Kinematic time migration and demigration of reflections in prestack seismic data

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- Kinematic time migration and demigration
- Numerical example
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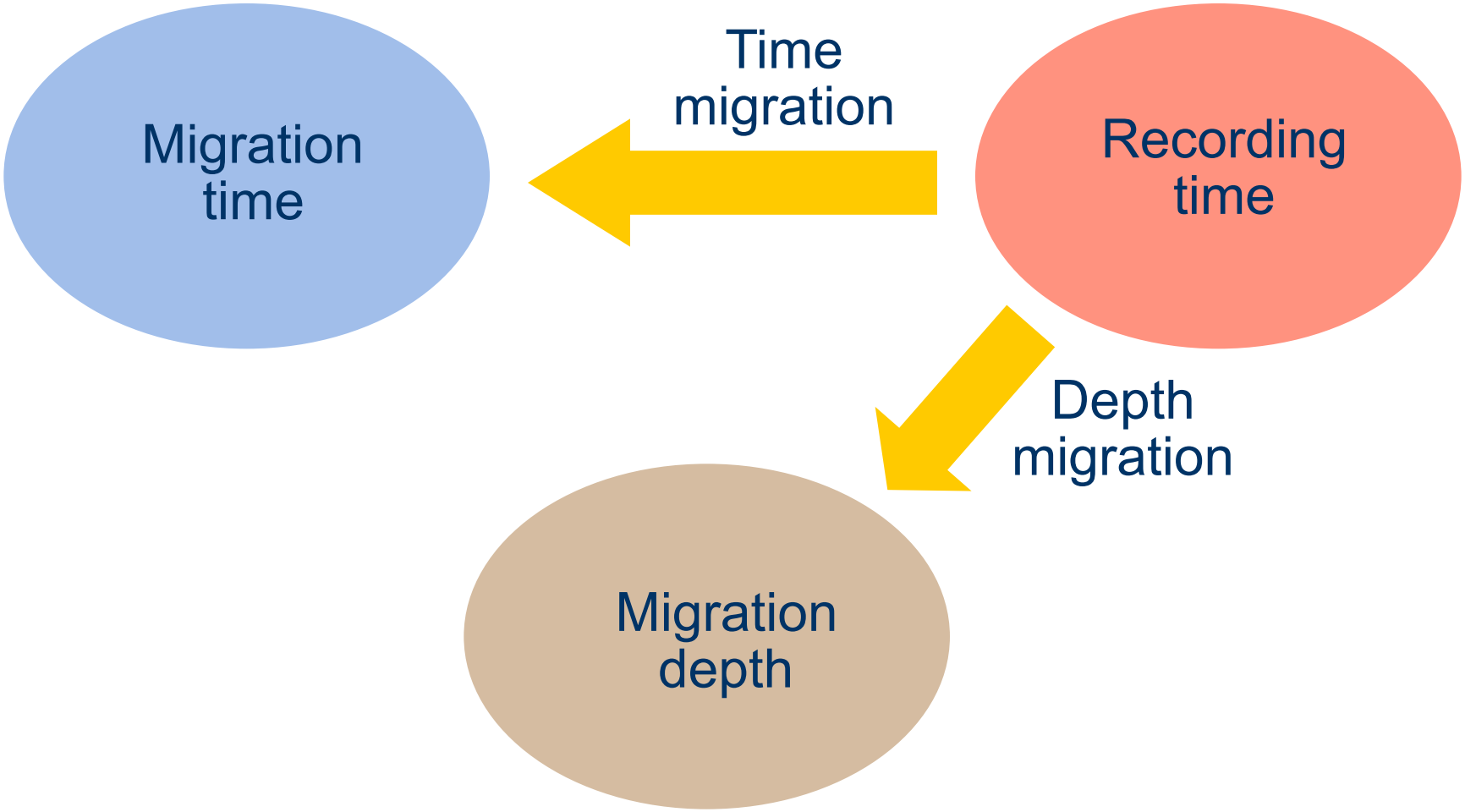
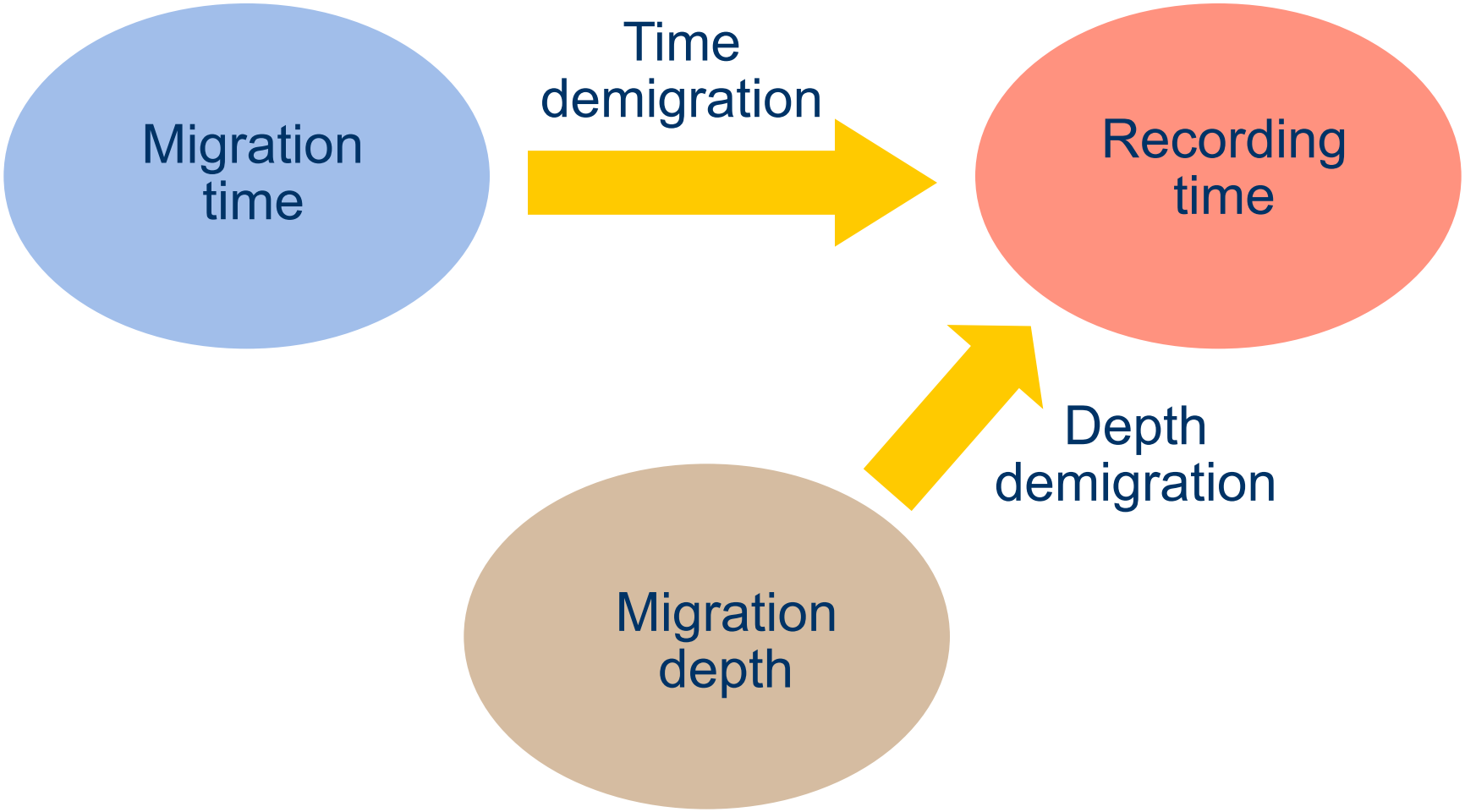
Seismic data domains and processes



