



# 3C VSP

Processing and Interpretation in IFPEN

IFP-Energies Nouvelles  
( ex - Institut Français du Pétrole )

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November 2003, revised July 2020*



- **Introduction: Why 3C processing**
- Seisdip method: dip & azimuth of reflectors
- True Amplitude 3C VSP processing: to investigate difficult exploration issues
- Polscan: a polarization analysis tool on adjacent 3C VSP traces to help identifying the nature and wavemode of 3C seismic events
- End product: a more RELIABLE 3D structural sketch around/below the well
- Conclusion



# Introduction

3 components always recorded (in any kind of well)

**BUT**

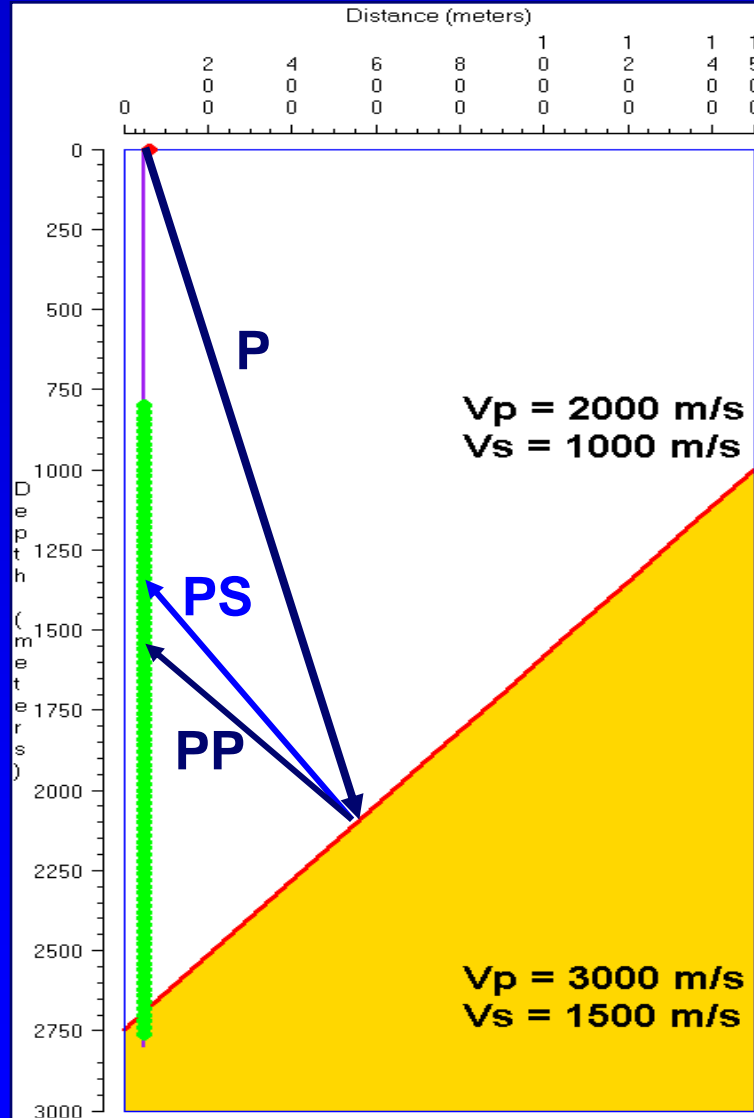
generally only one component (nearly vertical)

→ { is processed  
1D imaging around the well  
loss of information

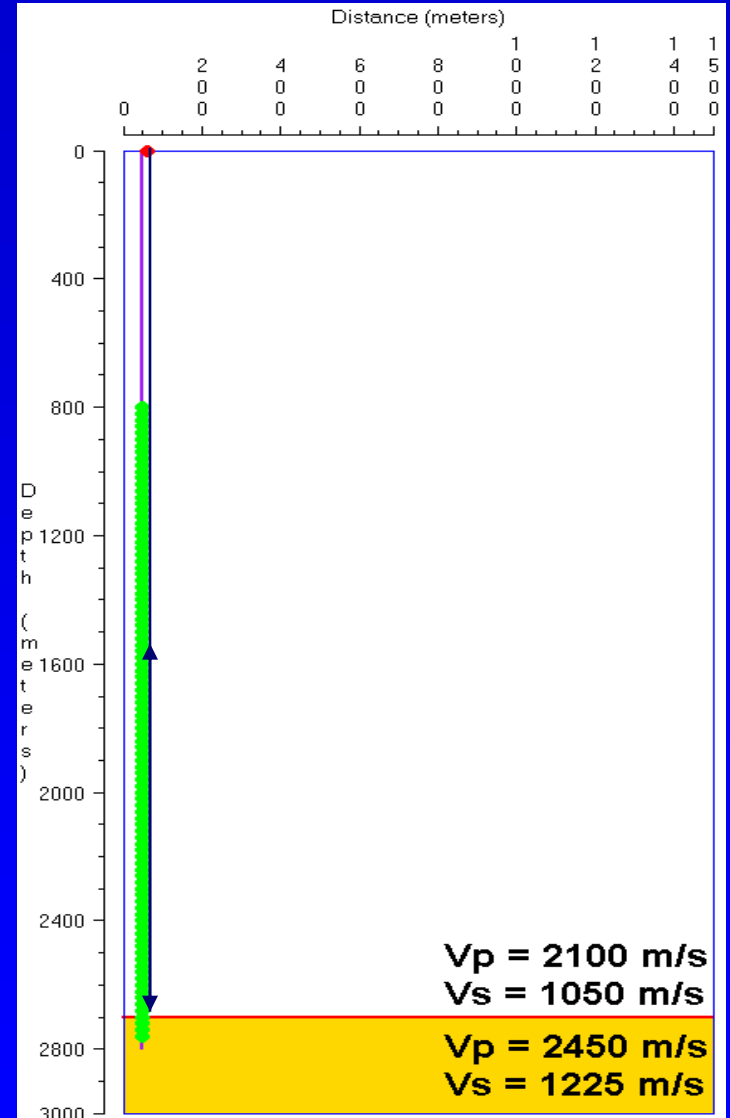
interpretation possibly erroneous



# Why processing 3 components ?



50° dipping model



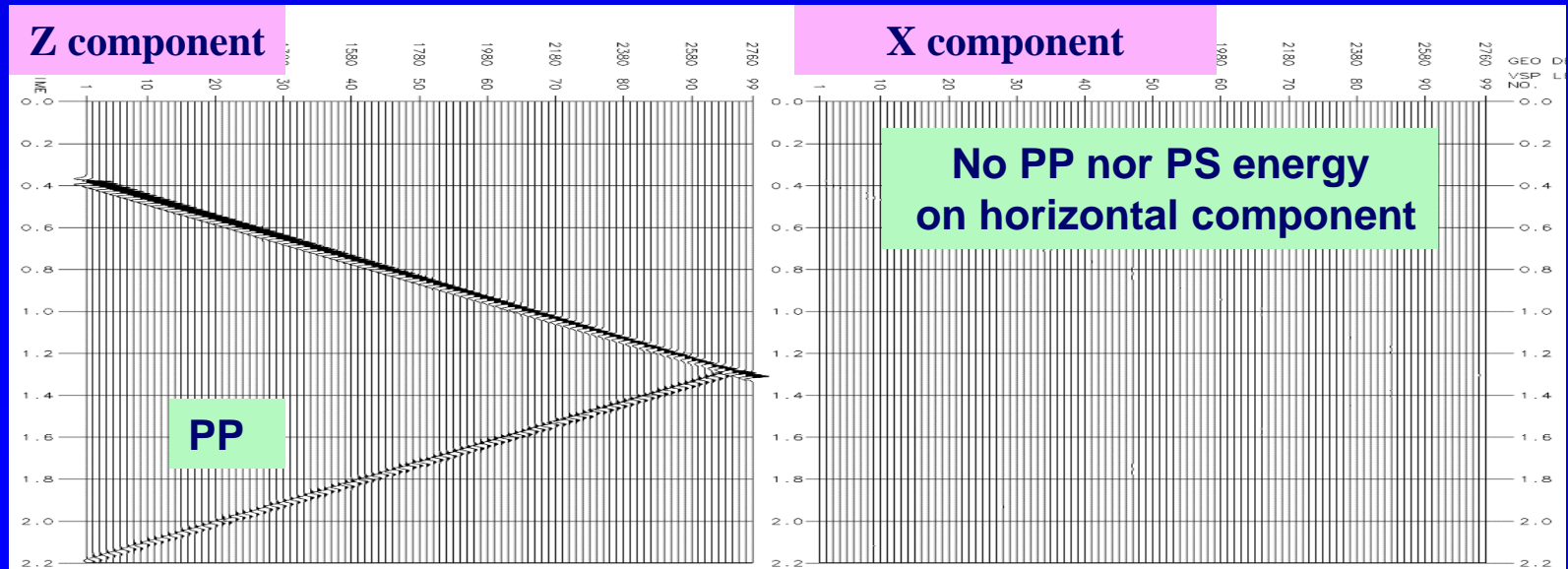
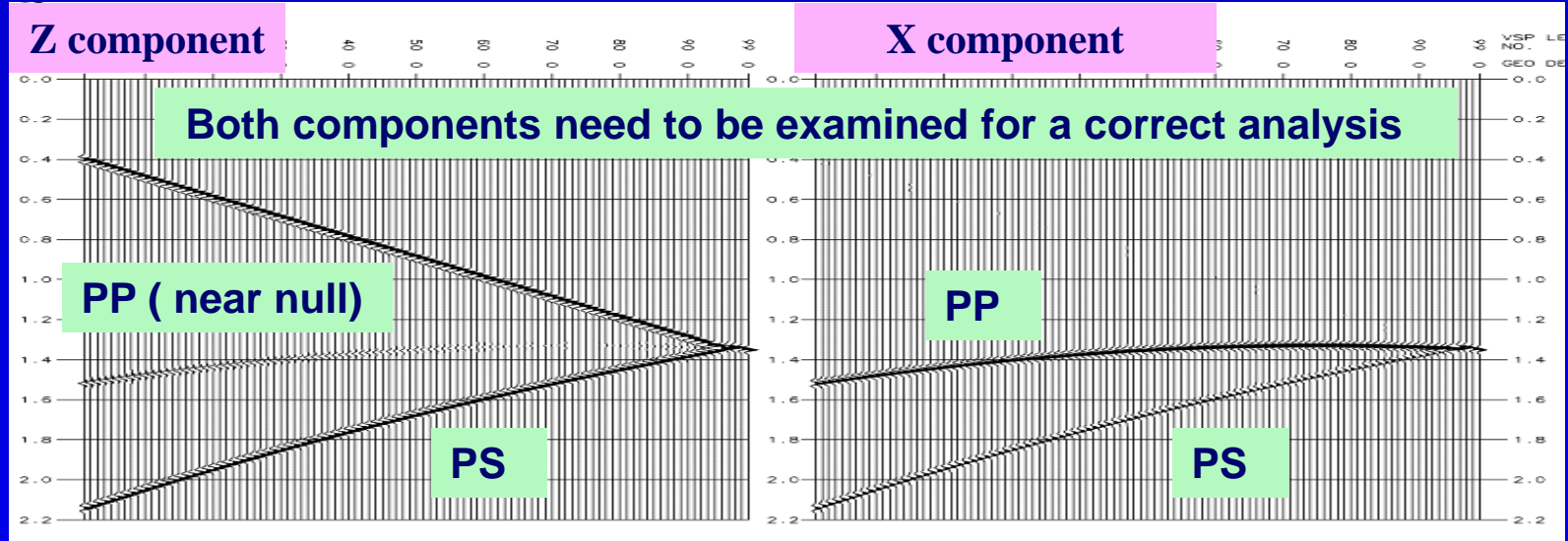
Flat model



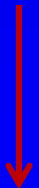
# Dipping versus flat model, 2C response

