3C VSP

Processing and Interpretation in IFPEN

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

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Outline

- 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)

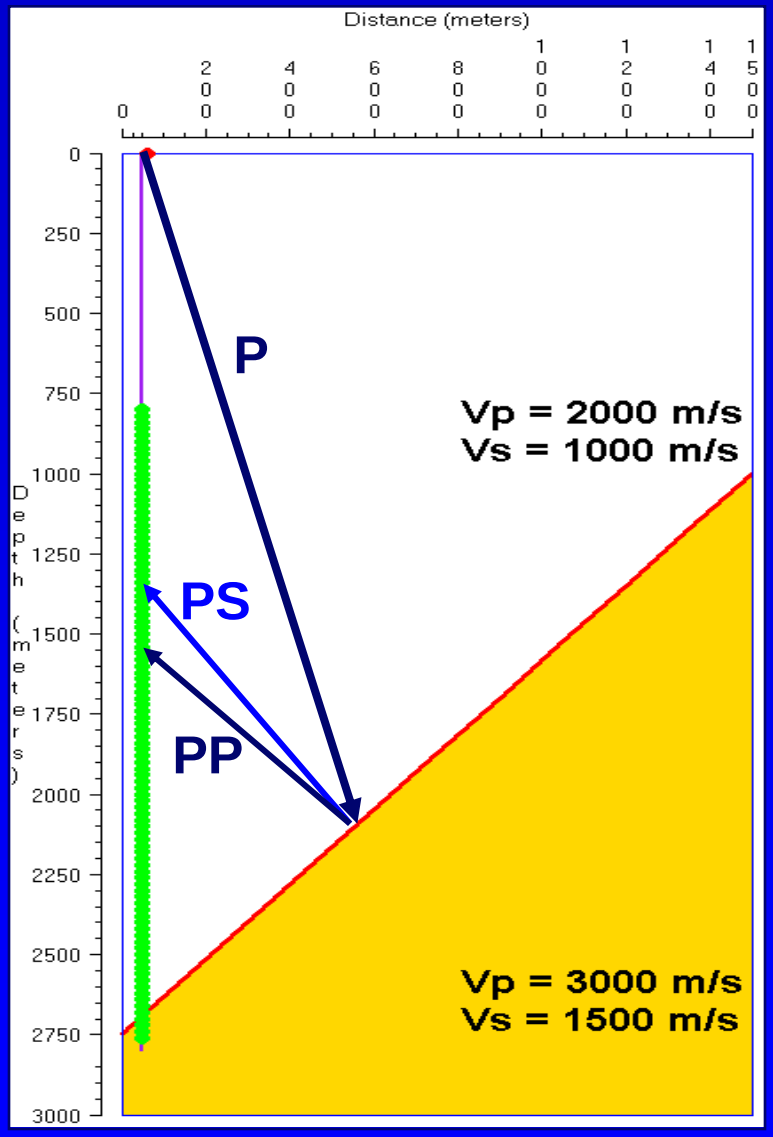
→ is processed

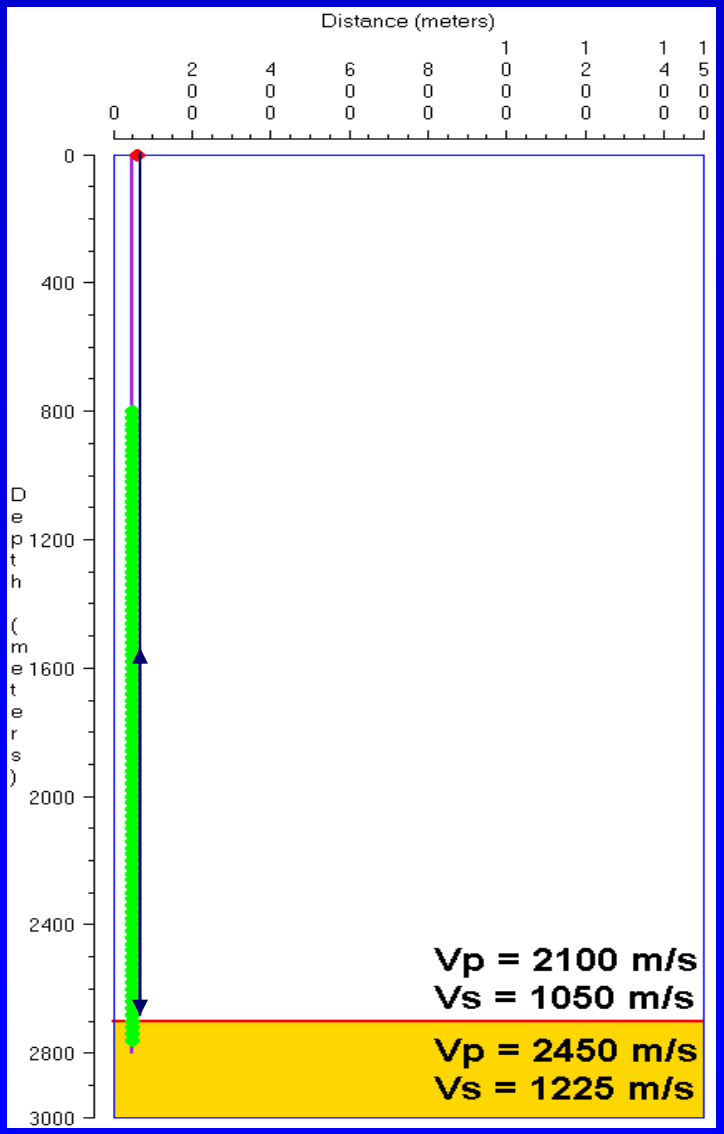
1D imaging around the well

loss of information

interpretation possibly erroneous

Why processing 3 components ?





