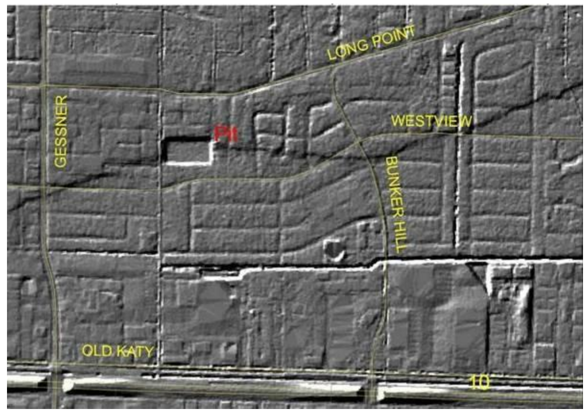
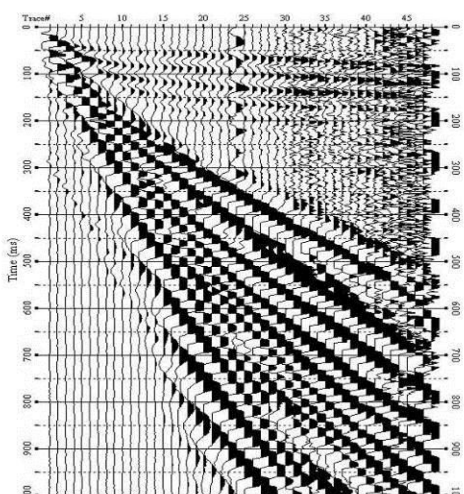
Applied Geophysics: University of Houston

Earth & Atmospheric Sciences



Robert R. Stewart
Director, AGL

Allied Geophysical Laboratories
UNIVERSITY of HOUSTON



Presented to the AGL Update Meeting

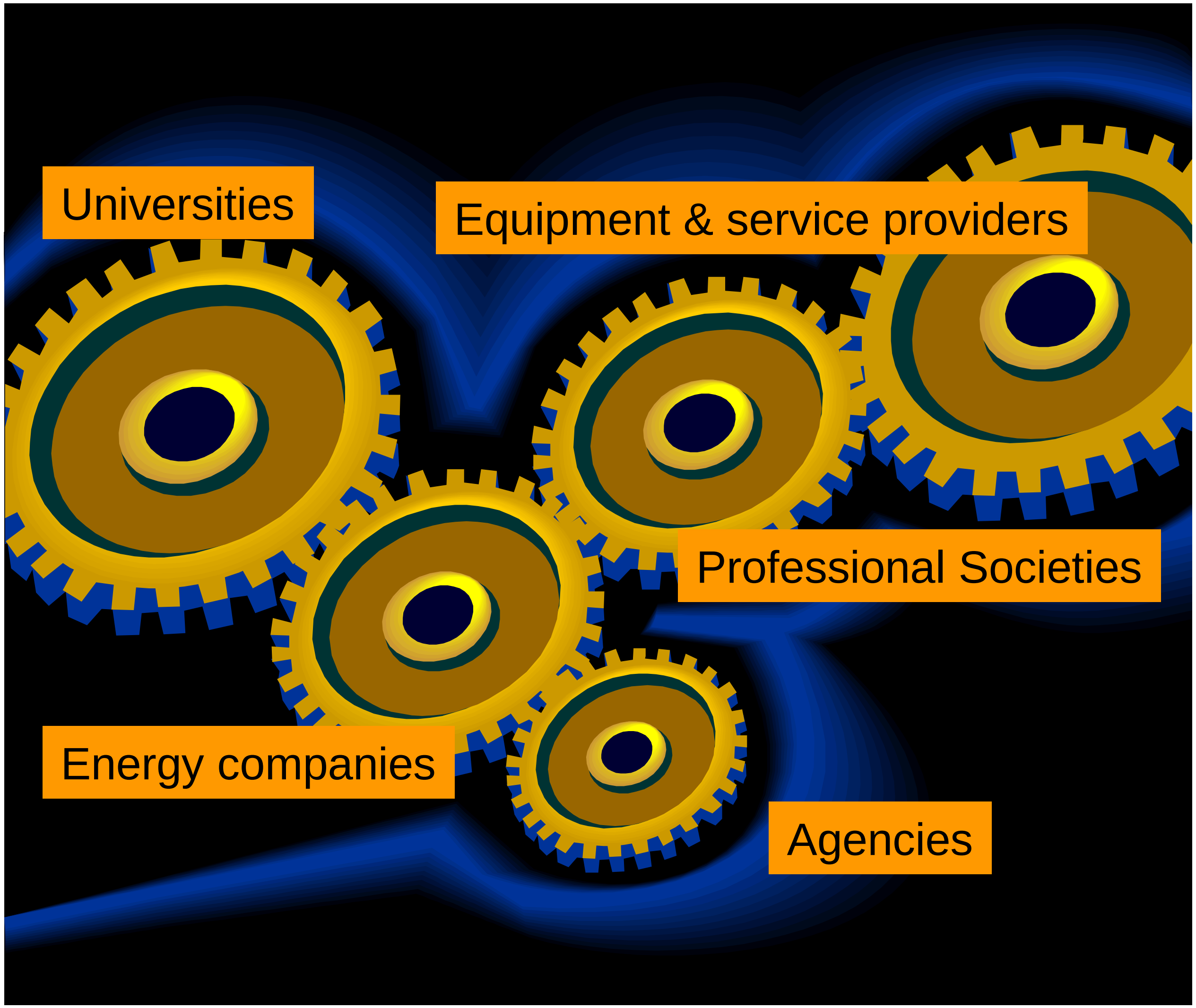
April 29th, 2011

Welcome to UH and AGL!

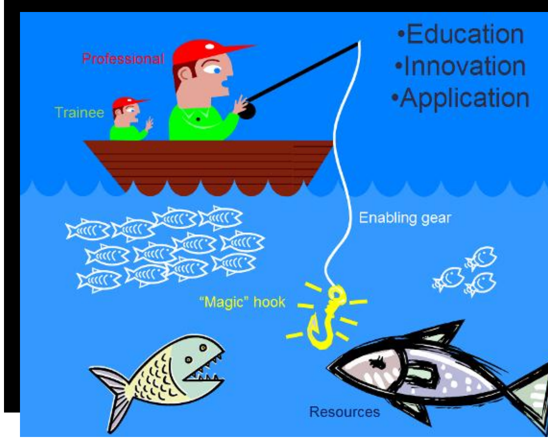
- Overview of the day
  - 9:00am – 10:30am Technical session 1 ***break***
  - 10:45am – noon Session 2 ***lunch (provided)***
  - 12:45pm – 2:15pm Session 3 (AGL students) ***displays, lab, posters***
  - 3:00pm Dobrin lecture (Thomas Bowman – resource plays)
  - 4:00pm Student awards, discussion
  - 5:30pm Mucky Duck Pub reception

Thank you so much to our AGL supporters:

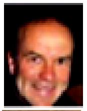
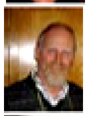
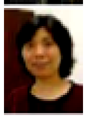
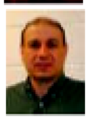
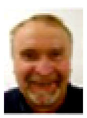
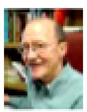
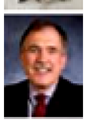
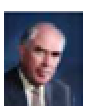
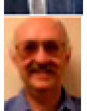
Interlocking geoscience partnerships



