3 COMPONENT VSP ORIENTATION

- **PITFALL OF USUAL ORIENTATION PROCEDURES**
- **LIMITATIONS OF STANDARD ASSUMPTIONS**
- **ANALYSIS ON FIELD DATA FROM A CASE STUDY**
- **REMEDIATION OF ORIENTATION ON AVAILABLE VSP DATASETS**
- **IMPROVING FUTURE RIG SOURCE VSP FIELD OPERATIONS**

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1993: VSP FIELD ACQUISITION (GEOTHERMIE SOULTZ + IPGP + CGG) , PREPROCESSING (CGG)

1998 : RE-EXAMINATION OF VSP DATA (IFPEN WITH IPGP)

2006: FULL 3C VSP PROCESSING (BY VSFUSION FOR ESG)

2009: POSITIVE TEST OF ORIENTATION REMEDIATION USING S-WAVE COHERENCY OF PARTICLE MOTION VERSUS DEPTH (IFPEN) , PATENT ON METHOD FOR ORIENTATING 3C VSP DATA (IFPEN).

2019-2020: COMPILATION AND PUBLICATION (IFPEN)

ACKNOWLEDGEMENTS: ***F. CORNET*** †, IPGP, ***N. CUENOT***, ES-G

† : *DECEASED*

Géothermie Soultz

IPGP INSTITUT DE PHYSIQUE DU GLOBE DE PARIS

CGG

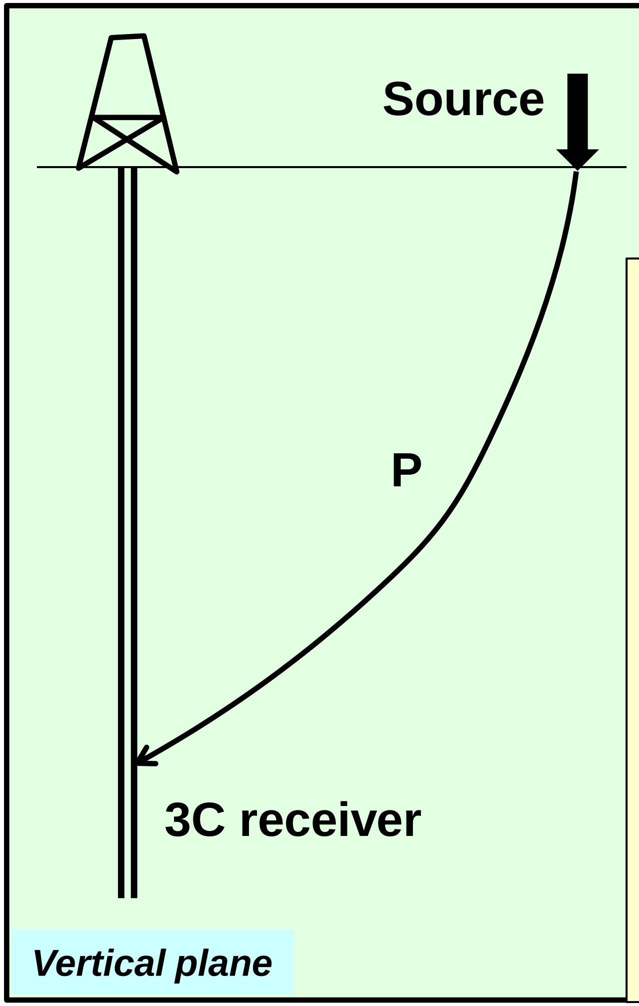
ESG és géothermie

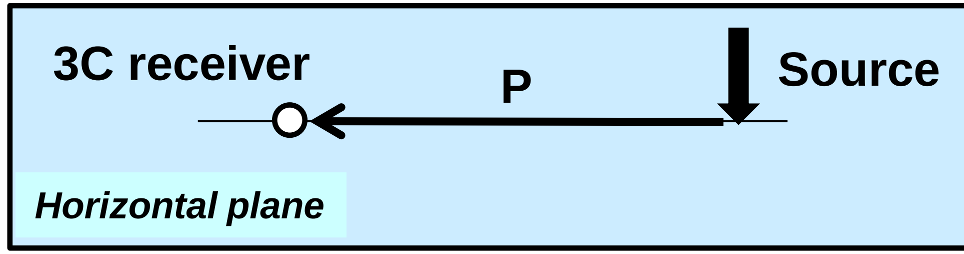
VSfusion A Baker Hughes – CGGVeritas Company

Baker Hughes

ifp Energies nouvelles

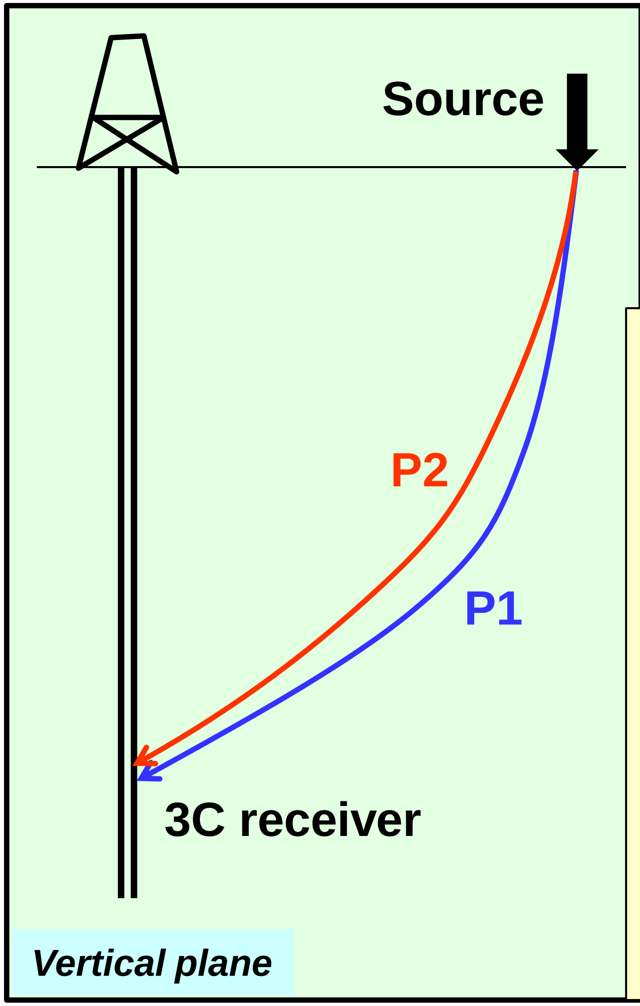
3C VSP orientation is commonly performed using the direct P-wave from an OVSP, assuming that the single direct P wave arrival is linearly polarized in the vertical plane of propagation containing source and receiver point positions

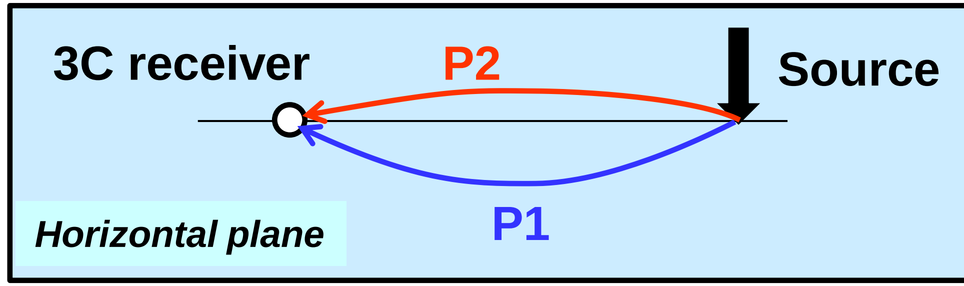




The direct ray arrival **P** is assumed to lye in the vertical plane containing the source and receiver positions, in vertical or deviated borehole. The particle motion (polarization) of the P wave first arrival recorded by the 3C downhole receiver is linear, along a spatial direction which does not differ notably from the actual ray propagation direction in a anisotropic medium (ref S. Crampin). The above orientation works correctly as long as the first P-wave arrival propagation direction makes an angle of at least 5° with the borehole axis at receiver depth. **Thus, when no orientation device is present on the VSP tool, orienting the downhole 3C receivers often requires recording an extra Offset-VSP <u>in the same run</u> as the Z-VSP…**

Limitation of 3C VSP orientation using the direct P-wave from an OVSP
P1 and P2 are two distinct P wave arrivals linearly polarized, traveling from surface source to downhole receiver with distinct raypaths





Direct ray arrivals P1 and P2 propagate at nearly the same travel time, and are received from different azimuths in the horizontal plane, and with different inclination in the vertical plane, so that an interfered elliptical mixed particle motion is recorded by the 3C seismic downhole seismic receiver (P1 and P2 signals are naturally added and superimposed).

Therefore it cannot be assumed that there is a unique linear direct P-wave arrival lying in the Source-to-receiver vertical plane, in order to derive the orientation of horizontal components of the 3C downhole receiver.

An orientation device on the VSP tool is desired.

SOULTZ well GPK1: this VSP case study demonstrates the high desirability for an orientation hardware device to be combined with the downhole VSP tool.

S-wave Zero-Offset VSP's (ZVSP) have been recorded in a near vertical well GPK-1, with a single level VSP tool with good vector fidelity, with an azimuthal S- wave anisotropy objective.
An Offset-VSP source is used for VSP tool orientation of Z-VSP recorded in same run. The offset distance was considered sufficient to apply the common orientation procedure by maximizing the direct P-wave at pre-processing stage.

Results:

- **Highly defective orientation is observed in the deep geothermal interval targeted in the granite basement, which rendered the data unusable for the initial S-wave study purpose.**
- **A remediation processing procedure was tested with success, using a criterion of particle motion coherence level to level (ref: US patent # 2012_0046871A1), however not fully accurate (5° jitter + about 10° azimuth regular drift versus depth).**
- **An azimuthal calibration using a hardware orientation device combined with the downhole VSP tool is desirable for quicker and more reliable VSP component orientation at preprocessing.**
- **Reflection processing of oriented 3 Component data shows reliable P-S events on Z component only, CONFIRMING the presence of tilted-faulted compartments in the borehole vicinity, generating direct arrival multipath interferences.**
- **One of the P-S converted seismic reflection occurs on a major highly dipping permeable fault intersecting the borehole at MD-3490m**
- **P-S reflection combined with P-wave refraction enable to determine fault sip and strike using a single oriented 3C VSP in favourable conditions.**

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Acknowledgements: F. Cornet †, IPGP, N. Cuenot, ES-G
† : deceased

SOULTZ well GPK1, May 1993 VSP campaign. An O-VSP source is used for VSP tool orientation of Z-VSP recorded in same run.

Well GPK-1, RUN1,
4 vibrators activated successively at each downhole sensor position

Z-VSP (A3):
131m from well head , N170°E
Vertical vibrator +
2 Horizontal vibrators in A2
oriented (S-N) and (E-W)

O-VSP (position C3):
490m from well head , N135°E
Vertical vibrator in offset position for downhole VSP tool orientation.
Min. ray inclination: 6° @ 3480m
Max. ray inclination: 9° @ 2700m

Hole GPK-1, Vertical Inclination
7° @ 2700m, < 4° below 2870m

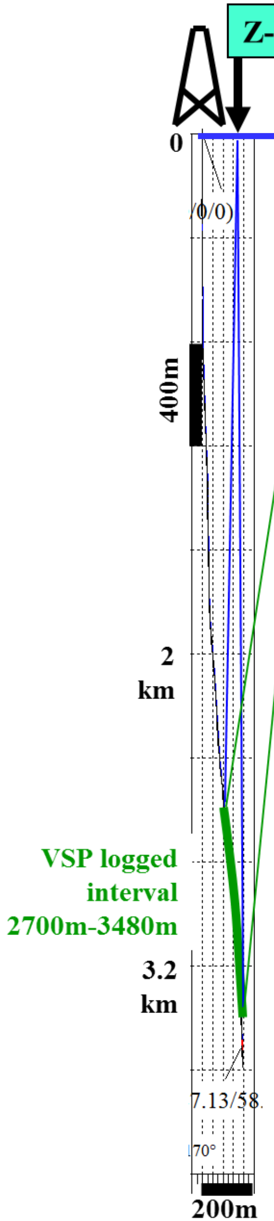
Observations:
GPK-1 hole nearly vertical in the VSP interval.

O-VSP (C3-run1): P-wave arrival used for downhole VSP tool orientation looks interfered below 3340m depth, with VERY LOW energy on horizontal components…
As a result, the Horizontal components of the S-wave VSP's A2-run1 and of the P-wave VSP A3-run1 look incorrectly oriented in the same interval 3360-3480m

A SUCCESSFUL orientation remediation test was carried out by IFPEN in 2009, using the coherency of the Downgoing S-wavetrain , to correct the azimuthal rotation angles where needed. (patent FR2942547… , now public)

Conclusion: *A slightly interfered O-VSP P-wave direct ray arriving at 7-9° vertical angle with well axis was inadequate for a correct orientation of the VSP tool.*

SOULTZ, well GPK1, 1993 VSP Run1 Geometry, SCALE 1:1



Well GPK-1, RUN1,
- 2 vertical vibrators in A3,C3

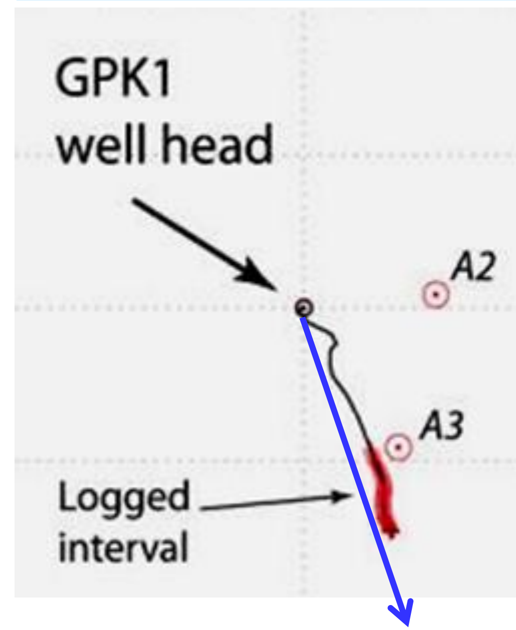
+ 2 horizontal vibrators in A2
activated successively
at each downhole sensor position
- Single level downhole VSP tool mounted with Fix 3C geophones

Z-VSP (A3):
131m from well head , N170°E
Vertical vibrator +
2 horizontal vibrators in A2
oriented (S-N) and (E-W)

O-VSP (C3):
490m from well head , N135°E
Vertical vibrator for
downhole VSP tool orientation.
Min. ray inclination: 6° @ 3480m
Max. ray inclination: 9° @ 2700m

Hole GPK-1, Vertical Inclination
7° @ 2700m, < 4° below 2970m

Vertical projection in azimuth N170° E



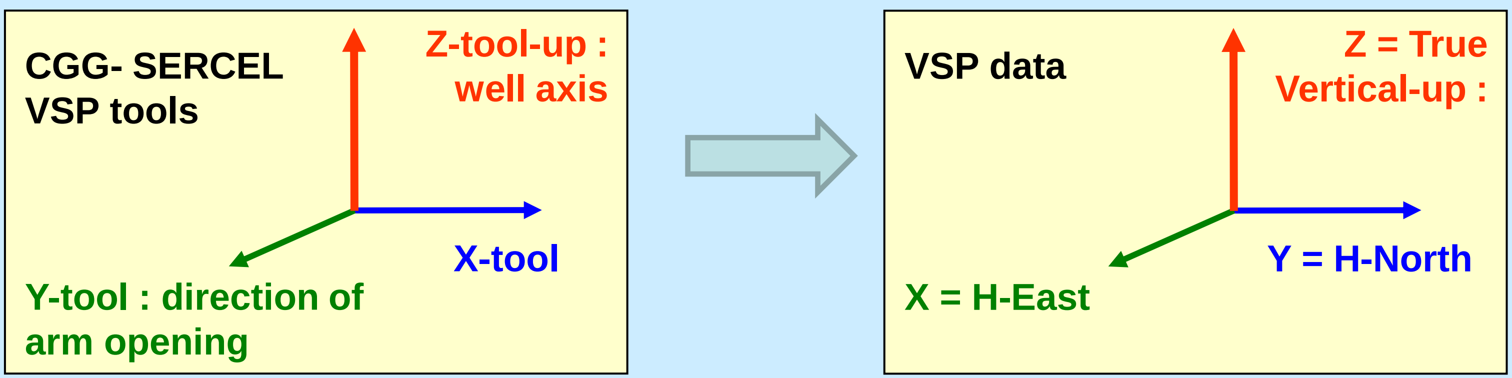
Projection
azimuth N170° E

Sketch of FIX 3C arrangement and POLARITIES in Geolock- S analog VSP tools used for the 1993 VSP operation in Soultz , simultaneously in GPK-1 and EPS-1 boreholes (single level VSP tool in each borehole)

Sketch of 3C VSP signal vectors in geographical system for delivery. by JJ. Chameau, field operation supervisor and preprocessing operator.