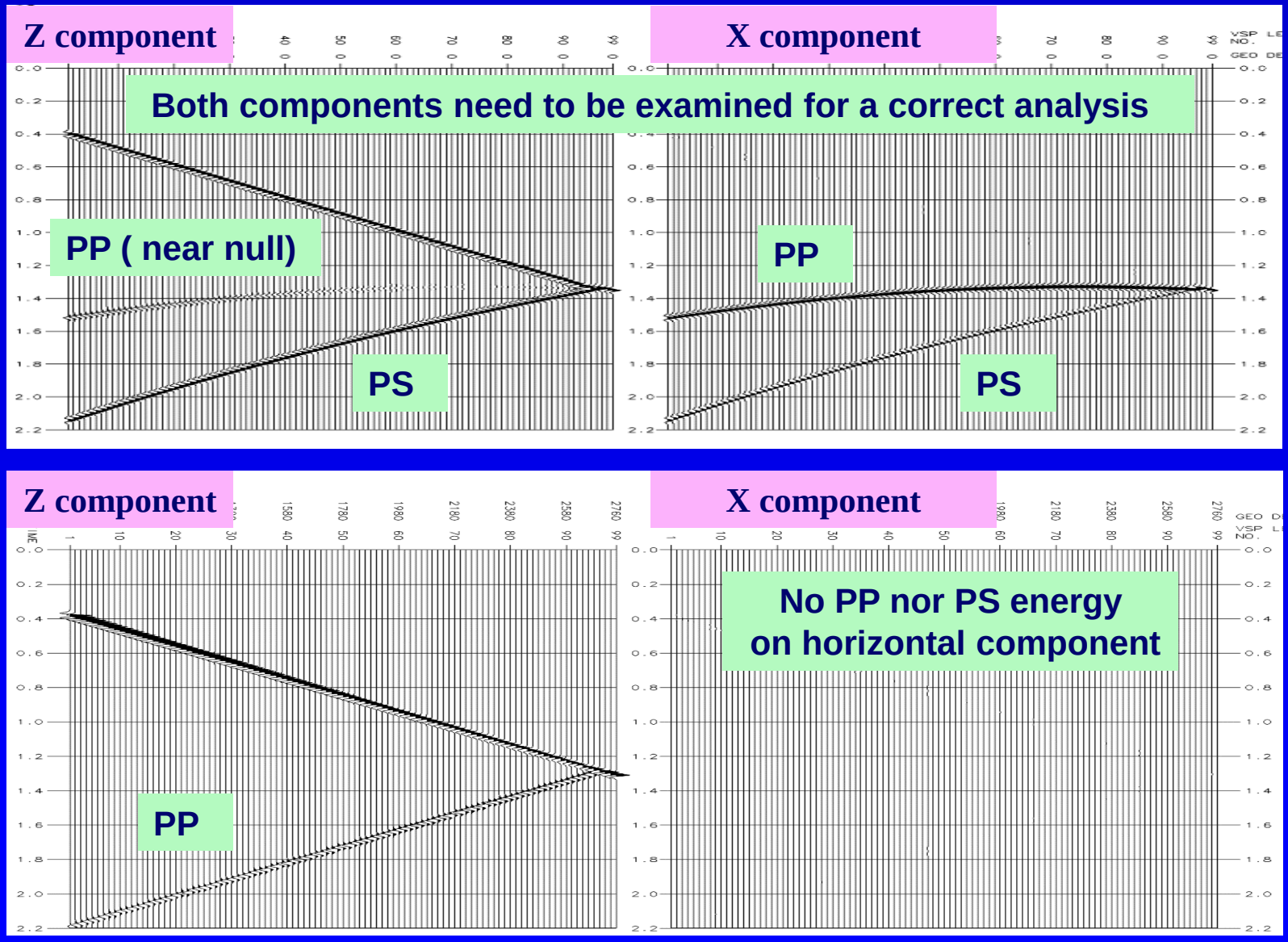
50 ° dipping model

Flat model

Dipping versus flat model, 2C response

50° dip

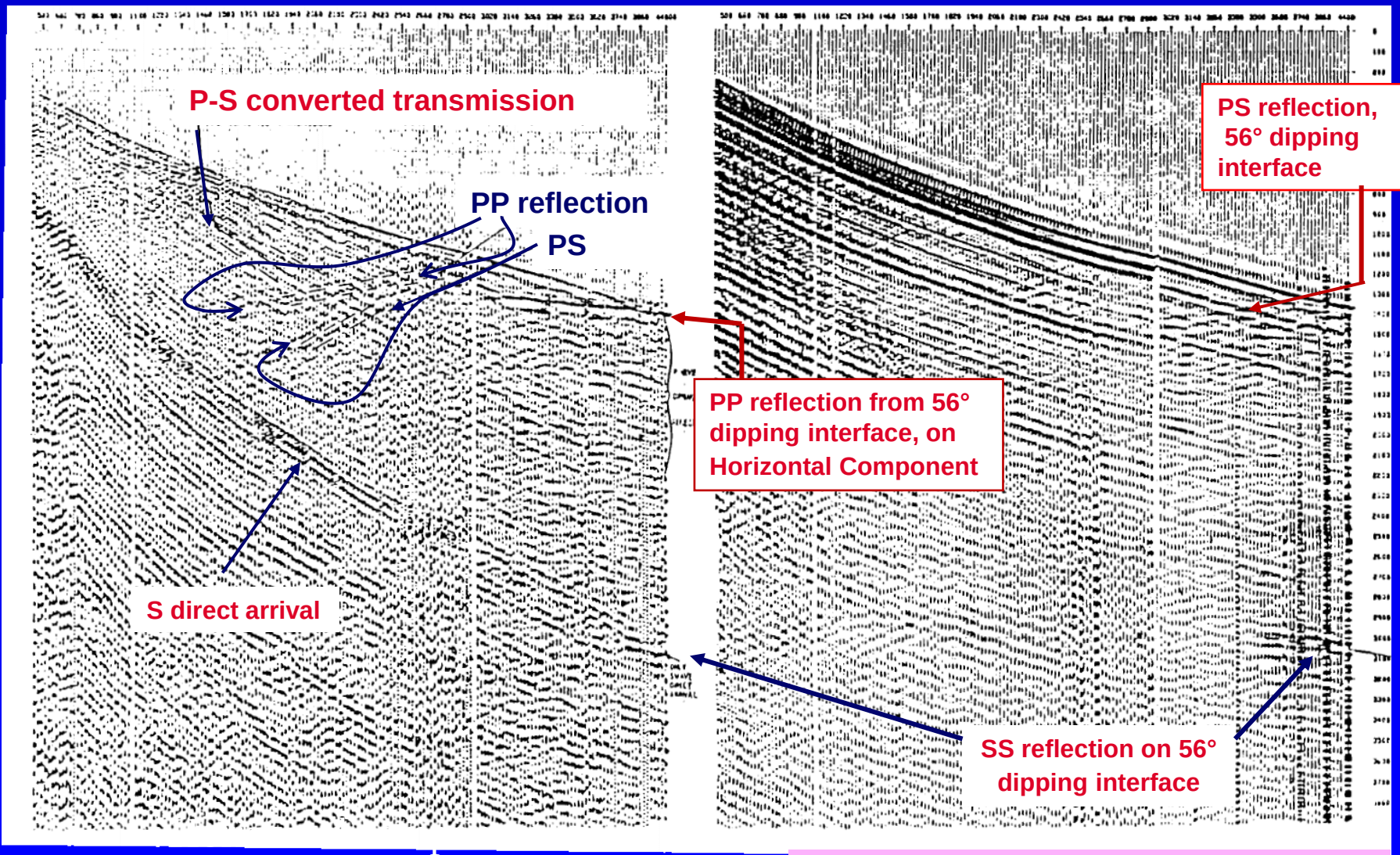
Flat model



Real seismic response on a dipping reflector

Horizontal component

Vertical component



H. component inline with tool arm

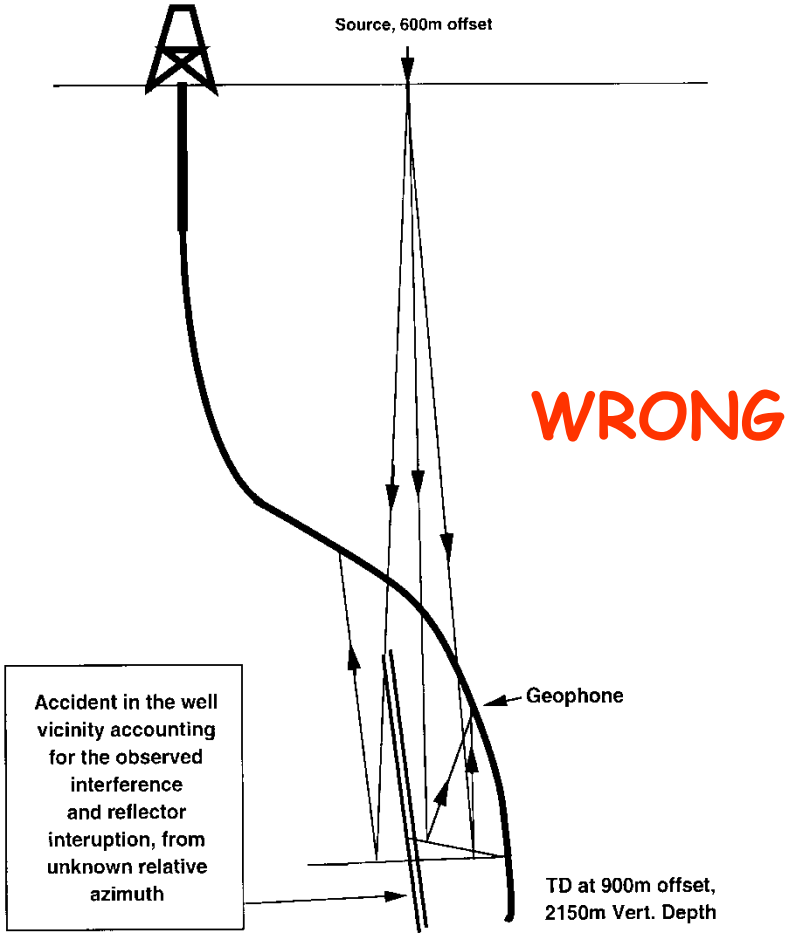
Courtesy of OMV-Austria, 1983

3C versus 1C processing

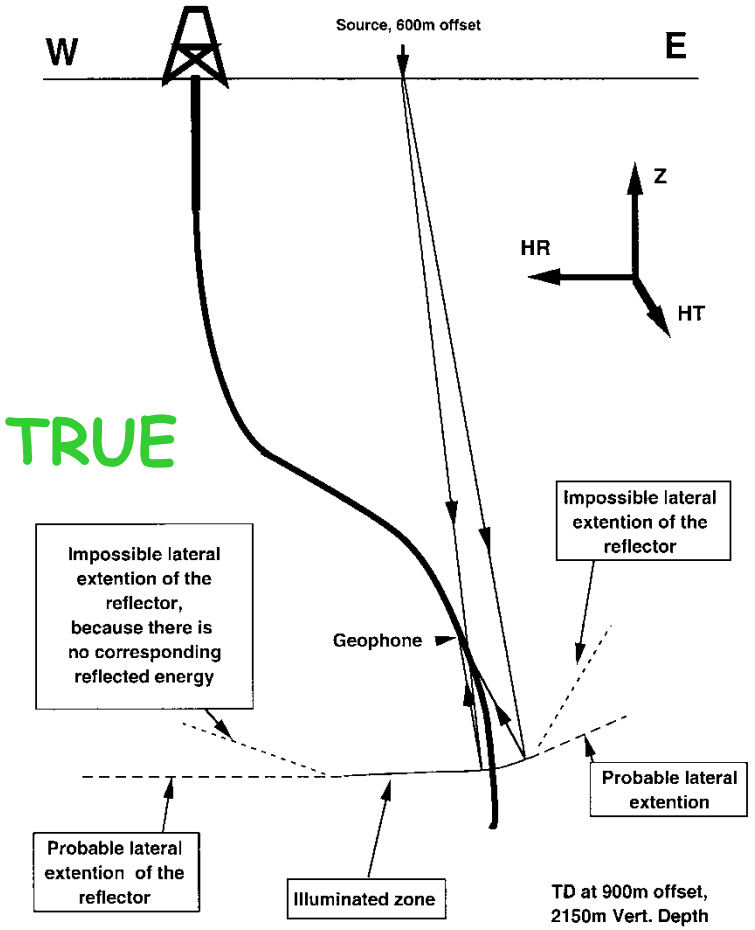
Naville, C., Serbutoviez, S., Bruneau, J., Japiot, H., Daures, R., Gaborit, J.Y.,

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:

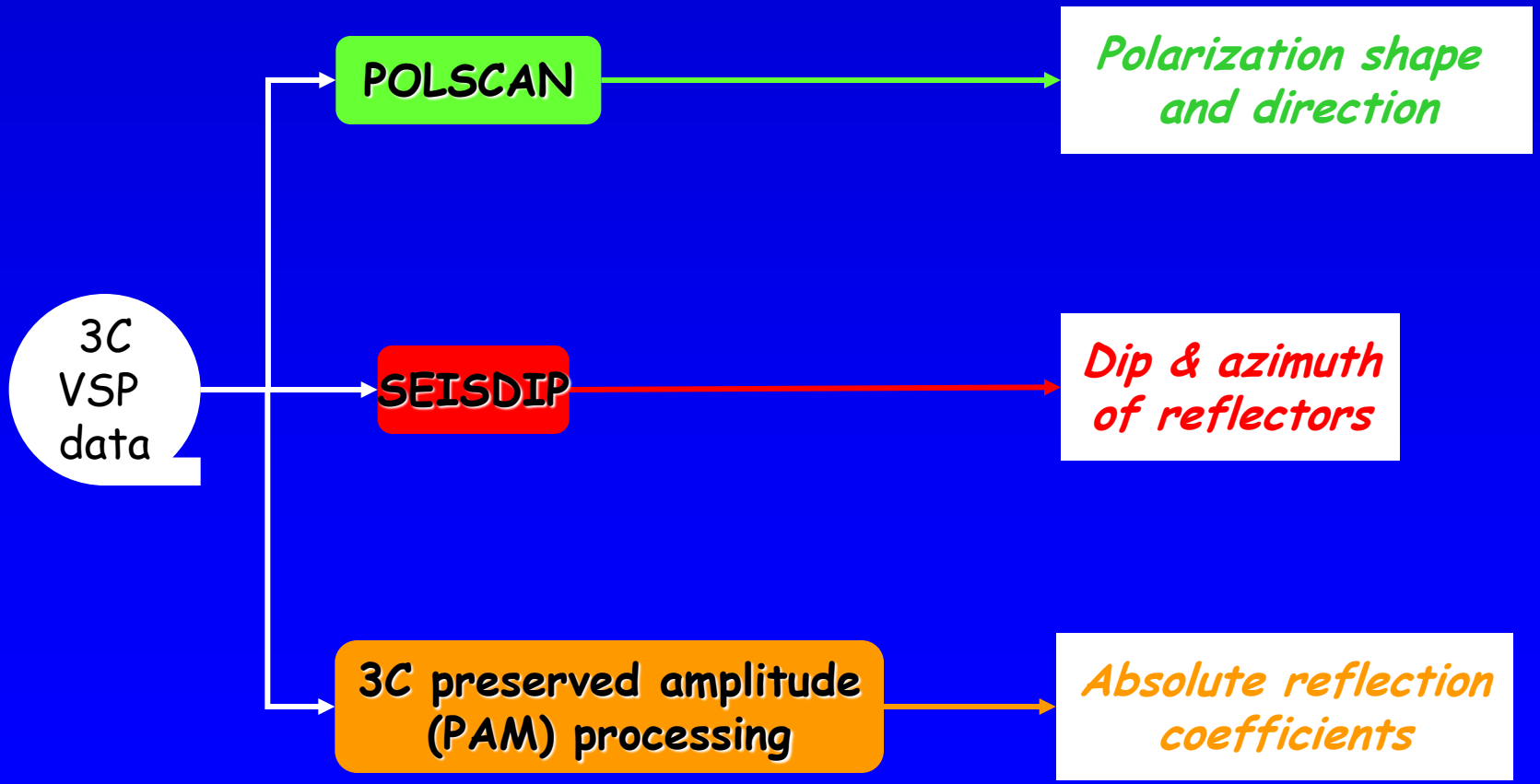
- -Hardware orientation device combined to the VSP tool
- -3C isotropic recording
- -3C isotropic processing