50° dip

Flat model



One way time

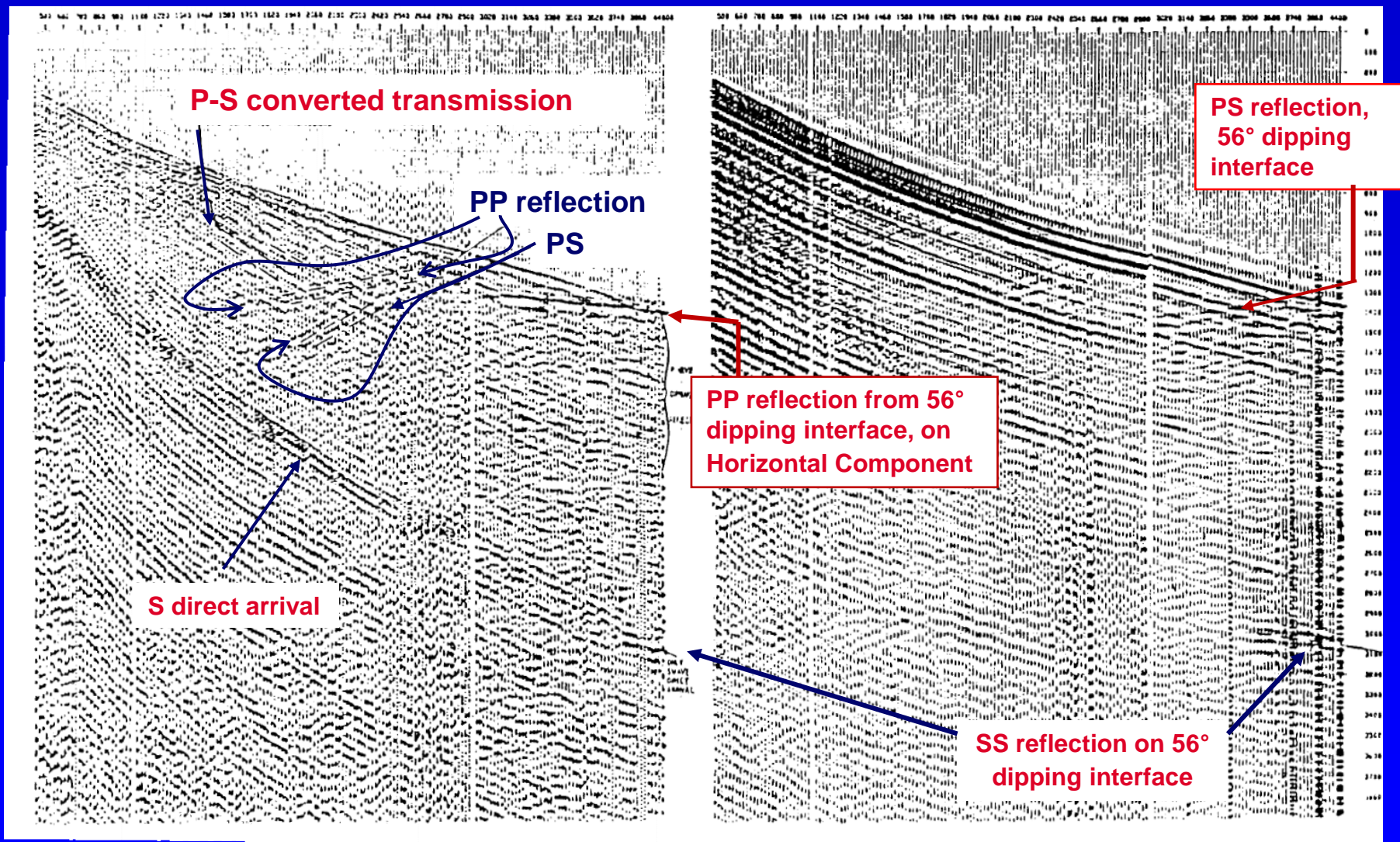




# Real seismic response on a dipping reflector

Horizontal component

Vertical component



H. component inline with tool arm

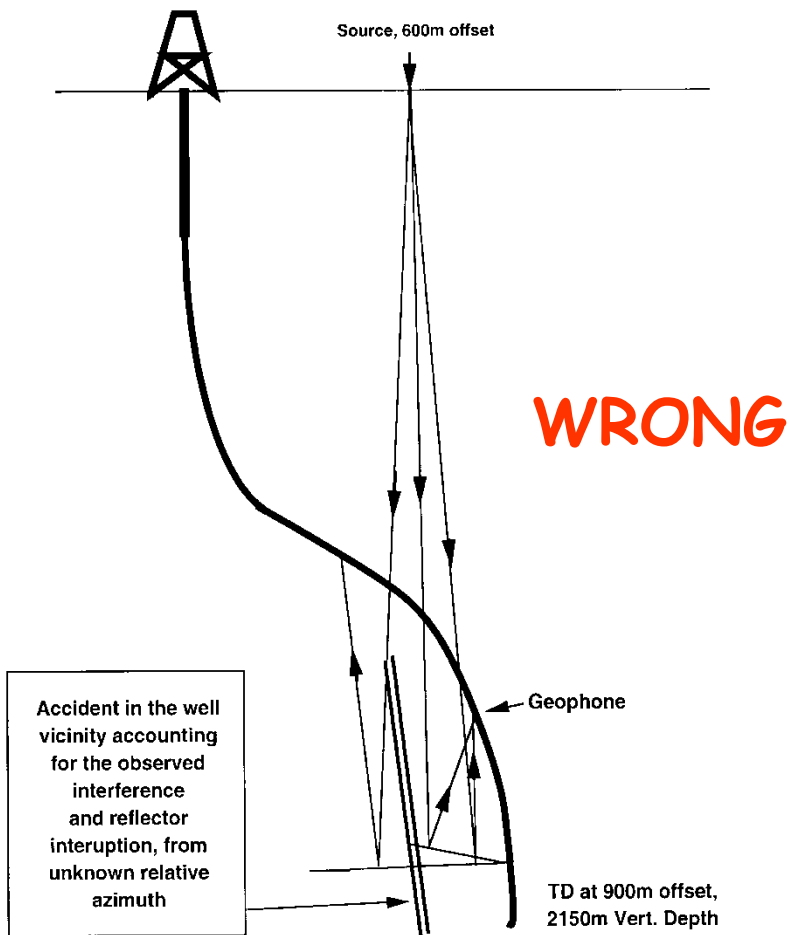
Courtesy of OMV-Austria, 1983



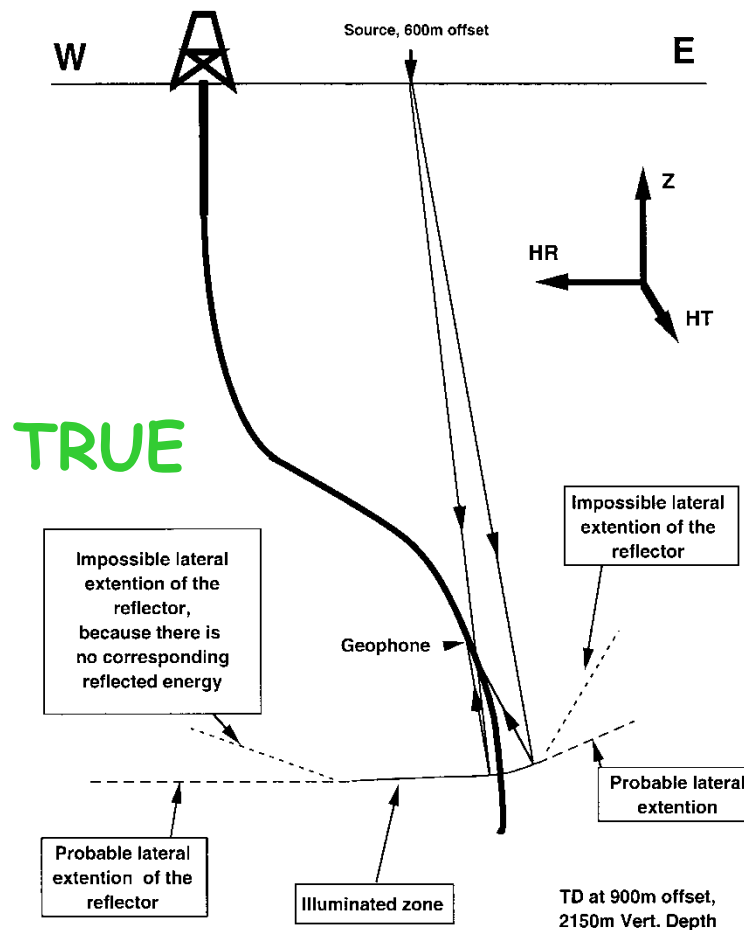
# 3C versus 1C processing

Naville, C., Serbutoviez, S., Bruneau, J., Japiot, H., Daures, R., Gaborit, J.Y.,  
SEISDIP : the " VSP dipmeter " from oriented 3 components, *AAPG 2001*

- *Open access publication: On a search engine, type « SEISDIP, extended abstract » or Seisdip ifp »*



*1C processing*



*3C processing*



## So why not using the 3 components ?

Not much extra work, but **a few necessary conditions:**

- Hardware orientation device combined to the VSP tool
- 3C isotropic recording
- 3C isotropic processing

**Additional important information and benefits:**

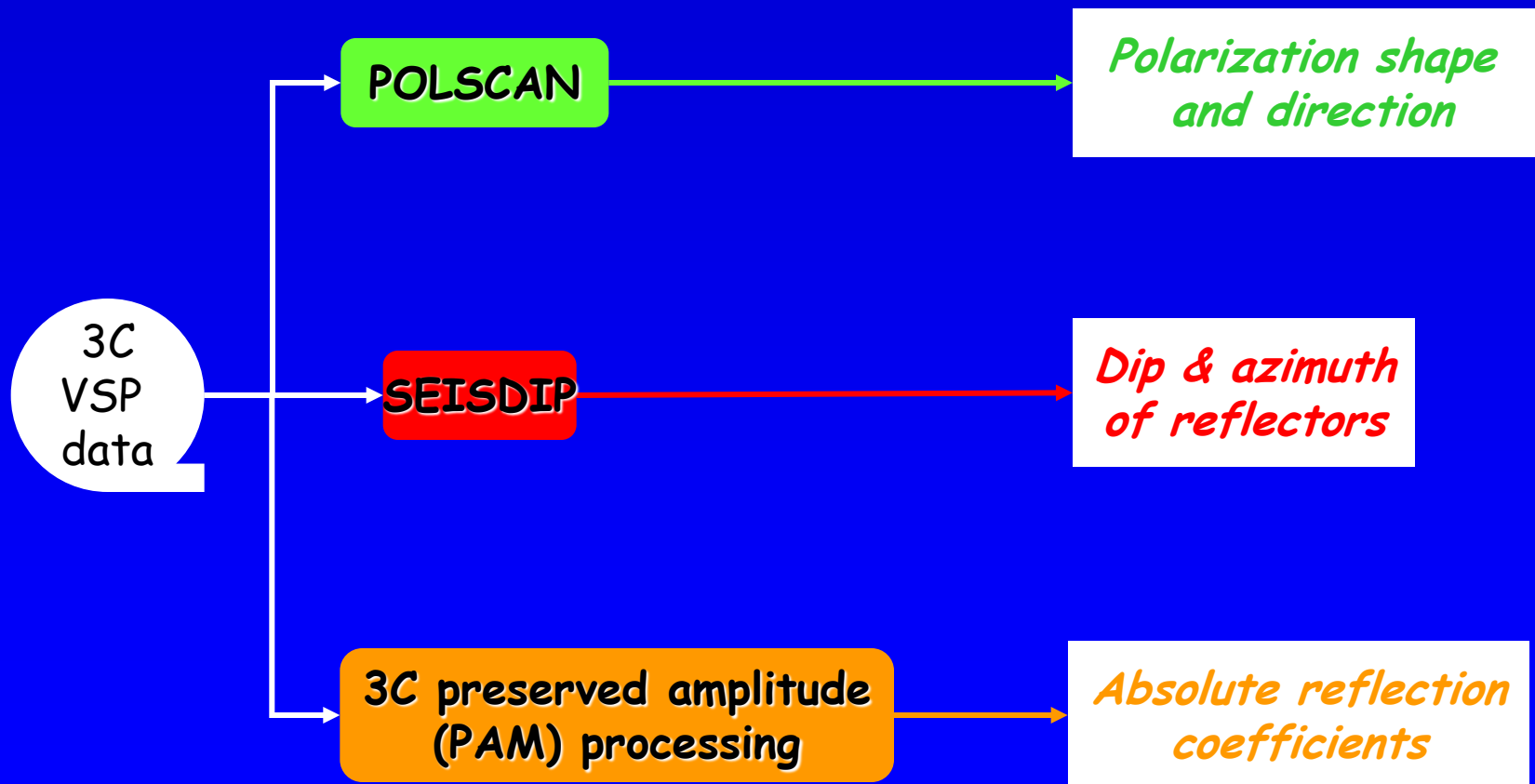
- 3D illumination of the seismic reflectors
- geological information such as **DIP AND AZIMUTH** of reflectors
- reliable identification, better discrimination and interpretation of the seismic wavefield.
- The Preserved Amplitude processing yields the **true REFLECTION COEFFICIENTS.**





