Months.
- No Environmental Citations/No Lost Time Accidents over First Year's Operation.

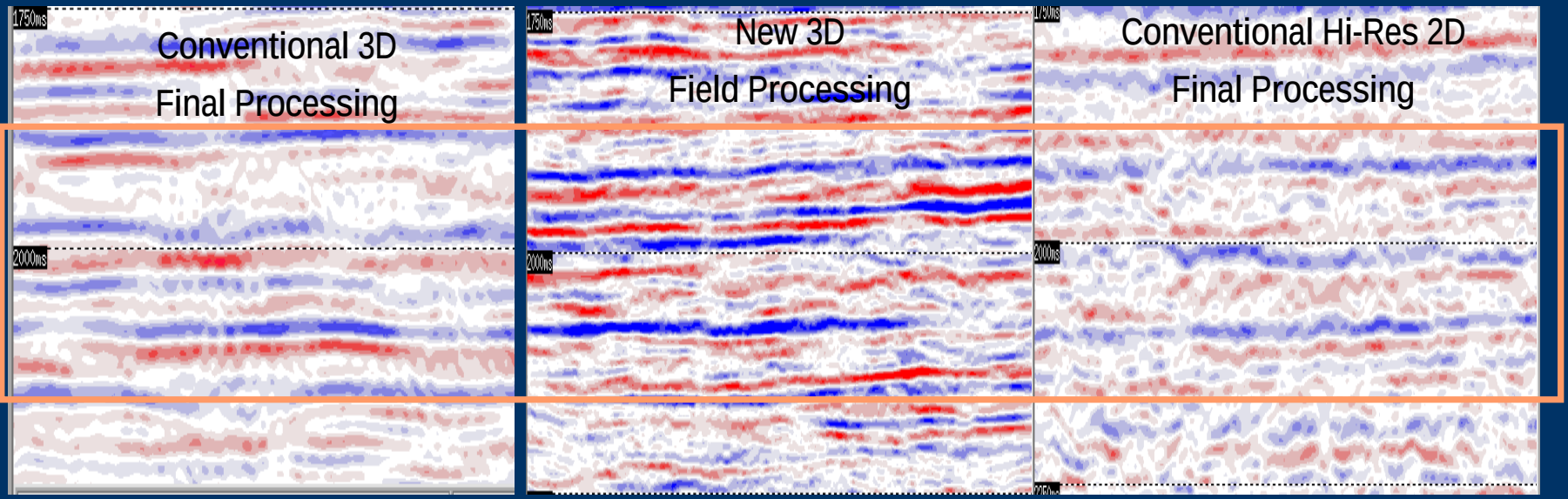
Challenges in CO_2 Sub-Surface Storage

- Technology & Process Gaps
  - Long-Term (100s->1000s of years) Assurance
  - Lack of Standard Industry Processes
  - Sub-surface characterization: a shared model for static and dynamic formation modeling
  - Integrated Teams Workflows
  - Rapid processing of static and dynamic models
  - Cost-effective permanent monitoring
  - Wellbore Integrity (often overlooked)
  - Modeling of Interaction between CO_2 and Formation

Challenges in Monitoring

- Time-Lapse Seismic (Surface, X-wellbore)
  - Resolution
  - Processing time: Need for AI-based inversion tools
- X-wellbore electrical & electro-magnetic tools
- Wellbore measurements (producers, injectors, monitoring wells)
  - Layer measurements (downhole sampling …)
  - Distributed Measurements (fiber optics …)