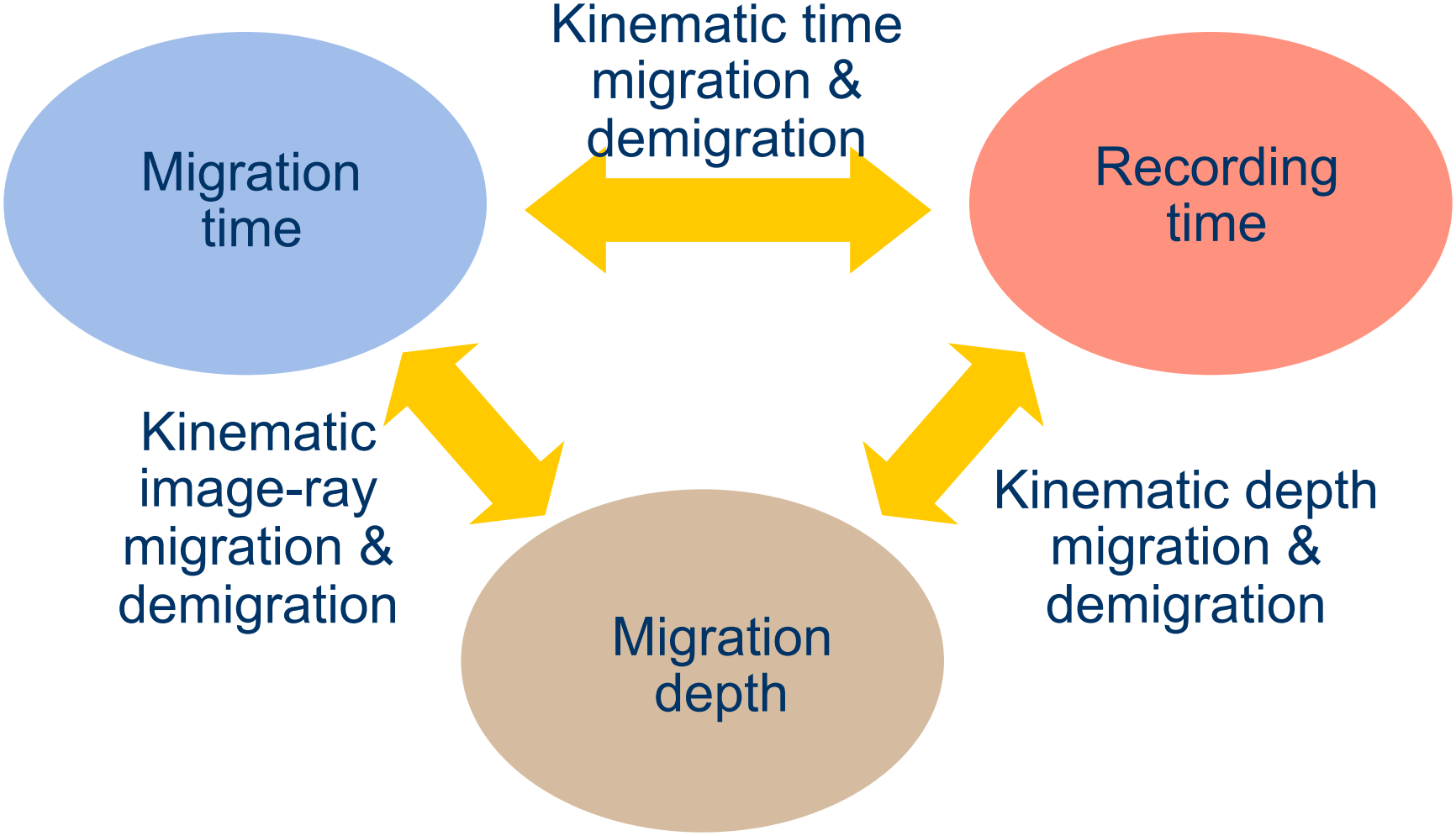
Parkes and Hatton, 1984

Reverse processes



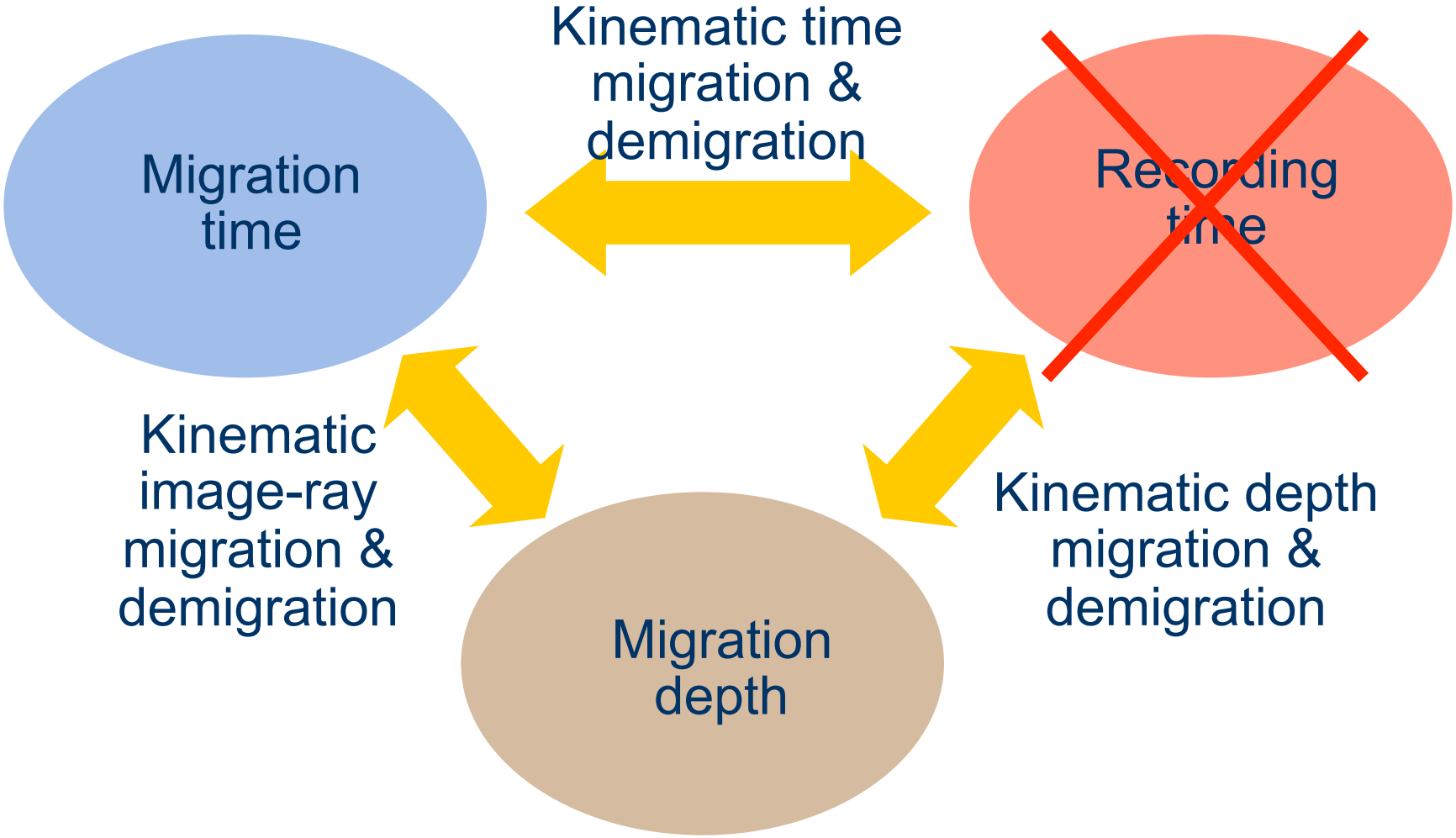
Schleicher, Tygel, and Hubral, 2007

Kinematic mapping between the domains

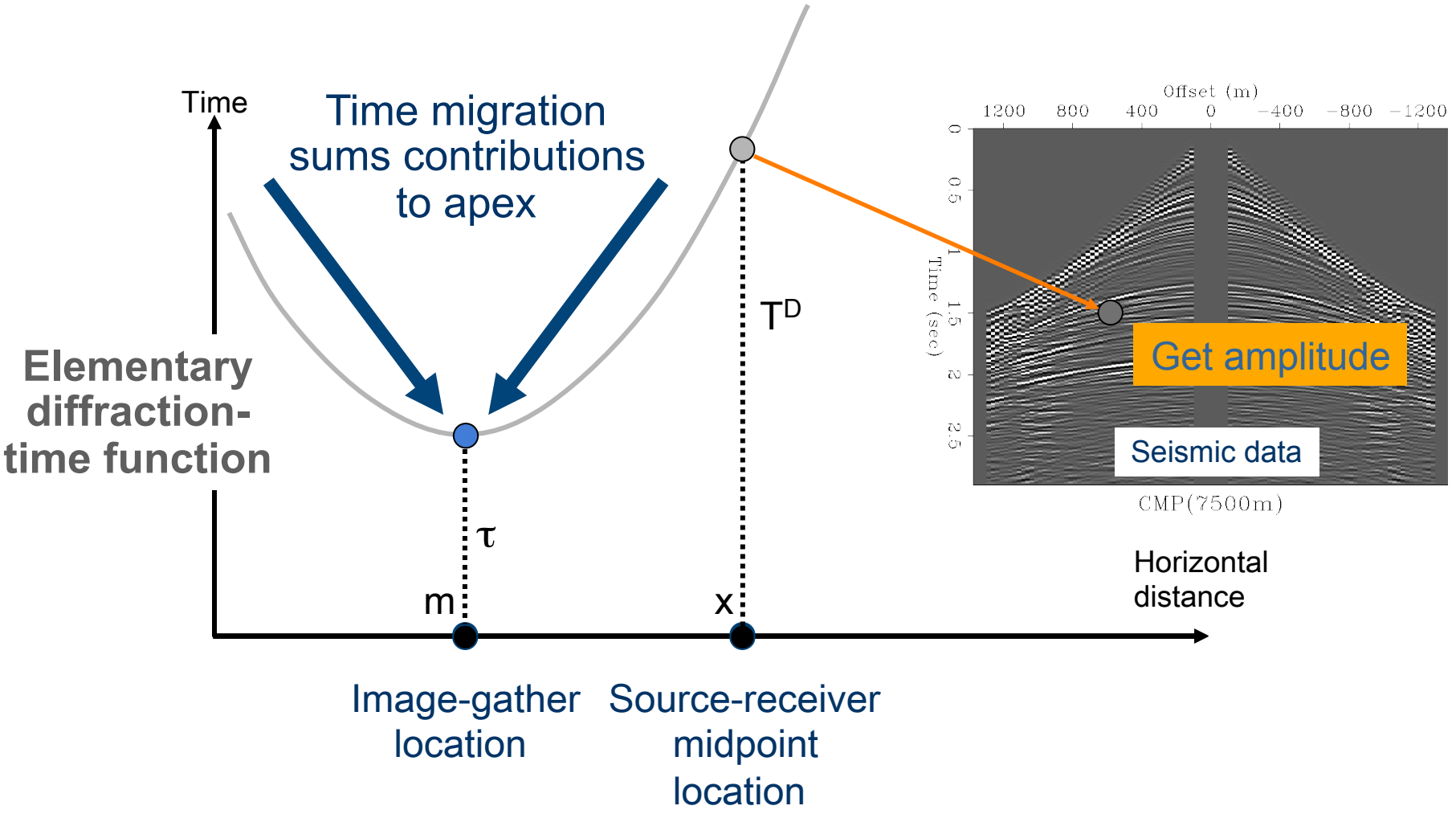


For velocity estimation and processing:

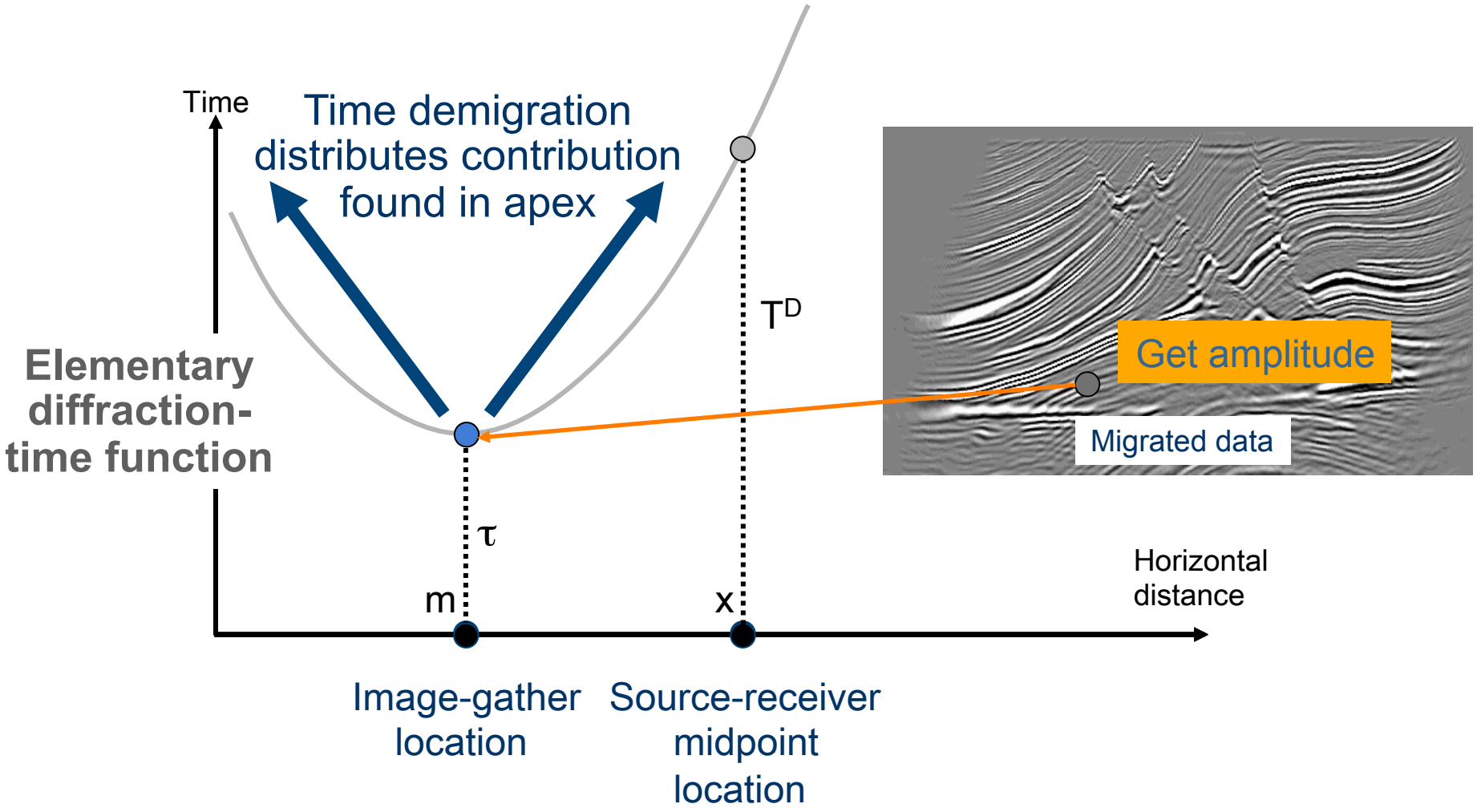
Where to interpret reflections?