University's 4C mandate:
Create
Conserve
Communicate,
Commercialize



UH/AGL geophysics faculty & their expertise

	**Robert Stewart** PhD, Massachusetts Institute of Technology Chevron, ARCO, Veritas, University of Calgary	Borehole geophysics (well logging, VSP, crosswell analysis), multicomponent seismic methods
	**Christopher Liner** PhD, Colorado School of Mines U. Tulsa, Aramco, Conoco, Western Geo	Seismic data processing, seismic interpretation, time series analysis, CO_2 sequestration
	**Aibing Li** PhD, Brown University Woods Hole Institute	Seismic tomography, inversion, crustal structure
	**John Castagna** PhD, University of Texas at Austin ARCO, Fusion Geophysical	Rock properties, seismic attributes, AVO
	**Evgeni Chesnokov** PhD, Moscow State University University College of London, University of Oklahoma	Theoretical seismology, anisotropy, fracture monitor
	**Gennady Goloshubin** PhD, Institute of Solid Earth, Moscow Western Siberian Institute	Seismic exploration, reservoir analysis, permeability prediction
	**De-hua Han** PhD, Stanford University Unocal, HARC	Laboratory rock properties, seismic monitoring
	**Fred Hilterman** PhD, Colorado School of Mines Geophysical Development Corp., Mobil	AVO, seismic processing, petrophysics
	**Leon Thomsen** PhD, Columbia University Amoco, BP, Delta Geophysics	Anisotropy, seismic processing, EM analysis
	**Robert Wiley** PhD, Colorado School of Mines Marathon Oil	Physical modeling, instrumentation, shallow seismic analysis

Further geophysics faculty and their interests

Edip Baysal – seismic imaging

Stuart Hall – potential fields

Bob Sheriff – exploration geophysics

Jolante Van Wijk – tectonics

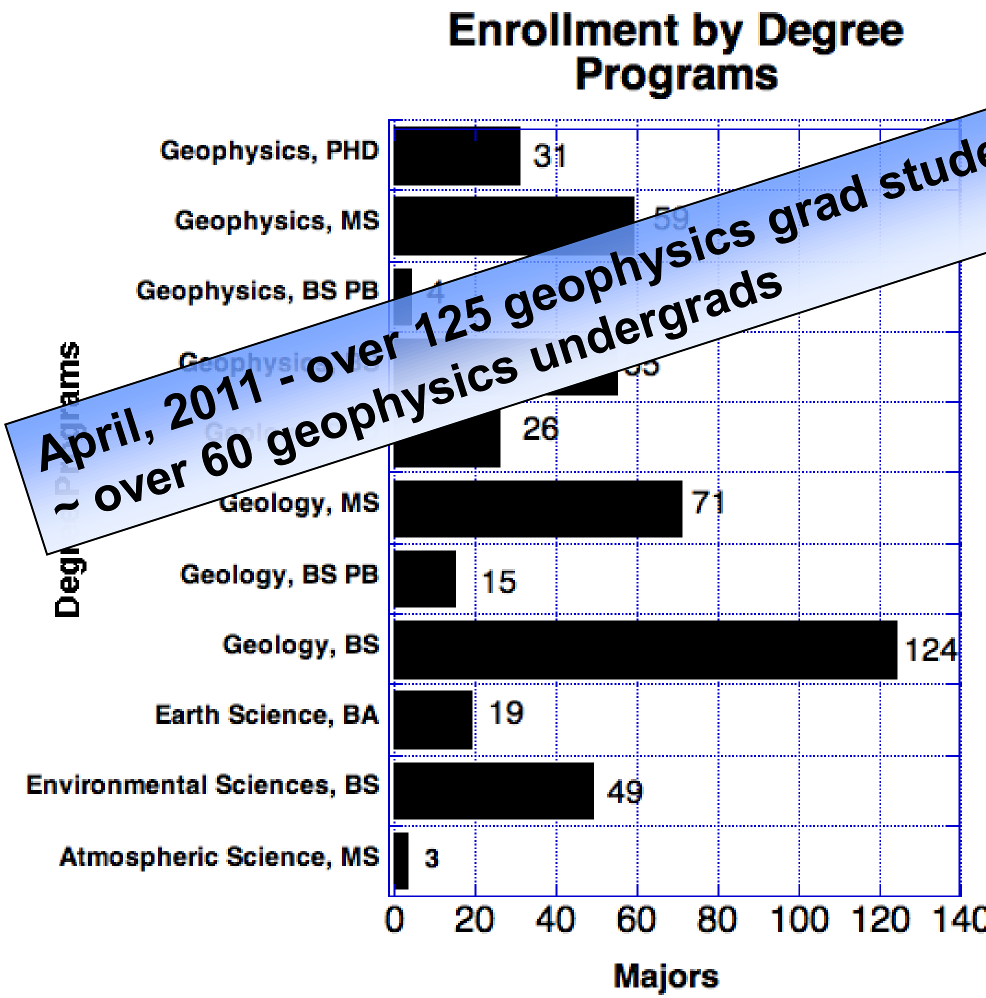
Three more geo-faculty joining us: Rock physics; Tectonics & hydrocarbons; Remote sensing & seismic

UH Graduate Geophysics Courses Fall 2011

3-D Seismic Exploration I	40	Liner
Remote Sensing	80	Khan
3-D Seismic Exploration II	32	Hilterman
Graduate Seminar (Applied Geophysics)	48	Castagna
Graduate Seminar (Solid Earth)	30	Khan
Computational Geophysics	30	Castagna
Multicomponent Seismic Exploration	60	Stewart
Rock Physics	60	Castagna/Chesnokov
Petrophysics & Formation Evaluation	32	Myers
Seismic Wave & Ray Theory	60	Chesnokov
Geophysical Data Processing	60	Liner
Geophysics of Plate Margins	30	Hall

Geoscience at the University of Houston

Earth & Atmospheric sciences



April, 2011 - over 125 geophysics grad students
~ over 60 geophysics undergrads

Allied Geophysical Lab

Allied Geophysical Laboratories
UNIVERSITY of HOUSTON

Applied Geophysics Research, Education, and Application for Hydrocarbon Exploration

Research

- Instrumentation, Robotic acquisition, Field surveys
- Near-Surface Methods
- Signal Processing & Imaging
- Multi-component Seismic Methods
- Well-logging, VSP, and Petrophysics

Education and Training

- Undergraduate (B.S.) and Graduate (M.S., Ph.D.) Programs
- International Training
- Continuous Professional Learning
- Professional Accreditation