# Methodology

## IFPEN method of borehole oriented 3C data processing



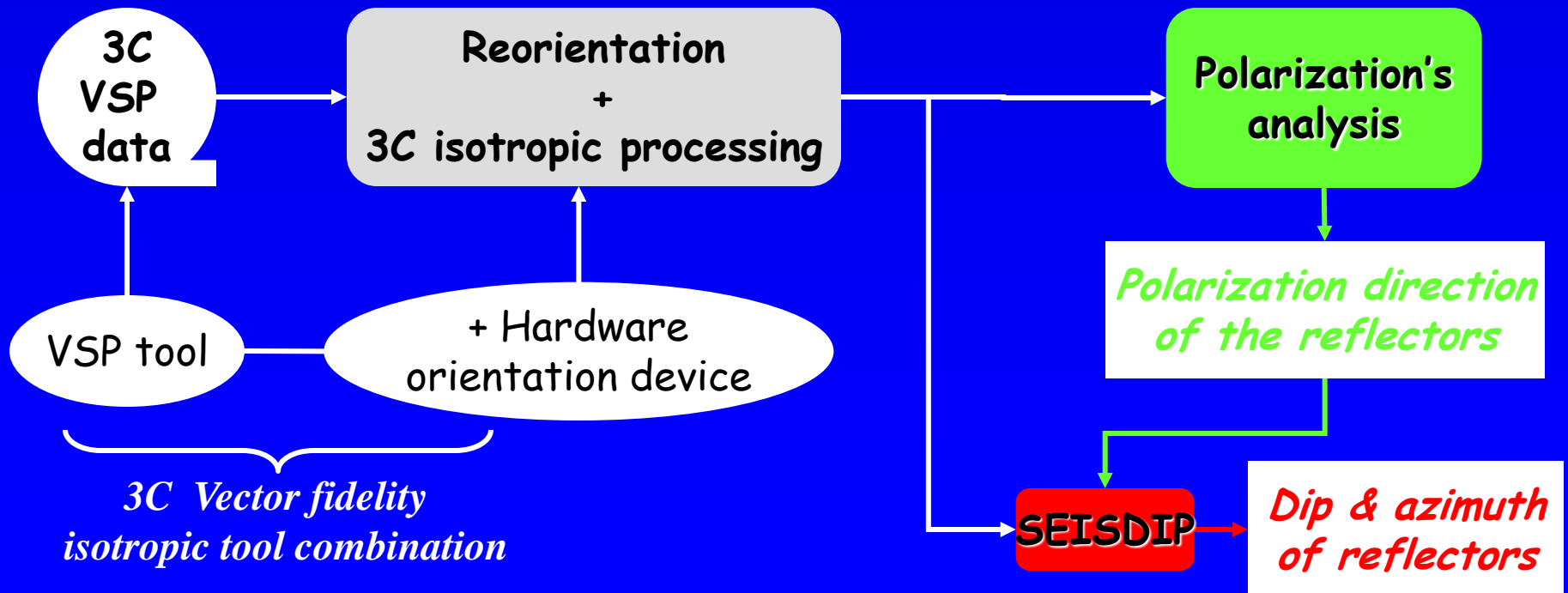


- Introduction: Why 3C processing
- **Seisdip method: dip & azimuth of reflectors**
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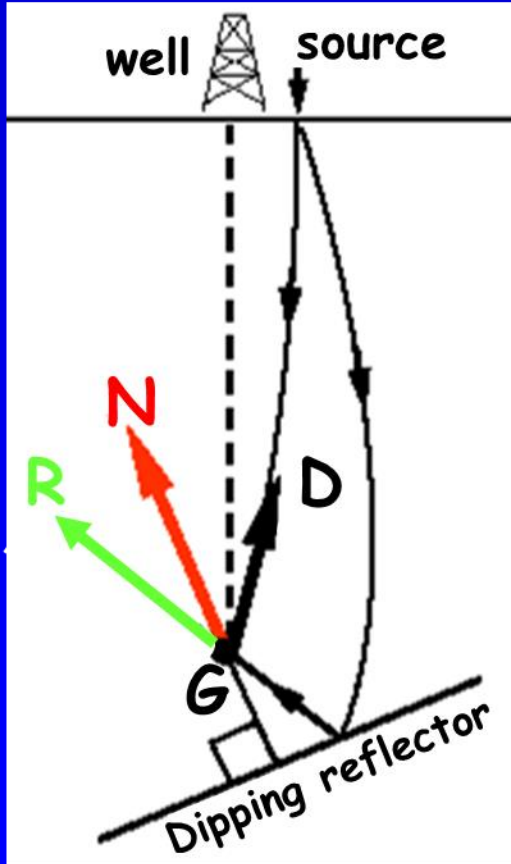
# Seisdip\* (\*Mark of IFPEN)

- To compute dip and azimuth of reflectors, near or far, around or below the borehole, intersecting it or not.
- To complement results obtained with other methods : surface seismic or borehole image logs (resistivity, acoustic)
- To offer an alternative solution when other methods fail





# Seisdip: principle



**D=Direct wave**

( First arrival polarization angles)

**R=Reflected wave**

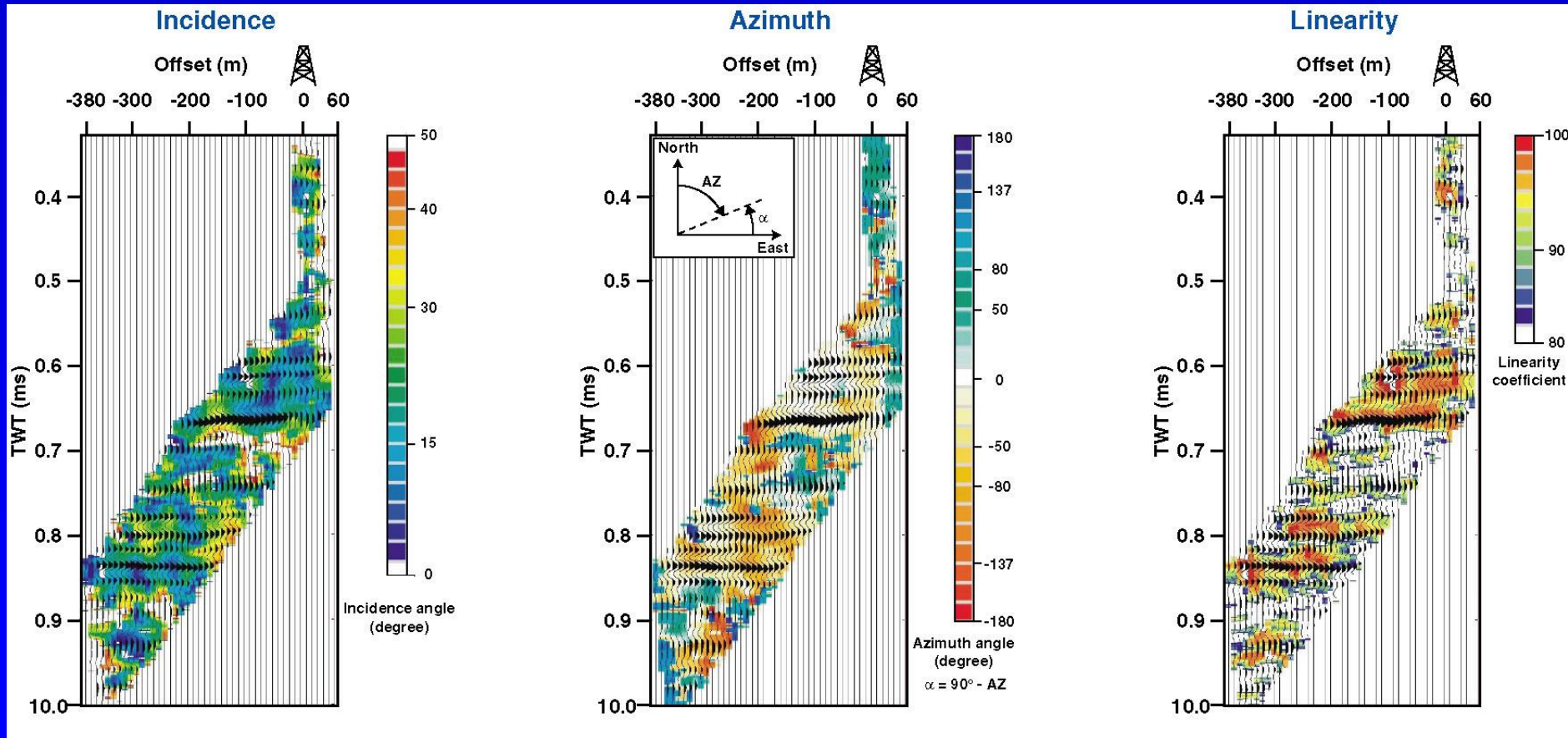
(reading from Polscan, or polarization angles after wave separation )

