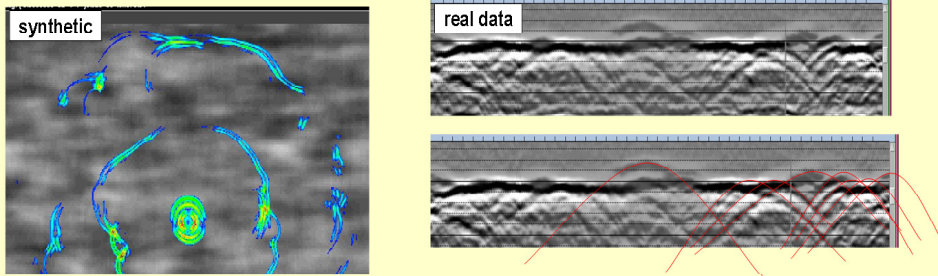


# Seismic imaging and monitoring with Virtual Sources

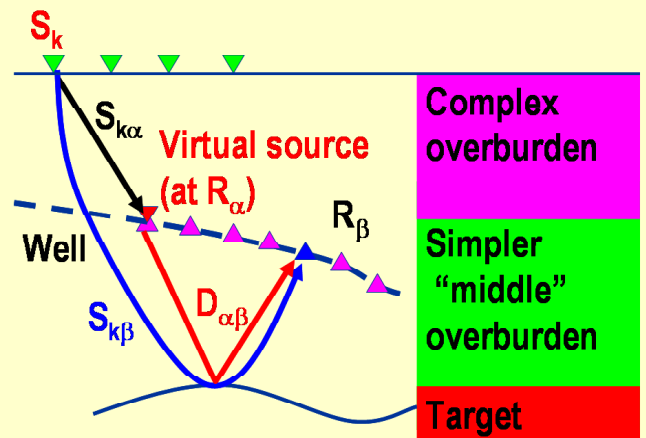
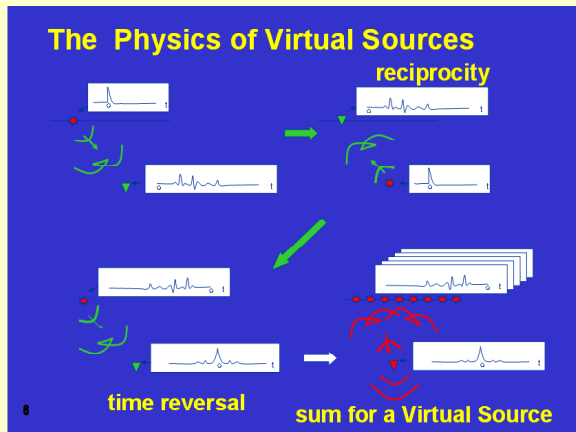
Andrey Bakulin, Rodney Calvert  
Shell International E & P, Houston

1. The problem: A heterogeneous overburden causes multi-path arrivals. This causes time variant and different wavelets for every shot and every dip.



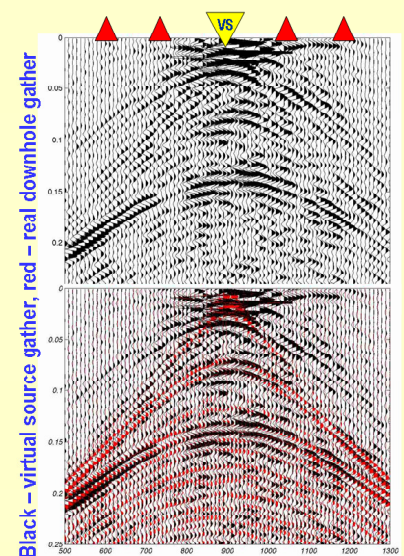
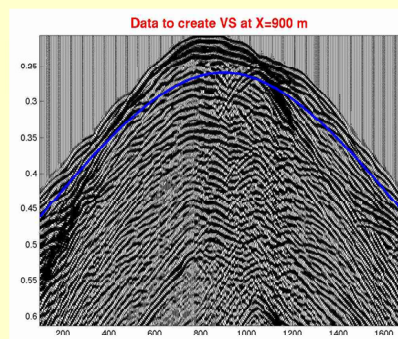
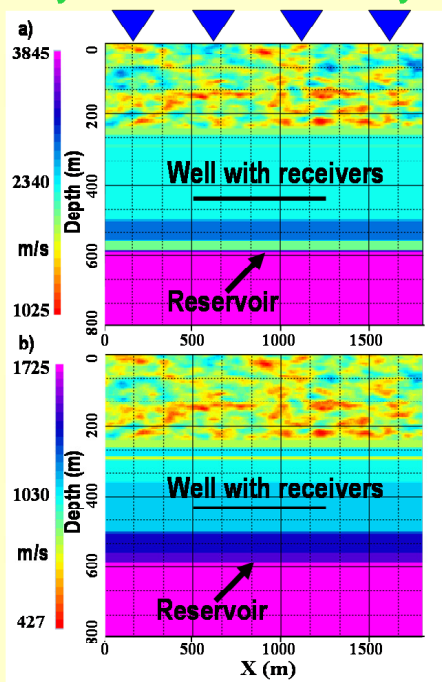
Conventional seismic data assumes some varying envelope of early arrivals as wavelet and treats the deviations as noise. Quantitative work is compromised.

