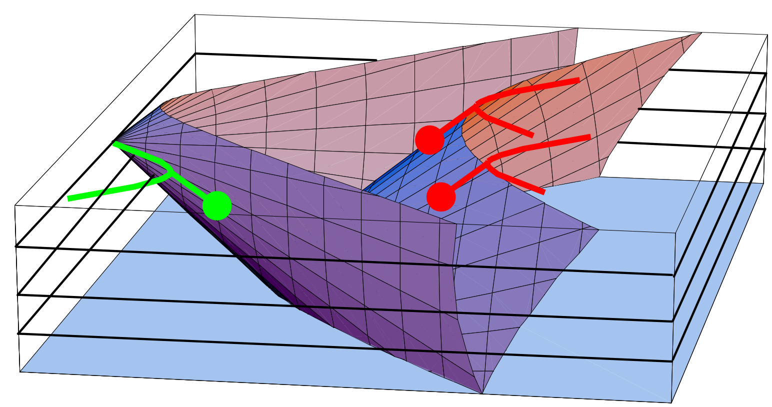
Automatic selection of reference velocities for recursive depth migration

Hugh Geiger and Gary Margrave



CREWES Nov 2004

POTSI* Sponsors:

Pacific Institute for the Mathematical Sciences

GEDCO

mitacs

CREWES

NSERC CRSNG

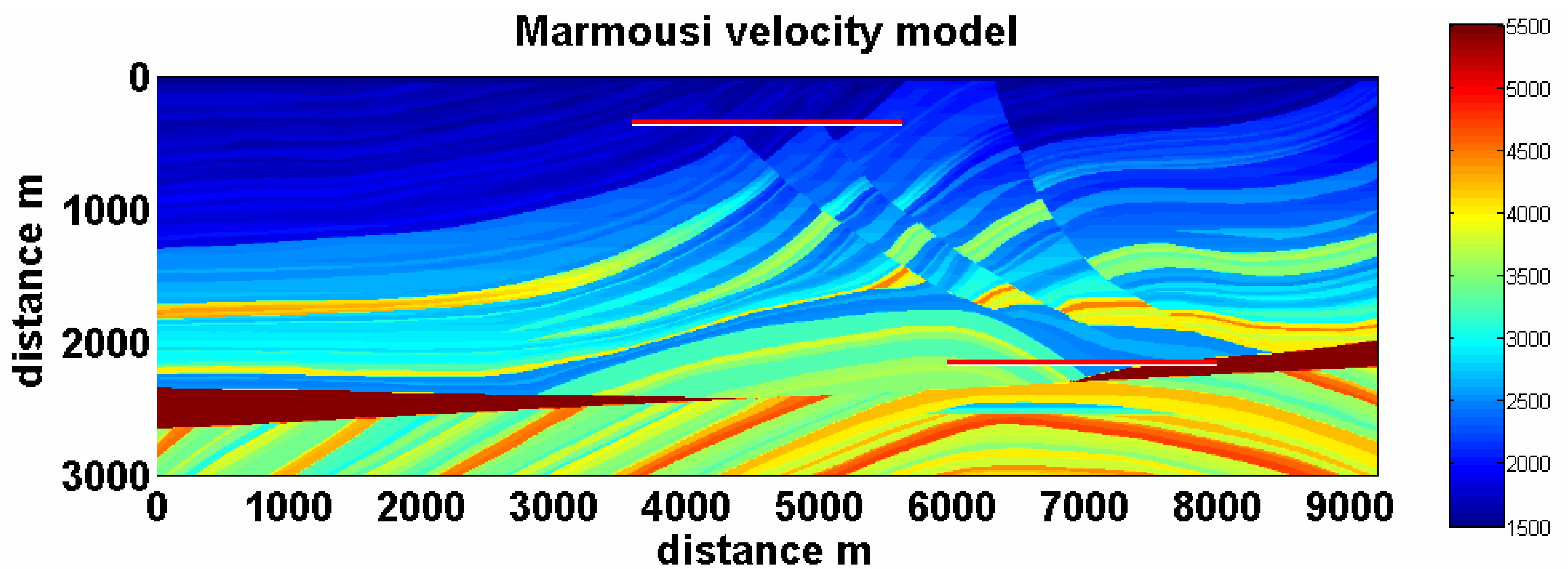
KEY SEISMIC

GEO·X SYSTEMS LTD.

*Pseudo-differential Operator Theory in Seismic Imaging

The problem:

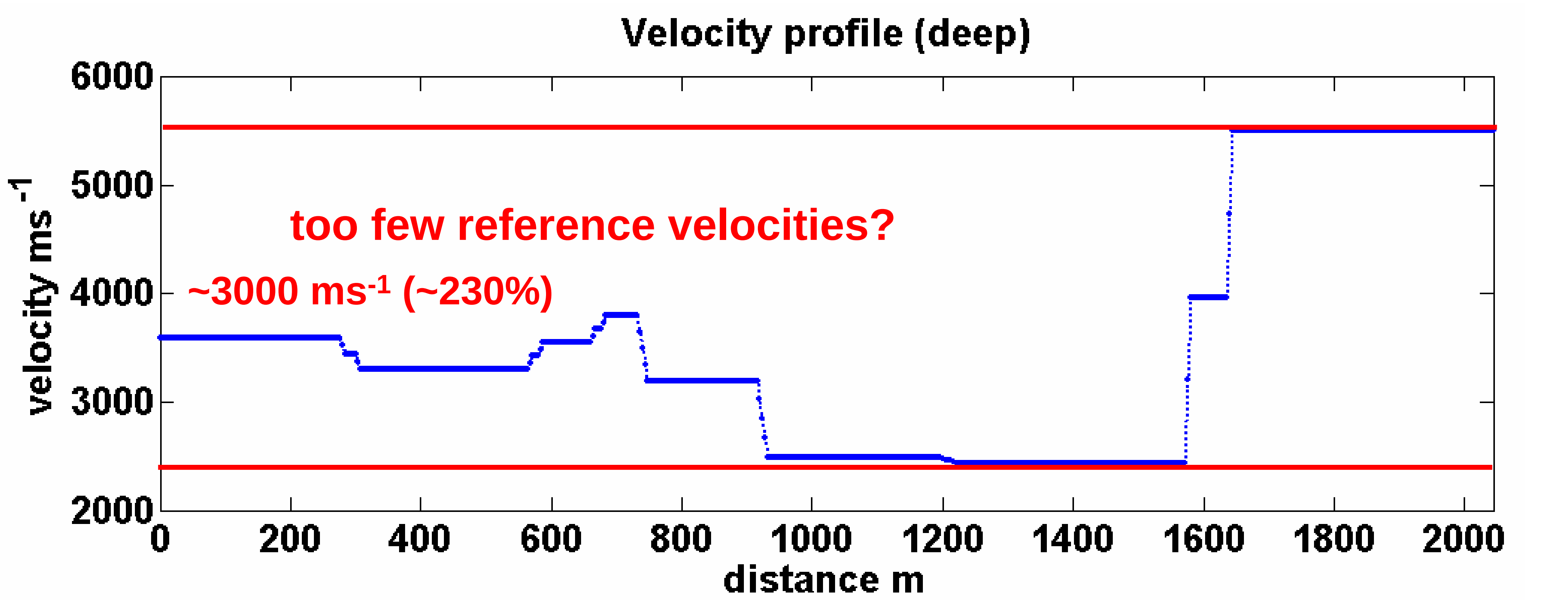
- Many recursive wavefield extrapolators require a limited set of reference velocities for efficient implementation
- How should these reference velocities be chosen?



example velocity profiles

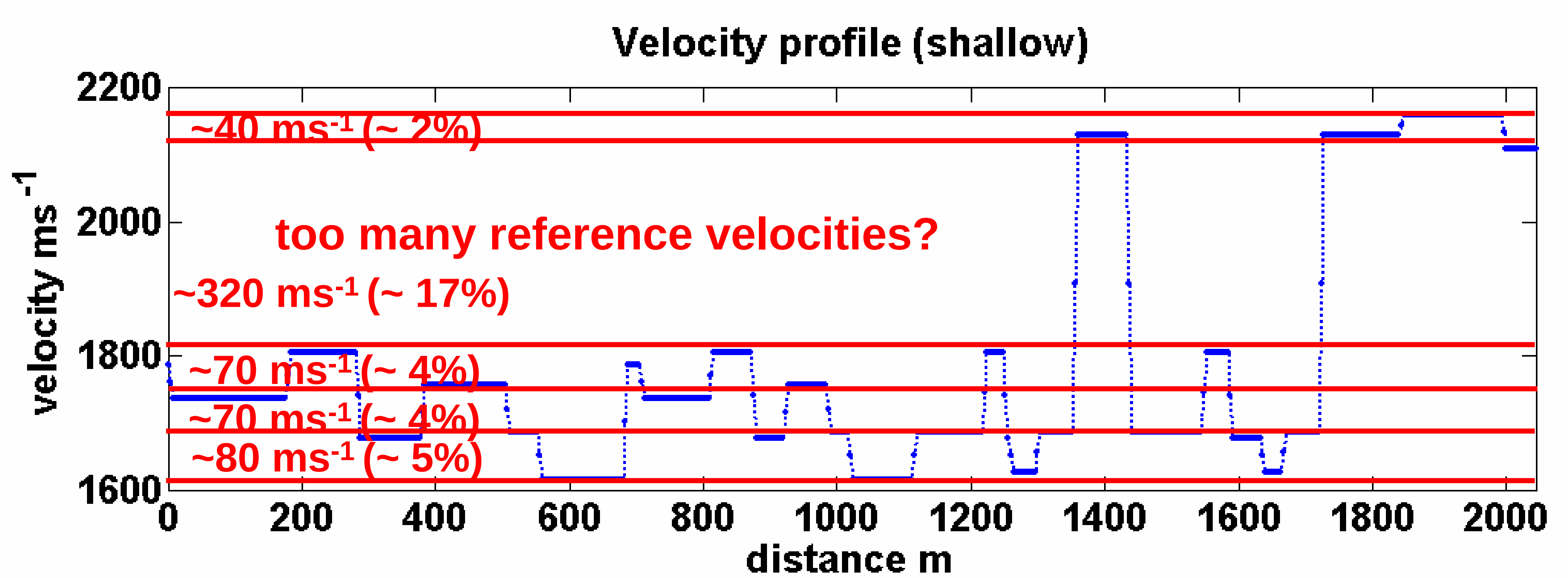
Objectives:

- Efficient computation
  - a minimum number of reference velocities
- Accurate wavefield extrapolation
  - reference velocities 'close' to model velocities



Some specific requirements

- PSPI – lower and upper bounding velocities (v_{min},v_{max})
  - ideally minimize large interpolations
    (wavefield is a weighted summation)
- Split-step – more accurate focusing
  with a slower velocity



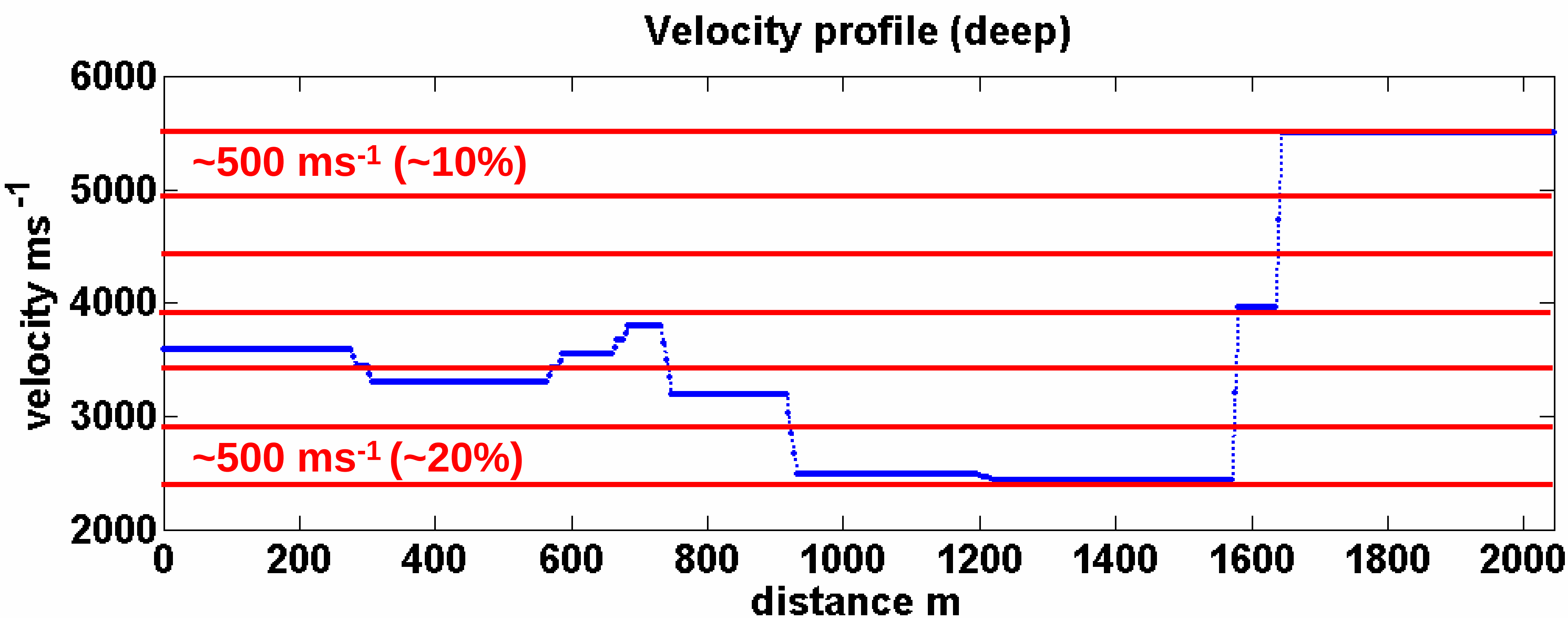
Basic approach 1: Linear progression

- choose an approximate velocity spacing dV

  $nV=round((v_{max}-v_{min})/dV)$

  $v_{step}=(v_{max}-v_{min})/nV$

- what is a good choice for dV?
  - empirical testing required
  - reasonable for both low and high velocities?



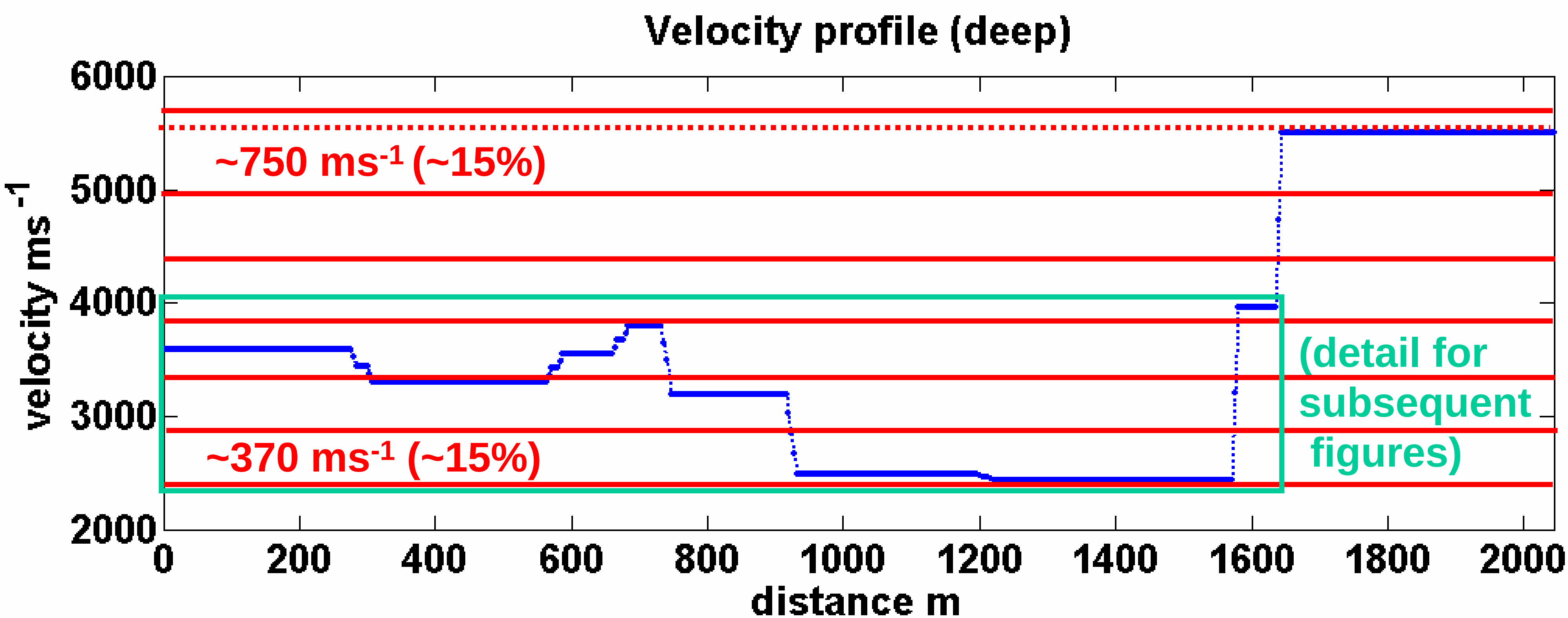
Basic approach 2a: Geometric progression

- choose an appropriate percentage step v_{prcnt}

  $v(i) = (1+v_{prcnt})*v(i-1)$

  - Kessigner (1992) recommends $v_{prcnt}=0.15$
    - start at v_{min} for profile?
    - start at v_{min} for complete velocity model?

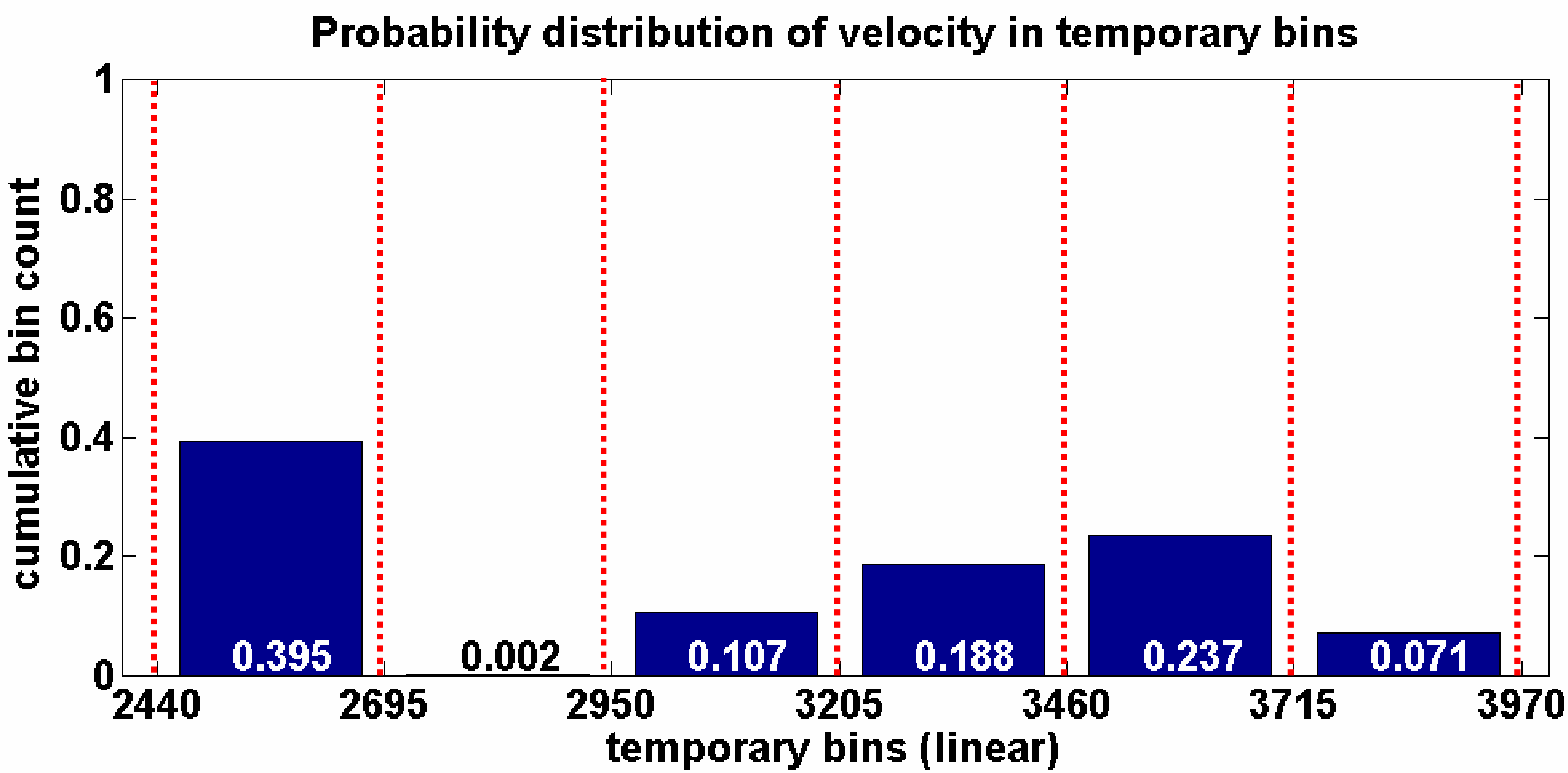
      (perhaps if using lookup tables)



Statistical method of Bagaini et al (1995)

- choose a preliminary dv (geometric?)
- equally spaced bins over v_{min}:v_{max} (e.g. nB_{temp} = 6)
- bin the velocities to give probability density P_i, $\Sigma P_i = 1$
- optimal number of bins by statistical entropy $S = \Sigma P_i \log P_i$

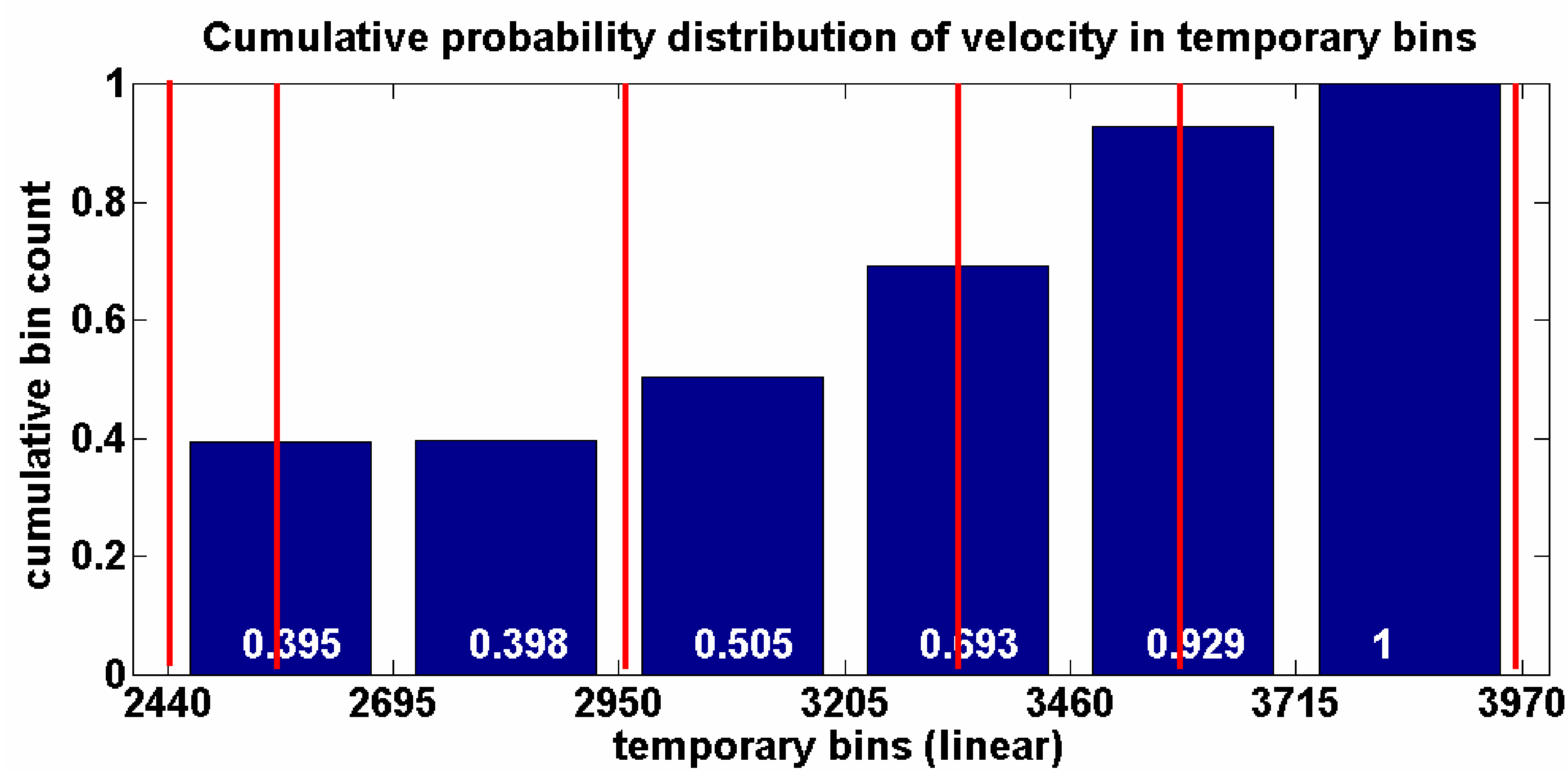
$$nB_{opt} = \mathrm{round}(\exp(S)+0.5) \qquad \text{(e.g. } nB_{opt} = 5\text{)}$$