**N=Normal to the reflector,**  
defining Dip & Azimuth

**N** is obtained as the bisector of (D,R) angle for a reflector located right below the 3C geophone G,



# 3C polarization attributes: 2 angles and ellipticity ( 0-linear, 100 circular )

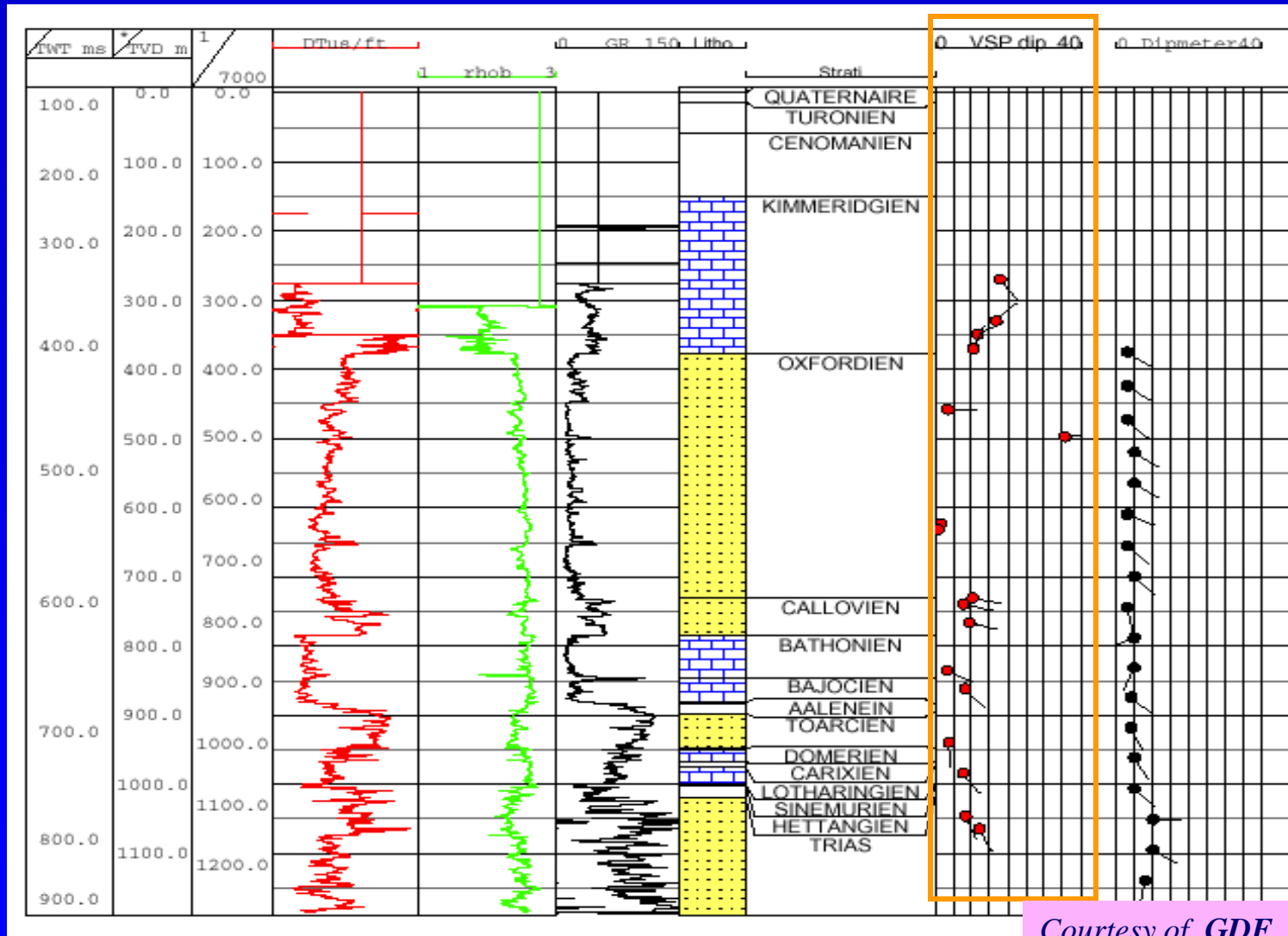


Display of wiggle Z component  
superimposed with color attribute

Courtesy of GDF



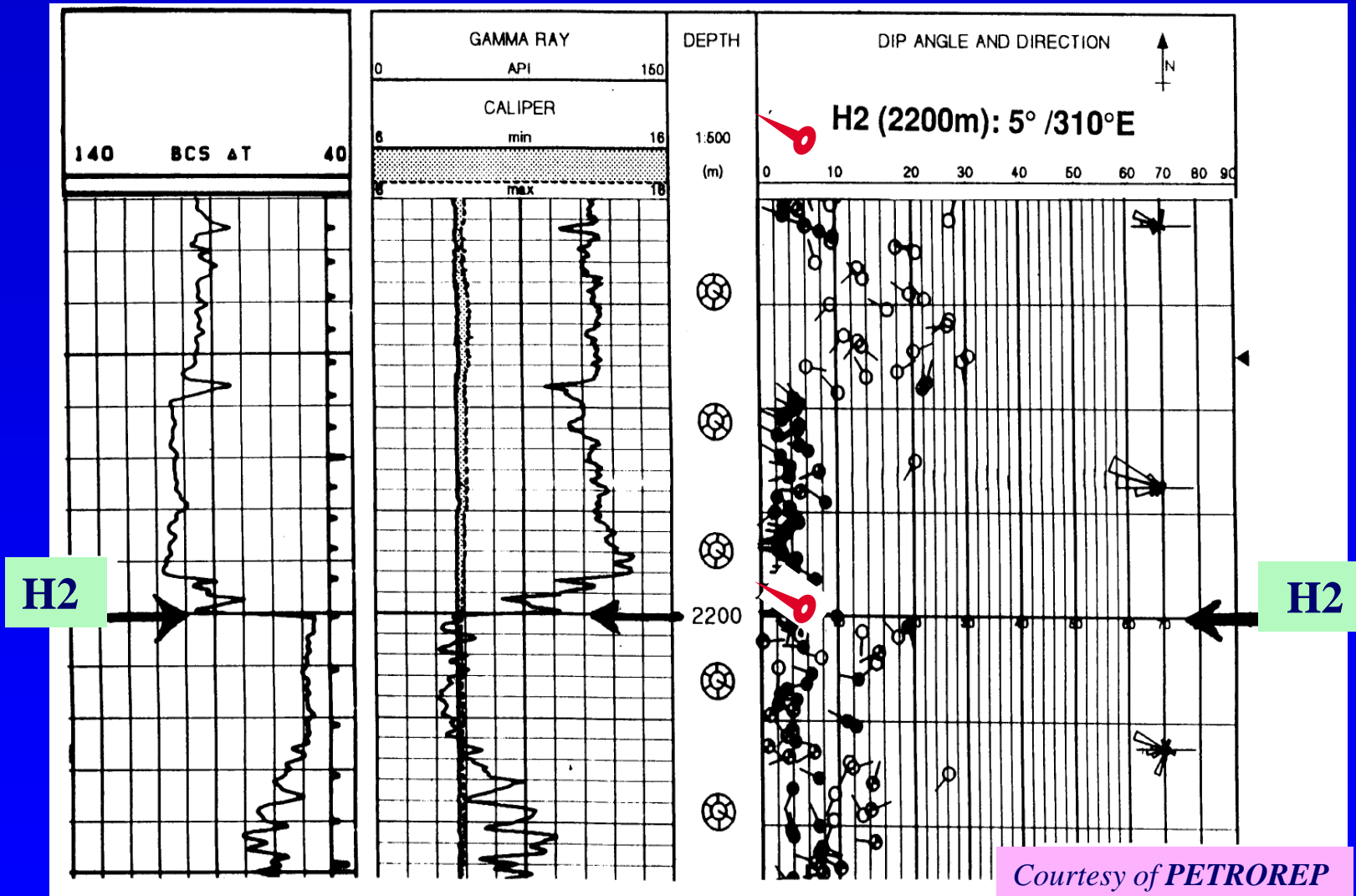
# Seisdip: composite plate example



A tad pole final display using the WellCAD software



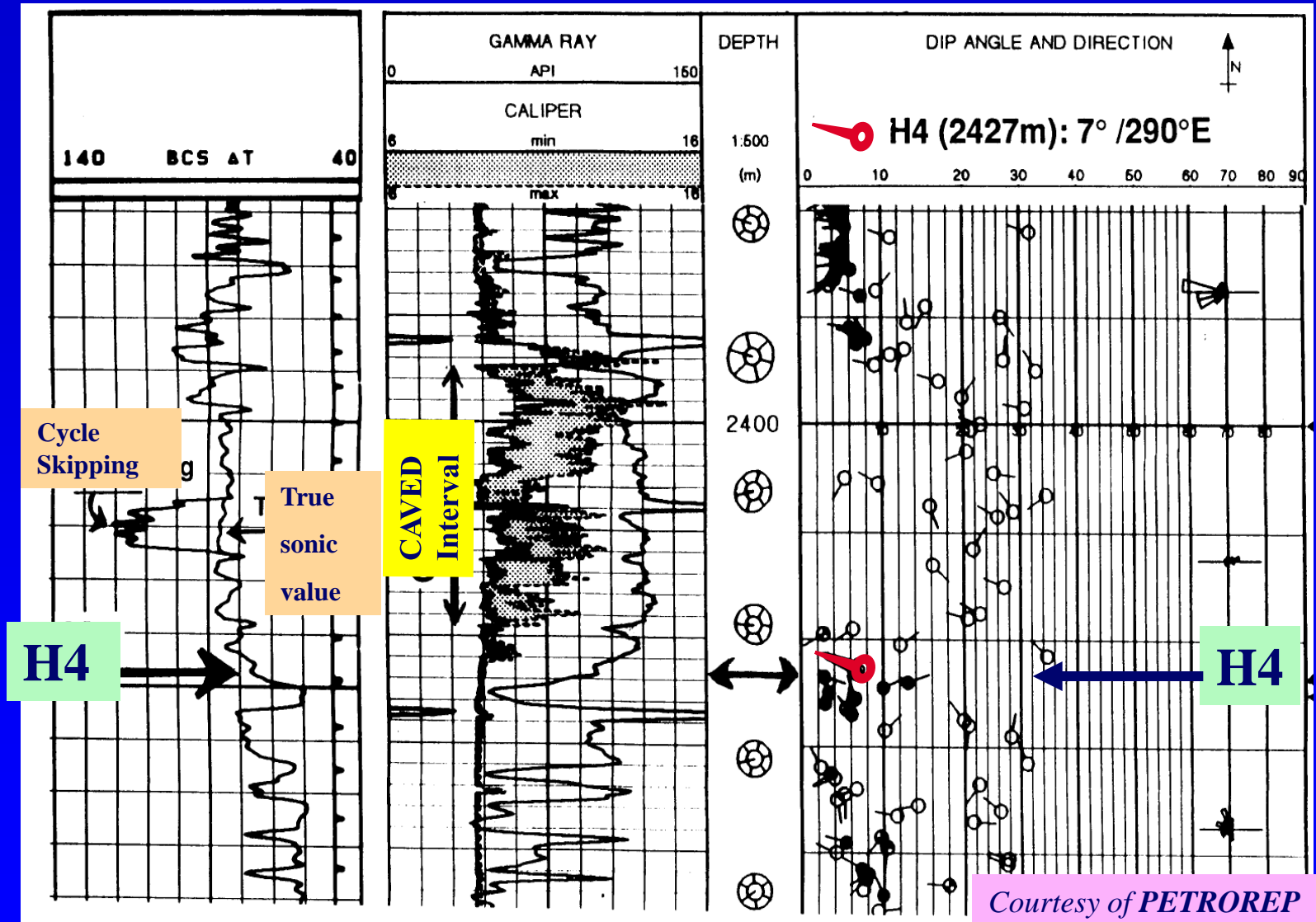
# SEISDIP result on H2 (2200m): 5°/310°E



Dip and azimuth determination at layer interface



# SEISDIP result on H4 (2427m): 7°/290°E



Dip and azimuth determination in a caving zone

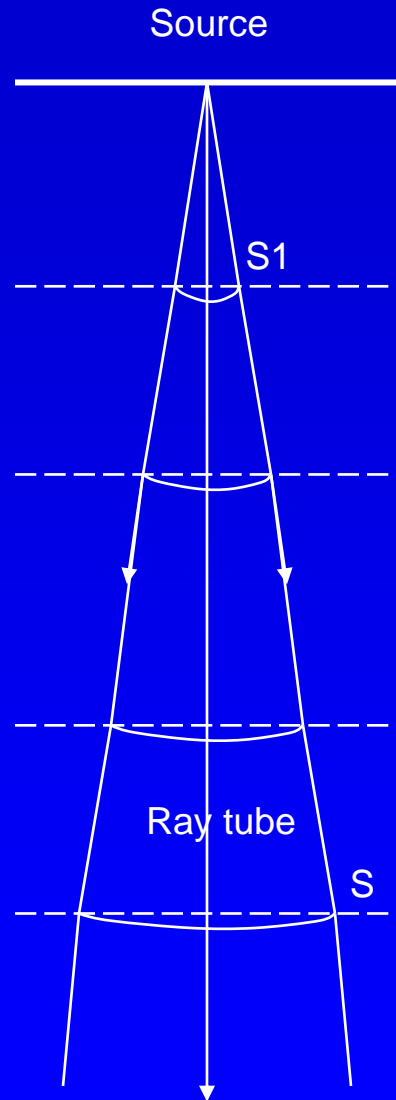




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# VSP Plane wave attenuation measurement



Surface energy density:  $E = \rho \cdot v \cdot A^2$

Wave front surface for a ray tube normal to the layering = Spherical divergence amplitude =  $S^{0.5} = V^2 \cdot t / V_0$

Plane wave amplitude for a constant impedance medium:  $A_p = A \cdot (\rho v)^{0.5} \cdot V^2 t$

For a deviated well:  $A_p = A \cdot (\rho v)^{0.5} \cdot V^2 t / \cos \alpha$

**S** = Surface of the wave front for a ray tube normal to layering

**A** = raw VSP amplitude

**V** = RMS velocity

**v** = interval velocity

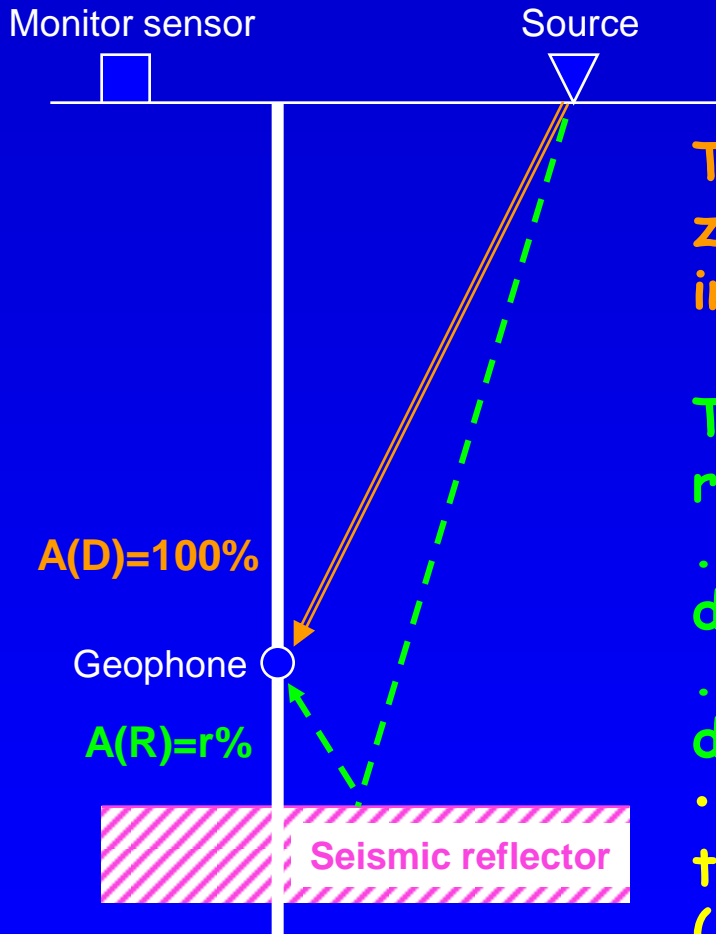
**t** = direct arrival time

**$\alpha$**  = angle between well axis and direct ray

Sub-Horizontal layering;

Method applicable in 1D approximation / deviated well

# Preserved amplitude VSP processing principle



The downgoing wavetrain is deconvolved in zero phase wavelet and normalized to 100% in the signal bandwidth.