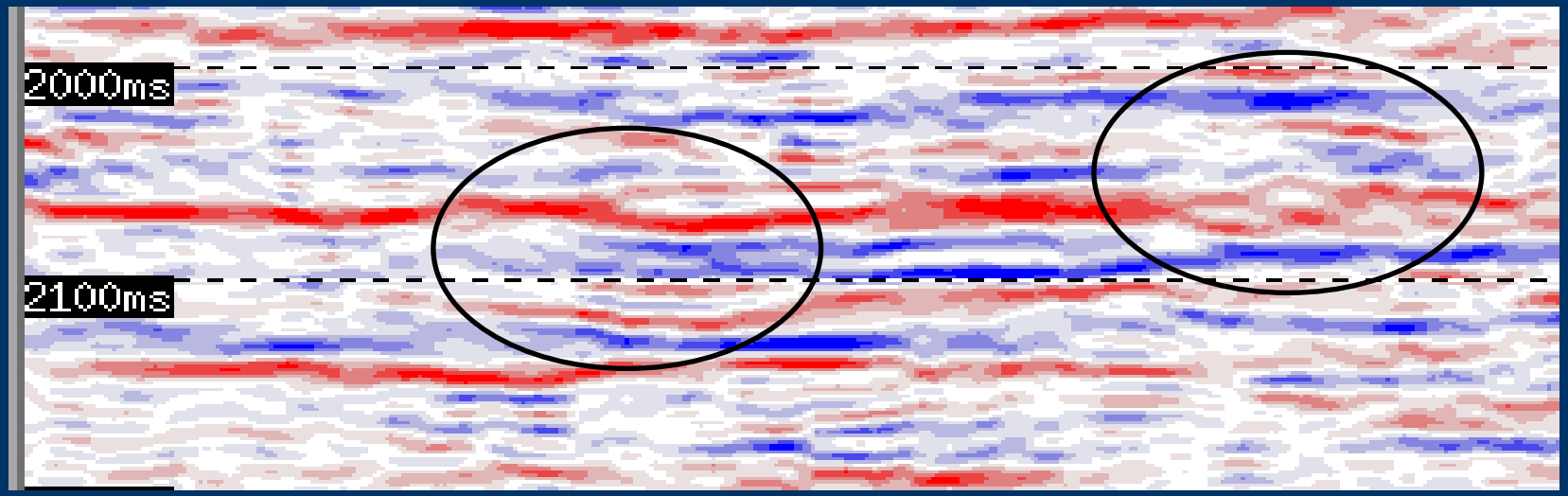
Higher Resolution Seismic for CO_2 Site Selection and Time-Lapse



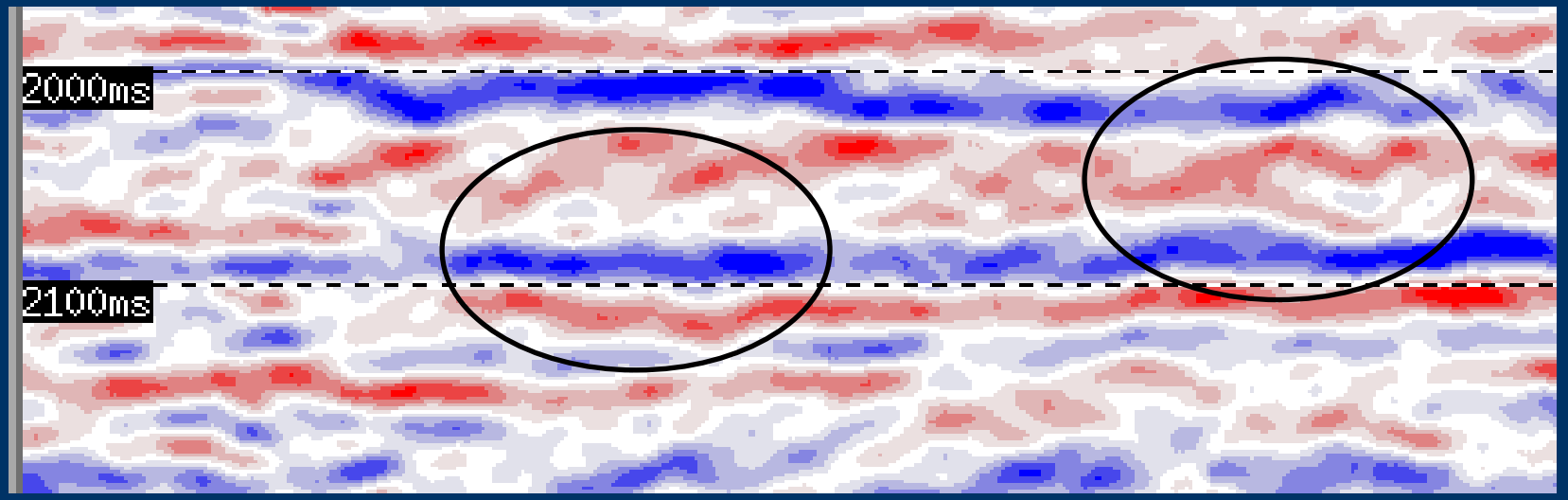
- 5.5 Terra bytes of data
- Proprietary Data format and seamless integration reduced turnaround time

