INTERPRETATIVE UNCERTAINTIES of surface seismic images investigated with a VSP and basic logs.

Case study in Alberta, Canada

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KEYWORDS: interbed multiple, coal, true amplitude VSP reflections, attenuation, gated deconvolution.

OVERVIEW OF PRESENTATION

VSP and surface seismic re-processing in 1996 by IFP using CGG seismic software

1- PROBLEM to analyze:

Surface seismic images plagued by a suspected interbed/internal multiple related to the presence of a 12m thick coalbed in western Alberta.

2- ANALYSIS of the Zero-Offet / Z-VSP data recorded in a vertical well, results in:

- Significant attenuation and phase rotation in transmission through the thin coalbed acting as a seismic screen. At deep target depth below coal, total frequency loss above 65Hz is observed.

- One of the interbed multiple is generated by the coalbed and significant reflector(s) above coal.

3- Advanced VSP reprocessing TESTS:

- True amplitude VSP processing.

- Innovative anti-multiple VSP processing test.

4 - Improvement of existing surface seismic processing route(s)

Suggestion for further possible improvement.

1- PROBLEM to analyze:

- **Surface seismic images plagued by a suspected interbed/internal multiple related to the presence of a 12m thick coalbed in Western Alberta.**

- **Differing seismic characters of seismic reflections in target interval depending on processing route and processing service companies.**

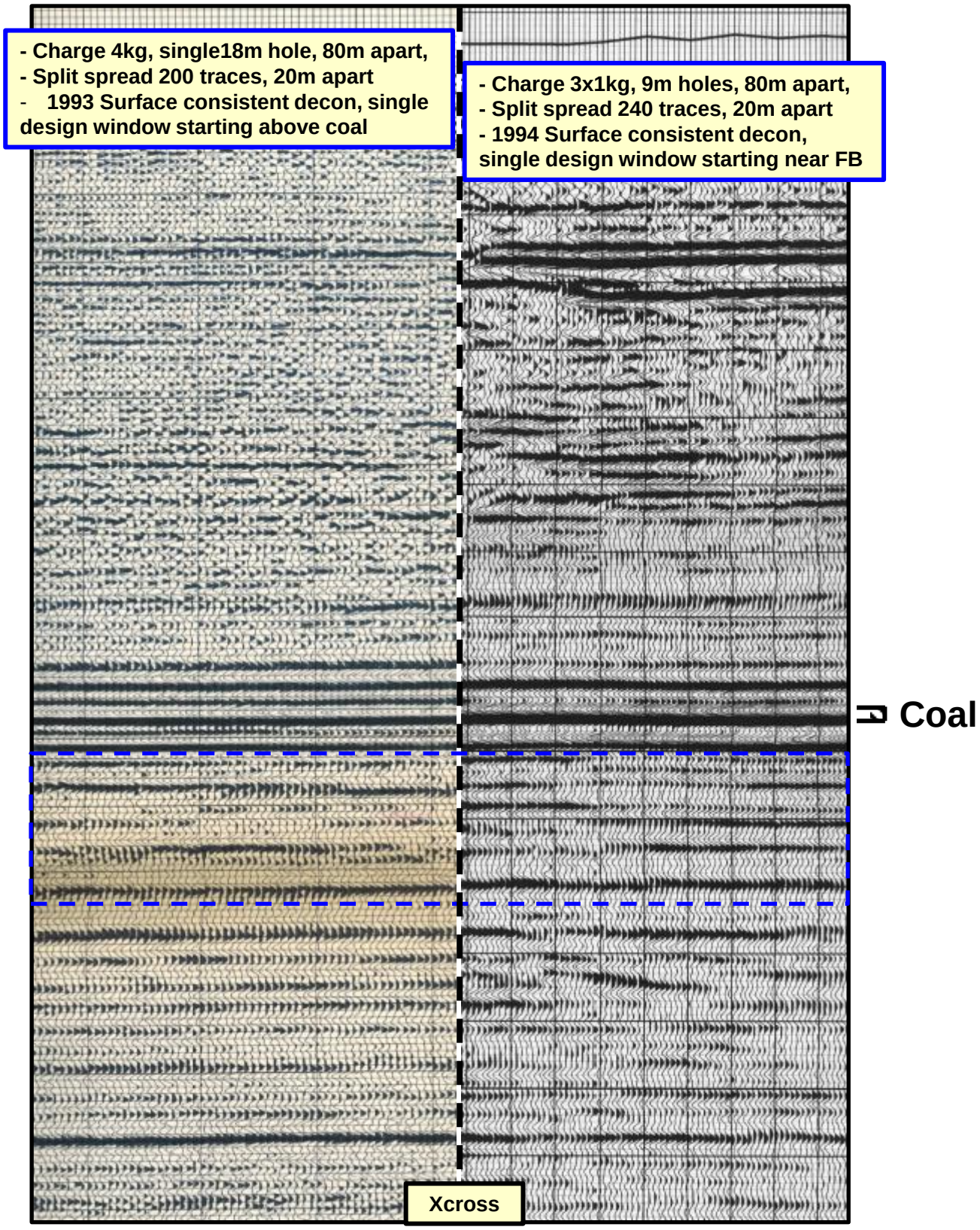
- **Removal internal multiple processing tests unsuccessful.**

- **Reliability of interpretation questioned by interpreters**

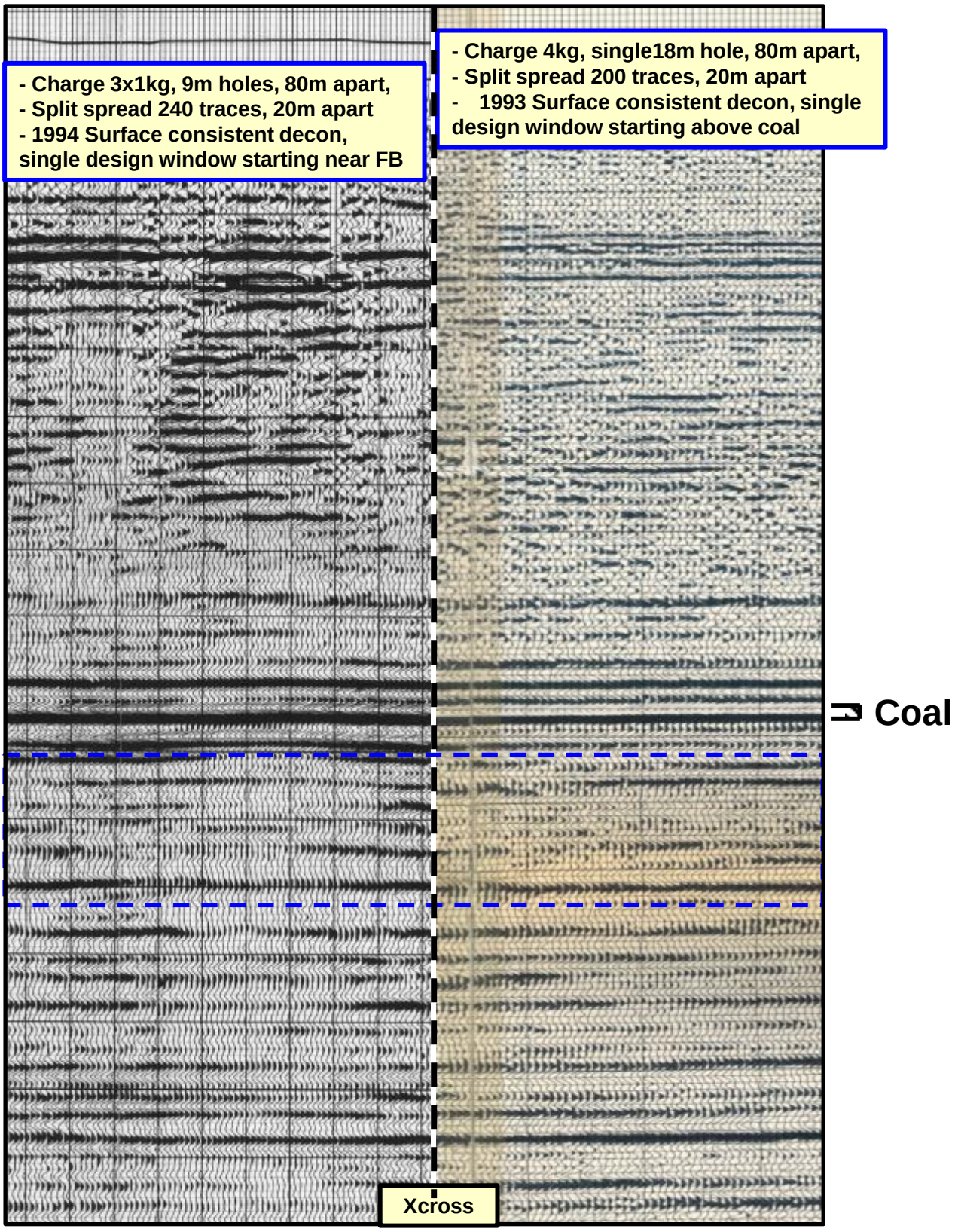
- **Difficulties to define and ascertain drilling targets.**

- **Following slides 1a,b,c,d,e: Existing surface seismic and Z-VSP / O-VSP results processed by service companies.**
- **VSP processing results indicate serious difficulties to obtain primary reflections when the VSP sensor is located ABOVE the coalbed**

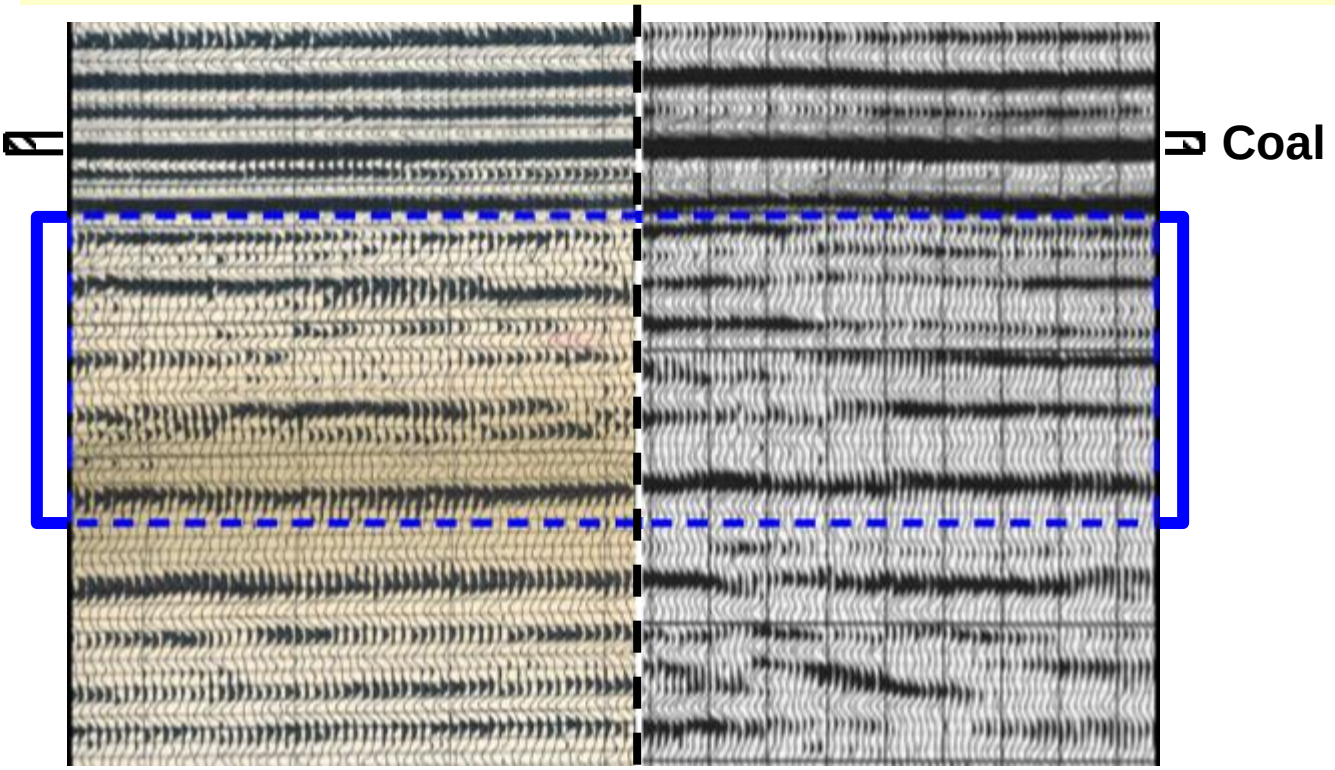
(1a) EXISTING DATA : SEISMIC LINE crossing:
Structure stacks, similar above coal, different below.

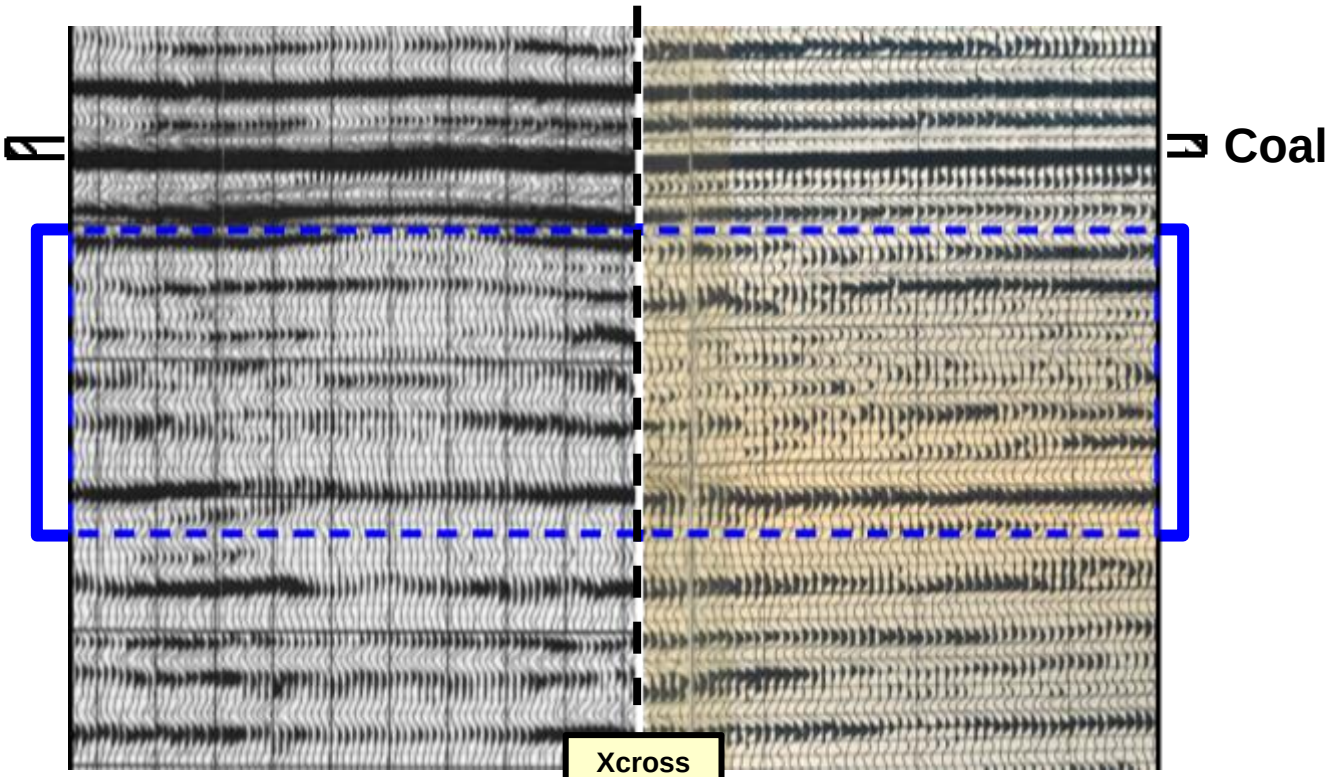


(1b) EXISTING DATA : SEISMIC LINE crossing:
Structure stacks, similar above coal, different below.