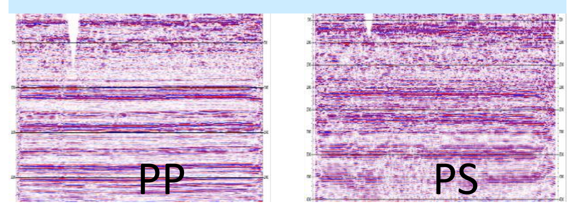
Collaborations & Applications

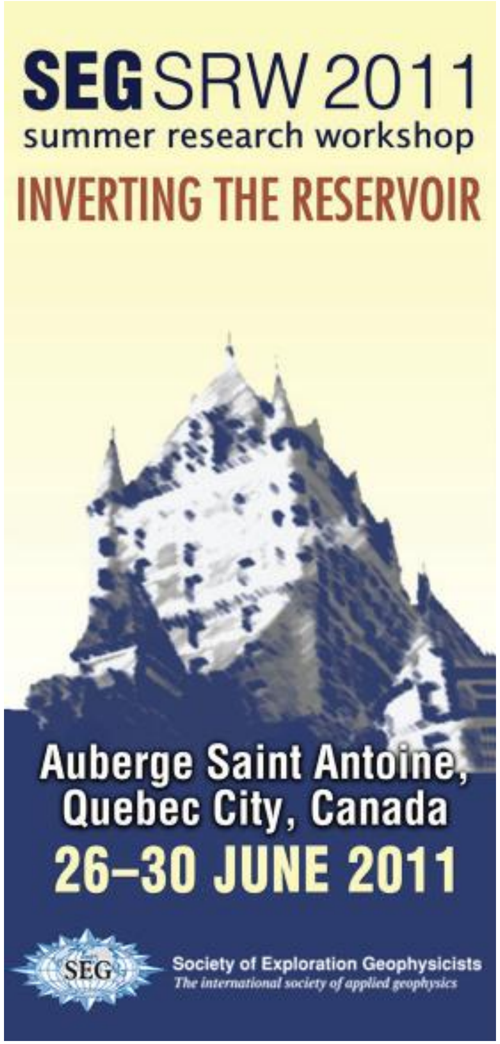
- Joint Projects/ Group Surveys
- Sponsored-research Transfer
- Other Institutions, Agencies, and Companies

Summary

- Pressing needs for better subsurface imaging, assessment, monitoring and personnel development
- Remarkable team of geophysical researchers and students assembled in the Allied Geophysical Lab
- Lots of exciting developments in land & marine acquisition and imaging – research needed
- AGL is looking to create further collaborations and projects with you (y'all)!

Bakken shale (Hess & AGL)





Organizing Committee

P. Williamson (Total), A. C. Ramírez (PGS), A. Cheng (Halliburton), S. Mallick (U. Wyoming), R. Lu (ExxonMobil), C. MacBeth (Heriot-Watt), K. Hokstad (Statoil), R. Stewart (U. Houston)

Time-lapse, 3C-3D imaging of SAGD reservoir changes

A. Kato[1] & R. Stewart[2]

[1]JACOS, Tokyo

[2]University of Houston

Hangingstone heavy oilfield, Alberta

Primer on heavy oil

API gravity

22.3º .... *920 kg/m³*

Heavy Oil

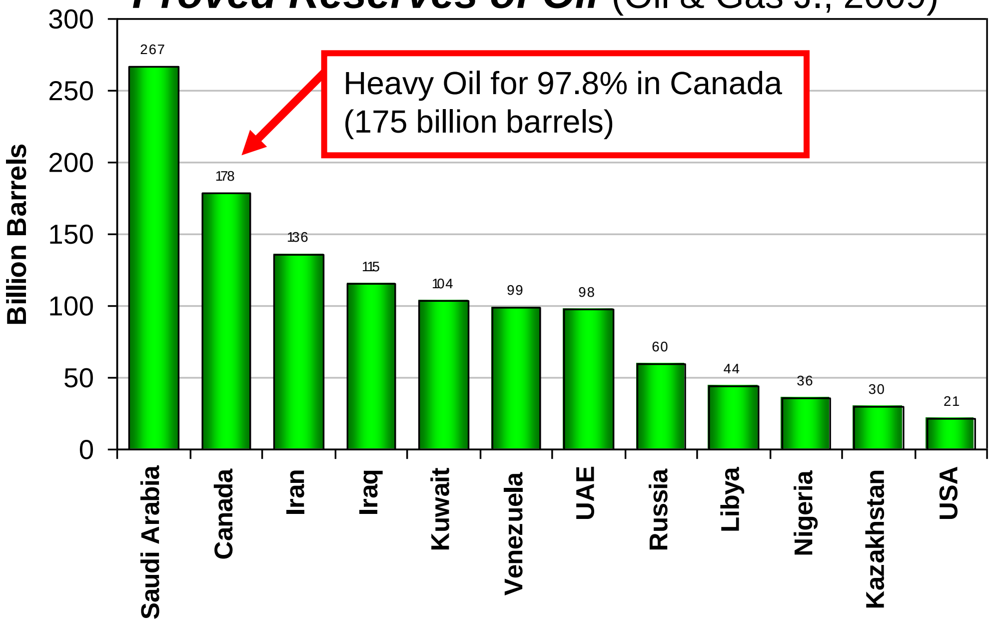
10.0º .... *1000 kg/m³*

Extraheavy Oil

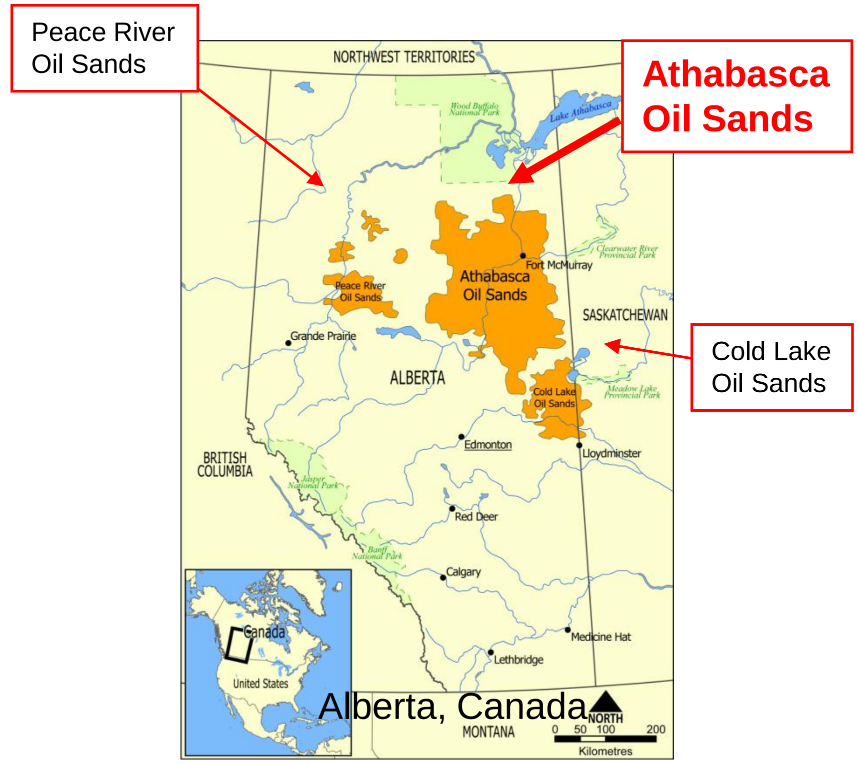
Heavy Oil Reservoirs

- 6 trillion barrels in place worldwide
  (= triple the total conventional oil/gas)
- Canada (1.7 trillion bbl)
- Venezuela (1.2 trillion bbl)

Proved Reserves of Oil (Oil & Gas J., 2009)