- calculate cumulative probability distribution Y_i,

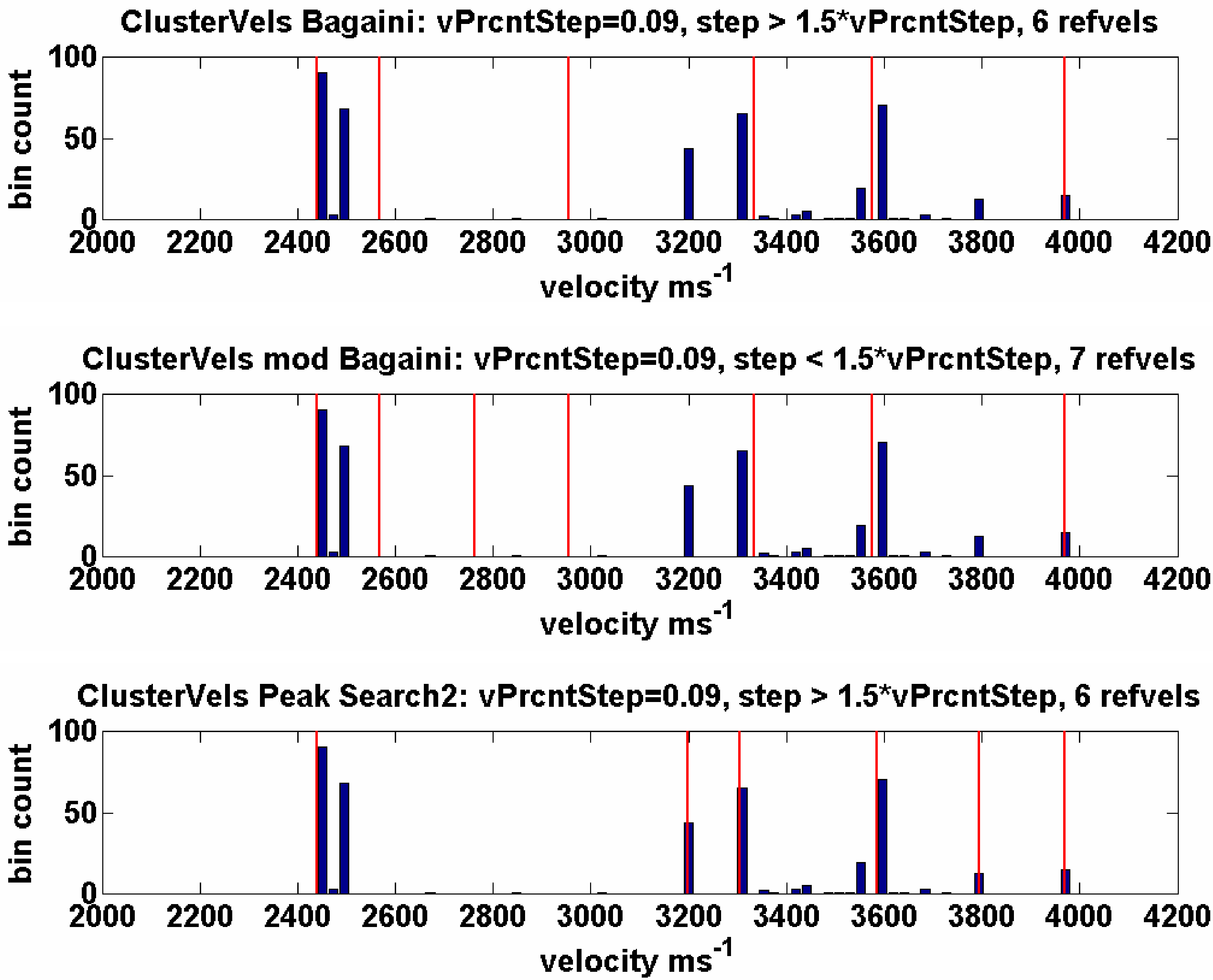
$$Y_i = \Sigma P_i$$

- each optimal bin to hold $1/nB_{opt}$ (e.g. 0.2)
  - start at v_{min}
  - linearly interpolate from temporary bin boundaries (e.g. at 0.2, 0.4, 0.6, 0.8)
- Is this optimal? - bins not necessarily close to peaks

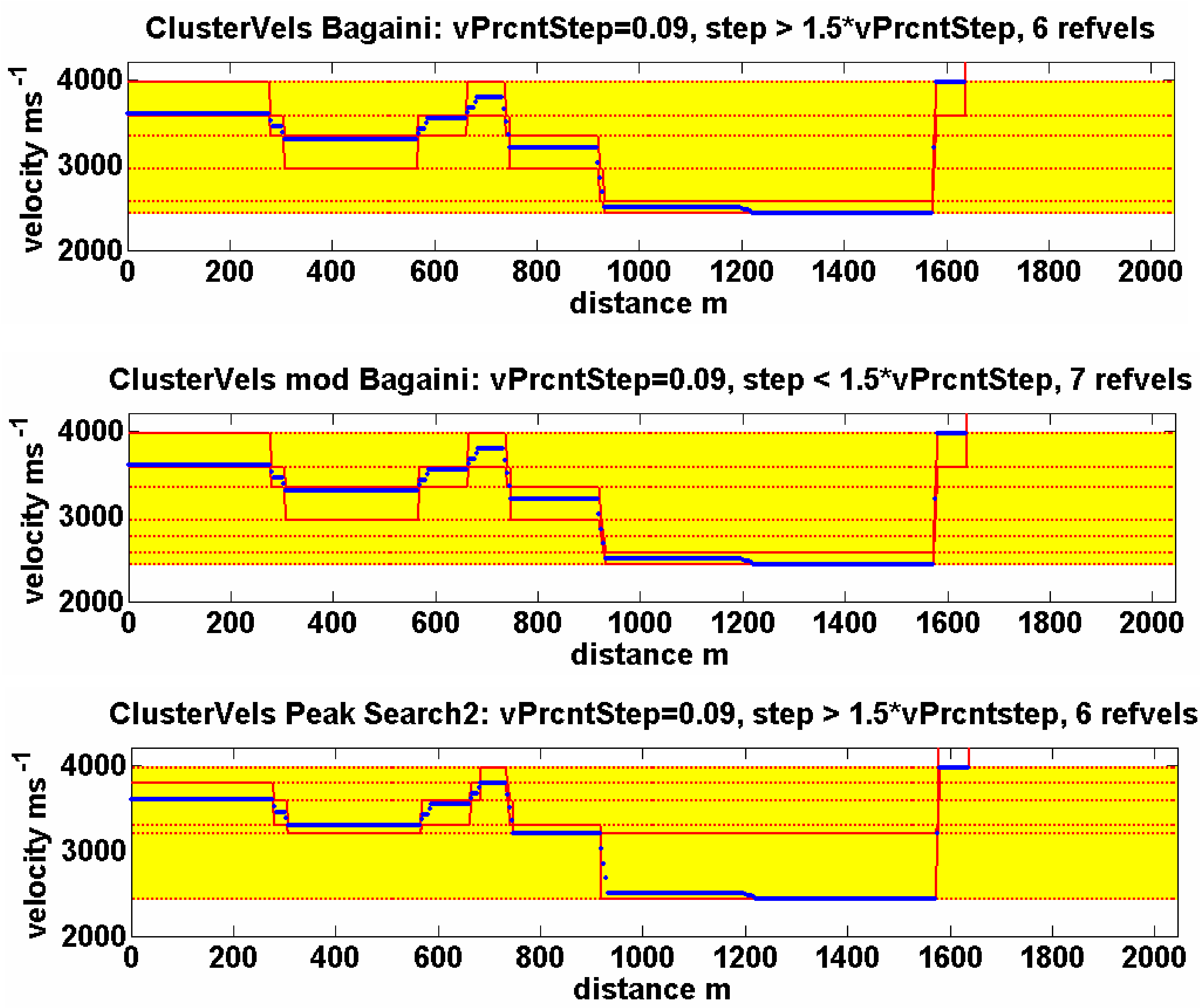


New peak search method

- cluster velocities
  - new cluster where jump exceeds $v_{prcntmax}$
- Now, within each cluster:
- use Bagaini method for optimal number of bins nB_{opt}
- create a new probability distribution with finer bins
- descending sort of P_i's, choose all P_i's where $\Sigma P_i < 0.9$
- place v_{temp} at all P_i's, include v_{min},v_{max}
- use 'greedy search' to combine closely spaced P_i's
  - start search at bin spacing of 1, then 2, etc.
  - weighted linear average to move v_{temp}
- stop when at v_{temp}= nB_{opt}

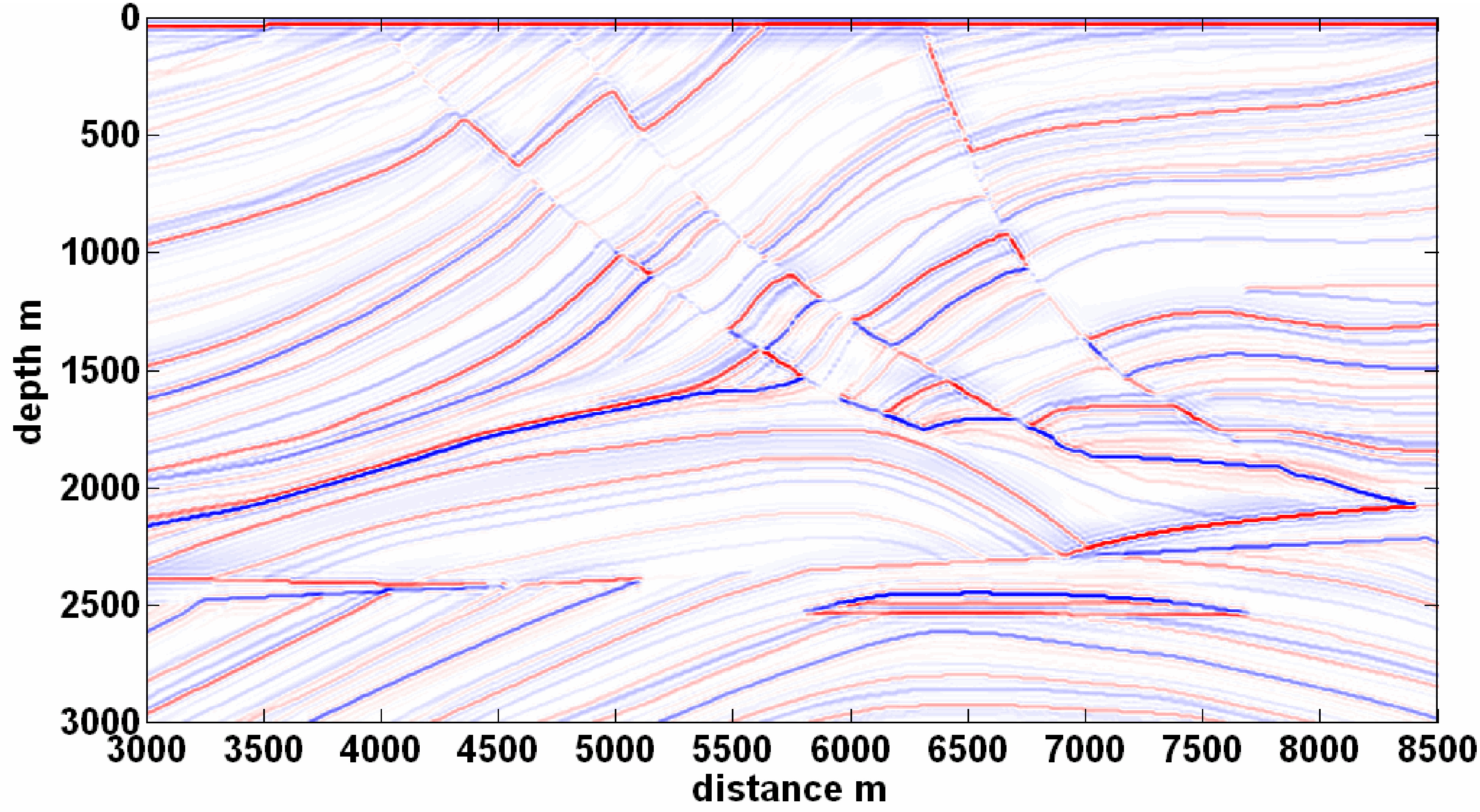


ClusterVels Bagaini: vPrcntStep=0.09, step > 1.5*vPrcntStep, 6 refvels
ClusterVels mod Bagaini: vPrcntStep=0.09, step < 1.5*vPrcntStep, 7 refvels
ClusterVels Peak Search2: vPrcntStep=0.09, step > 1.5*vPrcntStep, 6 refvels
bin count
velocity ms-1
0
50
100
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200

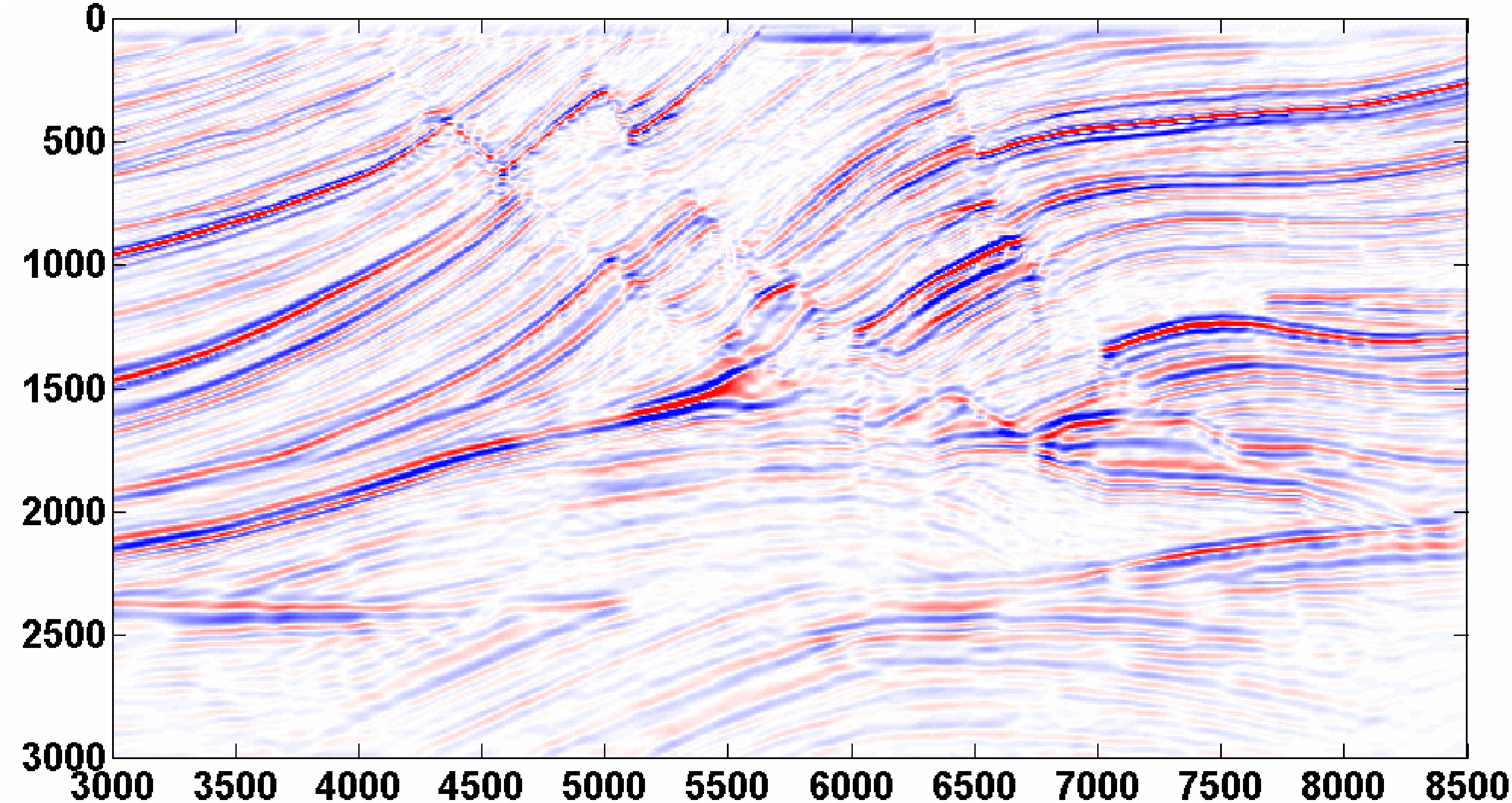


ClusterVels Bagaini: vPrcntStep=0.09, step > 1.5*vPrcntStep, 6 refvels
velocity ms -1
4000
3000
2000
0
200
400
600
800
1000
1200
1400
1600
1800
2000
distance m
ClusterVels mod Bagaini: vPrcntStep=0.09, step < 1.5*vPrcntStep, 7 refvels
velocity ms -1
4000
3000
2000
0
200
400
600
800
1000
1200
1400
1600
1800
2000
distance m
ClusterVels Peak Search2: vPrcntStep=0.09, step > 1.5*vPrcntstep, 6 refvels
velocity ms -1
4000
3000
2000
0
200
400
600
800
1000
1200
1400
1600
1800
2000
distance m

Marmousi bandlimited reflectivity

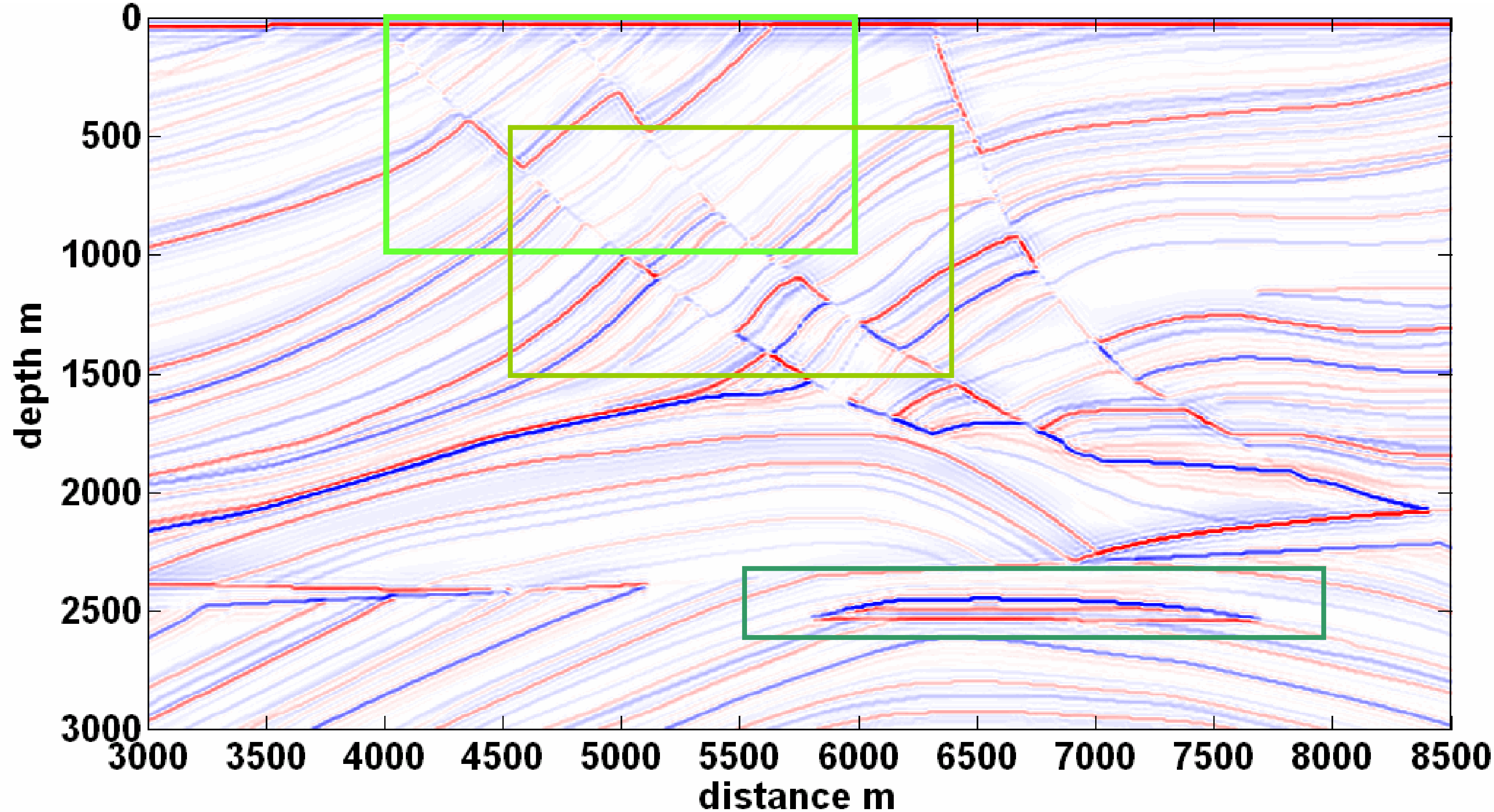


PSPI with velocity clustering algorithm

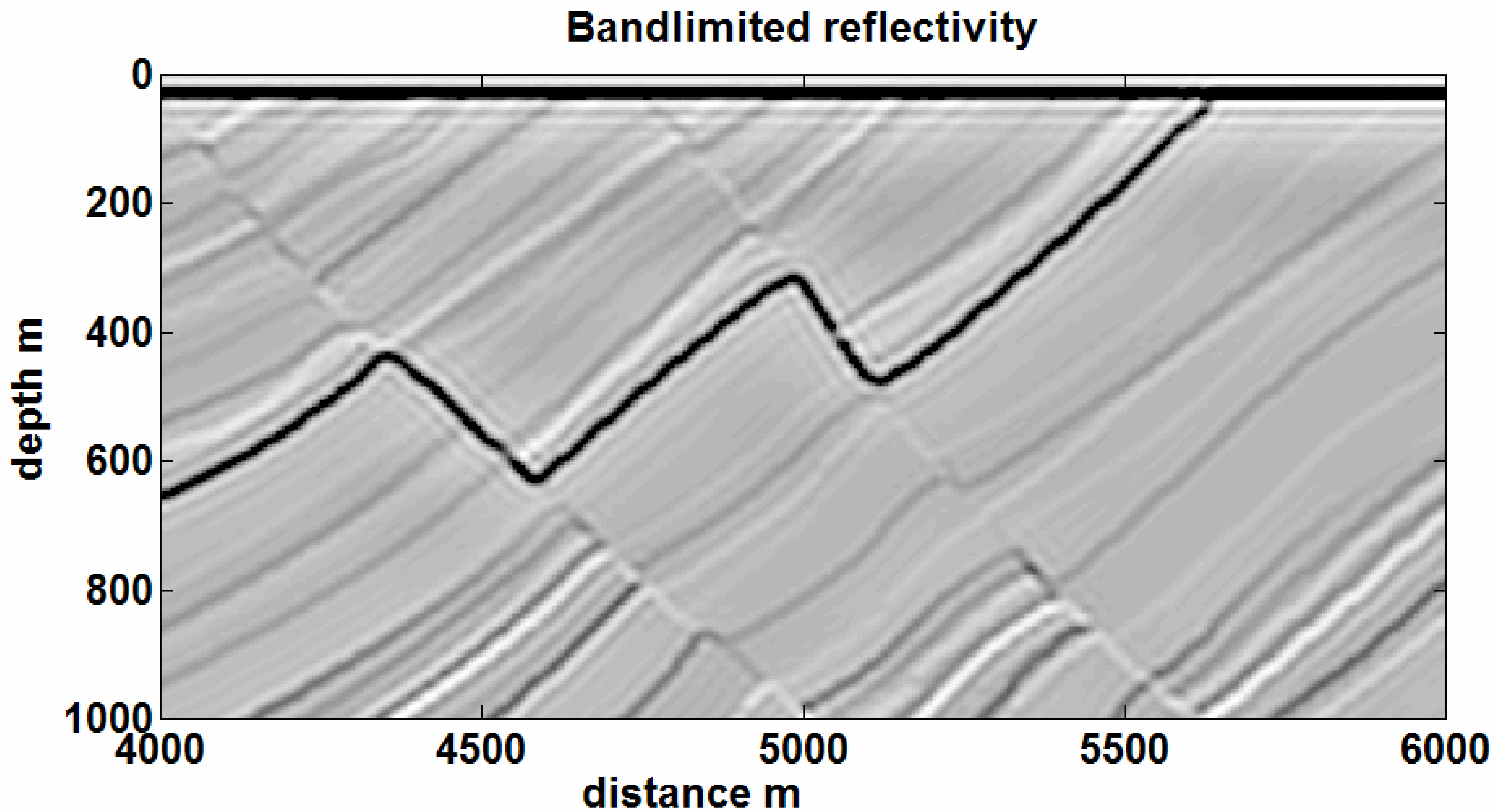


data: deconpr 50 13 .0002 whiten [4 16 35 60] static –60ms
shot: ricker fdom 24 ghost array phsrot –68 (to zp) whiten [4 16 35 60]