PROBLEM : Surface seismic images are adversely altered in the 250ms target interval (blue box) below a 12m thick coalbed in western Alberta, interbed multiples are suspected. Deeper reflectors look OK.





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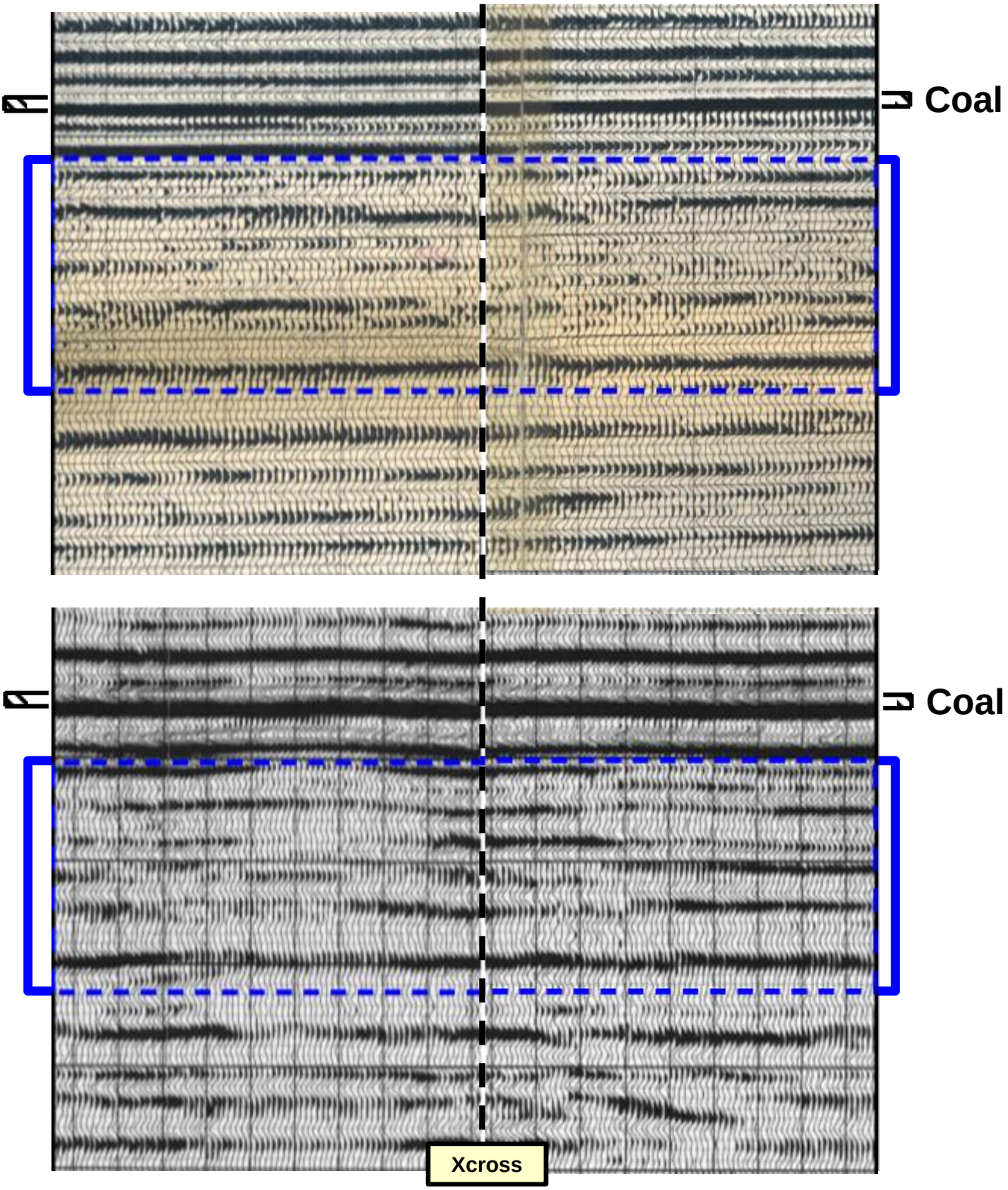
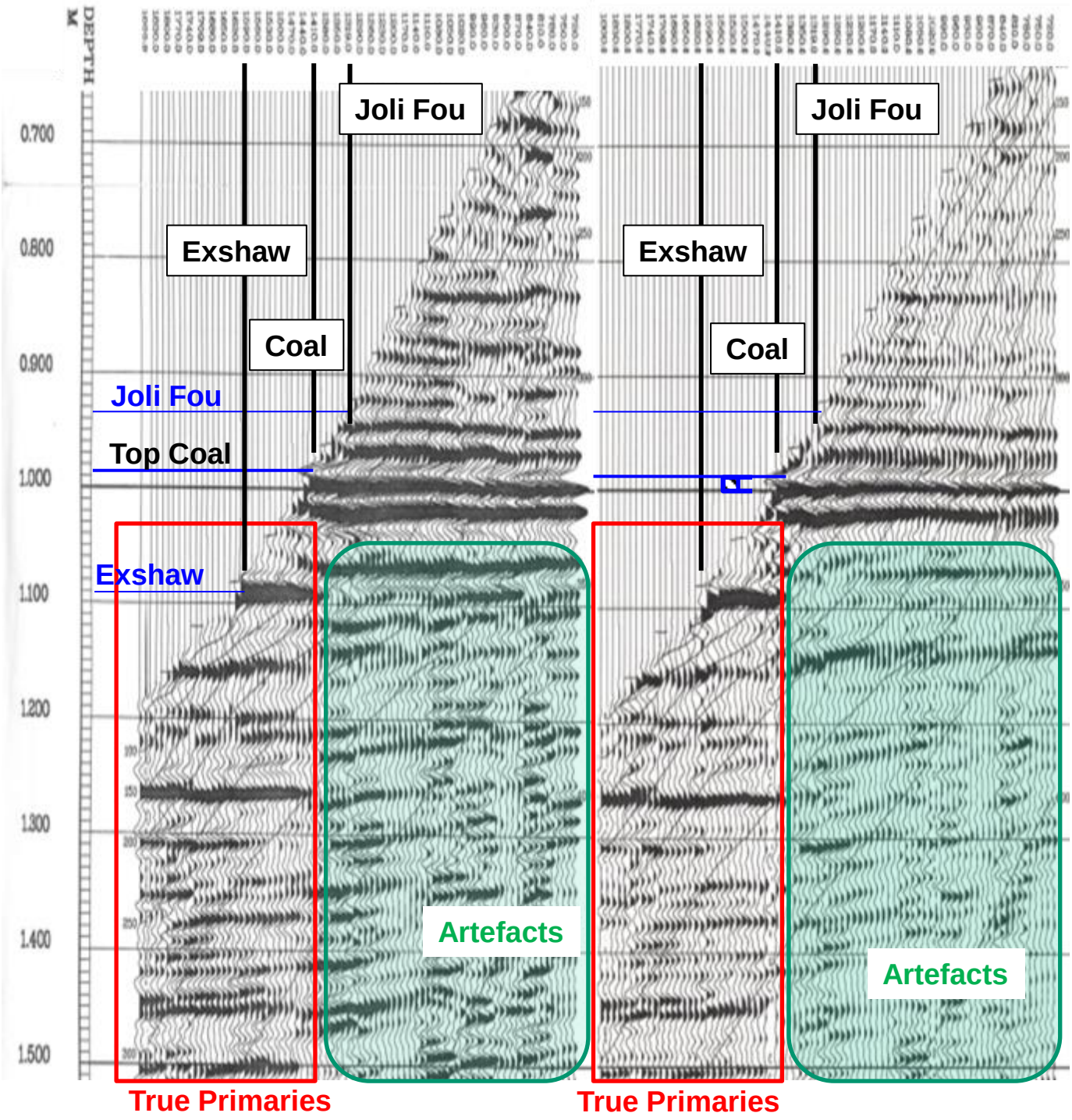


(1c) EXISTING DATA: OVSP deconvolution test

- RIGHT: trace to trace predictive deconvolution.

- LEFT: Single operator shaping decon with deepest level downgoing arrival: primary reflectors below coalbed DEPTH, but BOTH methods show artefacts below the coalbed TWT where the VSP receiver is above the coal.

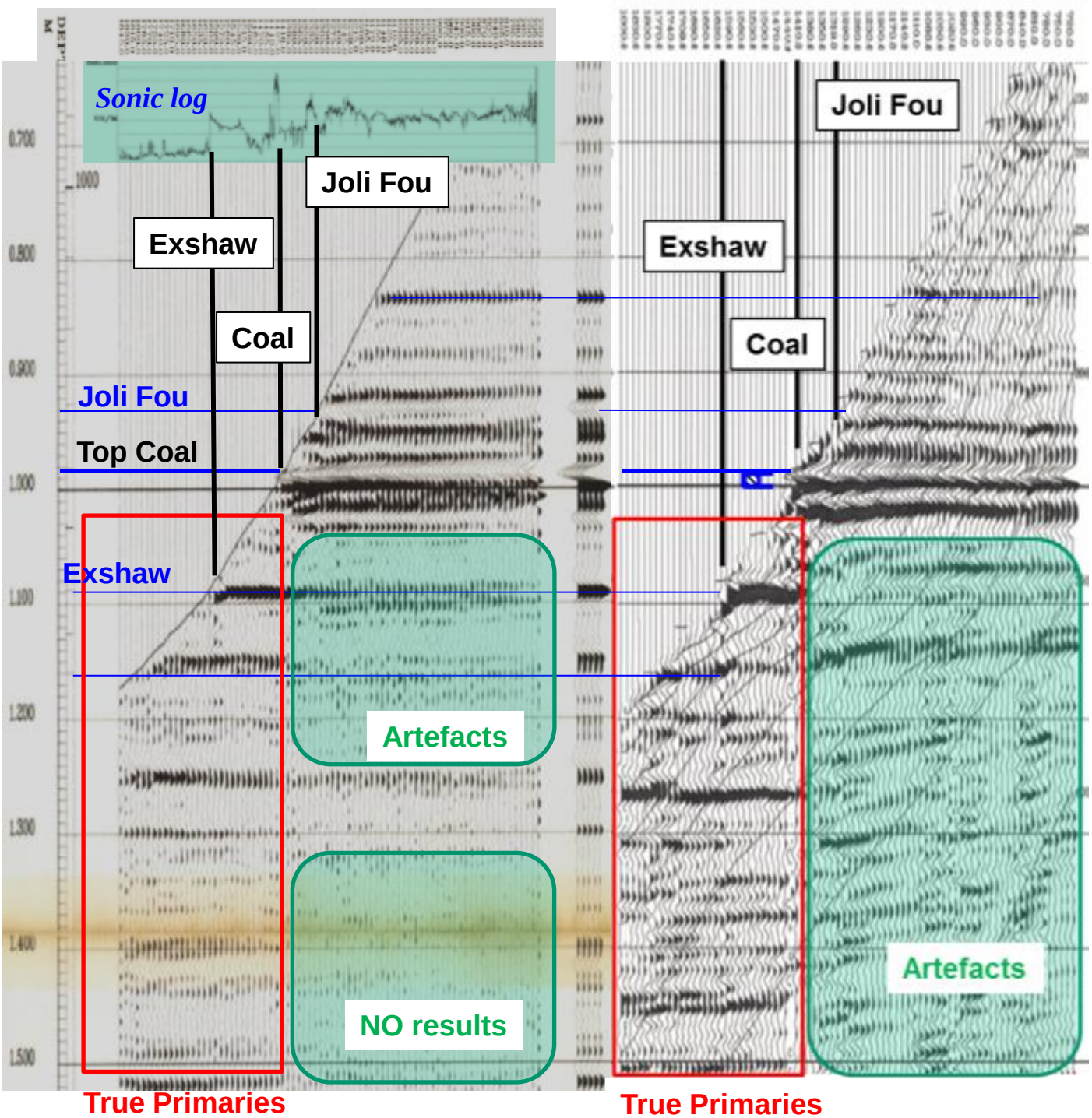


(1d) EXISTING DATA : Z-VSP versus O-VSP,

BOTH deconvolved trace to trace

- RIGHT: OVSP ; - MIDDLE: ZVSP Corr-stack

- LEFT: ZVSP: primary reflectors below coalbed DEPTH, but BOTH methods show artefacts below the coalbed TWT where the VSP receiver is located above the coalbed.

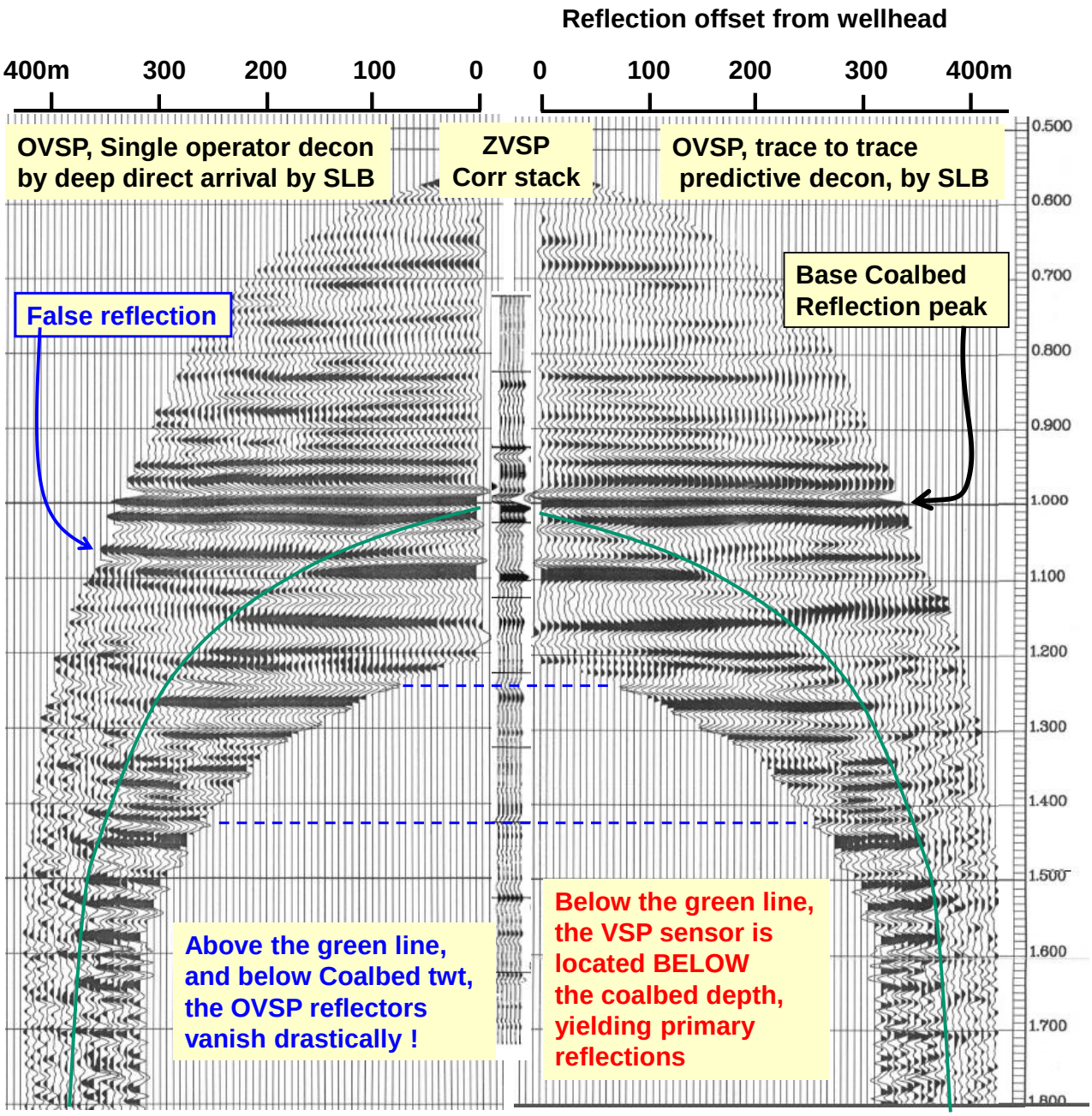


(1e) EXISTING DATA : VSP-CDP STACKS

OVSP deconvolved in two manners:

- RIGHT: trace to trace predictive deconvolution.