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



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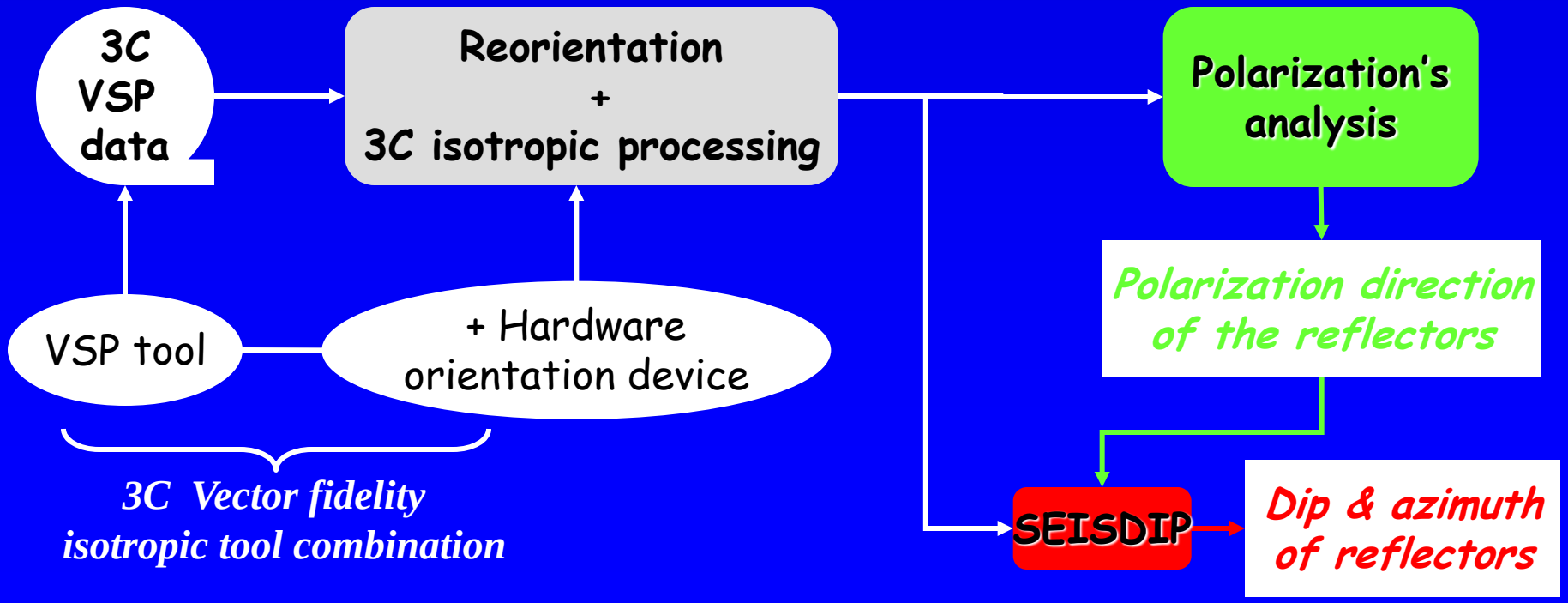
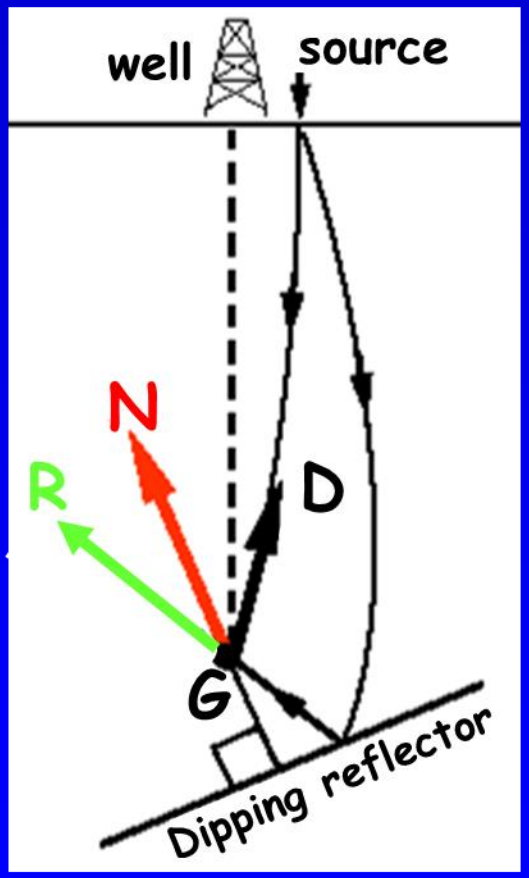
Seisdip* *(*Mark of IFPEN)*

- 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



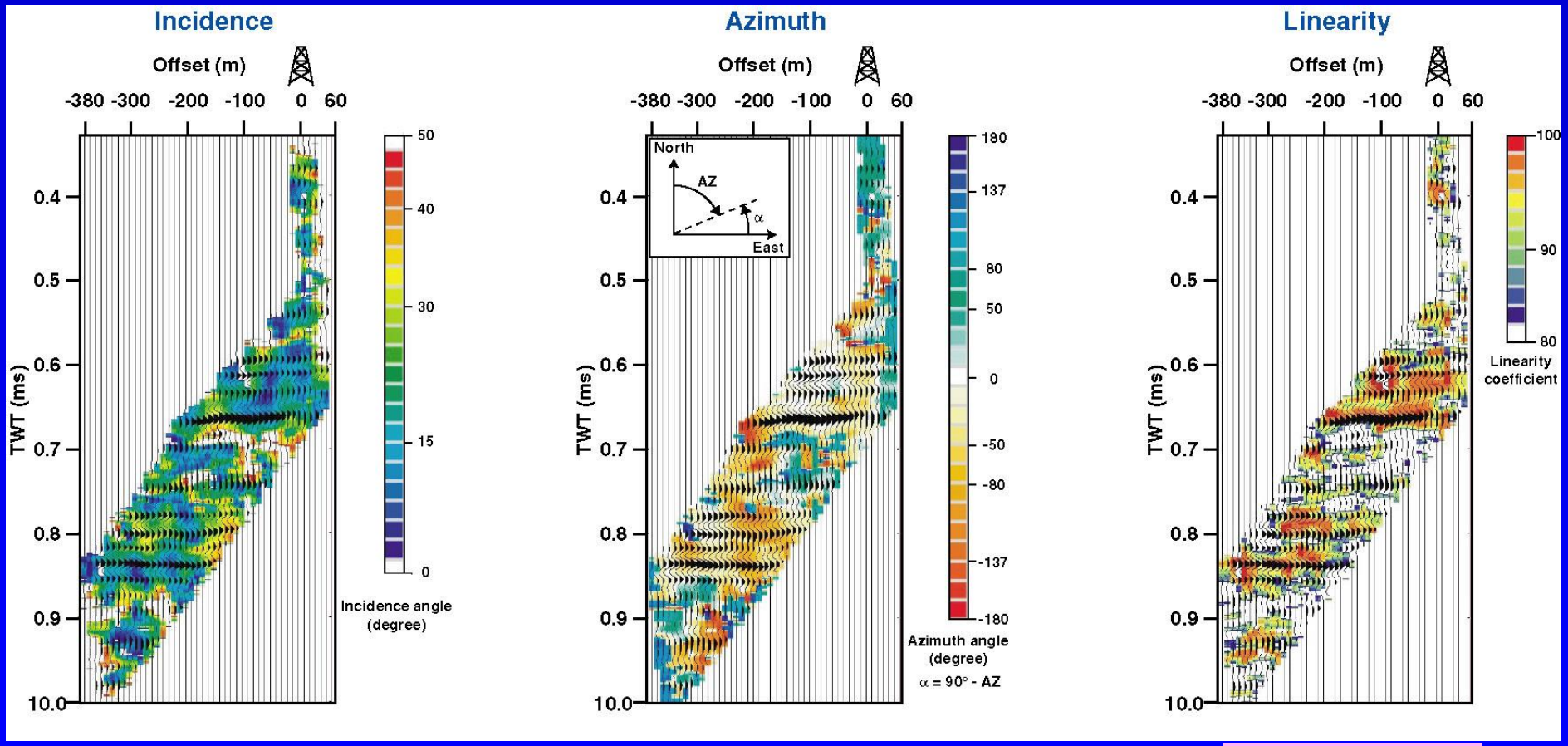
Seisdip: principle



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,

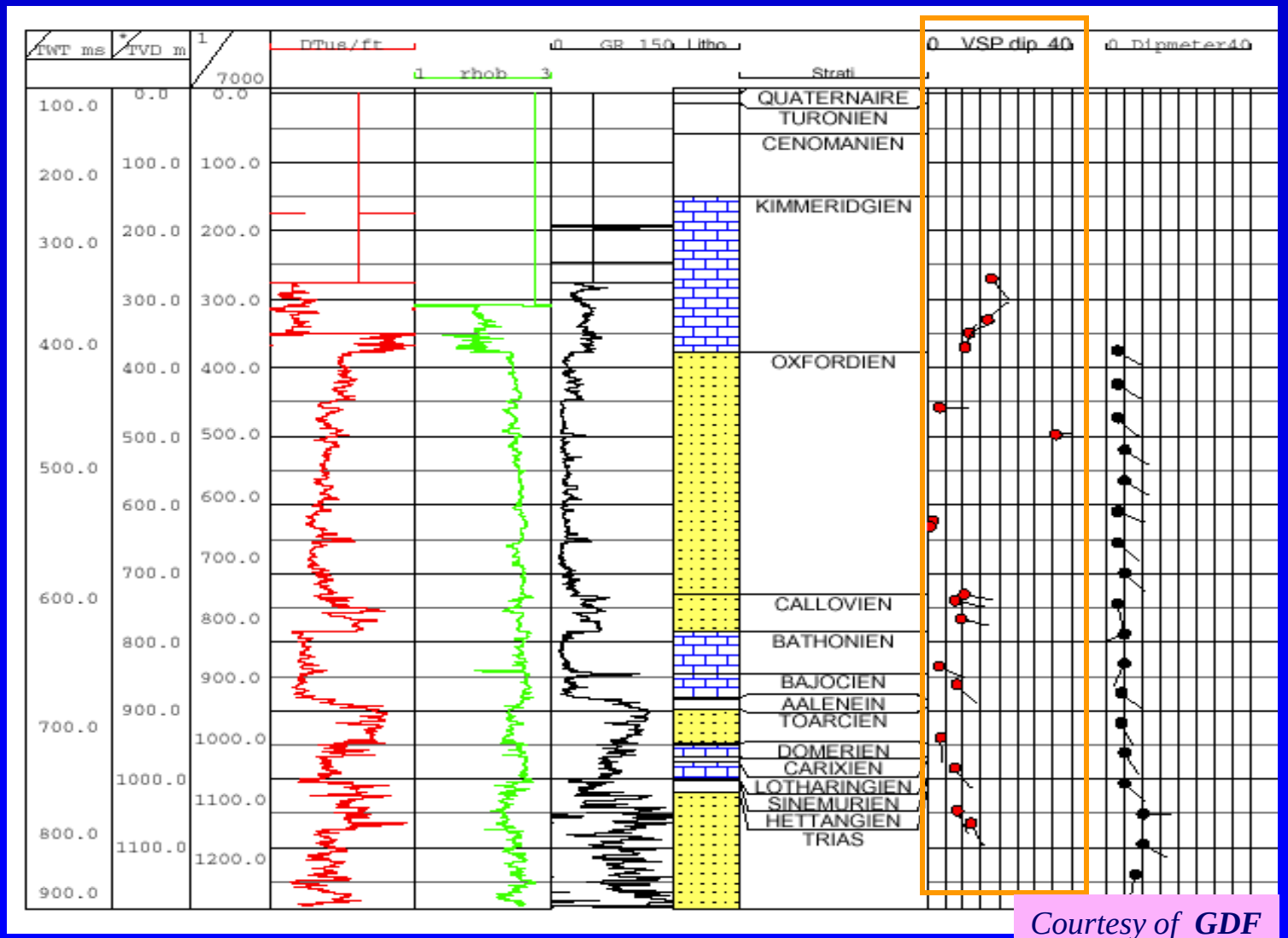
3C polarization attributes: 2 angles and ellipticity (0-linear, 100 circular)