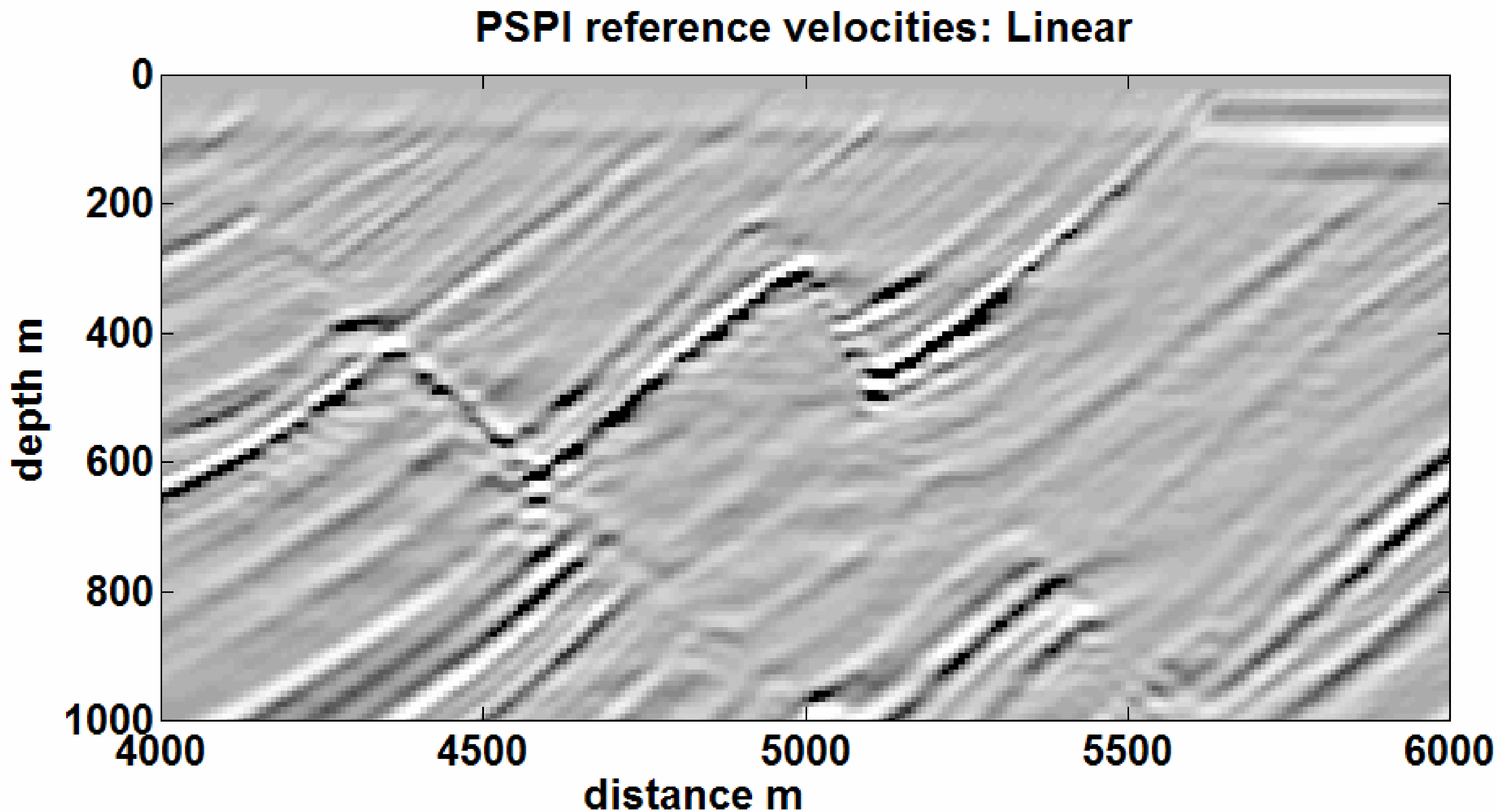
Marmousi bandlimited reflectivity



Marmousi shallow reflectivity

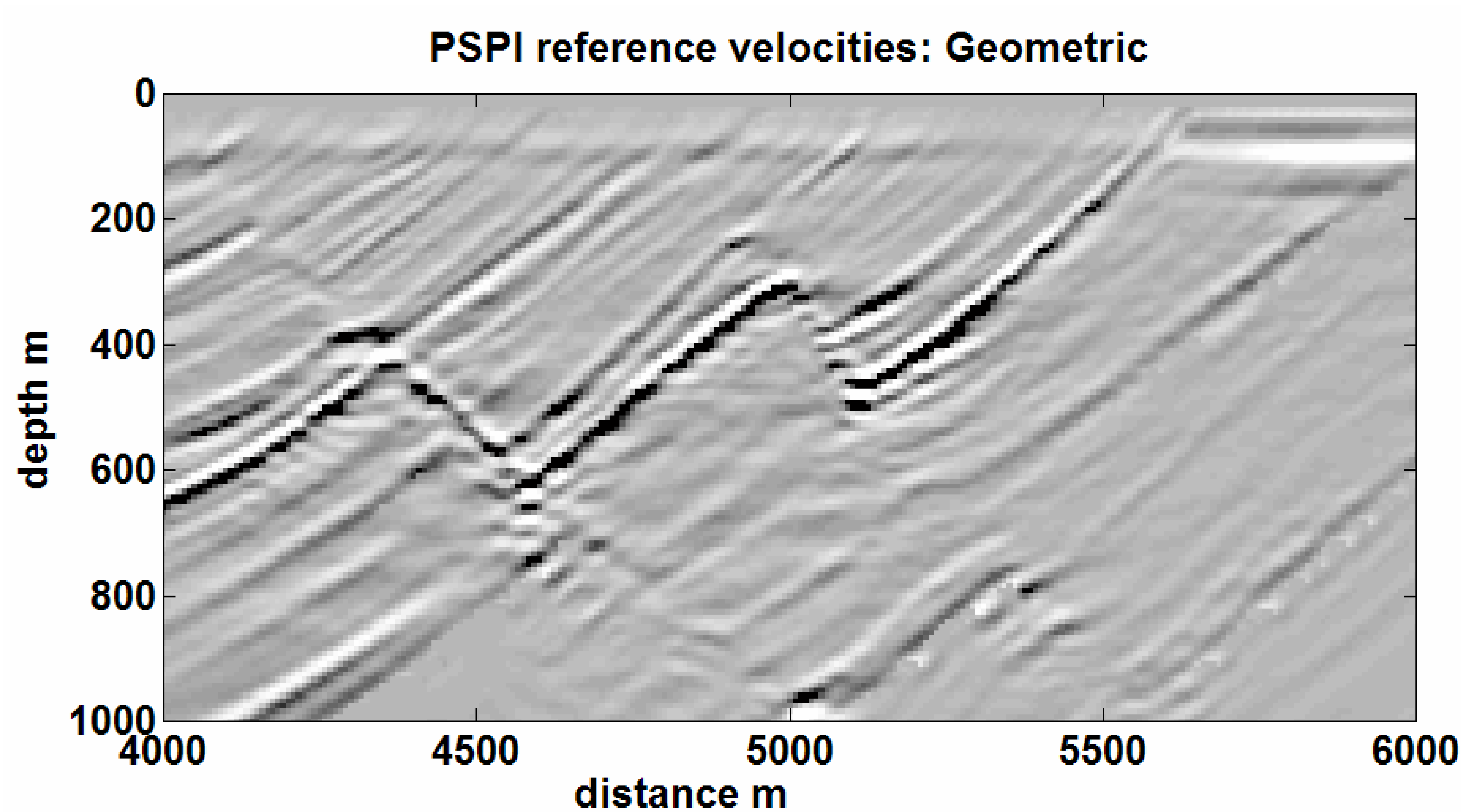


Linear

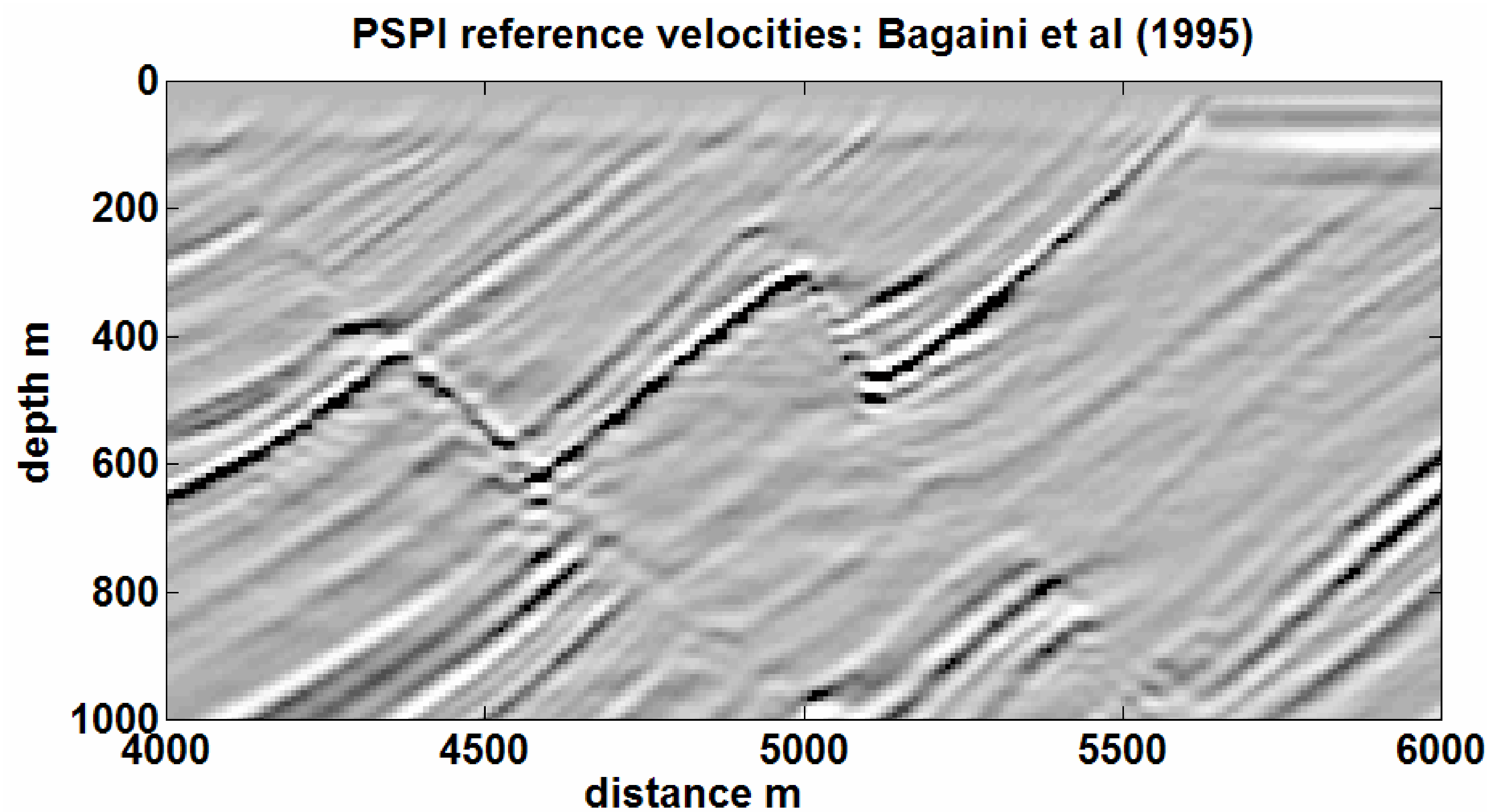


PSPI reference velocities: Linear
0
200
400
600
800
1000
depth m
4000
4500
5000
5500
6000
distance m

Geometric

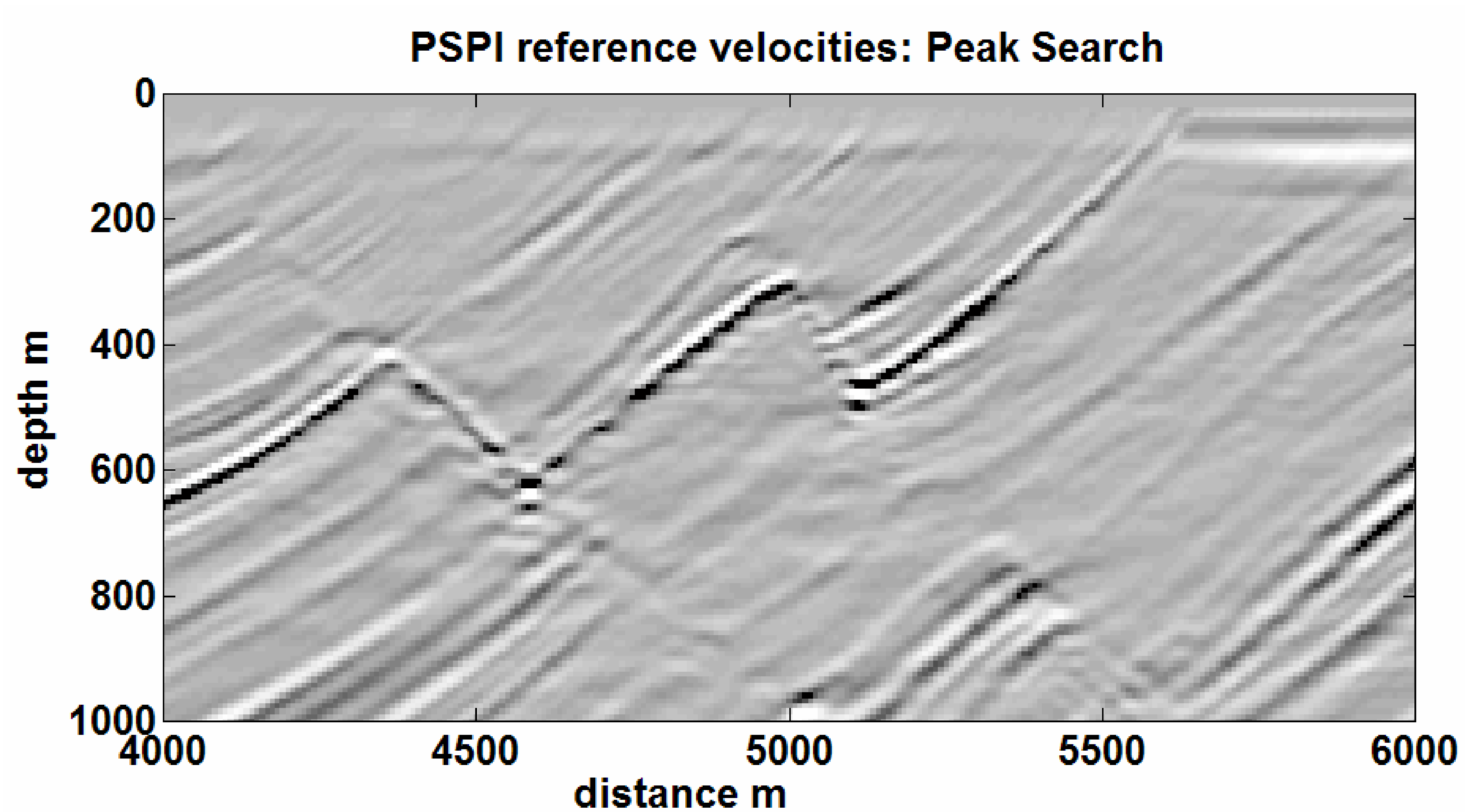

PSPI reference velocities: Geometric
depth m
distance m
0
200
400
600
800
1000
4000
4500
5000
5500
6000

Bagaini

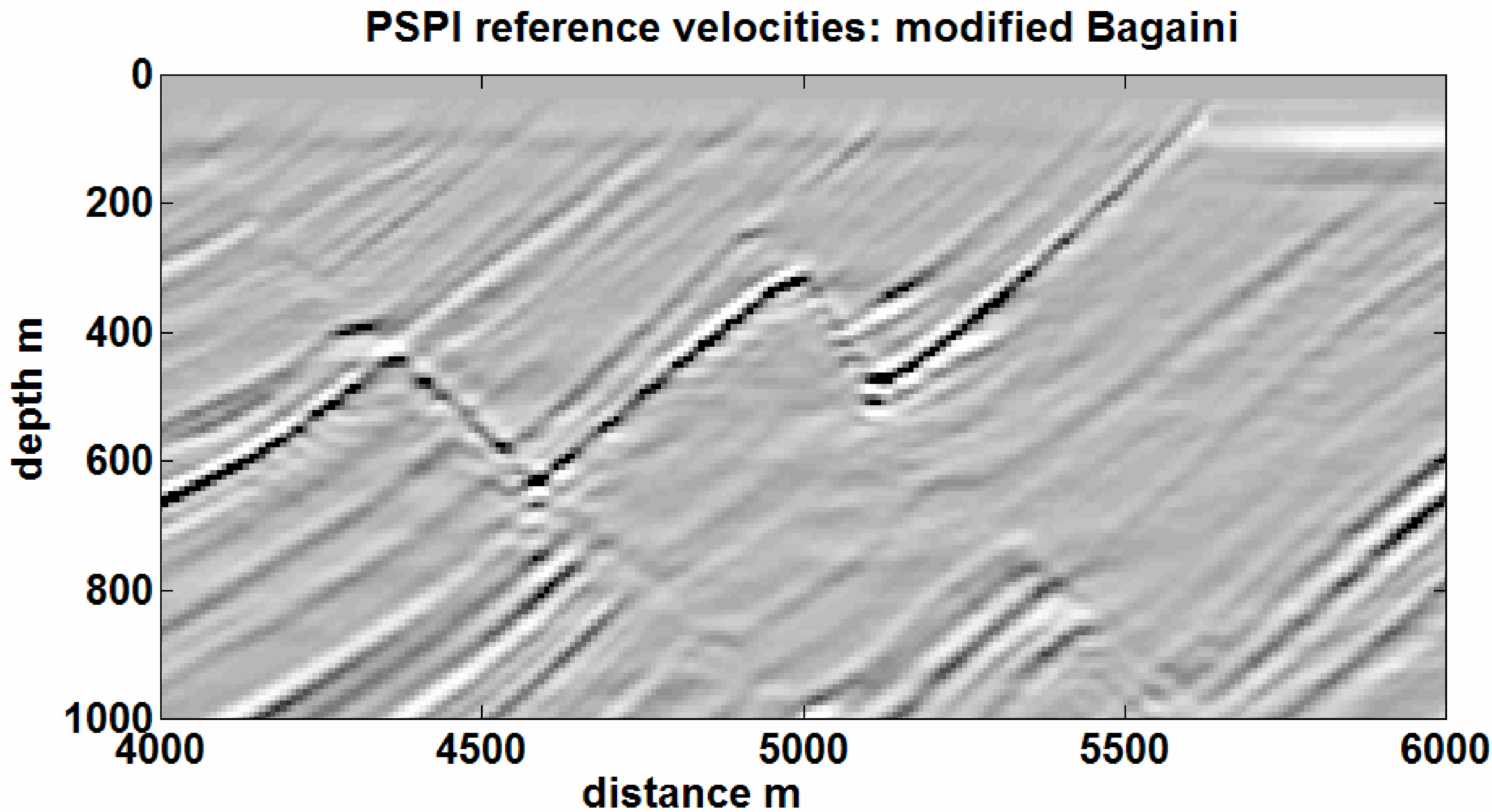


PSPI reference velocities: Bagaini et al (1995)
0
200
400
600
800
1000
depth m
4000
4500
5000
5500
6000
distance m

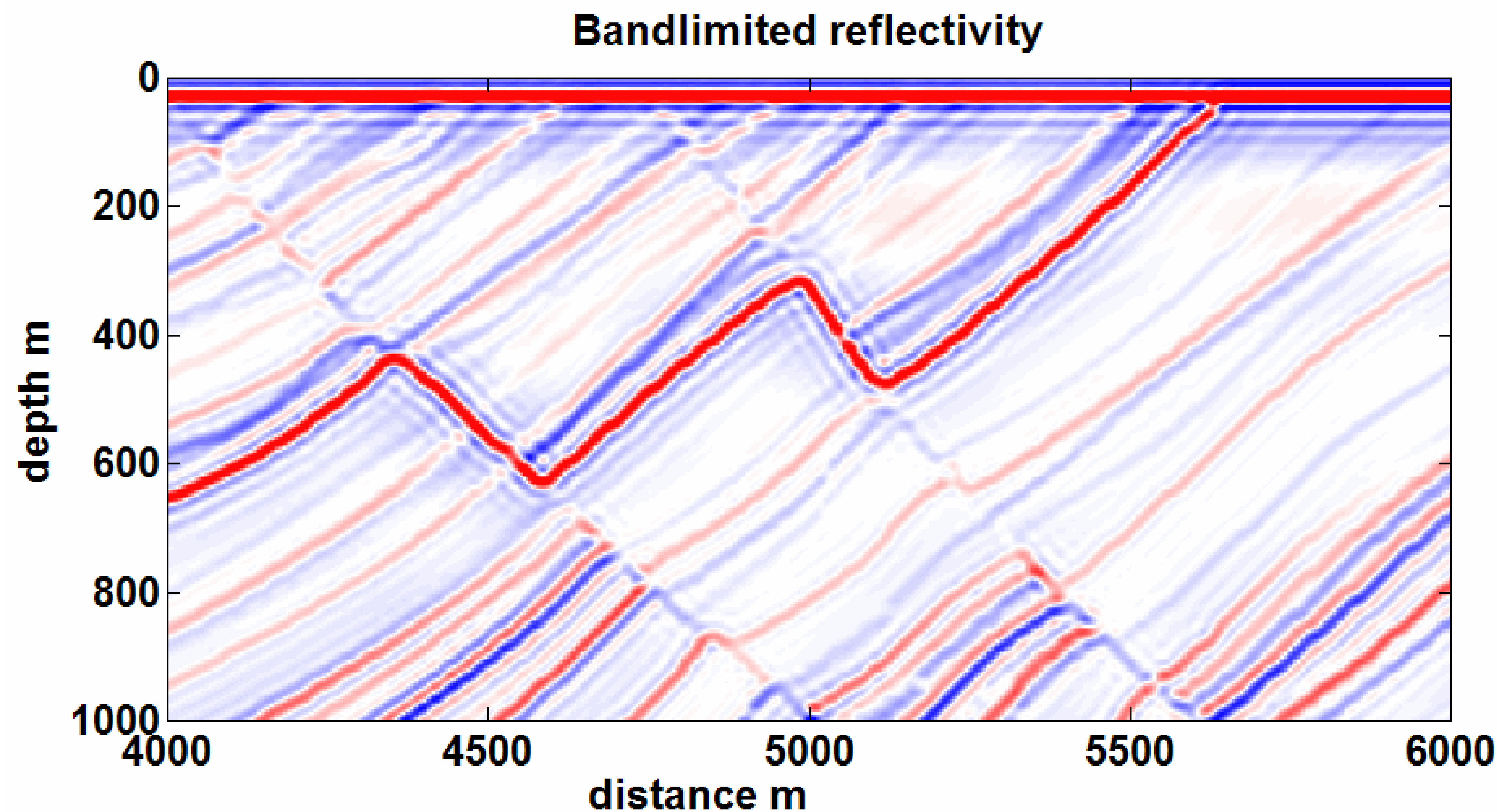
Peak Search


PSPI reference velocities: Peak Search
depth m
0
200
400
600
800
1000
4000
4500
5000
5500
6000
distance m