- LEFT: Single operator shaping decon using deepest level arrival improves the lateral continuity of artefact reflectors below coal depth and coal Two-Way Time domain. Below the green line, the primaries are preserved



2- ANALYSIS of the Zero-Offet / Z-VSP data recorded in a vertical well

- **Direct arrival amplitudes, compensated for geometrical spreading and local impedance versus depth, resulting in " Plane wave amplitude decay curve " (slides 2a, 2b)**

- **Amplitude decay of plane wave versus frequency , and band pass filtered first arrival traces in relative amplitudes (slides 2c, 2d)**

- **Transfer function or ONE WAY transmission operator through a interbed generating layer system, Principle and application to the present Z-VSP case (slides 2e, 2f, 2g,2h)**

- ***Results from downgoing VSP arrival study:***

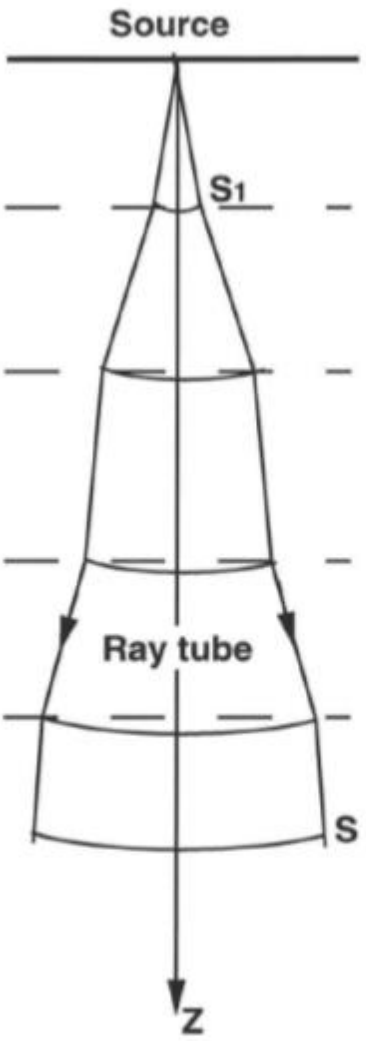
- Significant attenuation accompanied by phase rotation in transmission through the thin coalbed acting as a seismic screen. At deep target depth below coal, total frequency loss above 65Hz is observed.

- Interbed multiple is generated by the coalbed and significant reflector(s) above coal.

- Favorable increase of Vrms Velocity from VSP, stacking velocity with depth, to eliminate interbed multiple by stack fold in target interval

(2a) VSP-FIRST ARRIVALS AMPLITUDES

Principle of computed Divergence and local impedance corrections to obtain the PLANE WAVE Energy DECAY versus depth, in a 1D medium (vertical or deviated Well)



Energy density per surface unit:

$$E = \rho\, v\, A^2$$

Wavefront surface for a ray tube S is linked to Spherical Divergence SD by $SD = \sqrt{S} = V^2 t / V_0$

Plane Wave energy expression:

$$A_p = \sqrt{E} = \sqrt{\rho\, v}\,.\, A\,.\, SD$$

V = V rms, v = v interval velocity, t = direct time

First, the VSP source must be repeatable and its energy must be constant or compensated level to level

Plane Wave energy decay curves are represented in different frequency bands versus vertical time or versus vertical depth

In deviated well:

$$A_p = \sqrt{\rho\, v}\ A\, V^2\, t / \cos\alpha$$

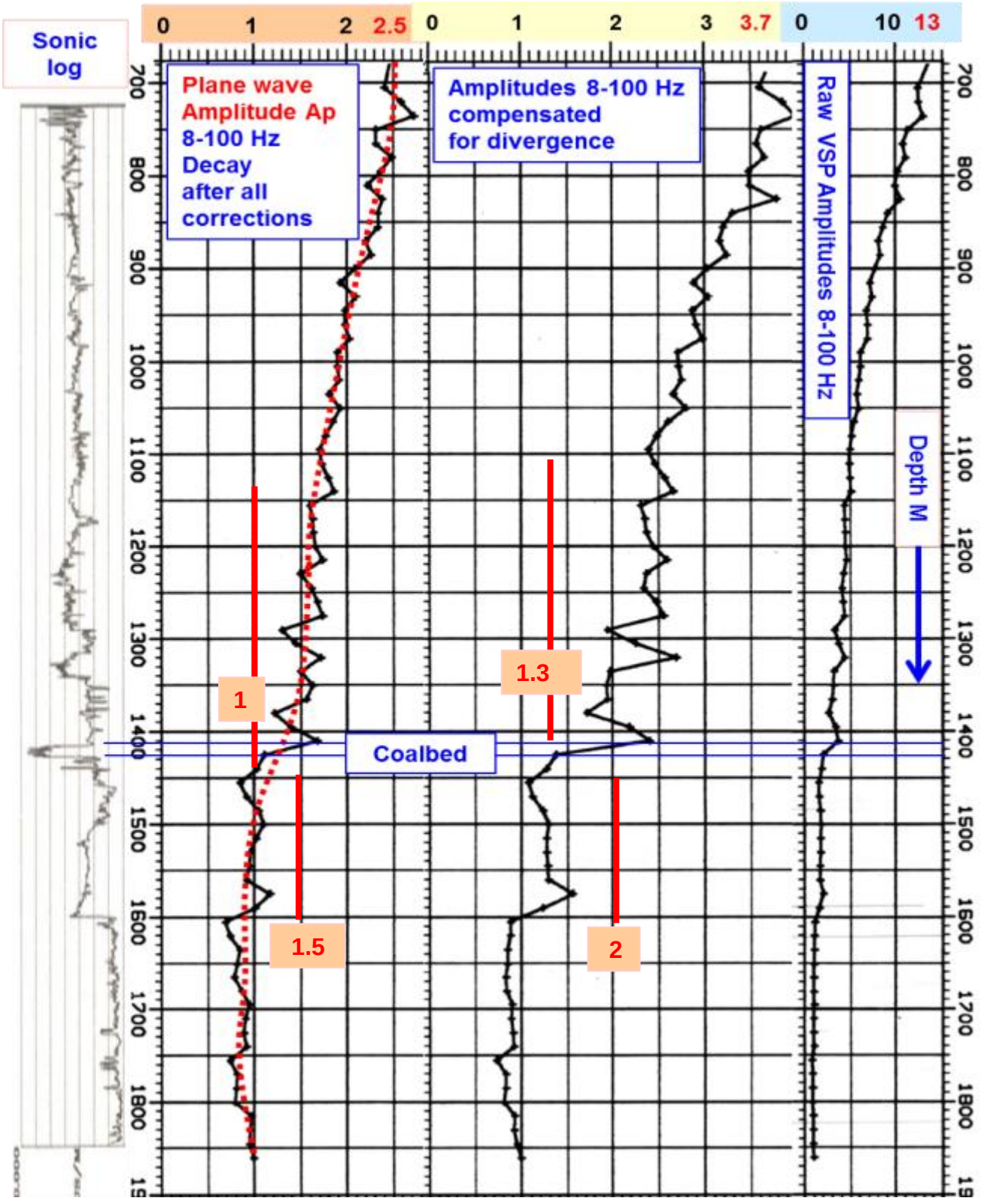
t = direct raw time of slanted ray

α = angle (Well axis to direct ray)

(2b) VSP-FIRST ARRIVALS : ONE WAY PATH

Compensated direct arrival amplitudes versus depth

- The coalbed alone attenuates the raw amplitude by 33%

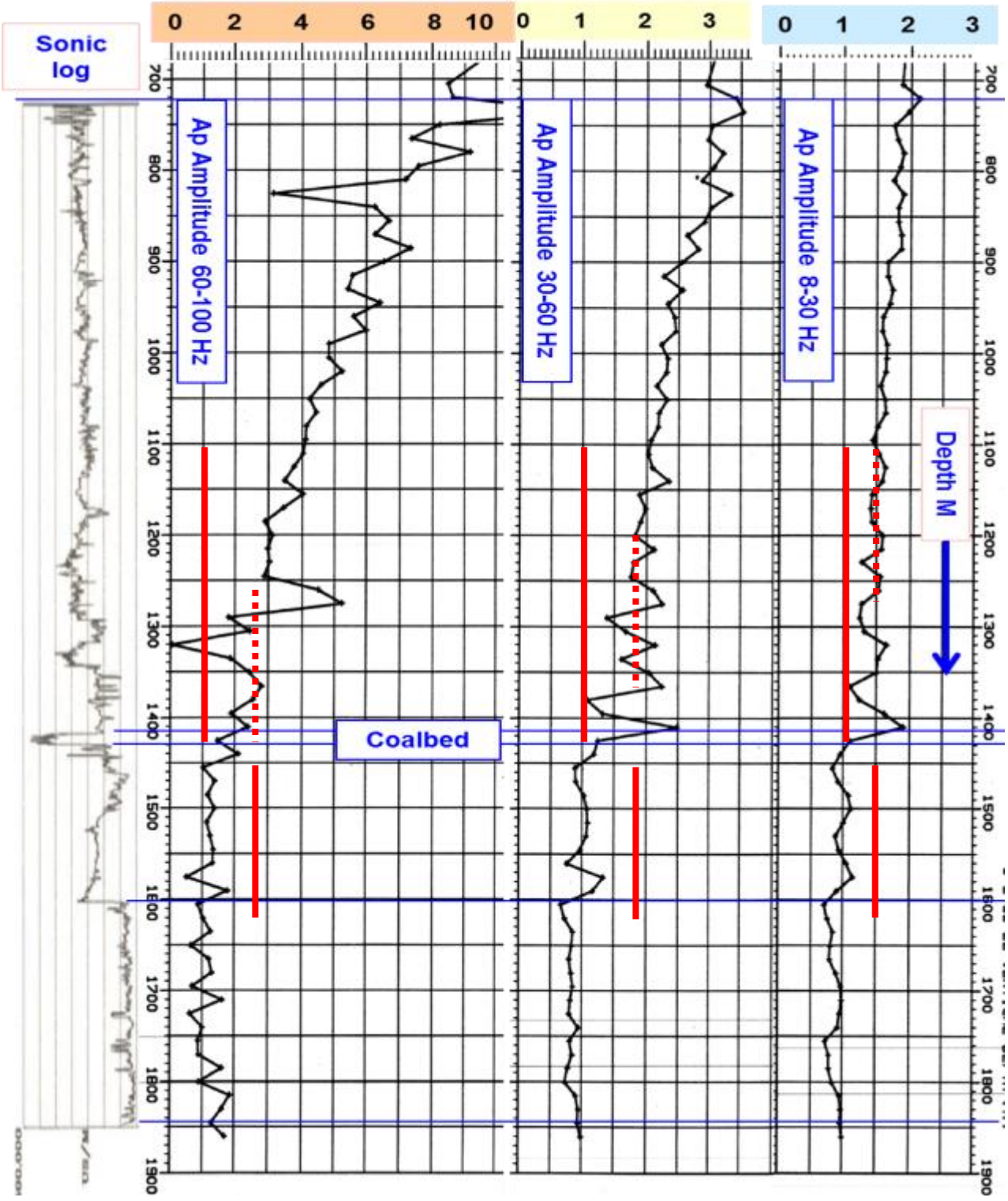


(2c) VSP-FIRST ARRIVALS : ONE WAY PATH

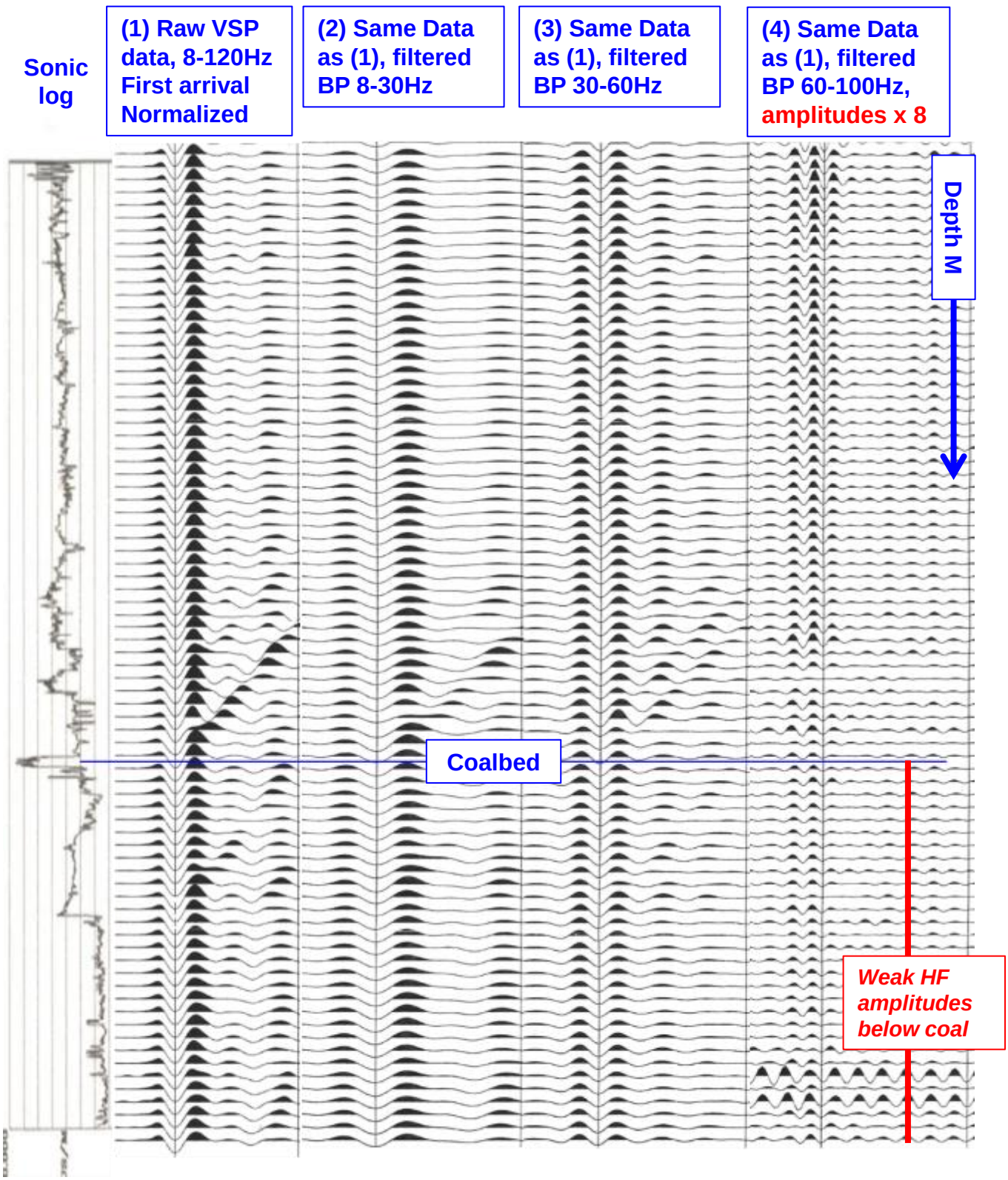
Plane wave amplitude curves versus frequency, in depth.