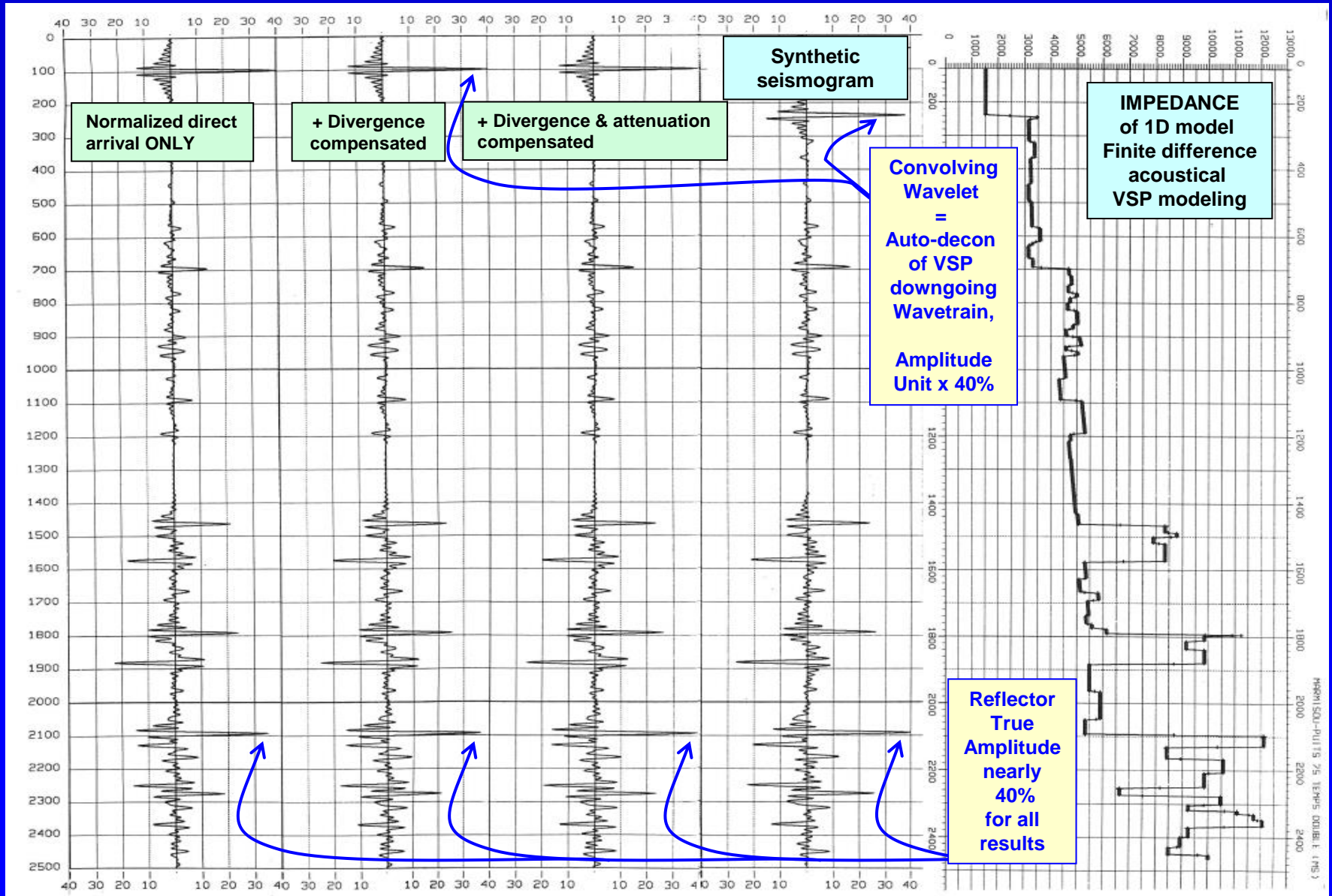
The deconvolved and bandpass filtered reflected arrivals are compensated for:

- Differential spherical divergence between direct time and reflection time
- Transmission attenuation relatively to the deconvolved Direct arrival
- In the corridor stack domain, these compensations are unnecessary ( example next slide )

True reflection Amplitude is expressed in percent %



# True Amplitude Corridor stack results from 1C-2D FD ZVSP model, vertical well





# The 3C VSP PAM processing method

A) Determine and compensate for all the causes of seismic wave attenuation from the HEAD of the Downgoing incident P-wave.

Normalization of the direct arrival  
**AFTER signature deconvolution**  
of the raw unseparated 3C VSP data  
by the down-going P wave train,  
filtered in the good S/N freq. bandwidth

Takes care of spherical spreading  
of the direct arrival,  
and local impedance variations

Amplitude and phase variations  
of the downgoing wavefield  
are eliminated, Direct arrival is a  
normalized band limited spiked  
wavelet of KNOWN amplitude  
( normalized to 100 )

Down-going and up-going waves **separation**  
by a multi-trace filter of velocity filter  
adjusted to the observed events  
( by time shift or time tracking)

*Continued on next slides*



# The 1C-3D PAM processing method in the corridor stack domain of a zero offset VSP recorded in a near vertical well

B1) *The plane wave approximation of the spherical wavefront  
Applies locally to the corridor stack domain,  
And results in the following simplifications:*

Spherical spreading : NO compensation needed for reflections  
Intrinsic attenuation: NO compensation needed for reflections

- Mute and construction of VSP corridor stack in two way travel time (TWT), and/or in Depth scale.
- True amplitude Reflectors, down to about 200ms below TD

For "look ahead VSP" Applications :

- 1) Apply best guess spherical divergence recovery below TD
- 2) Prior to Inversion of True amplitude VSP corridor stack provides **MORE RELIABLE** impedance results below TD



# The 3C-3D PAM processing method in the corridor stack domain of a zero offset VSP recorded in a near vertical well

B2) After signature decon with P-downgoing wavetrain polarized along Direct ray, and normalization of peak arrival to 100

*Compensations of reflection amplitudes are needed for:*

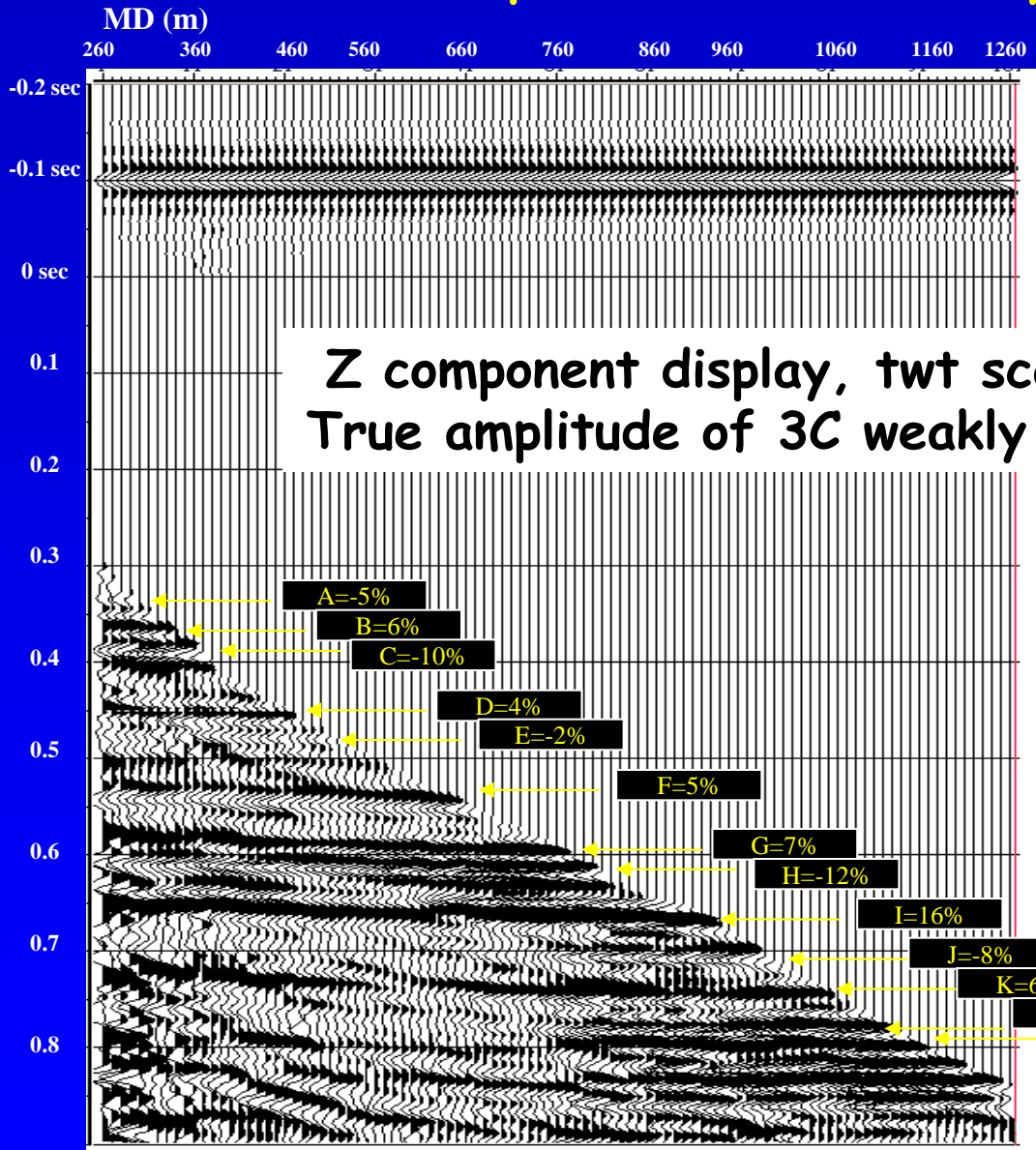
- a) Differential Spherical spreading occurring after direct arrival*
- b) Intrinsic attenuation for plane wave propagation after direct arrival*
- c) 1D approximation for a) and b) simplifies processing operations.*



- Dip and azimuth of reflectors, + incidence angle are computed
- Set Direct arrival in two way travel time (Time shift)
- Optional white noise rejection
- Optional Preserved amplitude spectral balancing
- Mute for 3C corridor stack if reflector time dips are NOT too high,
- Or VSP transposition if time dip of reflector events is important.



# Well G-1 - reflection coefficients from true amplitude 3C VSP processing



Wavelet normalized at 10% of the direct arrival amplitude

Z component display, twt scale, labeled with True amplitude of 3C weakly dipping reflectors

Polarity  
Black =  $KI < 0$



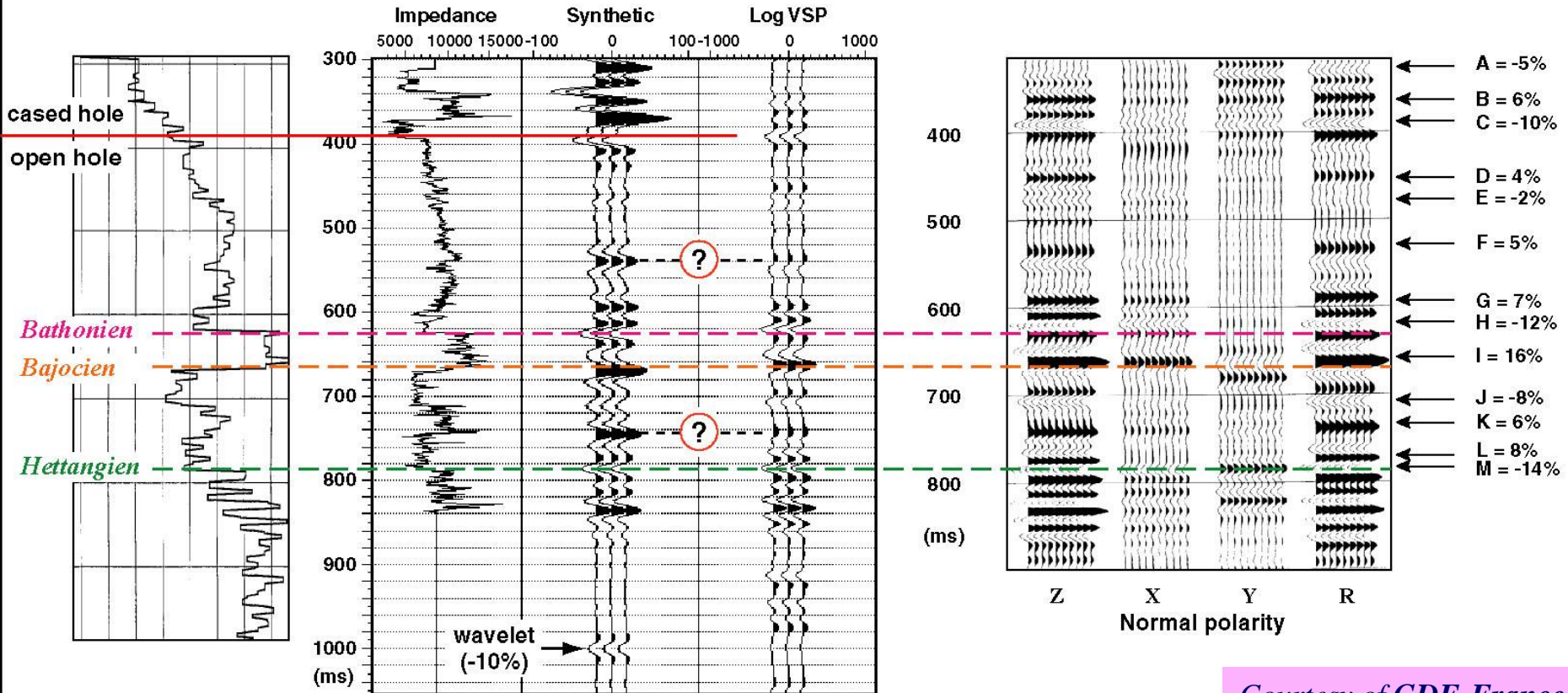


# 3C VSP True amplitude results

**a** VSP impedance

**b** Wireline results

**c** True amplitude corridor stack



Courtesy of GDF-France

- a** Result of the VSP log inversion / 3C resultant Component
- b** Wireline synthetic compared to the Log-VSP (Z-Cor. stack)
- c** 3C Corridor stack of X, Y, Z and the resultant component