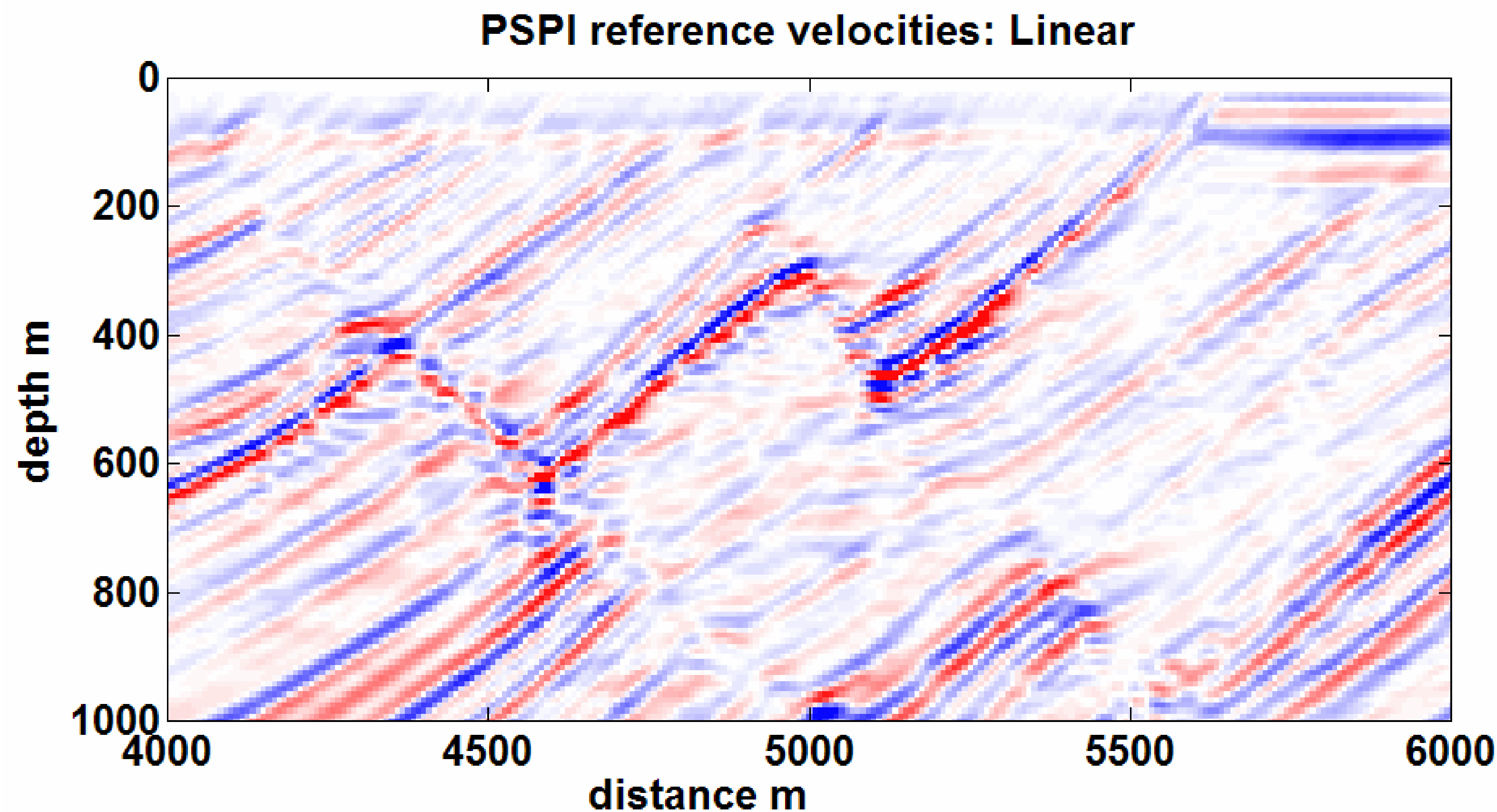
Modified Bagaini: clusters



Marmousi shallow reflectivity

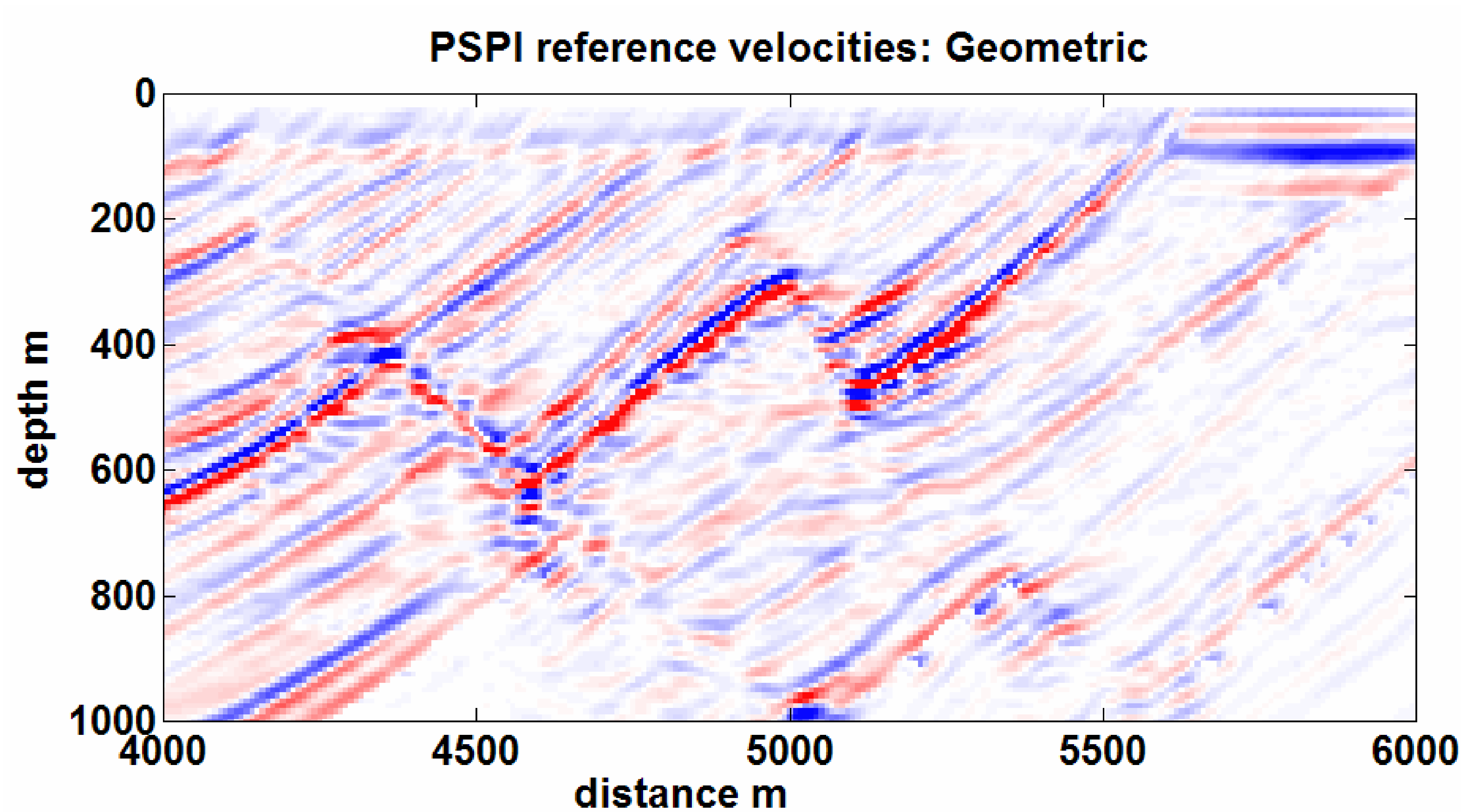


Linear



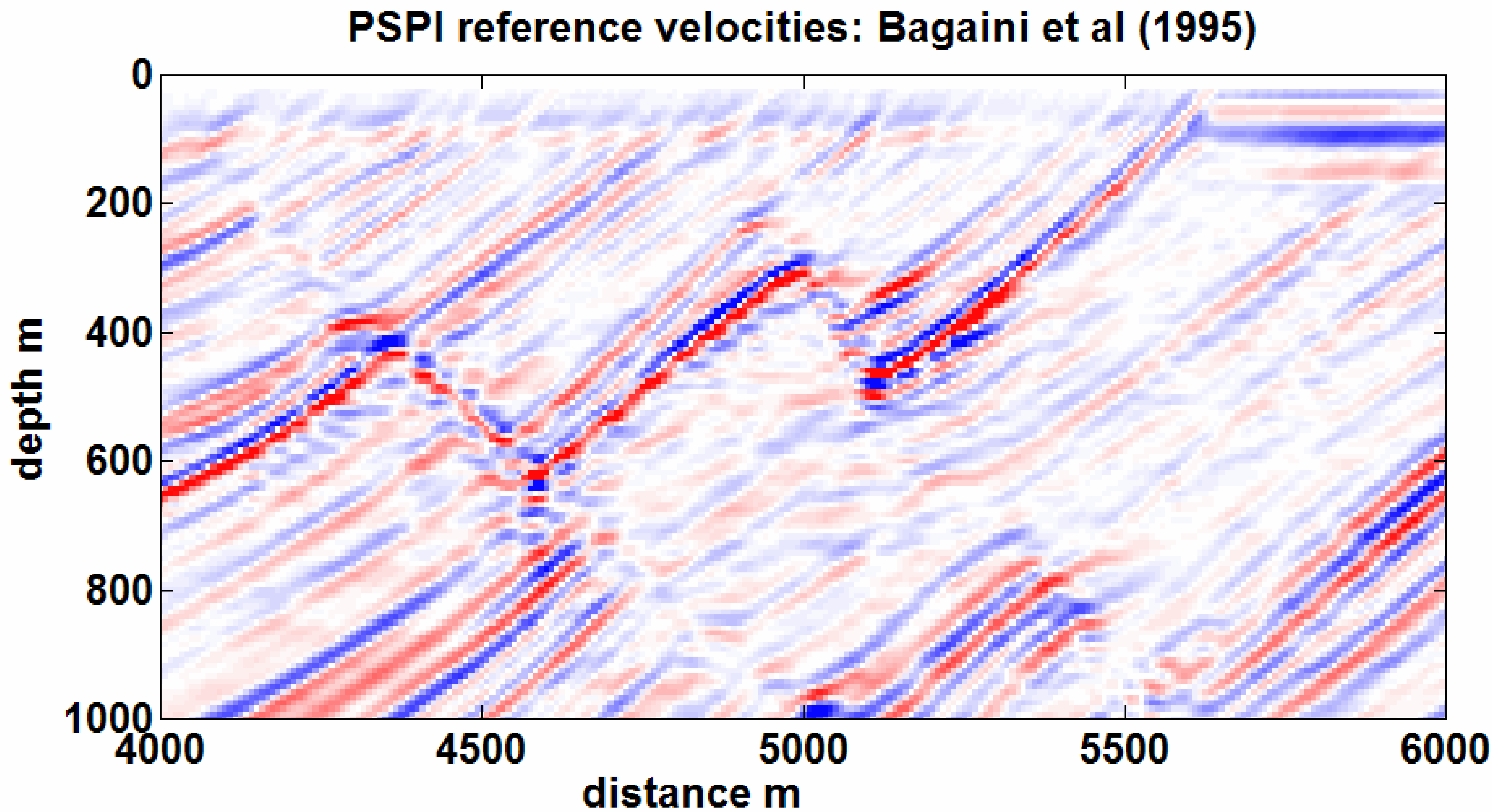
PSPI reference velocities: Linear
0
200
400
600
800
1000
depth m
4000
4500
5000
5500
6000
distance m

Geometric



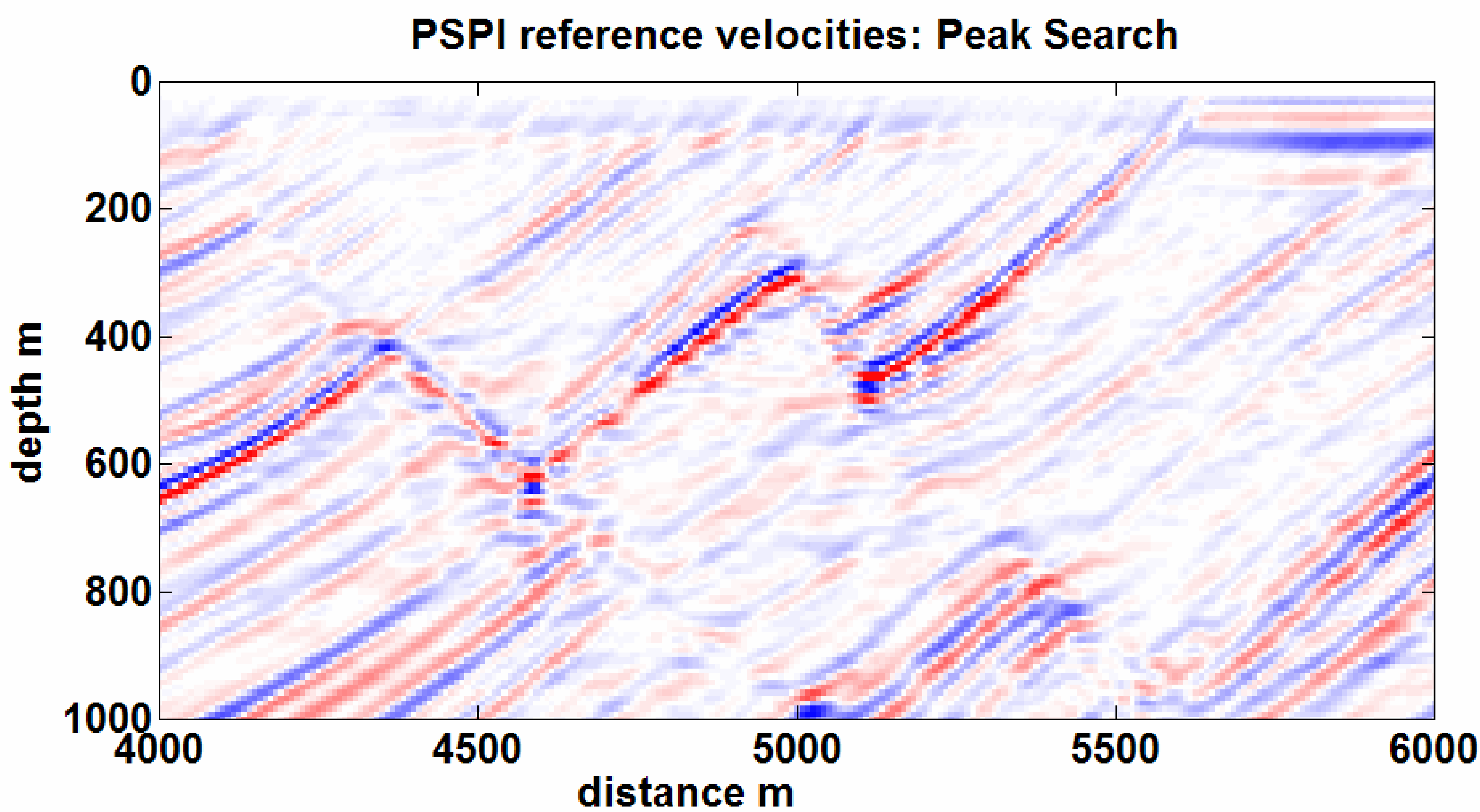
PSPI reference velocities: Geometric
0
200
400
600
800
1000
depth m
4000
4500
5000
5500
6000
distance m

Bagaini



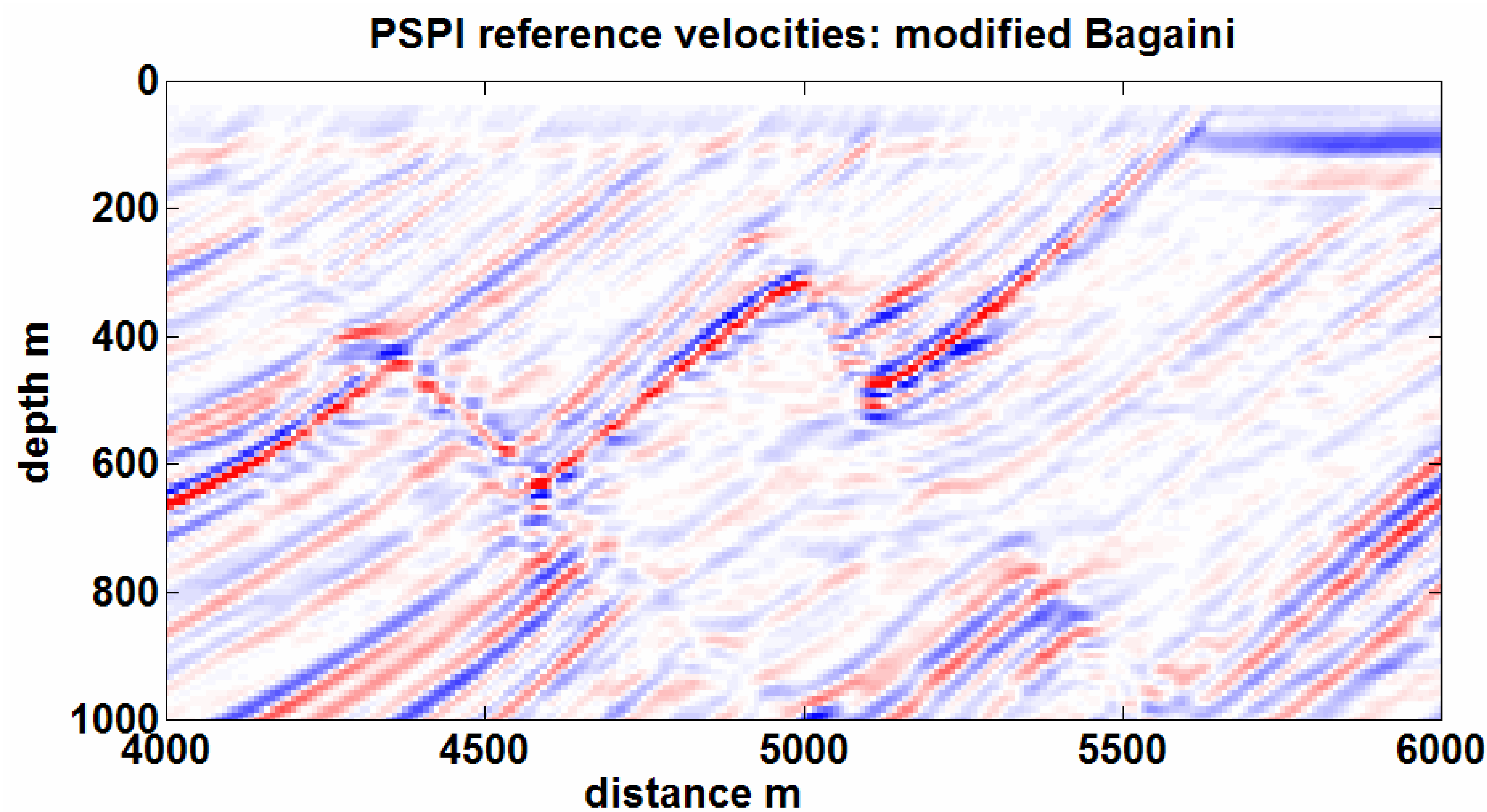
PSPI reference velocities: Bagaini et al (1995)
0
200
400
600
800
1000
depth m
4000
4500
5000
5500
6000
distance m

Peak Search

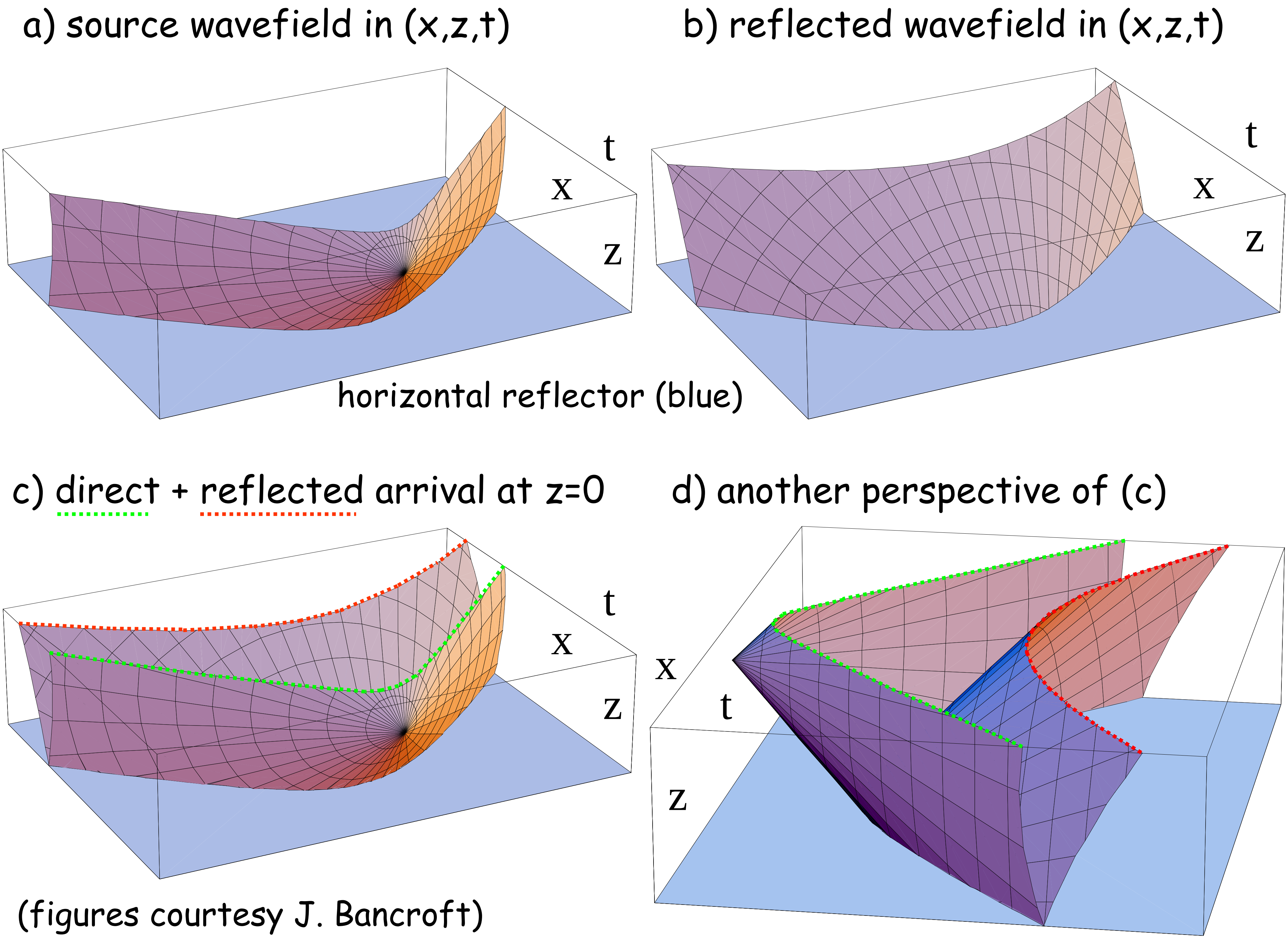


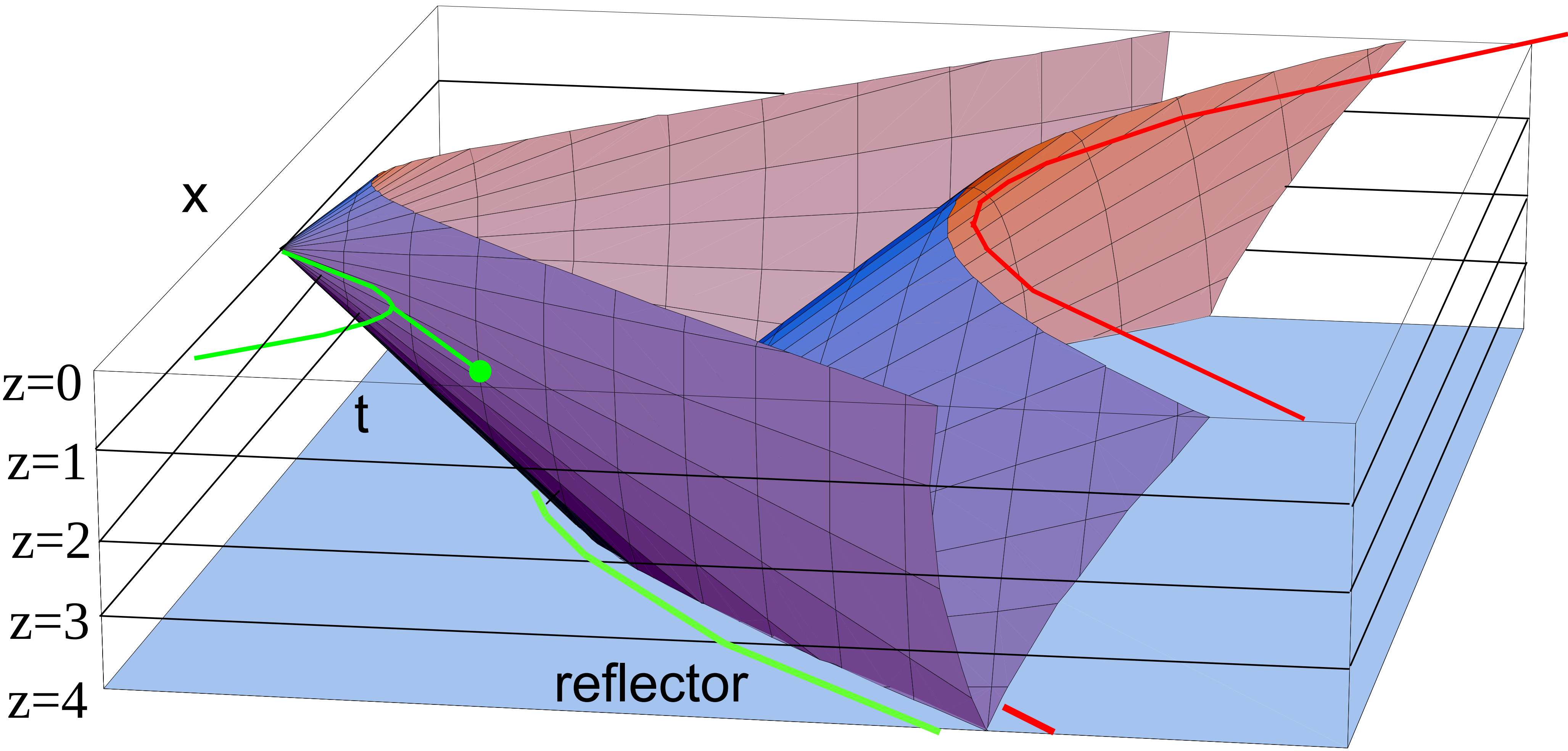
PSPI reference velocities: Peak Search
0
200
400
600
800
1000
depth m
4000
4500
5000
5500
6000
distance m