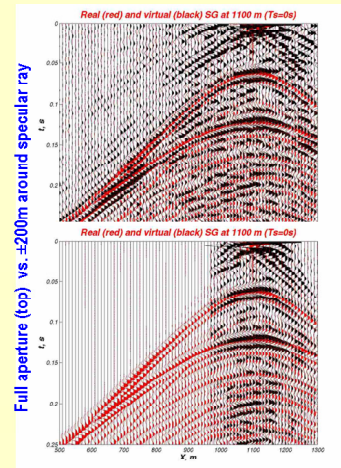
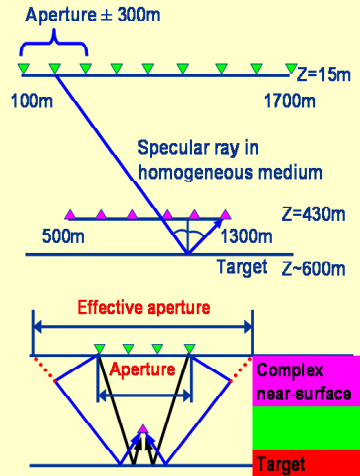
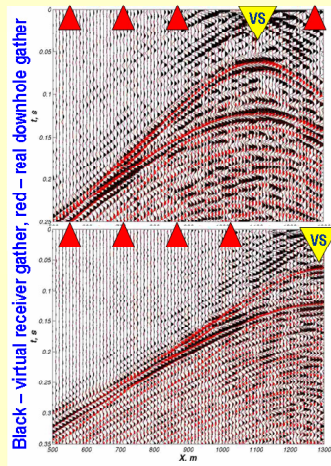
## 2. A solution – Virtual Sources



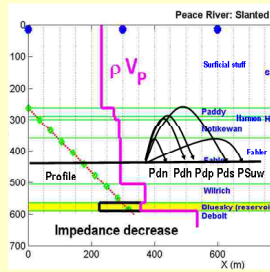
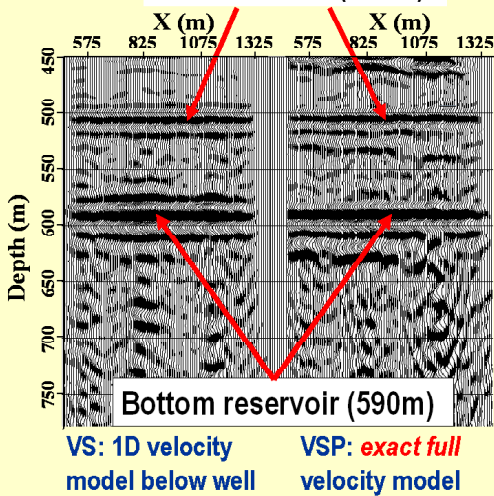
$$D_{\alpha\beta}(t) = \sum_{k=1}^N S_{k\alpha}(-t) \star S_{k\beta}(t)$$