- The thin coalbed attenuates 8-30Hz low frequencies by 25%, up to 60% (factor 2.4) above 60Hz (screen effect).

- High attenuation in overburden; quite NONE below coal

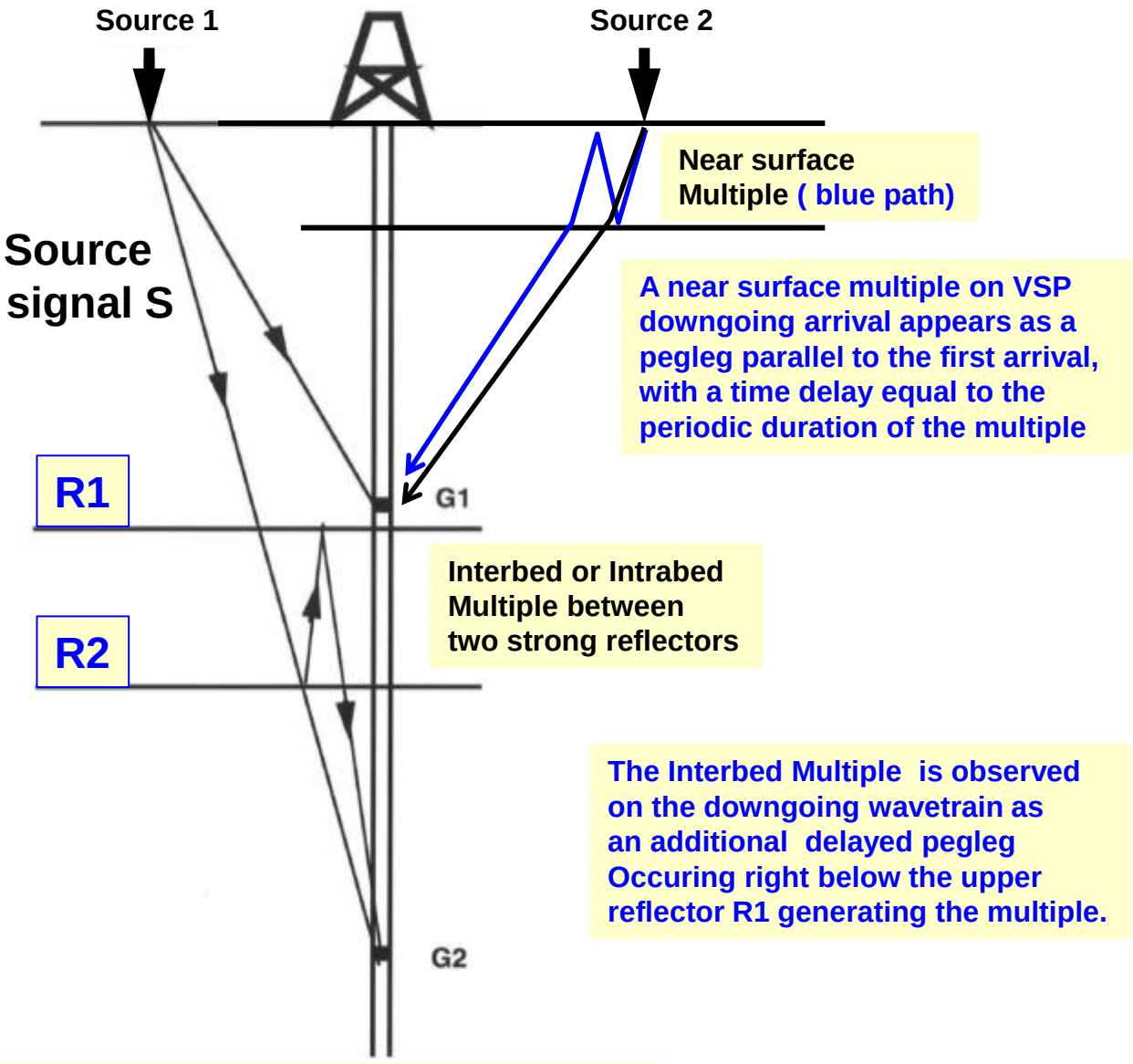


(2d) VSP-FIRST ARRIVALS : Normalized on first trough of fullband raw data, then filtered into adjacent frequency bands, to facilitate visual observation : *The thin coalbed drastically attenuates frequencies above 60Hz*



(2e) Onshore Seismic propagation Multiples:

1) A near surface multiple can be generated between the base of the Low Velocity Zone and Ground Level
2) An interbed or intrabed multiple may occur between TWO deep strong reflectors R1, R2
3) Sometimes, long period multiples may occur between a strong, deep reflector and the surface…



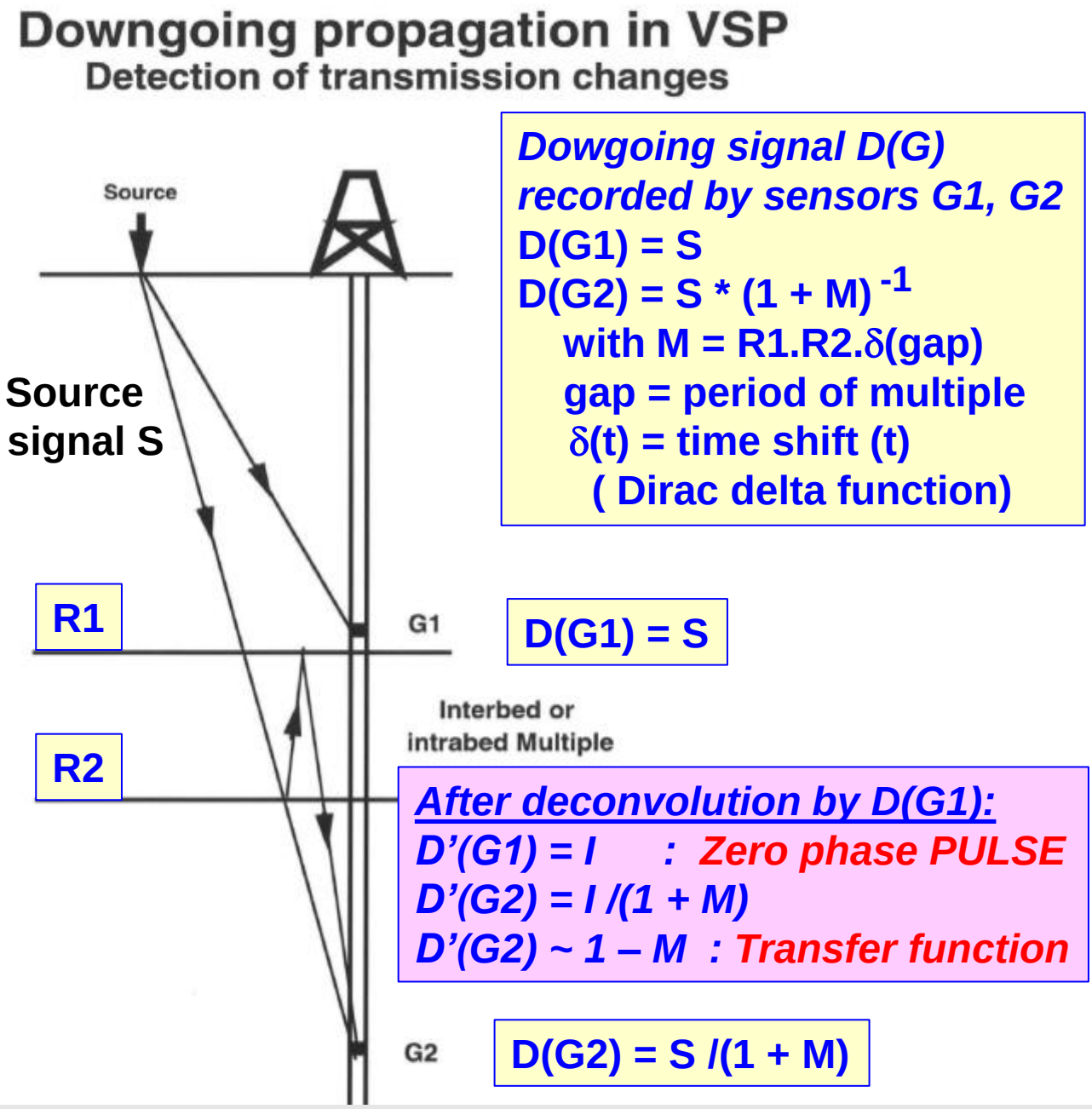
When processing the VSP data:

All short period multiples are cancelled out by the common shaping deconvolution of the upgoing wavefield by the downgoing incident wavelet in a thin the corridor stack domain ONLY, for instance within 50ms after Direct VSP arrival. But longer period multiple may NOT BE eliminated.

(2f) Computing the transfer function

between two downhole VSP sensor stations,

as the response to a band limited zero phase PULSE

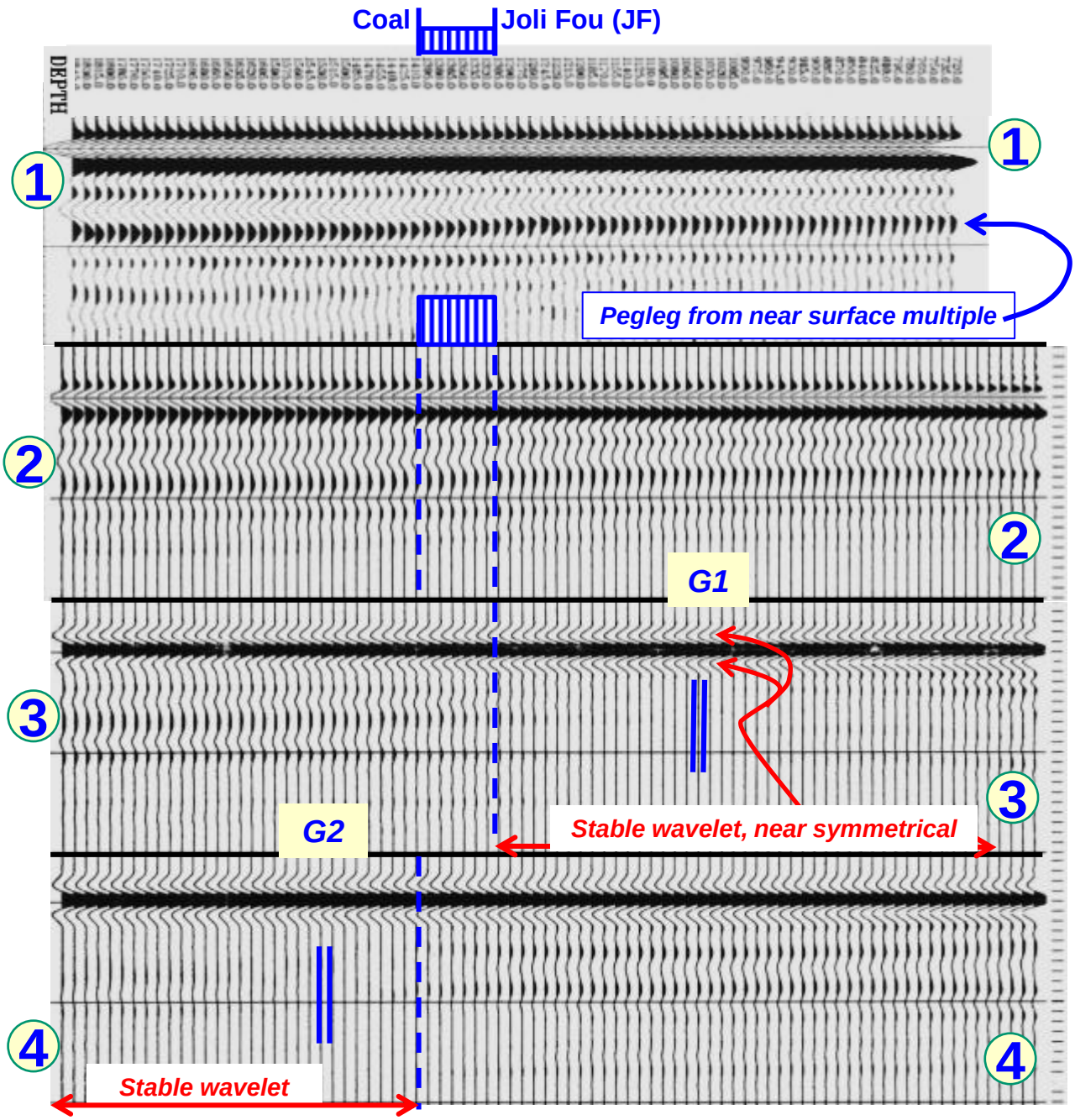


The transmission filter can be calculated from the VSP downgoing wave by signature shaping deconvolution of the deep wavelet recorded on G2 by a wavelet recorded on G1 above:

The changes in phase and amplitude, as well as all the multiples generated between G1 and G2 are expressed by the transmission filter.