Courtesy of ***GDF***

Display of wiggle Z component superimposed with color attibute

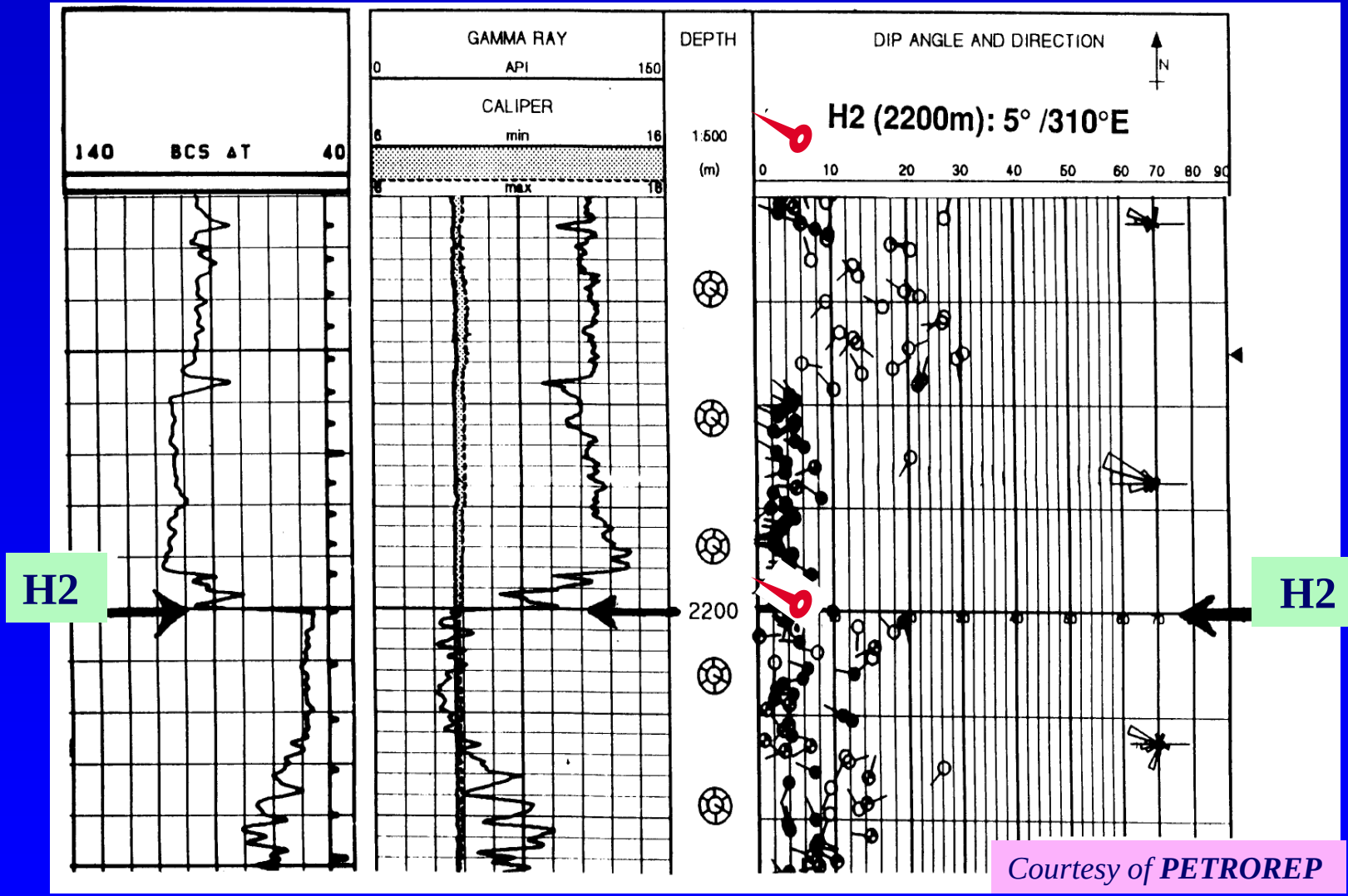
Seisdip: composite plate example



Courtesy of ***GDF***

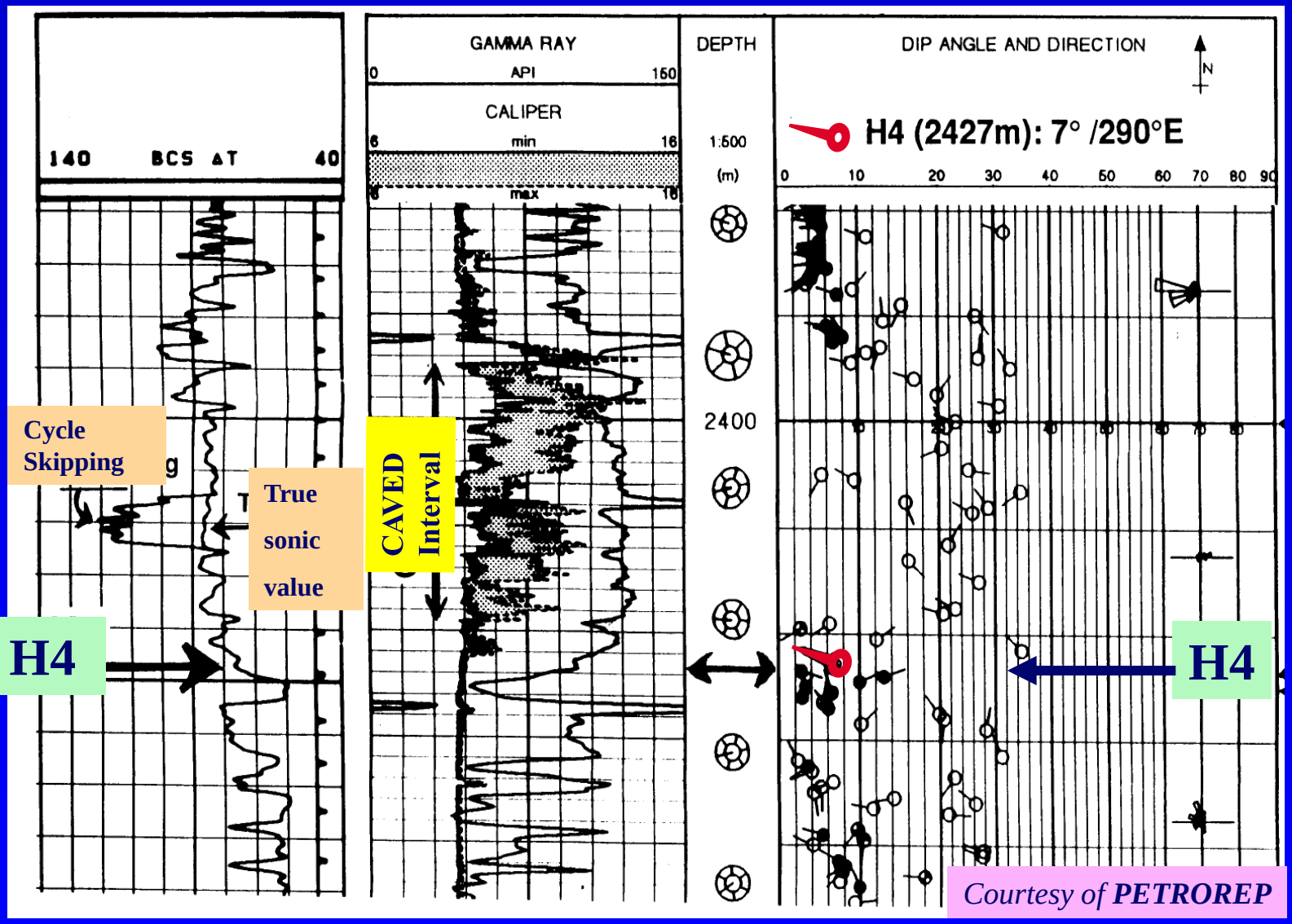
A tad pole final display using the WellCAD software

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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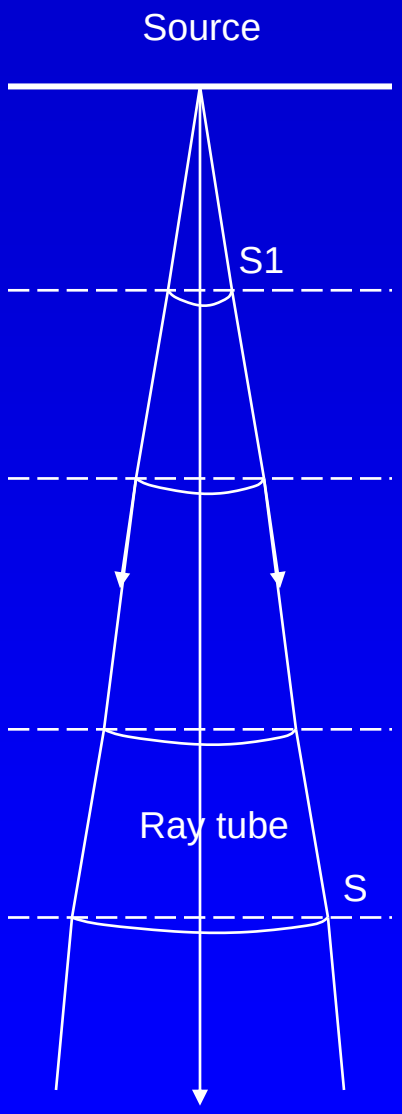
VSP Plane wave attenuation measurement



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

Wave front surface for a ray tube normal to the layering = Spherical divergence amplitude =

$$S^{0.5} = V^2.t/V_0$$

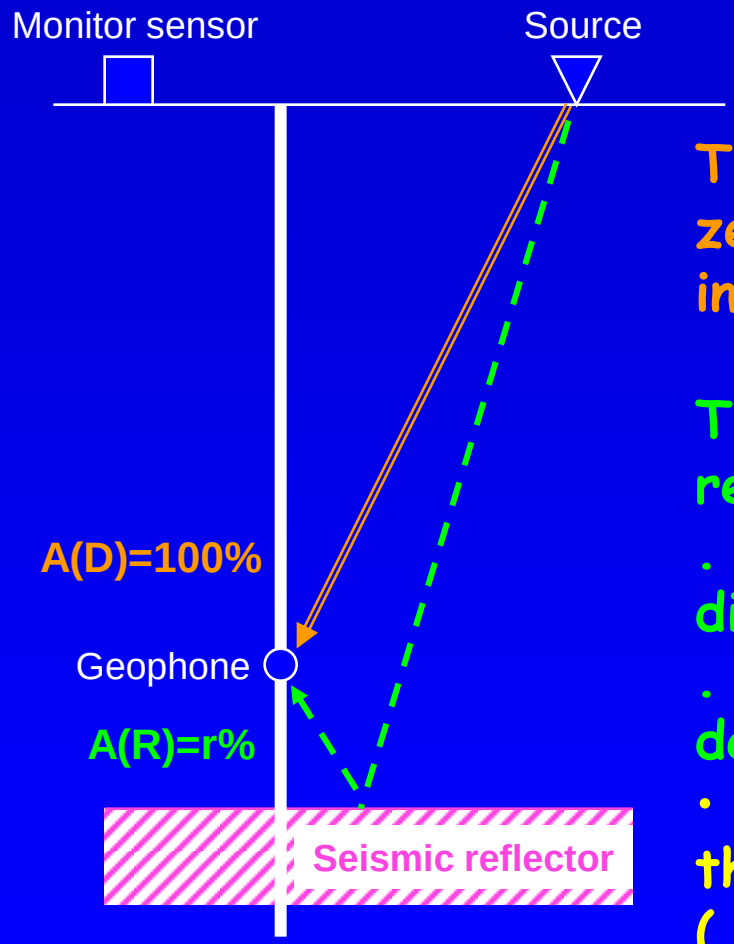
Plane wave amplitude for a constant impedance medium: $A_p = A.\ (\rho v)^{0.5}\ .\ V^2 t$

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

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
α = angle between well axis and direct ray