## 3. Synthetic case study: imaging

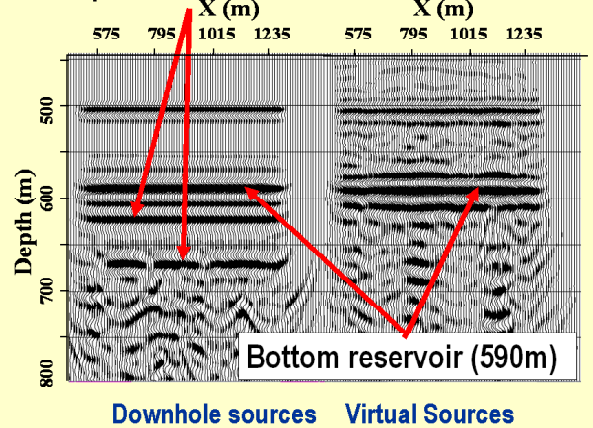




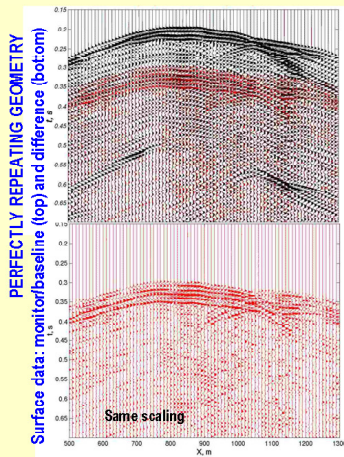
PSDM First interface (505m)



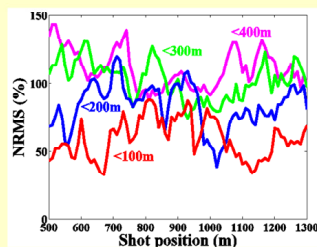
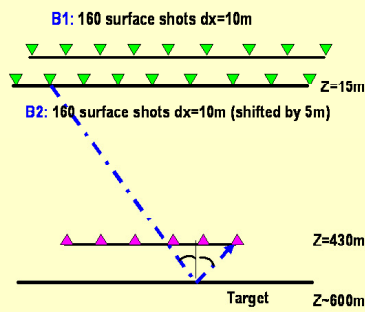
PSDM images Spurious reflections from above



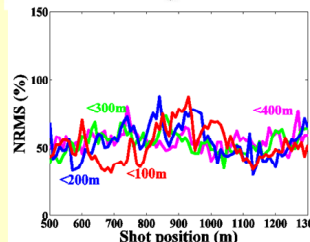
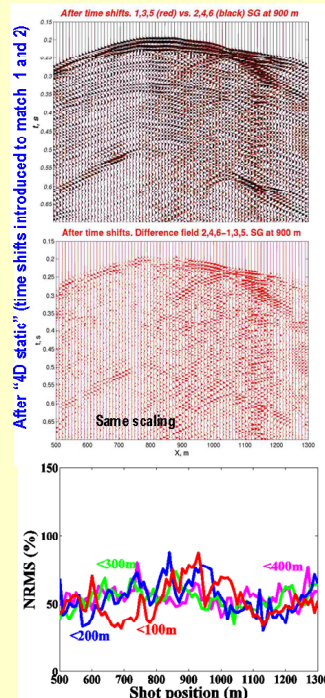
4. Synthetic case study: monitoring



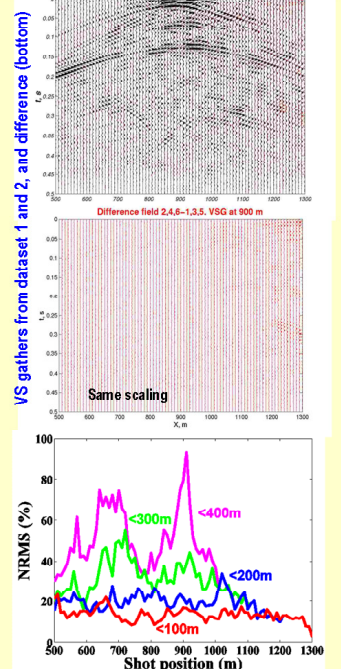
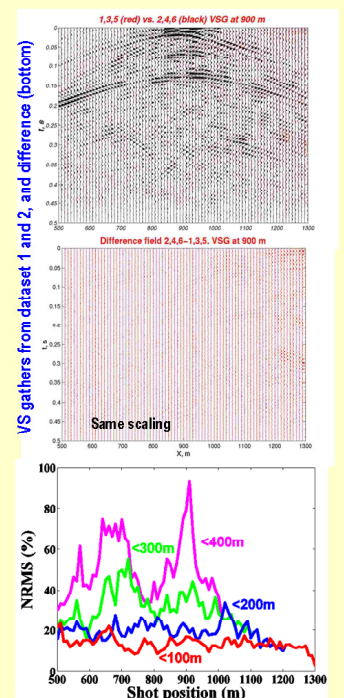
Model non-repeatable acquisition