(2g) VSP-FIRST ARRIVALS: Aligned, Separated

1) *Raw data, Normalized , amplitudes x 2*
2) *Raw data, Normalized , amplitudes x 1*
3) *Deconvolved by single signature taken at depth G1, stable downgoing signal down to Joli Fou (JF)*
4) *Deconvolved by single signature taken at depth G2, stable downgoing signal from Coalbed downwards. Therefore, the downgoing signal varies significantly between JF and Coal*



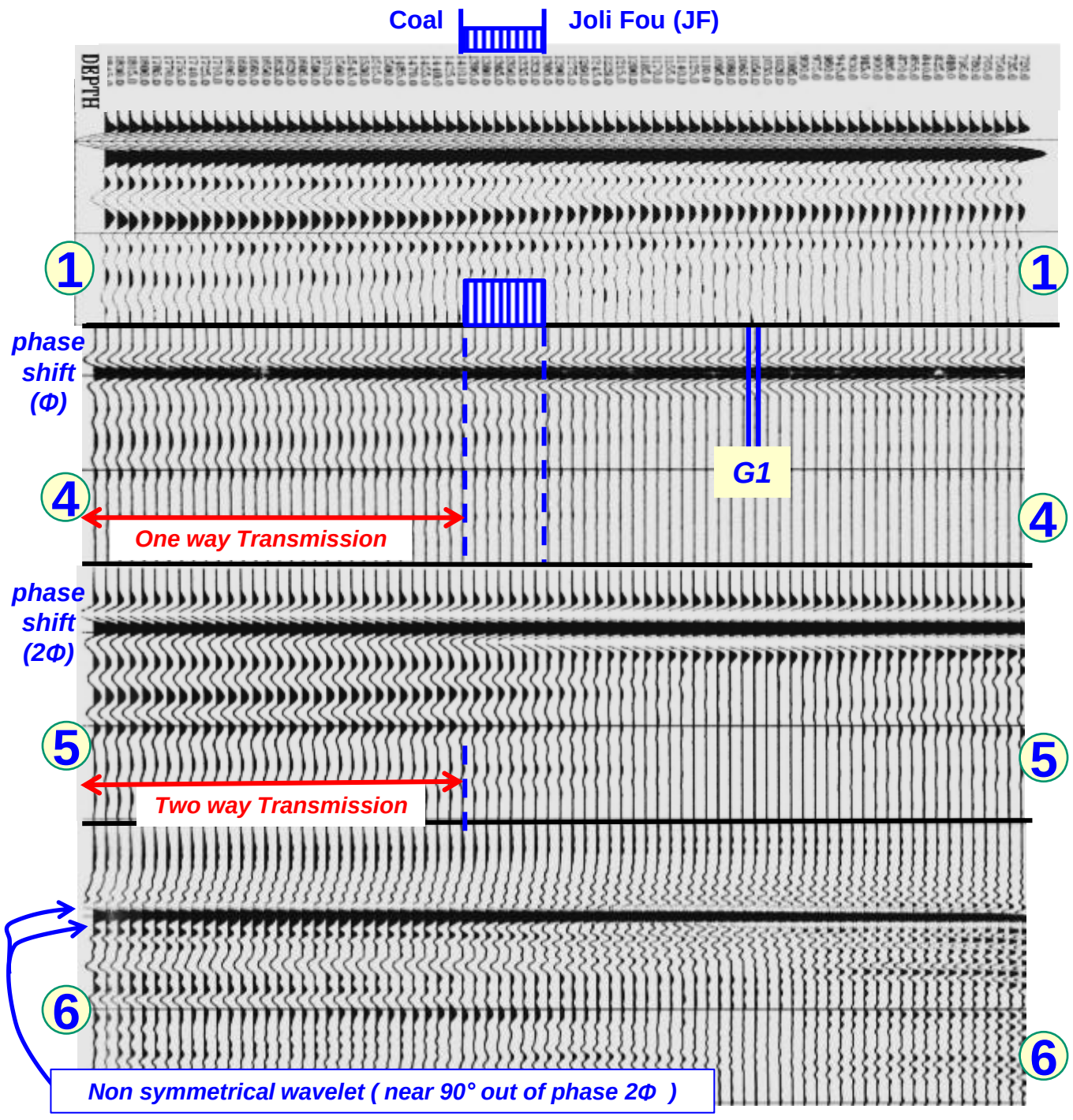
(2h) VSP-FIRST ARRIVALS: Aligned, Separated

1) Raw data, Normalized , amplitudes x 2

4) Deconvolved by single signature taken at depth G1 above Joli Fou, showing the ONE WAY transmission operator through layers from Joli Fou to Coal. Note the phase shift (Φ) below coal

5) Autocorrelation of above signal data 4), bell shaped spectrum =Two way transmission function . Phase shift doubled below coal

6) Autocorrelation of signal data 4), trapeze spectrum. (2Φ) shift



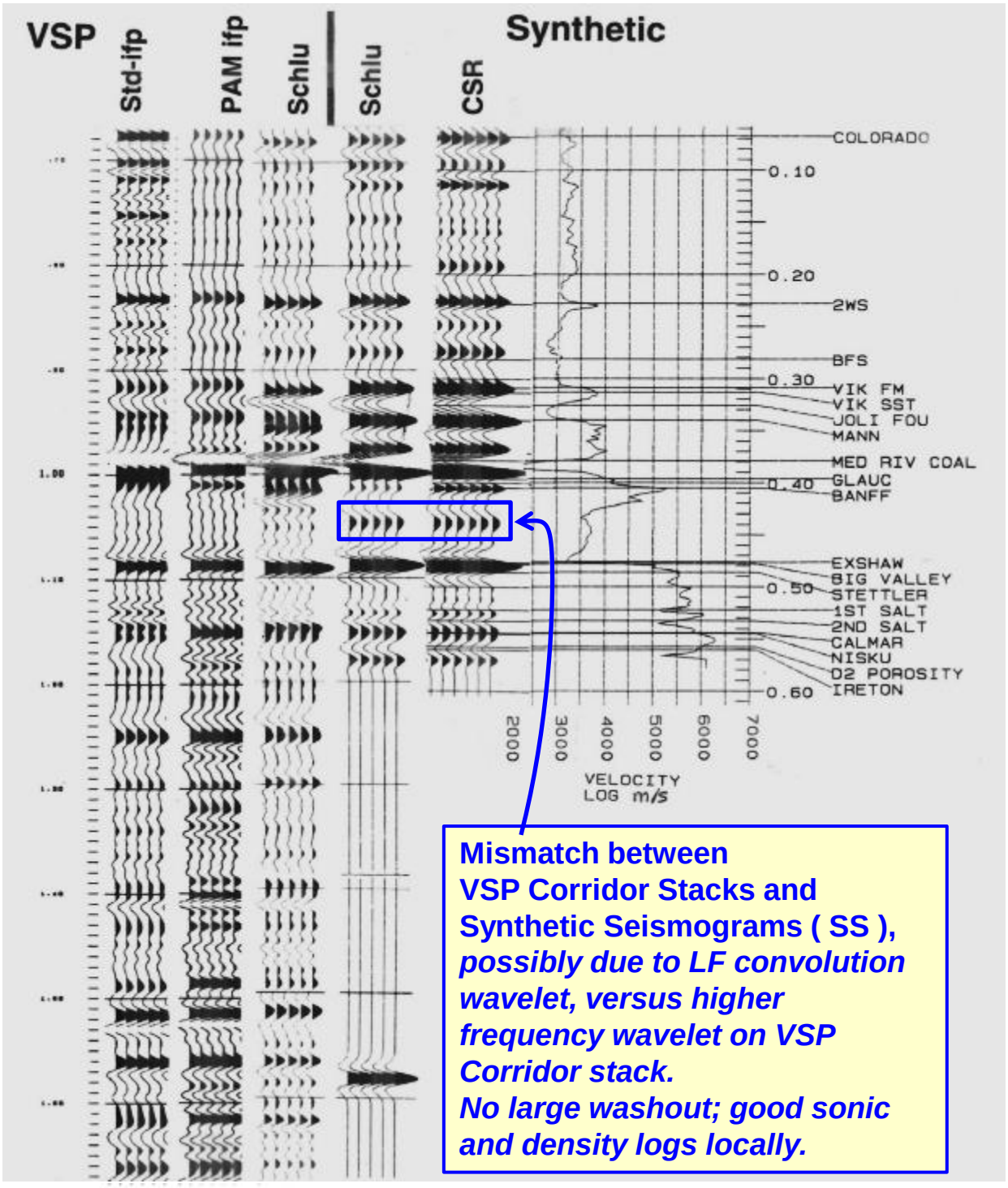
3- Advanced VSP Reprocessing TESTS:

- **True amplitude VSP reflection processing results and propagation model (slides 3a,b,c)**

- **Innovative ZVSP anti-multiple seismic reflection VSP processing test:**
  - **Principle : (slide 3d)**
  - **Comparative results (slides 3e,3f,3g)**
  - **Commented results (slides 3h,3i),**
  - **Spectacular improvement right below coal.**
  - **No improvement of VSP target interval reflections where the VSP tool is located above coalbed depth… (Not explained)**
  - **Very deep VSP reflections altered by predictive decon operator derived from VSP**

  - ***SUGGESTION: Further low cost VSP processing improvements could be routinely implemented by VSP processing service companies***

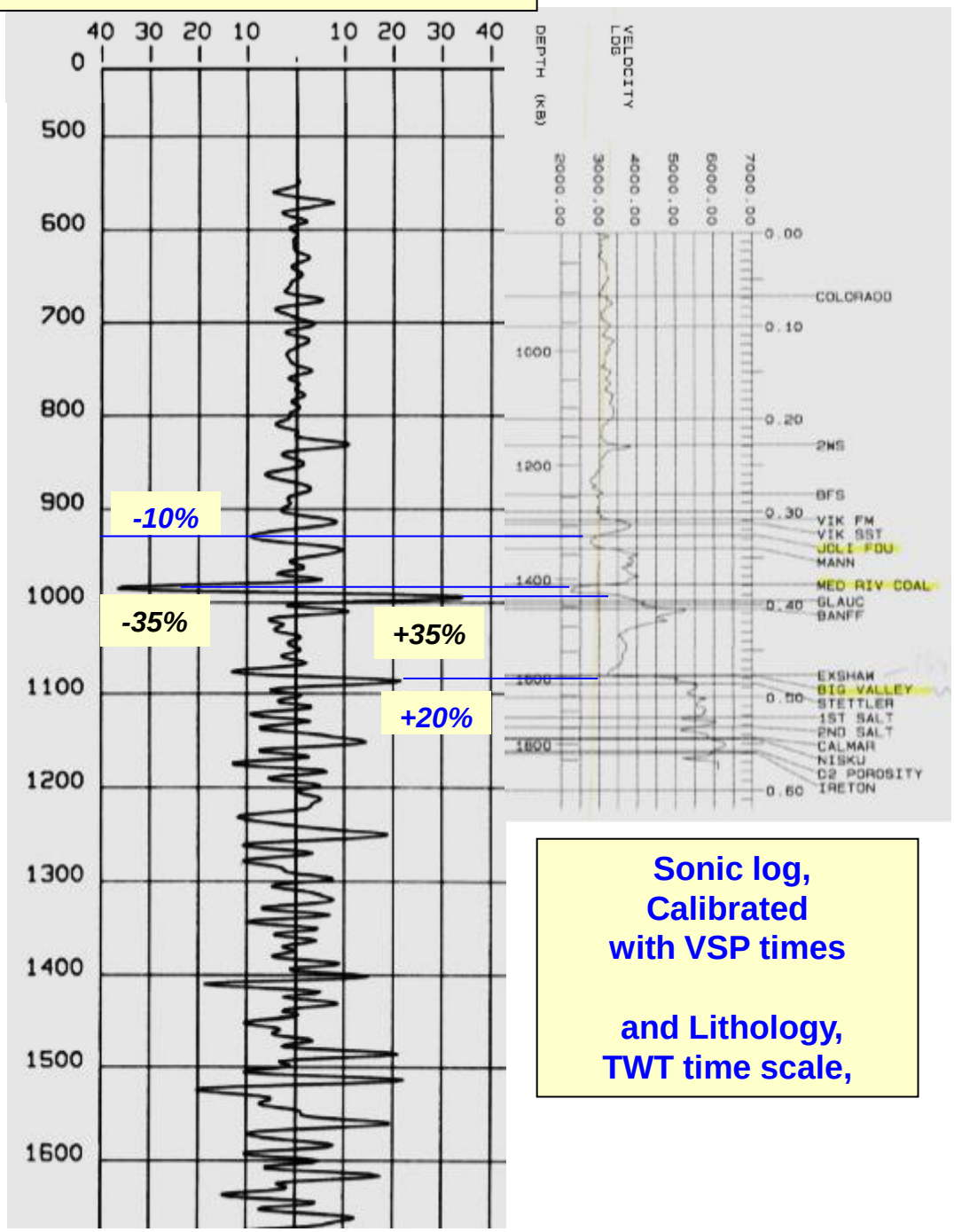
(3a) Confrontation between VSP Corridor Stacks and convolved Synthetic Seismograms



1 - VSP Std-ifp: Standard VSP, equalized. Coal misaligned before stack.
2 - VSP PAM ifp: Preserved amplitude VSP with horizontal coherency before stack
3 - VSP Schlumberger: Standard VSP with horizontal coherency before stack
4 - Schlumberger Synthetic seismogram from calibrated Sonic log only
5 - CSR Synthetic seismogram from calibrated Sonic and edited Density logs

(3b) True amplitude VSP processing results on VSP Corridor Stack, evidencing the high amplitude reflectors able to generate interbed multiples

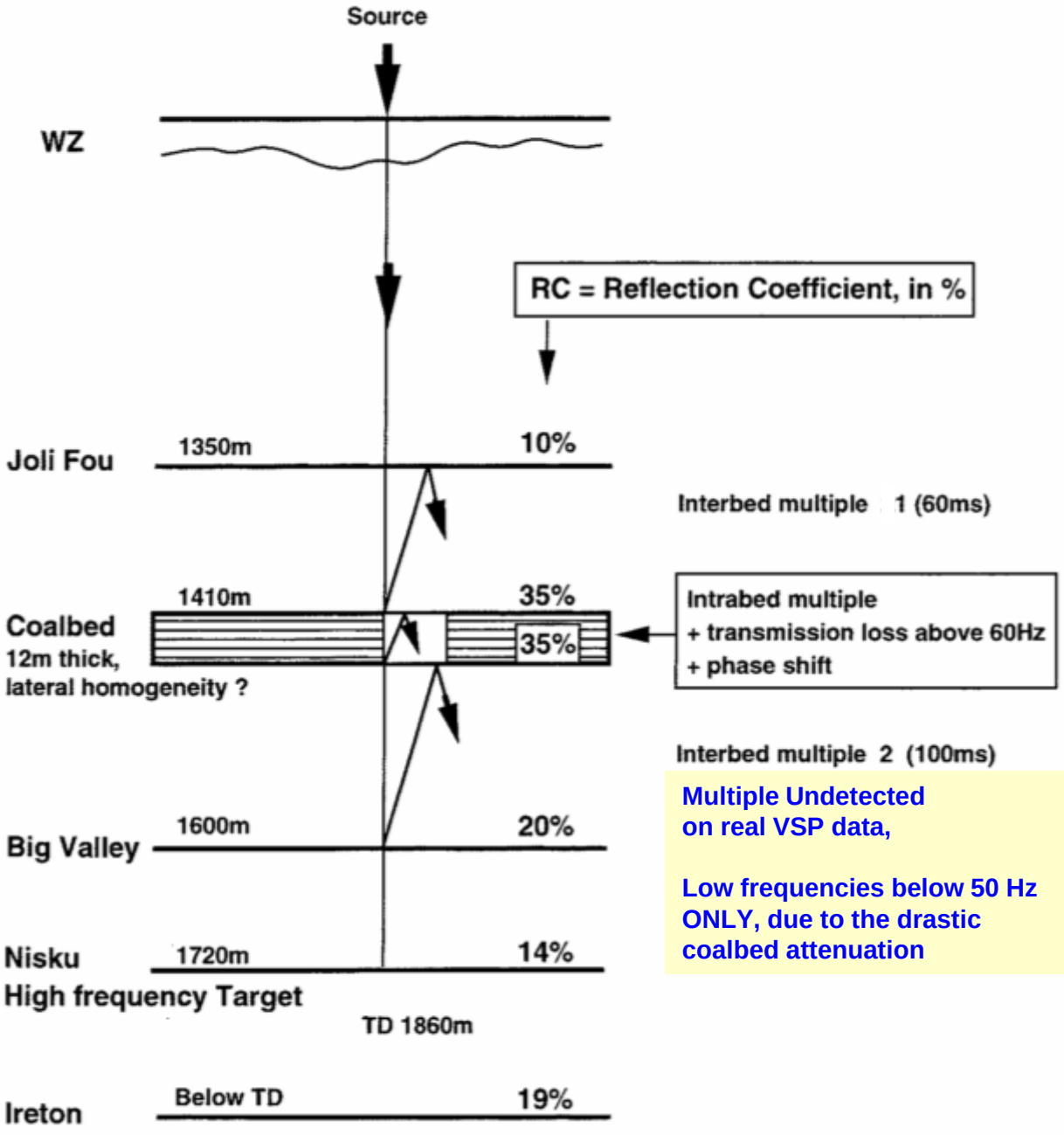
True amplitude, zero phase VSP corridor stack, Reflection amplitudes are in percent.
Incident pulse amplitude = 100%