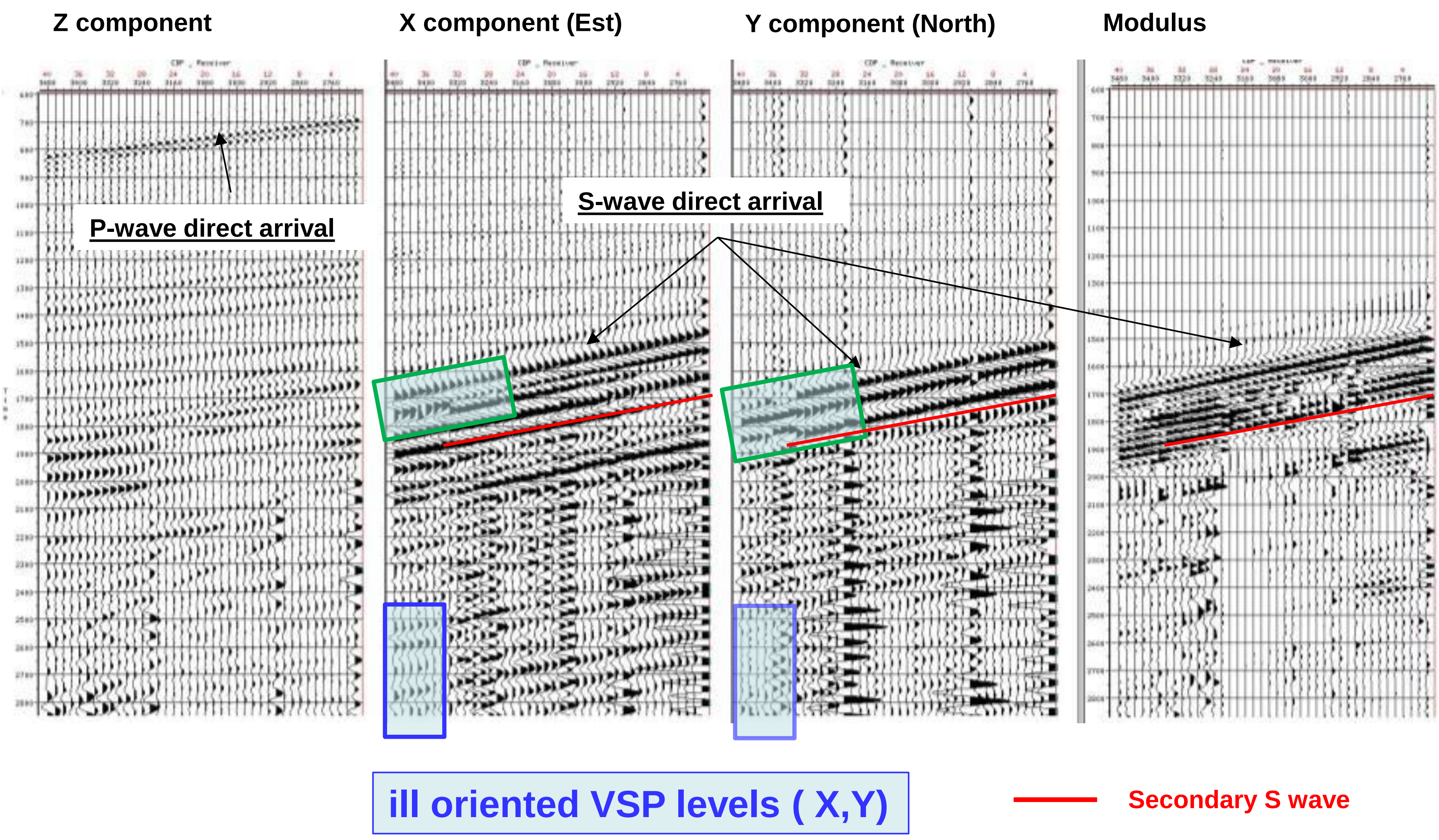
Raw VSP data output from the field :
3 Components Before orientation
Acquired in **SEG-B format**
Uncorrelated unit records

VSP data Pre-processed by CGG
3 Components After orientation
Delivered in **SEG-Y format**
Edited, stacked, correlated, oriented



Soultz GPK-1 well – VSP A2 run1 – S Source (E-W)
Three components Z-X-Y and modulus before reorientation

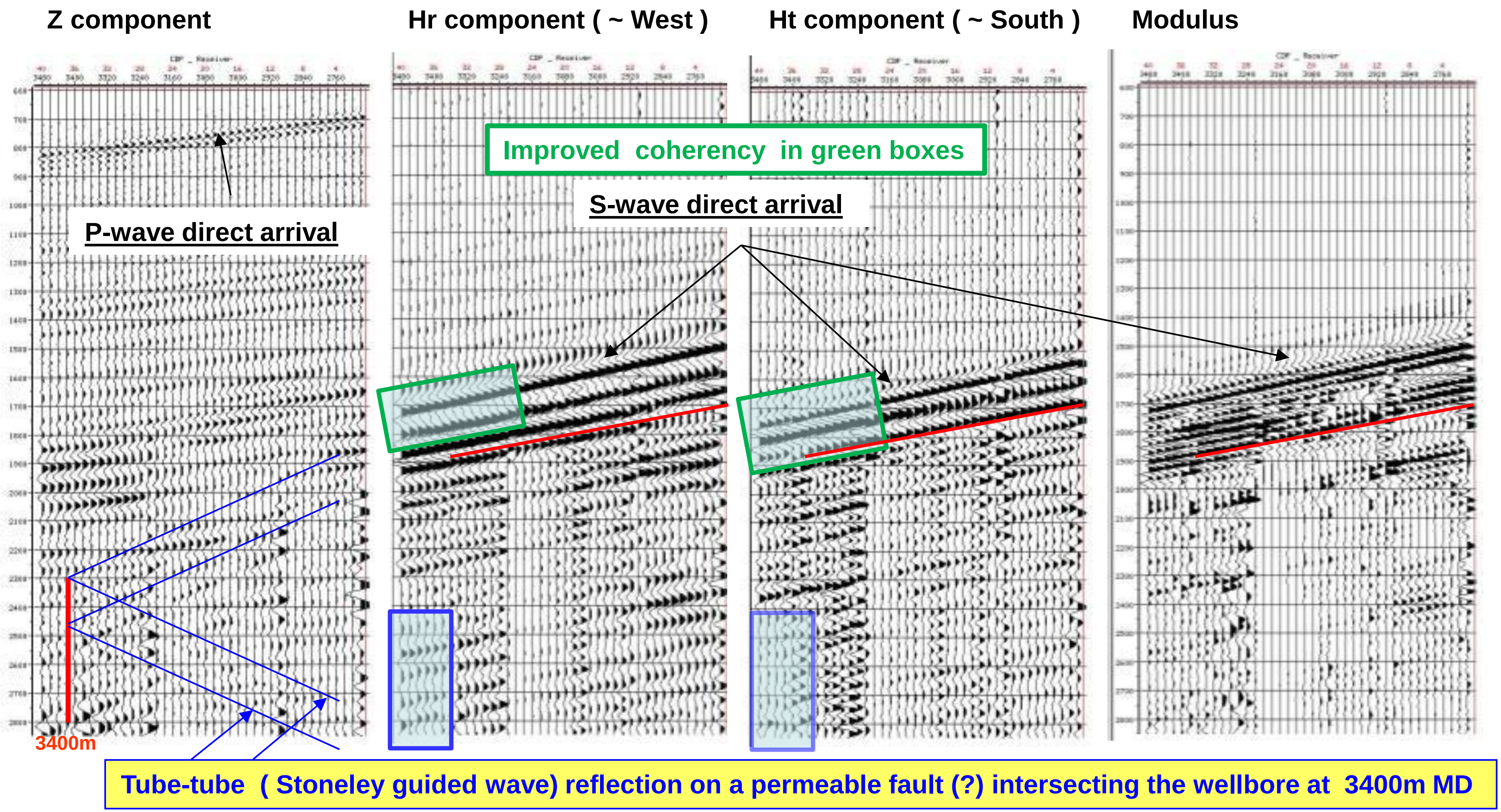
Gain 25



Soultz GPK-1 well – VSP A2 run1 – **S Source (E-W)**

Three components Z-X-Y and modulus after re-orientation

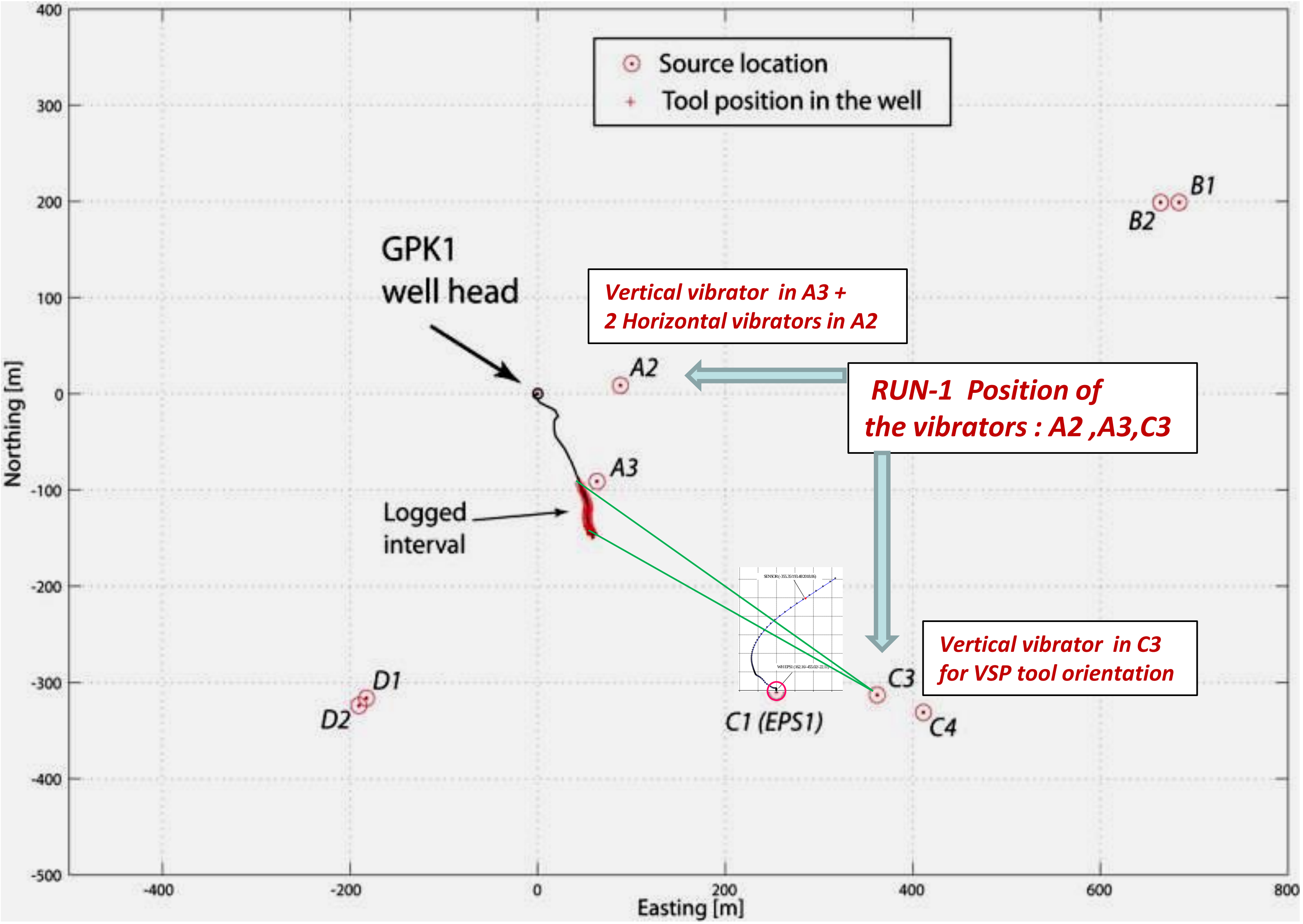
Gain 25



Coherent re-oriented VSP levels (X,Y)

Secondary S wave

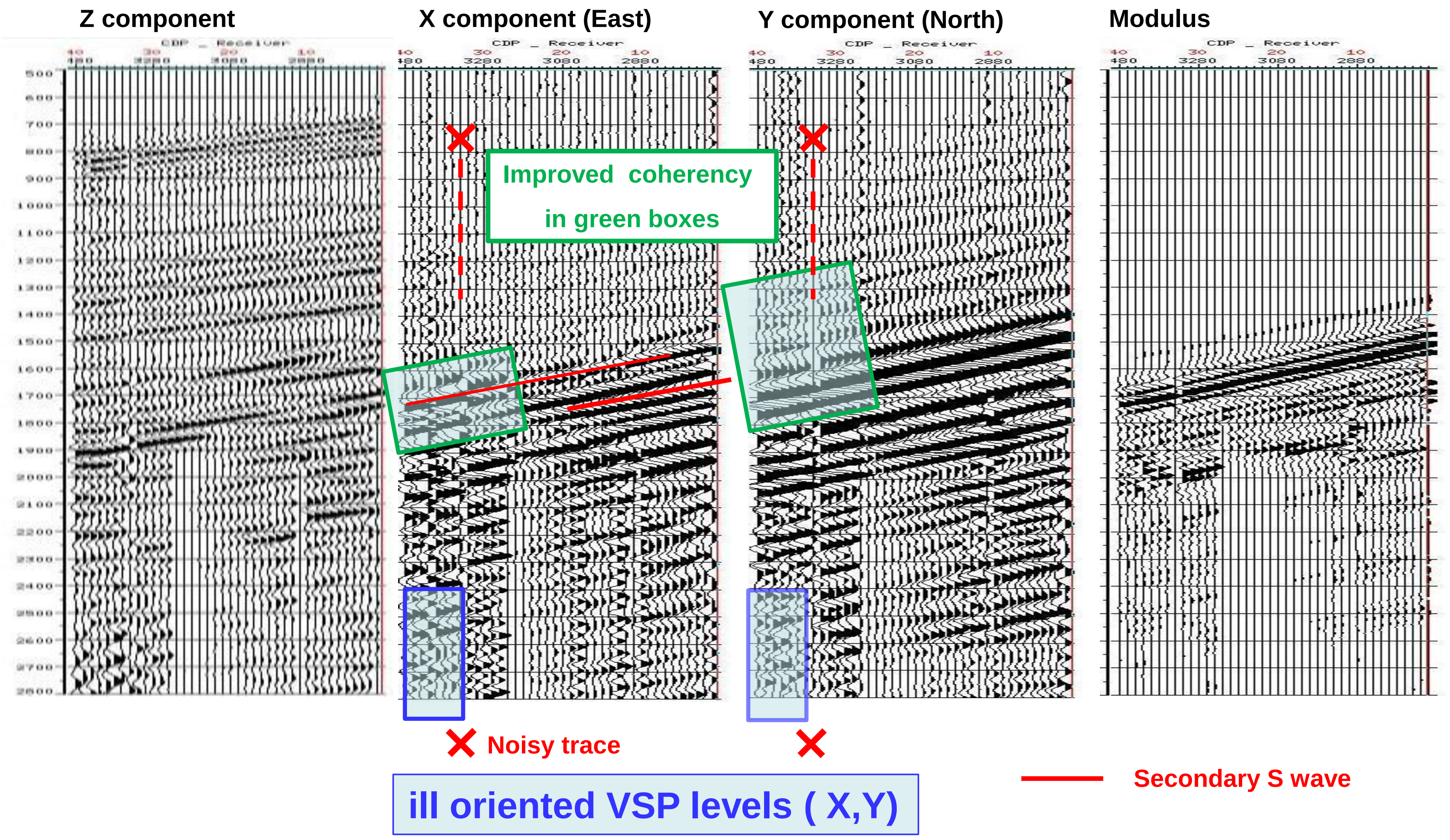
Soultz GPK-1 well – Location map; May 1993 VSP campaign