Modified Bagaini: clusters

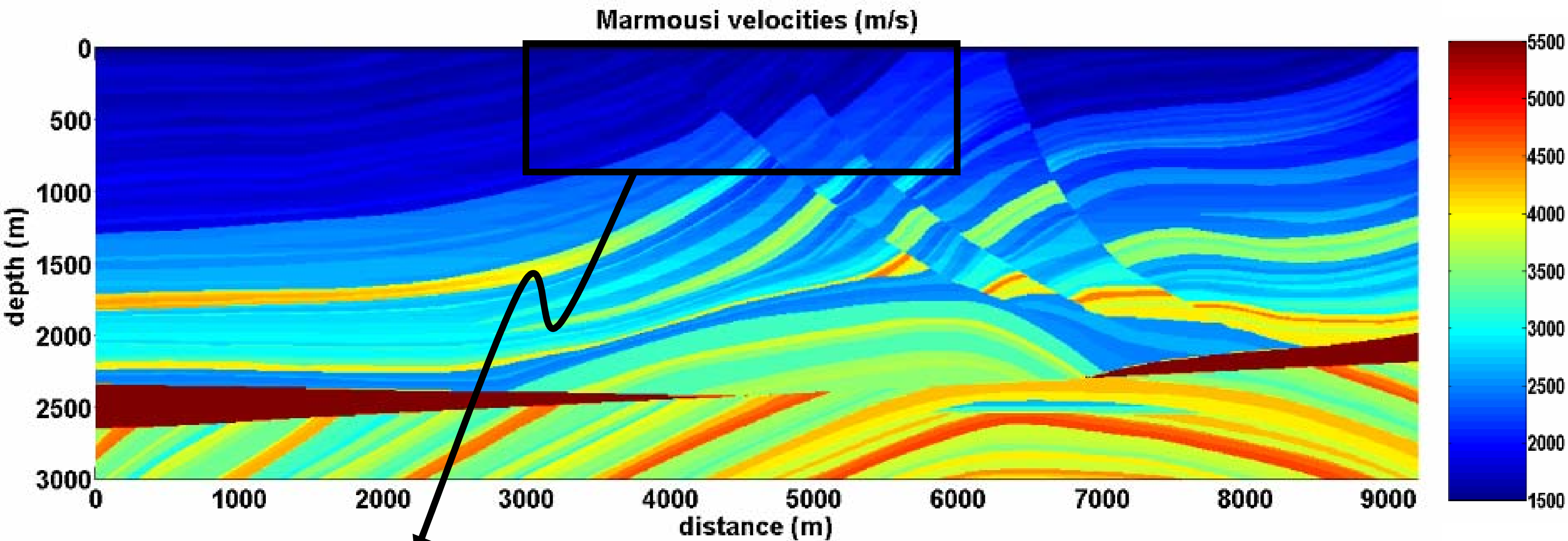


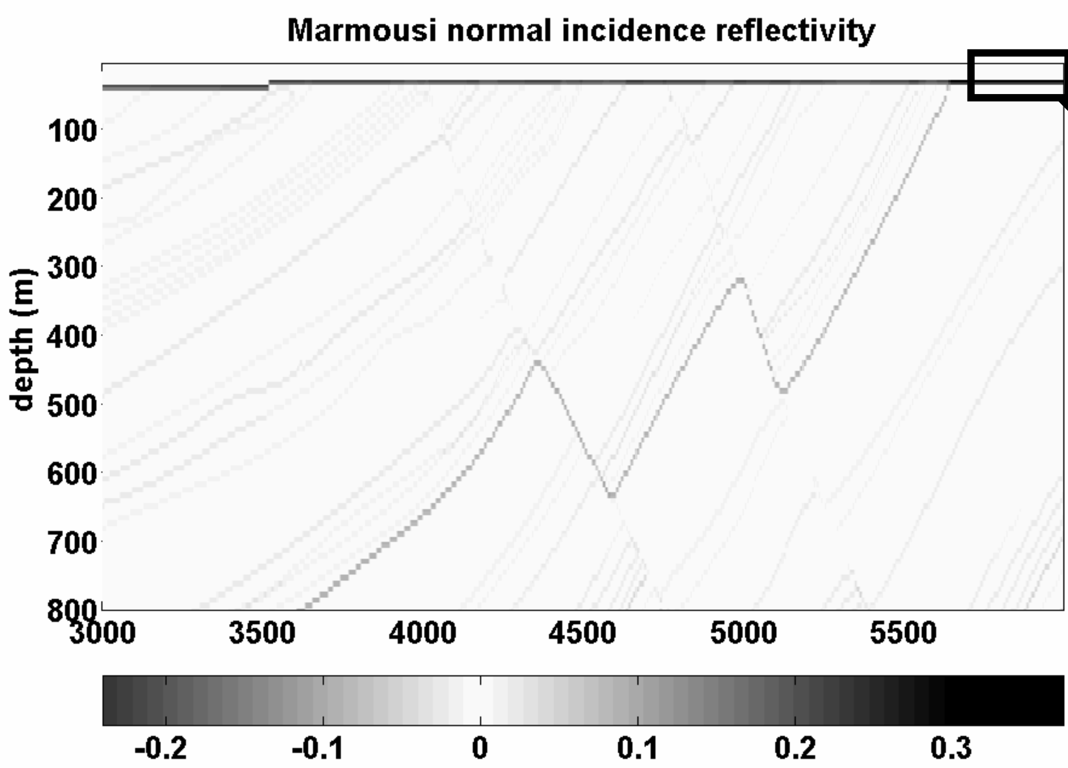
Static shifts – affect focusing

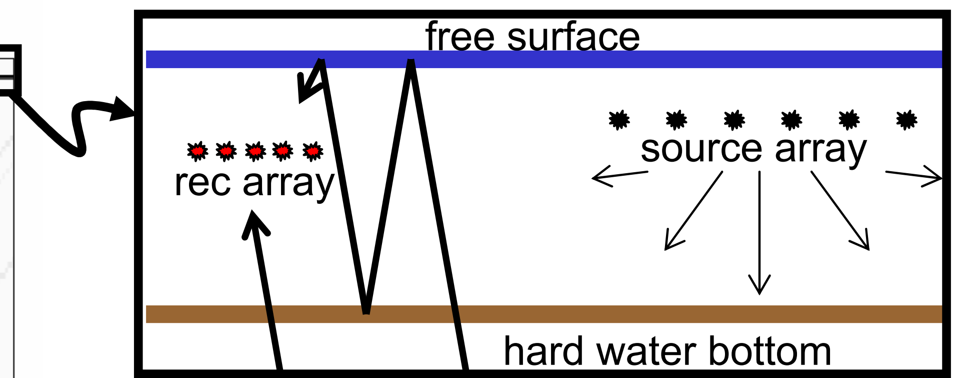

a) source wavefield in (x,z,t)
b) reflected wavefield in (x,z,t)
t
x
z
horizontal reflector (blue)
c) direct + reflected arrival at z=0
d) another perspective of (c)
(figures courtesy J. Bancroft)



With a static shift of the source and/or receiver wavefield, the extrpolated wavefields will not be time coincident at the reflector, causing Focusing and positioning errors.

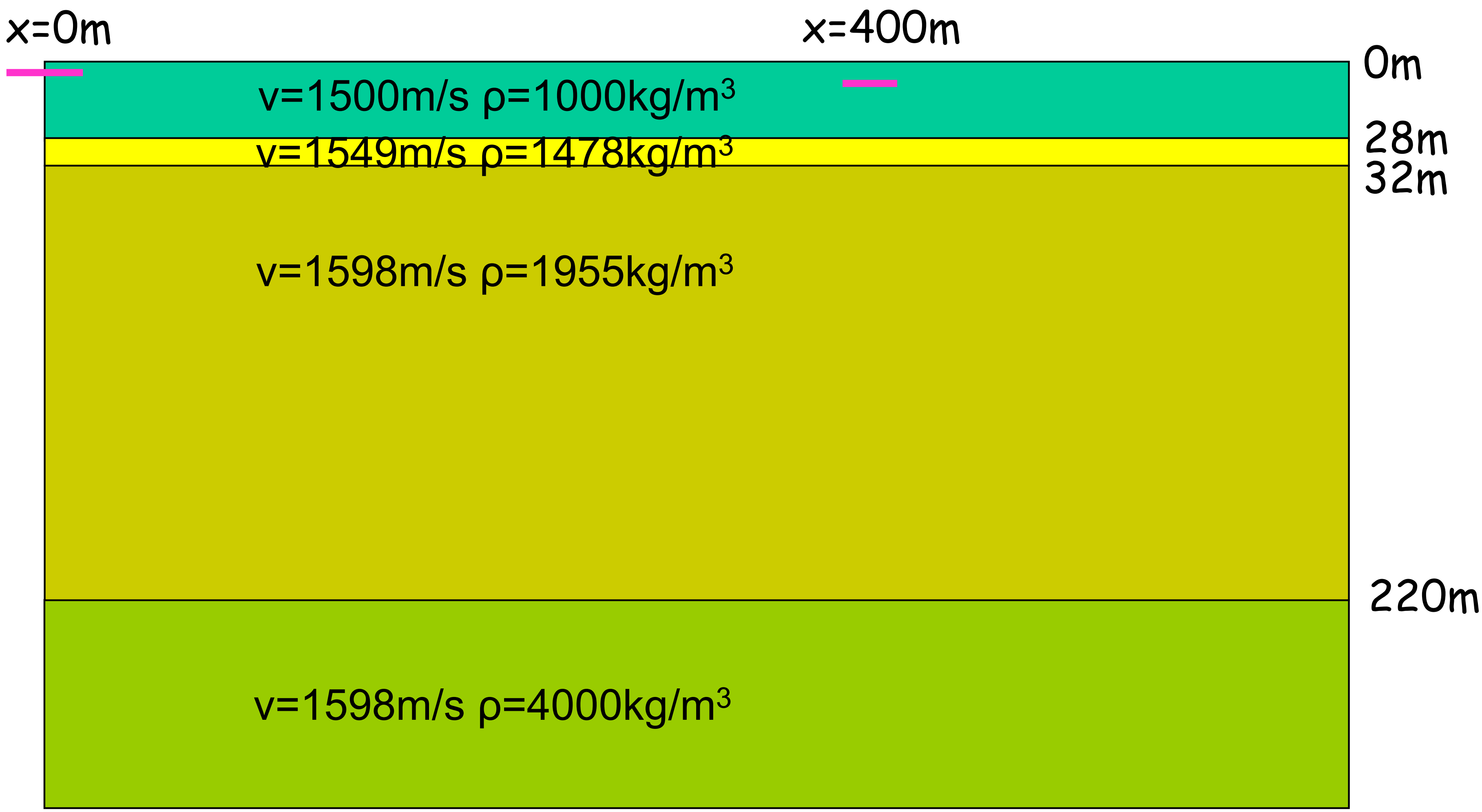






Complications for Marmousi imaging:

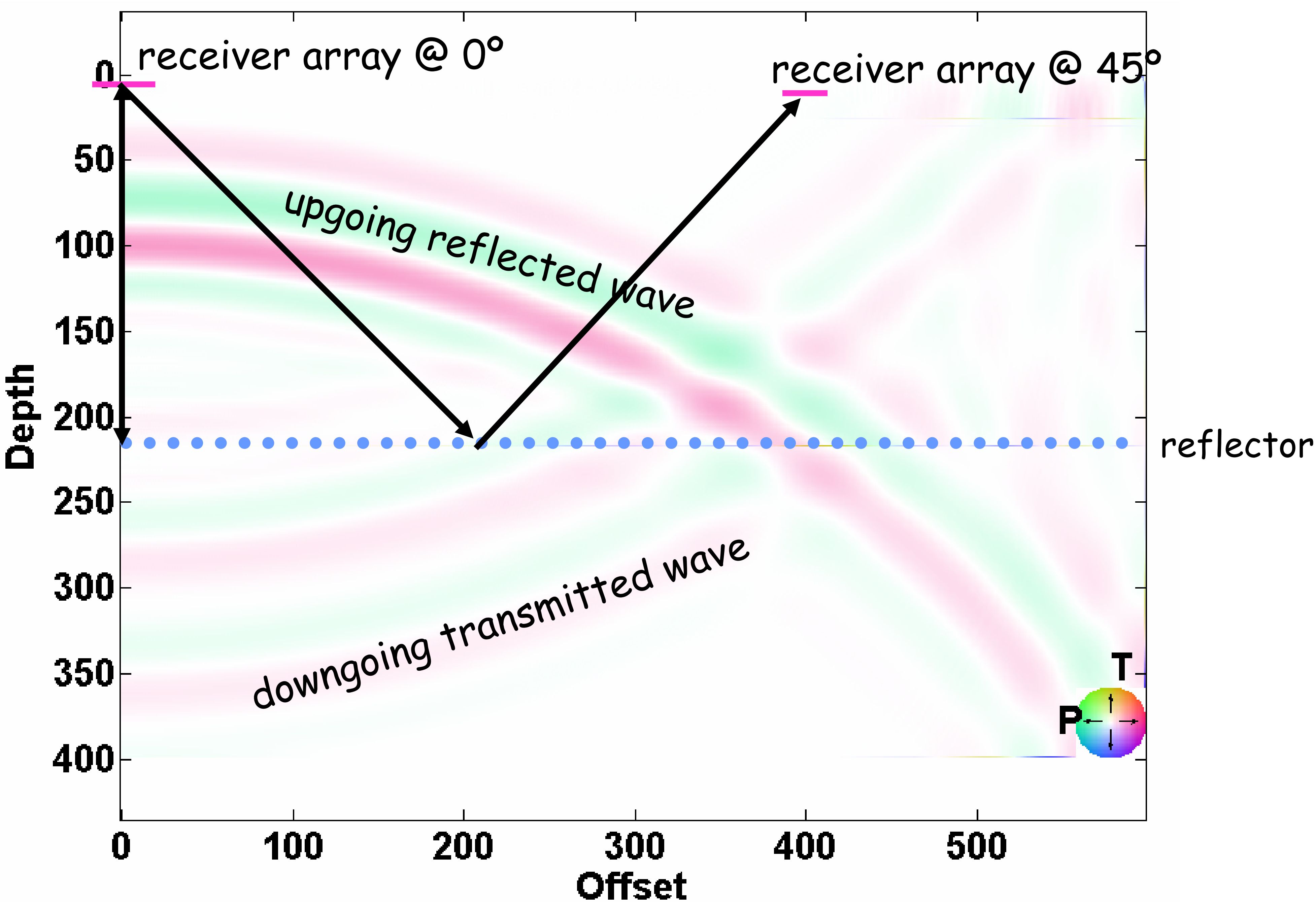
- free-surface and water bottom ghosting and multiples modify wavelet
- source and receiver array directivity
- two-way wavefield, one-way extrapolators
- heterogeneous velocity

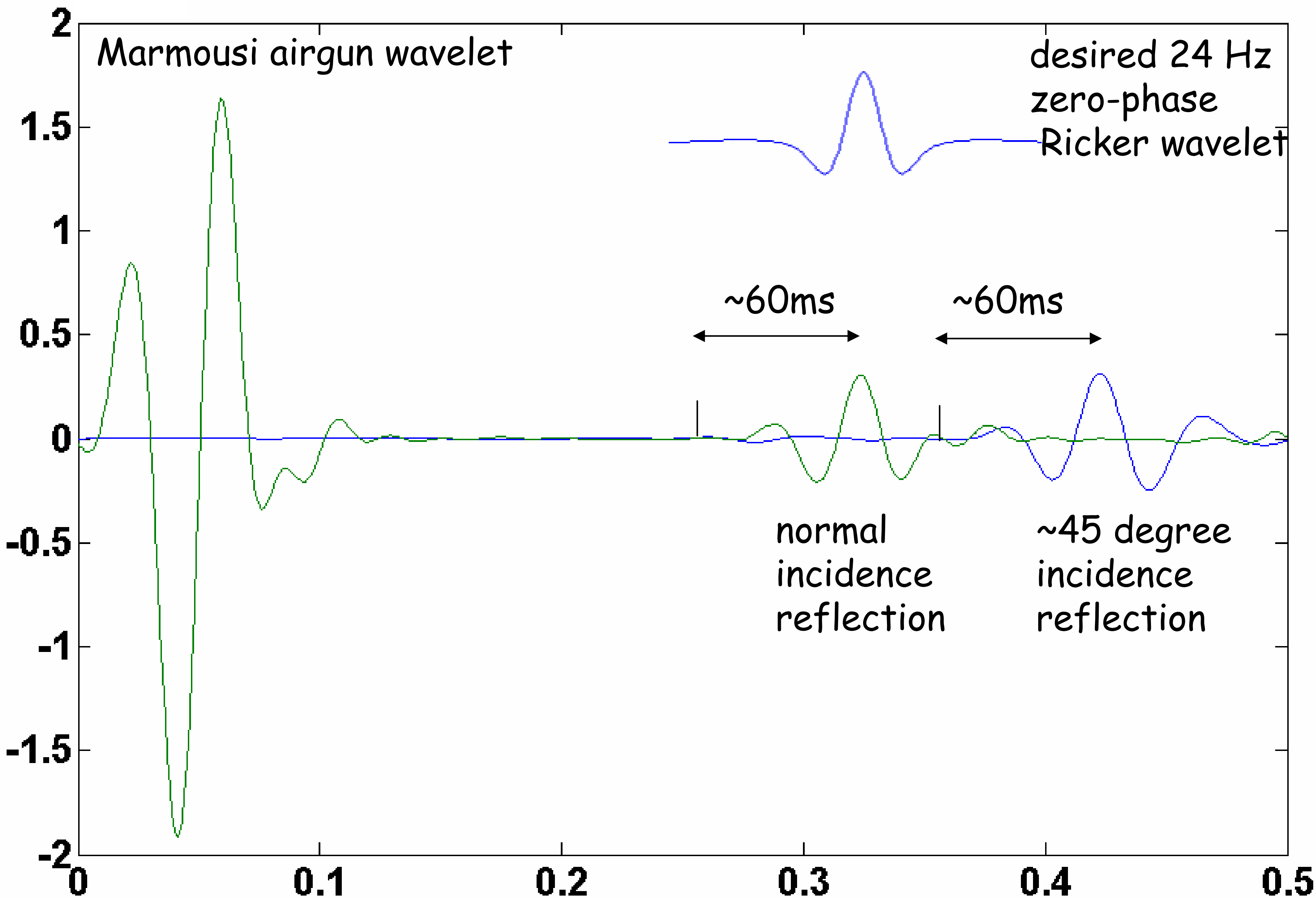


Marmousi source array: 6 airguns at 8m spacing, depth 8m

receiver array: 5 hydrophones at 4m spacing, depth 12m

Modeled with finite difference code (courtesy Peter Manning) to examine response of isolated reflector at 0° and ~45° degree incidence

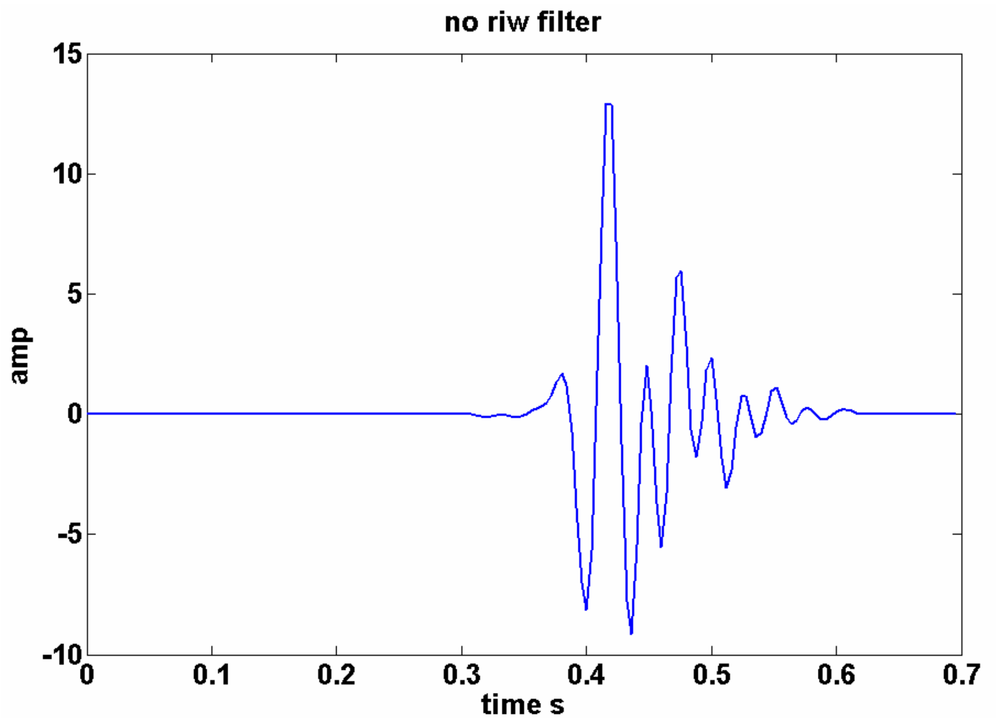


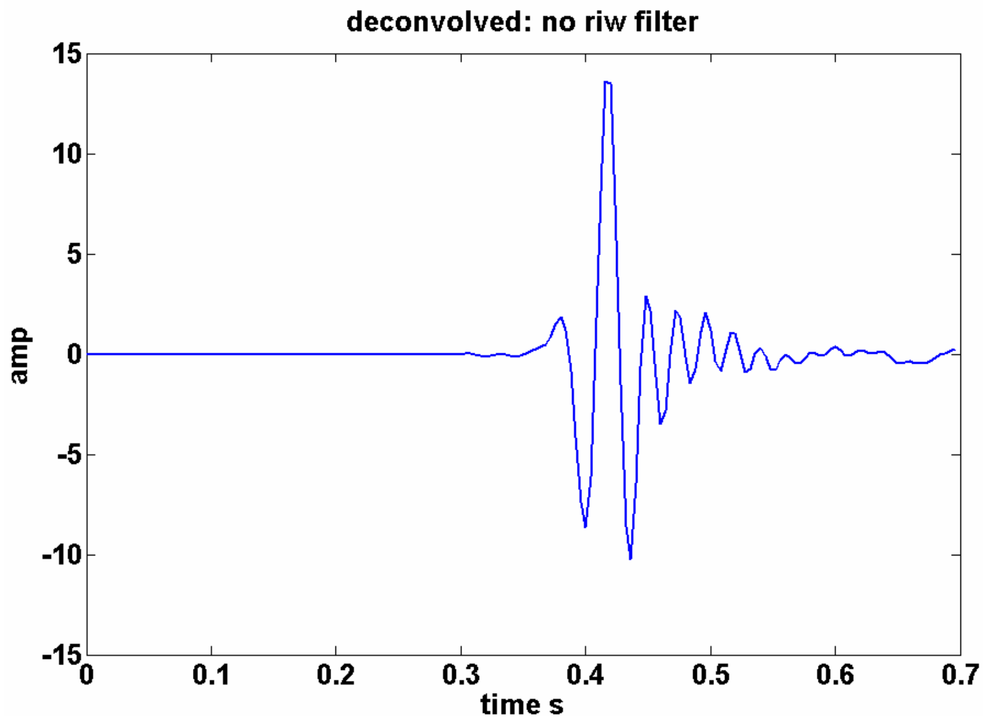


After free-surface ghosting and water-bottom multiples, the Marmousi airgun wavelet propagates as ~24 Hz zero-phase Ricker with 60 ms delay.