Field Cube available 3 days after acquisition

New vs. Conventional seismic

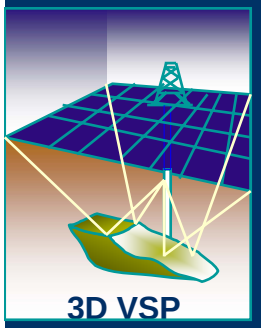


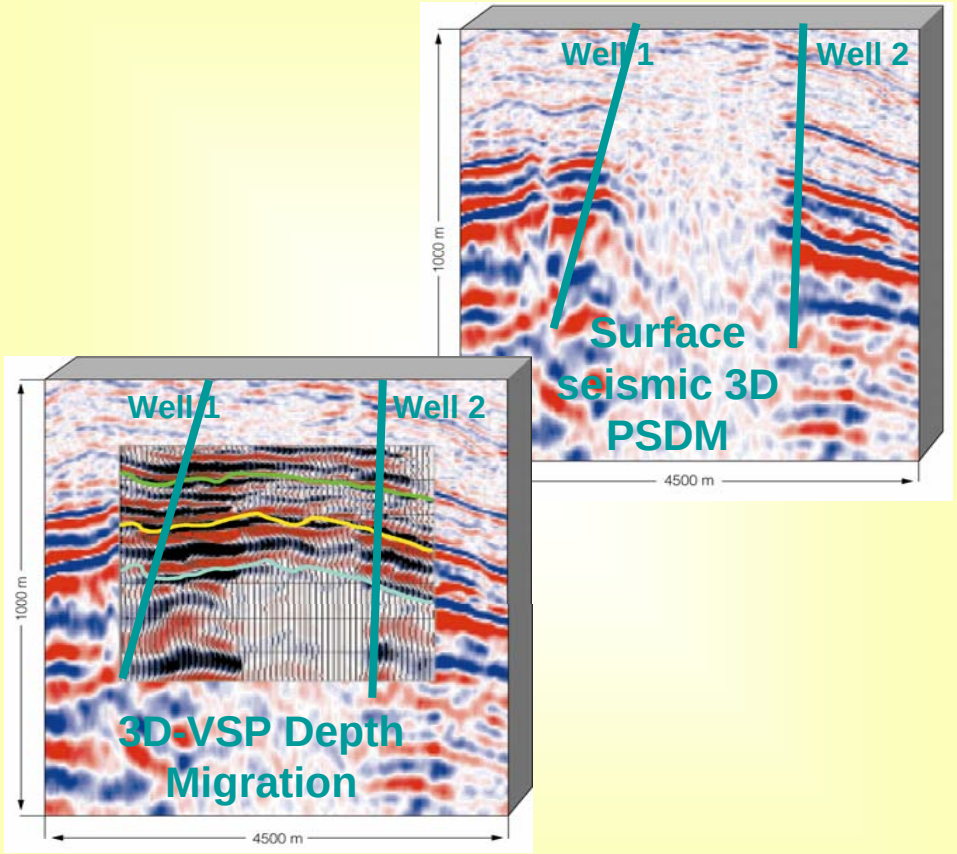
New



Conventional

3D Borehole Seismic vs. Surface Seismic





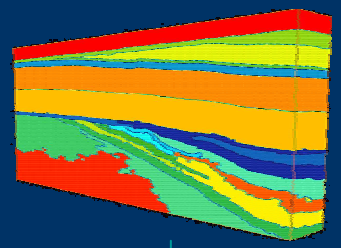
Very High Sub-Surface Imaging Resolution