Soultz GPK-1 well – VSP A2 run1– **S source (S-N)**

Three components Z-X-Y and modulus **before** reorientation

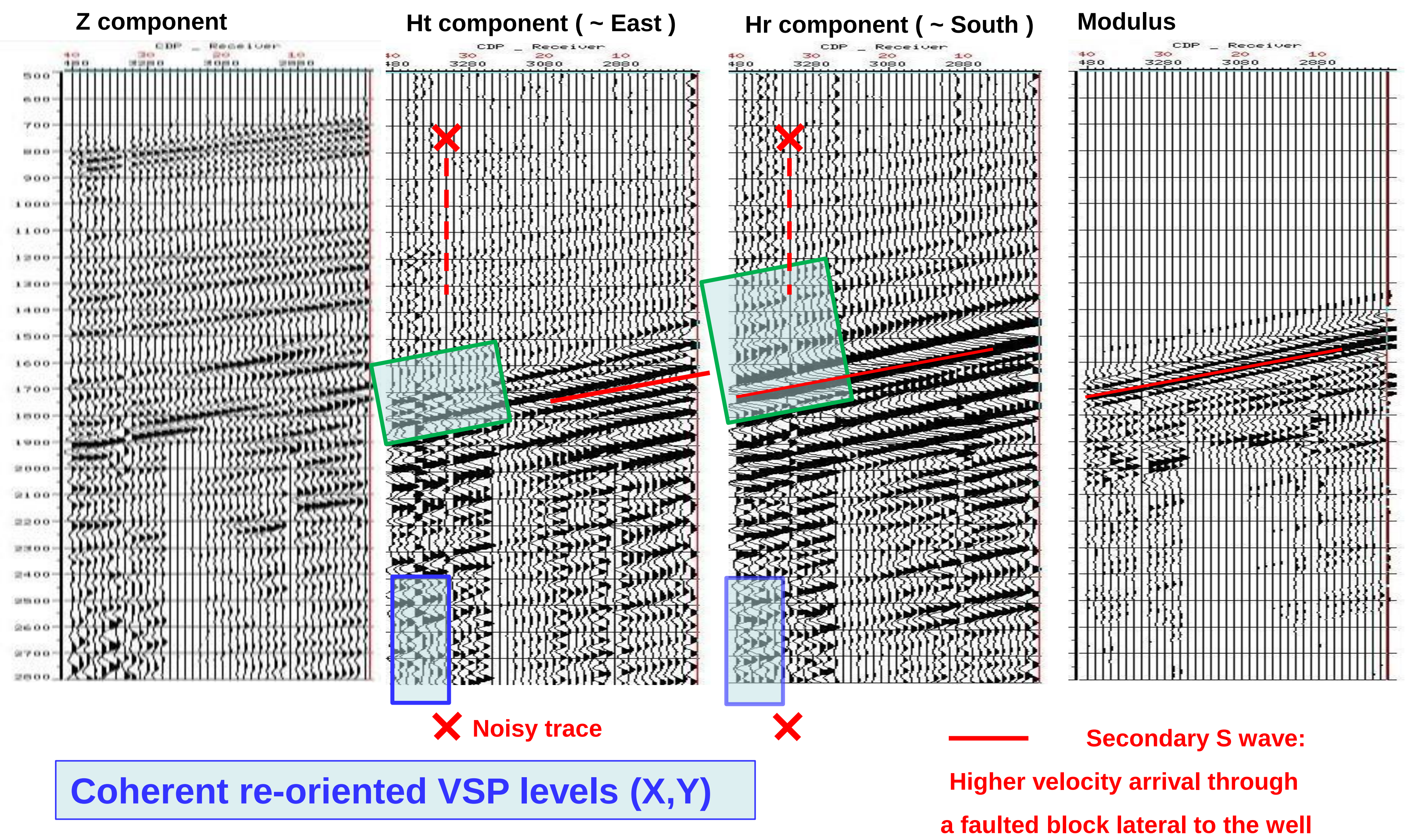
Gain 40



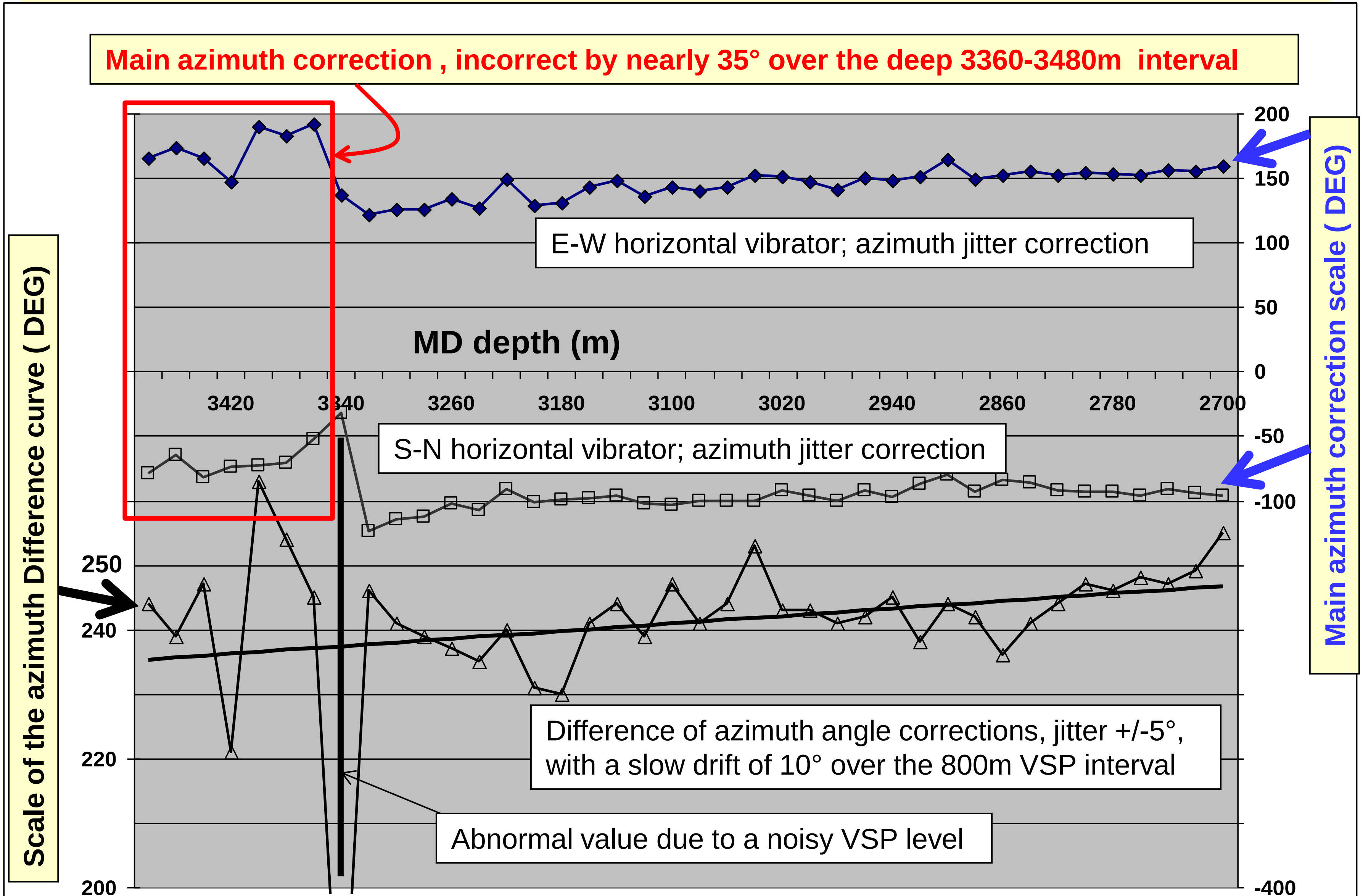
Soultz GPK-1 well – VSP A2 run1– S source (S-N)

Three components Z-X-Y and modulus **after** re-orientation

Gain 40



Azimuthal corrections angles independently determined from E-W and N-S Shear VSP datasets recorded in same run



The azimuth difference curve shows a small gradual drift of 10° over 800m, +/-5° jitter dispersion

Conclusions on the S-wave Z-VSP recorded in GPK1 from position A2

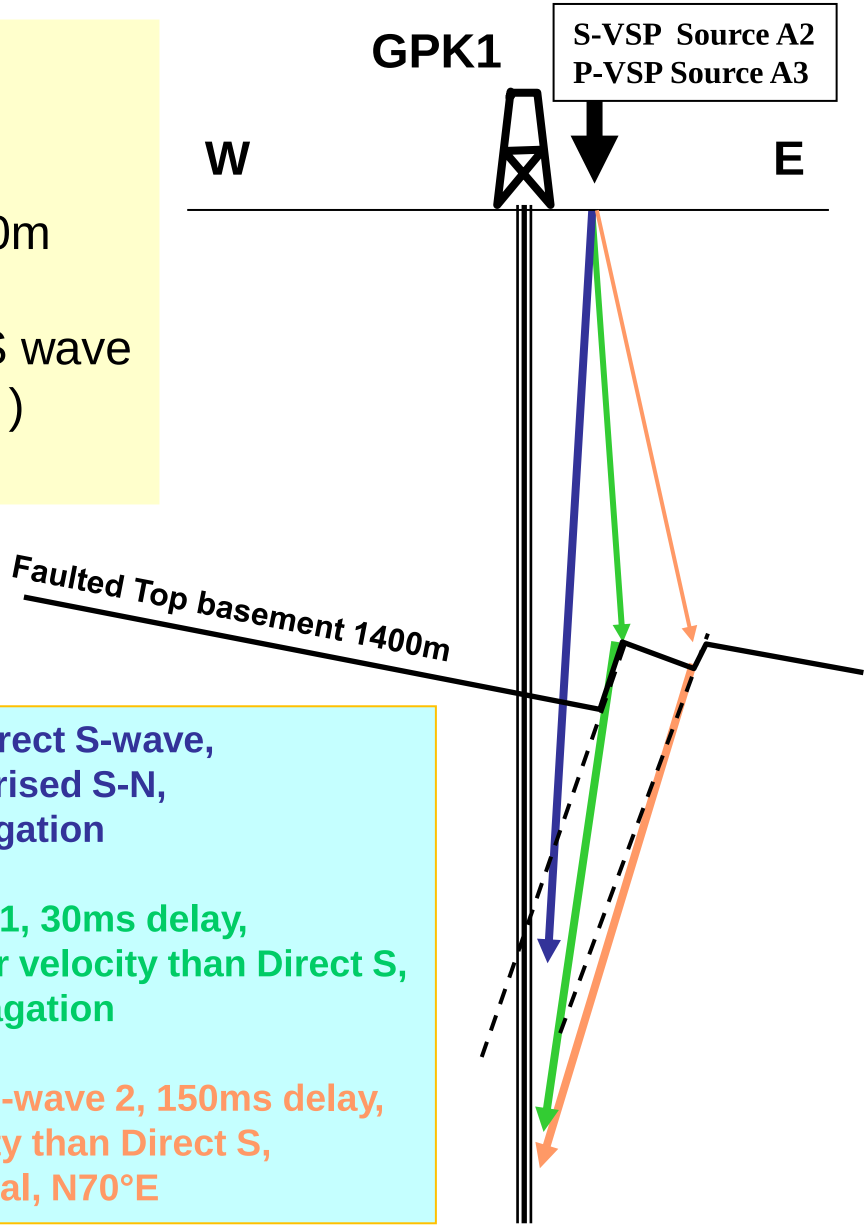
- The jitter orientation/rotation adjustments performed on the direct S wavetrain independently from the source polarizations S-N and E-W , using a maximization process of the polarized energy in a short window along a S wave time pick on the modulus (trough or peak), shows a precision of about 5 degrees for the correction angle of azimuthal orientation; an additional slow rotation trend of about 10 degrees remains over the 700m deep basement VSP logged interval (previous slide),
- This applied orientation process definitely improves the initial orientation results using the direct P-wave Offset VSP's recorded in the same run as the Zero offset S-wave VSP's; although with a too short offset . As the S-wave data is rendered more accurately oriented prior to VSP processing operations, the quality of processed results would subsequently be improved.

- Nevertheless, a magnetometer mounted on the VSP tool would definitely simplify and speed up the orientation preprocessing operations, for industrial or academic VSP’s .

- If present, the velocity anisotropy of the direct S wave does not exceeds 1.5% in the present case study, with fast S wave polarized nearly parallel to a known S-N fault.
- Two high amplitude secondary S wave arrivals have been clearly identified within a short time delay after the direct arrival and with higher apparent velocities, due to the presence of fault in the well vicinity.
- NO S-S reflected arrivals can be detected after downgoing S-wave filter removal, in spite of the imperfect orientation of horizontal components using a P-wave OVSP.
- Only P-S converted reflections are observed, mainly on the vertical component.

