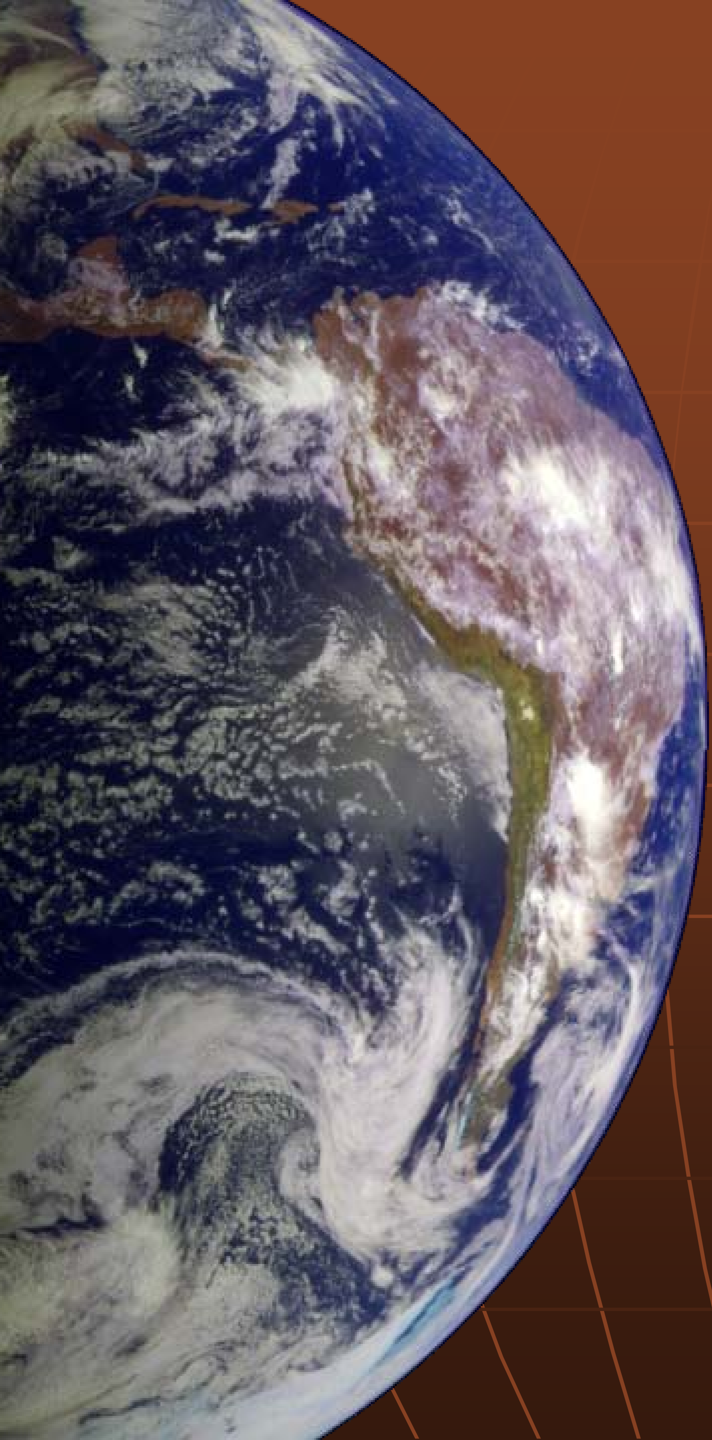


UT-AUSTIN EDGER FORUM

# Time Lapse Seismic for Monitoring in-situ Combustion in a Heavy Oil Field

**Mrinal K. Sen**

**and**

**Nimisha Vedanti**

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

# Objective

- Tracking fluid movement using time lapse seismic data during in situ combustion
- A Heavy oil field in India

# Challenges

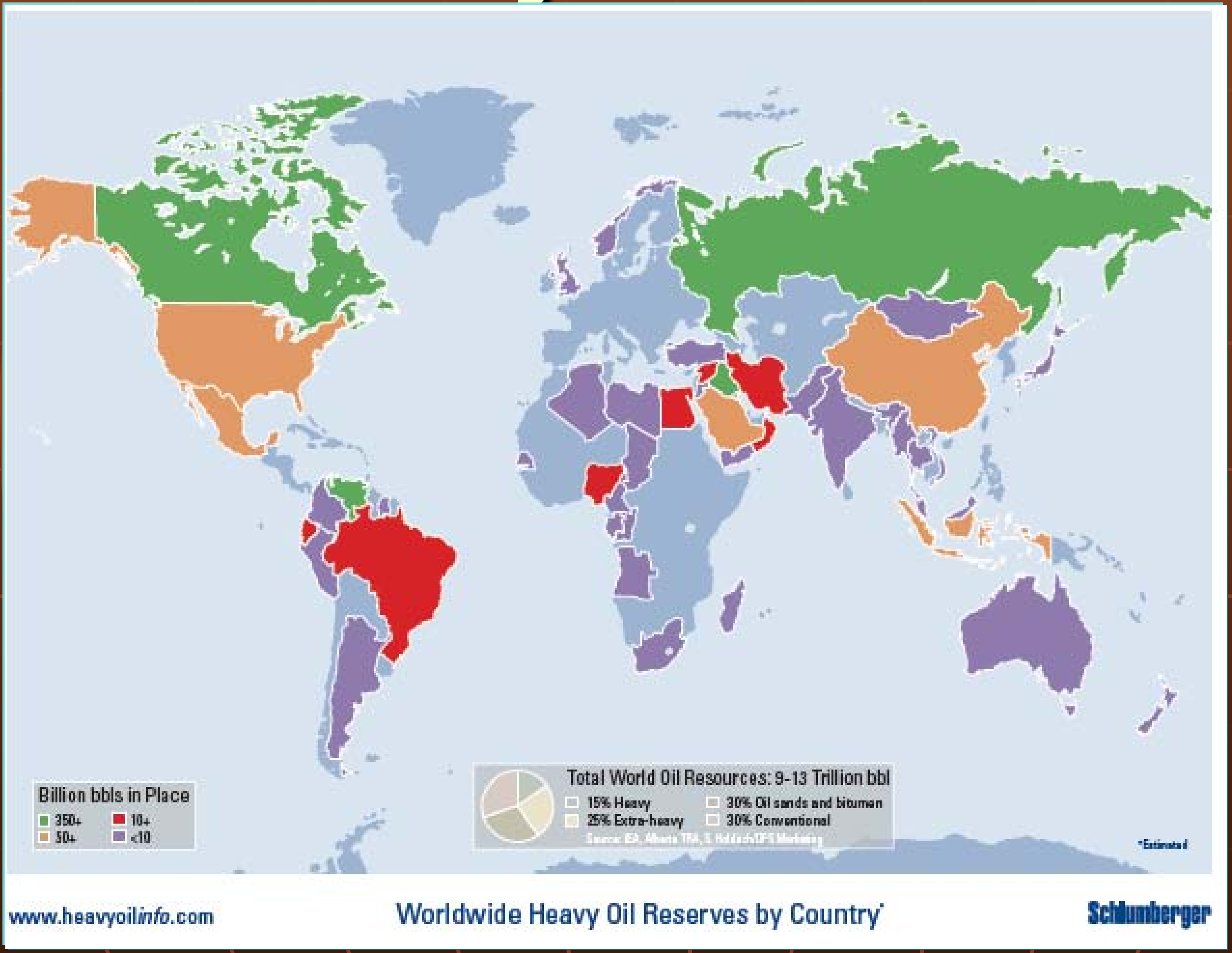
- Enhanced Oil Recovery (EOR) Monitoring
- Land 4D seismic data
- 4D data lack calibration
- Poor repeatability
- Heavy oil

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

# Background

- Heavy oil has recently become an important resource as conventional oil reservoirs are in decline.
- More than 6 trillion barrels of oil in place have been attributed to the heaviest hydrocarbons

# World Map of Heavy Oil




UT-AUSTIN EDGER FORUM

JACKSON SCHOOL OF GEOSCIENCES

# Heavy Oil

- Heavy crude oil or Extra Heavy oil is any type of crude oil which does not flow easily.
- It is referred to as "heavy" because its density or specific gravity is higher than of light crude oil.
- Heavy crude oil has been defined as any liquid petroleum with an API gravity less than 20°, meaning that its specific gravity is greater than 0.933.

# Heavy Oil

- Production, transportation, and refining of heavy crude oil present special challenges compared to light crude oil.
- The largest reserves of heavy oil in the world are located north of the Orinoco river in Venezuela, the same amount as the conventional oil reserves of Saudi Arabia, but 30 or more countries are known to have reserves.