Sonic log, Calibrated with VSP times

and Lithology, TWT time scale,

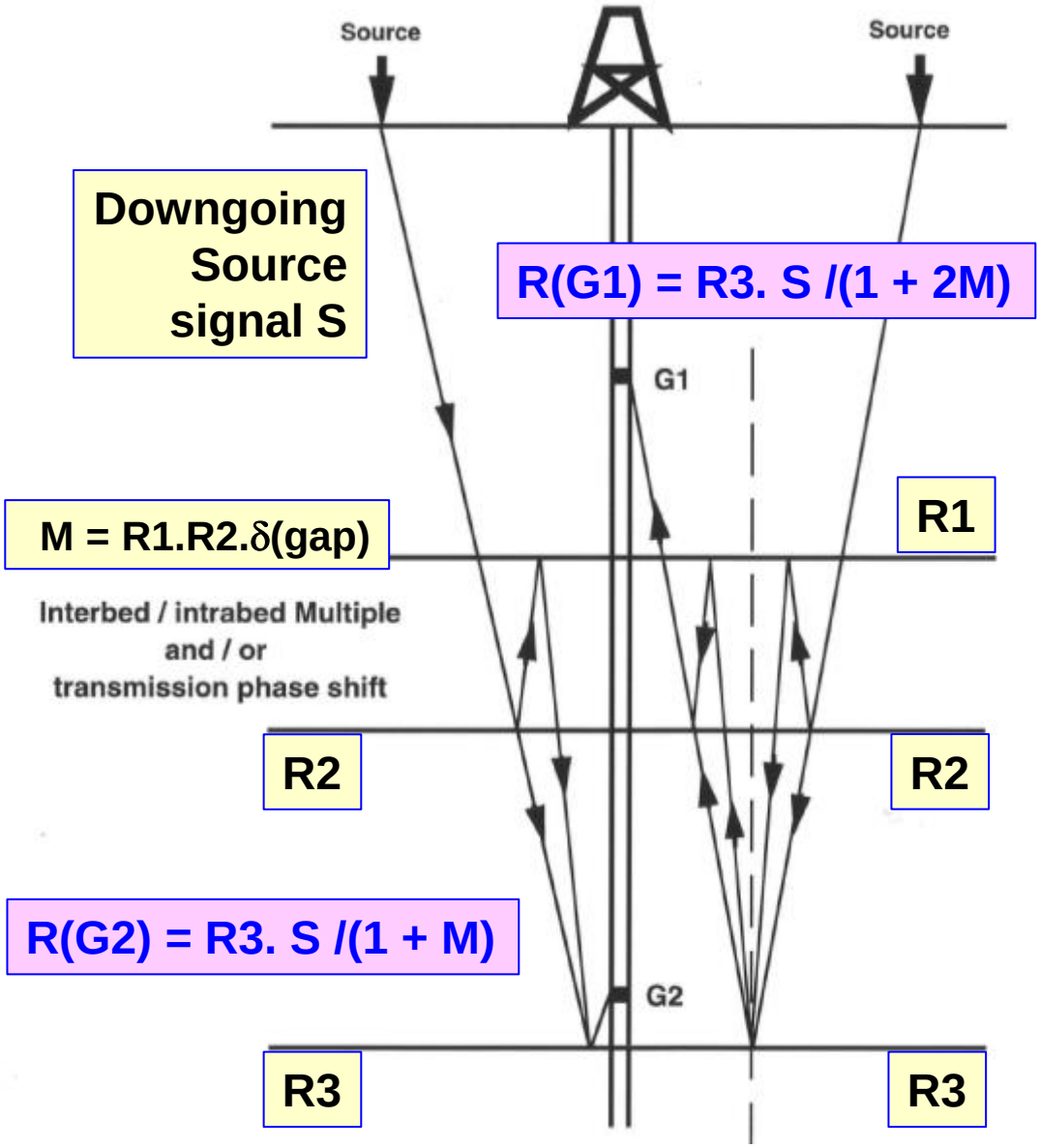
(3c) Seismic propagation model suggested by the true amplitude VSP results.



The transmission through the coalbed is characterized
by a drastic loss of high frequencies, a phase shift under 50Hz,
and a generation of short interbed multiple with neighbour reflectors:

Consequently, a two gate spiking / predictive deconvolution
of surface seismic is necessary above and below the coal bed marker.

(3d) Deep VSP reflections altered by interbed multiples. Expression of reflected signals R(G1) & R(G2) from deep R3 reflector(s) recorded at VSP stations G1 and G2

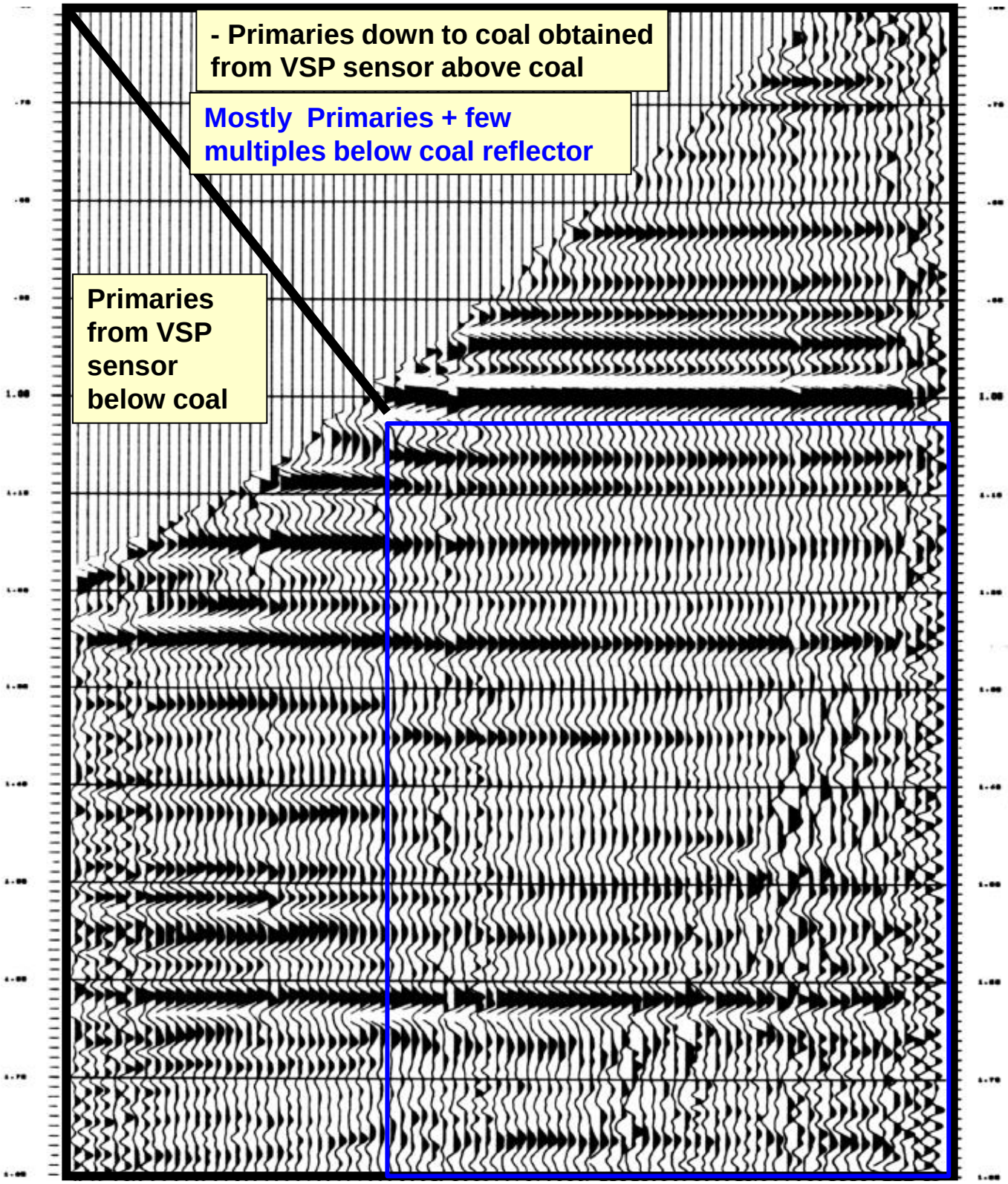


In a 1D medium, the near G2 deep reflection recorded on G1 need to be deconvolved by the downgoing wavelet recorded on G2 and by the transmission filter from G1 to G2

The transmission filter is calculated from the VSP downgoing wavelets

(3e) VSP UPGOING wavefield, Undeconvolved, Filter 8-30Hz, Equalized

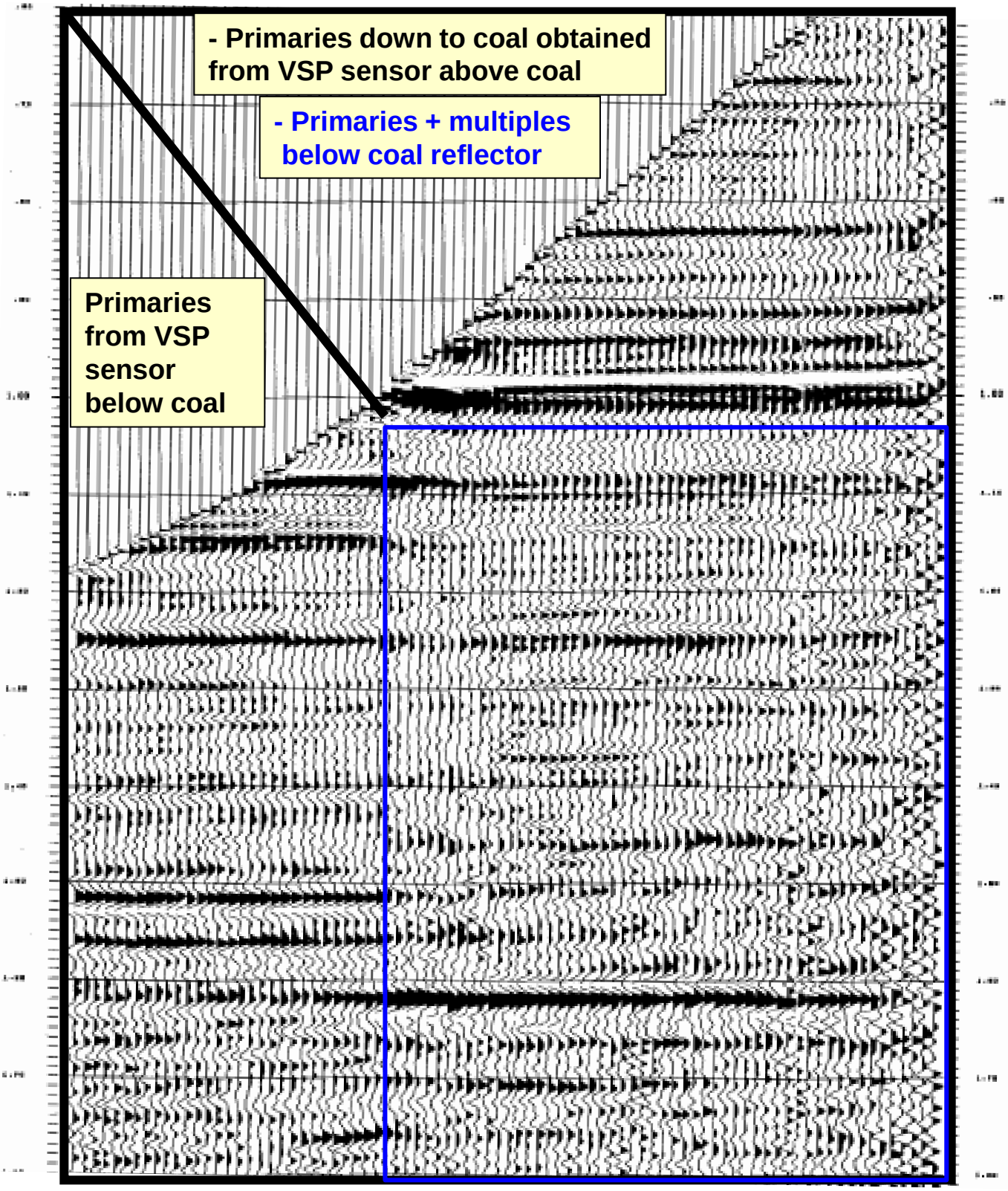
Primary + multiple reflections in blue box