CO_2 Planning and Monitoring Applications

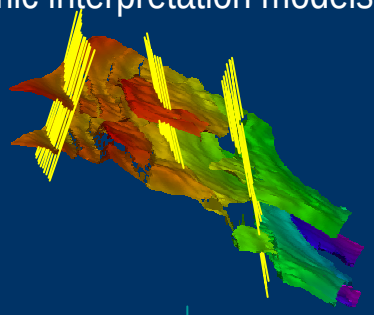
Detailed Preplanning and 3D Modeling Required

Shared Earth Model for CO_2 Management

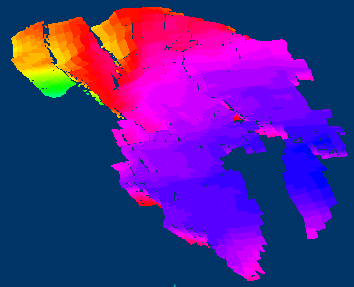
Seismic volume models



Seismic interpretation models



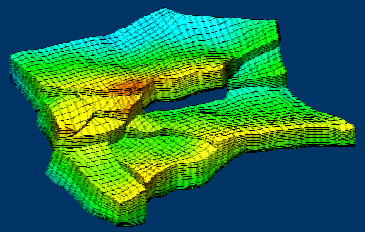
Reservoir simulation models



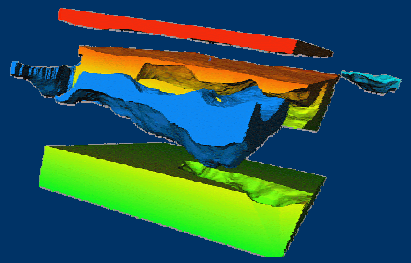
Model adapters
(SEMF interfaces)

Data Flow

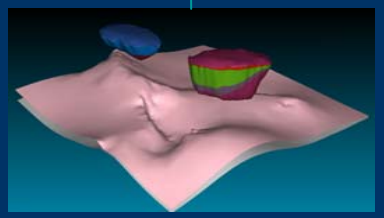
Shared Earth Model 'Bus'