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## Polscan *(IFP trademark)*

Polscan is a polarization analysis tool on depth adjacent 3C VSP traces to help identifying:

- the nature (reflected or diffracted event)
- and the wavemode (P or S) of 3C seismic events
- by scanning the 3C dataset in various geographically directions, displayed in a readable manner as a cylindrical projection set of geographical projections.

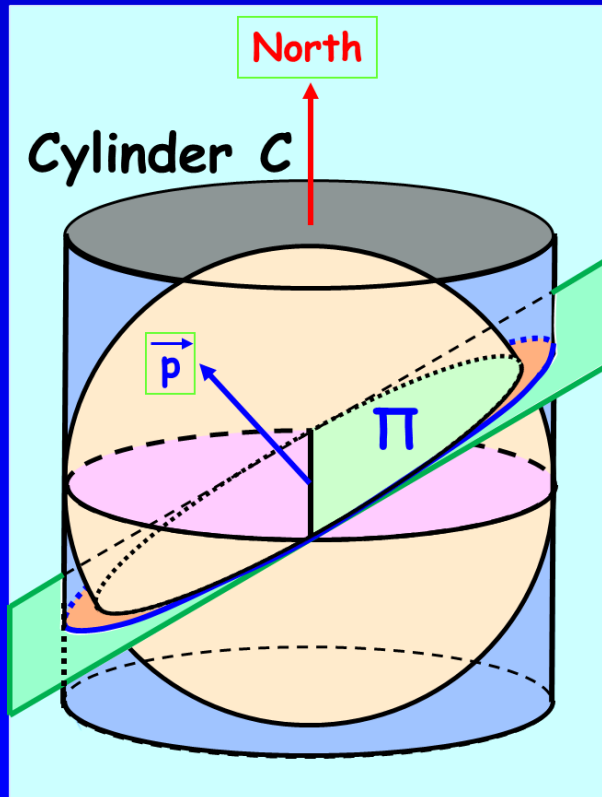
**It allows, after 3C reorientation:**

- to compute the direction of polarization of events
- to discriminate and separate interfered events

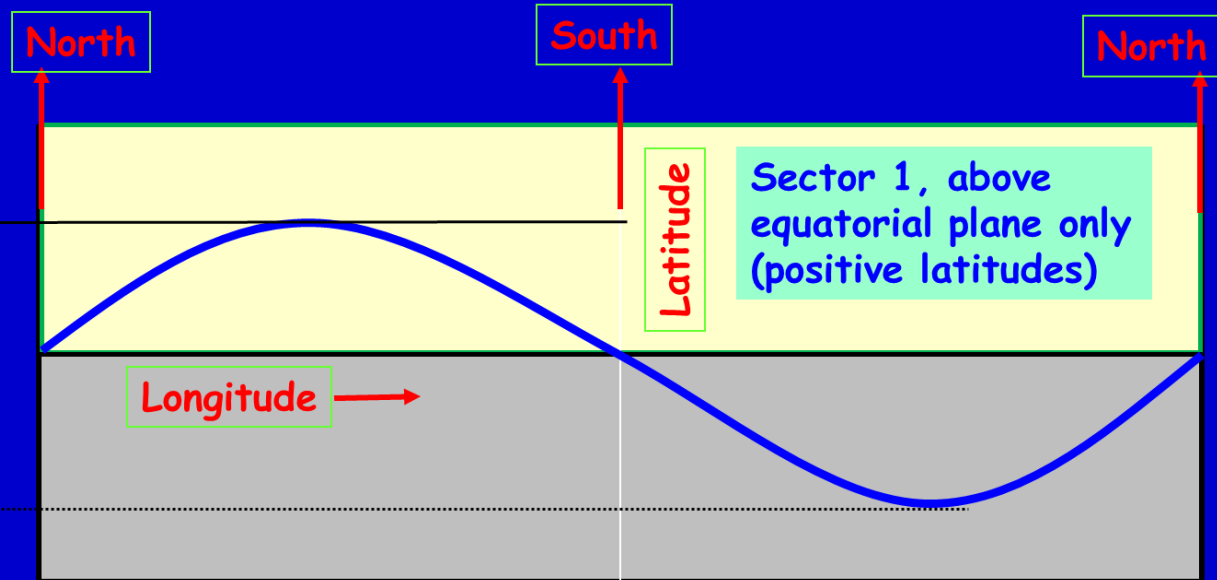


# Polscan principle (1)

The idea is to discriminate several interfering seismic events of different polarizations... through a readable plate display



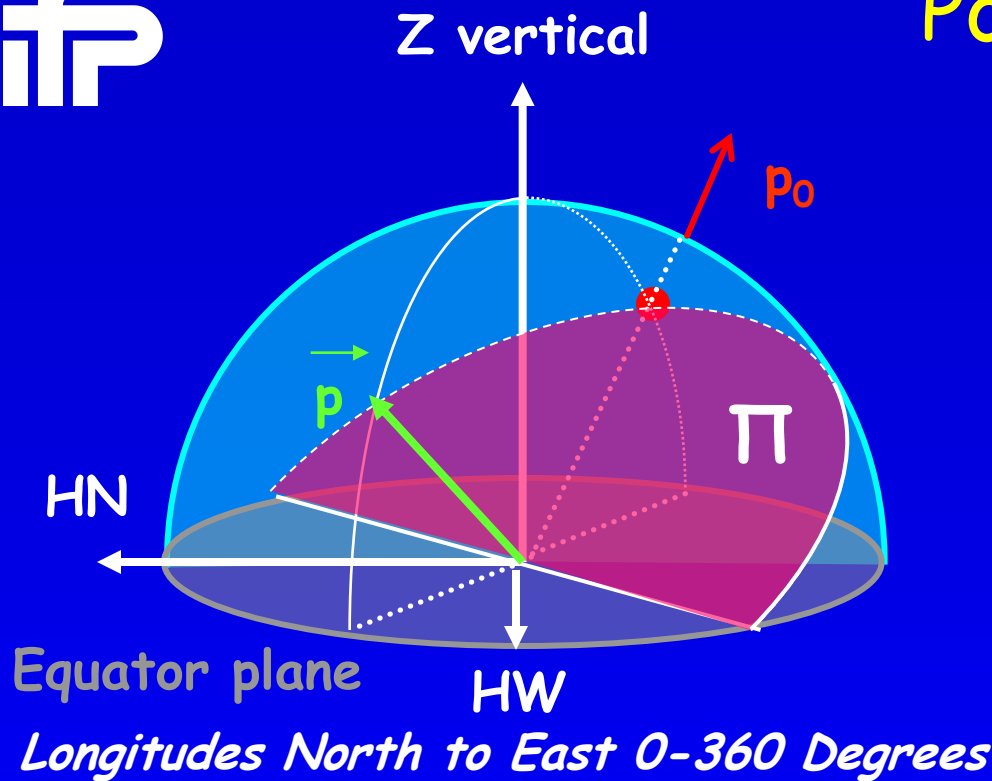
**Unwrapped cylindrical Projection:** amplitude of linear vector  $p$ , normal to plane  $\Pi$ , is null along the blue sine line below ( intersection with cylinder  $C$  )



**Intersection of plane  $\Pi$  with cylinder  $C$  = SINE CURVE**  
For Scan analysis of 3 Component seismic signals of various sign, it is sufficient to compute projections of the seismic wavefield **Sector 1 ONLY**, so as to reduce the size of the display )



# Polscan principle (2)



$\vec{p}$ : polarization direction of a linear event

$\Pi$ : plane orthogonal to polarization vector  $\vec{p}$

$p_0$ : intersection point of  $\Pi$  with the sphere

## Azimuth and incidence of $\vec{p}$ ?

A linearly polarized event shows a null amplitude in the plane ( $\Pi$ ) orthogonal to its polarization

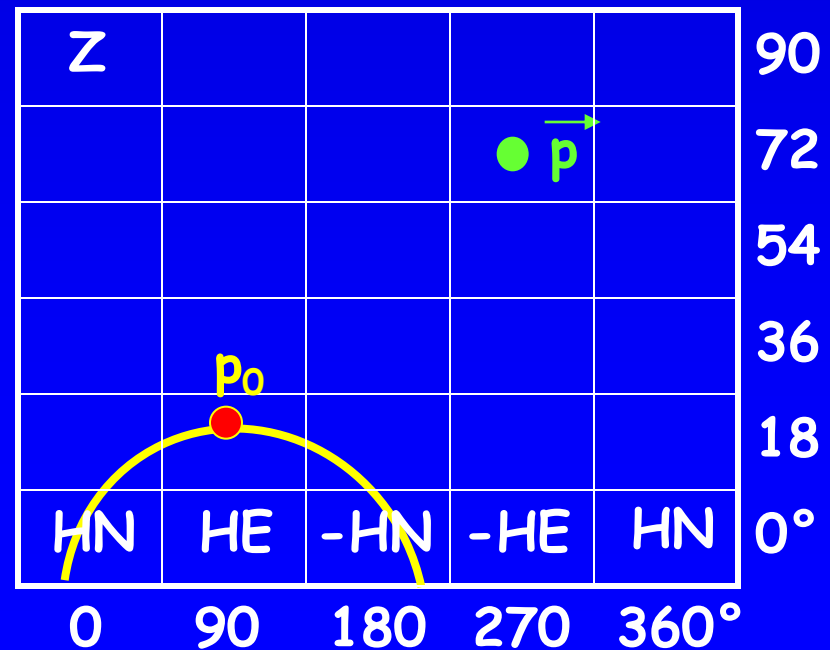


# Polscan: in practice

- A single depth-time window of 3 component traces
- is selected , then projected along parallel and meridians.
- Computation of incremental projections along longitude angles from 0 to 360° and incidence angles from 0 to 90°
- Display as a cylindrical Projection of a half sphere

**CYLINDRICAL PROJECTION  
DISPLAY  
( positive latitudes only )**

**Sine curve of Null amplitude  
in the plane  
orthogonal to vector P**



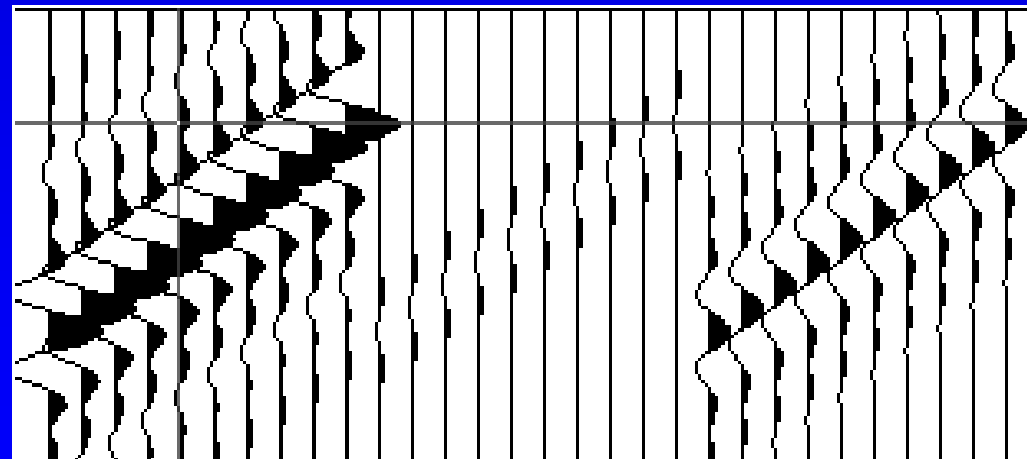


# Polscan: example

Input: Single linear event (A)