Sub-Horizontal layering;
Method applicable in 1D approximation / deviated well

Preserved amplitude VSP processing principle

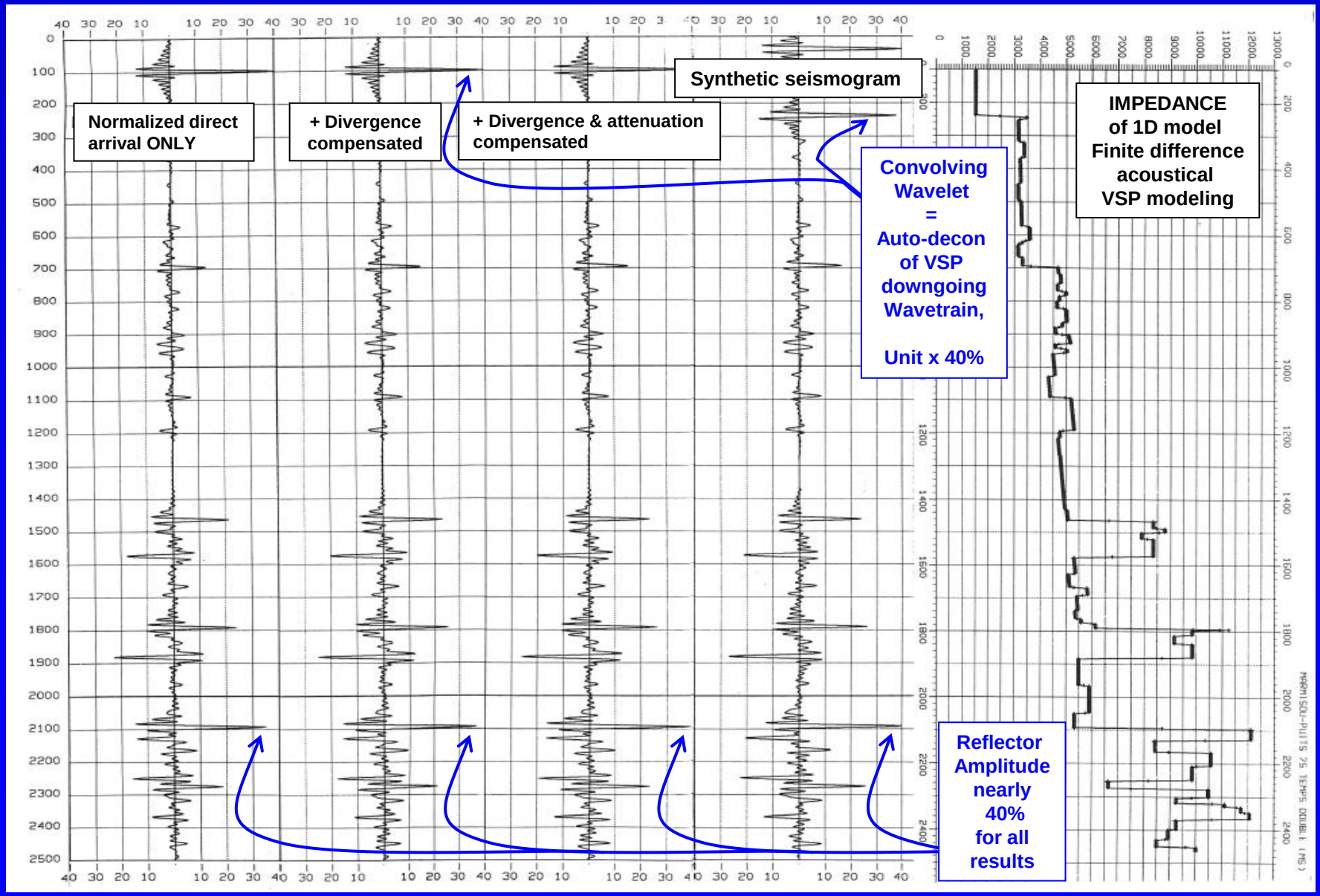


The downgoing wavetrain is deconvolved in zero phase wavelet and normalized to 100% in the signal bandwidth.

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 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:

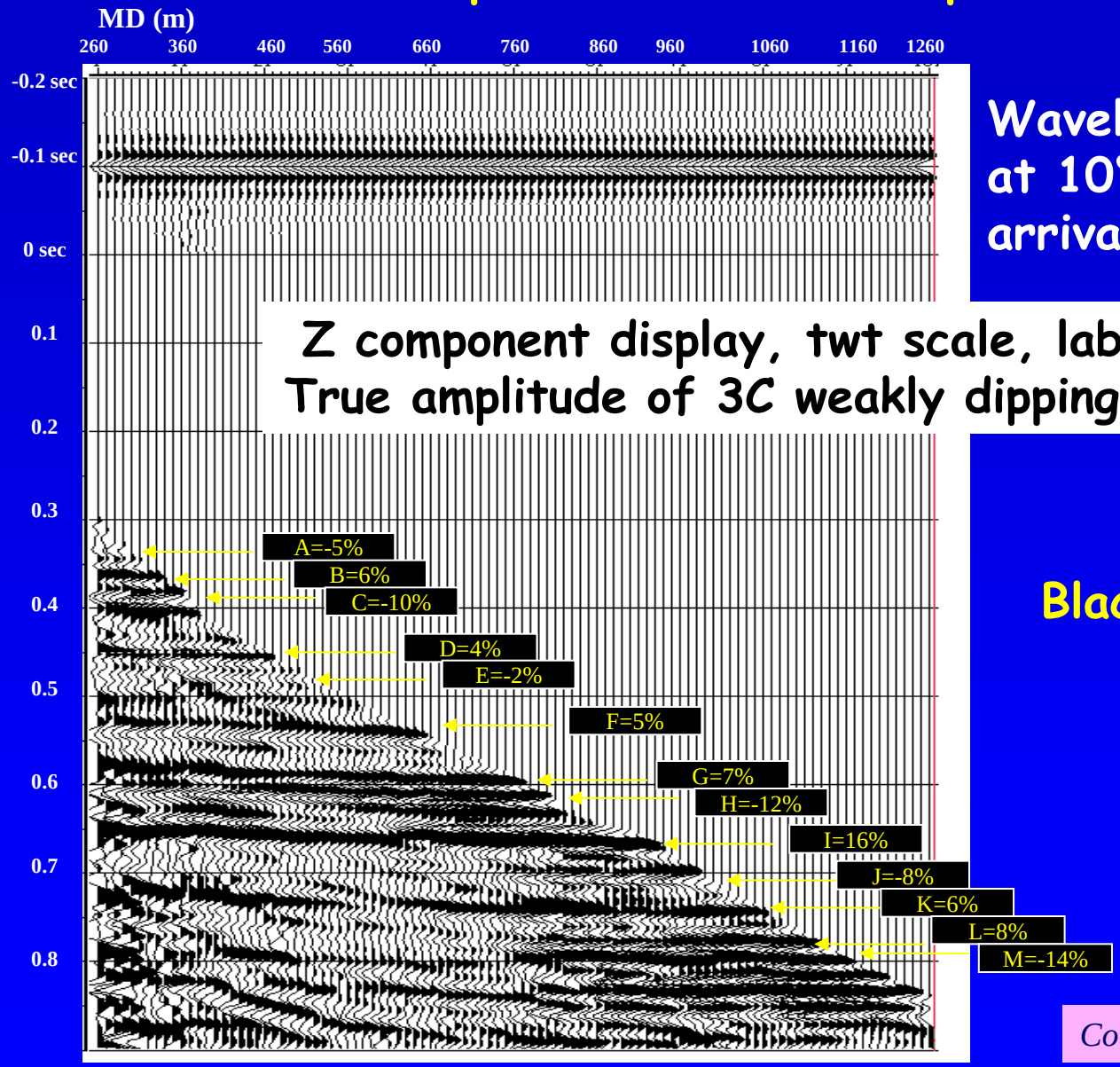
a) Differential Spherical spreading occurring after direct arrival

b) Intrinsic attenuation for plane wave propagation after direct arrival

c) 1D approximation for a) and b) simplify processing operations.

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

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



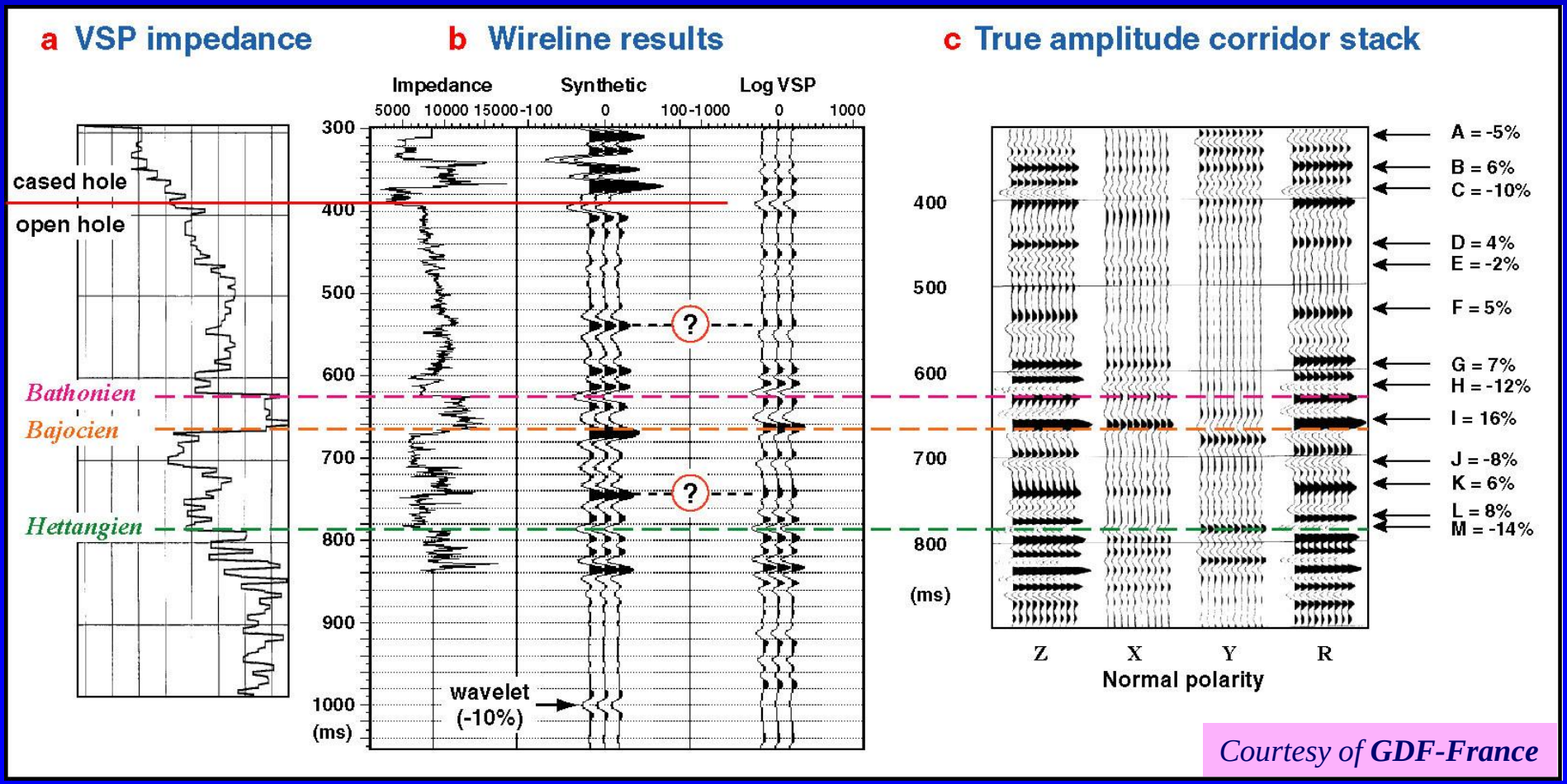
Wavelet normalized at 10% of the direct arrival amplitude