Conventional VSP

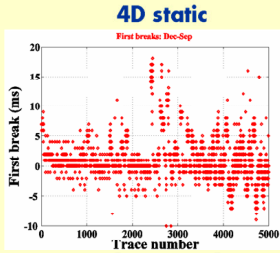
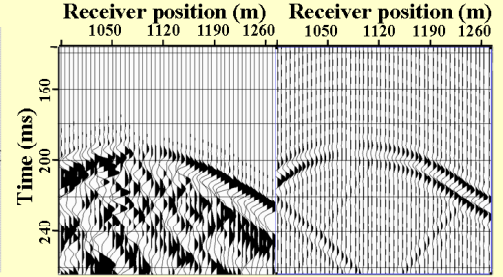
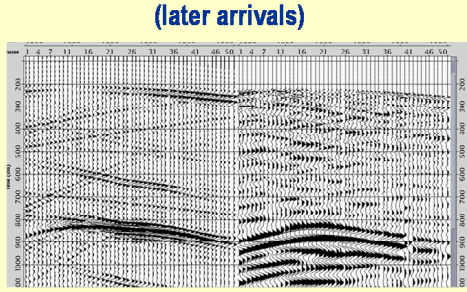
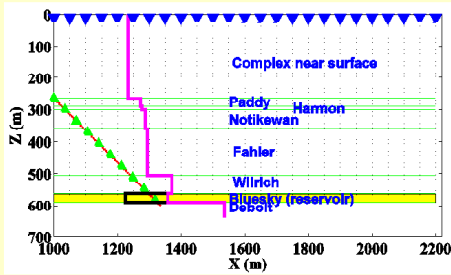


Virtual Source



# 5. Field case study: 4D VSP at Peace River

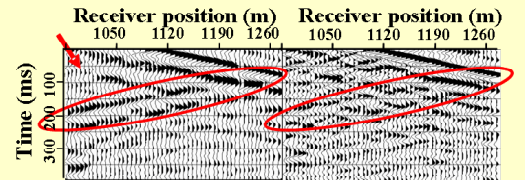
Comparing VSP synthetic vs. data (first arrivals)



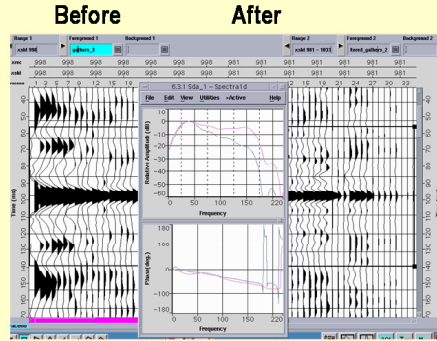
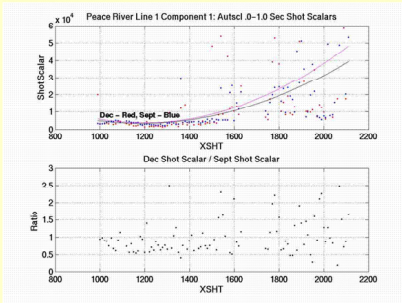
## Spectral balancing