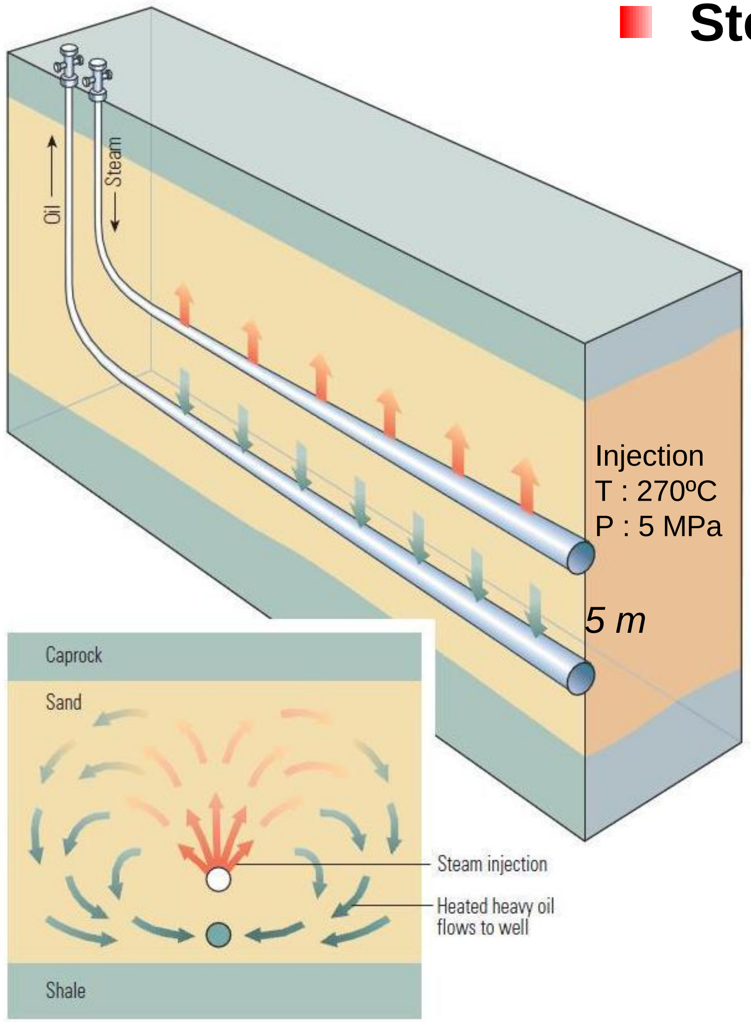
Einstein (2006)



Athabasca Oil Sands

- Large deposit of heavy oil
- McMurray formation
- Estimated reserves : 133 billion bbl

SAGD Method



Curtis et al., (2005)

- **Steam Assisted Gravity Drainage (SAGD)**
  - 2 parallel horizontal wells
  - Inject steam to heat reservoir and improve mobility of heavy oil
  - Heated oil and condensed steam drain by gravity
  - Steam movement is highly affected by geological heterogeneities within reservoirs (impermeable shale)

For reservoir management

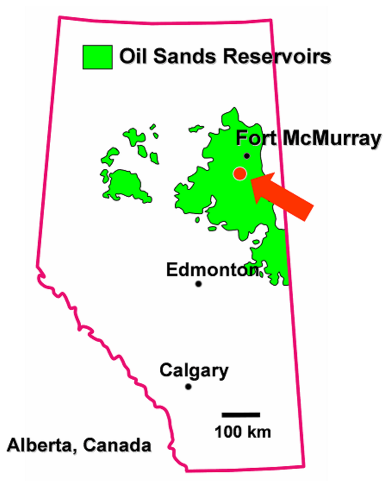
Before Production **Reservoir Delineation**

During Production **Steam Monitoring**

⇧

3D Surface Seismic Data

Study Area (Hangingstone Heavy Oilfield)

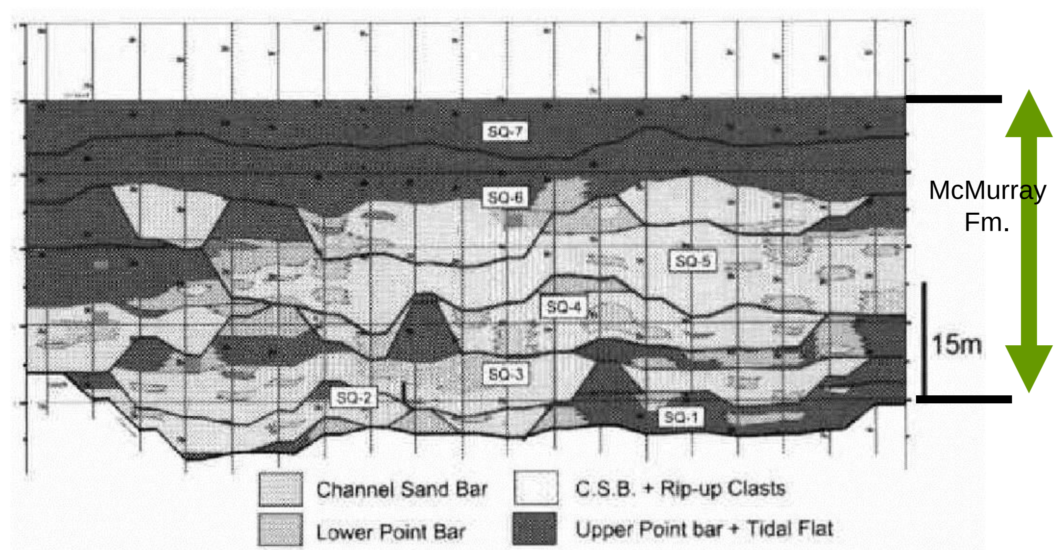


Geology

- Formation :
  - Lower Cretaceous McMurray formation
  - Low-stand, fluvial-estuarine incised valleys
- Heavy Oil Reservoirs :
  - Vertically stacked channel sands
  - Horizontally and vertically very complex distribution
  - About 300 m deep

Hangingstone Oilfield

- JACOS has operated
- (Extra) heavy oil of 8.5º API gravity
- SAGD Production
- 10,000 barrels/day



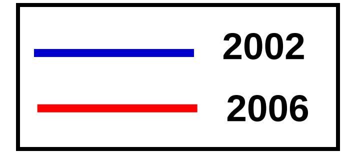
Takahashi et al., (2006)

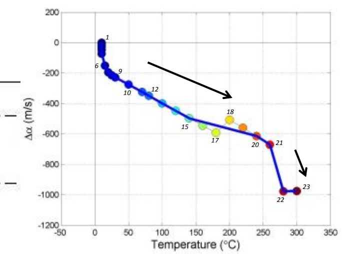
* JACOS (Japan Canada Oil Sands Limited)