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

Polarity
Black = KI < 0

Courtesy of ***GDF-France***

3C VSP True amplitude results



a Result of the VSP log inversion / 3C resultant Component

b Wireline synthetic compared to the VSP log

C 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:

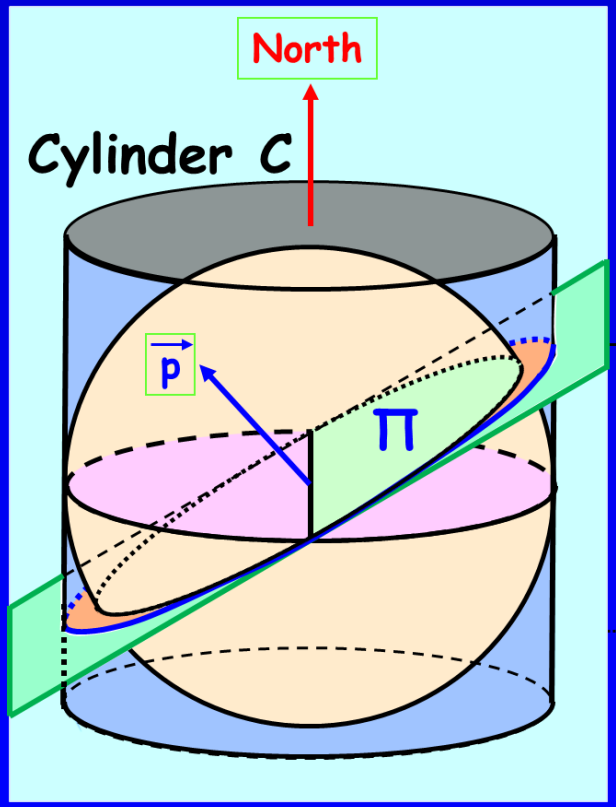
- the nature (reflected or diffracted event)
- and the wavemode (P or S) of 3C seismic events
- by scanning the 3C dataset in various geographically directions, displayed in a readable manner as a cylindrical projection set of geographical projections.

It allows, after 3C reorientation:

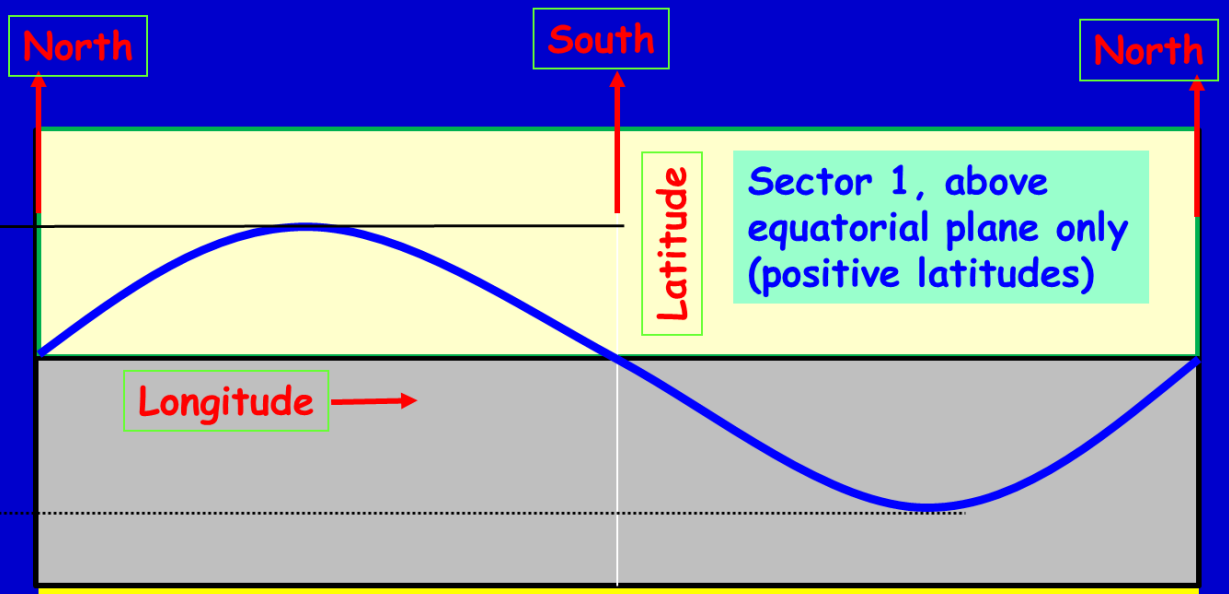
- to compute the direction of polarization of events
- to discriminate and separate interfered events

Polscan principle (1)

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



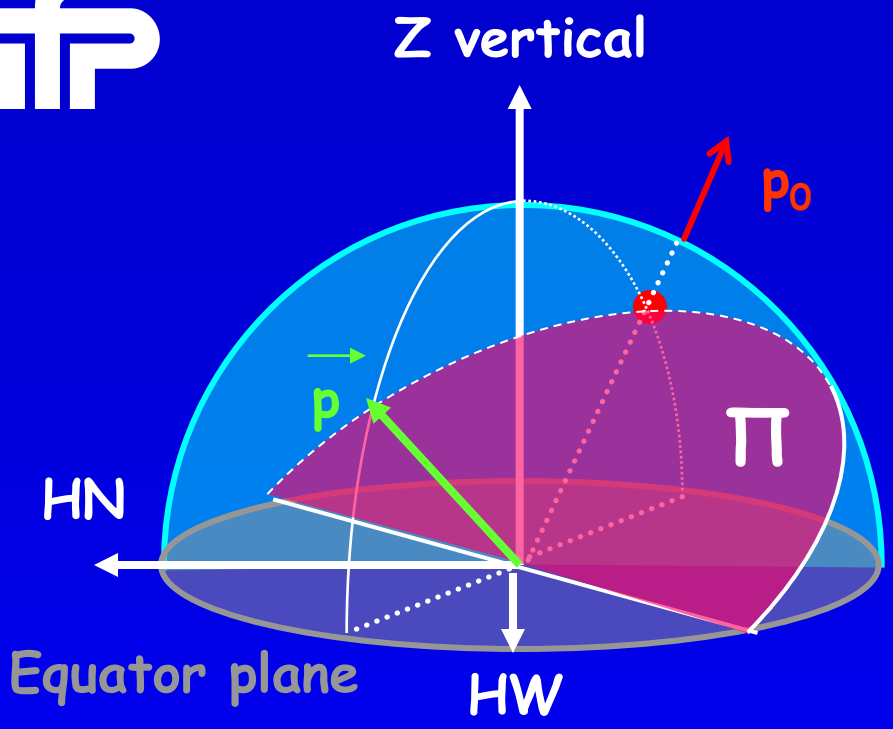
Unwrapped cylindrical Projection: amplitude of linear vector p, normal to plane Π, is null along the blue sine line below (intersection with cylinder C)



Intersection of plane Π 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)



Longitudes North to East 0-360 Degrees

p: polarization direction of a linear event

Π: plane orthogonal to polarization vector p

p_0: intersection point of Π with the sphere

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

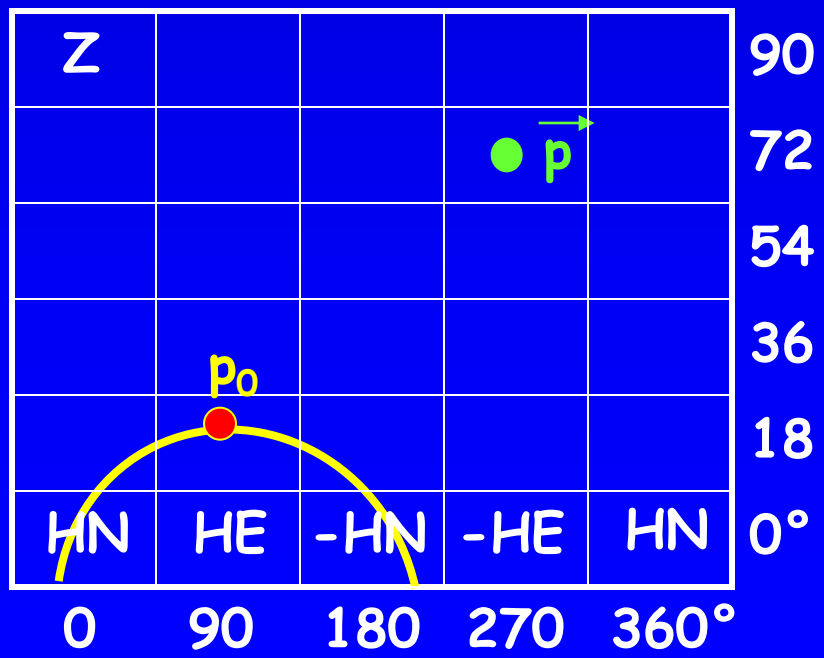
A linearly polarized event shows a null amplitude in the plane (Π) orthogonal to its polarization

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)

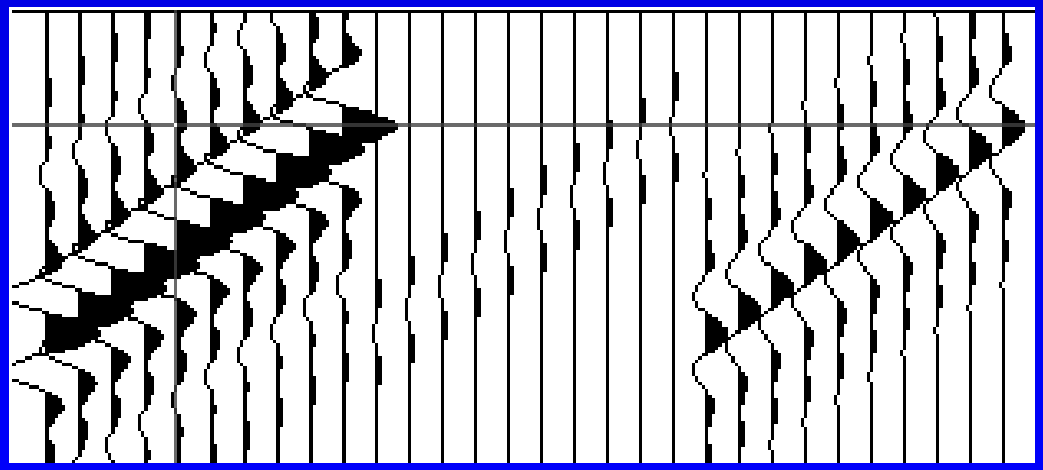
Sine curve of Null amplitude in the plane orthogonal to vector P