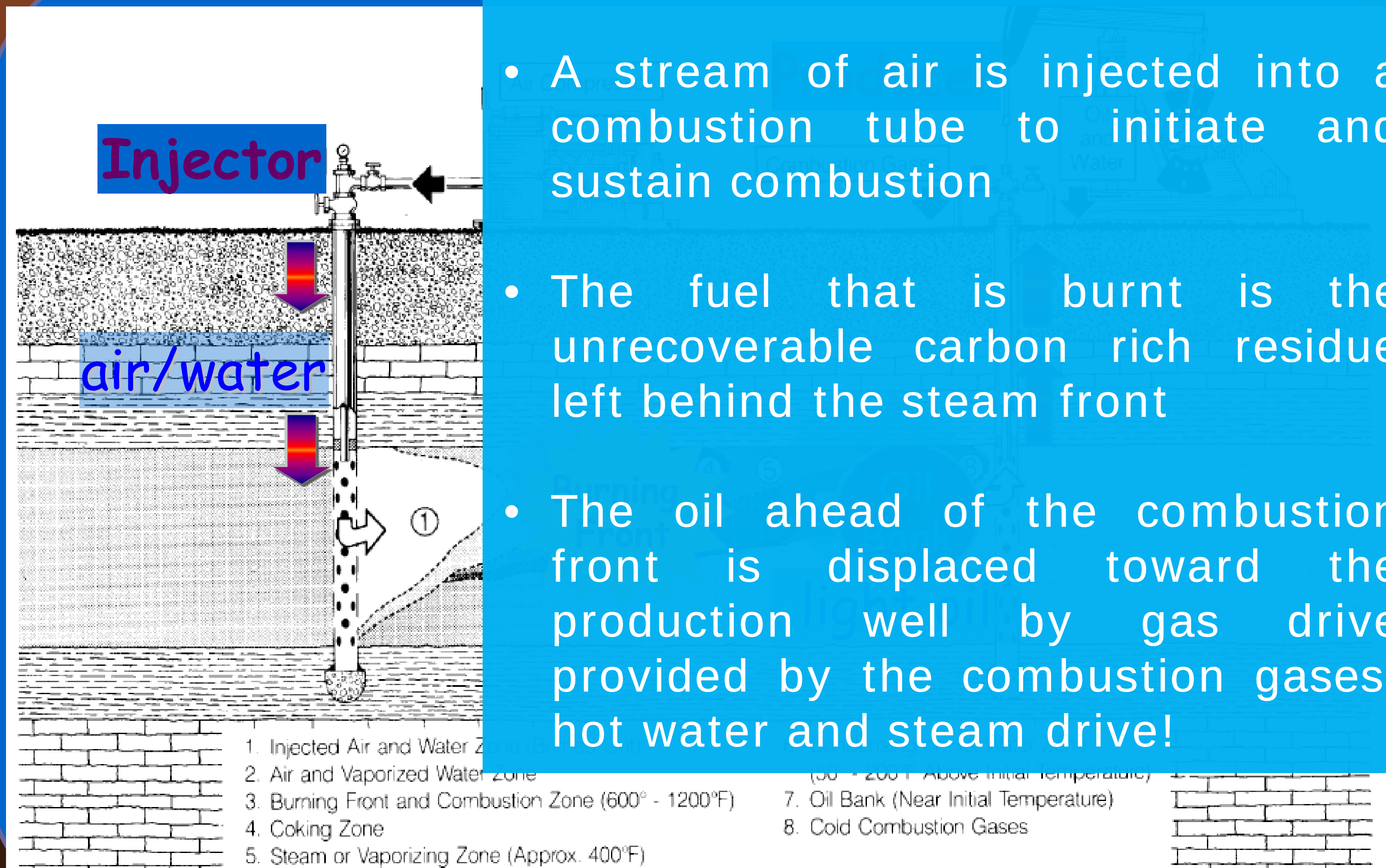
# Heavy Oil

- Heavy crude oil is closely related to tar sands, the main difference being that tar sands generally do not flow at all. Canada has large reserves of tar sands, located north and northeast of Edmonton, Alberta.

- Physical properties that distinguish heavy crudes from lighter ones include higher viscosity and specific gravity, as well as heavier molecular composition. Extra heavy oil from the Orinoco region has a viscosity of over 10,000 centipoise [citation needed] and 10° API gravity. Generally a diluent is added at regular distances in a pipeline carrying heavy crude to facilitate its flow.

# Insitu Combustion

- Recovery of heavy oil crude with low API and high viscosity needs successful implementation and monitoring of enhanced oil recovery (EOR) process.
- To enhance the recovery of heavy oil, one of the most common methods is to employ in-situ combustion process in which a part of heavy oil-in-place is burnt to generate heat.
- This heat brings reduction in viscosity of the crude oil attaining improved mobility and hence increased oil production rate.




- Process of ignition is initiated by using electric heater
- A stream of air is injected into a combustion tube to initiate and sustain combustion
- The fuel that is burnt is the unrecoverable carbon rich residue left behind the steam front
- The oil ahead of the combustion front is displaced toward the production well by gas drive provided by the combustion gases, hot water and steam drive!

# Can we monitor combustion process?

- Monitoring of fluid movement during pre-burn, mid-burn and post-burn phases is essential to well placement and reservoir management.
- 4D seismic (Greaves and Fulp 1987) - post stack amplitude analysis after cross-equalization

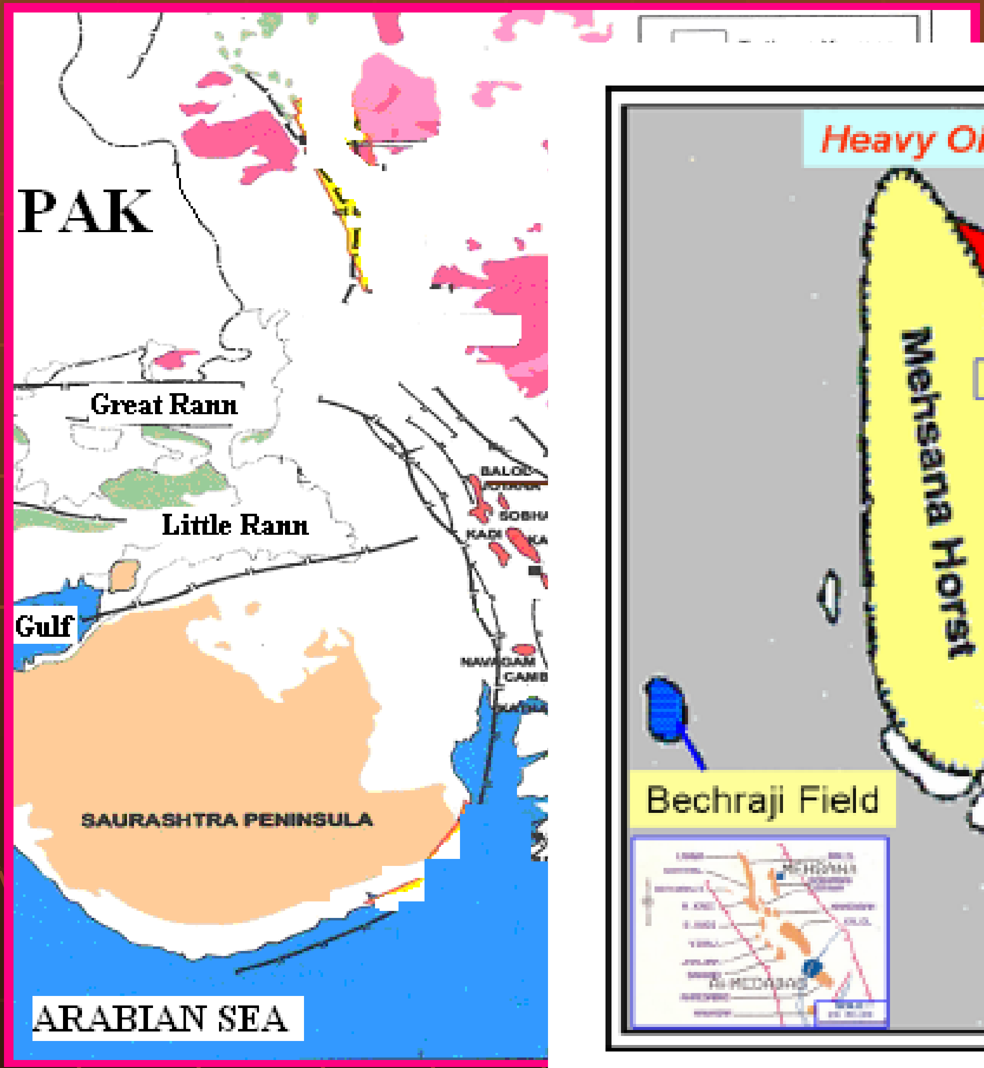
Cross-equalization (Rickett and Lumley 1988)

