MIGRATION OVERVIEW

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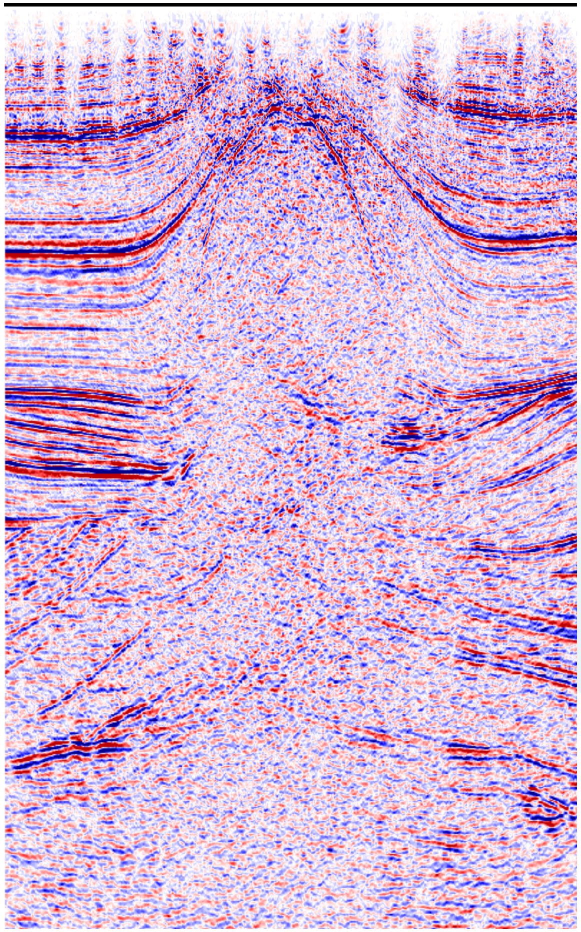
Contents

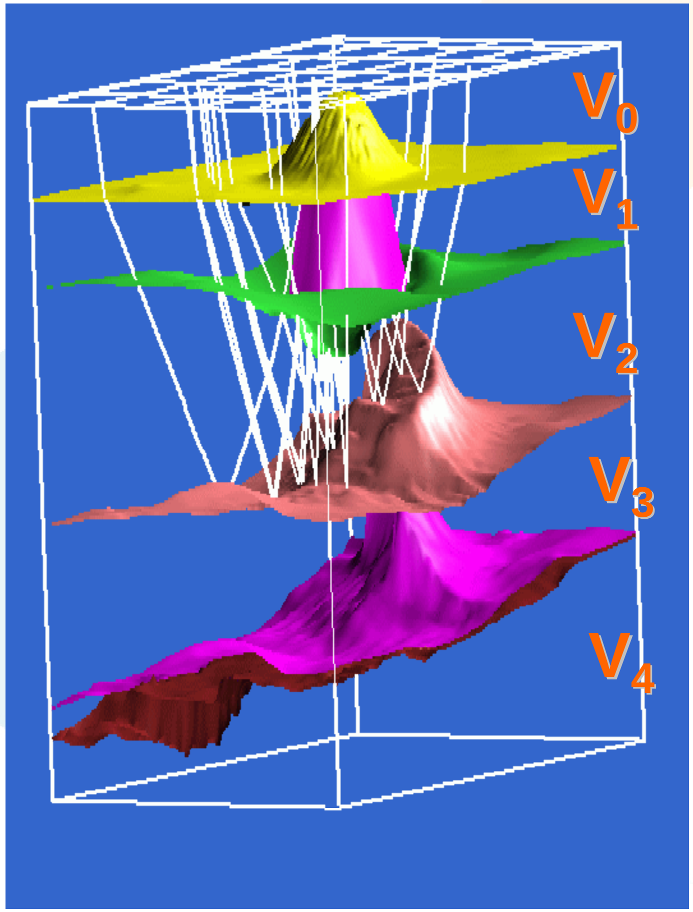
- Overview of migration methods
- Spatial Aliasing
- DMO

- 2D data can be migrated only in the plane of the section
- All migration methods are based upon simplified models of the real Earth