Petrel PillarGrid model

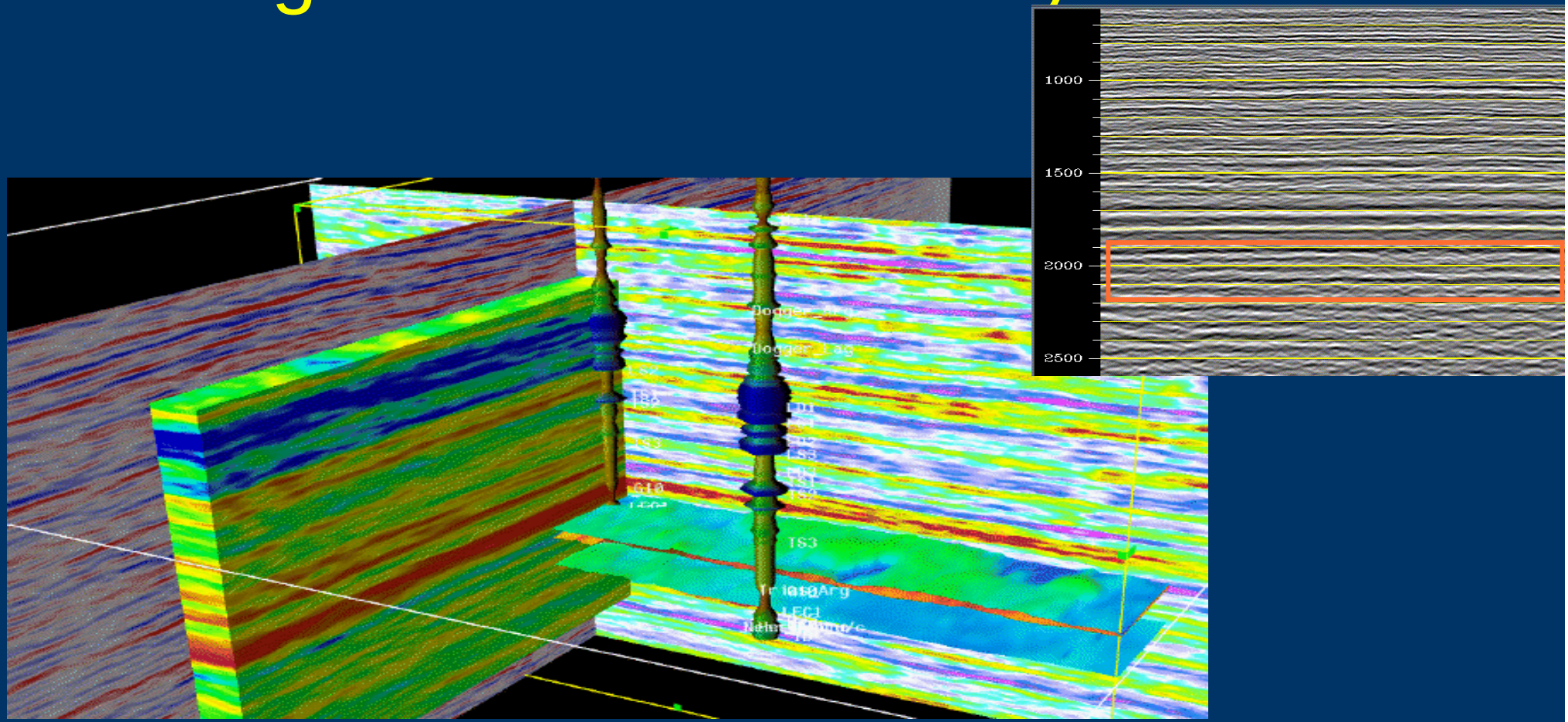


Velocity model



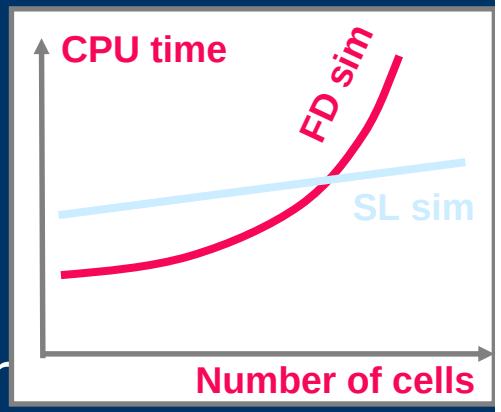
Structural model

Improved Visualization & Team Integration: Virtual Reality Centers



Challenges of CO_2 Simulation
Impact of Uncertainties/Heterogeneities

- Formation vertical and lateral heterogeneities play a significant role in CO2 movement
- Current finite-difference grid-cell models are slow to perform multi-scenarios analysis due to computational requirements
- Streamline methods being developed to facilitate Monte-Carlo simulations of CO2 injection
  - Speed-up factor by orders of magnitude
  - Need to include capillary forces
- Industry/Academia efforts could be combin



Wellbore Integrity & Flow Assurance

- Current cementing practices (API-RP, Class 1 & 2 wells) do not address long-term storage requirements, hence a significant risk of leakage
- Monitoring of cement integrity during the life of the well, and subsequent repairs
- Need to optimize metallurgy composition to minimize subsequent intervention

Largest Risk from Analogues

- W. Heidug (Shell)
  - Biggest risk from CO2 Storage due to:
    - Leakage through poor quality or injection well completions
    - Leakage up abandoned wells
    - Leakage due to inadequate caprock characterization

Wellbore Isolation with Cement

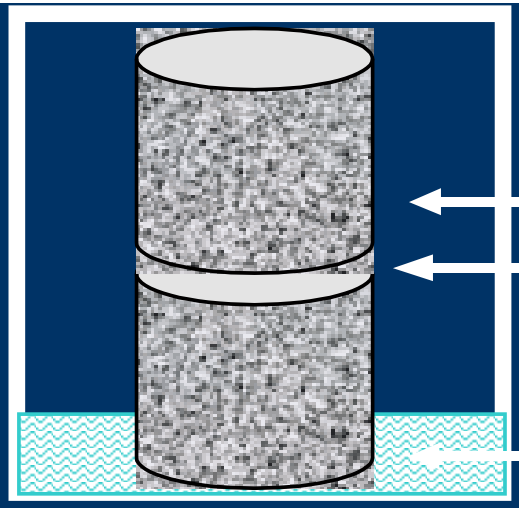
Does Conventional Testing simulate Actual Conditions ?