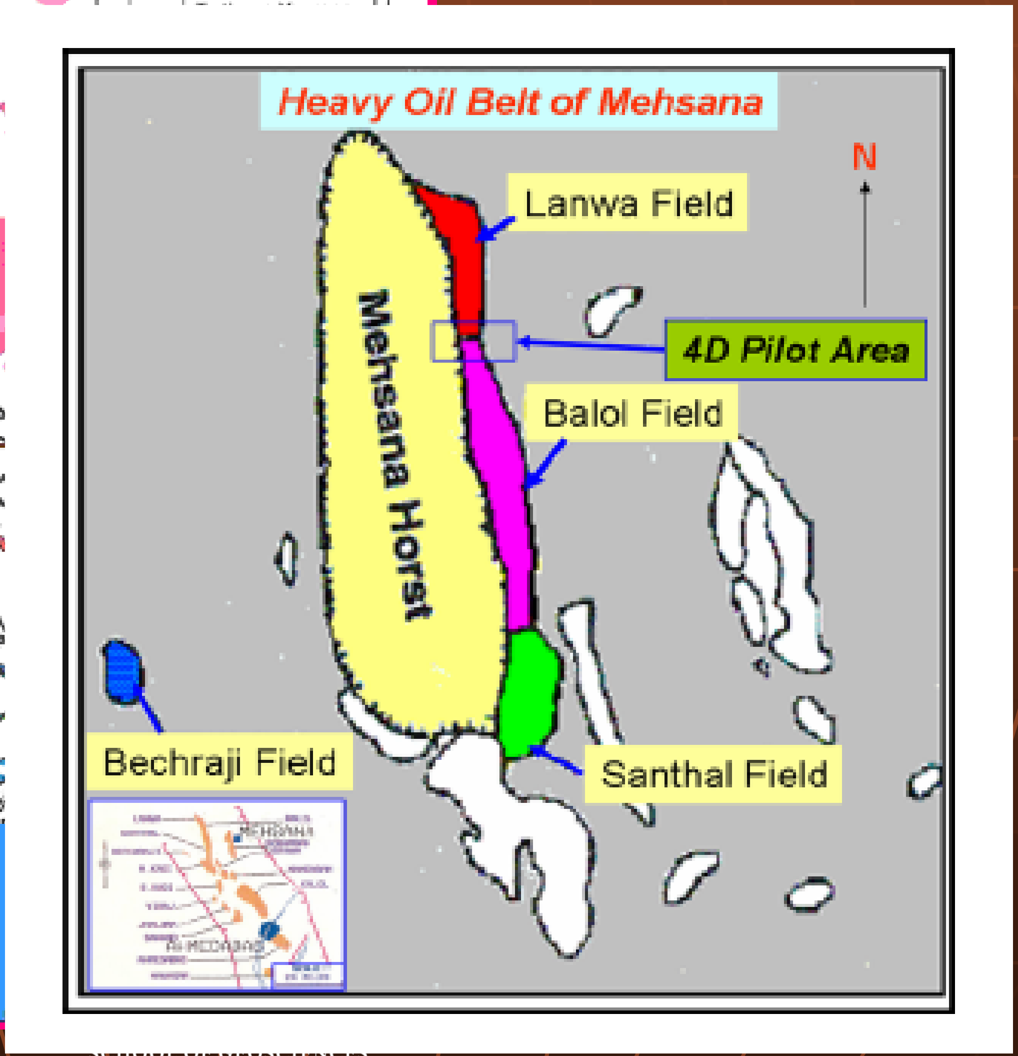
1. Spatial alignment to a common grid
2. Bandwidth and phase equalization to compensate for different source wavelets
3. Amplitude balancing

# Cross Equalization

4D cross equalization removes processing and acquisition differences between the surveys and makes the post-stack data repeatable so that the comparison between the time lapse surveys can be interpreted in terms of genuine fluid related changes!

# Location Map of Balol Field



# Geology

- The field being studied is located in heavy oil belt of Mehsana, which is a part of Cambay basin, India.
- The pay sands, underlain by Cambay shale and overlain by Tarapur Shale are deposited during the early and mid Eocene and represent the characteristic regressive cycle intervening between major transgressive shale deposits.
- In addition, the Cambay Tertiary basin was also influenced by set of fault lineaments aligned NE-SW, which are more pronounced in the northern part of the Cambay basin. These faults extend well into the overlying sedimentary cover.

# Geology

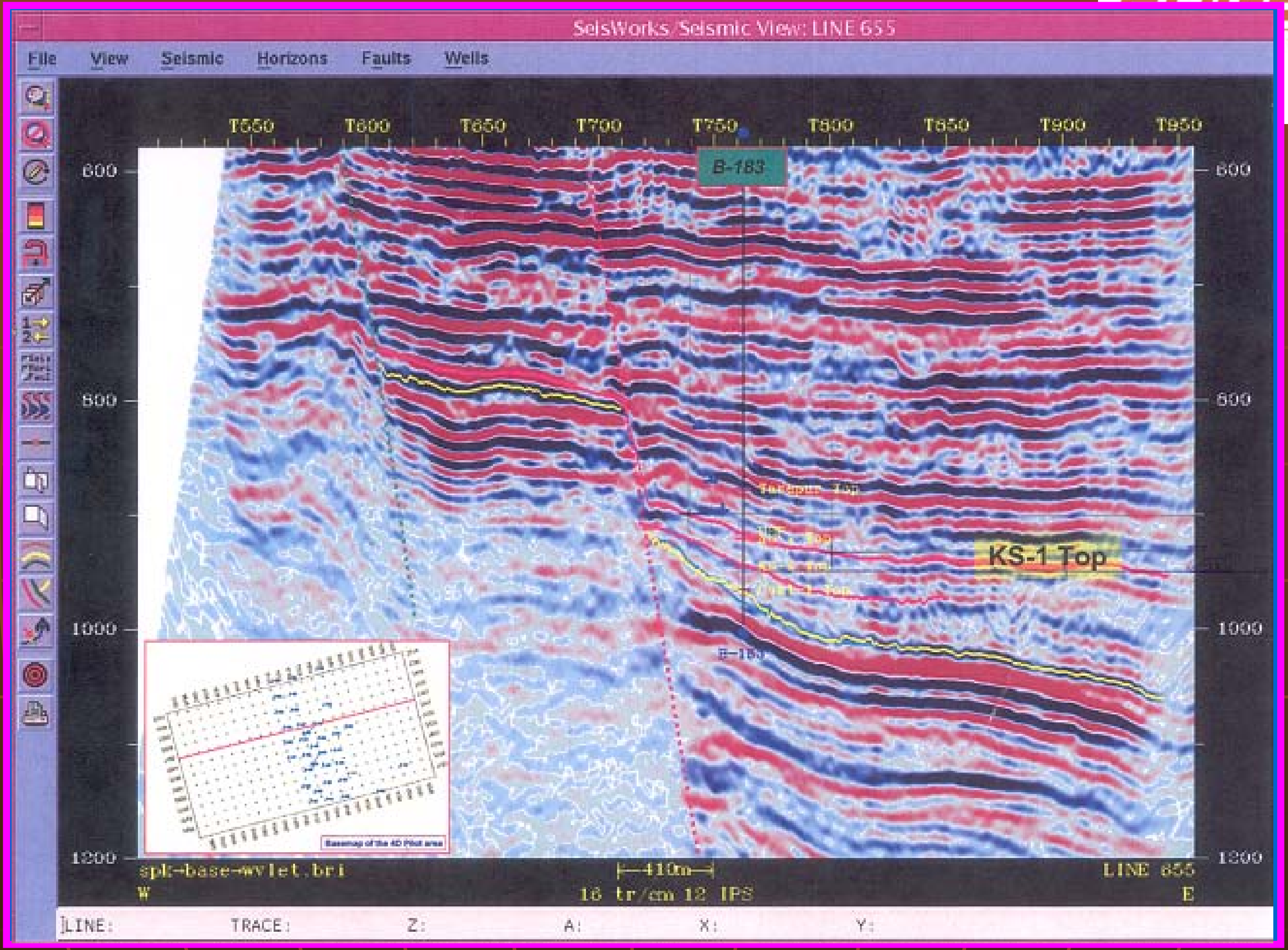
- The major hydrocarbon–bearing sand in the area is KS-1 sand of Middle Eocene age at a depth of about 1000m.
- Mostly unconsolidated with porosity in the range of 25-30 % and permeability varying between 1-5 darcies.
- The primary recovery of viscous oil from Balol Field is about 13%.
- Insitu combustion process is being carried out in parts of the field on commercial scale for improving the recovery of oil from the reservoir.
- A time-lapse study was planned in a small pilot area of 0.96x1.36 sq. km. in the northern part of Balol Field to track the movement of thermal front and estimation of areal sweep for the placement of future injector and producer wells.

# Experiment

- A time-lapse study was planned in a small pilot area of 0.96x1.36 sq. km. in the northern part of Balol Field to track the movement of thermal front and estimation of areal sweep for the placement of future injector and producer wells.

- The baseline 3D seismic data, representing the pre-combustion stage, was acquired by ONGC, India during November 2003

- The two monitor 3D surveys representing post-combustion cases were recorded at an interval of one year i.e. in December 2004 and November 2005, respectively.