Soultz GPK-1 well
Proposed Sketch
for S-wave propagation
in the interval 2700m - 3480m

(Hints of interfered P and S wave
Direct arrivals are apparent)

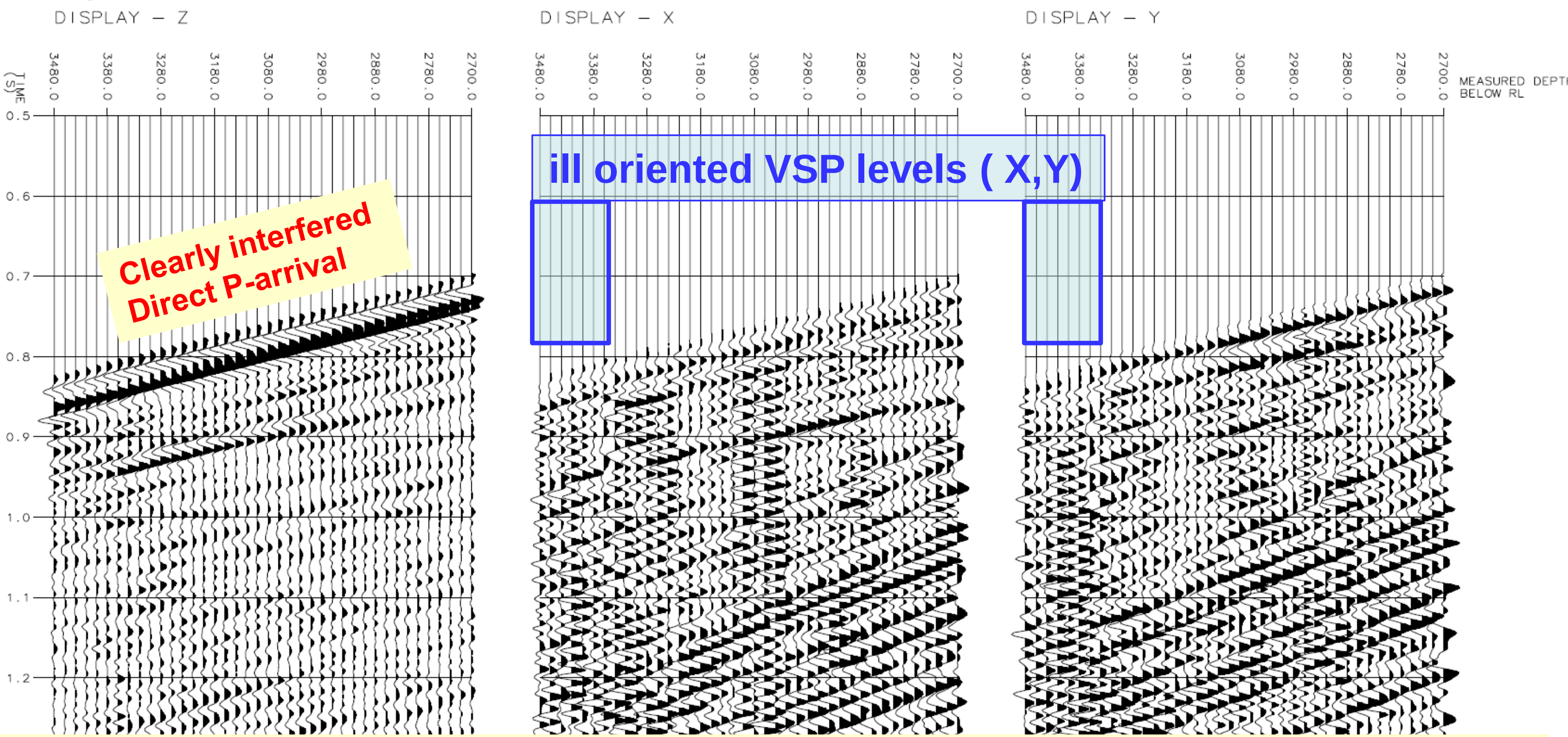


**First downgoing Direct S-wave,
in first arrival, polarised S-N,
near vertical propagation**

**Secondary S-wave 1, 30ms delay,
with slightly higher velocity than Direct S,
near vertical propagation**

**FAST Secondary S-wave 2, 150ms delay,
with slower velocity than Direct S,
polarized 15°vertical, N70°E**

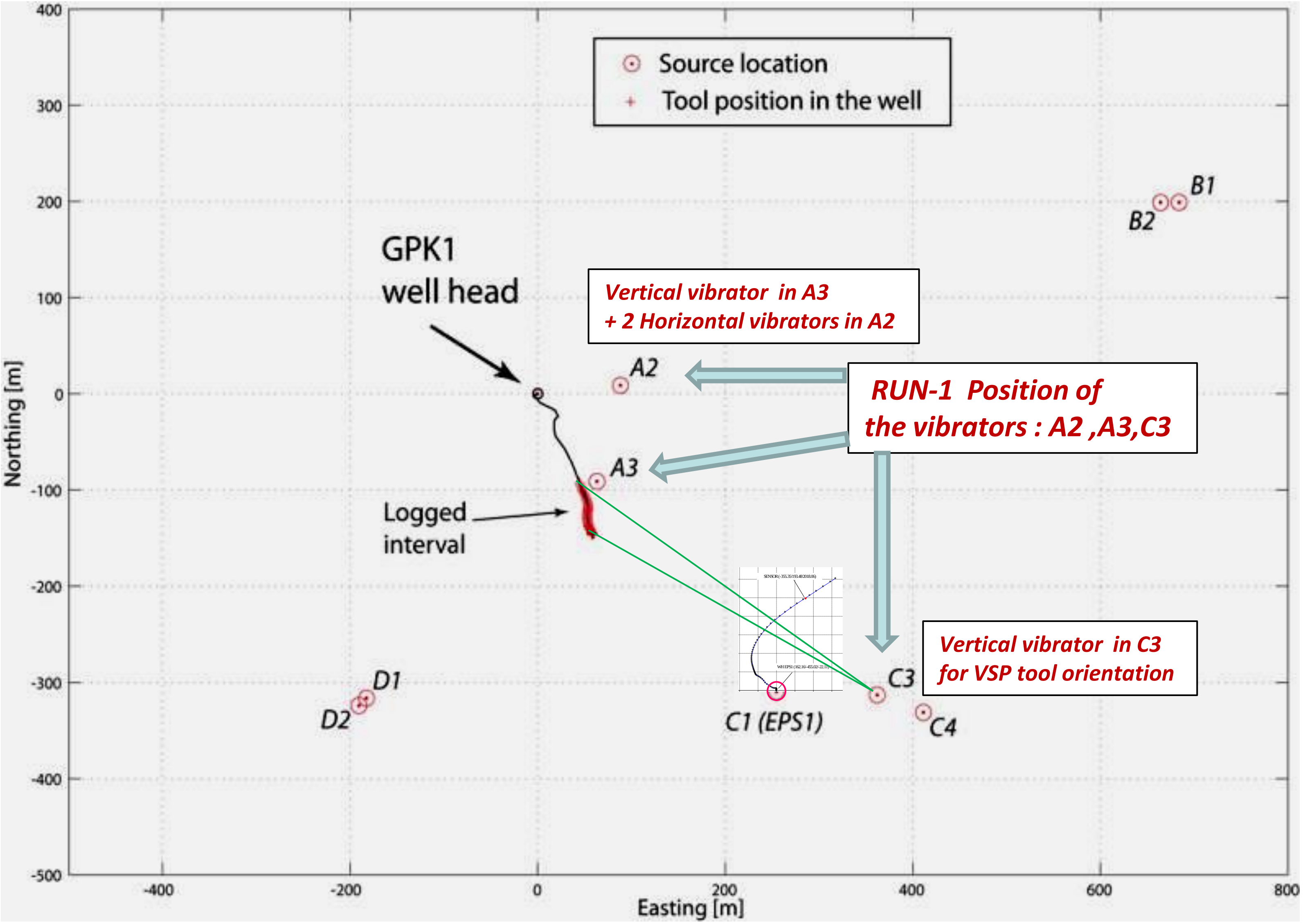
GPK-1: O-VSP C3-Run1 used for orientation of Z-VSPs; Vertical vibrator



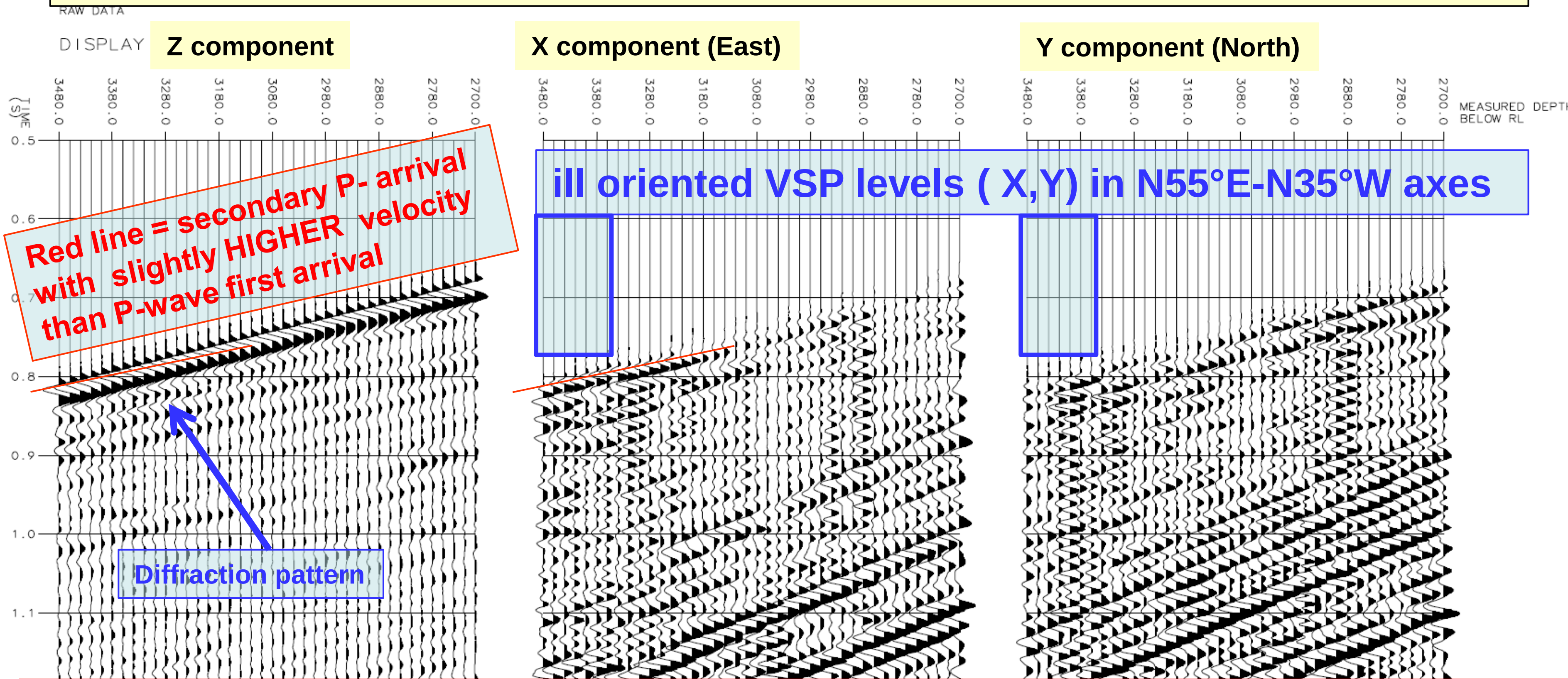
The deep VSP levels are incorrectly oriented on (X,Y) components due to the interfered Direct P-arrival;
Signs of interference are clear on the vertical Z- component. The interference is NOT due to any gradual variation of the vibrator source signal level to level.

EXPLANATION: ***The seismic propagation follows multiple distinct paths through several adjacent faulted-tilted compartments within the basement.***

Soultz GPK-1 well – Location map; May 1993 VSP campaign



GPK-1: ZVSP A3-Run1, Vertical vibrator; raw data orientated with O-VSP C3-run1



The deep VSP levels are incorrectly oriented on (X,Y) components

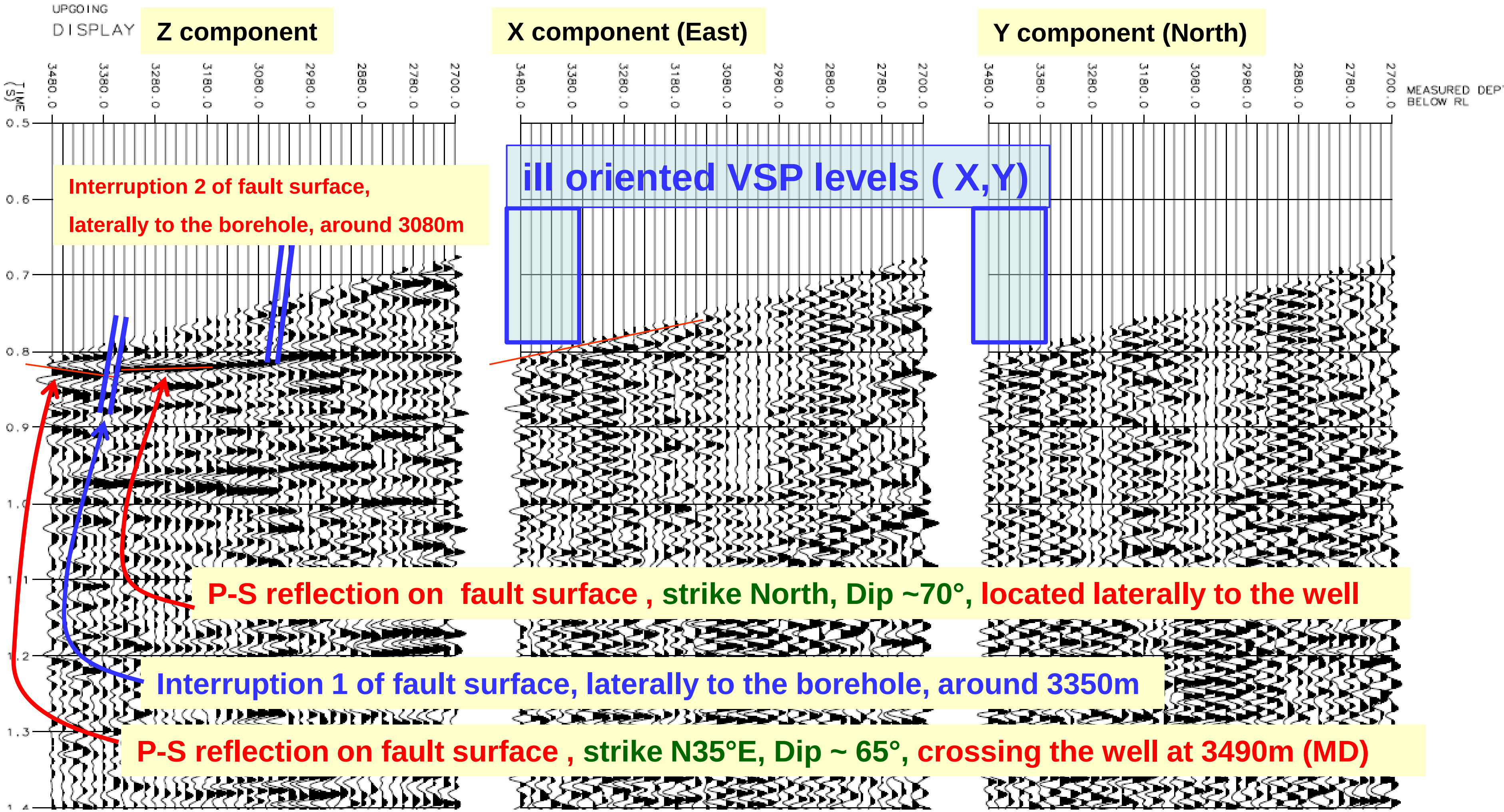
No interference clearly observable on the direct P-arrival / Vertical Z - component.

A direct P - wave secondary arrival CLEARLY appears on Horizontal component (X-East), related to a refracted along the fault surface crossing the well at 3490m, confirmed by a well defined seismic P-S reflection and many logs.

Here, the refracted arrival azimuth is normal to the fault strike, downdip.