Neat cement: core after one month at 90deg.C-280 bars in Na_2CO_3 solution (4%): perfectly preserved neat cement procedure not realistic in terms of severity criteria

Neat cement: core with micro cracks and strong carbonation after one month at 90deg.C-280 bars under wet CO2 supercritical environment

Wet supercritical CO2 experimental set up

Experimental design, titanium made vessel, (opened, at left) , disposition of two material cores crown in the vessel, vessel closed in its running configuration (right)



CO2 phase saturated with water
(fluid 1 in supercritical state)

Two Cores crowns isolated by " viton" slices

Water phase saturated with CO2 (fluid 2)

Wellbore Monitoring using Downhole Fluid Analysis

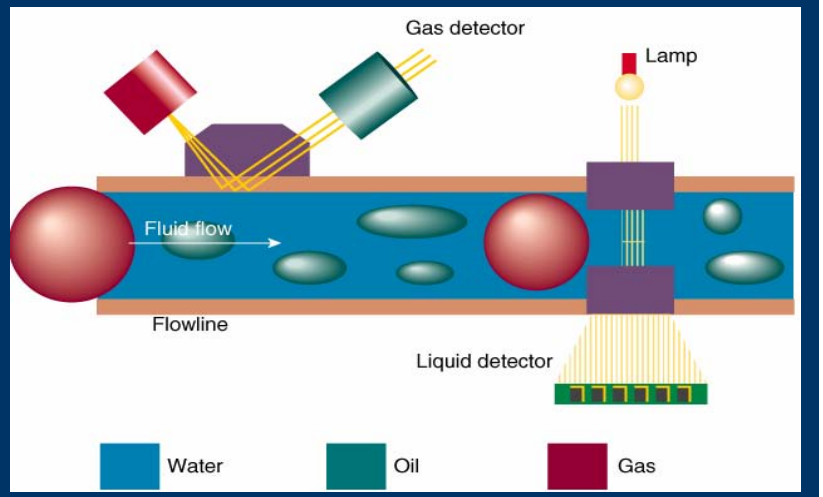
Pumpout module

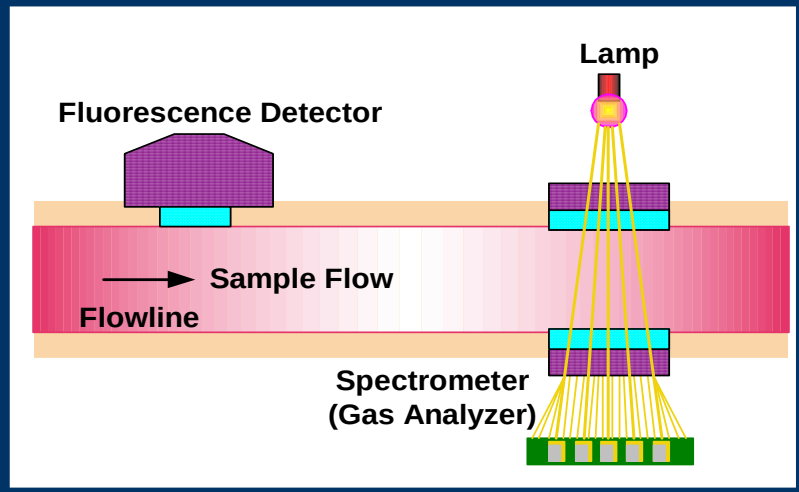
Multisample module(s)
(Six 450cc samples)