Polscan: example

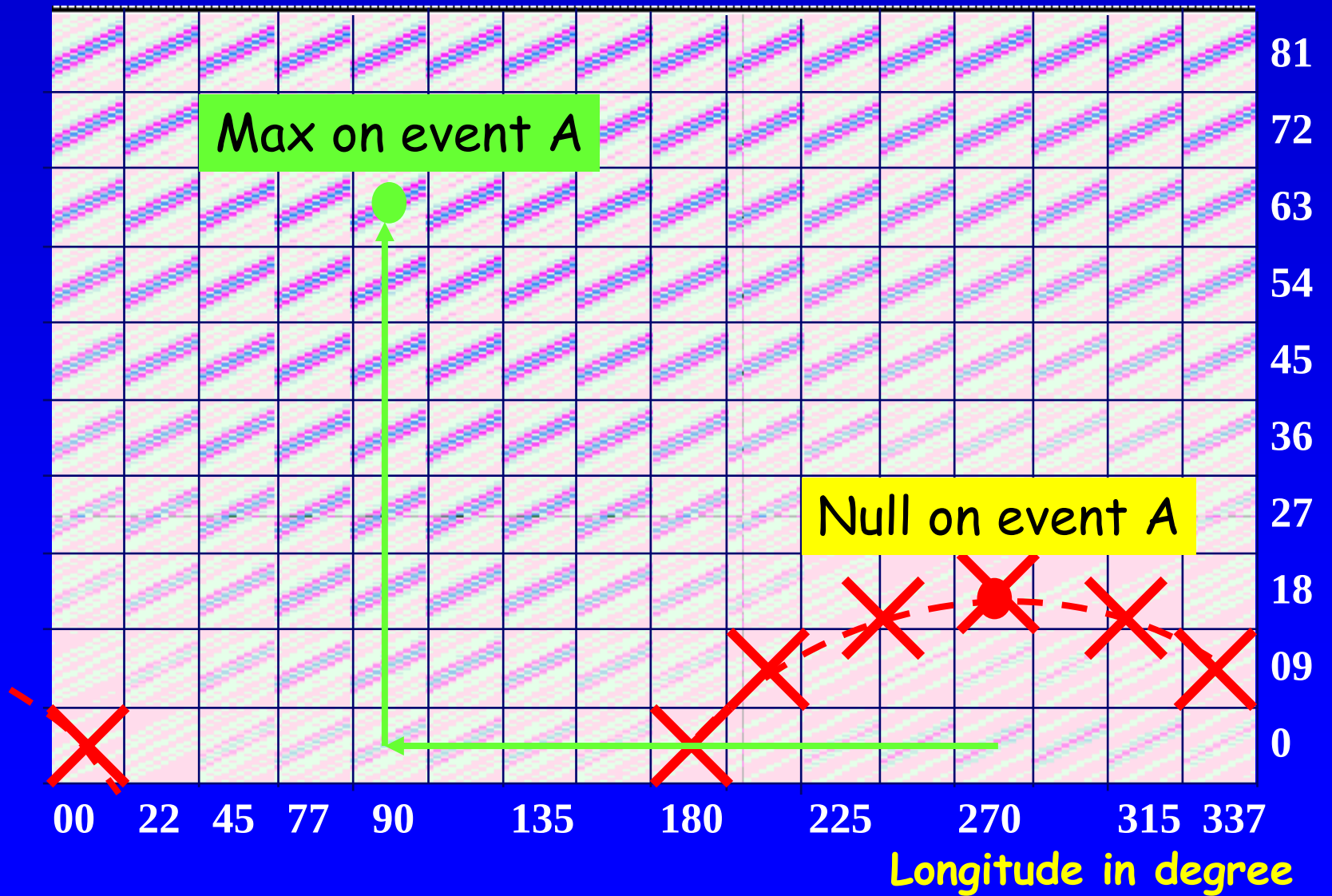
Input: Single linear event (A)

Incidence : 20°
Azimuth : ~ 87°



Z vertical H-North H-East

Polscan : a readable cylindrical projection display



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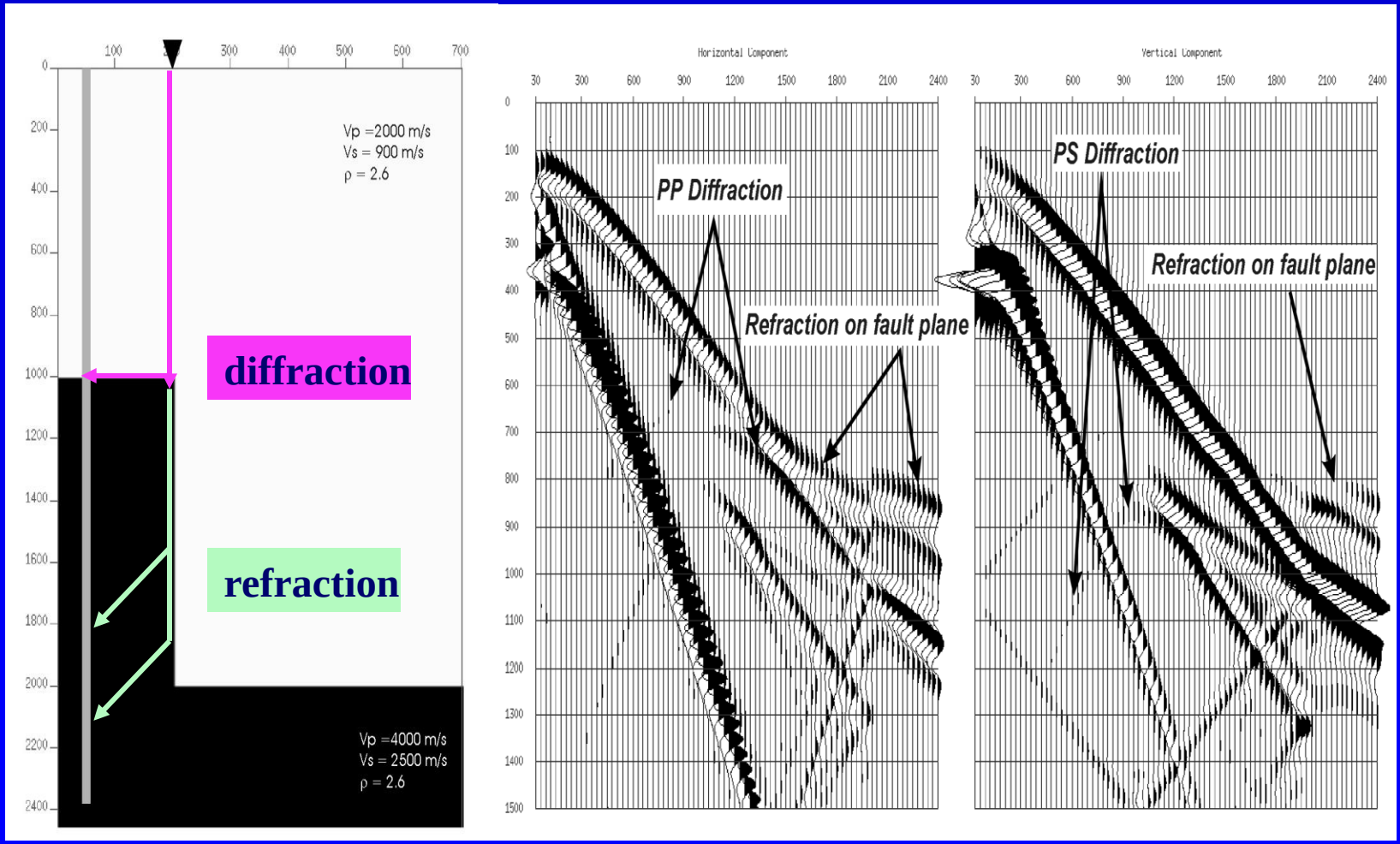
Corner fault diffraction and refraction

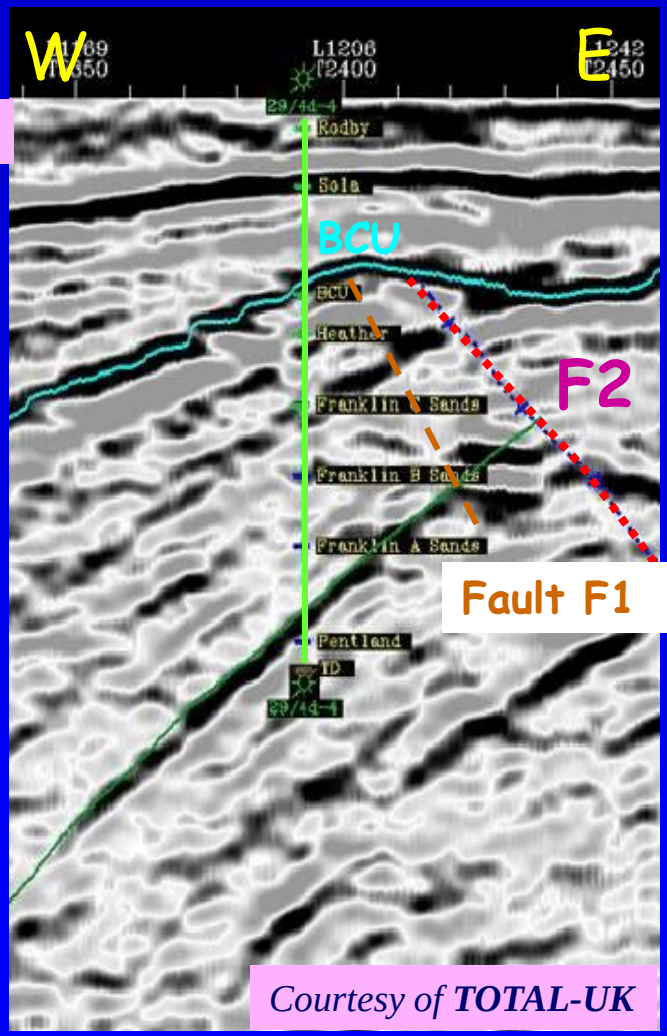
Geologic model | Horizontal component | Vertical component