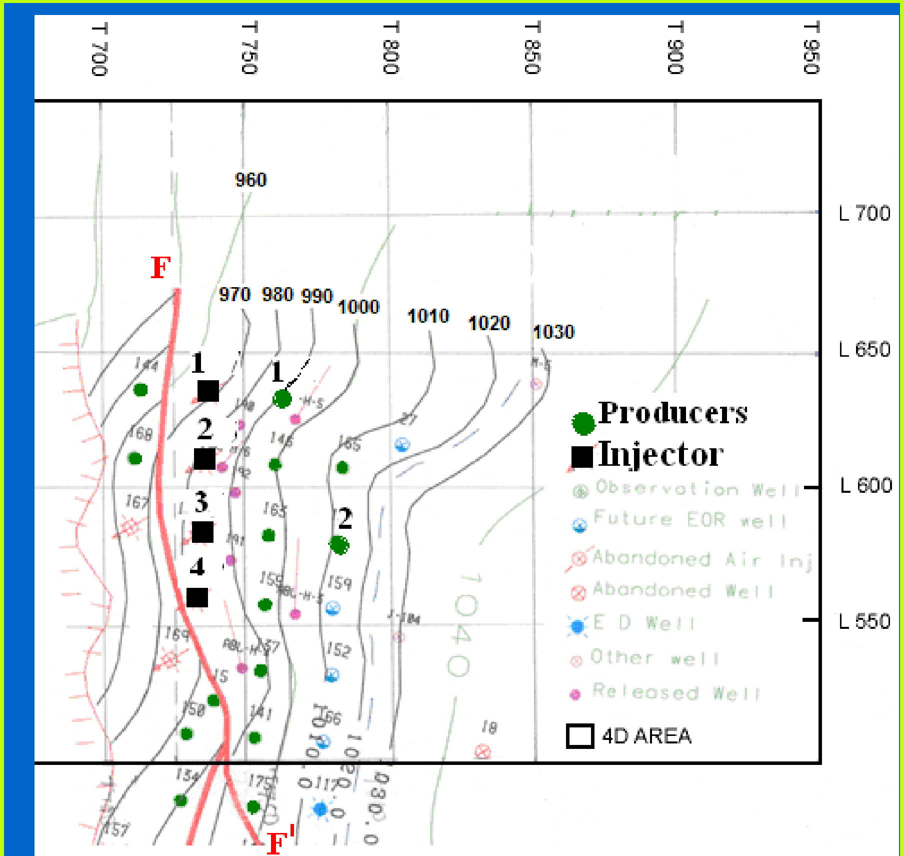



Top Reservoir is at ~952ms at well B-183(ONGC)

# Base Map of 4D Area

- The injectors (1, 2, 3 and 4), sitting right to the major fault FF', have been active since November, 2003.

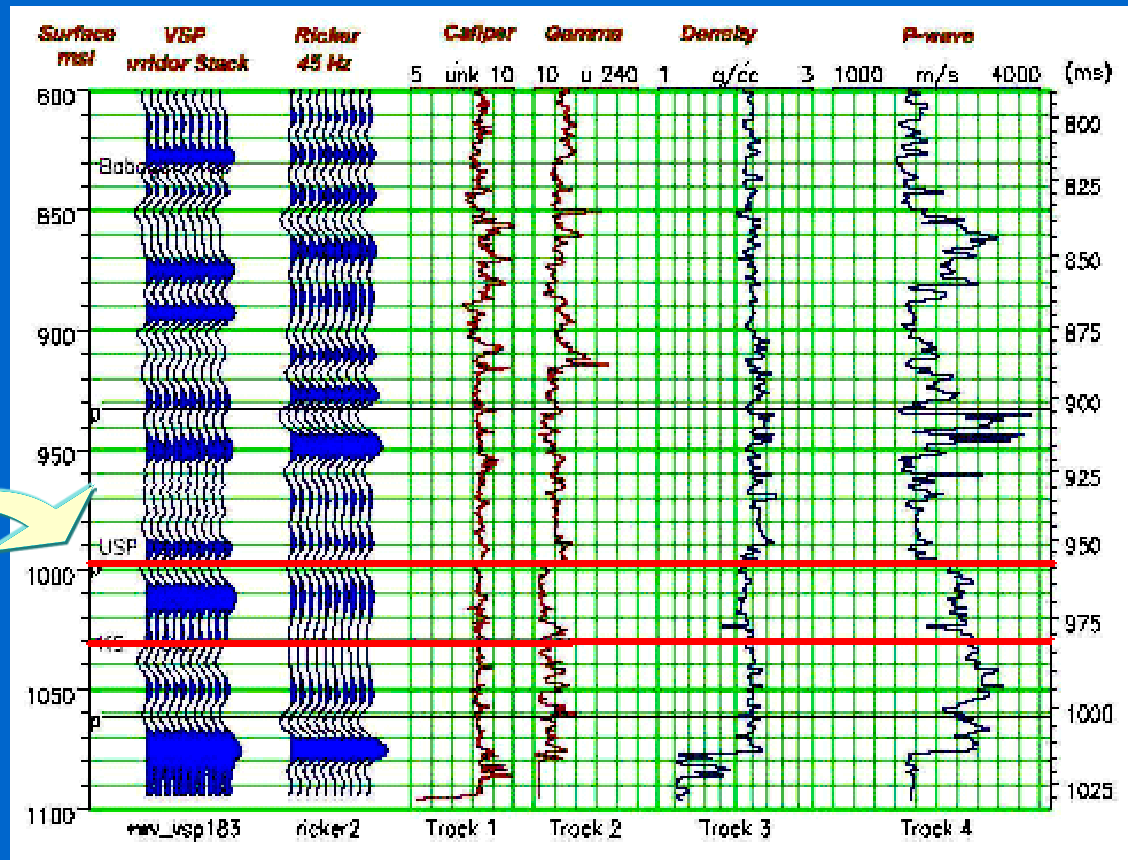
- Separation distance between each inline and crossline is 10 m (both directions). Black solid lines are depth contours of top reservoir.




KS - I / Structure Top (M)

| Thickness (m) | Vp [m/s] | Density (g/cc) |
| --- | --- | --- |
| 996 (OB) | 2200 | 2.3 |
| 32 | 2800 | 2.1 |
| 100 | 3100 | 2.2 |

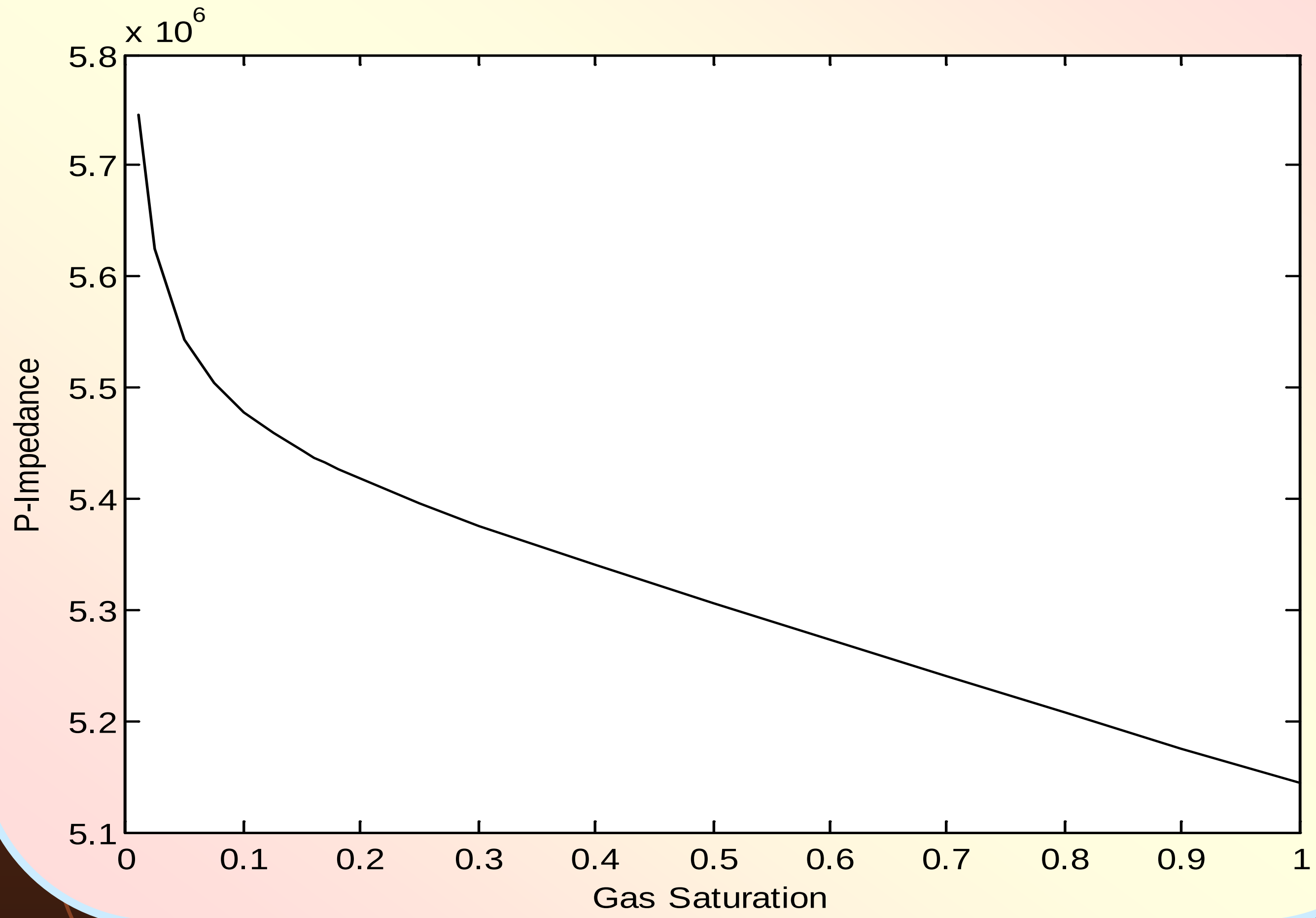
Well Log




Reservoir Layer

# Rock Physics Modeling

- During the EOR process, typical seismic parameters like Vp, fluid saturation and density within the reservoir matrix change under the influence of the movement of the thermal front.
- These changes may contribute to changes in effective bulk density and elastic moduli of the reservoir rock which can be monitored by 4D seismic data.
- We used a simple rock physics model by employing fluid replacement modeling with standard Gassmann equation since the reservoir is a clastic reservoir.