LFA / CFA

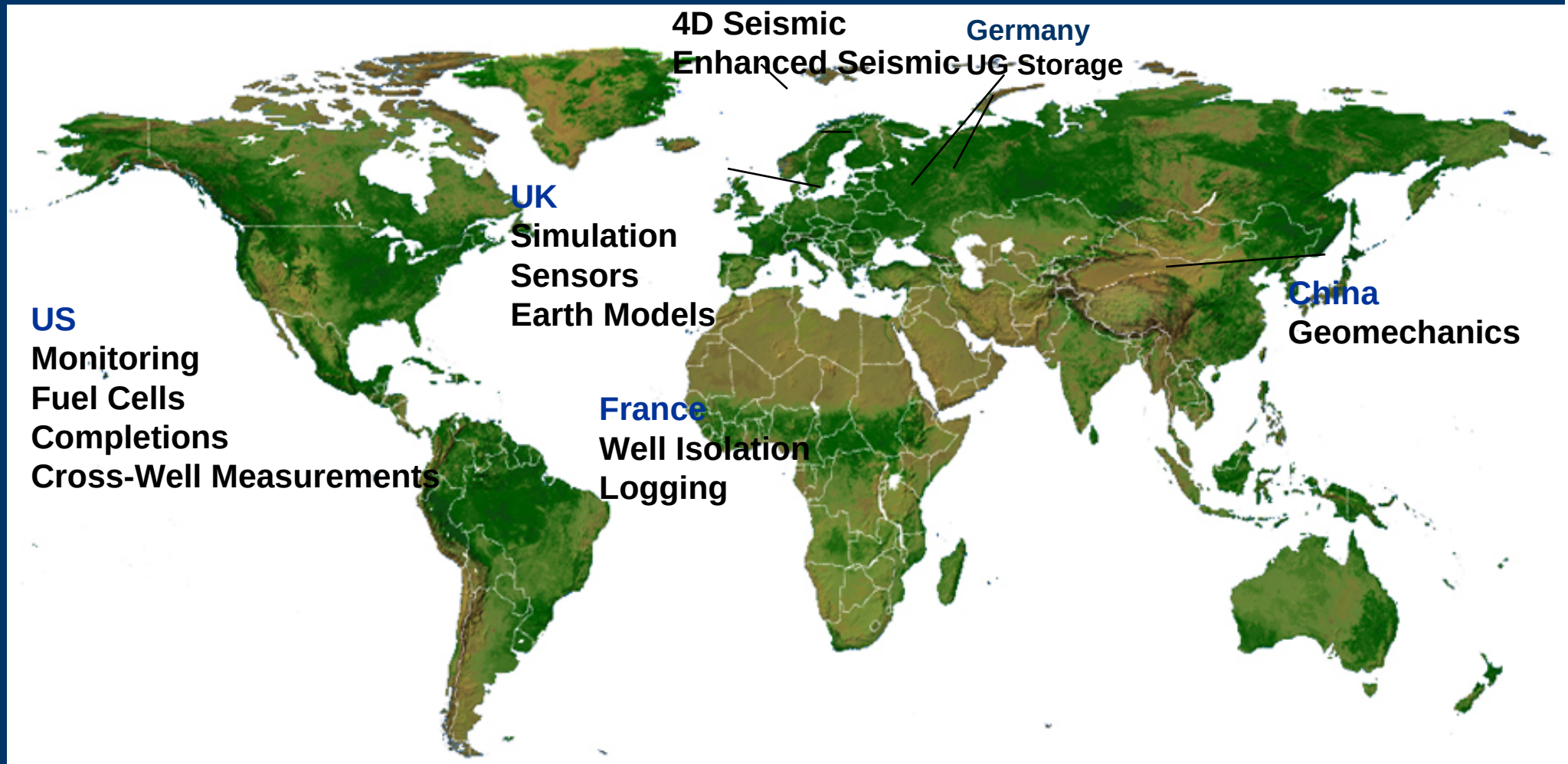
Single probe module

Packer module





CO_2-Related R&D in Schlumberger



Recommendations

- In order to mitigate risks, Industry needs to:
  - Develop comprehensive G&G databases and use common Earth Models
  - Standardize integrated static and dynamic workflows
  - Develop improved understanding of geochemical interactions
  - Incorporate such models in more-efficient reservoir simulation models
  - Use enhanced resolution surface seismic techniques

Continued….

Recommendations

- Expand use of x-wellbore measurements
- Cooperate on development of chemical sensors and other wellbore measurements
- Develop standard testing procedures for injectors and producers
- Develop a standard methodology for wellbore isolation (cementing)
- Share experiences and lessons learned