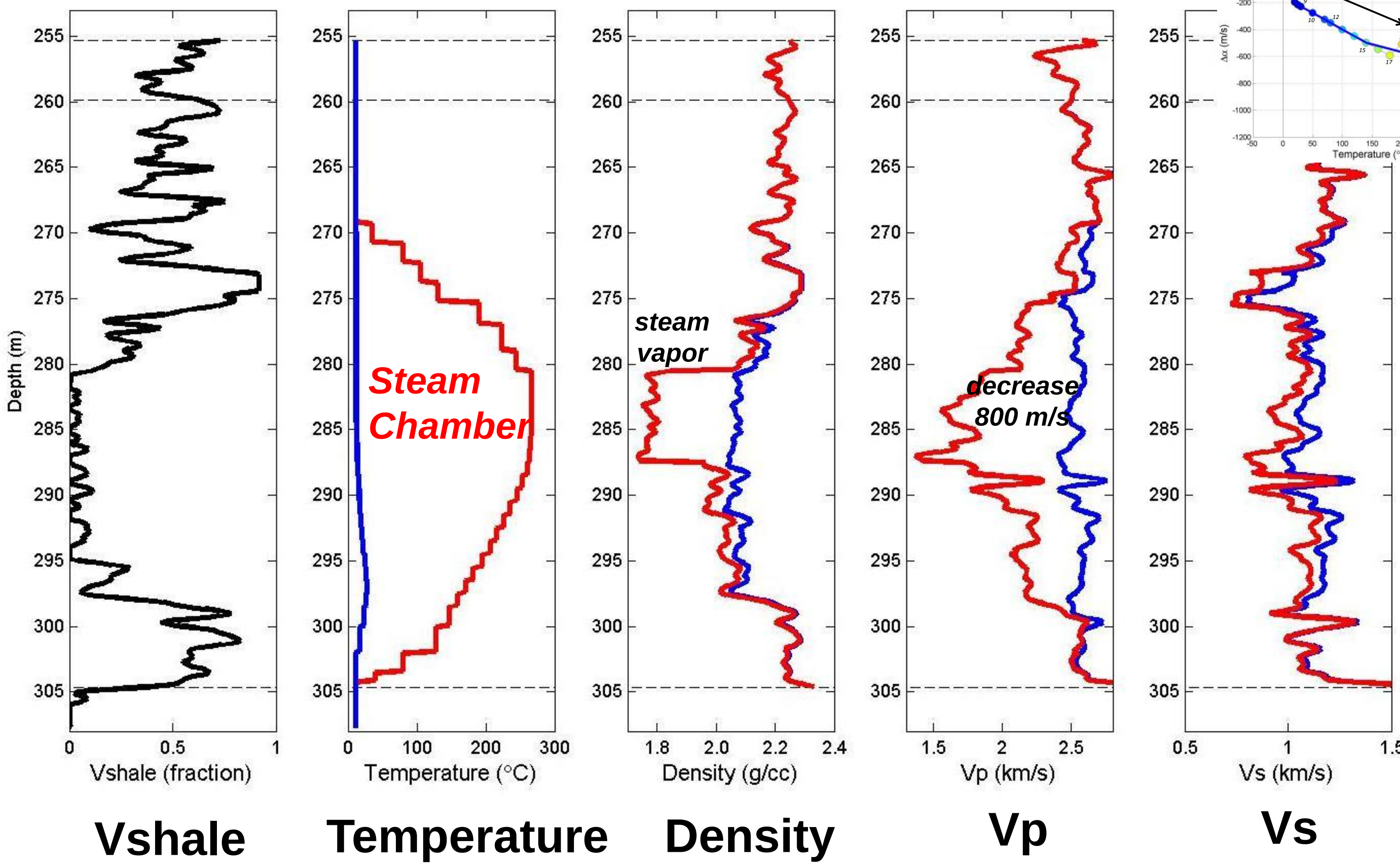
Elastic Property Changes

- **Well B (10 kHz)**

Heavy oil is assumed to be replaced by injected steam at higher temperatures than 200C.

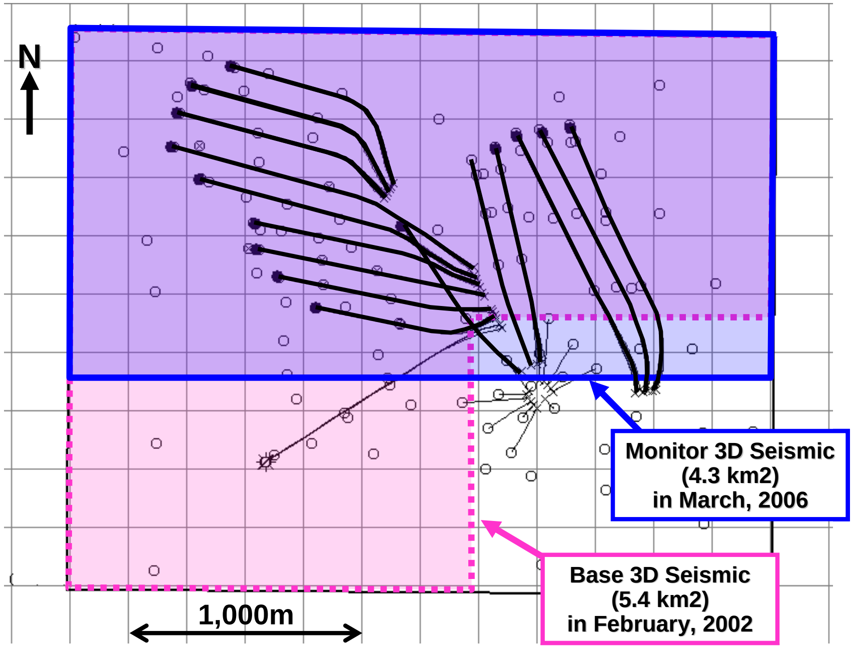


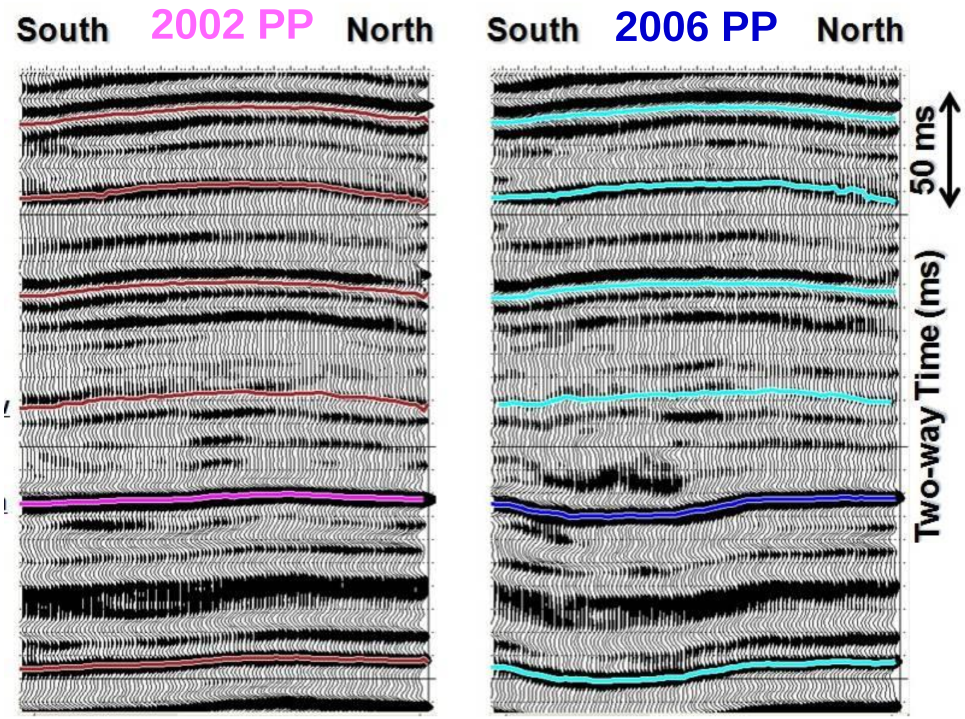




Study Area (Hangingstone Heavy Oilfield)

Field Map





Nakayama et al. (2008)

Time-lapse seismic data

- Base Survey (2002) : PP
  - Analog geophone array
- Repeat Survey (2006) : PP + PS
  - 3 C digital sensors

Three-term AVO Inversion

- Perform P-P and P-S joint three-term AVO inversion
- Use Bayesian theorem for constraints

Linear system

$$\mathbf{d} = \mathbf{G}\mathbf{m}$$

$$\mathbf{G} = \mathbf{WAD}$$

G : Forward modeling operator
m : model parameter
d : Observation data
W : wavelet matrix
D : derivative operator

AVO coefficients based on AR's approximation

$$\mathbf{A} = \begin{bmatrix} \mathbf{a}_\alpha(\theta_1) & \mathbf{a}_\beta(\theta_1) & \mathbf{a}_\rho(\theta_1) \\ \vdots & \vdots & \vdots \\ \mathbf{a}_\alpha(\theta_m) & \mathbf{a}_\beta(\theta_m) & \mathbf{a}_\rho(\theta_m) \\ \mathbf{0} & \mathbf{b}_\beta(\theta_1) & \mathbf{b}_\rho(\theta_1) \\ \vdots & \vdots & \vdots \\ \mathbf{0} & \mathbf{b}_\beta(\theta_m) & \mathbf{b}_\rho(\theta_m) \end{bmatrix}$$