JACKSON
SCHOOL OF GEOSCIENCES

# nrms

- To quantify the differences between time lapse images
  - Diff = (M-B)/rms(B); B=Base; M=monitor
- Quantify the repeatability using normalized rms (nrms)
  - nrms = 200s[rms(M-B)]/[rms(M)+rms(B)];

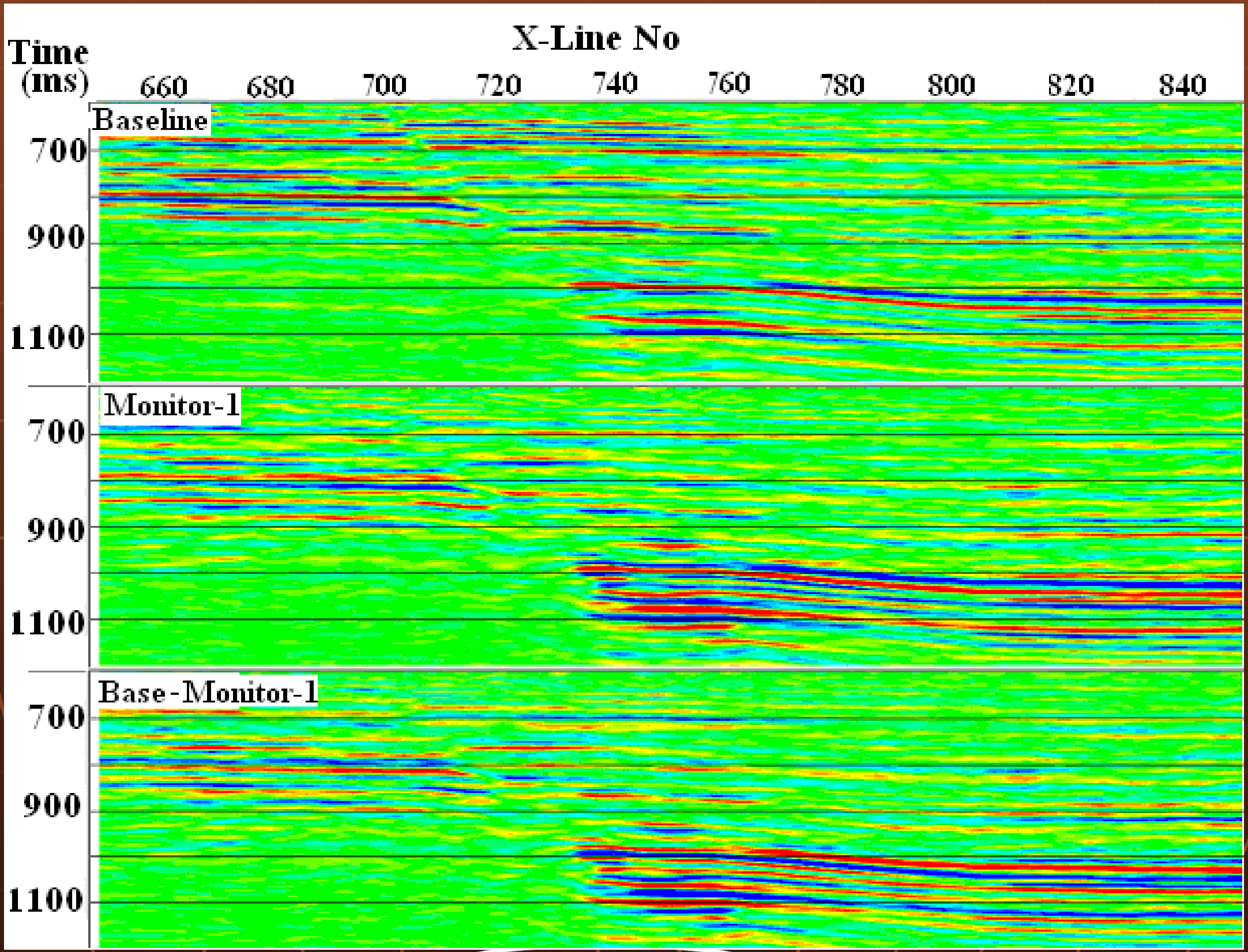
$$\mathrm{rms}(A) = \sqrt{\frac{\Sigma_1^N A^2}{N}}.$$

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

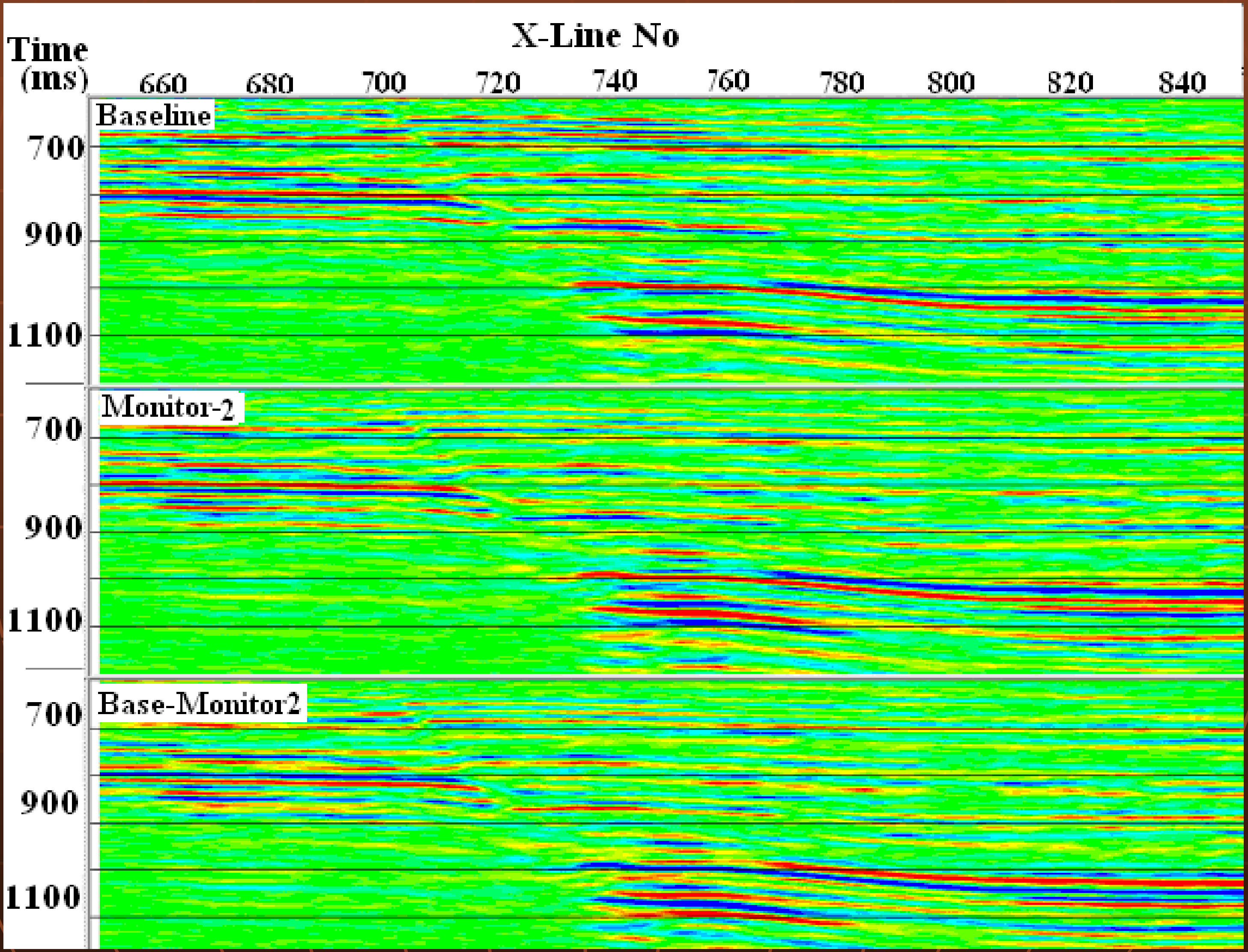
# Comments

- The repeatability level of the two monitor surveys as compared to the baseline survey was relatively low (Mehdizadeh et. al., 2007), i.e. approximately 100%  for monitor 1 and 75% for monitor 2; repeatability was measured in normalized RMS (NRMS) error (Kragh et al., 2002).
- Thus, a direct interpretation of difference of seismic volumes was not possible as the residual differences in the repeated surveys, which were not related to the changes in the reservoir, affect the applicability of 4D studies and acted as time lapse noise.