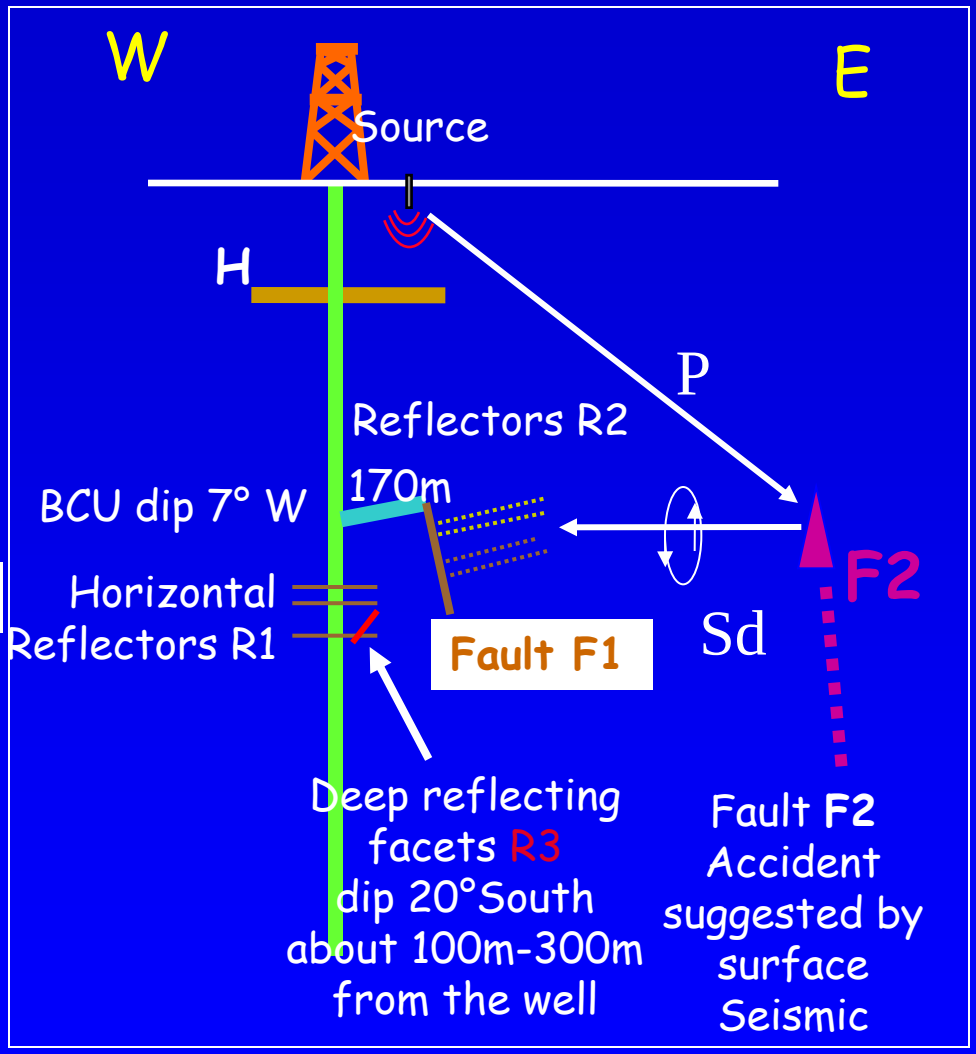


2D FD elastic modeling for complex seismic response analysis

W-E Structural Sketch from 3C VSP

Case 1

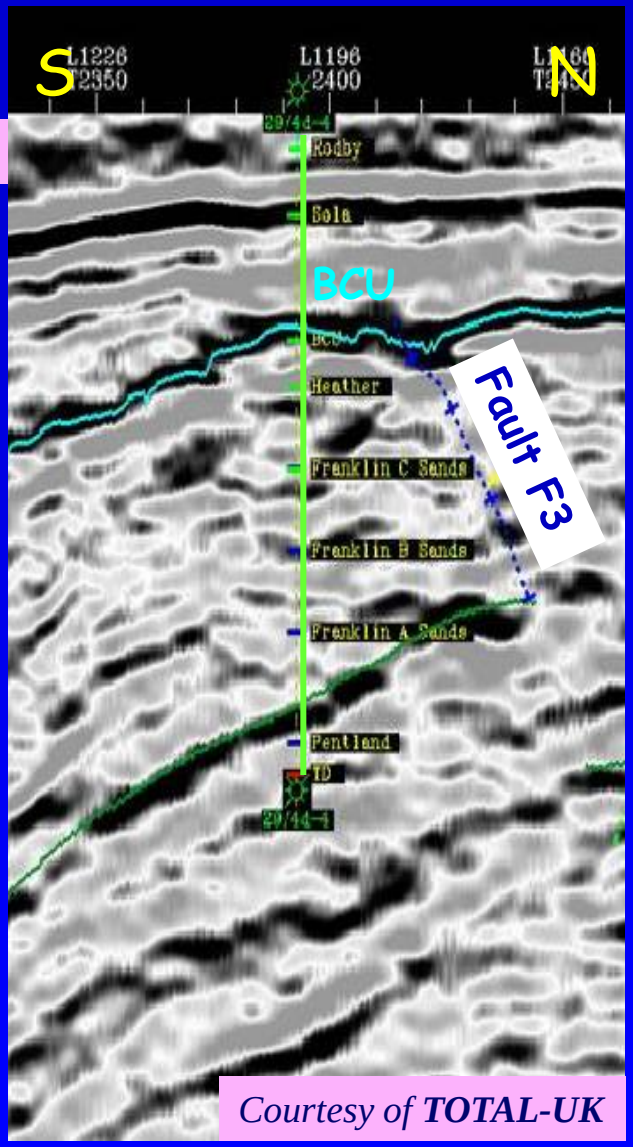


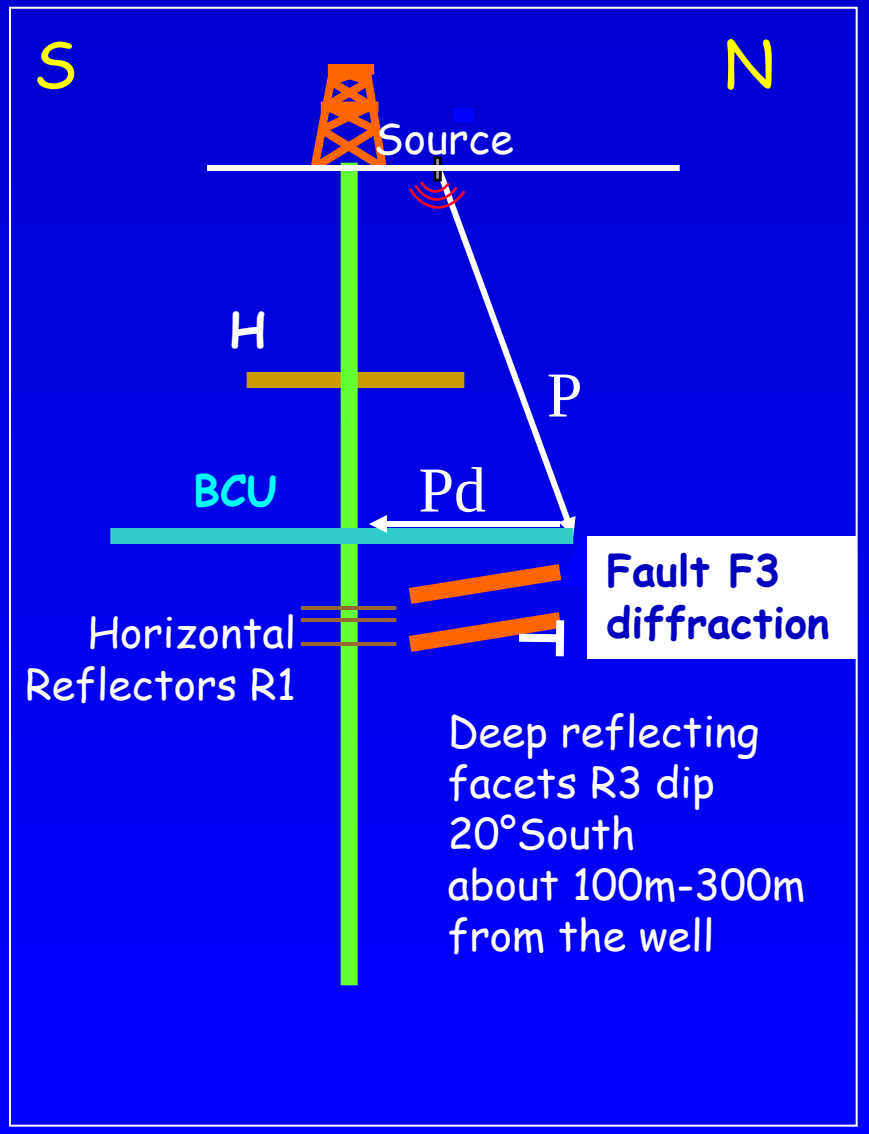


Confrontation of 3C VSP results with surface seismic (left side)

S-N Structural Sketch from 3C VSP

Case 1

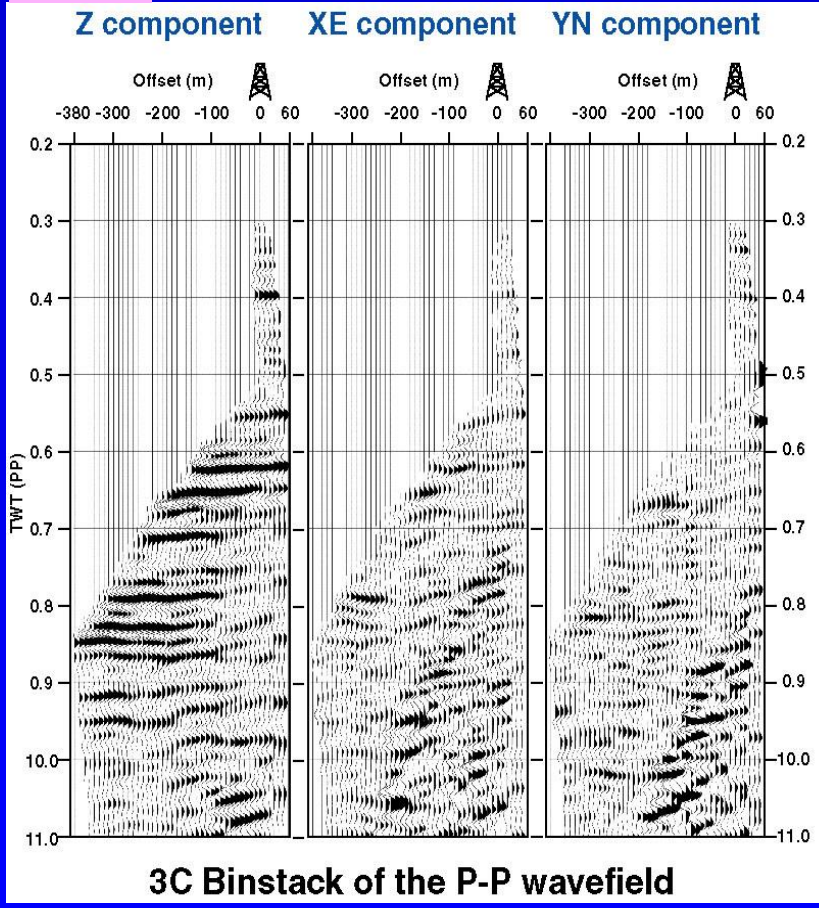




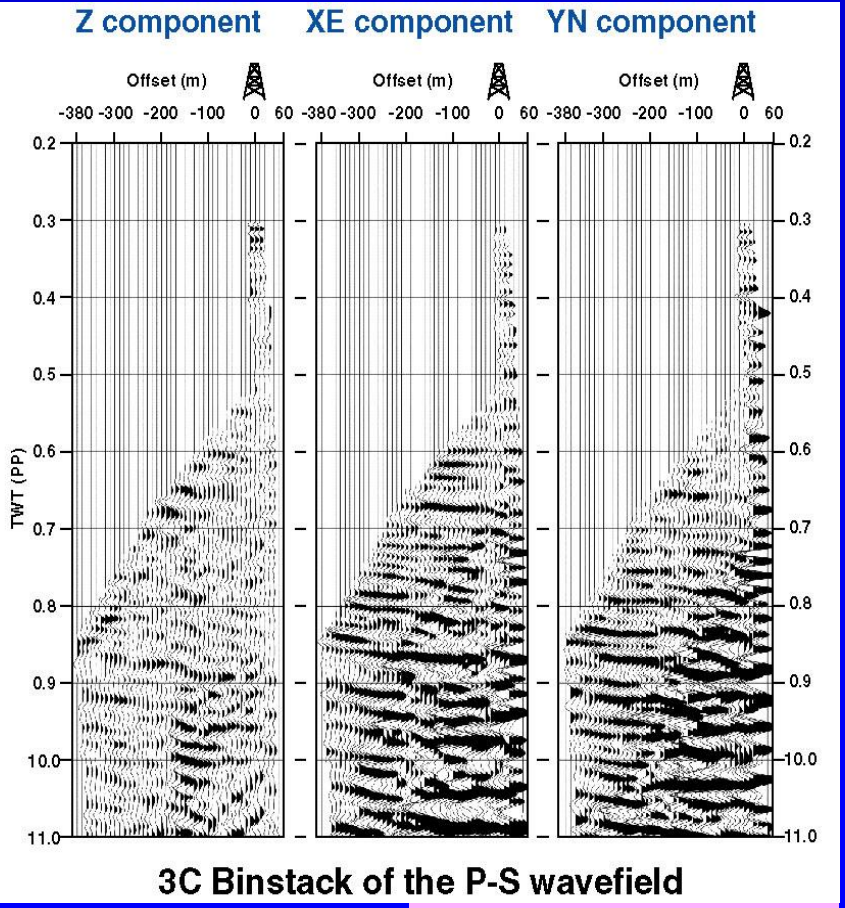
Confrontation of 3C VSP results with surface seismic (left side)

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.*