Time migration



Time demigration



Time migration/demigration

- Input and output traces are in **TIME**
- A *time-migration velocity model* is needed as input, e.g.,

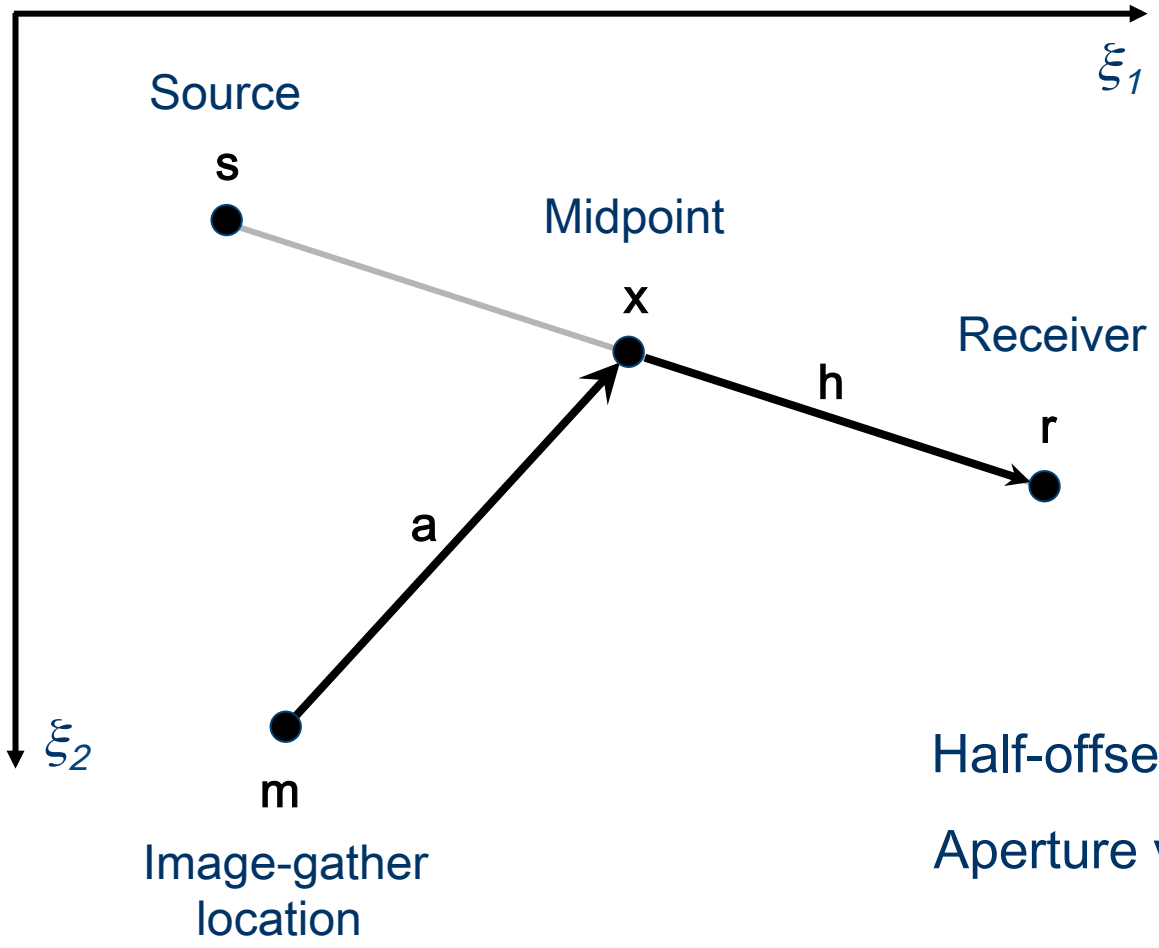
$V^M(m, \tau)$, migration velocity
$\mathbf{S}^M(\mathbf{m}, \tau)$, time-migration matrix (describes the time-migration ellipse)

- Time migration yields useful images only if the lateral velocity variation is small or moderate
- Diffraction-time function must be single valued

Kinematic time migration and demigration

Whitcombe, 1994
Söllner and Andersen, 2005

Lateral coordinates



Half-offset vector: $\mathbf{h} = (\mathbf{r} - \mathbf{s})/2$

Aperture vector: $\mathbf{a} = \mathbf{x} - \mathbf{m}$

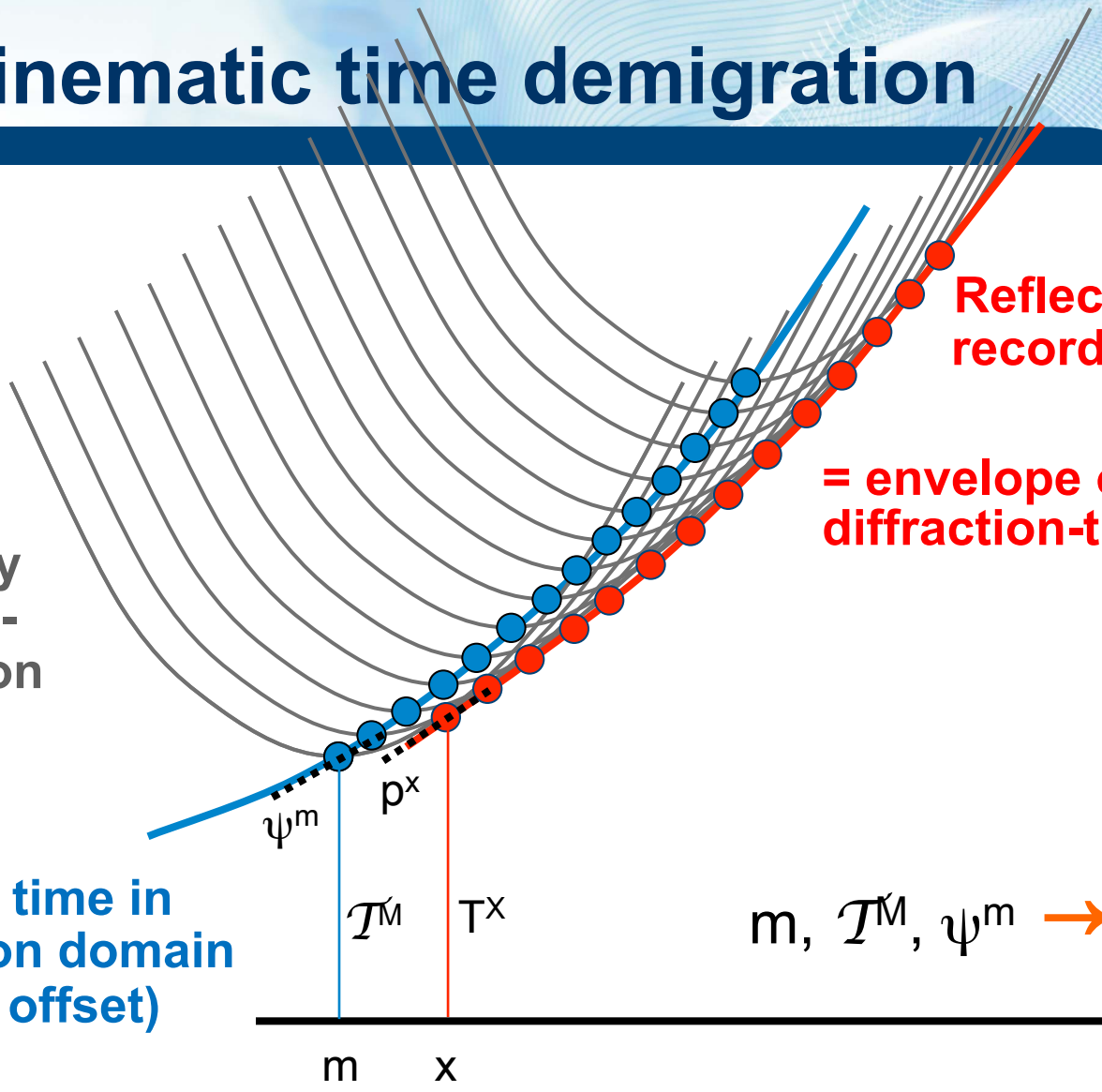
Diffraction-time function $T^D(\mathbf{h},\mathbf{a},\mathbf{m},\tau)$

An example is
the standard double-square-root (DSR) function:

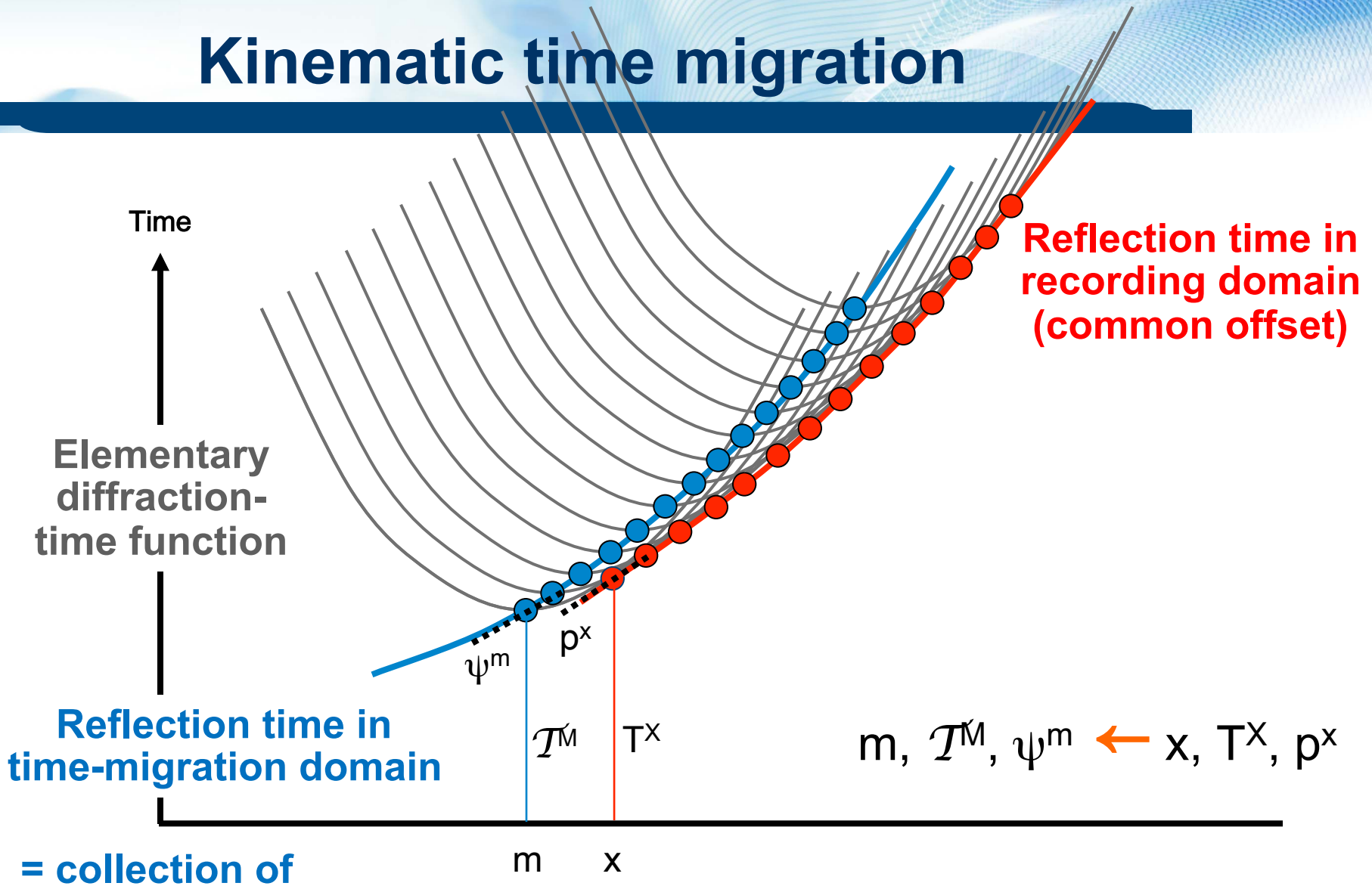
$$T^D(\mathbf{h},\mathbf{a},\mathbf{m},\tau) = \sqrt{\frac{\tau^2}{4} + (\mathbf{a}-\mathbf{h})^T \mathbf{S}^M(\mathbf{m},\tau)\,(\mathbf{a}-\mathbf{h})} + \sqrt{\frac{\tau^2}{4} + (\mathbf{a}+\mathbf{h})^T \mathbf{S}^M(\mathbf{m},\tau)\,(\mathbf{a}+\mathbf{h})}$$