P-P wave

P-S wave

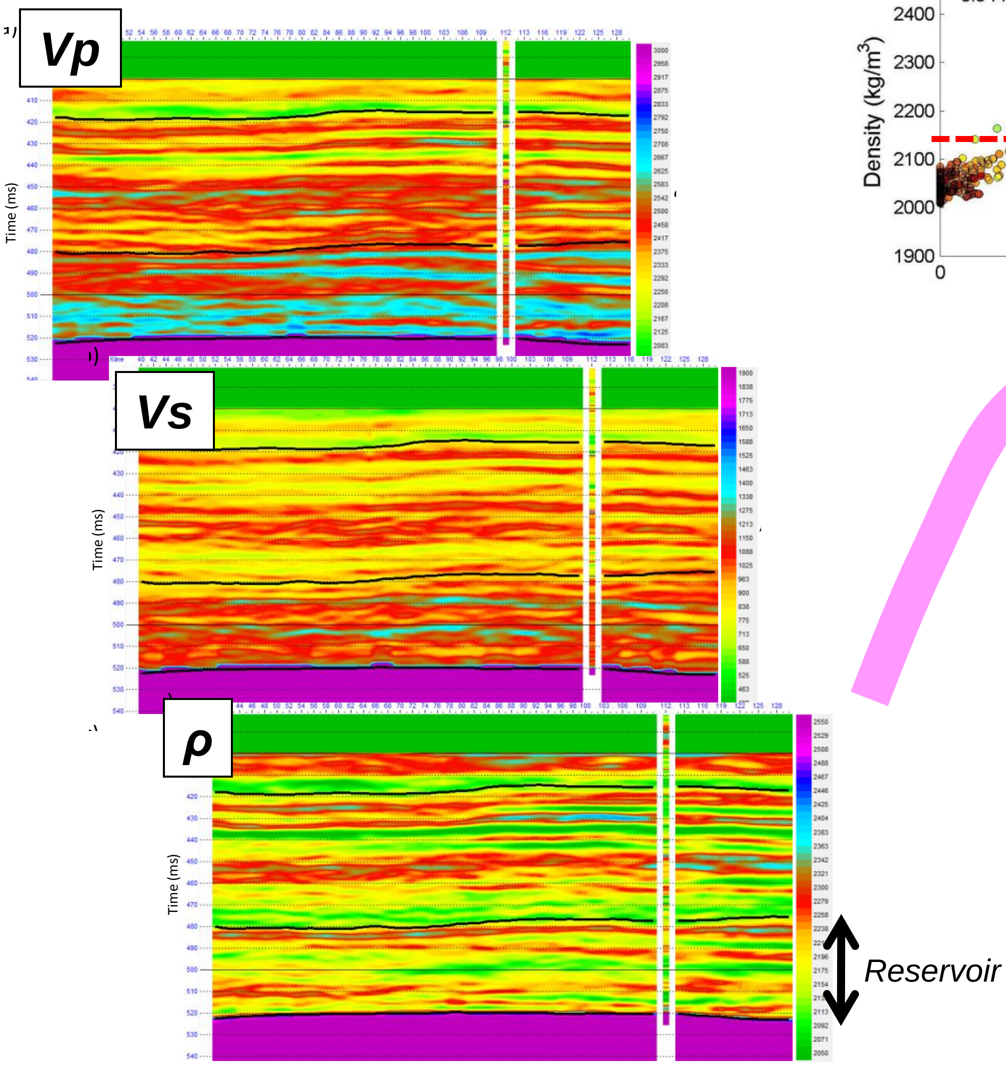
Bayesian inversion

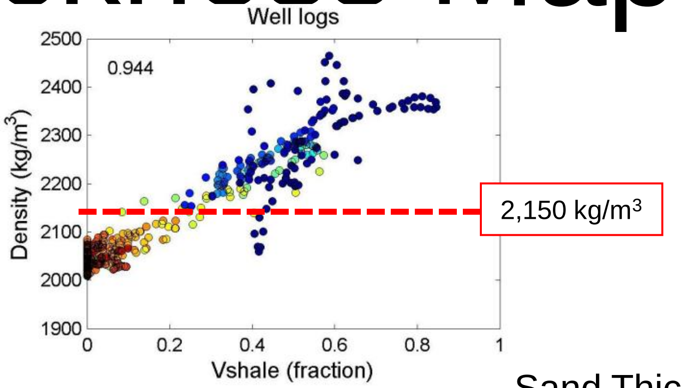
$$\hat{\mathbf{m}} = \left(\mathbf{G}^{\mathrm{T}}\mathbf{C}_{\mathbf{n}}^{-1}\mathbf{G} + \mathbf{C}_{\mathbf{m}}^{-1}\right)^{-1}\left(\mathbf{G}^{\mathrm{T}}\mathbf{C}_{\mathbf{n}}^{-1}\mathbf{d} + \mathbf{C}_{\mathbf{m}}^{-1}\mathbf{m}_{\mathbf{0}}\right)$$

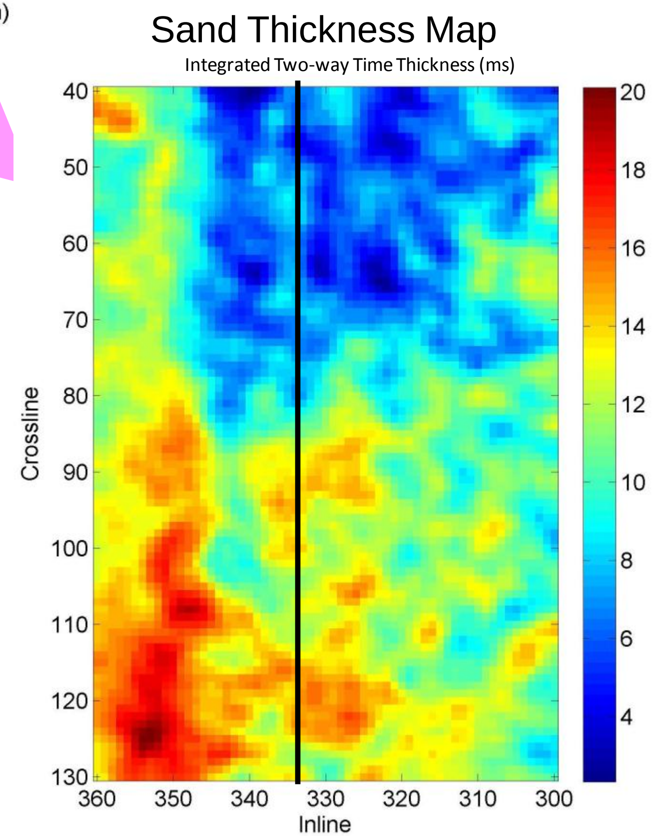
C_n : Data covariance matrix (Data Uncertainties)
C_m : Model covariance matrix (Prior information)
m_0 : A prior mean values (Background model)