# Cross-equalization



# Cross-equalization



# Our Approach – Seismic Inversion

- Use pre-stack gather
- Perform pre-stack inversion to estimate P-velocity, S-velocity and density or Acoustic impedance, shear impedance and density
- Input data: starting low frequency model, wavelet

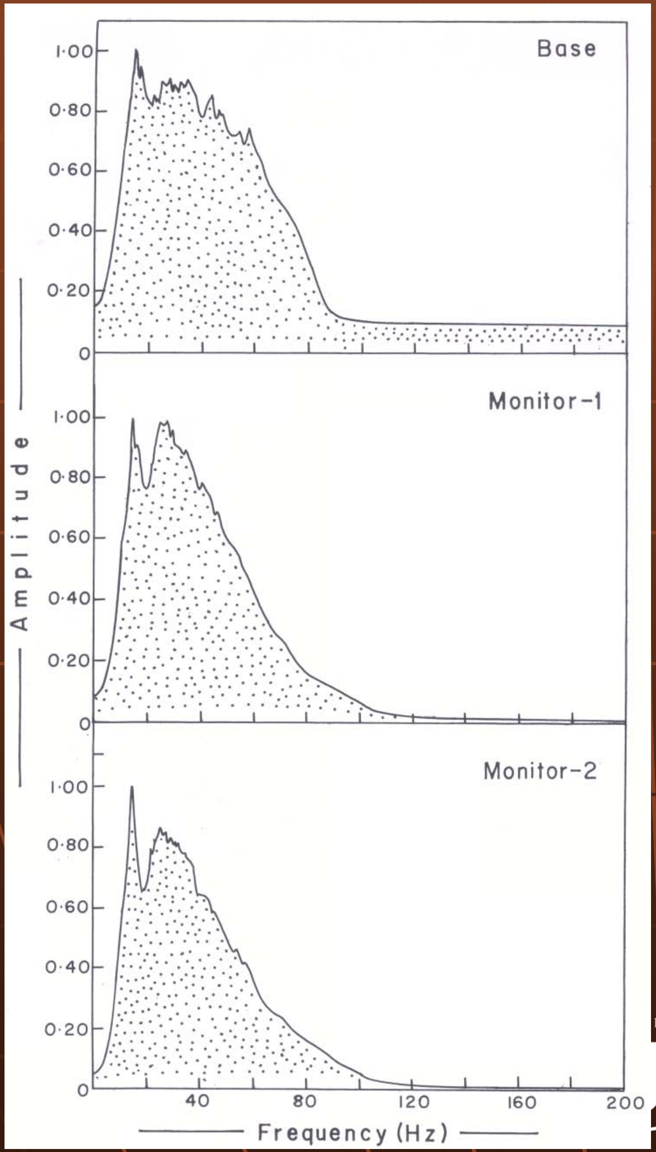
# Our Approach

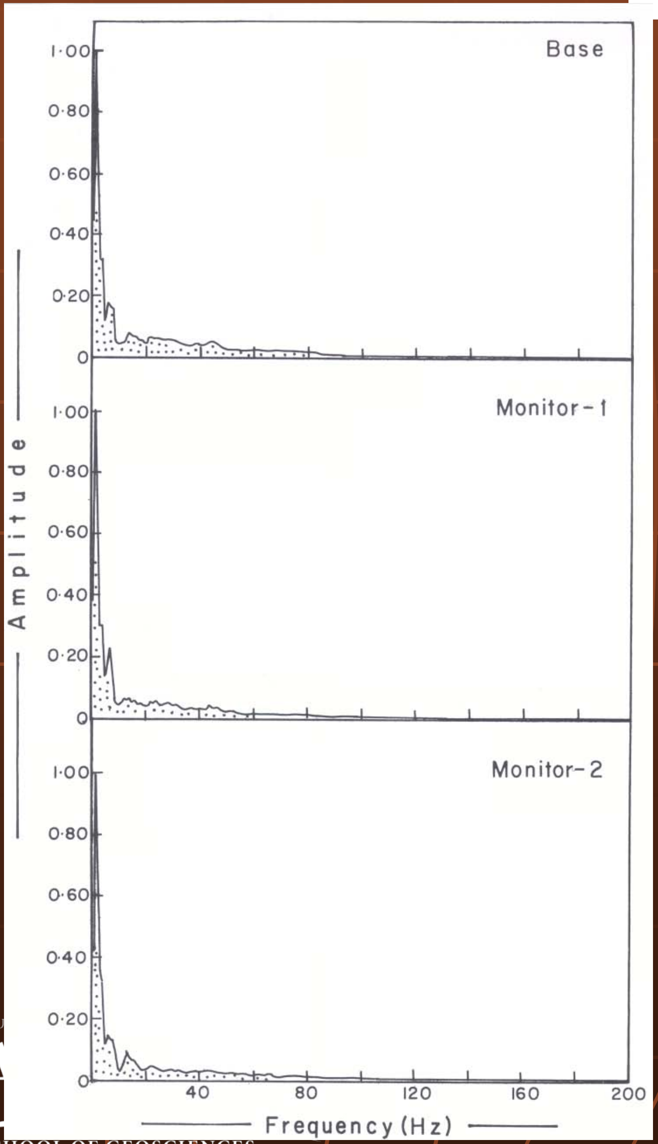
UT-AUSTIN EDGER FORUM

- Treat each data independently
- Derive wavelets for each one of the surveys
- Apply pre-stack inversion of each gather from each survey using their corresponding wavelets
- Derive low frequency starting solution of Zp, Zs and density from well log and its extrapolation using the horizon map.