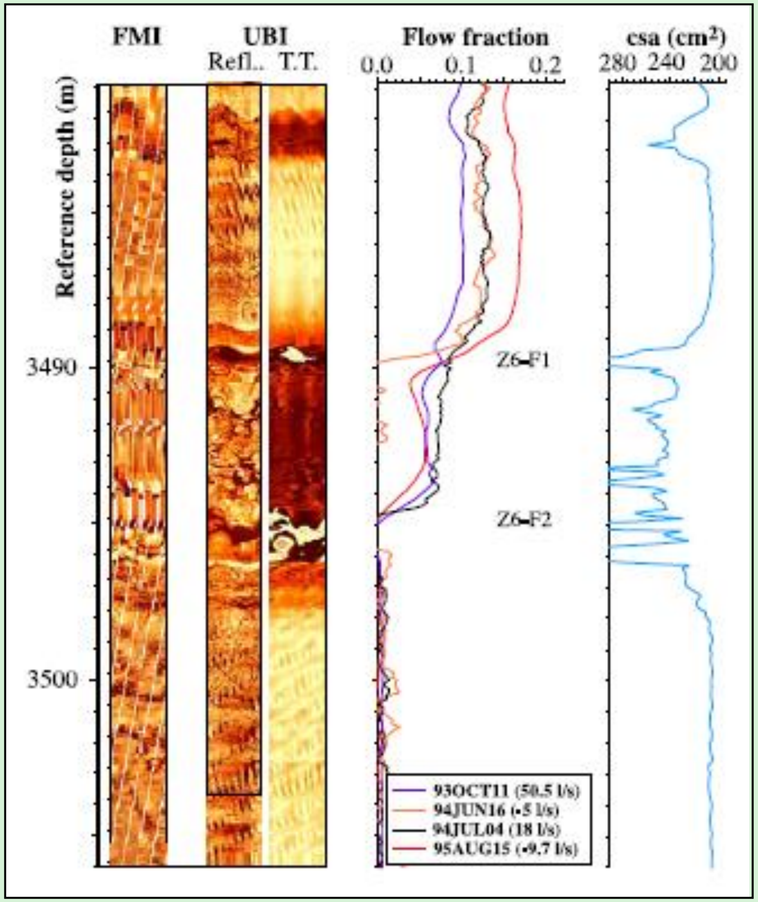
More generally, the approximate propagation plane includes the source, receiver and reflection positions, the polarization direction of P-S converted reflections and the polarization direction of P-wave refraction along the fault surface…

GPK-1: ZVSP A3-Run1, Vertical vibrator; 3C upgoing wavefield, non deconvolved

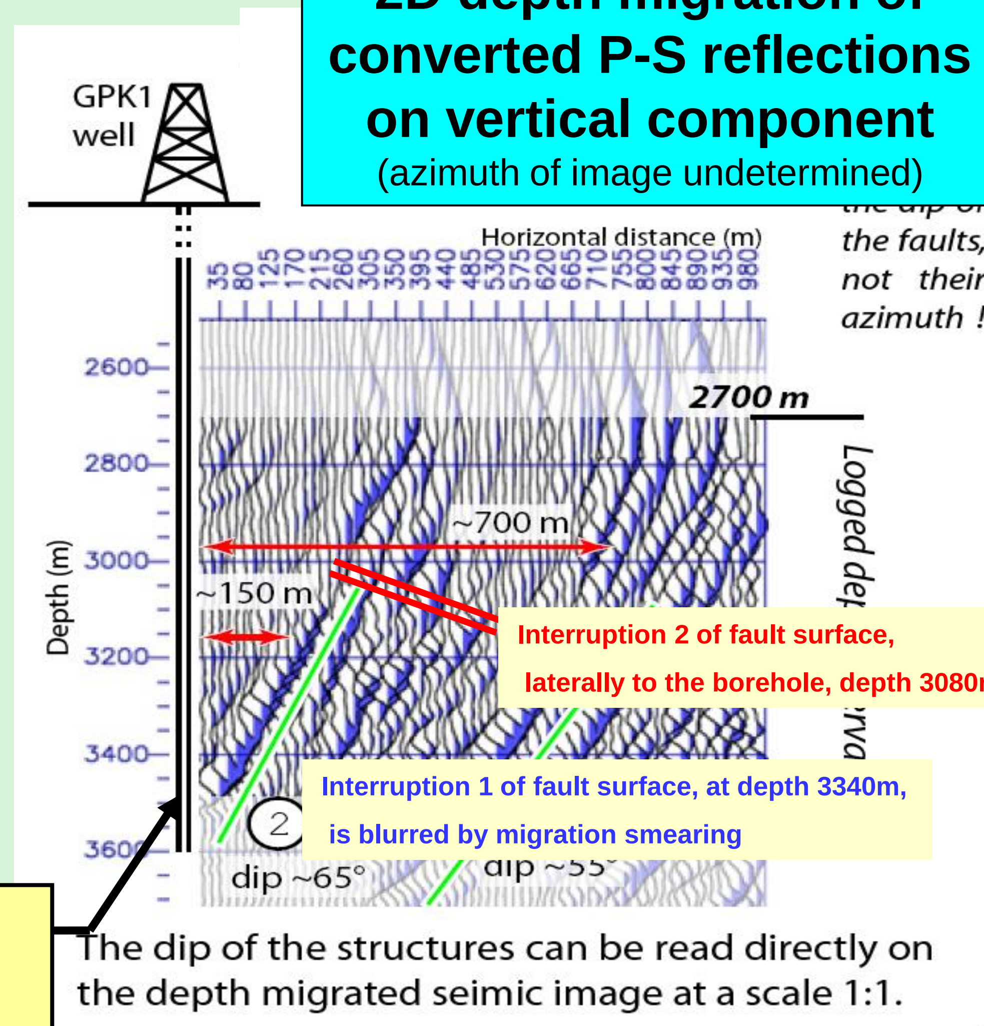


Ugoing 3C VSP wavefield in same raw VSP time as on previous slide (raw 3C data).
Isotropic 3C VSP processing by Martin COX, VSFUSION-UK

SELECTIVE reflection imaging of highly dipping permeable fault **in CONVERTED P-S MODE ONLY,** using **oriented three component** Vertical seismic Profiling (**VSP**).



2D depth migration of converted P-S reflections on vertical component
(azimuth of image undetermined)



Interruption 2 of fault surface, laterally to the borehole, depth 3080m

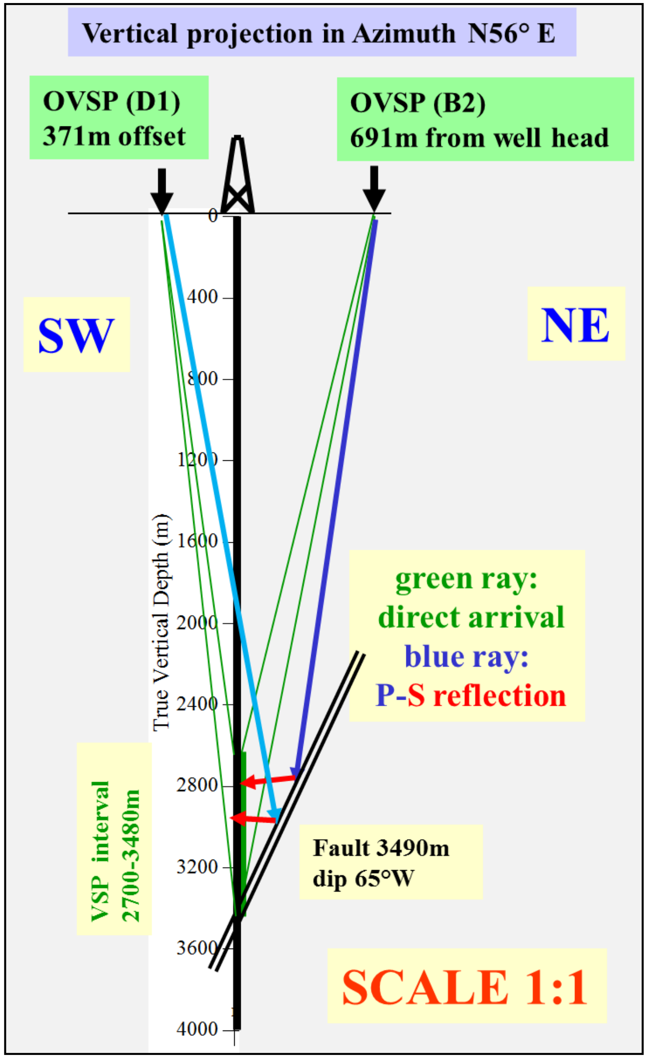
Interruption 1 of fault surface, at depth 3340m, is blurred by migration smearing

Fault intersecting the well at depth 3490m,
Permeability is confirmed by Flow logs,
65°DIPvalue is confirmed by the UBI-FMI logs

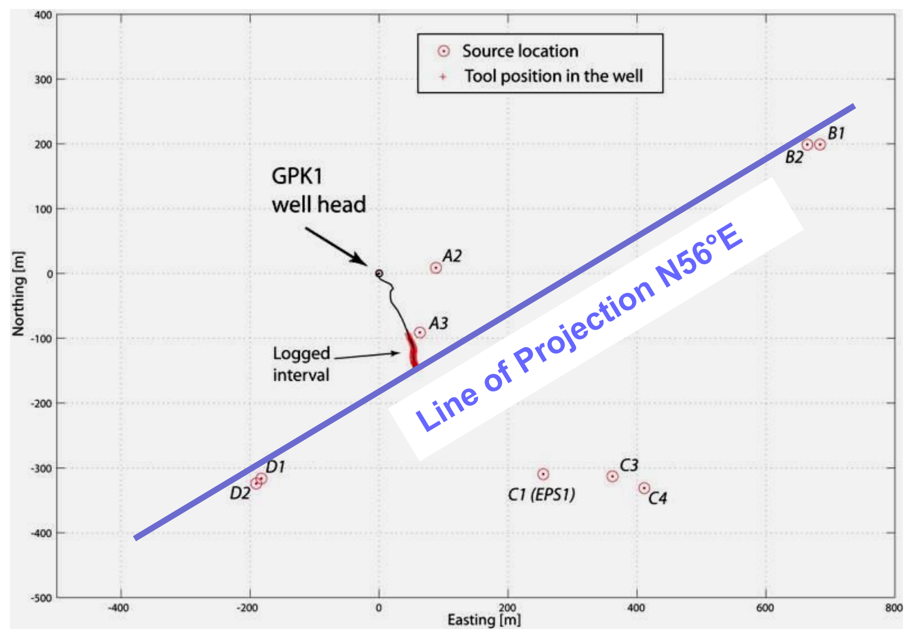
ADDENDUM IN FOLLOWING SLIDES:

Overview of OVSP 3C data, raw data and reflected wavefield from point B (run3) and point D (run4).

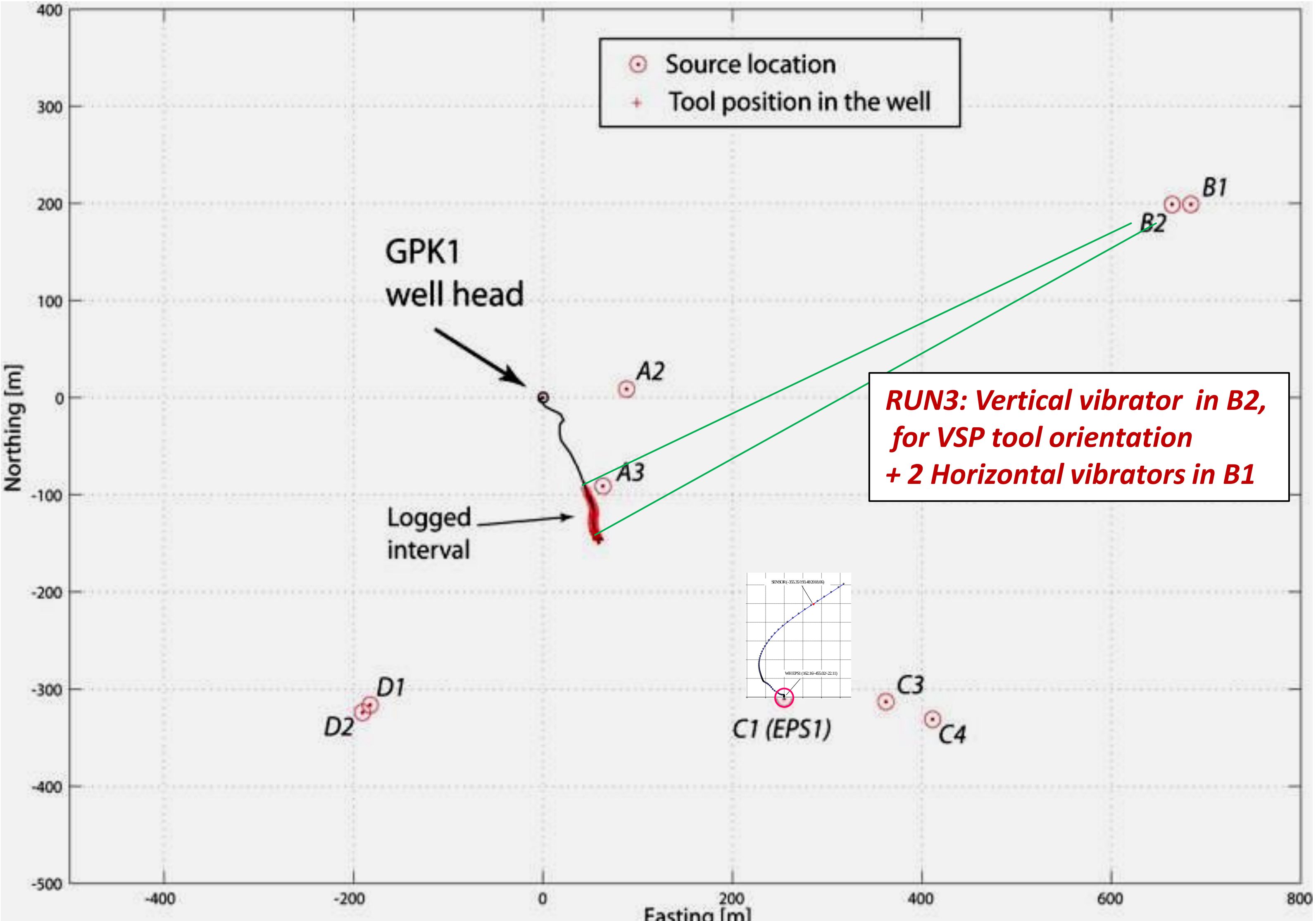
All displays in CONSTANT GAIN , identical gain on the 3C



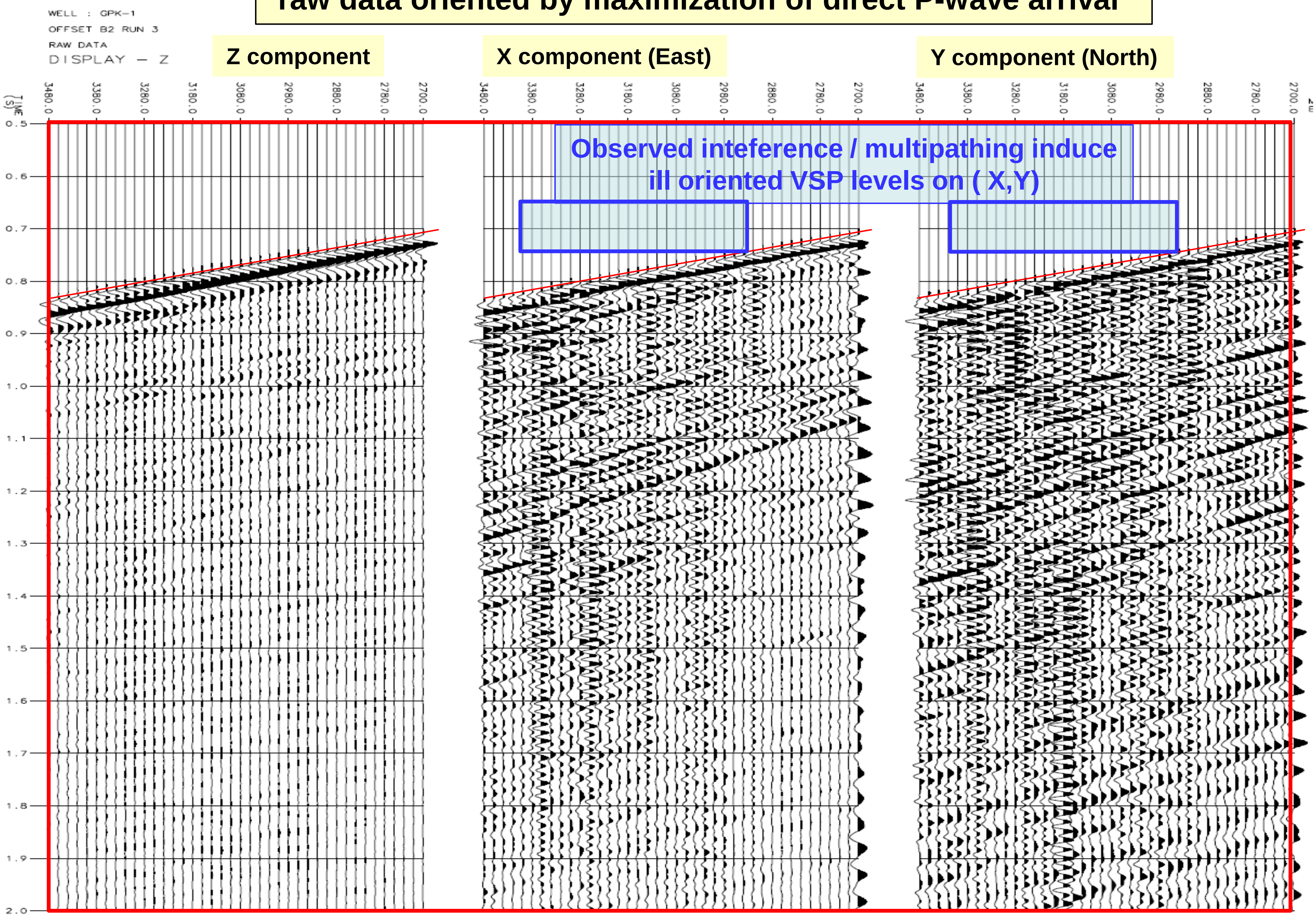
OBSERVATION on ALL GPK-1 VSP's : Interferences of P-wave direct arrival occur from ALL source azimuths, subsequently generating inaccurate polarization based 3C orientations.