Sand Thickness Map

Joint Inversion Result







Basic concept of the method

- **P-P time lapse data**

$$R_{PP} = A_\alpha(\theta)L_\alpha + A_\beta(\theta)L_\beta + A_\rho(\theta)L_\rho$$
$$R_{PS} = B_\beta(\theta)L_\beta + B_\rho(\theta)L_\rho$$

$$\begin{bmatrix} d_{PP02} \\ d_{PP06} \end{bmatrix} = \begin{bmatrix} A_{\alpha 1} & A_{\beta 1} & A_{\rho 1} & 0 & 0 & 0 \\ A_{\alpha 2} & A_{\beta 2} & A_{\rho 2} & A_{\alpha 2} & A_{\beta 2} & A_{\rho 2} \end{bmatrix} \begin{bmatrix} L_\alpha \\ L_\beta \\ L_\rho \\ \Delta L_\alpha \\ \Delta L_\beta \\ \Delta L_\rho \end{bmatrix}$$

- **If P-S data is available in the repeat survey,**

$$\begin{bmatrix} d_{PP02} \\ d_{PP06} \\ d_{PS06} \end{bmatrix} = \begin{bmatrix} A_{\alpha 1} & A_{\beta 1} & A_{\rho 1} & 0 & 0 & 0 \\ A_{\alpha 2} & A_{\beta 2} & A_{\rho 2} & A_{\alpha 2} & A_{\beta 2} & A_{\rho 2} \\ 0 & B_{\beta 2} & B_{\rho 2} & 0 & B_{\beta 2} & B_{\rho 2} \end{bmatrix} \begin{bmatrix} L_\alpha \\ L_\beta \\ L_\rho \\ \Delta L_\alpha \\ \Delta L_\beta \\ \Delta L_\rho \end{bmatrix}$$

Observation Data

Forward Modeling Operator

Model Parameters

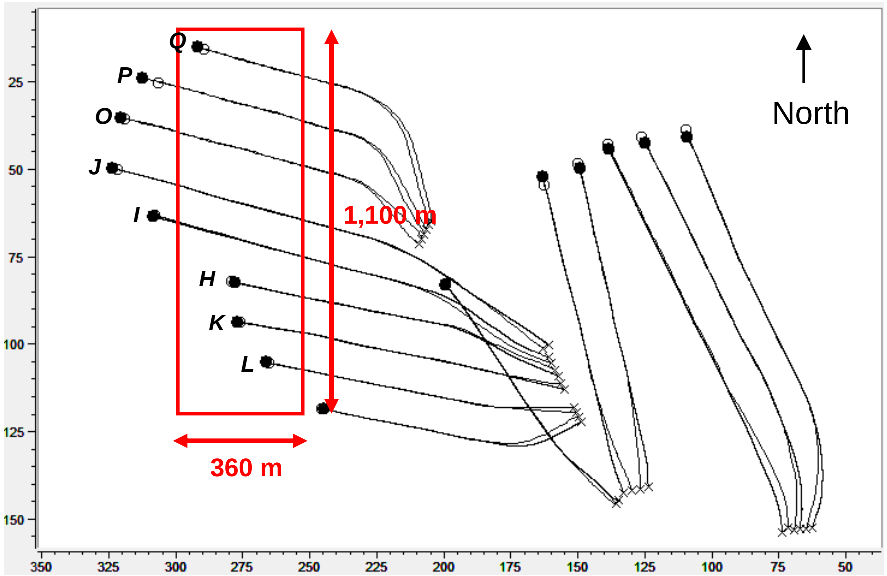
Linear system

d=Gm

This process is repeated at each time step for angle-dependent amplitude data

Implementation with Field Data

- **Study Area** : (1,100 m x 360 m)



8 SAGD well pairs penetrate the study area

Well	Steam injection start
H, I	***Feb. 2002***
J, K	***Aug. 2003***
L	***Jun. 2004***
O, P, Q	***Aug. 2005***

- **Combination of PP and PS waves used in the inversion**

1) 02PP → (α, β, ρ)

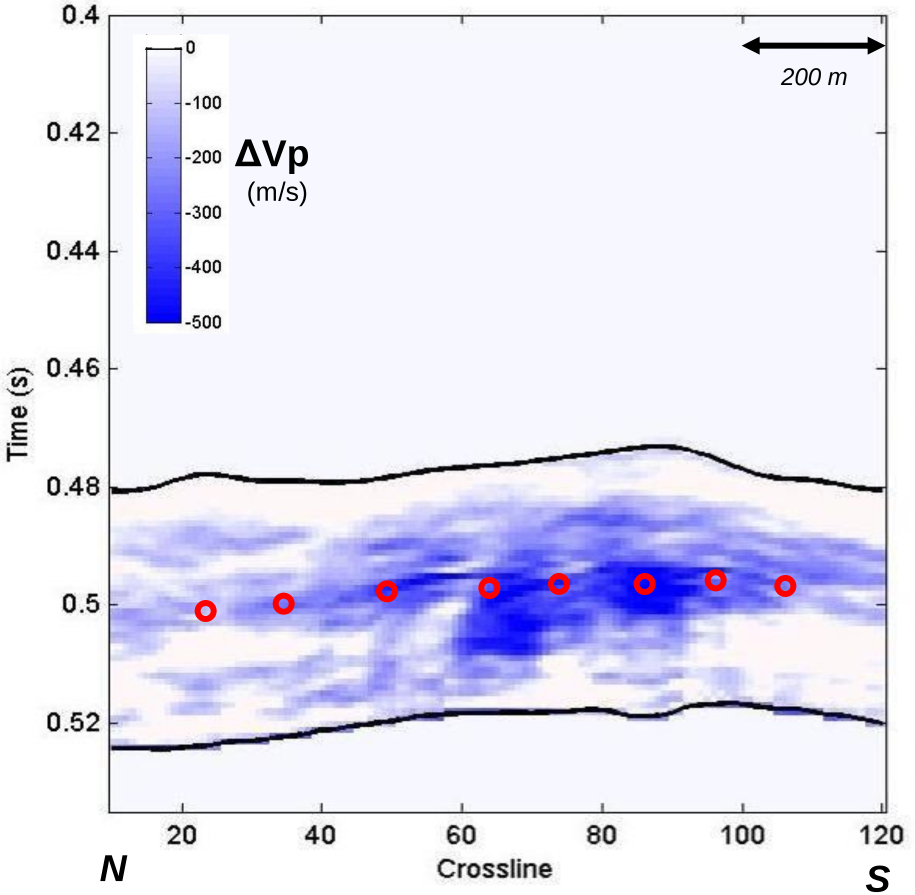
2) 02PP + 06PP → $(\alpha, \beta, \rho) + (\Delta\alpha, \Delta\beta, \Delta\rho)$

3) 02PP + 06PP + 06PS → $(\alpha, \beta, \rho) + (\Delta\alpha, \Delta\beta, \Delta\rho)$