- Equalize the signatures
- Do not touch the phase!
- Extend the bandwidth

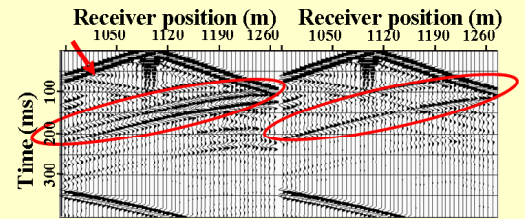
## Pre-stack VS



## Shot scalars

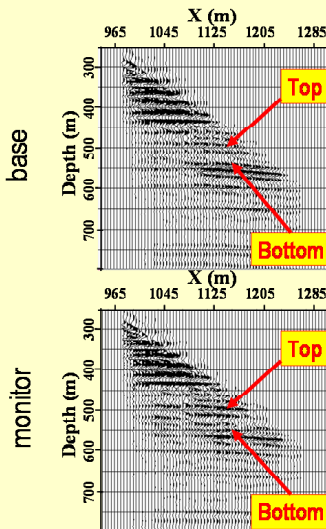


## Synthetic VS

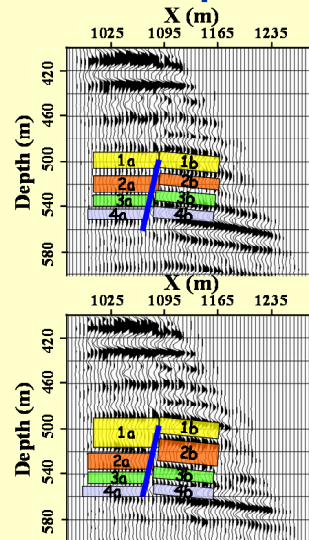
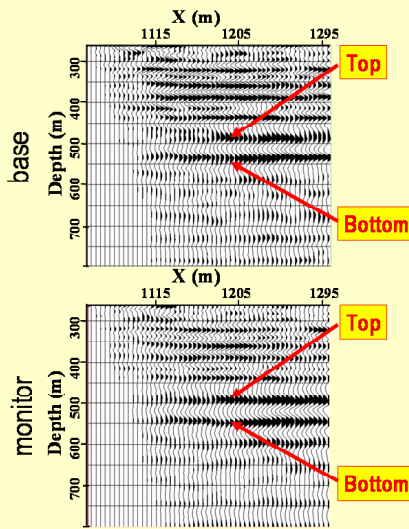


## Track changes in small compartments

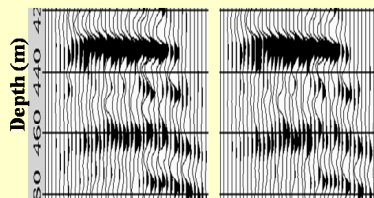
### Virtual Source



### 4D surface seismic



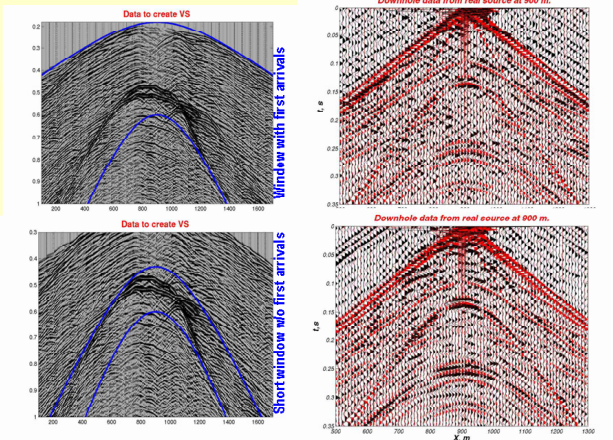
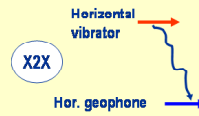
- Does not require velocity model between surface and geophones in a well
- Automatically takes care of 4D static and other changes in the near surface
- May relax requirements to repeat surface shots positions exactly
- More repeatable and high-frequency images



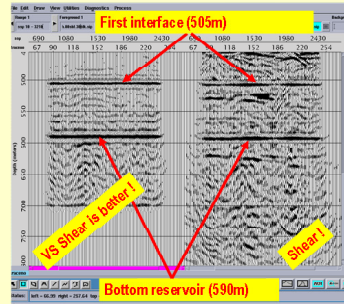
Even funny wiggles are repeatable on VS data!