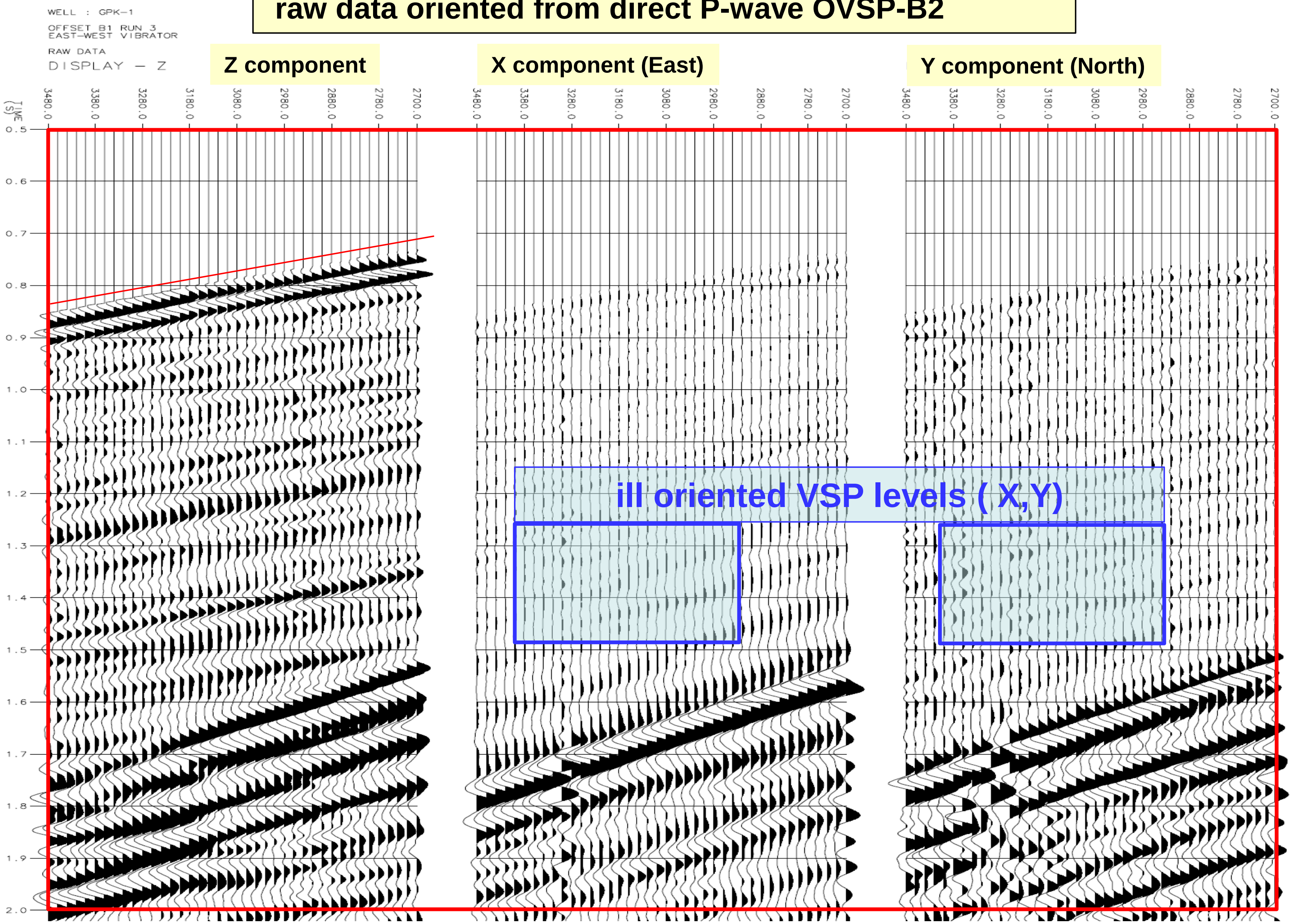
Soultz GPK-1 well – Location map; May 1993 VSP campaign



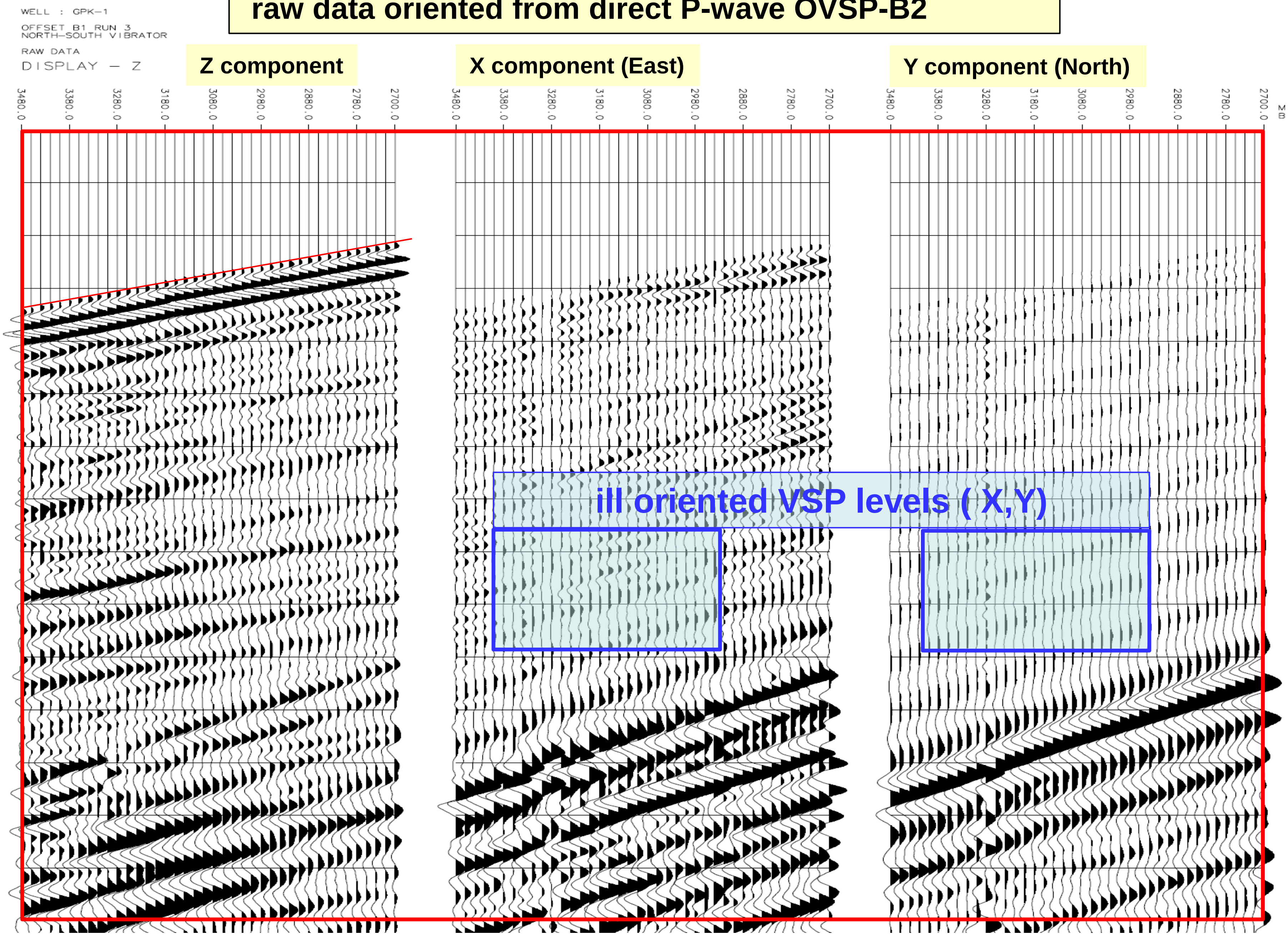
GPK-1: OVSP B2- Run3, Vertical vibrator;
raw data oriented by maximization of direct P-wave arrival



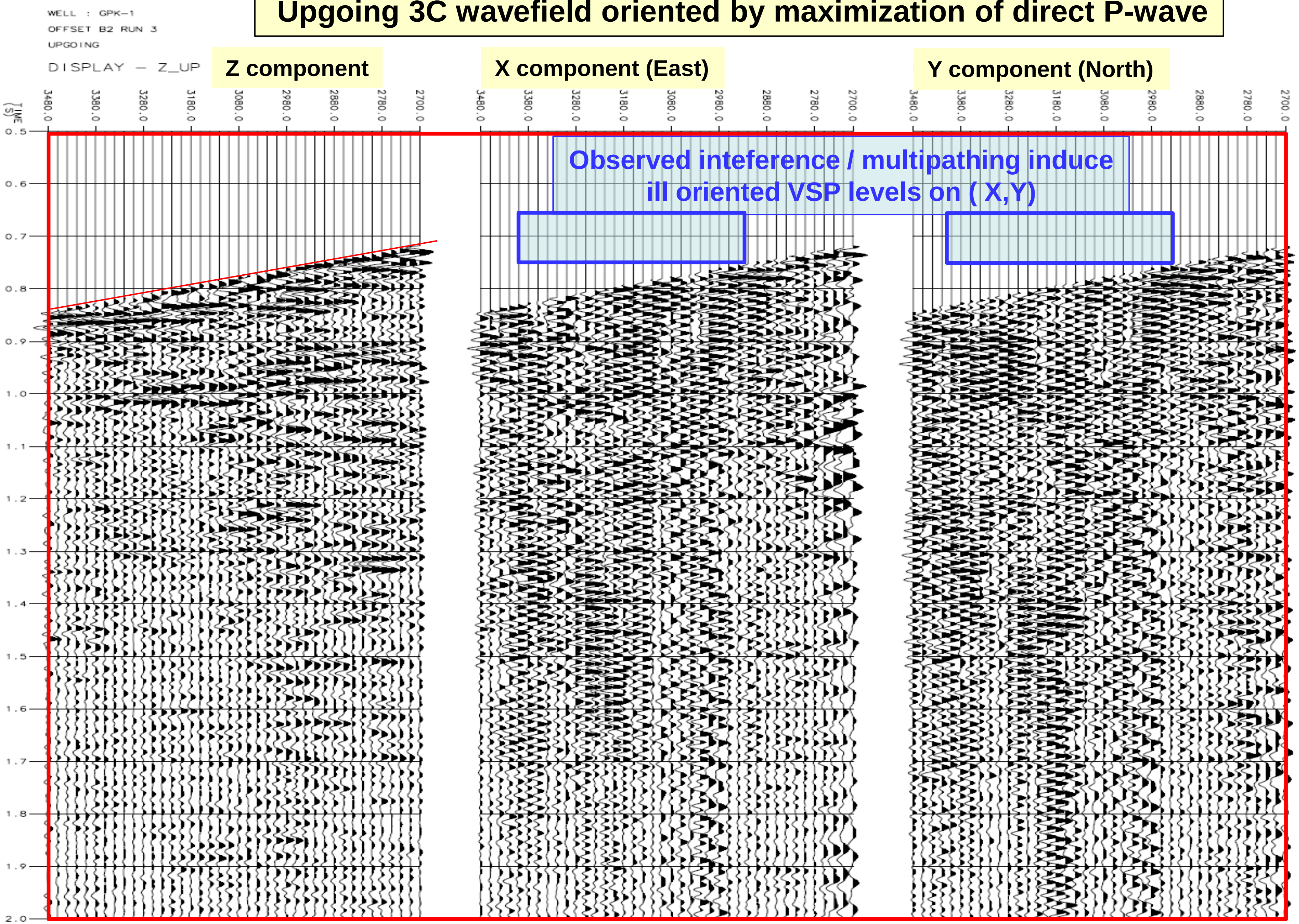
GPK-1: OVSP B1- Run3, Horizontal vibrator E-W raw data oriented from direct P-wave OVSP-B2



GPK-1: OVSP B1- Run3, Horizontal vibrator N-S raw data oriented from direct P-wave OVSP-B2



GPK-1: OVSP B2- Run3, Vertical vibrator;
Upgoing 3C wavefield oriented by maximization of direct P-wave