# Amplitude Spectra





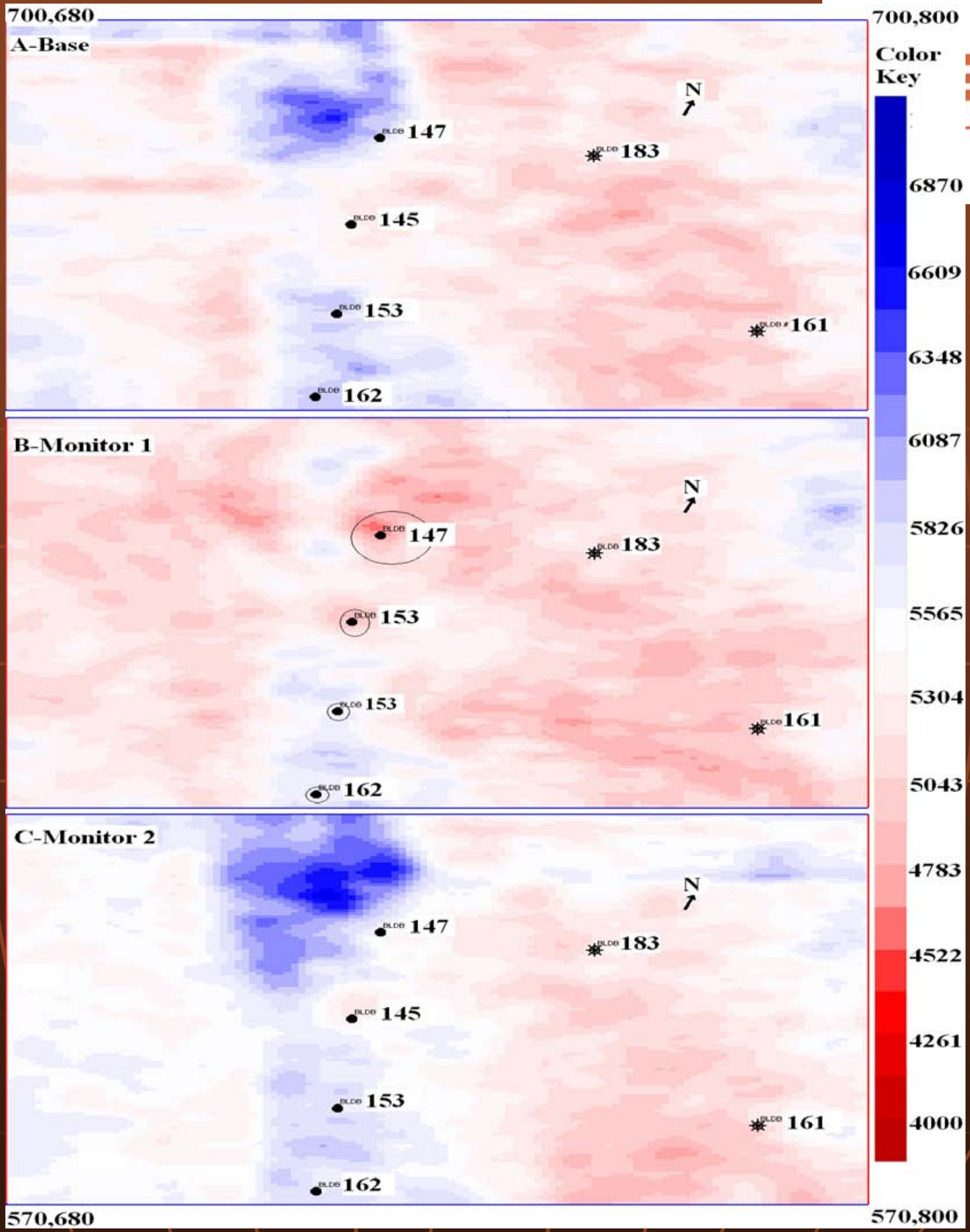




Base

Monitor1

Monitor2

# Acoustic Impedance

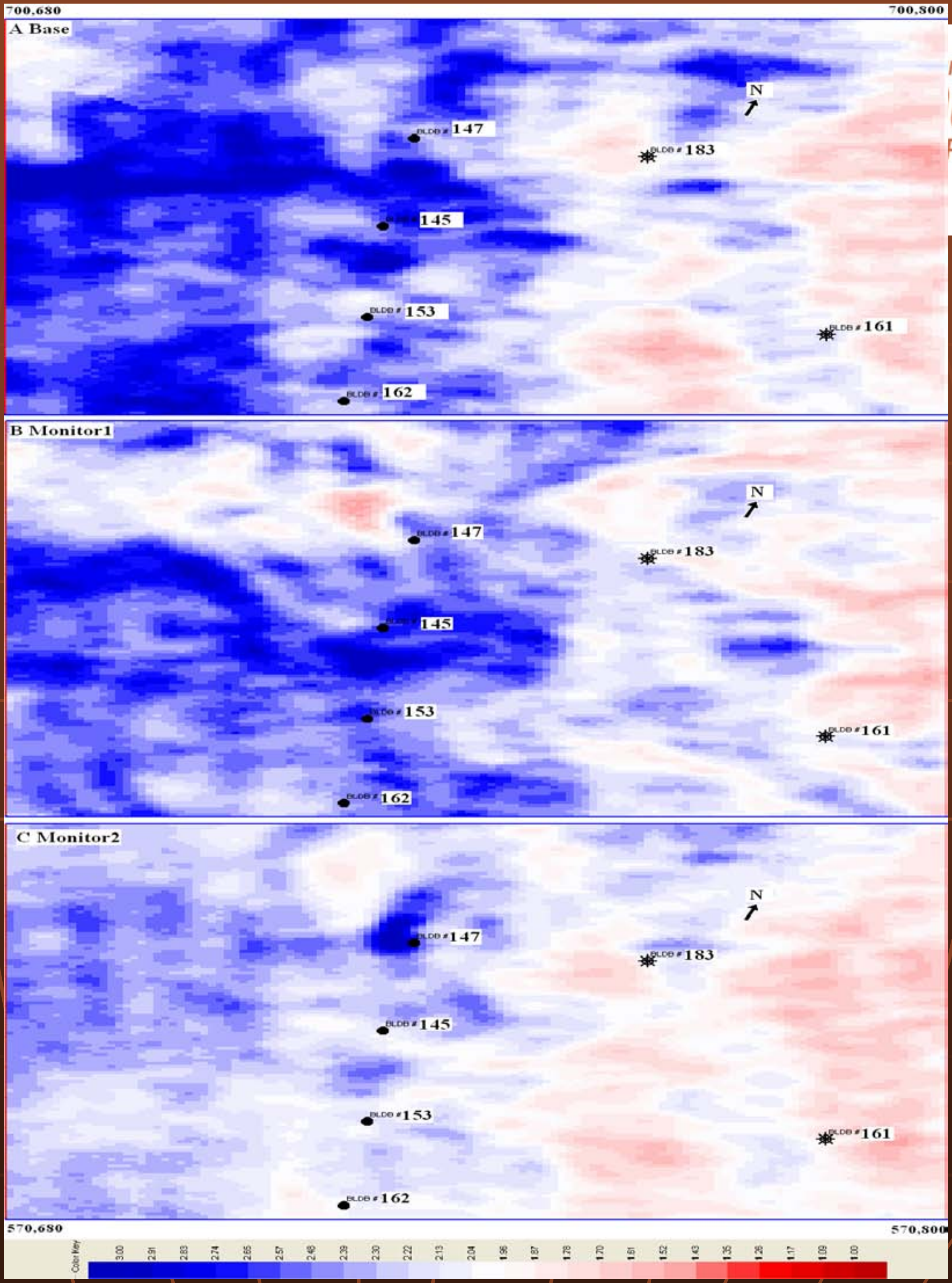



Base

Monitor1

Monitor2

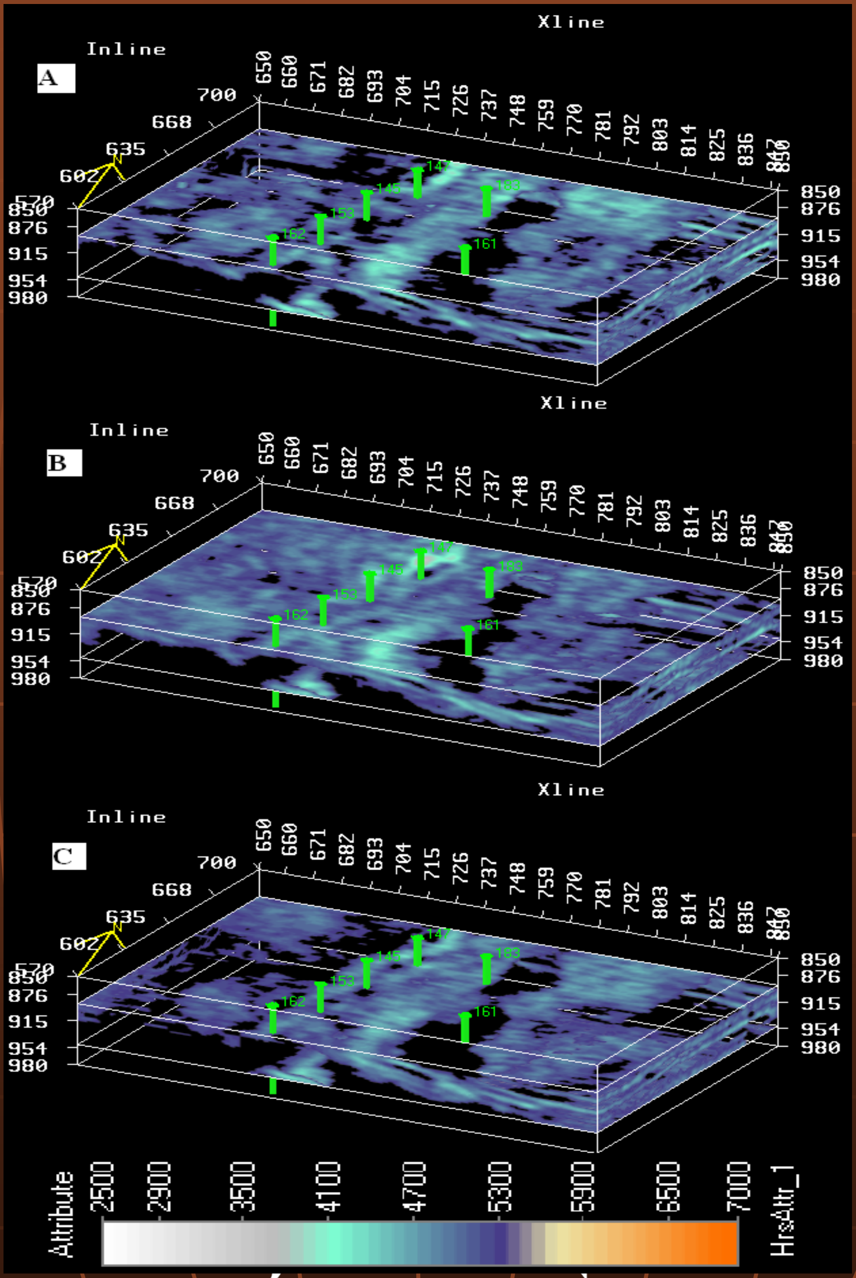
# Vp/Vs ratio




Base

Monitor1

Monitor2




Base

Monitor 1

Monitor 2

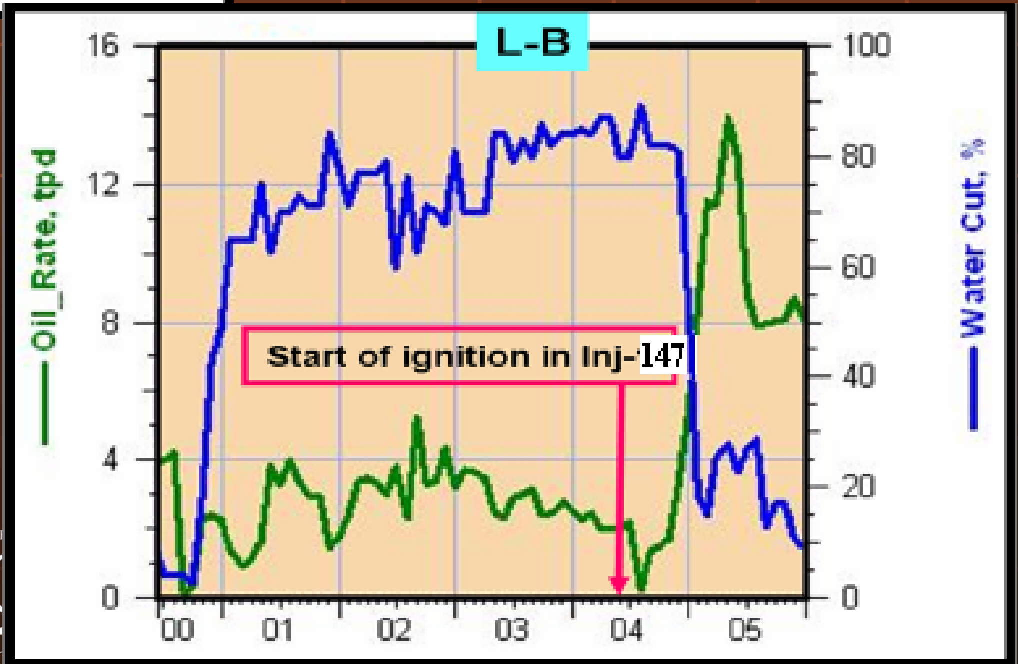
SCHOOL OF GEOSCIENCES

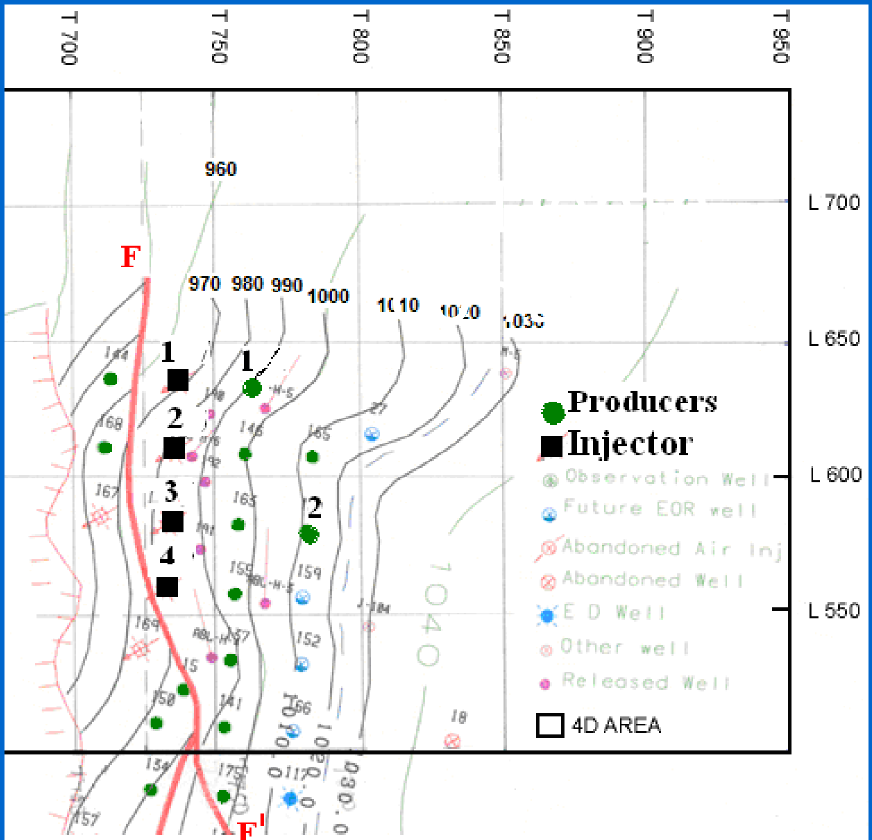
| Well | Base | Monitor1 | | Monitor2 | |
|---|---|---|---|---|---|
| | $Z_p$ | $Z_p$ | drop w.r.t Base | $Z_p$ | drop w.r.t Base |
| 1 | 5696 | 4783 | 16% | 5565 | 2.3% |
| 2 | 5433 | 4913 | 9% | 5304 | 2.3% |
| 3 | 5826 | 5565 | 4.5% | 5696 | 2.2% |
| 4 | 5826 | 5565 | 4.5% | 5696 | 2.2% |

- The 900ms time slices approximately correspond to the upper zone of combustion/injection at wells 147 and 145. At both of these locations, the aerial extents of the affected zones are also visible but we see clear anomaly in the north and NW of well 147 in impedance time slice.