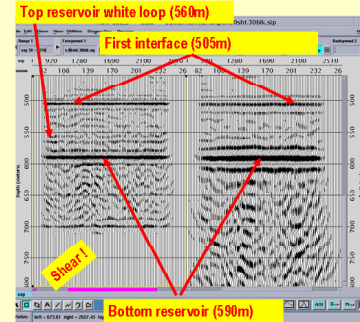
# 6. Virtual Shear Source



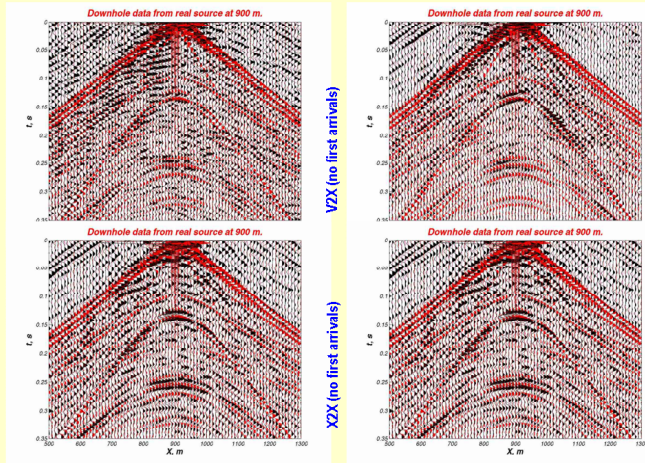
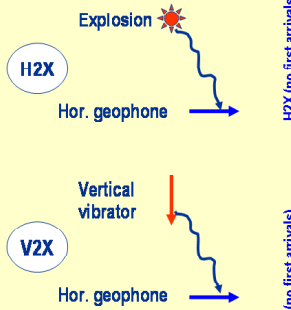
VS data (full aperture)      Surface data migrated with exact velocity model of the overburden



VS S-wave image (full aperture)      VS P-wave image (full aperture)



Buy one get one free?



Summary of VS data quality with multicomponent data

Source/Receiver	Explosion	Vert. force	Horizontal force
Hydrophone	Good	Good	Poor
Vertical component	Good	Good	Poor
Horizontal component (inline)	Poor	Poor	Poor

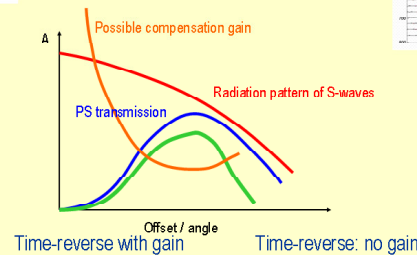
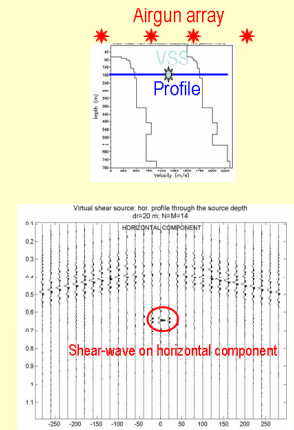
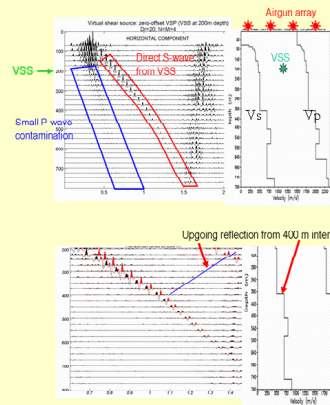
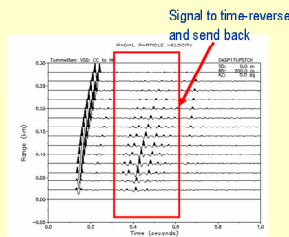
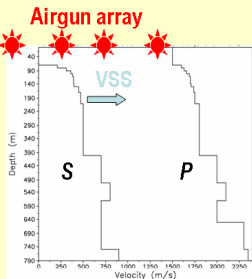
Table 1. Quality of P-wave VS data generated by different sources recorded at various components.