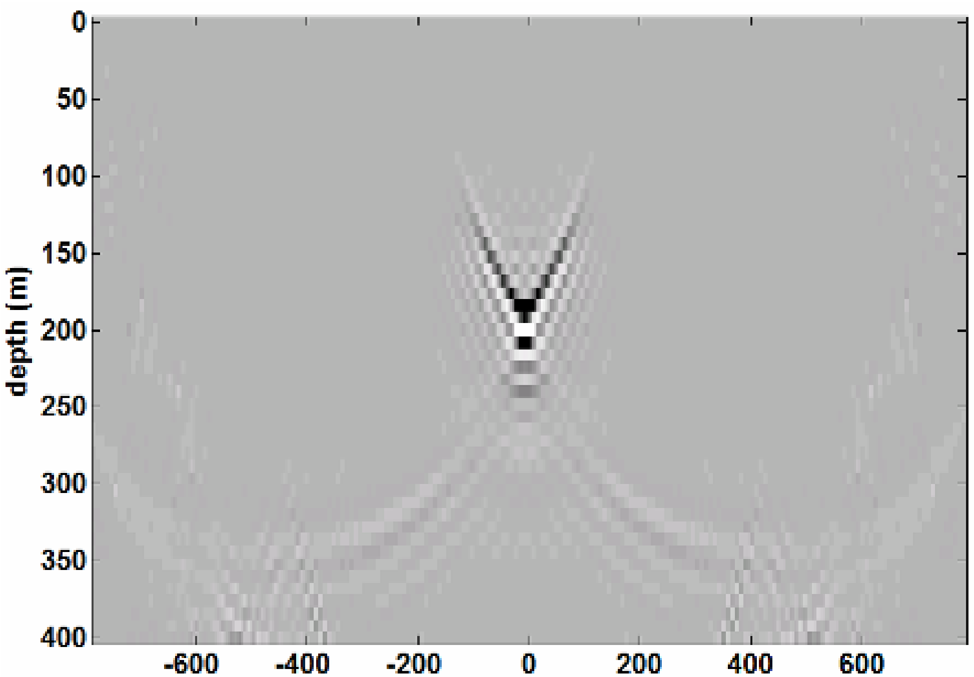
Deconvolution

- The deconvolution chosen for the Marmousi data set is a simple spectral whitening followed by a gap deconvolution (40ms gap, 200ms operator)
- this yields a reasonable zero phase wavelet in preparation for depth imaging

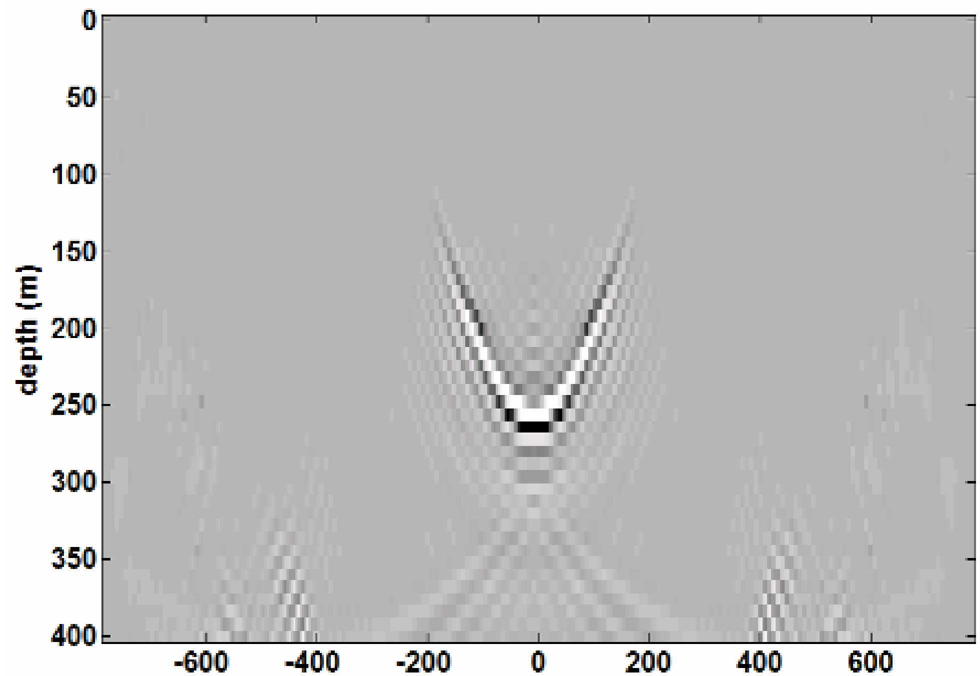




- the receiver wavefield is then static shifted by -60ms to create an approximate zero phase wavelet
- if the receiver wavefield is extrapolated and imaged without compensating for the 60ms delay, focusing and positioning are compromised, as illustrated using a simple synthetic for a diffractor

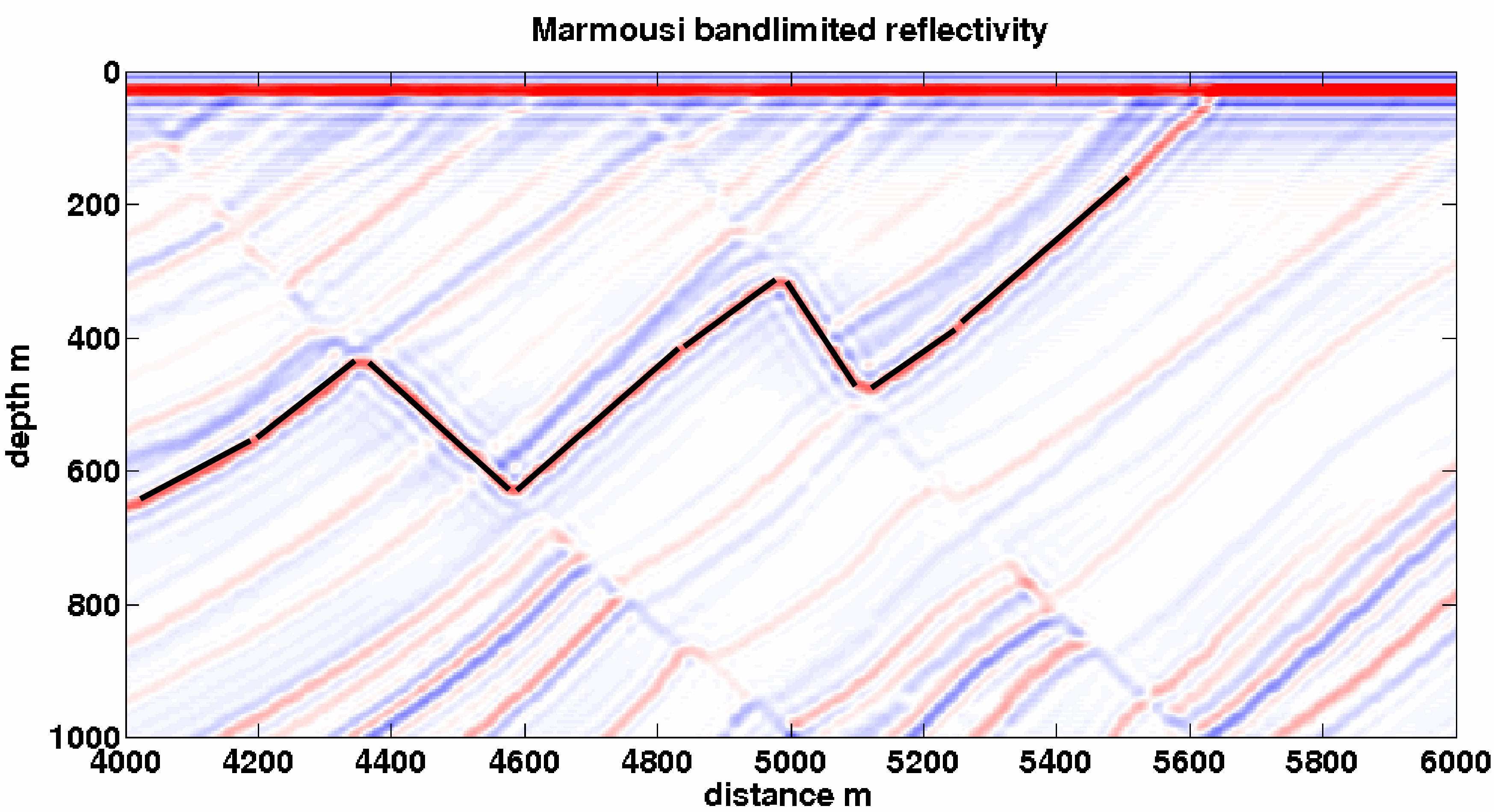


diffractor imaging with no delay

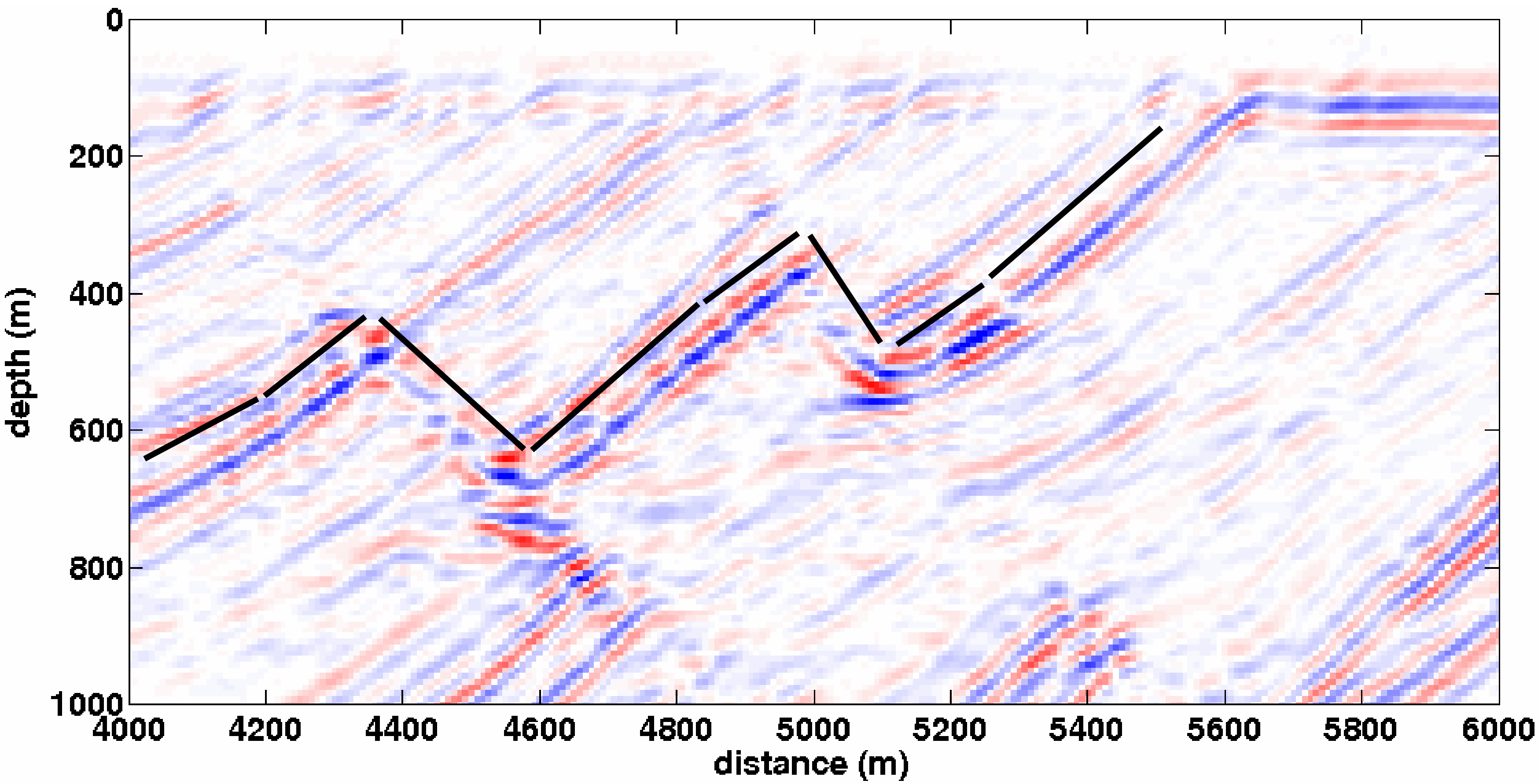


diffractor imaging with 60ms delay

reflectivity x: 4000-6000 z: 0-1000

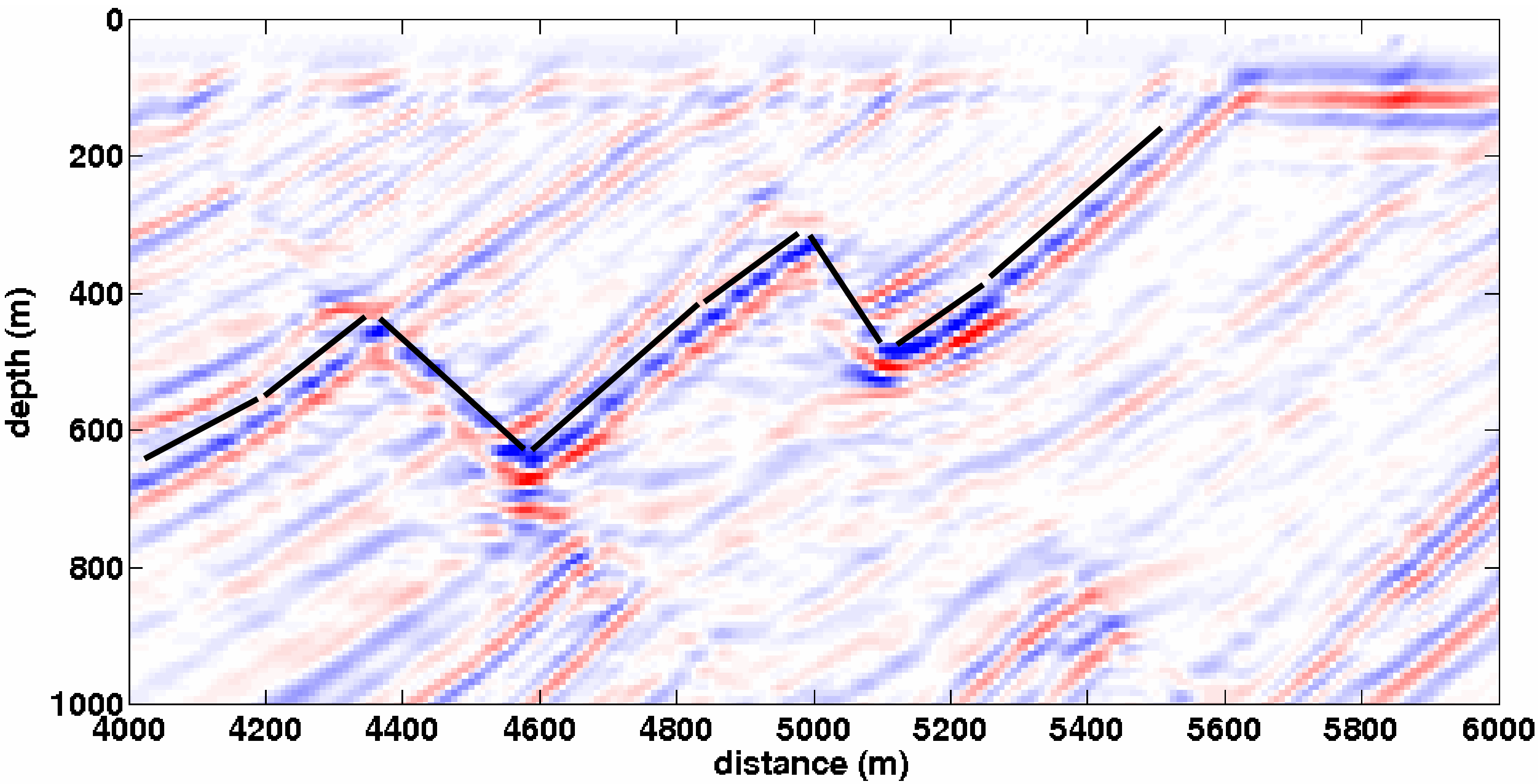


PSPI whiten [4 16 35 60] cvel .2% clip 6



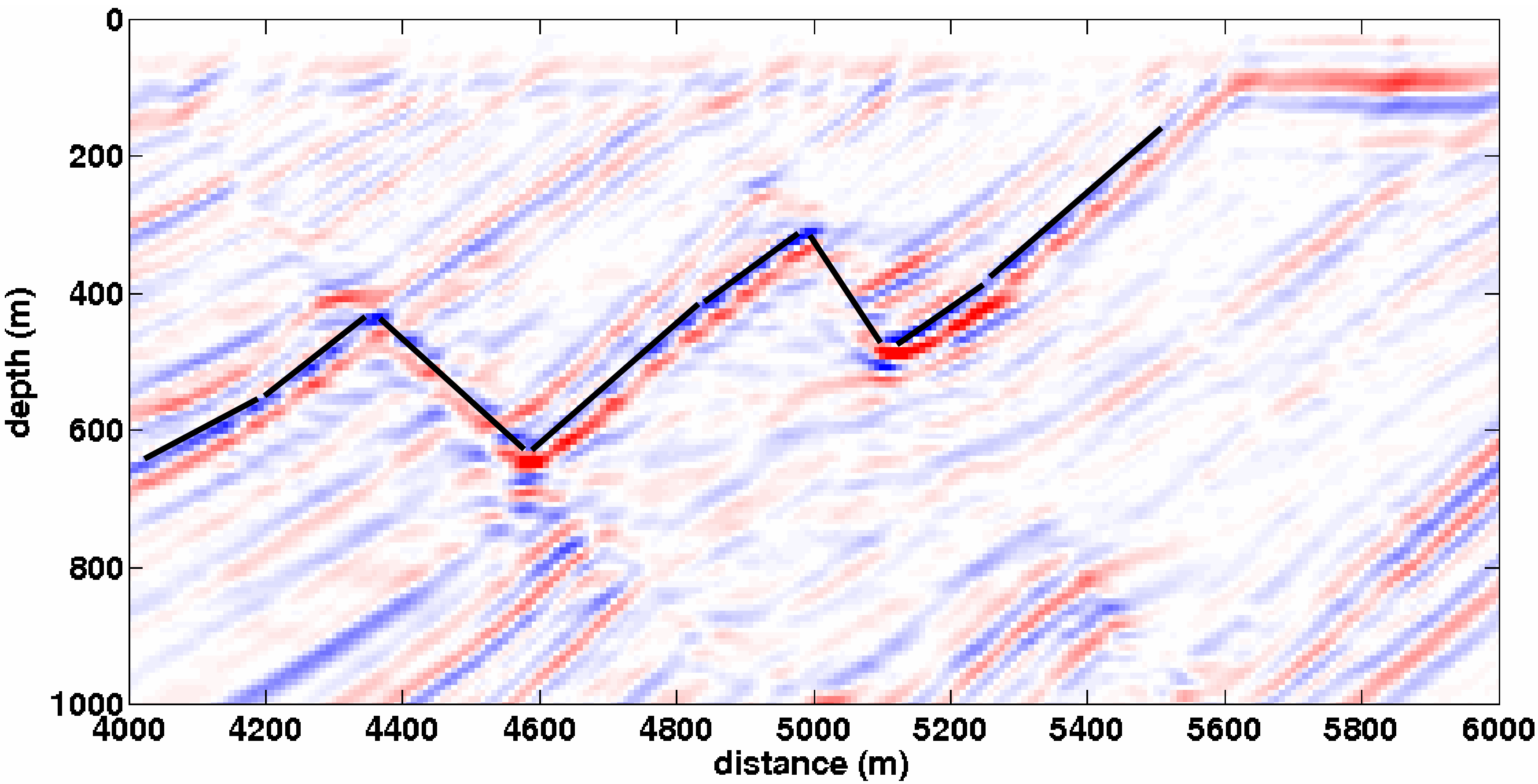
data: deconpr 50 13 .0002 whiten [4 16 35 60] static 0ms
shot: ricker fdom 24 ghost array phsrot -68 (to zp) unwhiten

PSPI whiten [4 16 35 60] cvel .2% clip 6



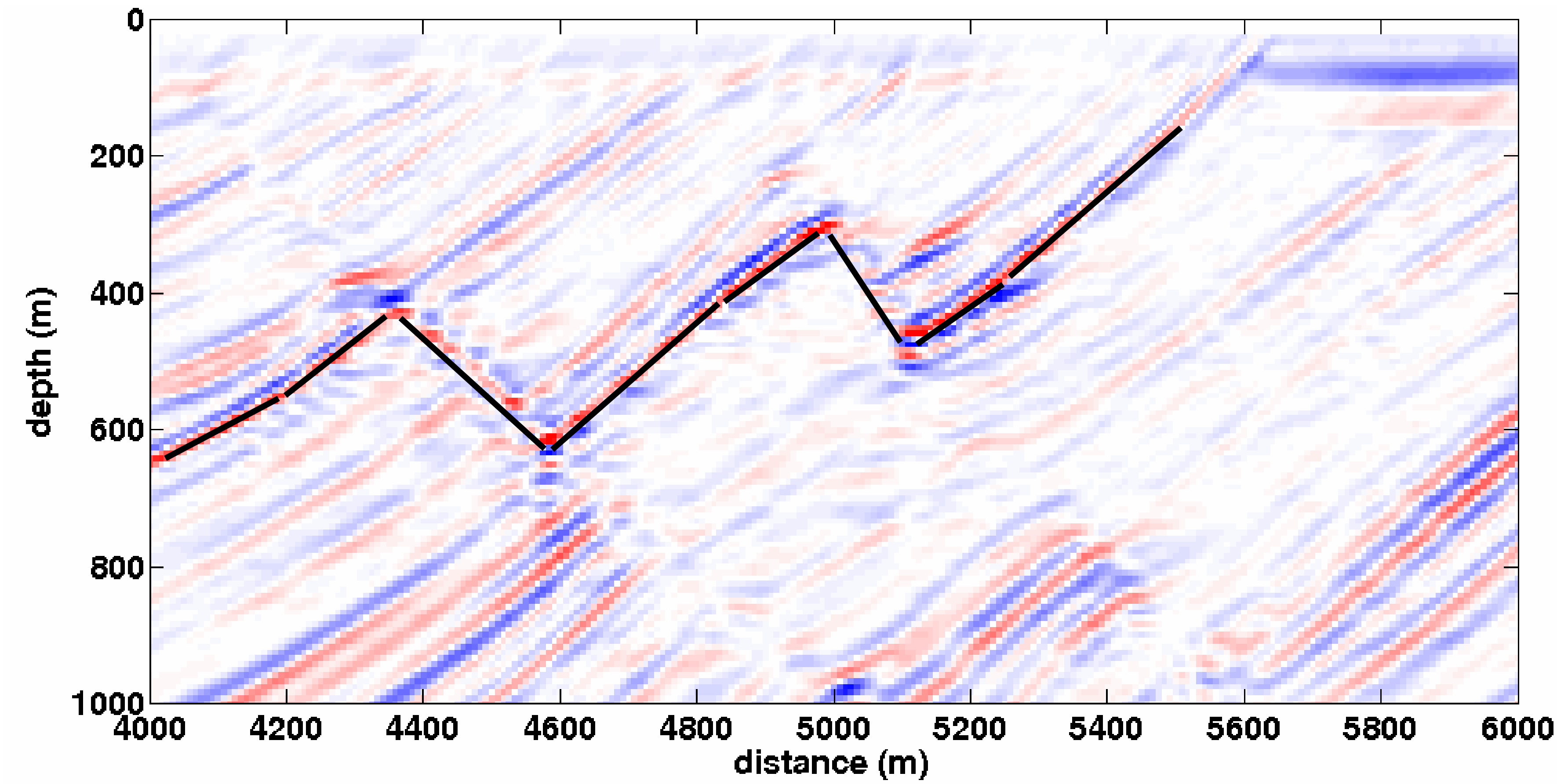
data: deconpr 50 13 .0002 whiten [4 16 35 60] static -16ms
shot: ricker fdom 24 ghost array phsrot -68 (to zp) unwhiten

PSPI whiten [4 16 35 60] cvel .2% clip 6



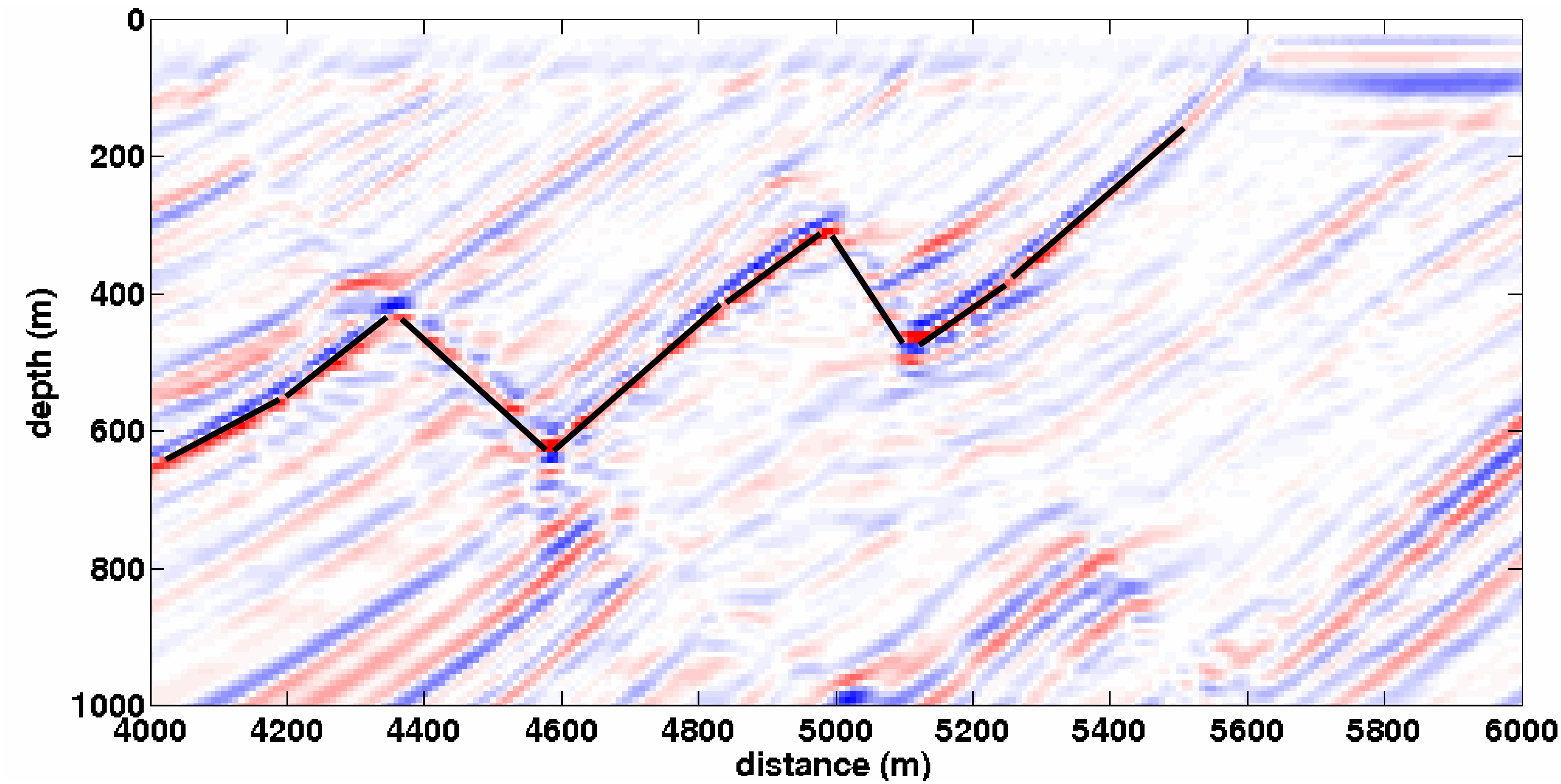
data: deconpr 50 13 .0002 whiten [4 16 35 60] static -32ms
shot: ricker fdom 24 ghost array phsrot -68 (to zp) unwhiten