(but we permit use of more general functions)

Kinematic time demigration



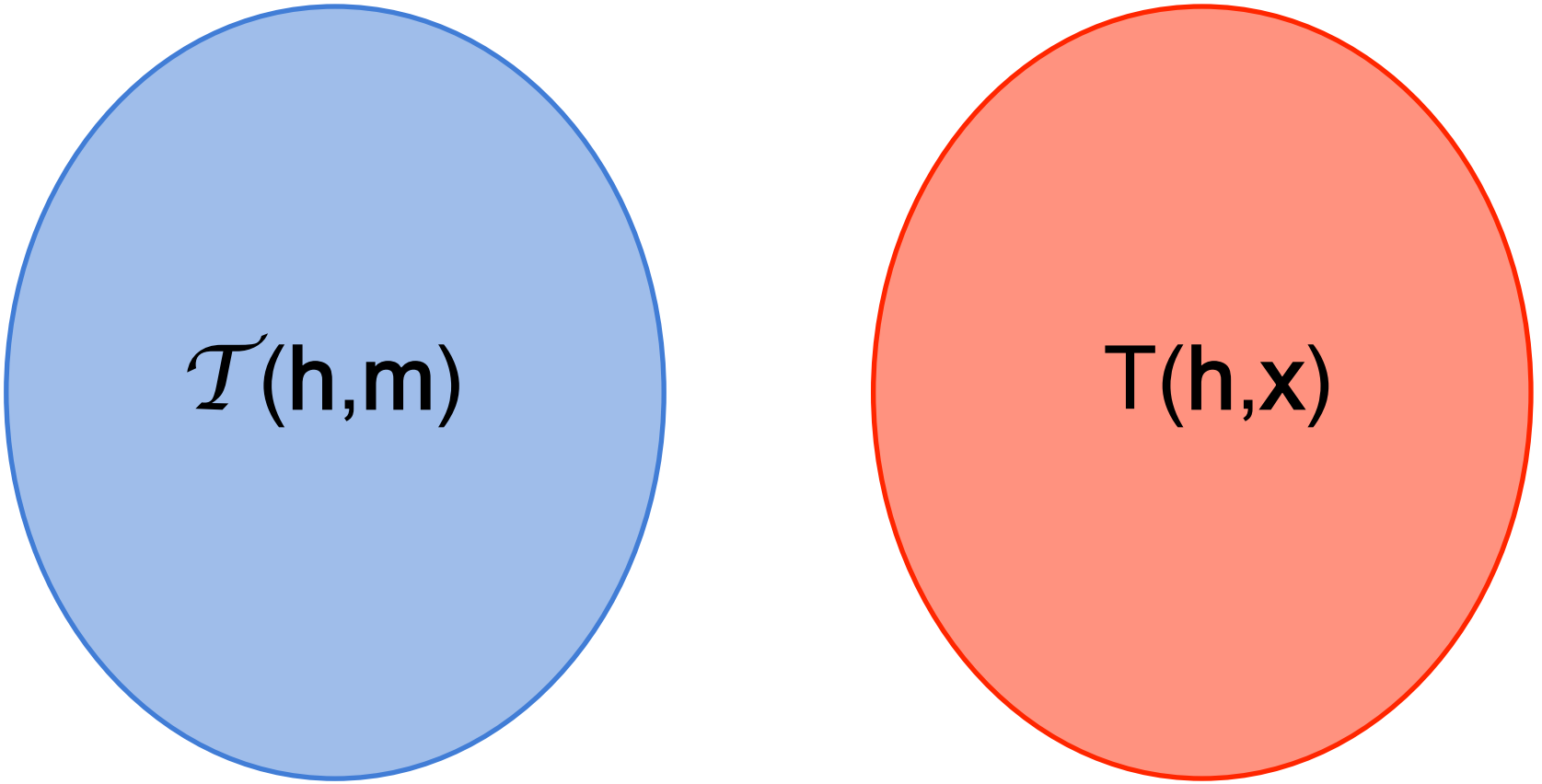
Kinematic time migration



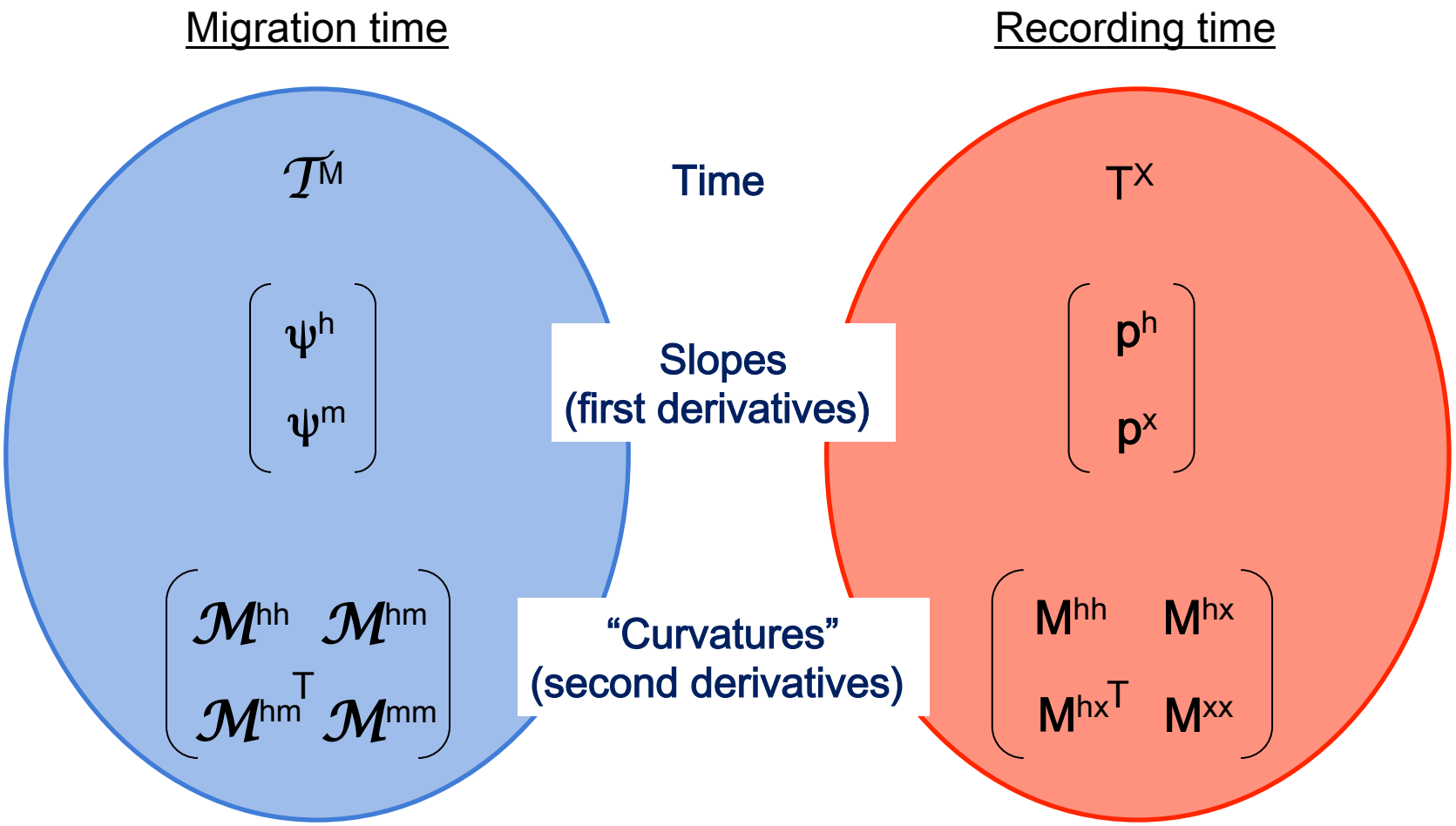
Common reflection surface (CRS)

Migration time

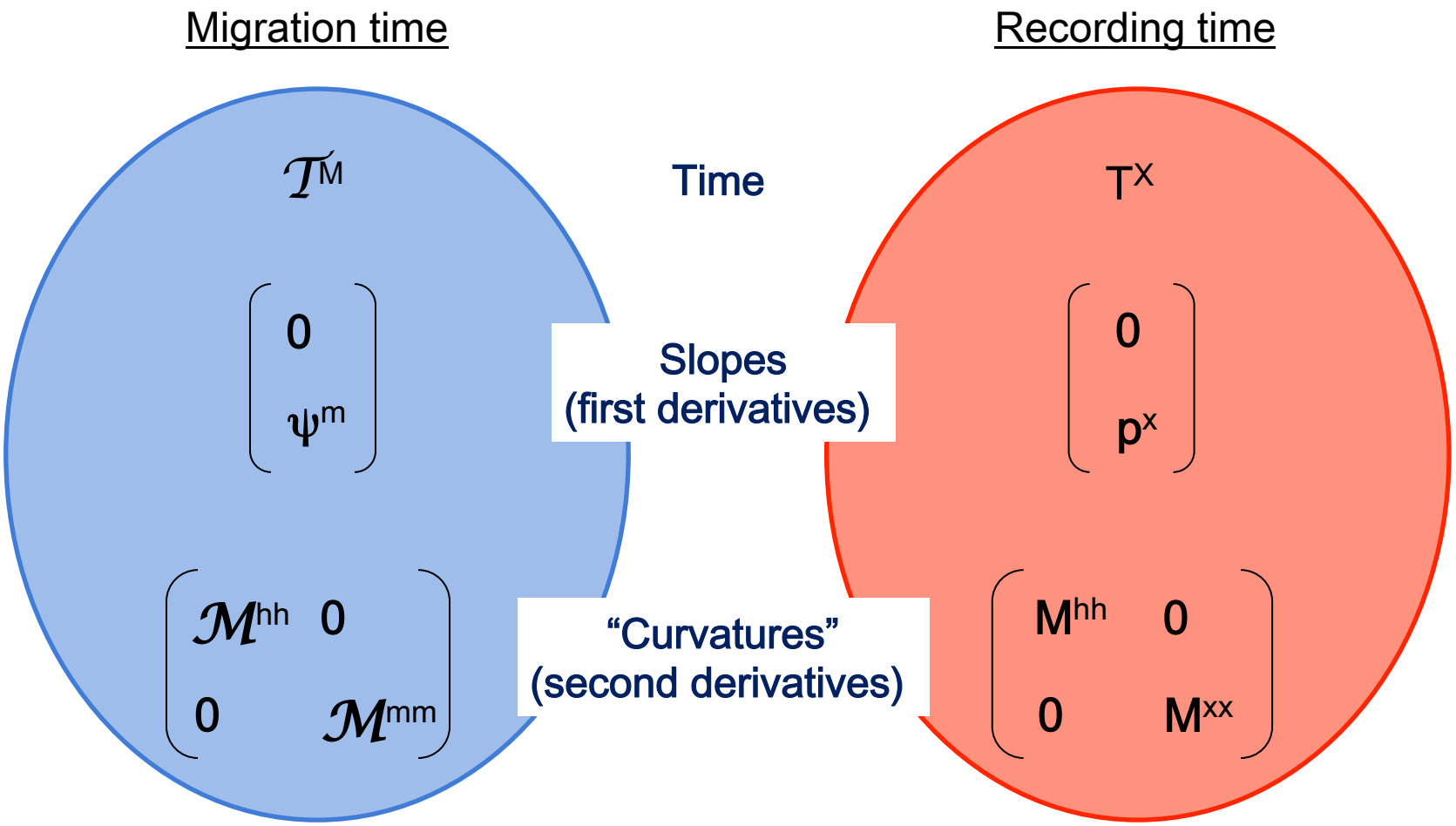
Recording time



Reflection-time parameters at finite offsets



Reflection-time parameters at zero offset (standard CRS parameters)