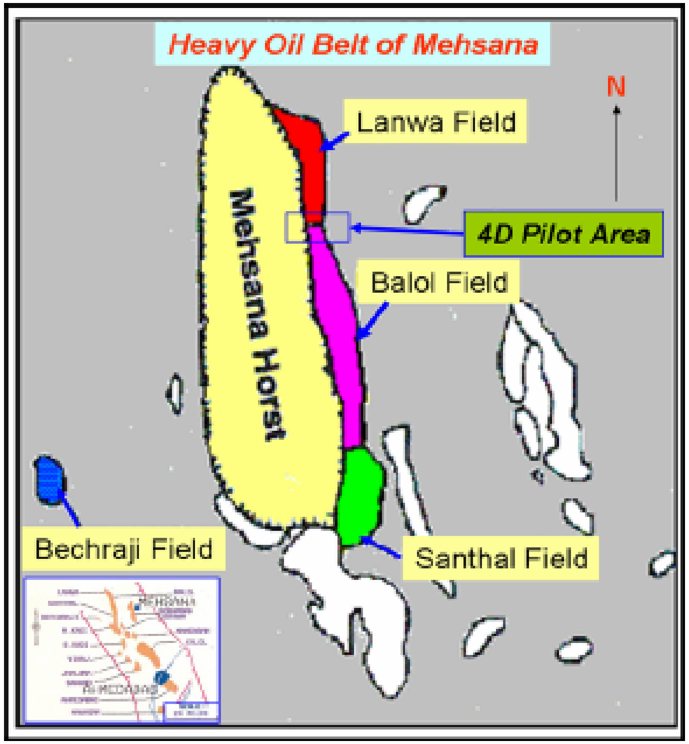
- This indicates that the gas has a tendency to move up dip and thus it appears that the front is moving up-dip


From Kumar et. al
2008



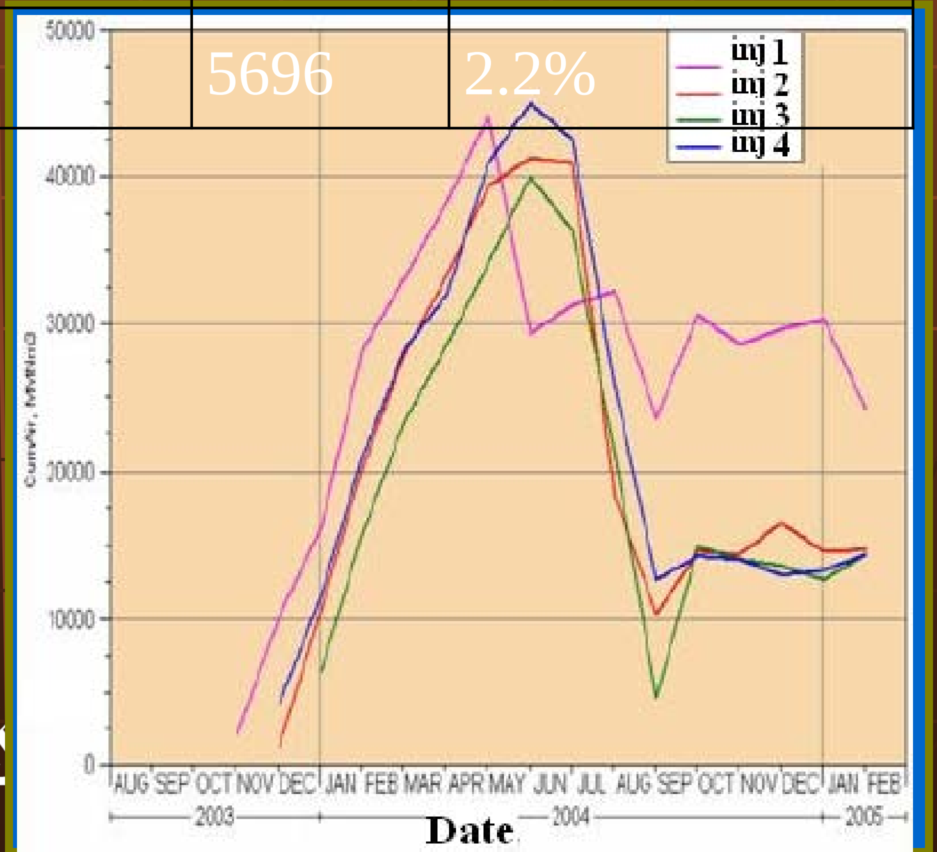



KS - I / Structure Top (M)



| Well | Base | Monitor1 | | Mo[illegible] | |
|---|---|---|---|---|---|
| | $Z_p$ | $Z_p$ | drop w.r.t Base | $Z_p$ | dr[illegible] |
| 1 | 5696 | 4783 | 16% | 5565 | 2.3% |
| 2 | 5433 | 4913 | 9% | 5304 | 2.3% |
| 3 | 5826 | 5565 | 4.5% | 5696 | 2.2% |
| 2 | 5826 | 5565 | 4.5% | 5696 | 2.2% |

From Kumar et. al 2008



# Concluding Remarks

- Independent inversion circumvents the cross-equalization process.
- The possible fairways of flue gases and/or propagation of combustion have been brought out through seismic inversion.
- Our results indicate preferential movement of flue gases towards north through the finer N-S discontinuities.
- This observation is supported by production behavior of wells in the area.