Incidence :  $20^\circ$

Azimuth :  $\sim 87^\circ$



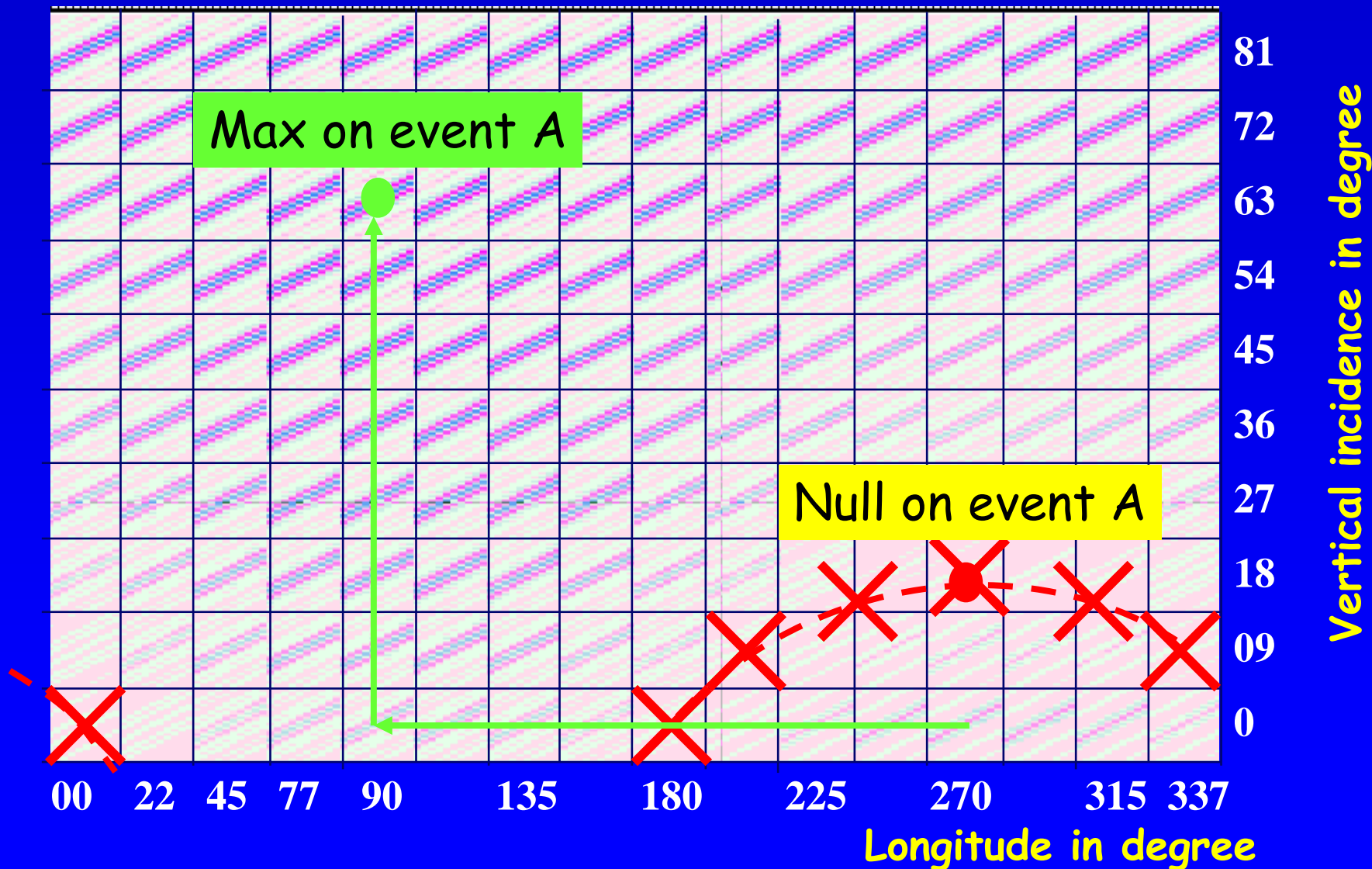
Z vertical

H-North

H-East



# Polscan : a readable cylindrical projection display







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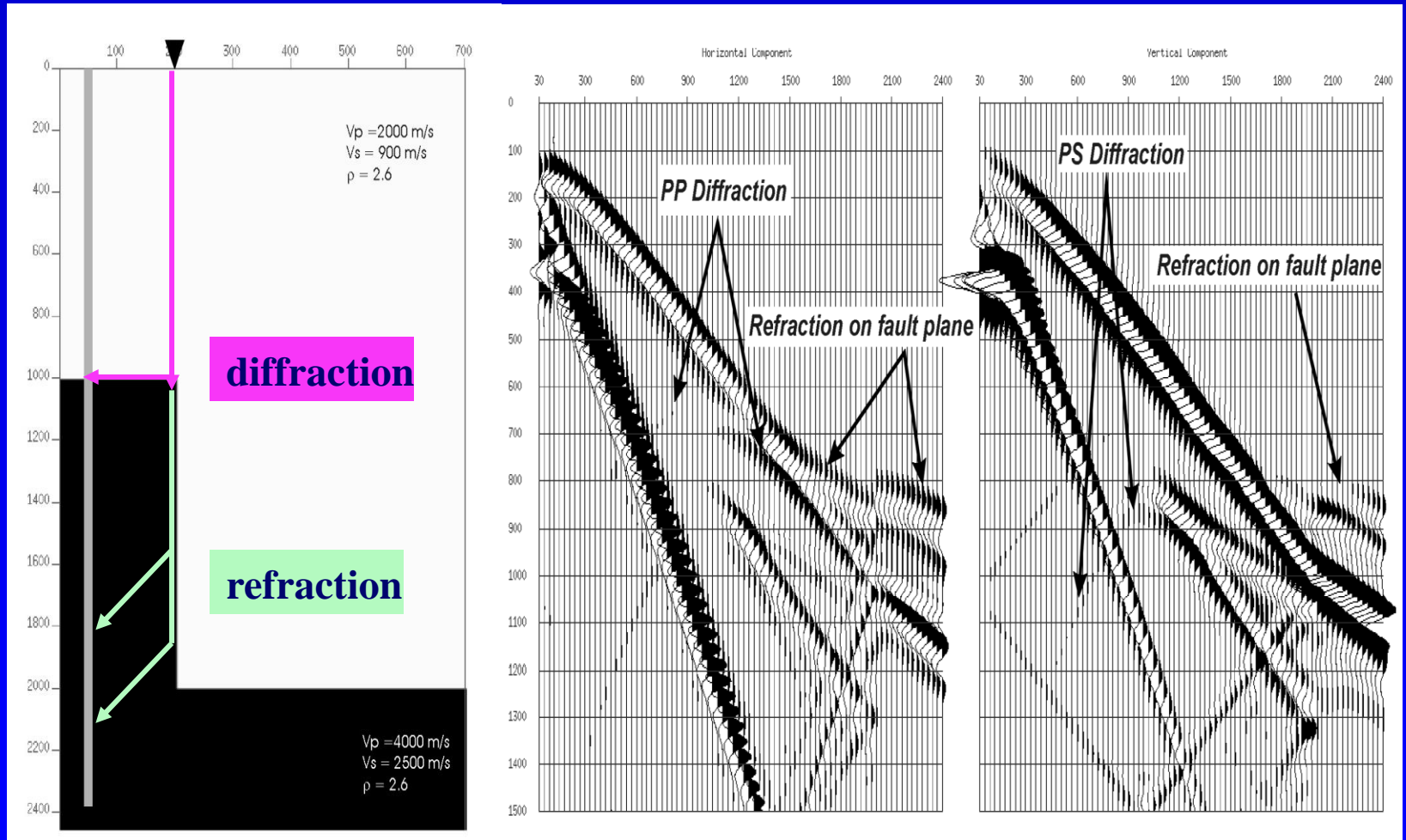


# Corner fault diffraction and refraction

Geologic model

Horizontal component

Vertical component

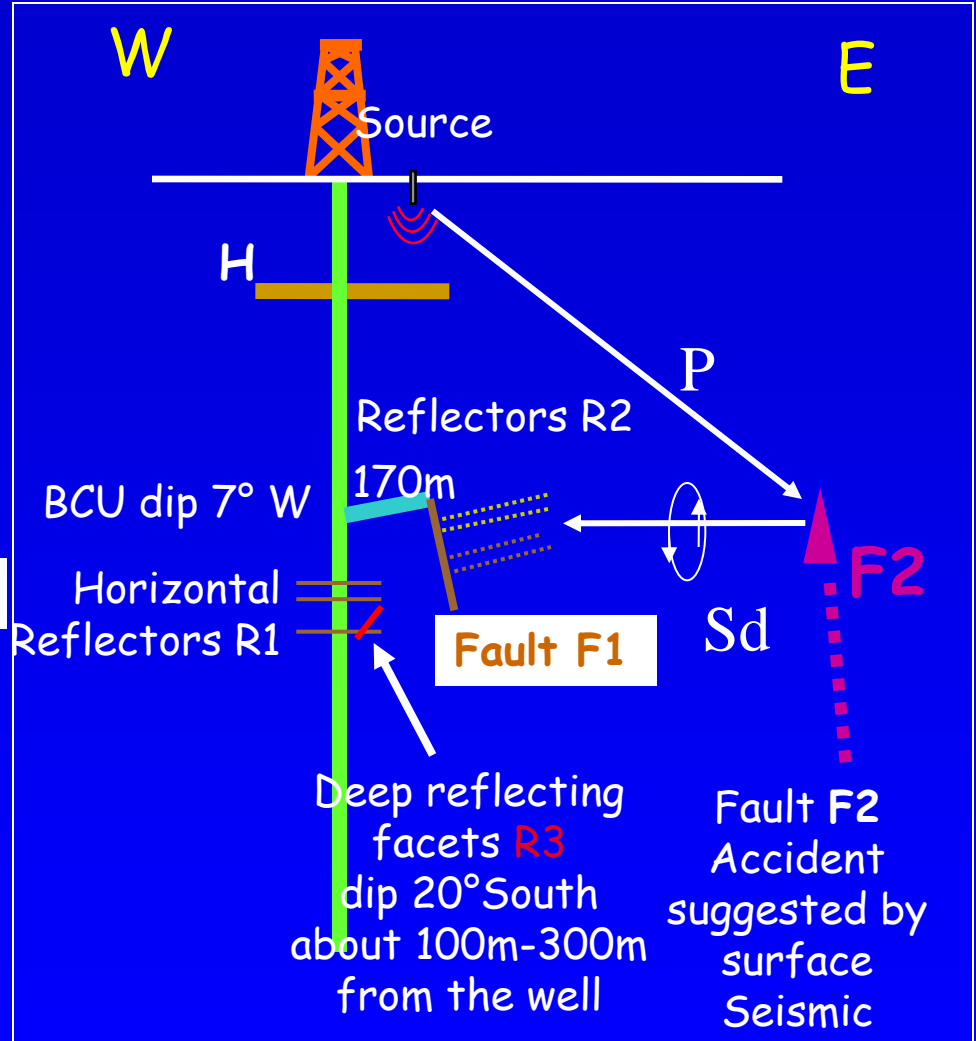
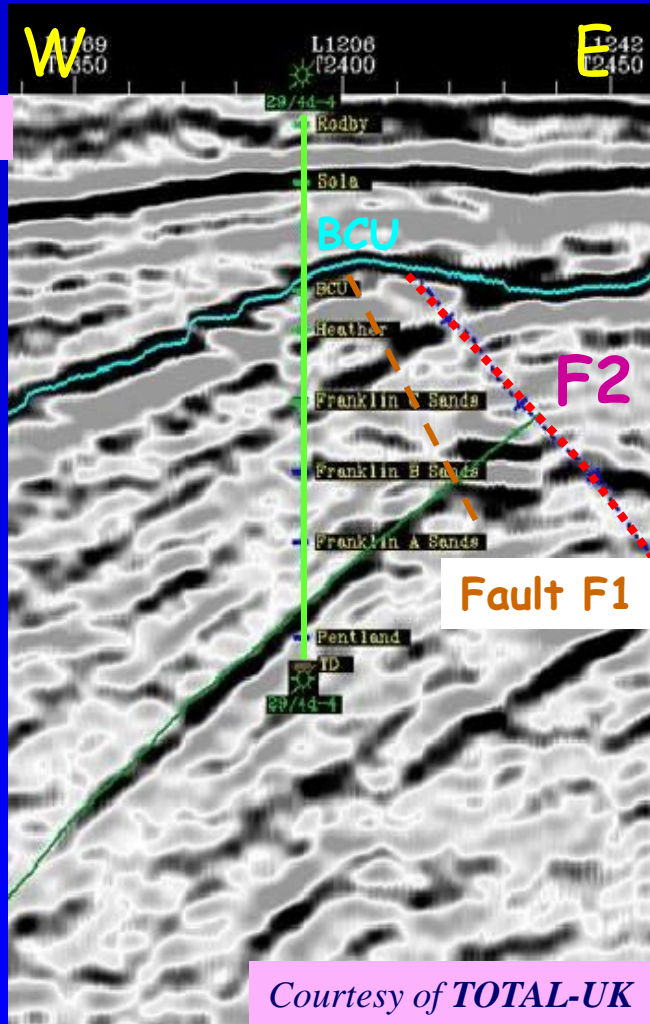