Basic conditions for kinematic time migration/demigration

$$T(\mathbf{h}, \hat{\mathbf{x}}) = T^D[\mathbf{h}, \hat{\mathbf{x}} - \mathbf{m}, \mathbf{m}, \mathcal{T}(\mathbf{h}, \mathbf{m})]$$

$$\frac{\partial T}{\partial \mathbf{x}}(\mathbf{h}, \hat{\mathbf{x}}) = \frac{\partial T^D}{\partial \mathbf{a}}[\mathbf{h}, \hat{\mathbf{x}} - \mathbf{m}, \mathbf{m}, \mathcal{T}(\mathbf{h}, \mathbf{m})]$$

Time-migration velocities
↕
normal-moveout velocities

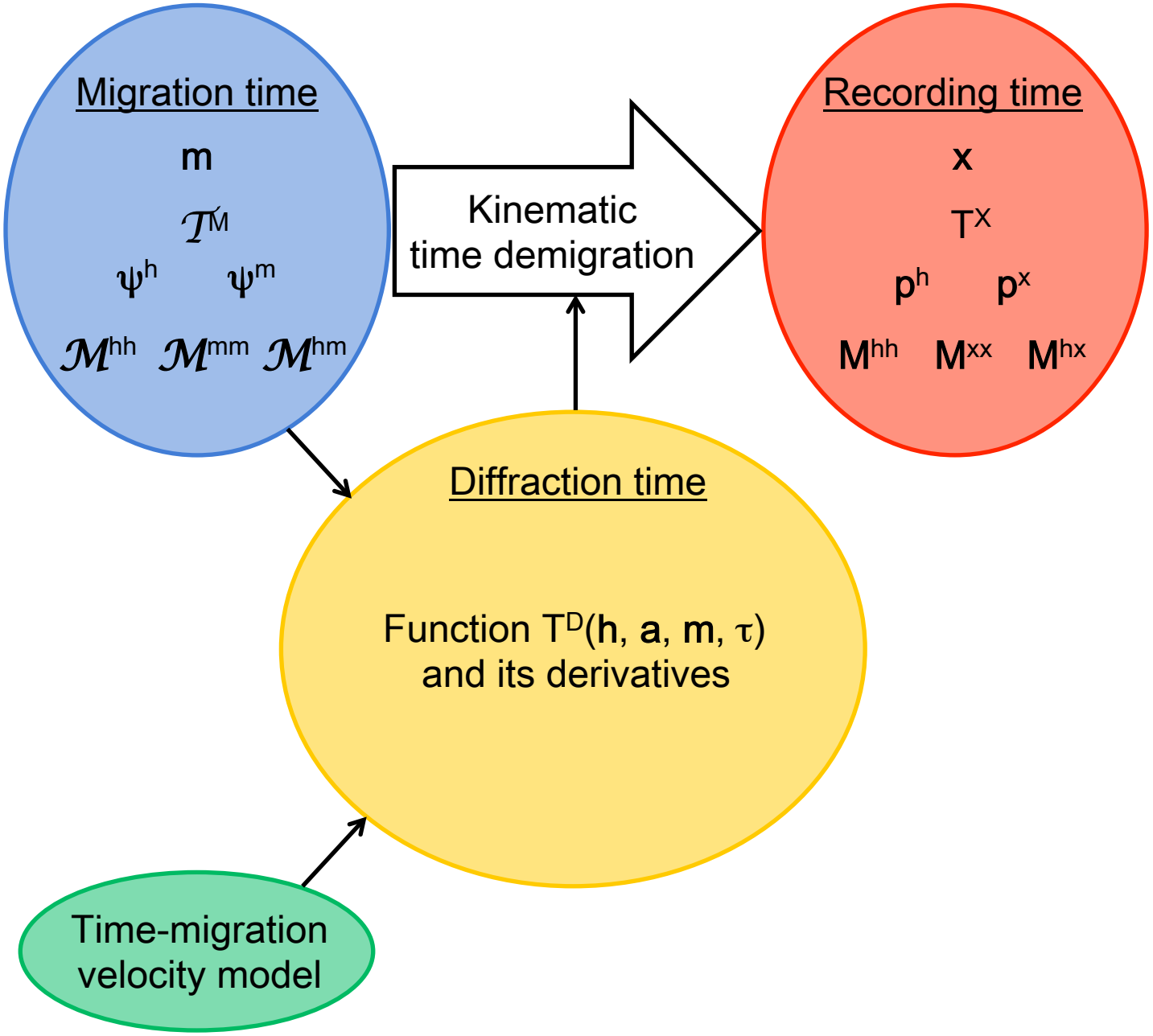
$$\mathbf{S}^{M} = \mathbf{S}^{\mathrm{NMO}} + \frac{1}{4}\mathbf{p}^{x}\ \mathbf{p}^{x\ T}$$

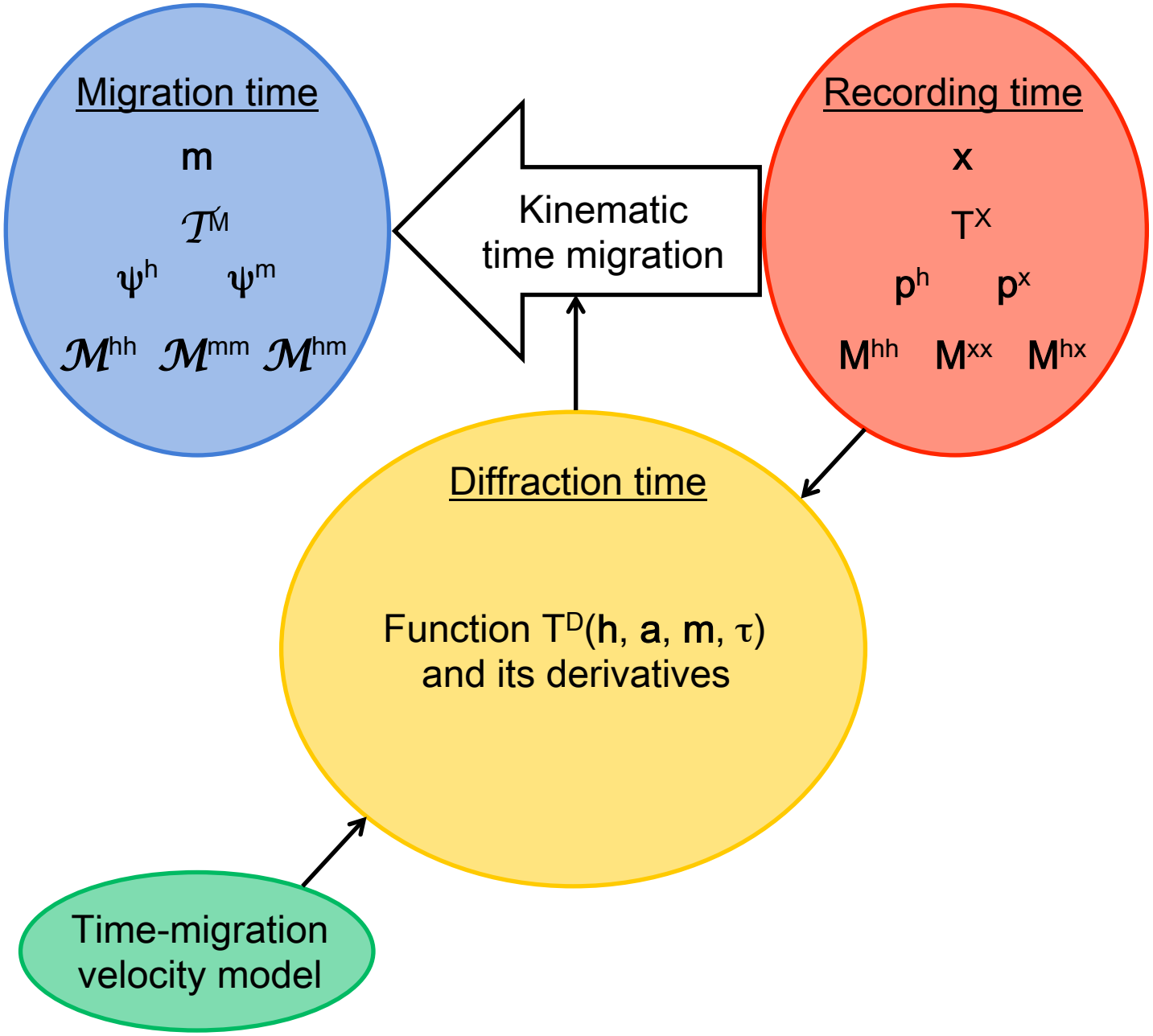
Time-migration matrix

Normal-moveout matrix

Slopes (first derivatives) In recording domain

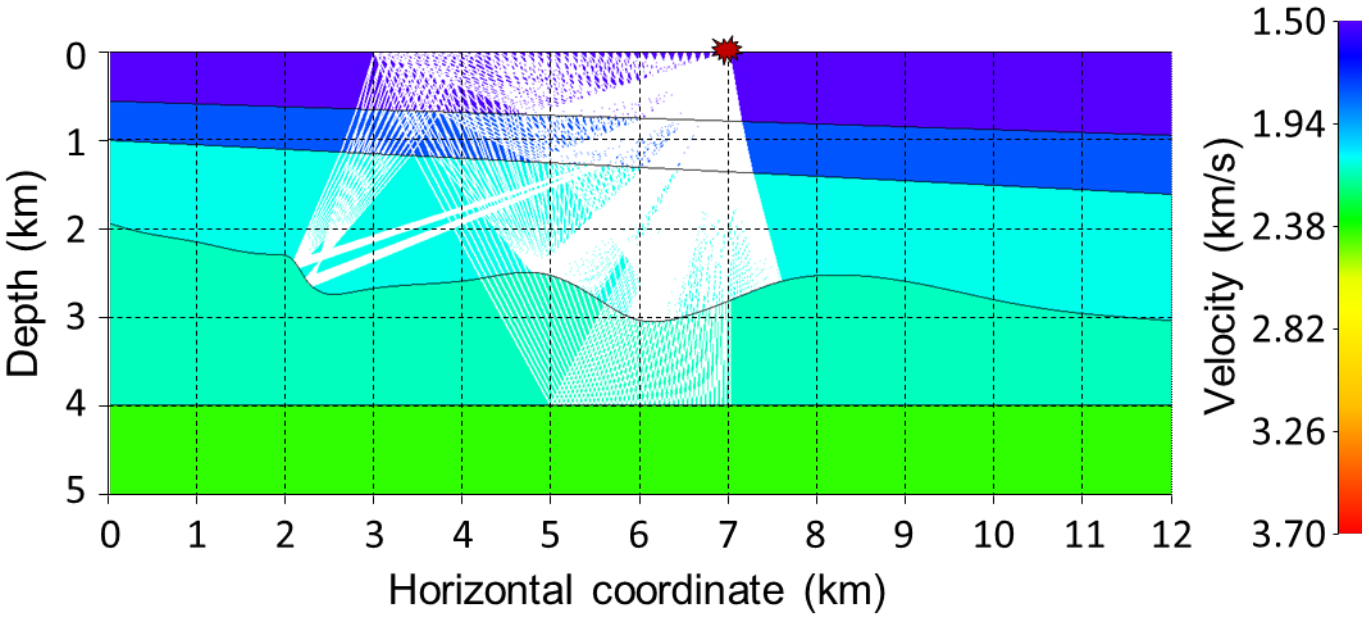
(based on standard double-square-root function)