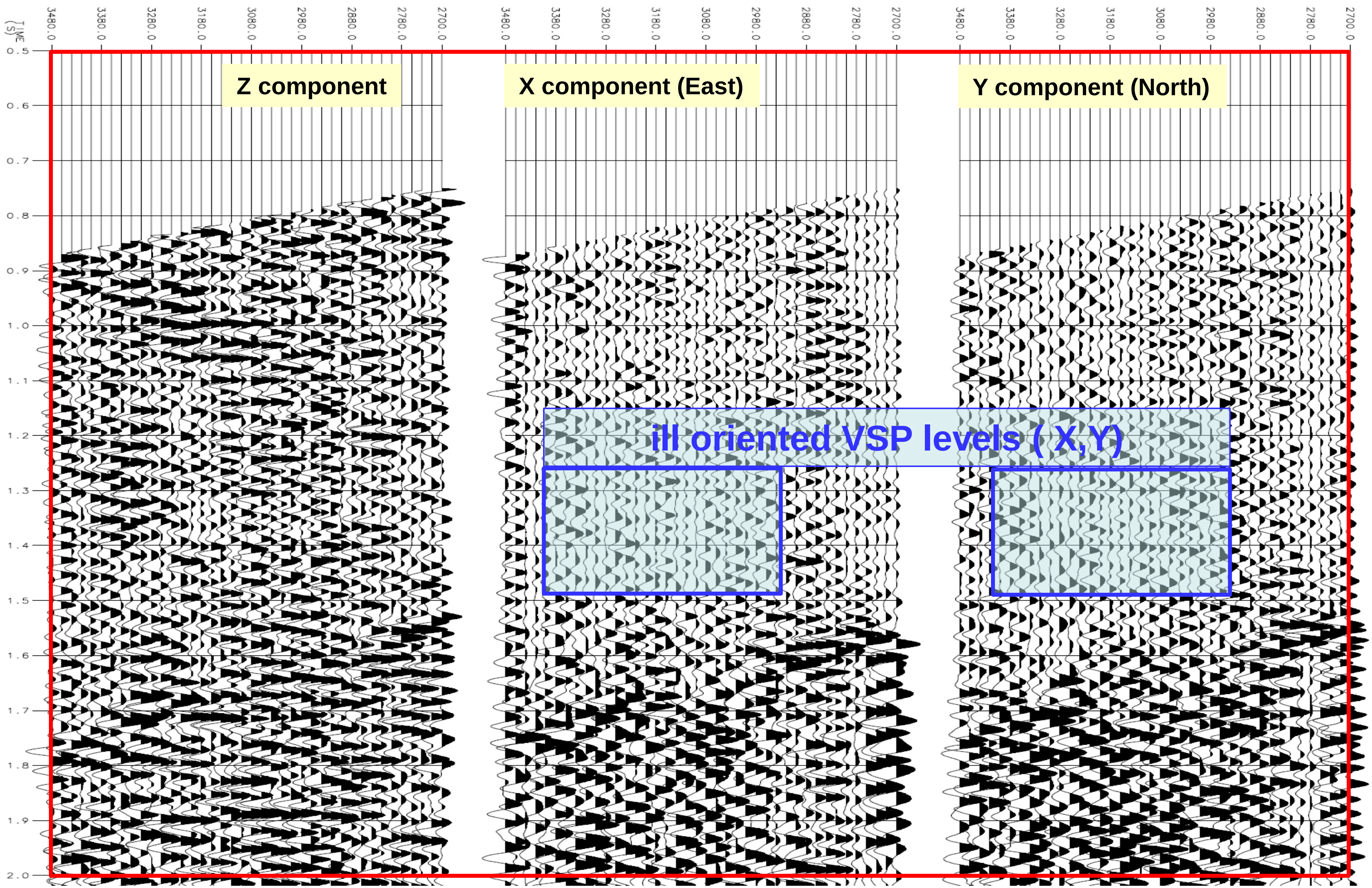


GPK-1: OVSP B1- Run3, Horizontal vibrator E-W

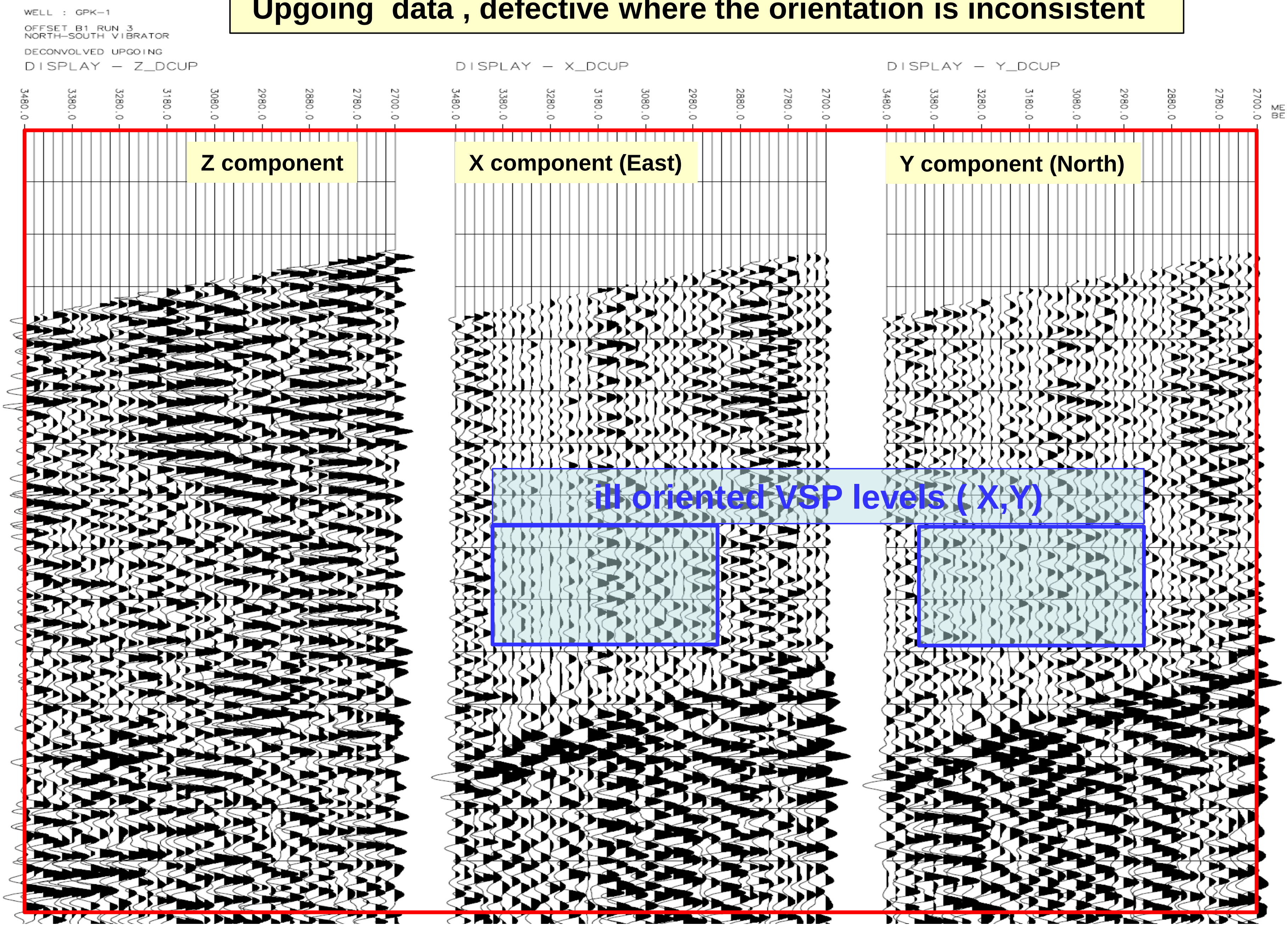
Upgoing data , defective where the orientation is inconsistent

Direct S-wave residuals are due to remaining orientation angle jitter

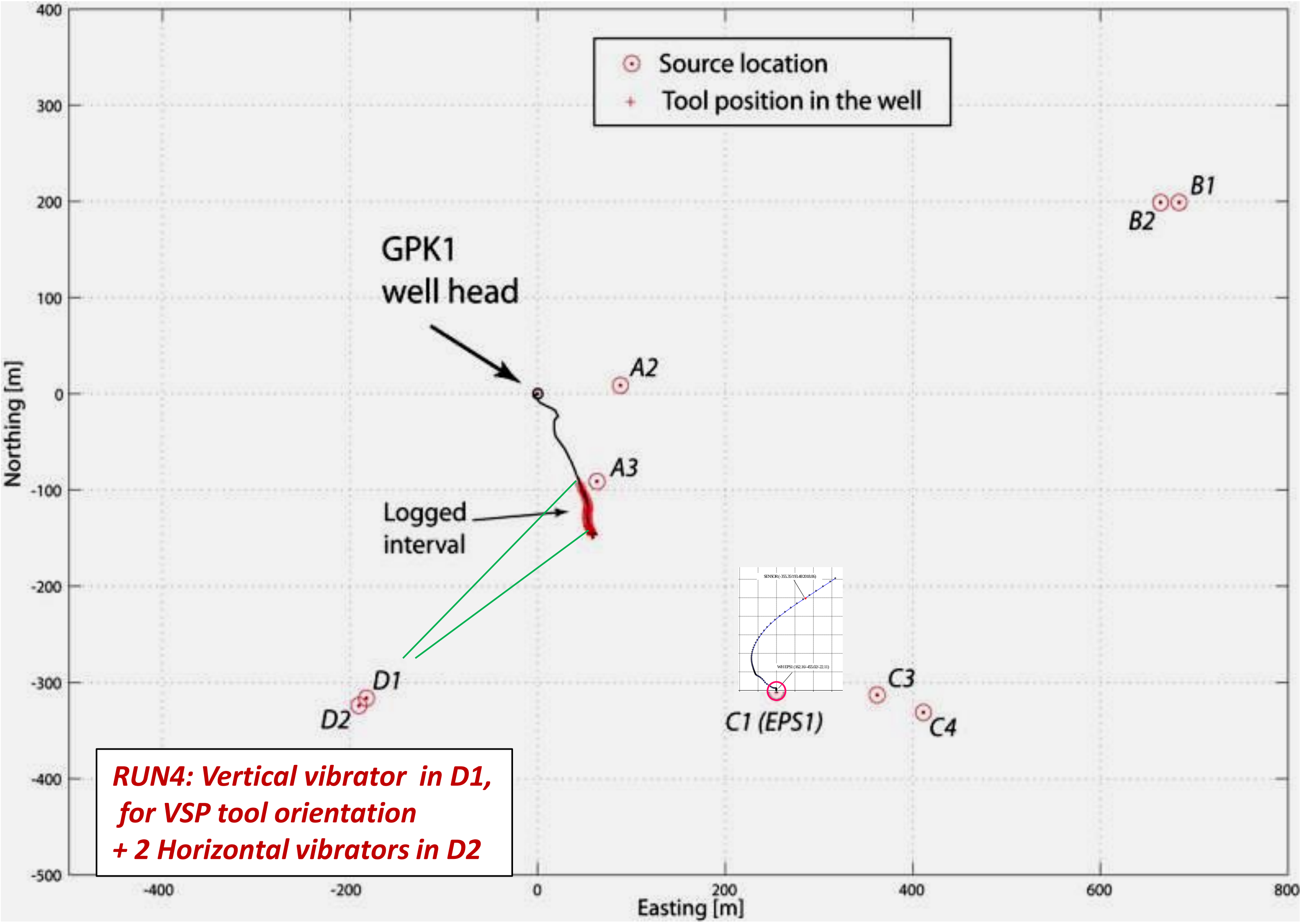
WELL : GPK-1
OFFSET B1 RUN 3
EAST-WEST VIBRATOR
DECONVOLVED UPGOING
DISPLAY — Z_DCUP



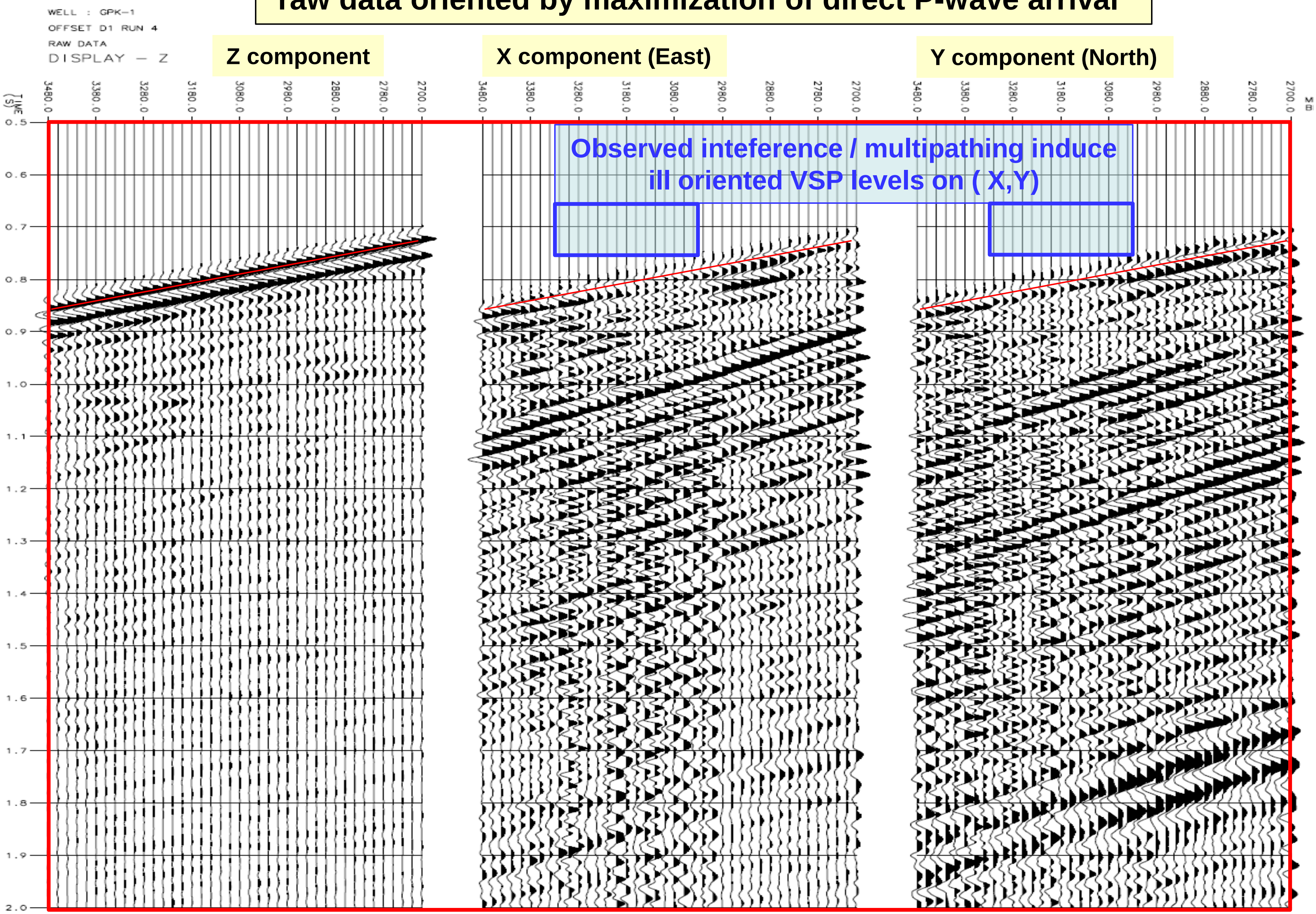
GPK-1: OVSP B1- Run3, Horizontal vibrator N-S
Upgoing data , defective where the orientation is inconsistent



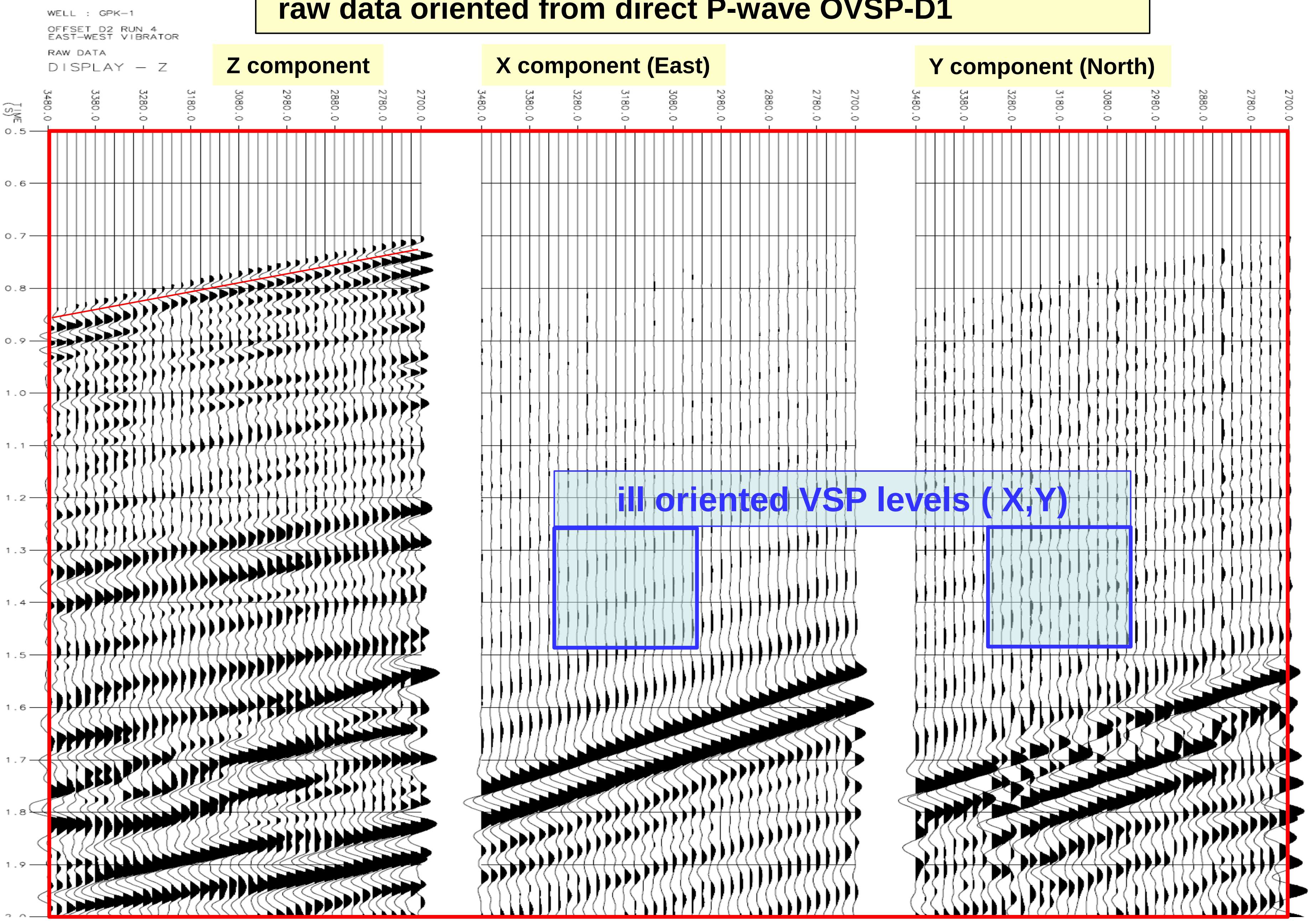
Soultz GPK-1 well – Location map; May 1993 VSP campaign



GPK-1: OVSP D1- Run4, Vertical vibrator;
raw data oriented by maximization of direct P-wave arrival