2D FD elastic modeling for complex seismic response analysis



# W-E Structural Sketch from 3C VSP

Case 1

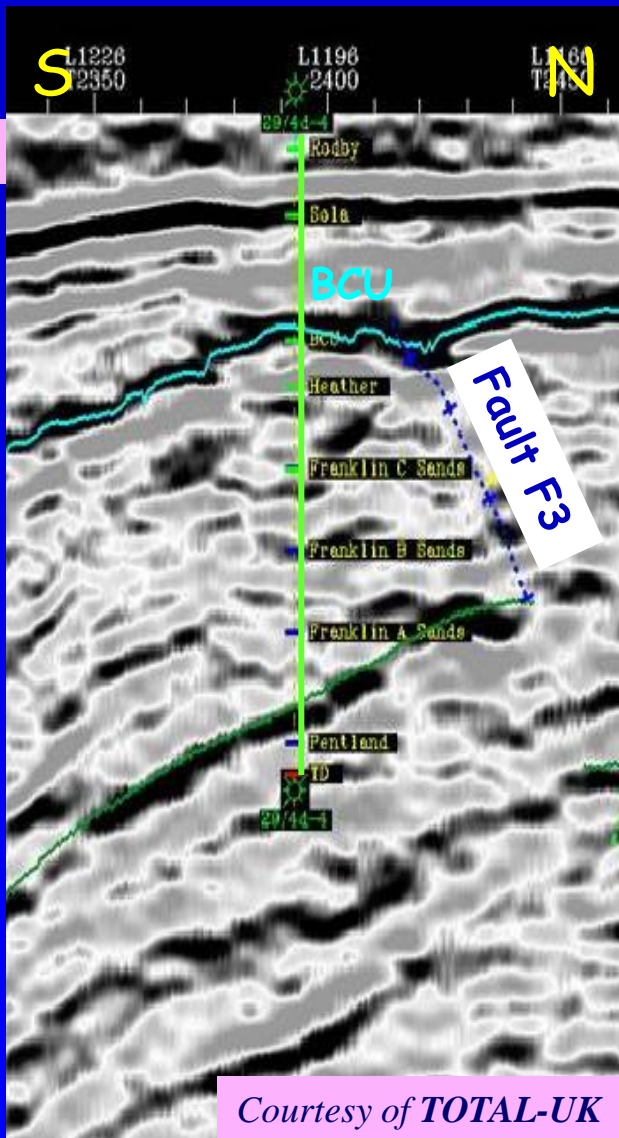


Confrontation of 3C VSP results with surface seismic (left side)

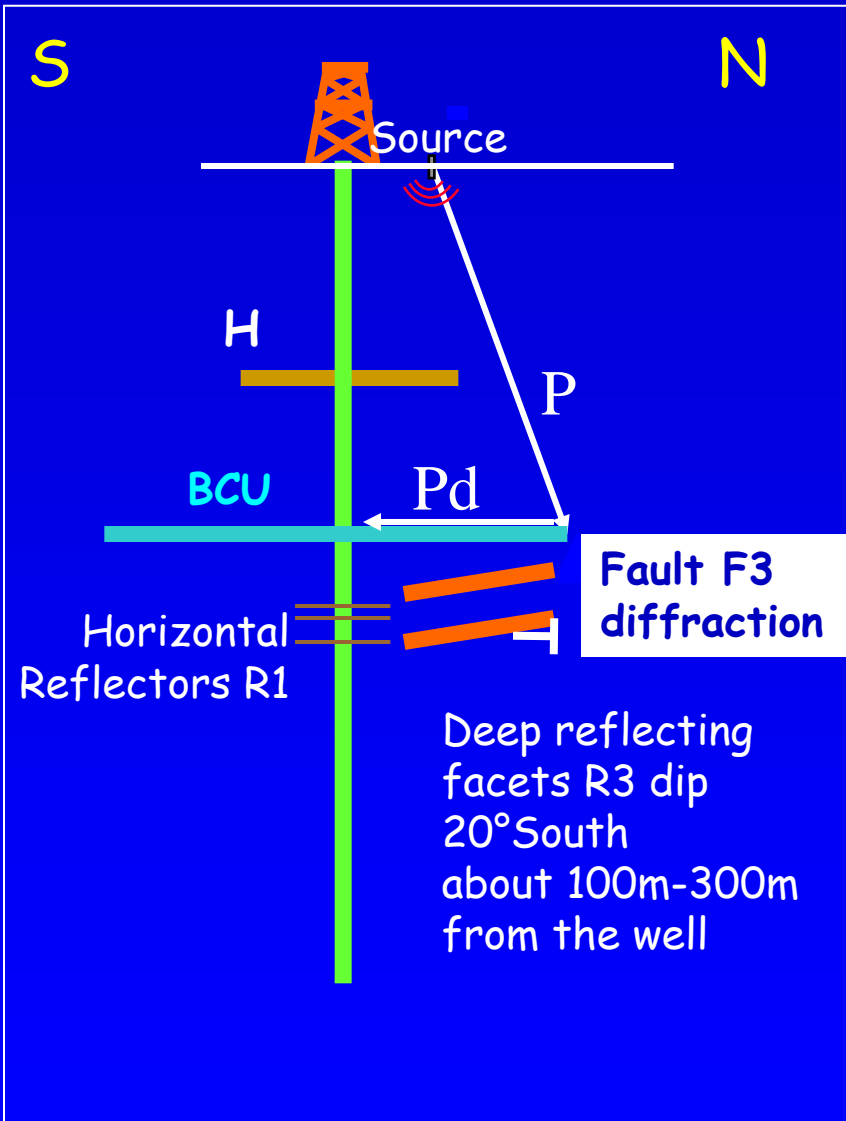


# S-N Structural Sketch from 3C VSP

Case 1



Courtesy of TOTAL-UK

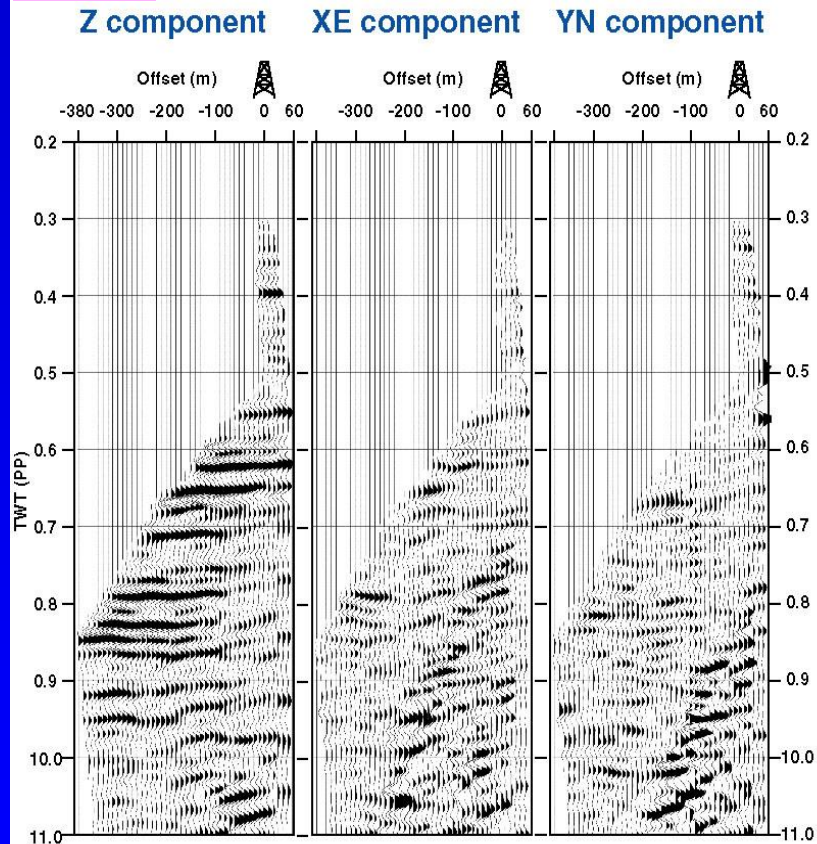


Confrontation of 3C VSP results with surface seismic (left side)

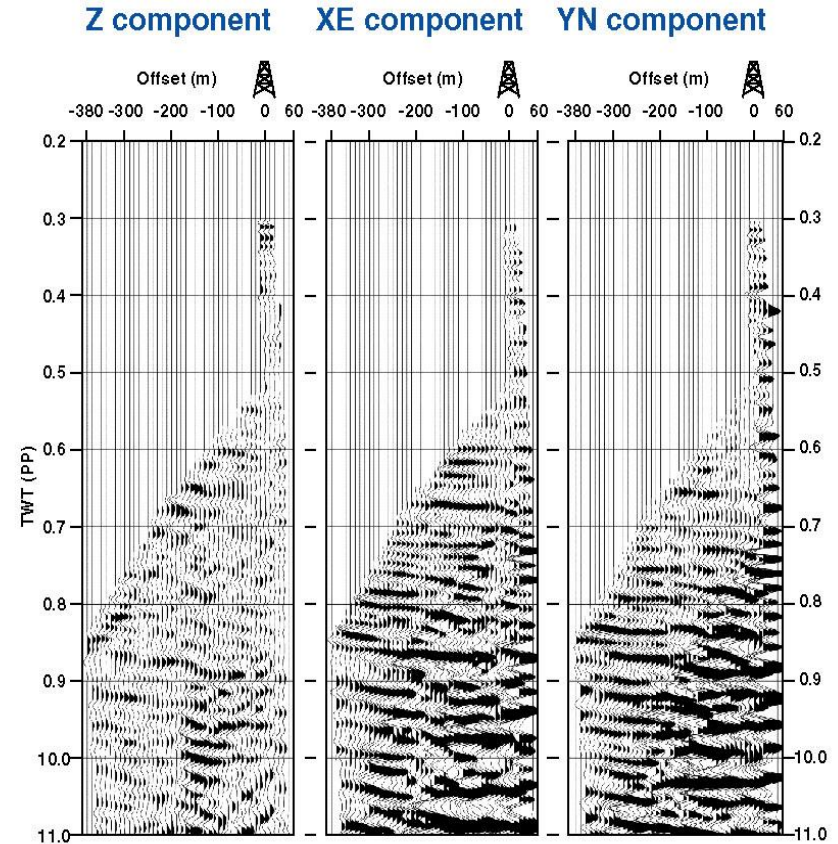


# 3C isotropic P-P and P-S VSPCDP stacks can be systematically produced

## Case 2



3C Binstack of the P-P wavefield



3C Binstack of the P-S wavefield

Courtesy of GDF-France

Reflected events in TWO wavemodes confirm the geological structure



# Conclusions (1/2)

The need for deep information is felt important for the exploration wells where a zero offset VSP (rig-source VSP) is generally acquired.

These wells being mostly vertical, or with intervals of low inclination, a hardware reorientation tool often needs to be combined with the VSP tool, in the deep depth intervals useful to the reservoir imaging.

Independently from all other methods, the 3C VSP processing yields dip and azimuth of reflectors, including from reflectors which do not intersect the borehole. In contrast the borehole wall images yields the formation dip right on the borehole wall, in open hole only.

Diffracted arrivals and interfered direct arrivals denotes the presence of accidents in the well vicinity which also helps updating the geological model around the well.



## Conclusions (2/2)

- The use of the 3 component geophones brings additional and important information for the geologist, with improved confidence in the results.  
*Obvious but not practiced industrially yet!*
- IFP explored and tested 3C processing techniques on many VSP dataset, demonstrating the feasibility and the interest of 3C VSP processing, *evidencing the need for improving the VSP tool orientation at acquisition stage.*