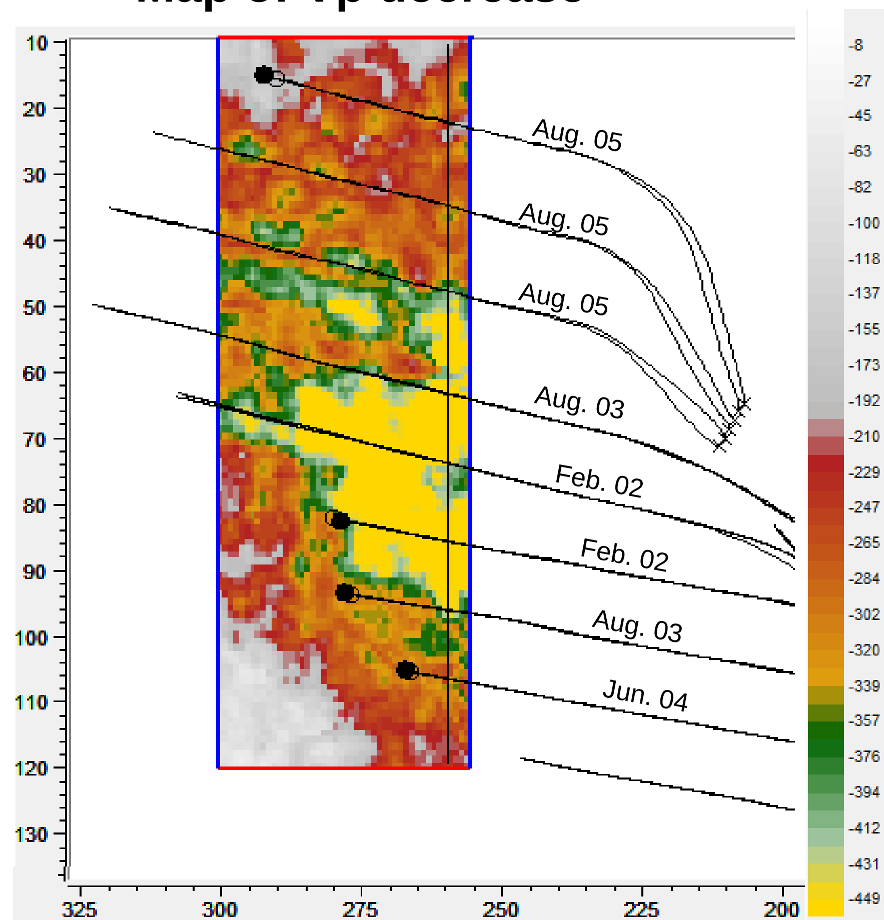
Initial elastic properties — Elastic property changes

Time-lapse inversion result

- **Vertical Section of Vp Change**



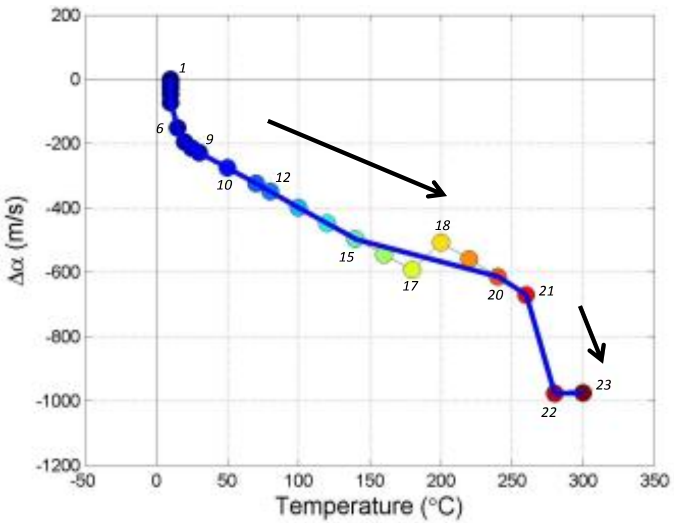
- **Map of Vp decrease**



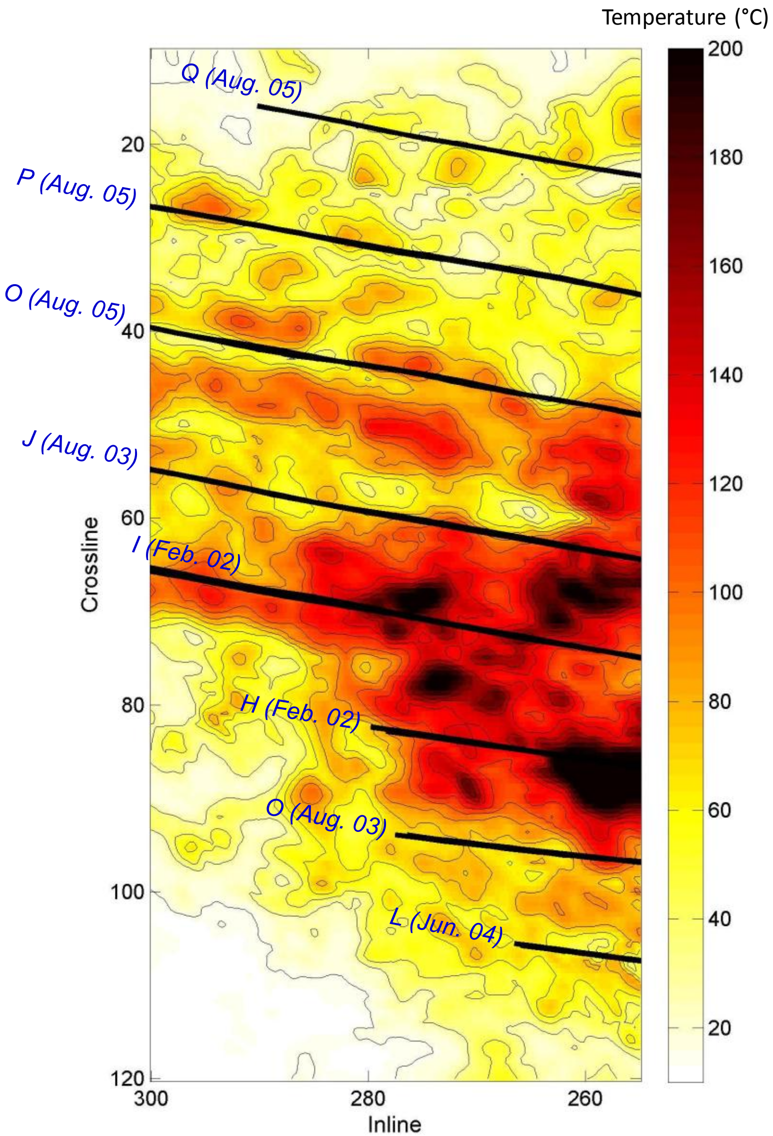
Vp change is consistent with interpretation based on start time of steam injection

Temperature Map

Based on Rock Physics Model



Using ΔVp – temperature,
Convert ΔVp to temperature maps



Initial reservoir temperature : 11C

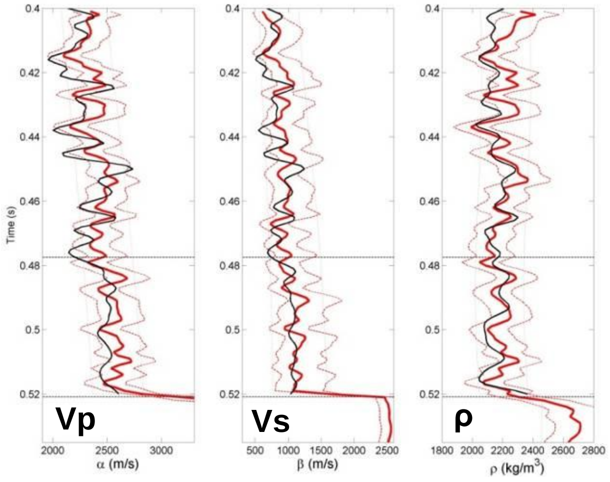
Summary: 4D-3C thermal mapping

❑ Reservoir Delineation

- Developed P-P and P-S joint AVO inversion
  Bayesian inversion method
- Implementation with field data

⇨ ***Reservoir distribution map***

Joint inversion result



❑ Steam Monitoring

- Develop time-lapse AVO inversion
  Bayesian inversion method
- Implementation with field data

⇨ ***Temperature map***

Temperature at 2006