PSPI whiten [4 16 35 60] cvel .02% clip 6



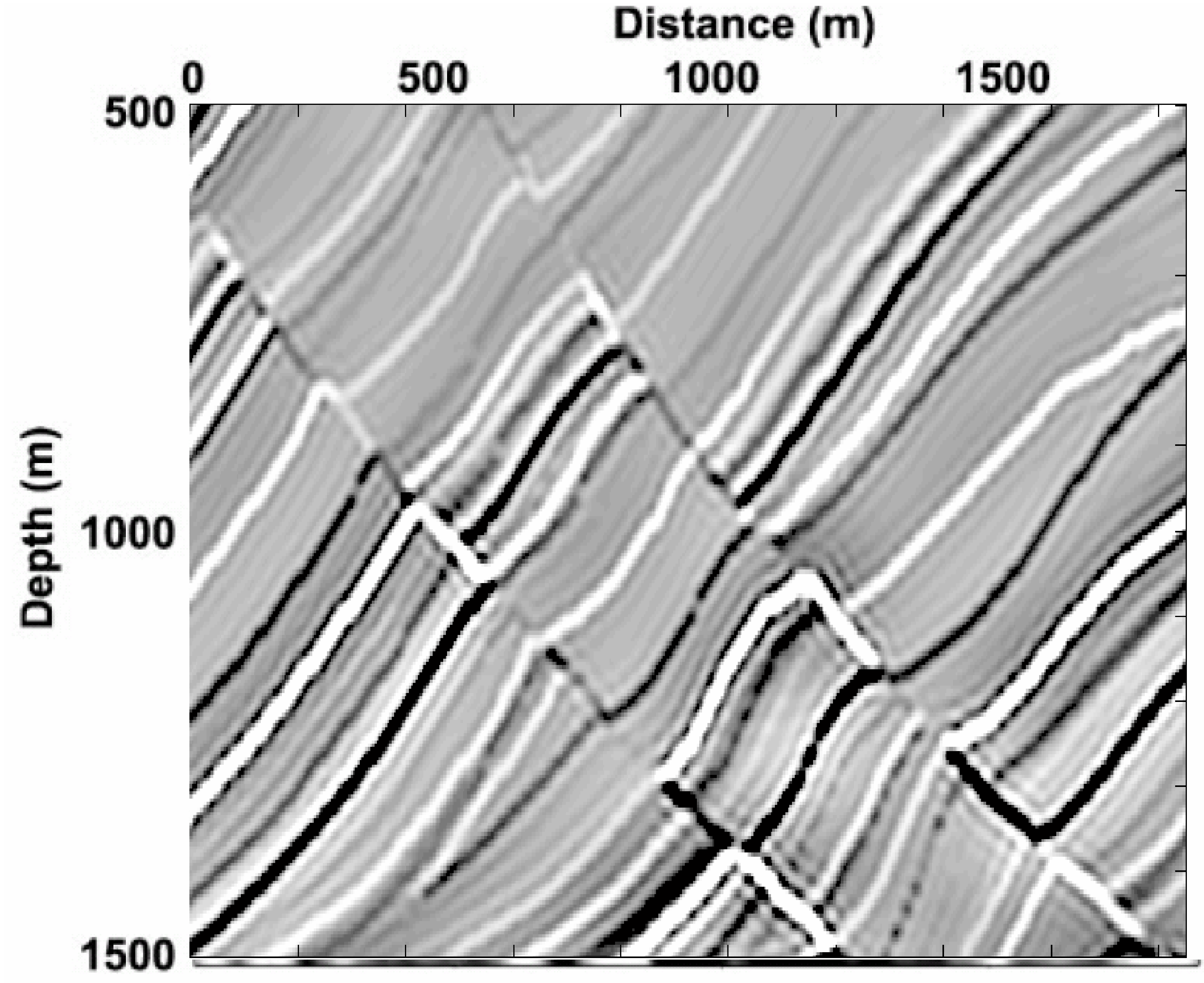
data: deconpr 50 13 .0002 whiten [4 16 35 60] static -56ms
shot: ricker fdom 24 ghost array phsrot -68 (to zp) unwhiten

PSPI whiten [4 16 35 60] cvel .02% clip 6

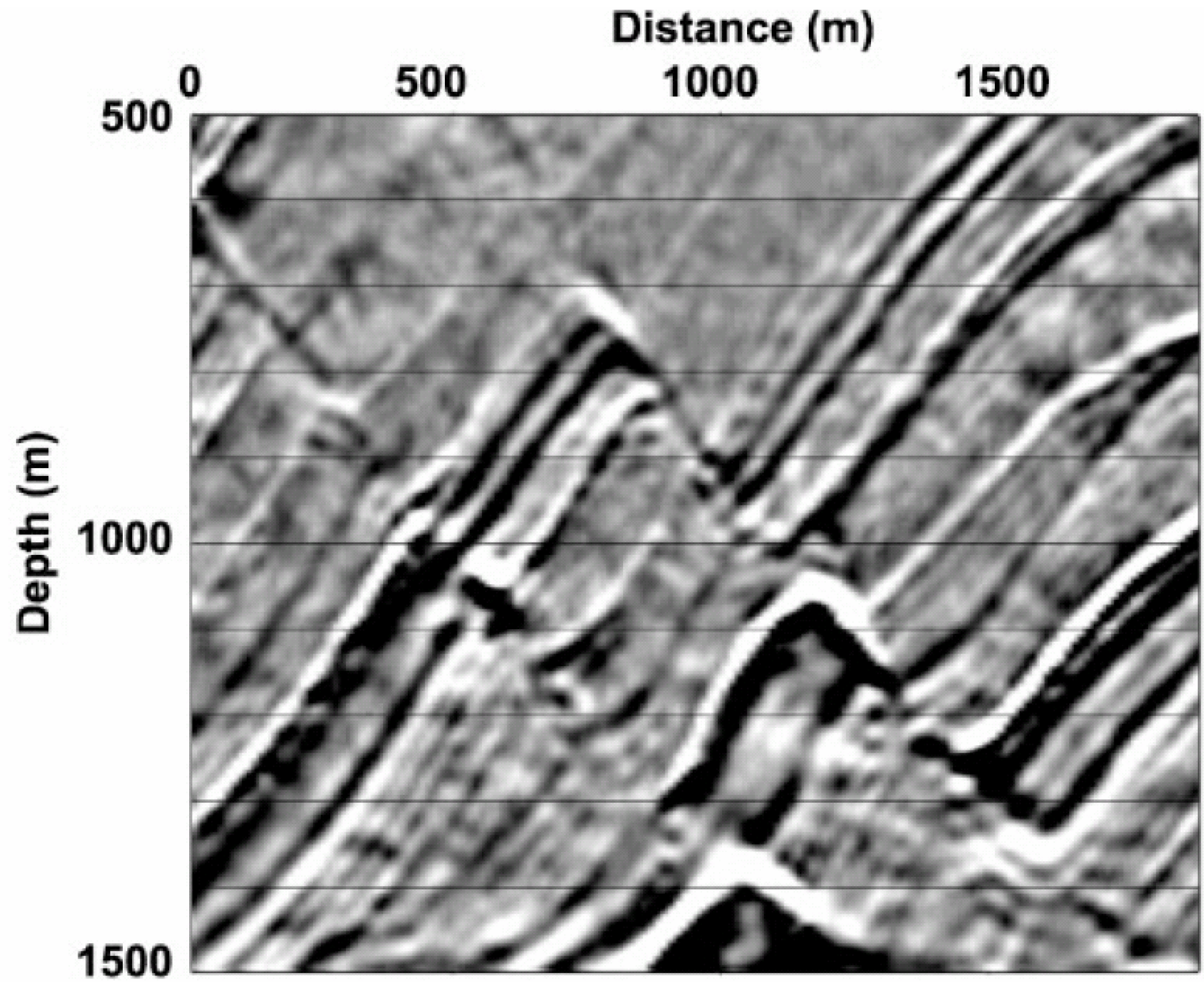


data: deconpr 50 13 .0002 whiten [4 16 35 60] static -56ms
shot: ricker fdom 24 ghost array phsrot -45 (to zp) whiten [4 16 35 60]

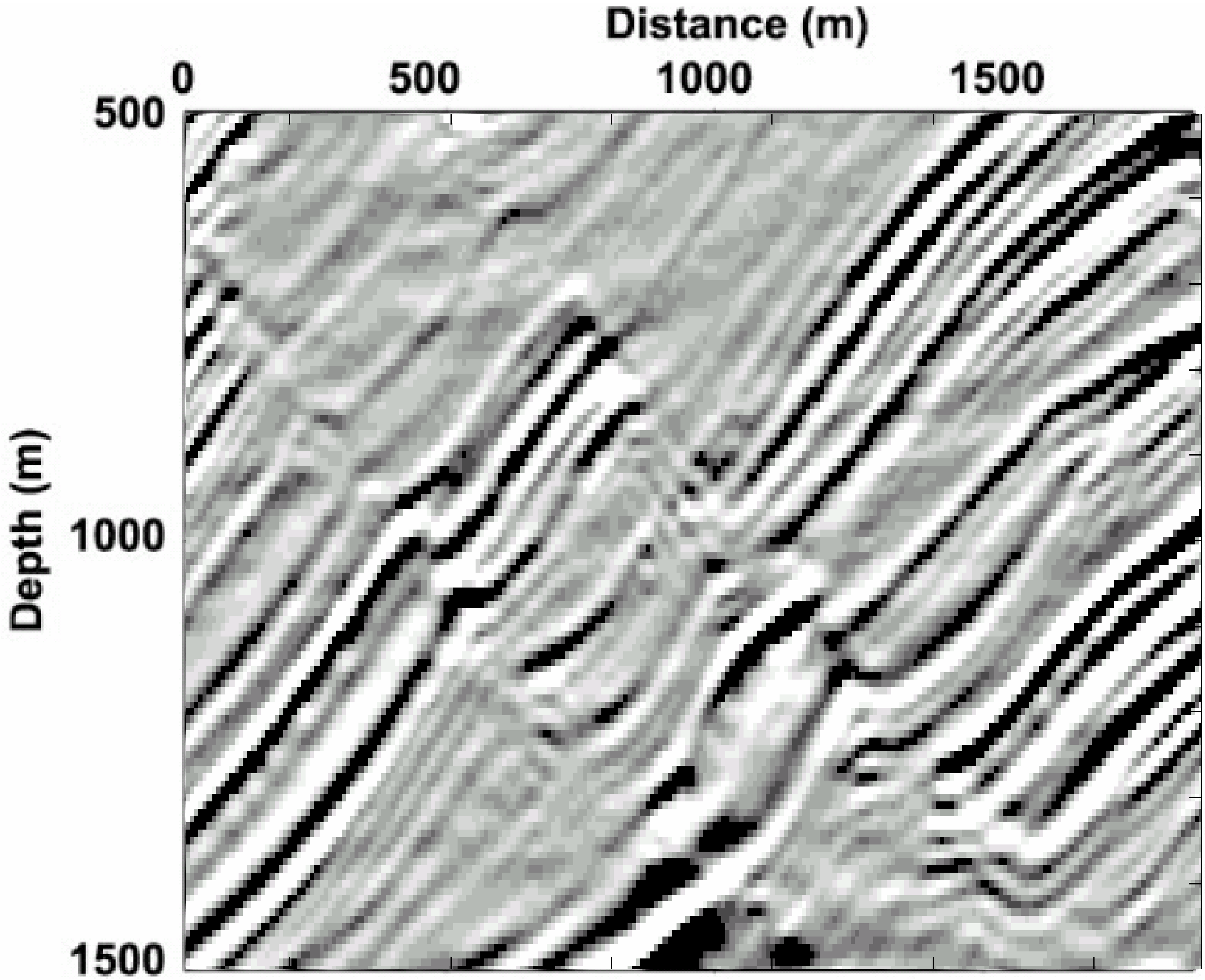
Marmousi bandlimited reflectivity
- shifted to match Zhang et al. (2003)



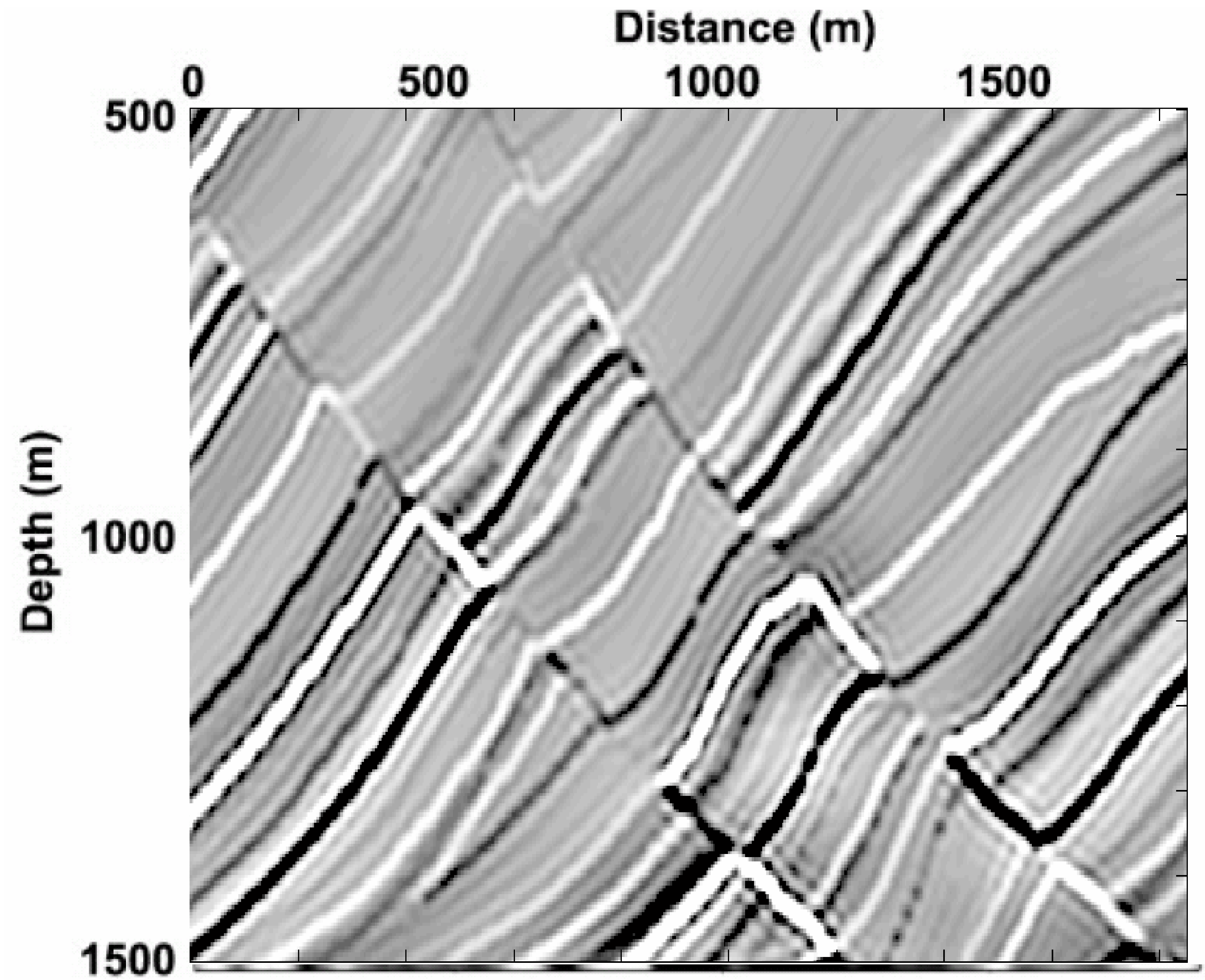
Zhang et al. (2003) – positioning not accurate



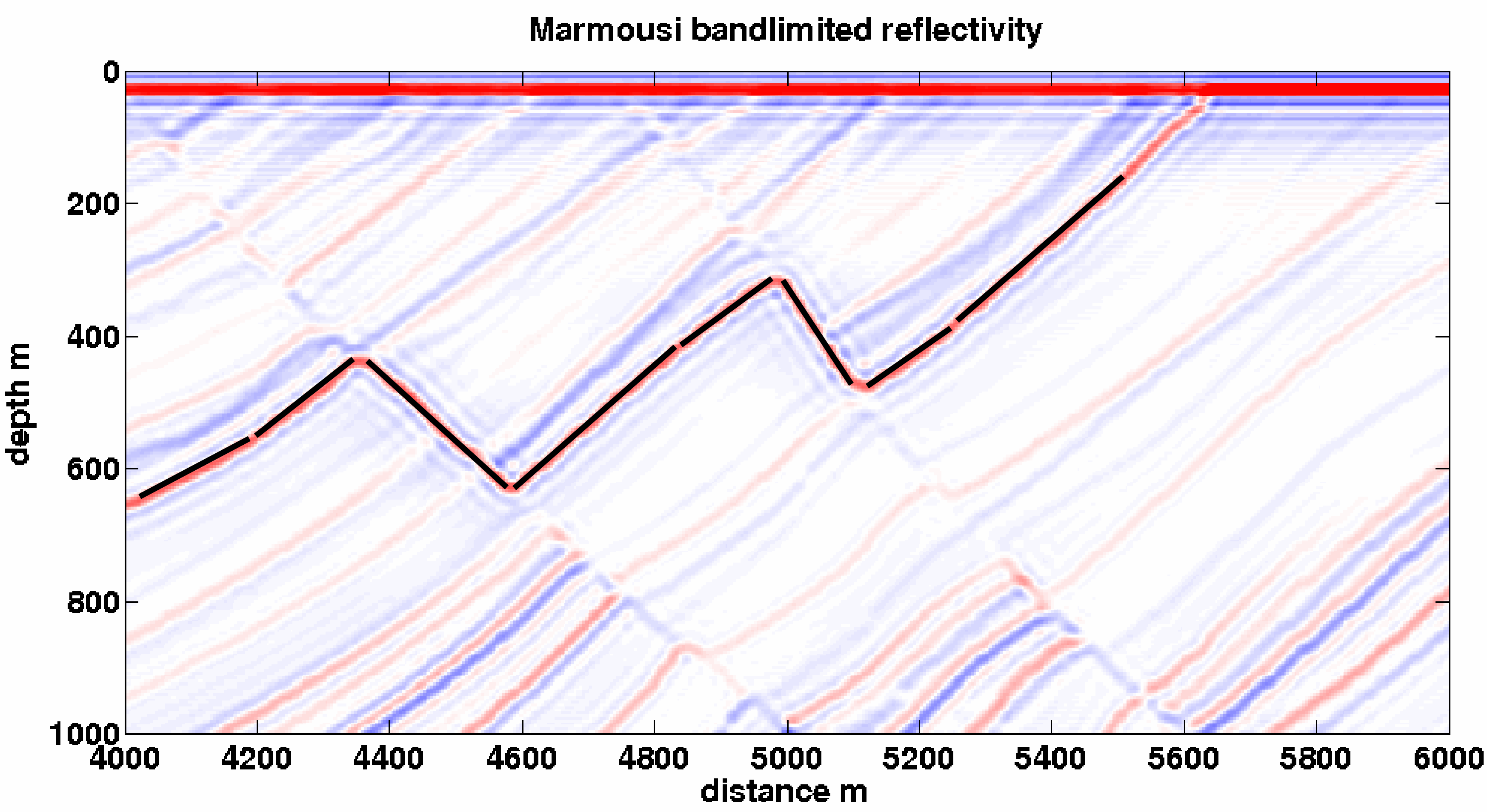
PSPI reference velocities: peak search
- shifted to match Zhang et al. (2003)



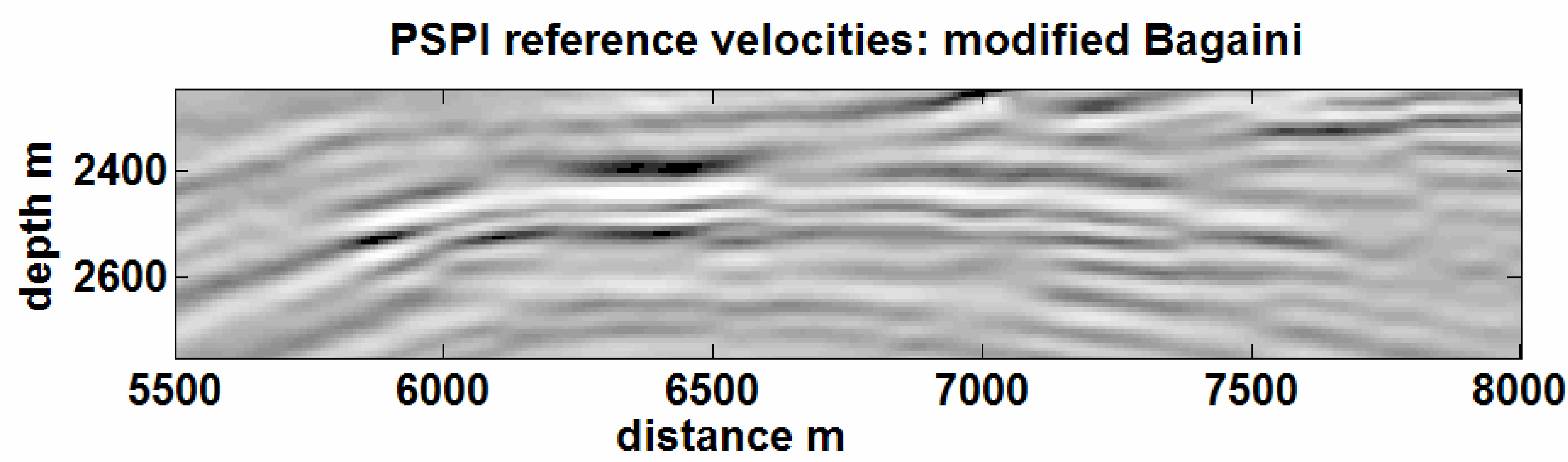
Marmousi bandlimited reflectivity (as before)