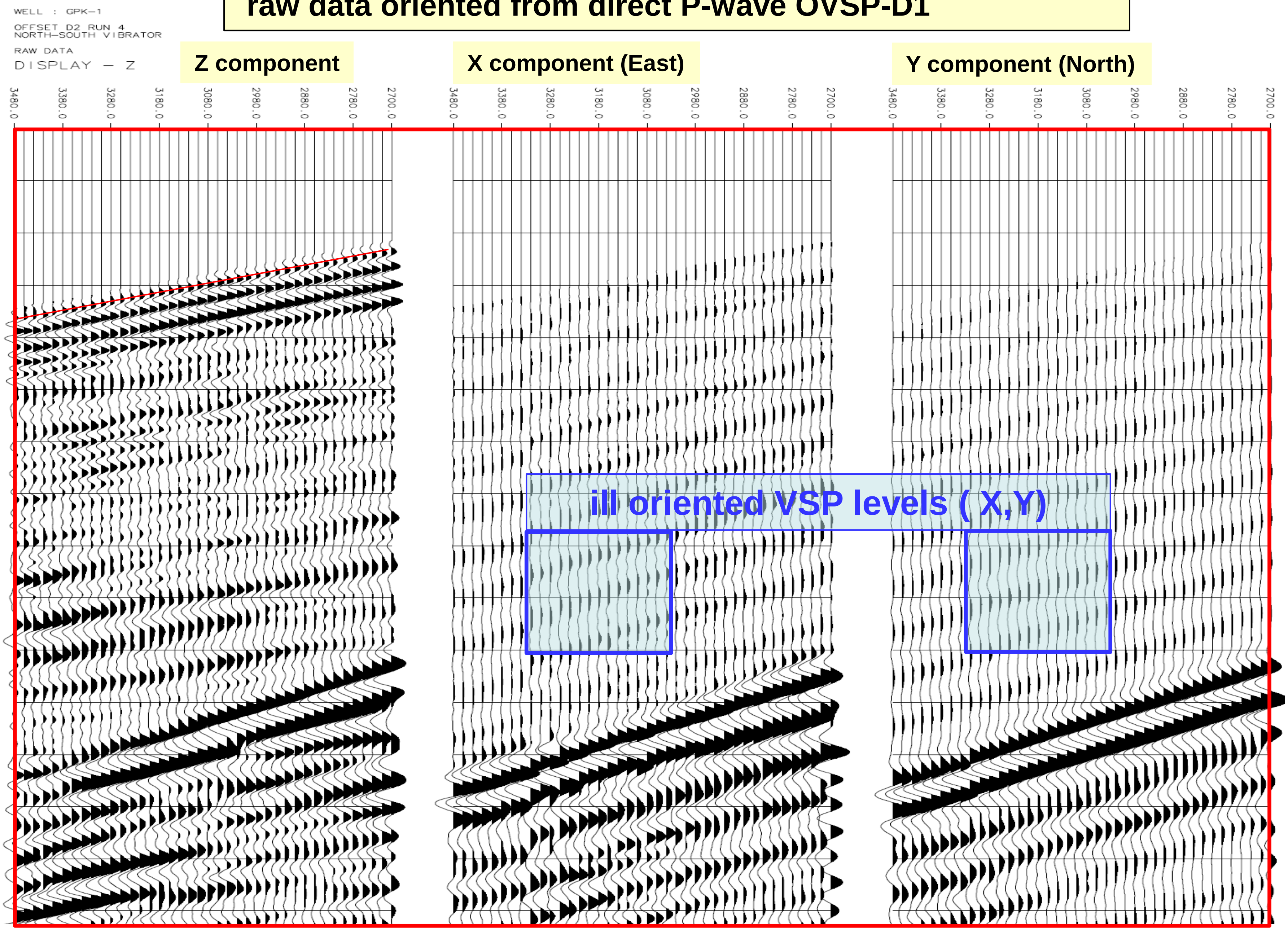


GPK-1: OVSP D2- Run4, Horizontal vibrator E-W raw data oriented from direct P-wave OVSP-D1

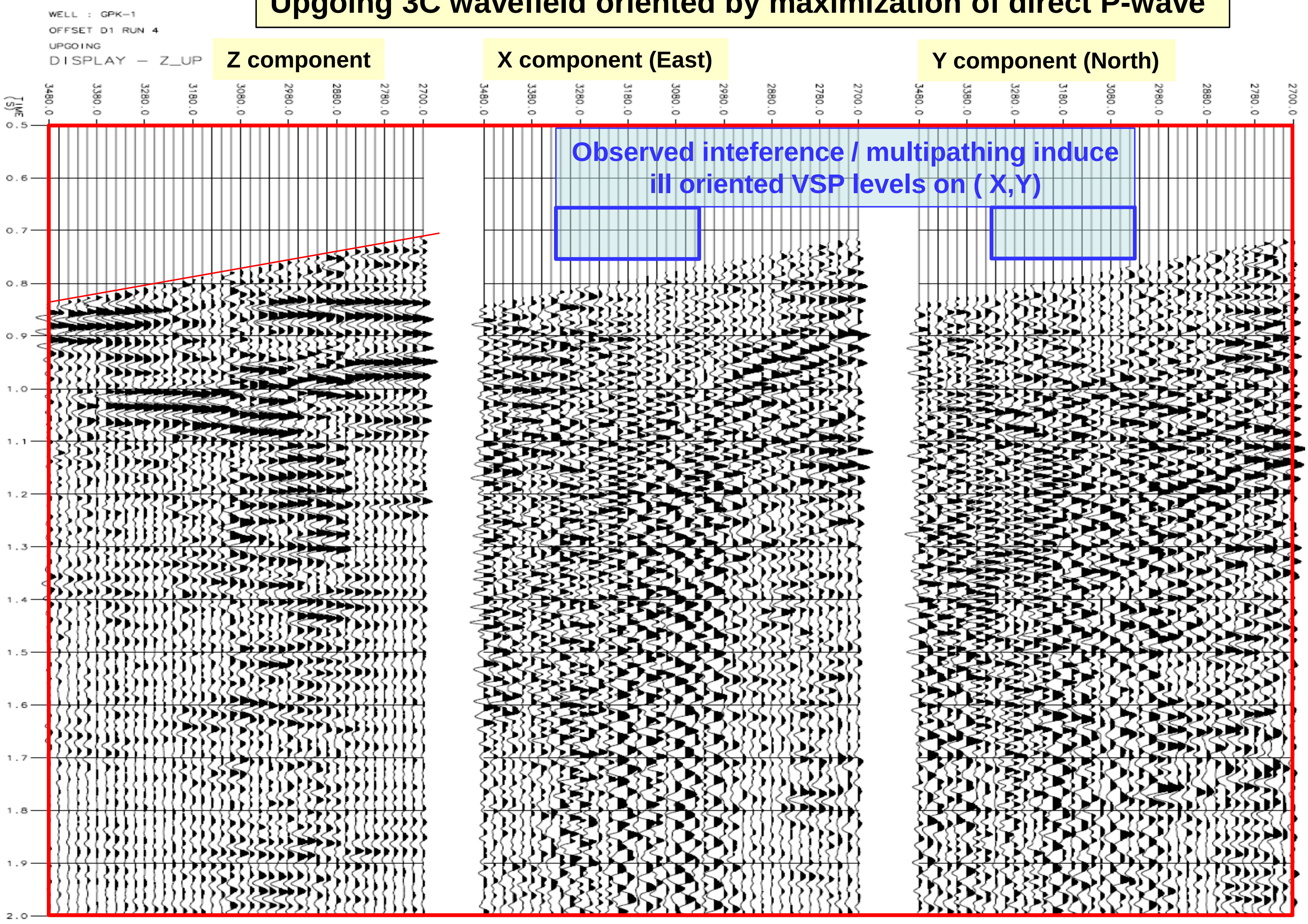


GPK-1: OVSP D2- Run4, Horizontal vibrator N-S

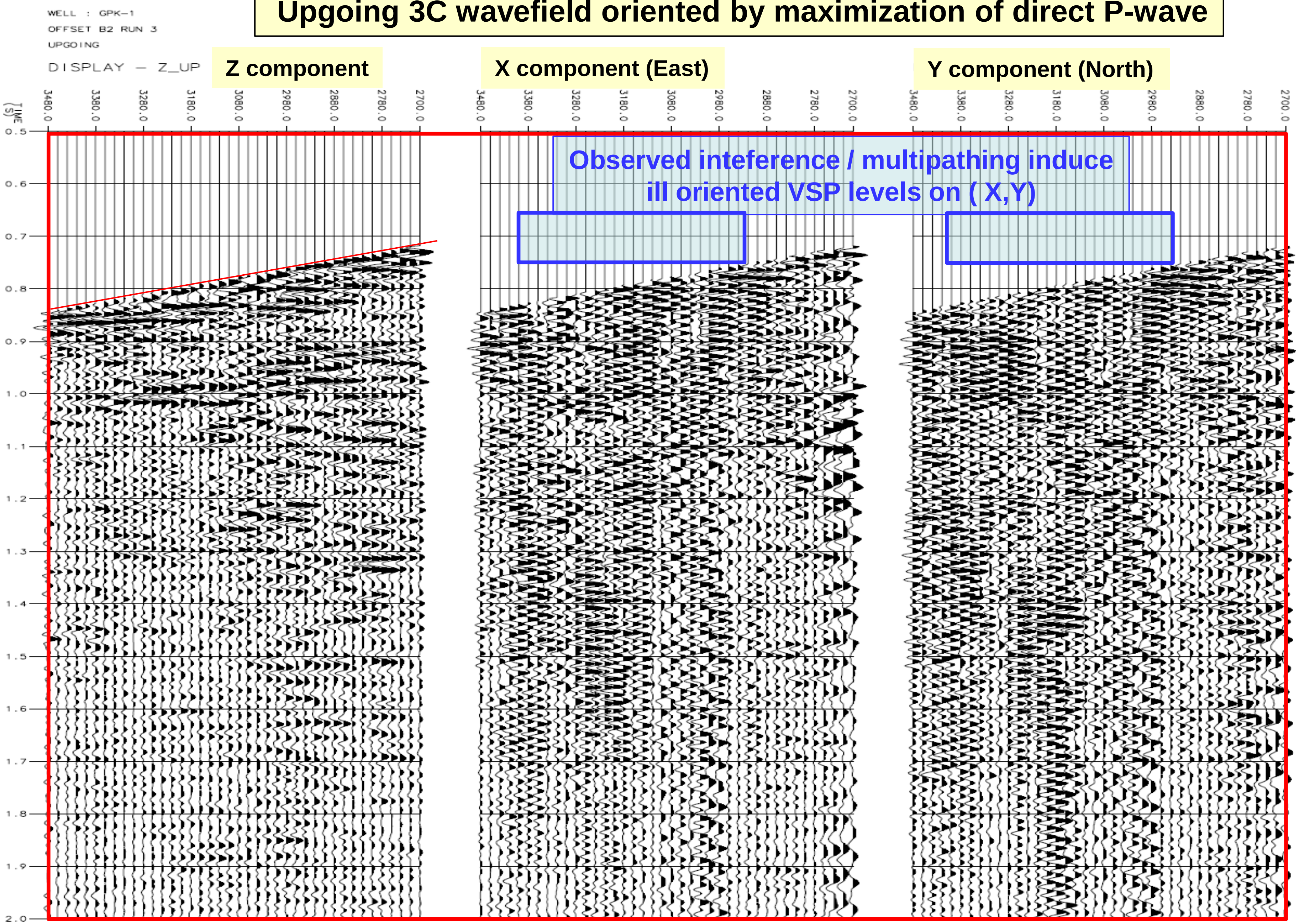
raw data oriented from direct P-wave OVSP-D1



GPK-1: OVSP D1- Run4, Vertical vibrator; Upgoing 3C wavefield oriented by maximization of direct P-wave



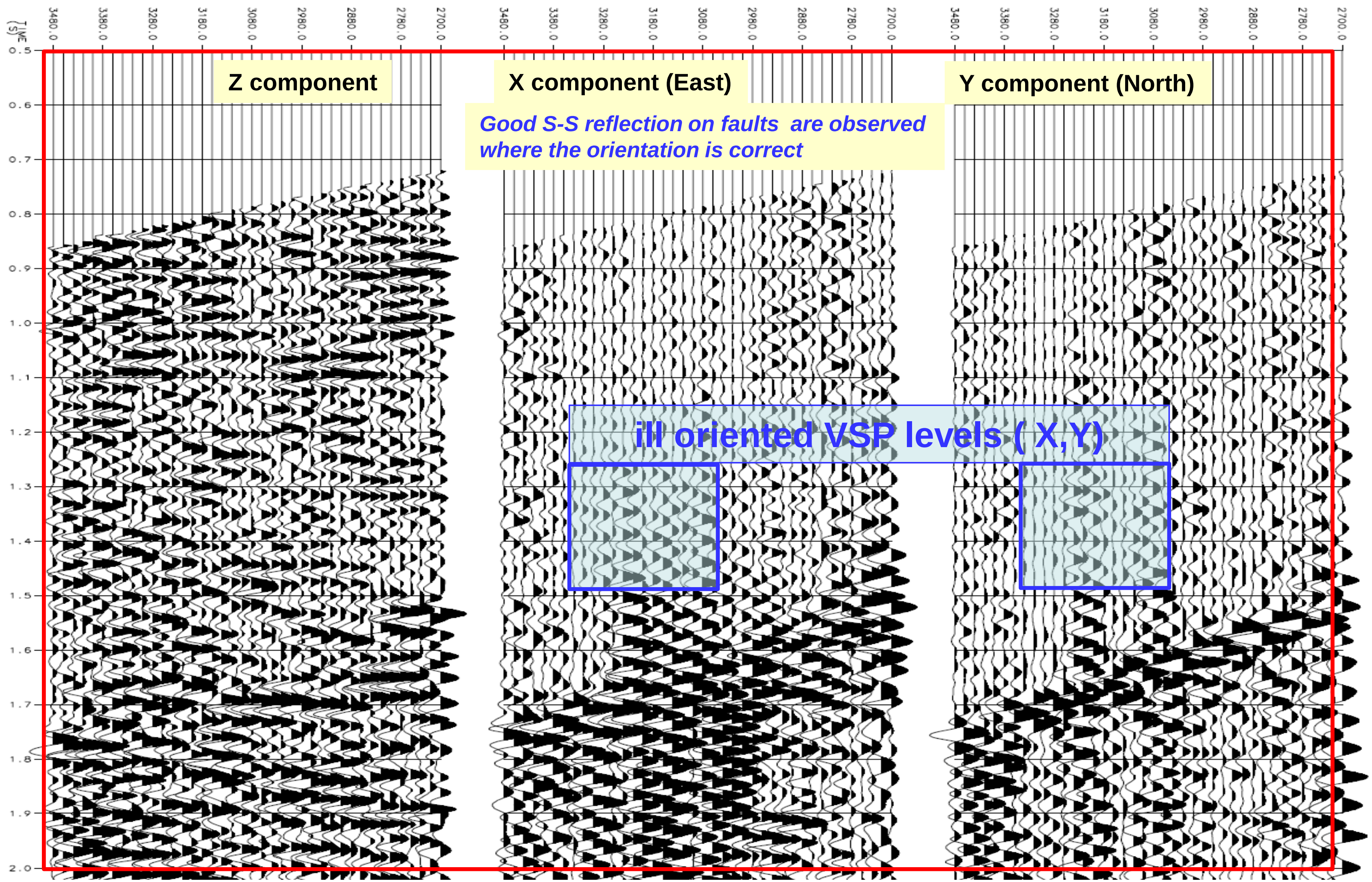
GPK-1: OVSP B2- Run3, Vertical vibrator;
Upgoing 3C wavefield oriented by maximization of direct P-wave



GPK-1: OVSP D2- Run4, Horizontal vibrator E-W

Upgoing data , defective where the orientation is inconsistent

Direct S-wave residuals are due to remaining orientation angle jitter



GPK-1: OVSP D2- Run4, Horizontal vibrator N-S

Upgoing data , defective where the orientation is inconsistent