Migration time
m
$\mathcal{T}^M$
ψ^h ψ^m
$\mathcal{M}^{hh}$ $\mathcal{M}^{mm}$ $\mathcal{M}^{hm}$
Kinematic
time demigration
Recording time
x
T^X
p^h p^x
M^{hh} M^{xx} M^{hx}
Diffraction time
Function $T^D(\mathbf{h}, \mathbf{a}, \mathbf{m}, \tau)$
and its derivatives
Time-migration
velocity model

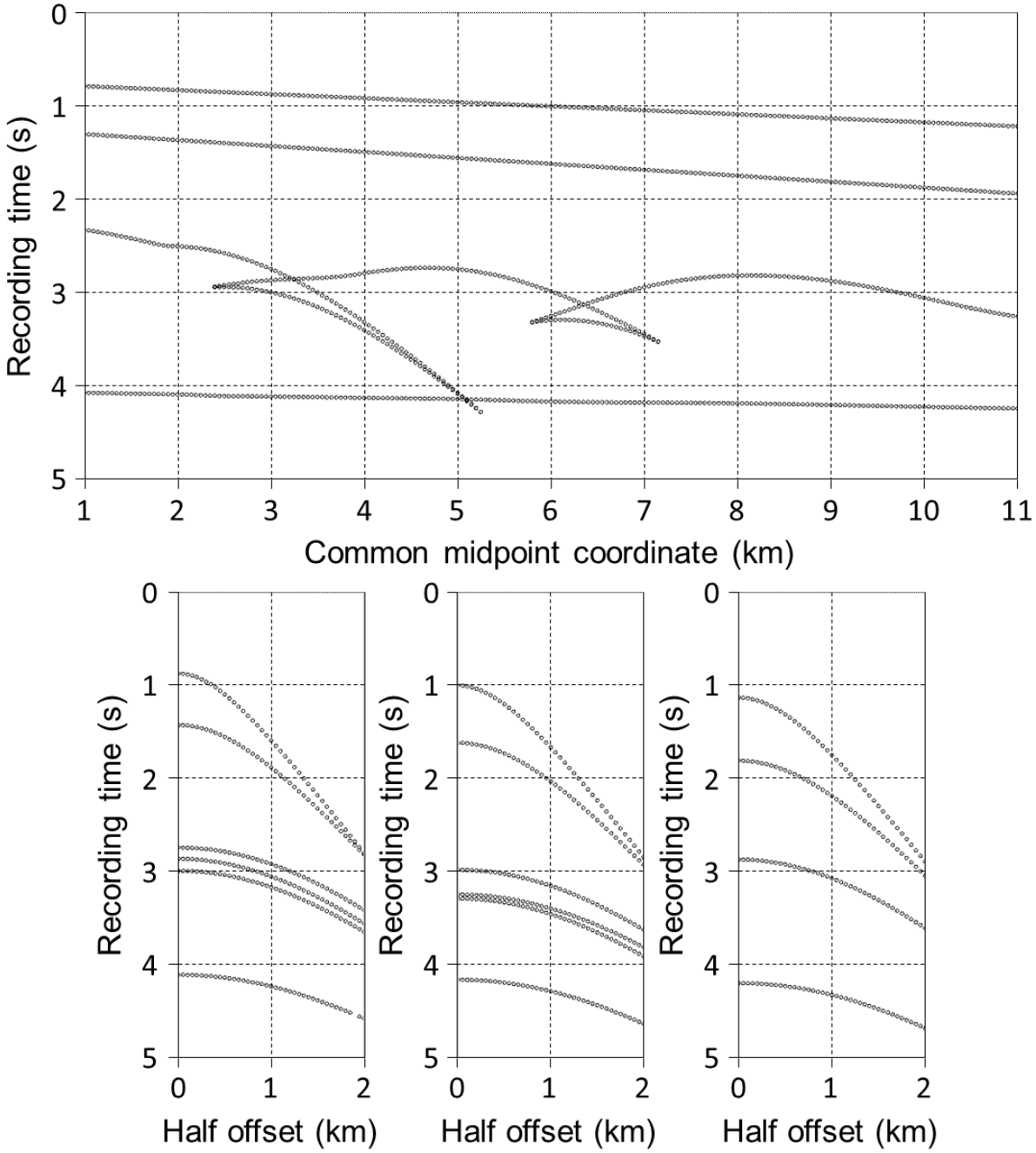

Migration time
m
$\mathcal{T}^M$
ψ^h ψ^m
$\mathcal{M}^{hh}$ $\mathcal{M}^{mm}$ $\mathcal{M}^{hm}$
Kinematic time migration
Recording time
x
T^x
p^h p^x
M^{hh} M^{xx} M^{hx}
Diffraction time
Function $T^D(\mathbf{h}, \mathbf{a}, \mathbf{m}, \tau)$ and its derivatives
Time-migration velocity model

Numerical example

Generation of reflection data by ray tracing:



Reflections in the recording domain:



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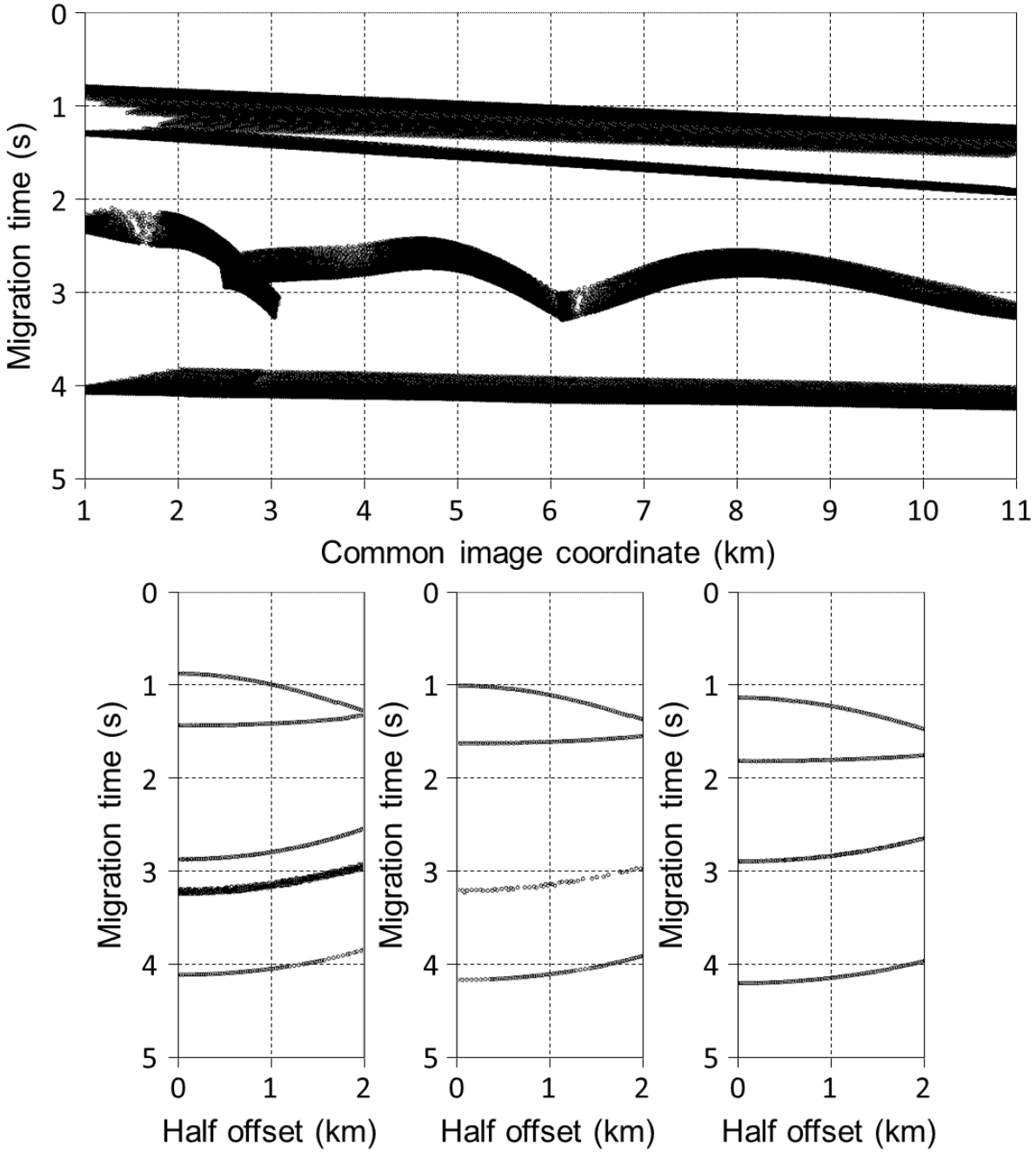
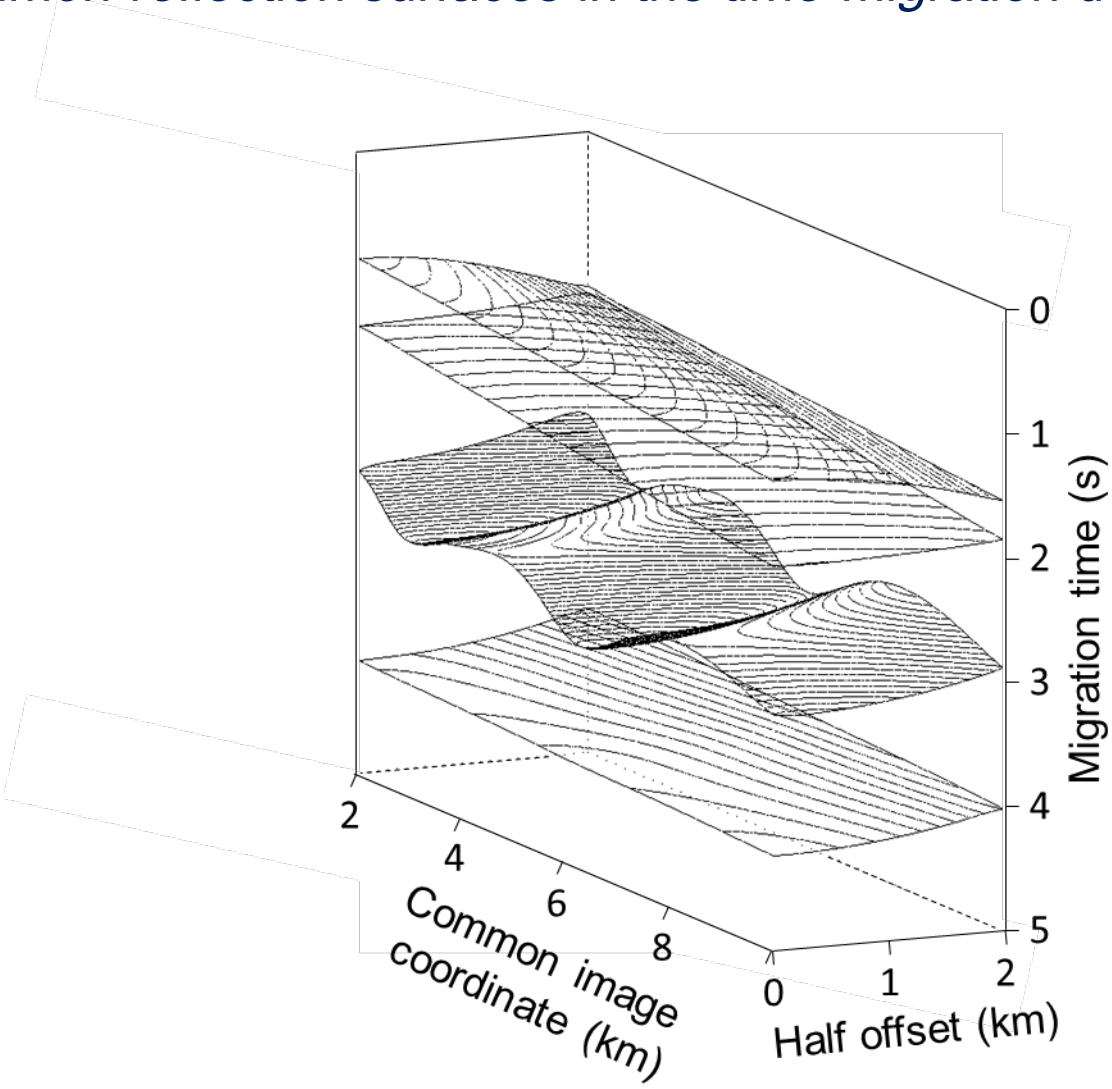
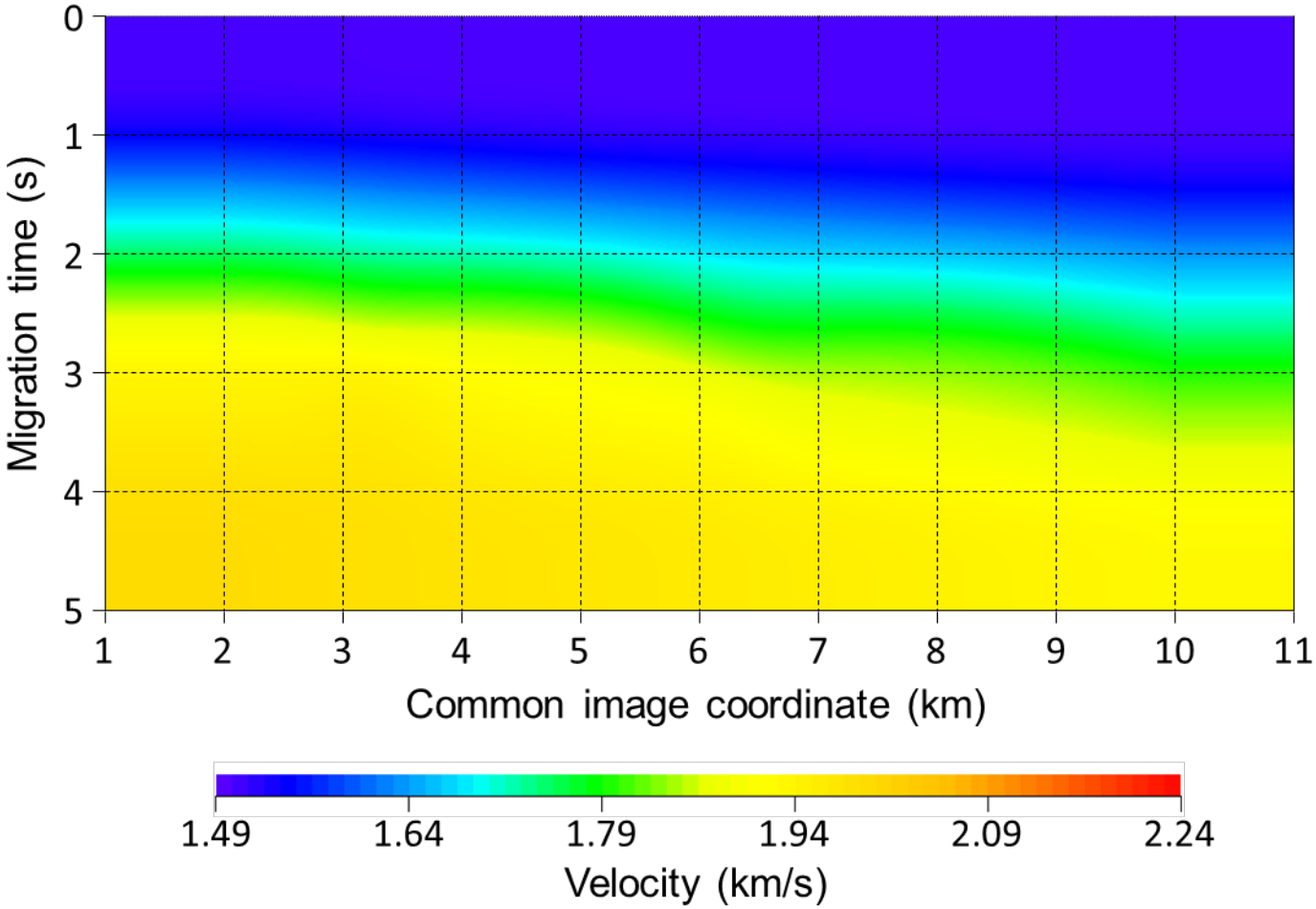
Reflections in the time-migration domain:



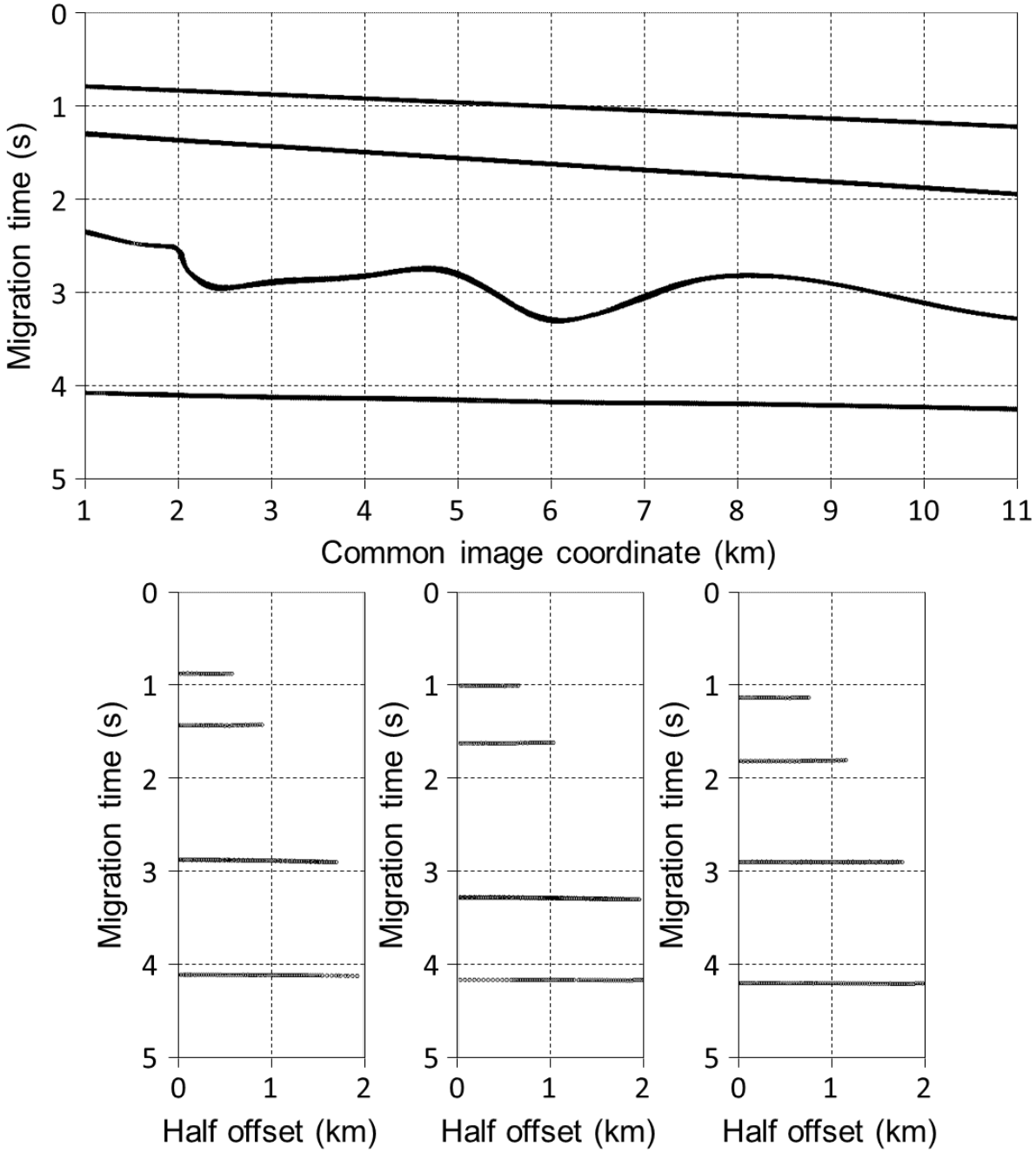
Common-reflection surfaces in the time-migration domain:



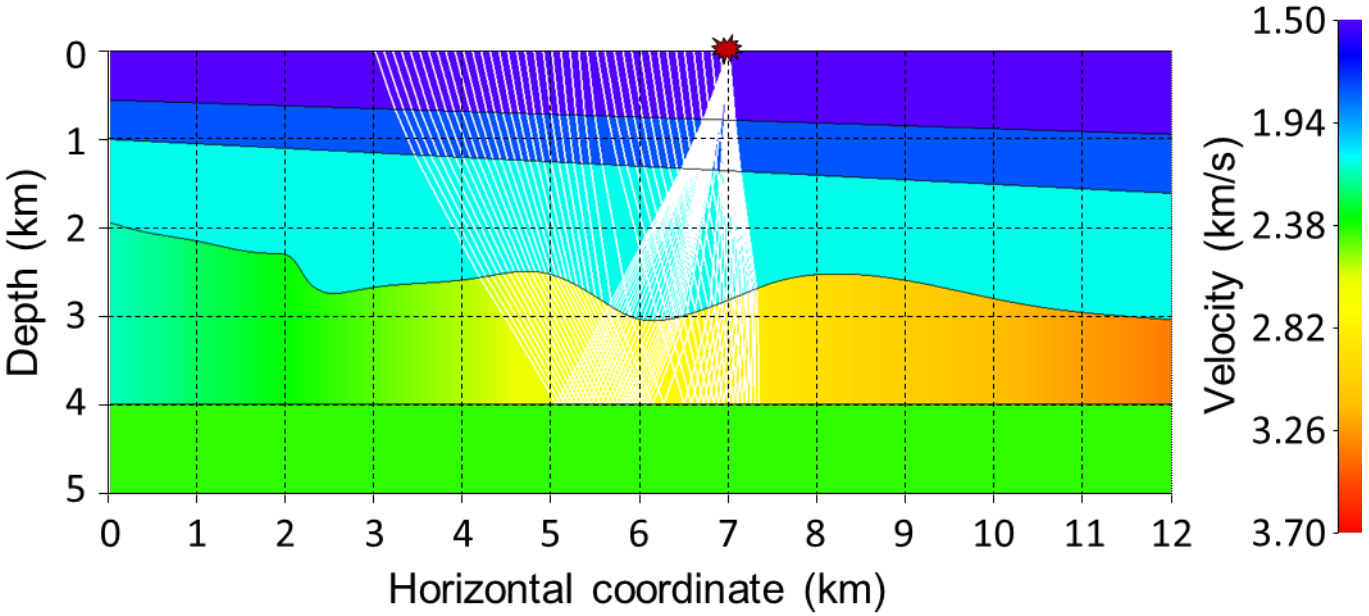
Time-migration velocity model:



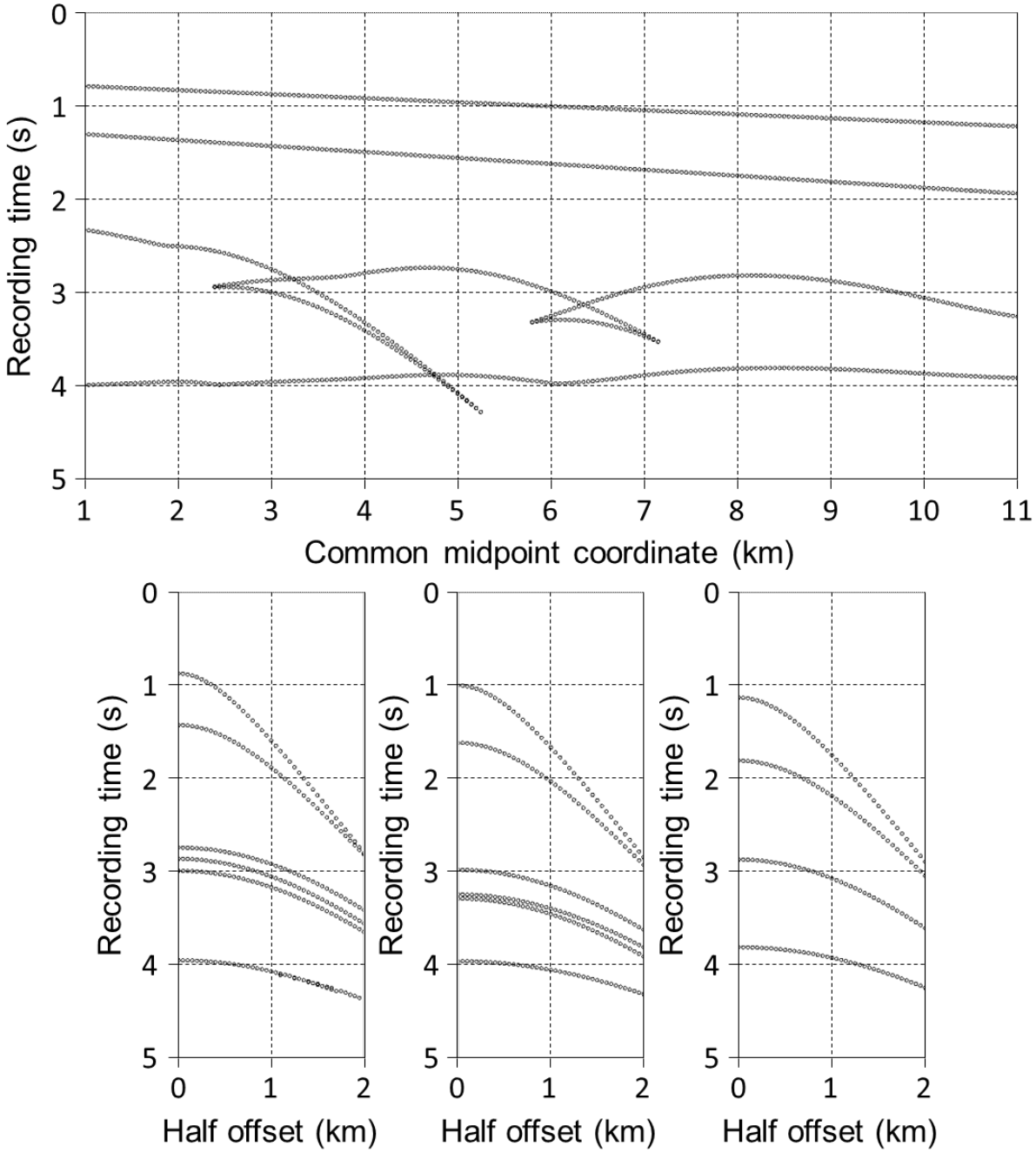
Reflections in the time-migration domain:



Generation of reflection data by ray tracing in modified depth model:



Reflections in the recording domain:



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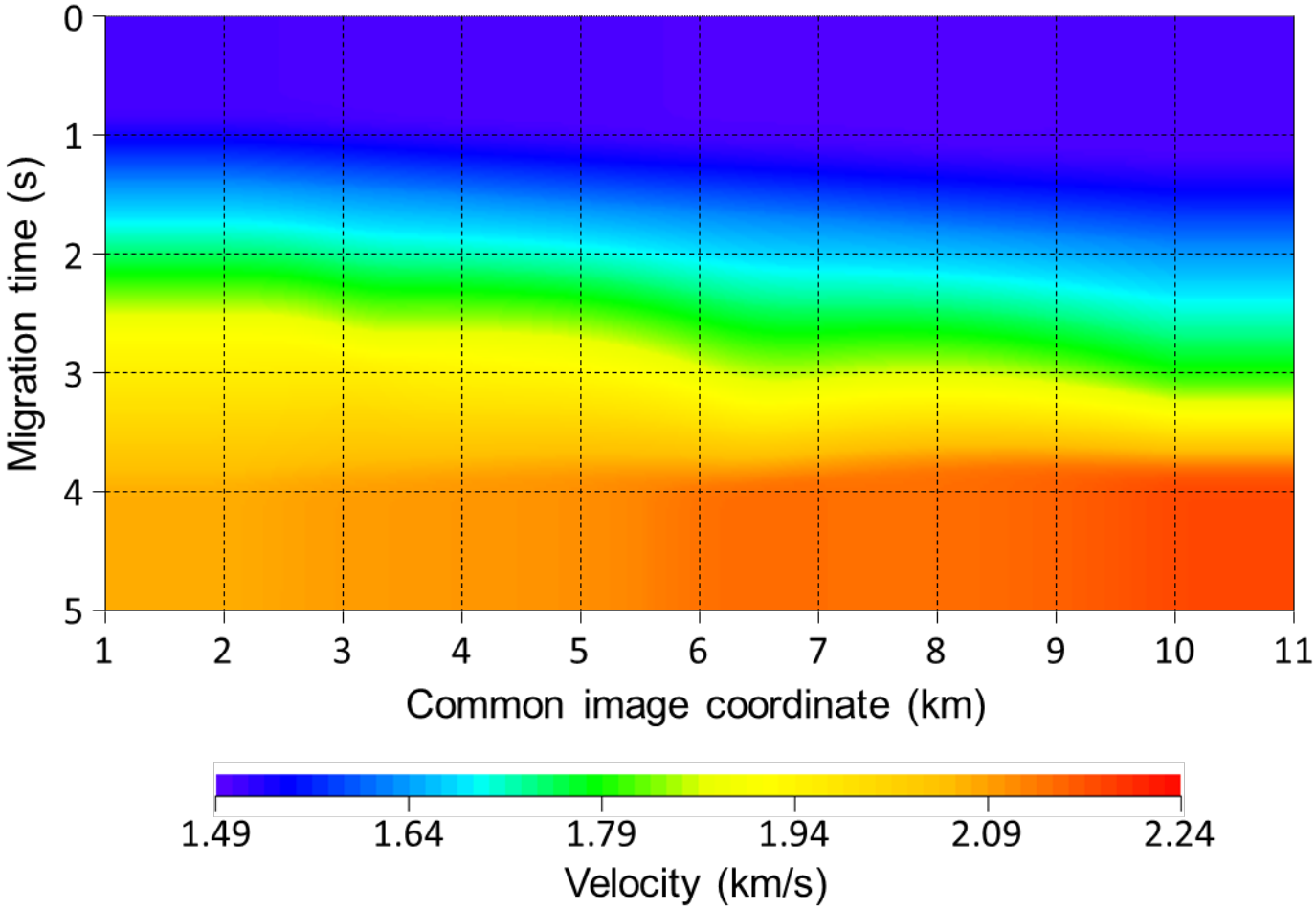
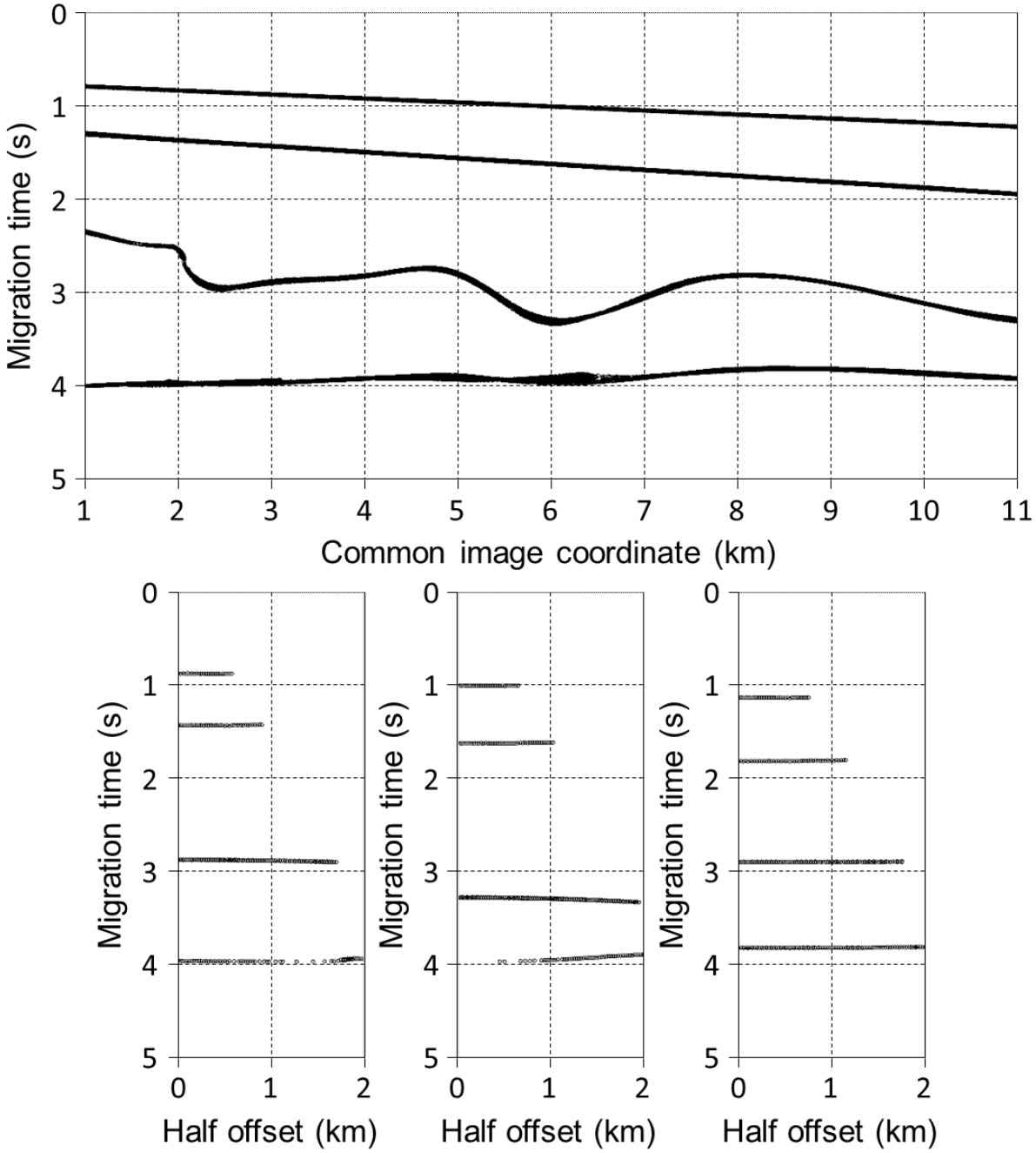
Time-migration velocity model:



Reflections in the time-migration domain:



Concluding remarks

- We have extended previous approaches from zero offset to finite offsets
- Our approach allows to map the full set of reflection-time second derivatives
- The mapping formulas are independent
  - of the type of diffraction-time function
  - of the parametrization of the migration-velocity model
- Applications in
  - multi-midpoint stacking techniques
  - time-migration tomography
  - depth-migration tomography