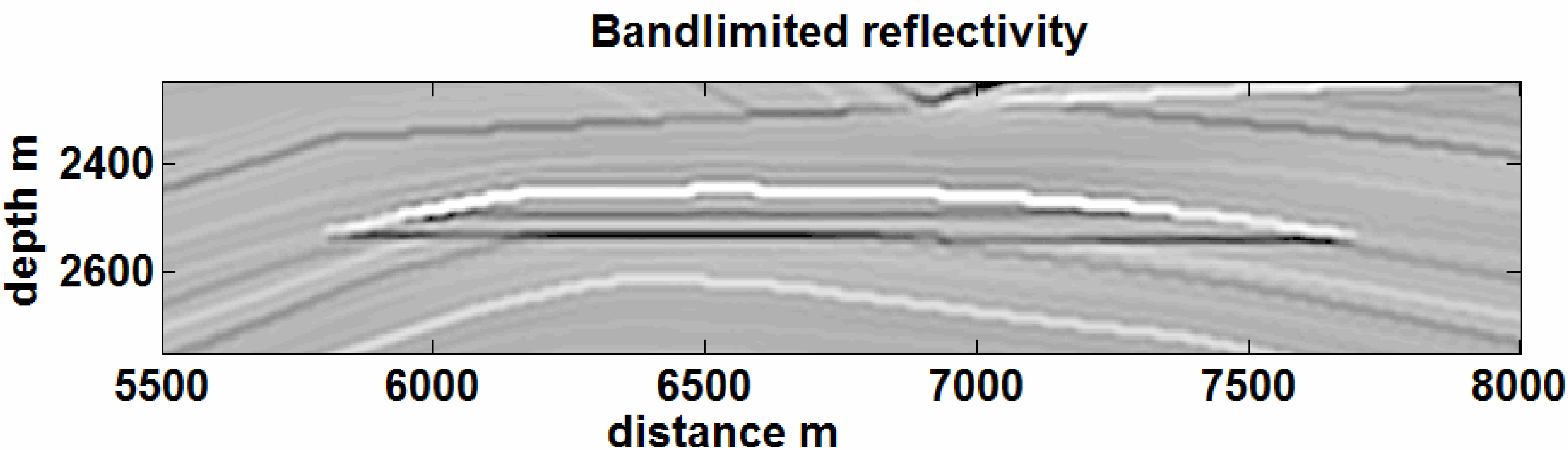
Marmousi shallow reflectivity



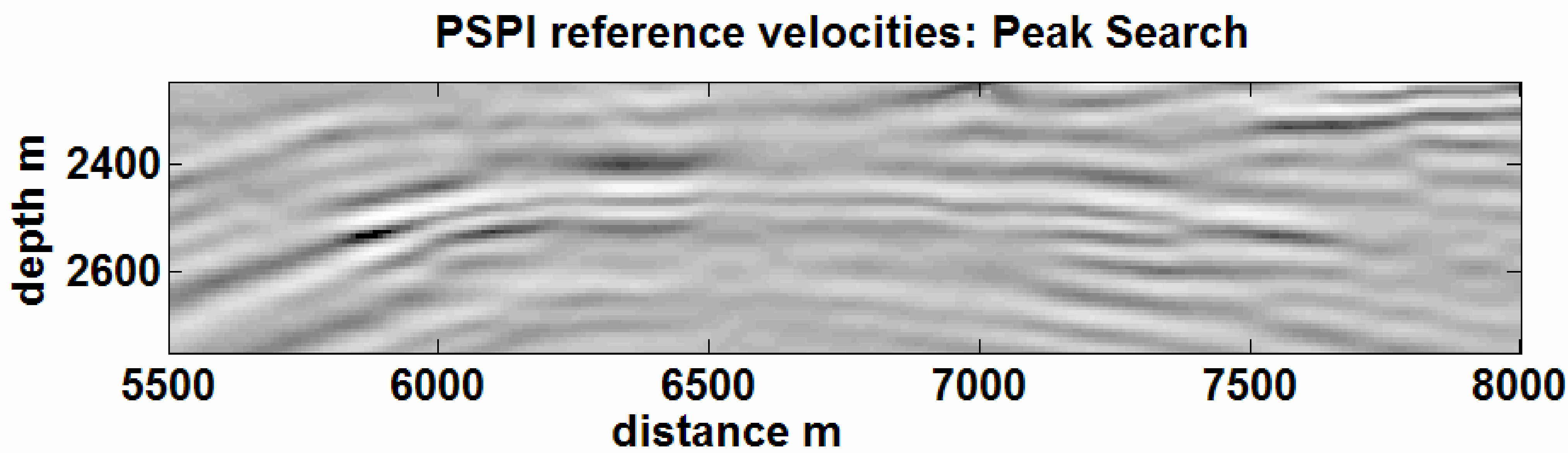
Marmousi target reservoir



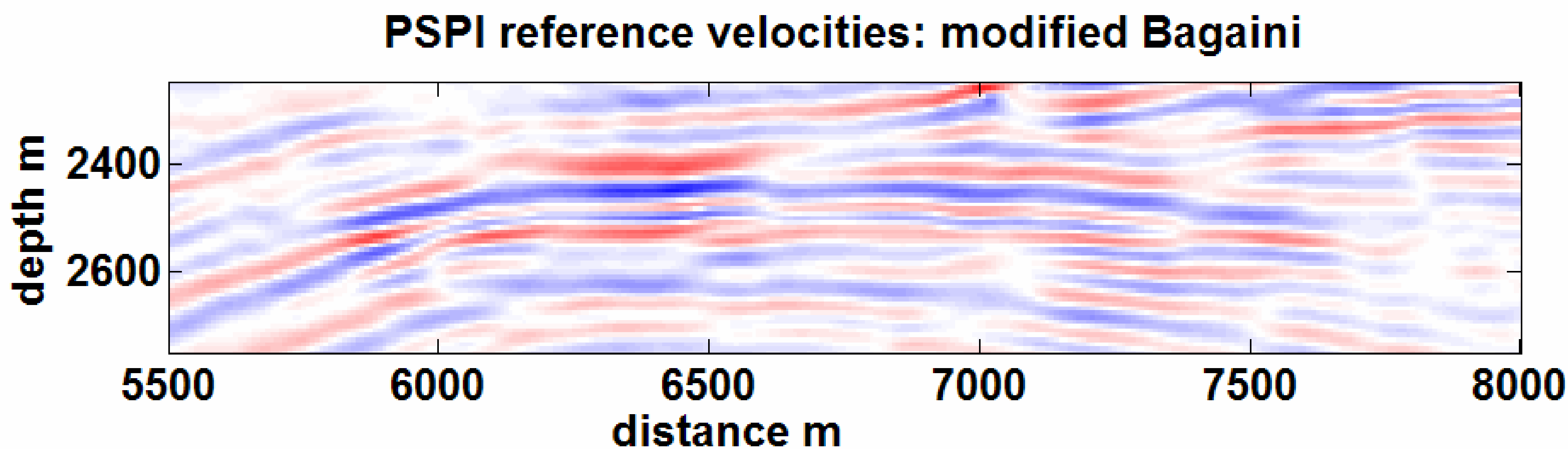
Marmousi target reservoir



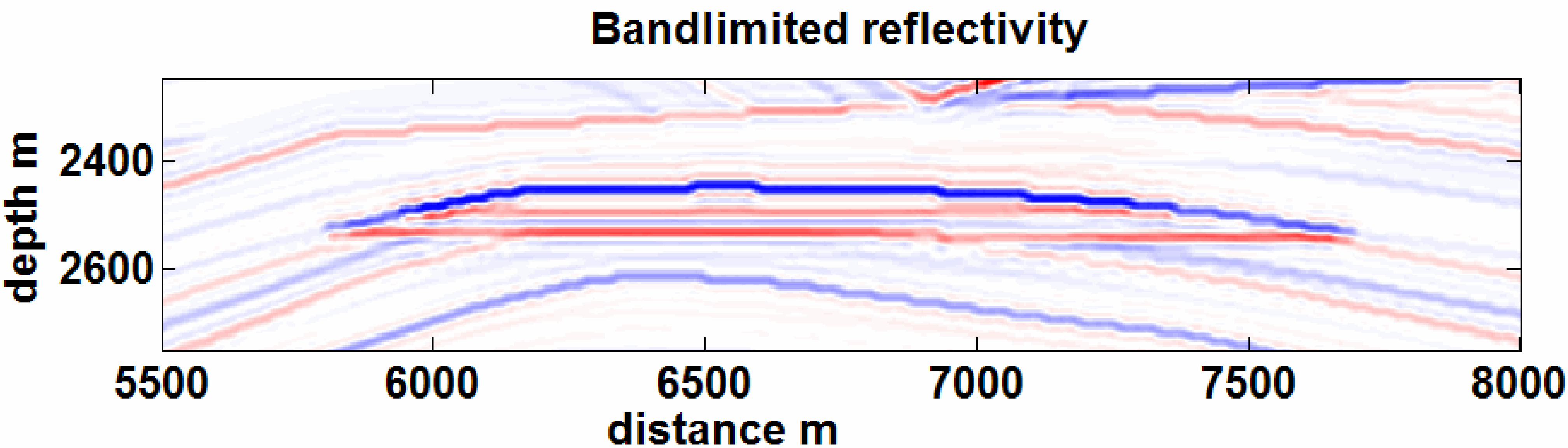
Marmousi target reservoir



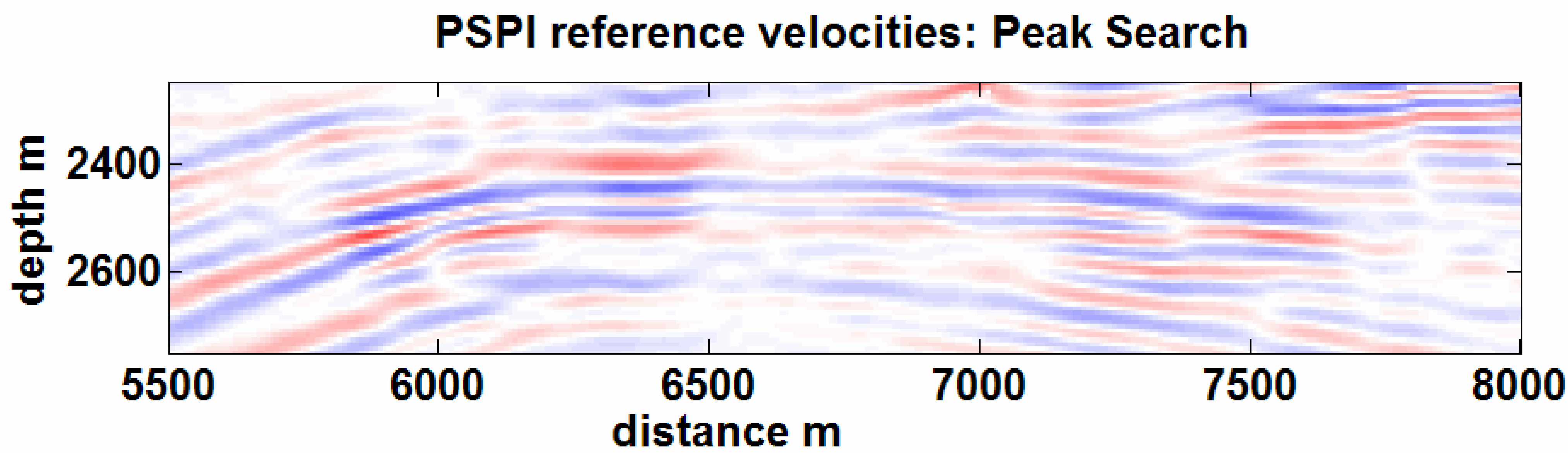
Marmousi target reservoir

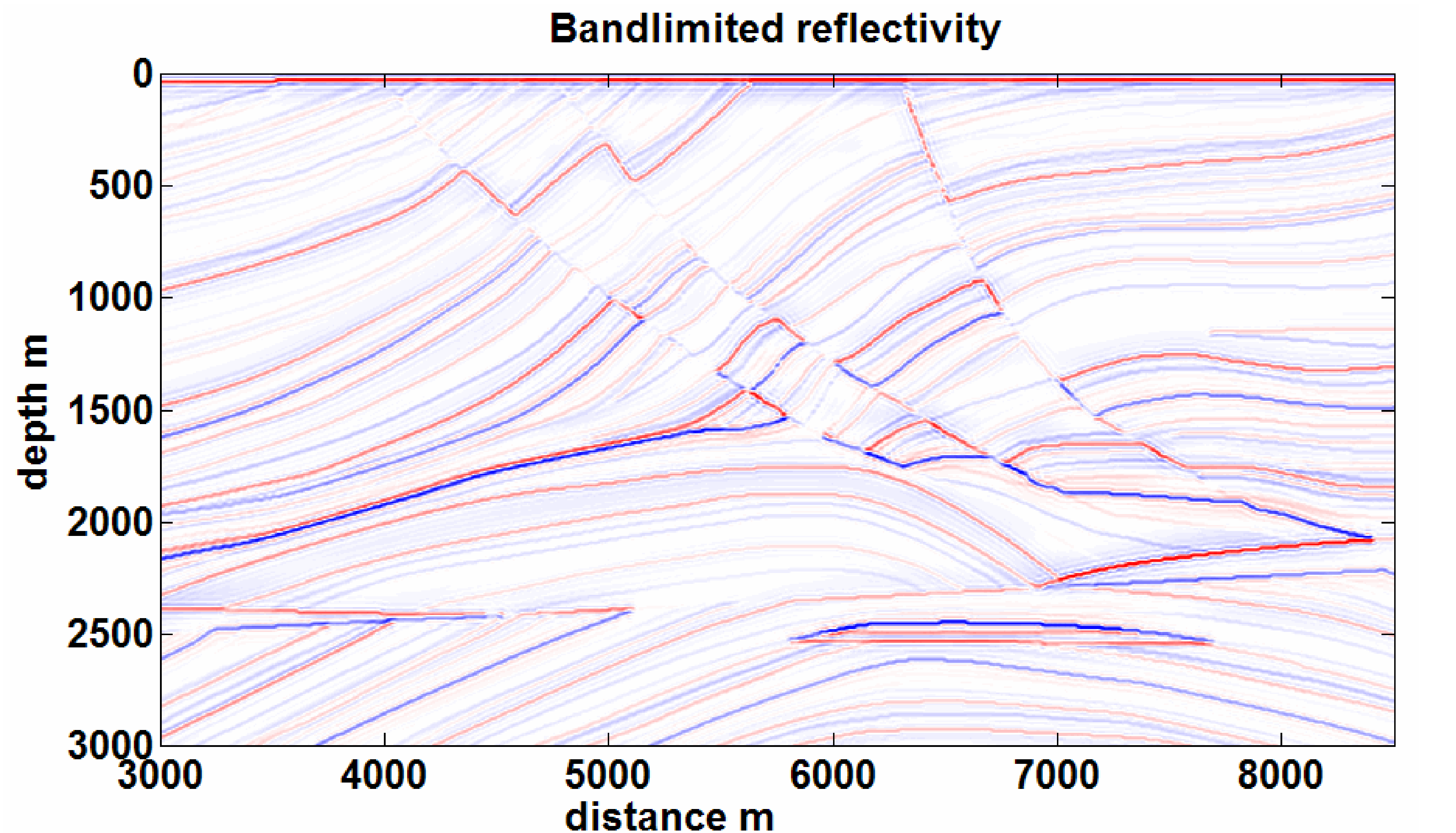


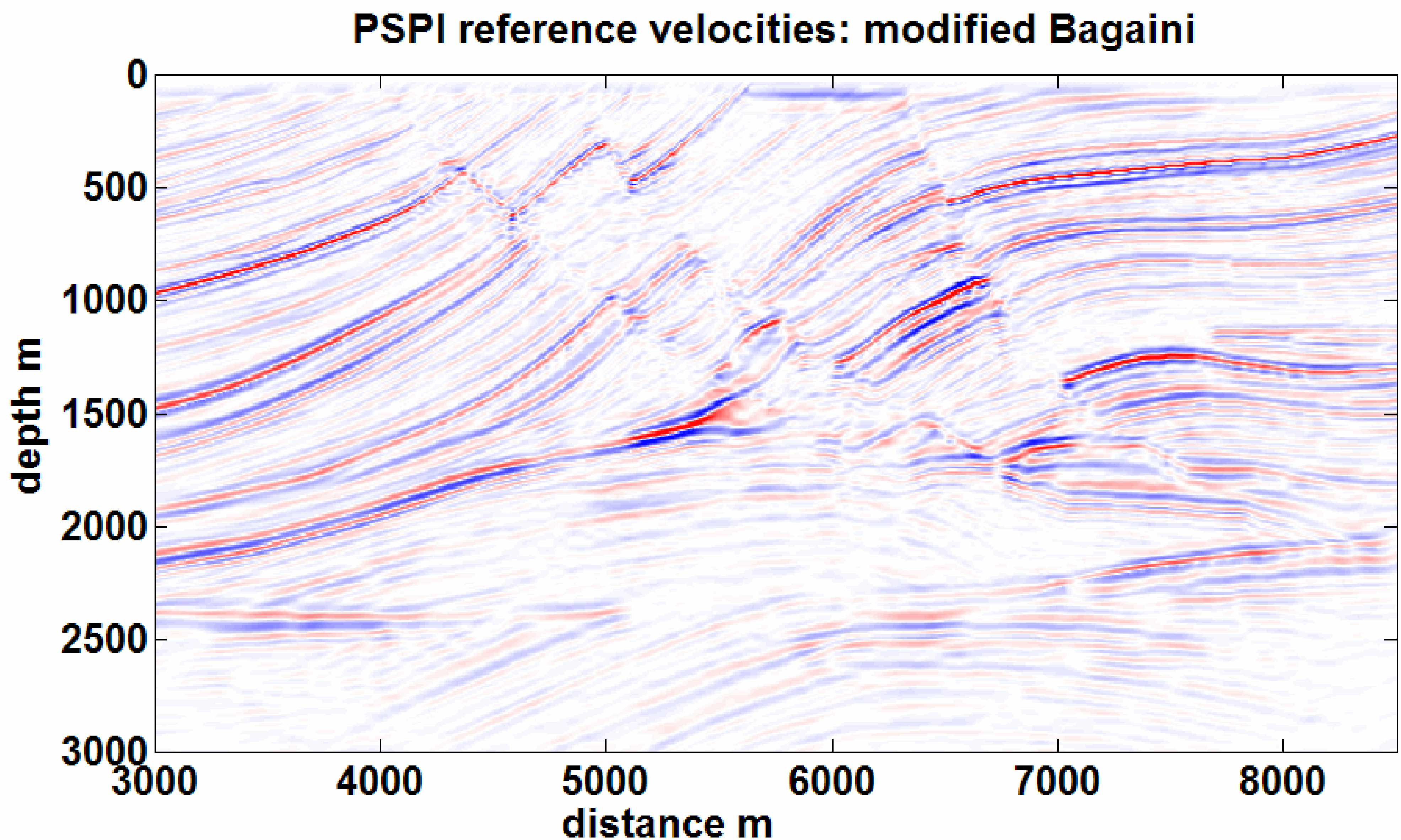
Marmousi target reservoir



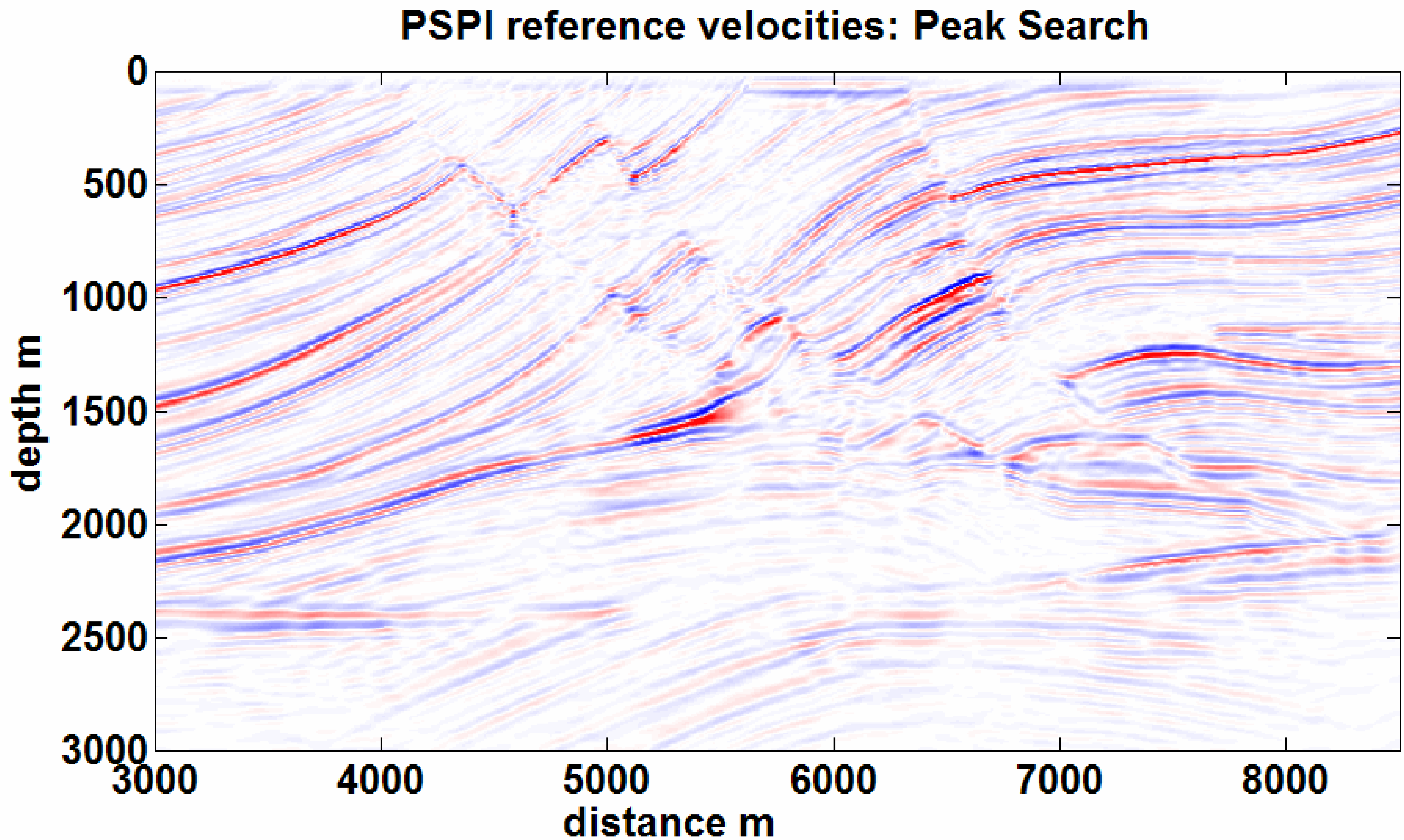
Marmousi target reservoir



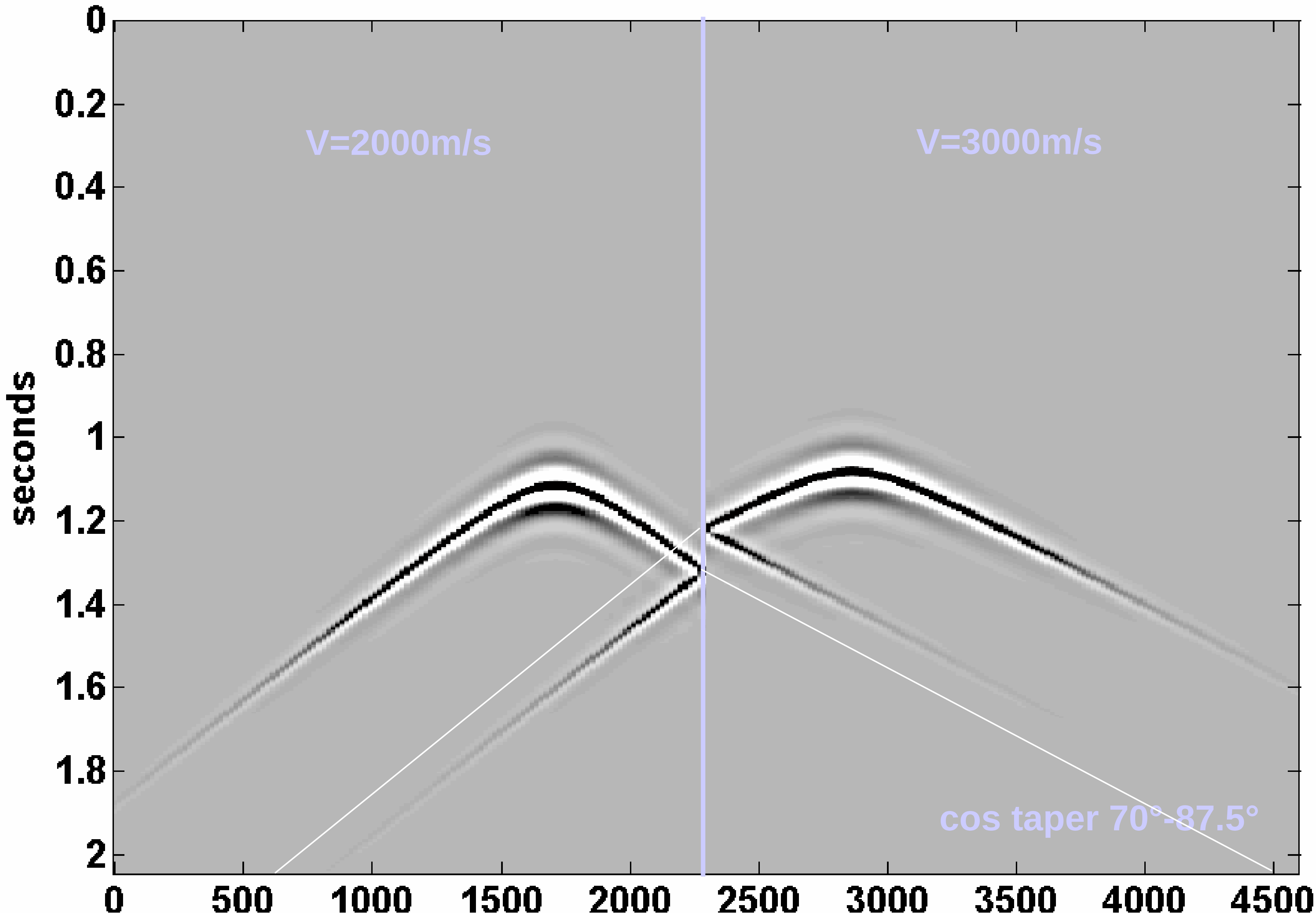

Bandlimited reflectivity
depth m
0
500
1000
1500
2000
2500
3000
distance m
3000
4000
5000
6000
7000
8000



PSPI reference velocities: modified Bagaini
depth m
distance m
0
500
1000
1500
2000
2500
3000
3000
4000
5000
6000
7000
8000


PSPI reference velocities: Peak Search
depth m
distance m
0
500
1000
1500
2000
2500
3000
3000
4000
5000
6000
7000
8000

PSPI creates discontinuities at boundaries – smoothing may be good!



Conclusions

- Preprocessing to zero phase, shot modeling, and correction of static shifts important for imaging
- Optimal selection of reference velocities desired to maximize accuracy and efficiency of wavefield extrapolation
- Linear or geometric progression does not take into account distribution of velocities
- Bagaini et al. method does not necessarily pick reference velocities close to model velocities
- New peak search method selects reference velocites close to model velocities

Conclusions (cont)

- However, Bagaini method performs well on Marmousi!
- Our PSPI implementation provides a good standard for judging our other algorithms