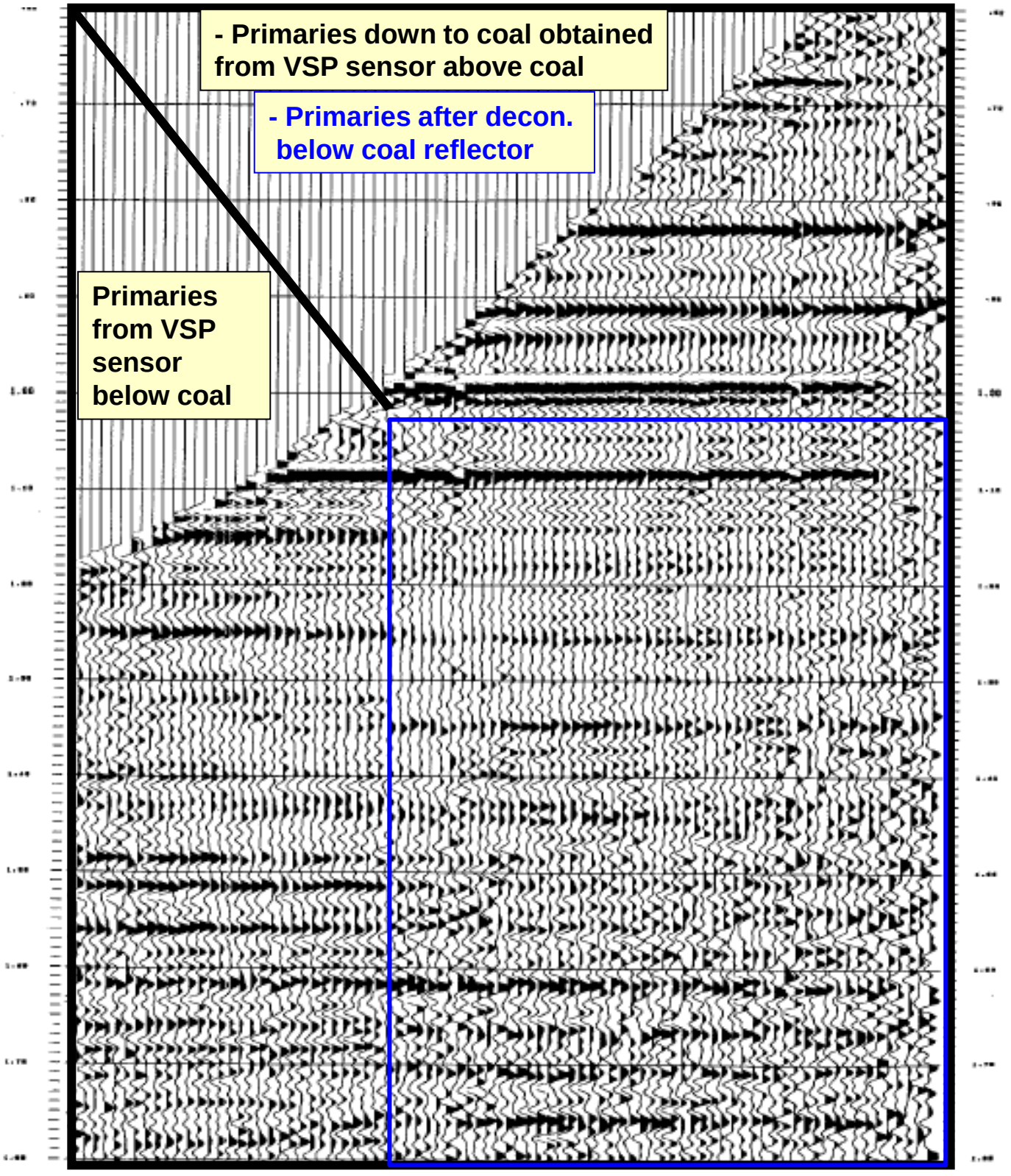
(3f) VSP UPGOING wavefield, de-noised

after standard trace to trace shaping decon

Primary + multiple reflections in blue box

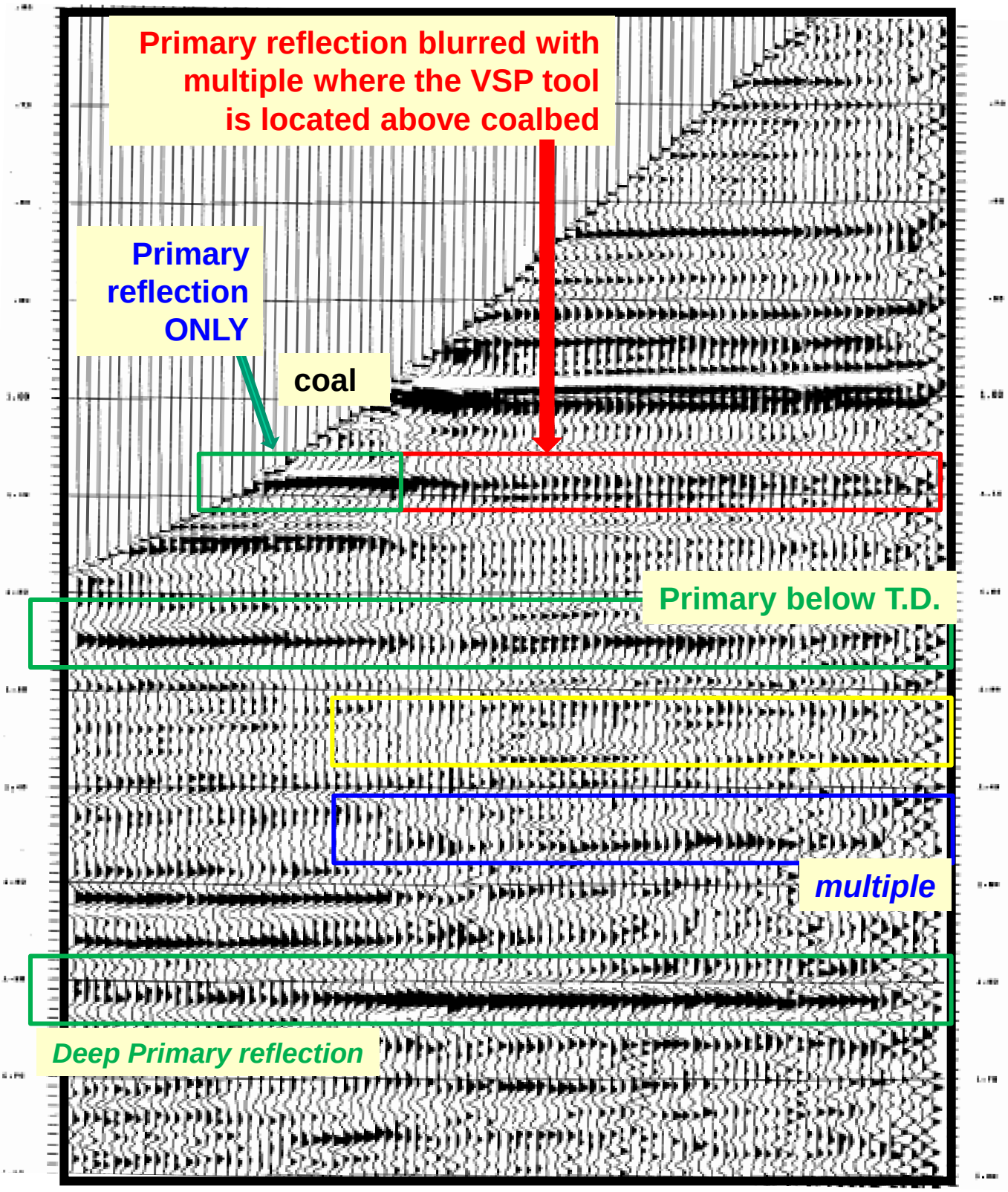


(3g) VSP UPGOING wavefield, after shaping decon, *with additional anti-multiple decon specifically designed for VSP data, in blue box*

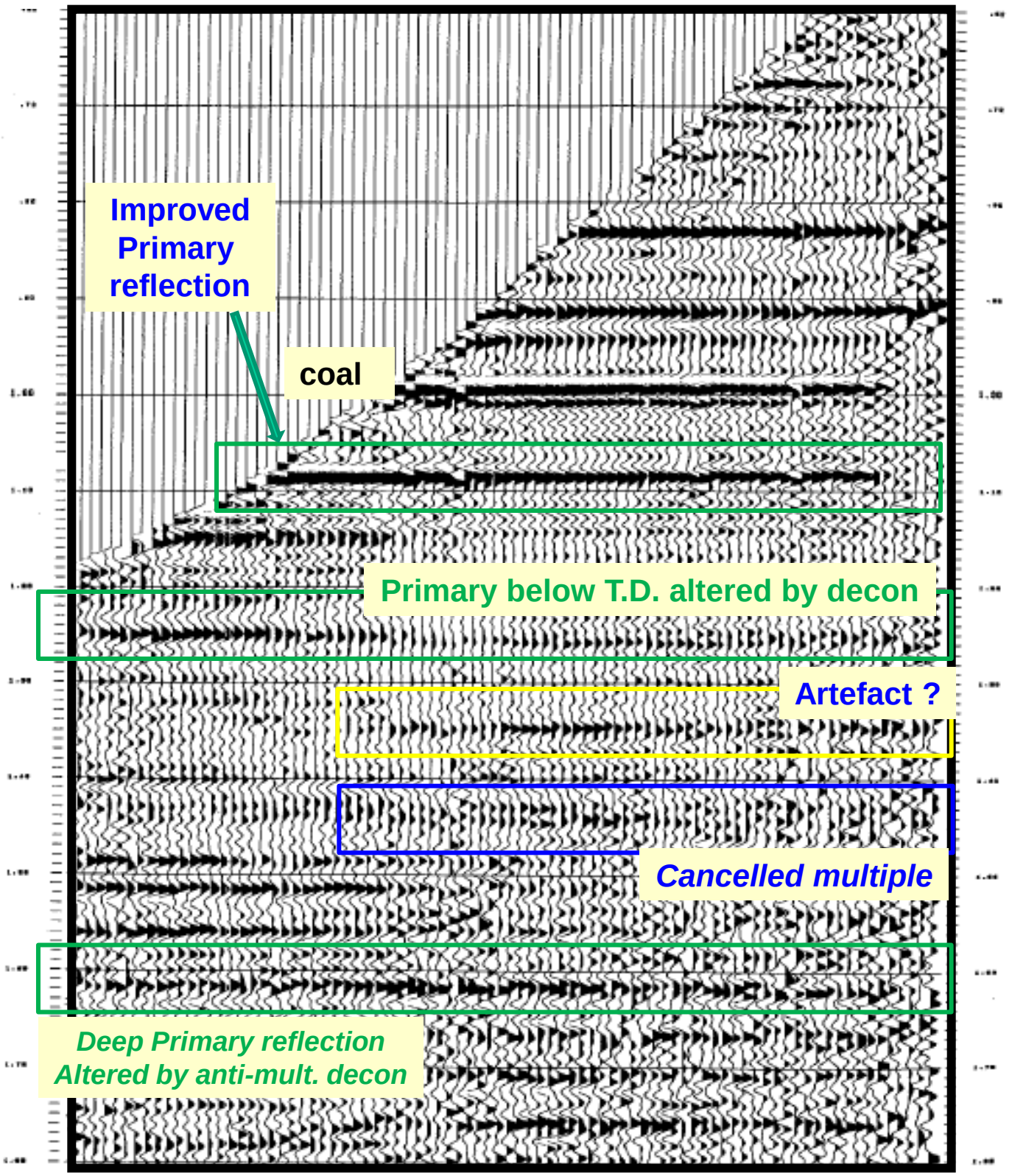


(3h) VSP UPGOING wavefield, de-noised

after standard trace to trace shaping decon



(3i) VSP UPGOING wavefield, after shaping decon, *with anti-multiple decon applied below coal reflector , only on VSP stations above coal depth.*



4 - Improvement of existing surface seismic processing routes.

- **The Zero phase SLB VSP corridor stack is spliced into 2D Surface seismic section across the well : slide 4a**

- **The Zero phase true amplitude VSP corridor stack is spliced into the two gate deconvolution 2D Surface seismic section across the well reprocessed in IFPEN :slide 4b**

- **Both results are compared and briefly commented on slide 4c**

(4a) Standard processing by SEIS-PRO, LTD

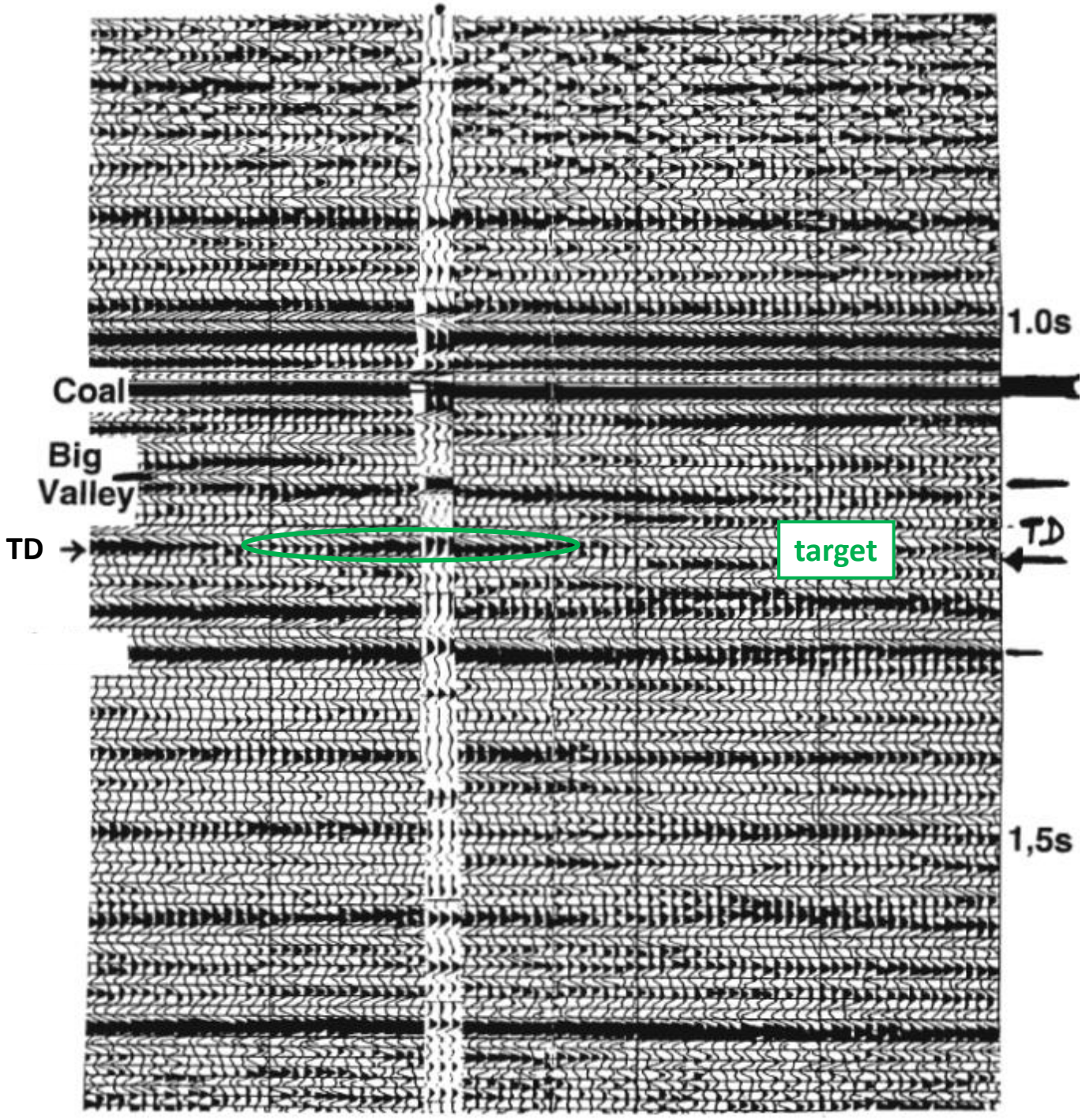
Note the lack of lateral continuity and the time delay (or 90° phase shift) of below coal reflections