Source/Receiver	Explosion	Vert. force	Horizontal force
Hydrophone	Poor	Poor	Poor
Vertical component	Poor	Poor	Poor-to-medium
Horizontal component (inline)	Poor	Poor-to-medium	Good

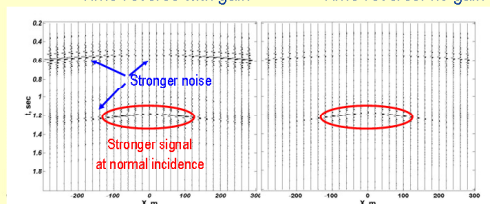
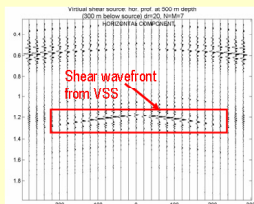
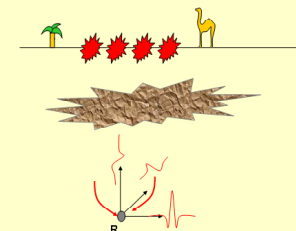
Table 2. Quality of S-wave (SV-wave) VS data generated by different sources recorded at various components.

## Virtual Shear Checkshot with airguns

Detailed S-wave velocity model from surface wave inversion on Tommeliten field (North Sea) by Alnor et al. (1997)

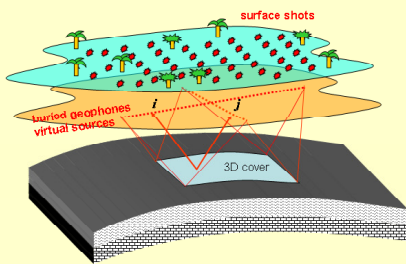


We can control polarization of shear waves

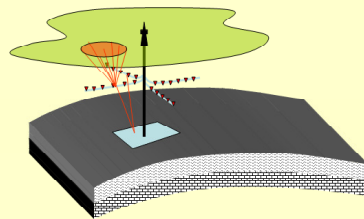


## 7. New applications

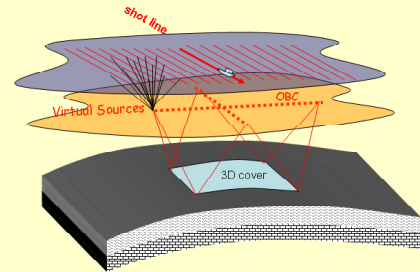
Virtual Source patch geometry



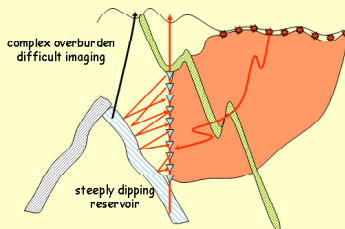
Virtual source sidetrack for appraisal and monitoring



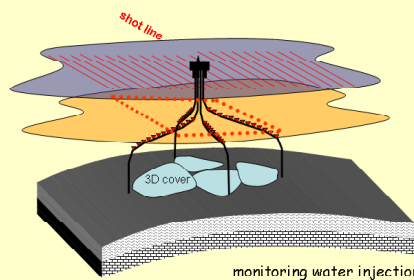
OBC Virtual Source patch geometry



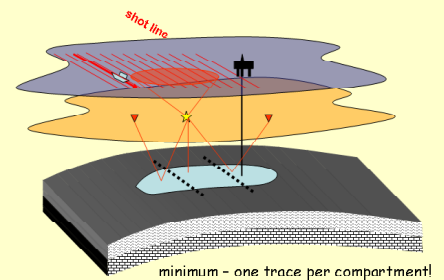
Given vertical wells the steep dips are an advantage.



OBC/VSP Virtual Source patch geometry



Are compartments connected?



## 8. Conclusions

• **Virtual Source Method consists of re-datuming surface shots into downhole receiver locations (through most complex overburden part) using experimentally measured Green's function (propagator)**

- Gains:
  - no velocity information is required
  - full wavefield is redatumed with correct phase.
- Pains:
  - requires downhole geophones (below troublesome part of the overburden)

• **VSM imaging advantages:**

- Can handle any complexity of overburden and near surface
- Increased overburden complexity may indeed enhance the VSM
- VS has advantageous downward radiation pattern (better than real !)
- VS has known controlled signature

• **VSM monitoring advantages:**

- Automatically takes care of regular and 4D statics and changes in the near surface
- May relax requirements for exact repeat of surface shots positions for 4D
- Much more repeatable data compared to surface seismic or conventional VSP

• **Shear VSM:**

- Better image than surface SS seismic (even with known velocity model)
- Comparable image with *P*-wave Virtual Source
- Shear-wave checkshot and images are possible with *P*-wave sources
- Complexity of the overburden helps

• **Many more great applications**