SLB's VSP Corridor Stack spliced at well location

Polarity: RC>0 = Black Peak

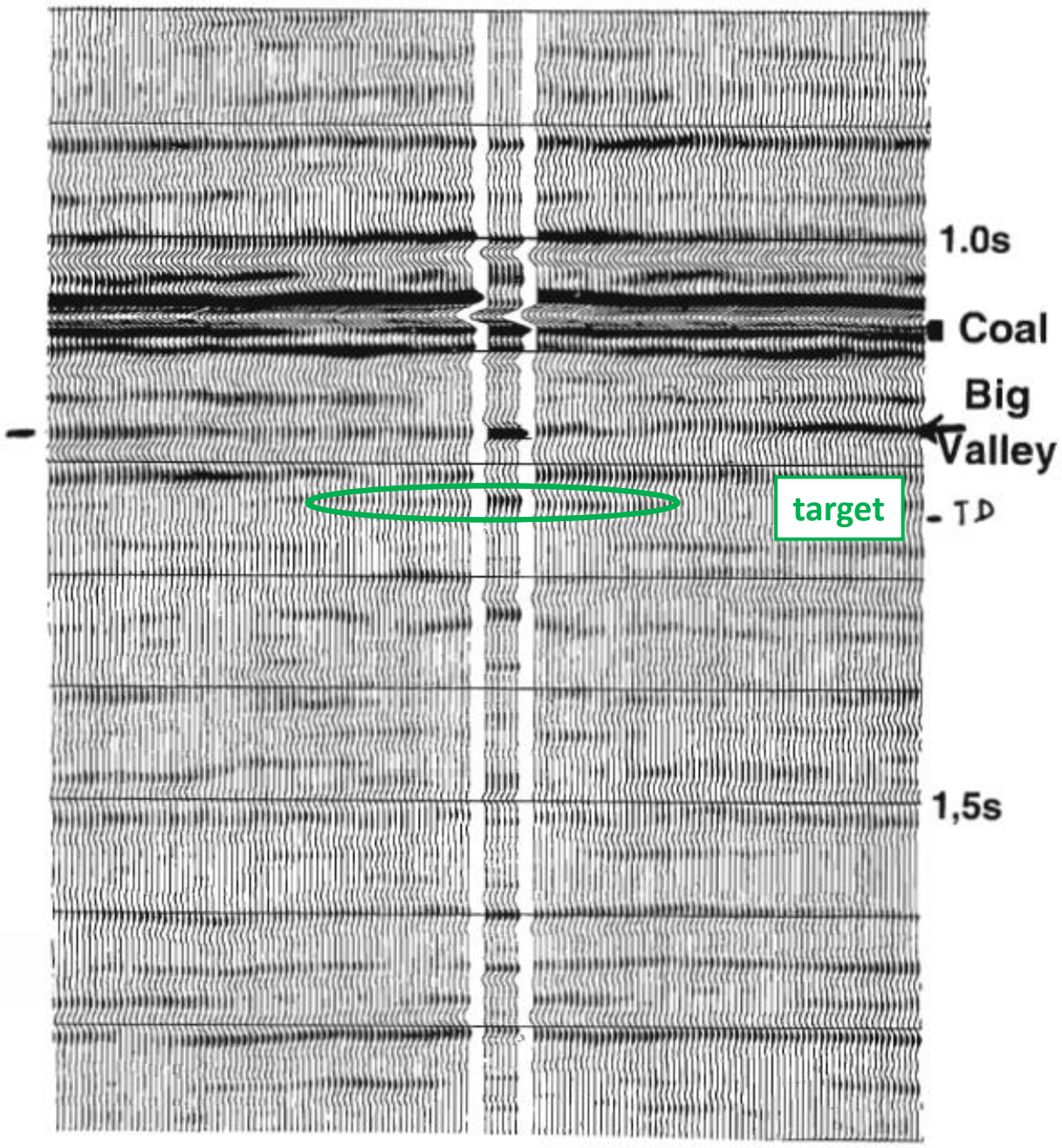
Well

Phase shift noticeable below Coal, Deep reflections in phase at 1.6-1.7s



(4b) 2D line reprocessed by IFPEN, using CGG seismic software, for BOTH VSP and surface seismic

- Spiking decon down to and including Coal reflector
- Predictive decon below Coal. NO surface consistency
- Spectral balancing; Stack velocity ~ 1.05 VSP Vrms
- VSP corridor stack spliced into section
- Polarity: Reflection Coeff. RC > 0 = Black Peak

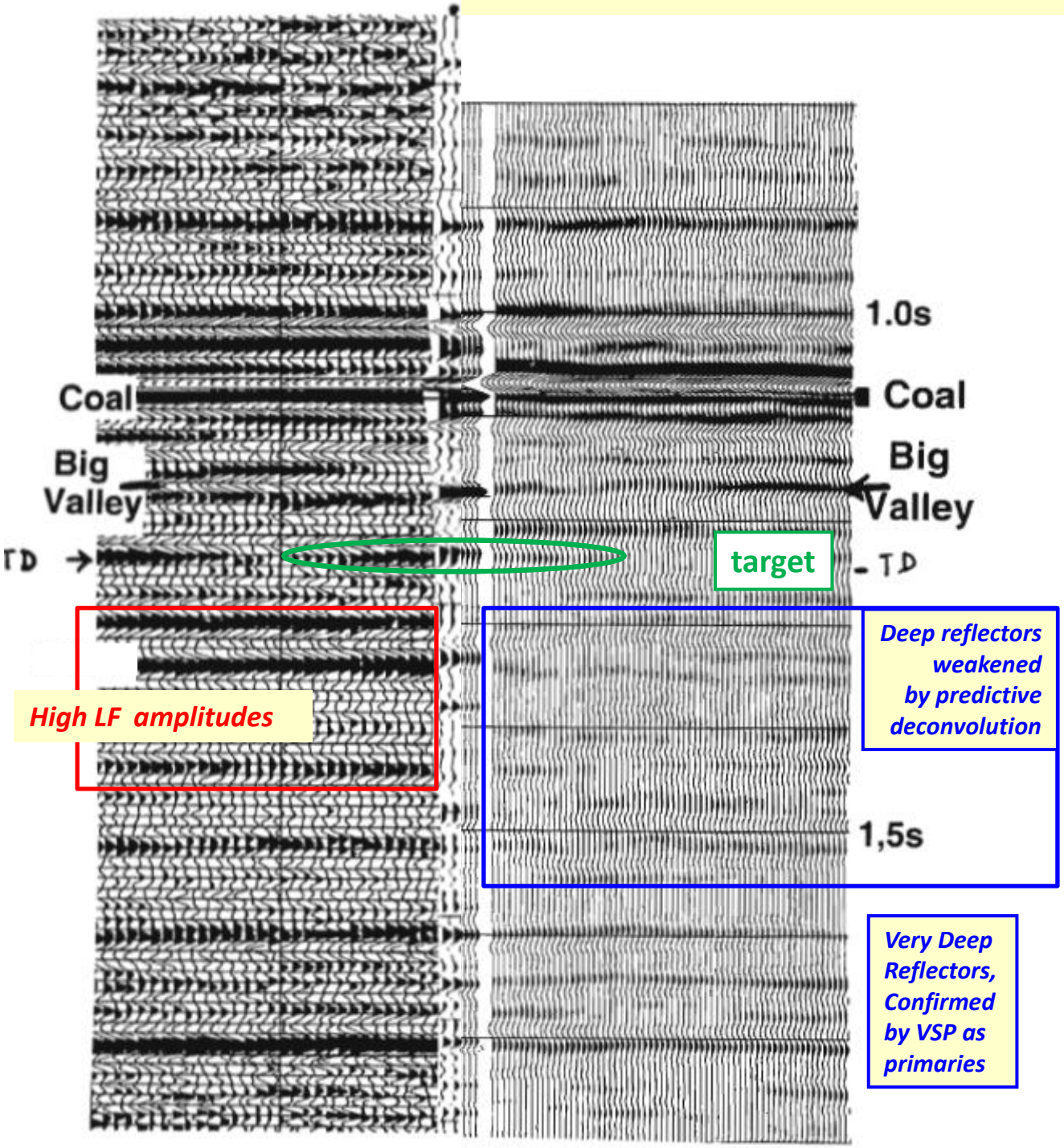


(4c) LEFT: Processed by SEIS-PRO, LTD

- *SINGLE window surface consistent Spiking decon over whole section*

RIGHT: Reprocessed by IFPEN

- *TWO decon time gates, above and below coal. Predictive decon. looks too severe.*



(4a) Standard processing by SEIS-PRO, LTD

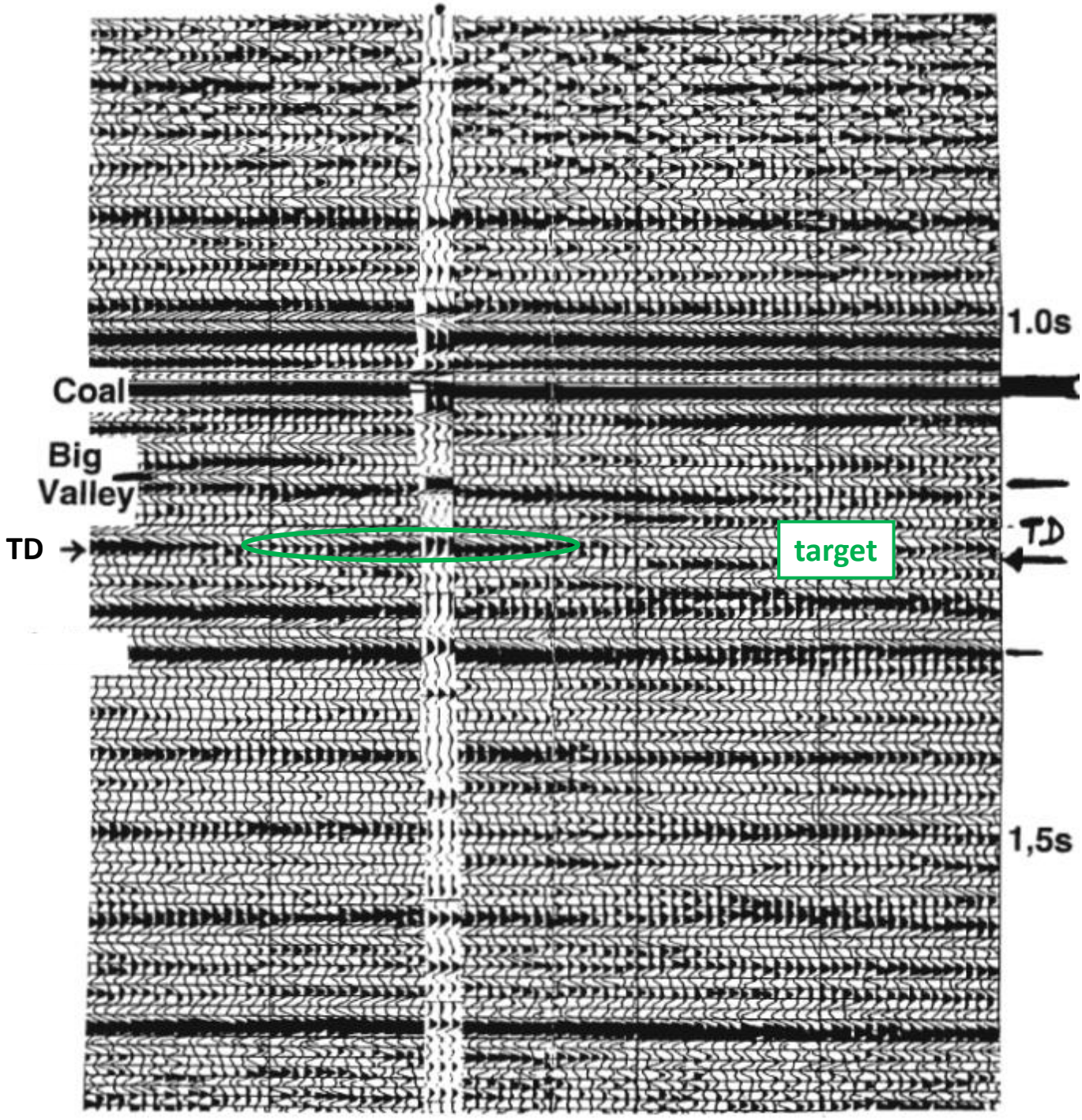
Note the lack of lateral continuity and the time delay (or 90° phase shift) of below coal reflections

SLB's VSP Corridor Stack spliced at well location

Polarity: RC>0 = Black Peak

Well

Phase shift noticeable below Coal, Deep reflections in phase at 1.6-1.7s



4 - Improvement of existing surface seismic processing routes.

- **Commented confrontation of surface seismic processing/reprocessing results (slide 4c)**
  - ***As suggested by careful observation VSP direct arrivals, reprocessing surface seismic data using TWO deconvolution design time gates improves the zero-phase response below the coalbed and in the target interval immediately underneath.***
  - ***Very deep reflections around 1.6-1.7s look correctly restituted, possibly improved on reprocessed section***
  - ***When compared with deep VSP corridor stack reflection reference, SEIS-PRO & Consultants Service company section actually exhibits low frequency reflections below coal, many reflections are mitigated , possibly altered, by a too severe predictive deconvolution applied by IFPEN reprocessing.***
  - ***TO GO FURTHER:***
    - ***Refining the parameters of the TWO gate surface consistent spiking or predictive deconvolution would help correcting the phase distortion induced by the presence of the coalbed.***
    - ***Fine adjustment of the stacking velocity on the major Exshaw/Big valley reflector might further improve the reliability of the surface seismic images in the regional area.***
    - ***Weighed stack may improve quality of primaries.***
    - ***Inversion into impedance of stack sections with phase adjustment on VSP corridor stack below coalbed. (phase adjustment might be different above coalbed).***
    - ***Anti interbed multiple approach looks difficult, unnecessary, it may damage the target reflections.***

5 –Acknowledgements:

- **CS-RESOURCES initiated the present collaborative study with IFPEN in 1996, completed in early 1997.**
- **TAQA petroleum for their open mind collaboration and permission to publish**
- **VERITAS for their powerful 1993 2D surface seismic acquisition, and SEIS-PRO processing.**
- **SCHLUMBERGER for their excellent VSP tool and 1995 field acquisition quality.**
- **IFPEN for providing the time to collect and present the joint VSP + surface seismic advanced results.**

6 – Suggested references

- **CSEG RECORDER,** JUN 1997 | VOL. 22 NO. 06 **:** Transmission filtering by high-amplitude reflection coefficients: Theory, practice, and Processing, by Craig A. Coulombe and D. Neil Bird, CHEVRON CANADA RESOURCES, CALGARY, CANADA; ref: https://csegrecorder.com/articles/view/transmission-filtering-by-high-amplitude-reflection-coefficients-theory-pra
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- https://www.slb.com/reservoir-characterization/seismic/seismic-data-processing/multiple-attenuation/inverse-scattering-internal-multiple-prediction
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- **SEG** abstracts 19890, SP3.7: Non stationarity in Seismic data: A VSP Case Study, by T.H. Wilson, West Virginia Univ.; https://library.seg.org/doi/epdfplus/10.1190/1.1890096