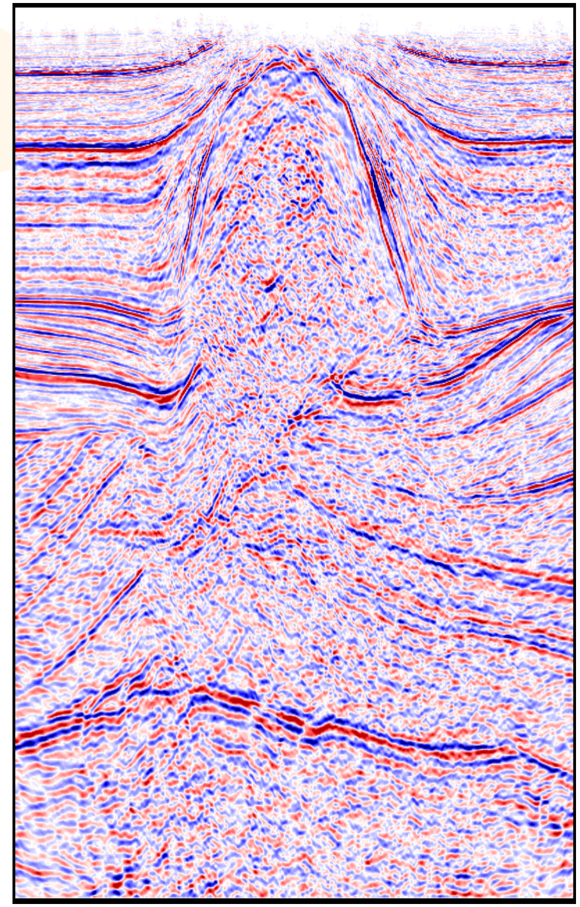
3D migration



Post-stack time migration



model



Pre-stack depth migration

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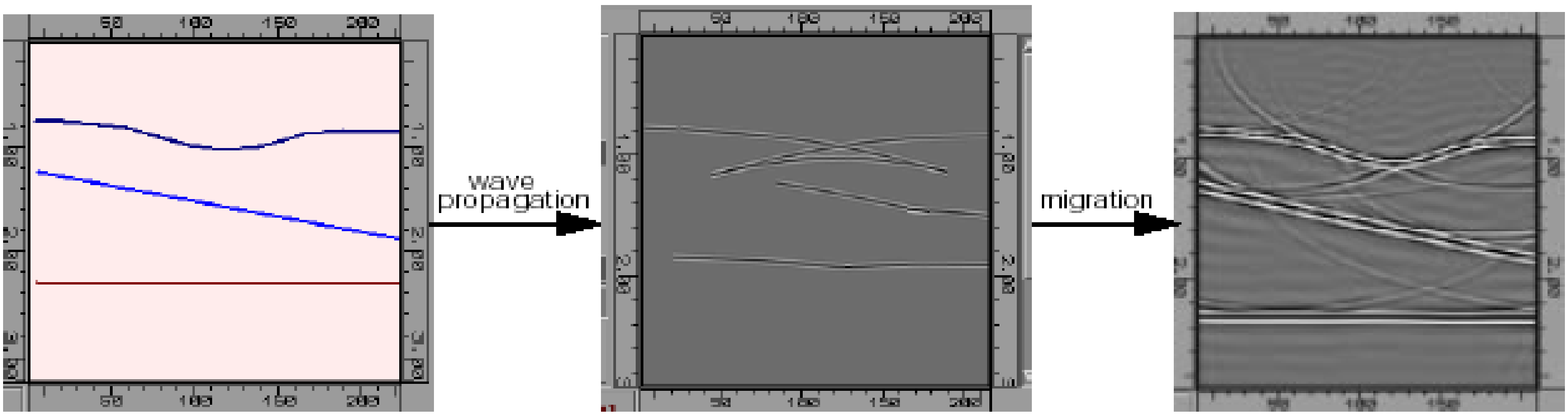
What is Migration?

Migration is the process which removes the effect of wave propagation from the seismic data!



geological model

seismic section

seismic data
after migration

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Migration Purpose

- The recorded wave field is measured at the surface : **P(x,y,t,z=0)**

- What is the sub-surface **Image (x,y,z)** ?

- The propagation of a wavefield **P(x,y,z,t)** is defined as :

$$\frac{\partial^2 P(x,y,z,t)}{\partial x^2}+\frac{\partial^2 P(x,y,z,t)}{\partial y^2}+\frac{\partial^2 P(x,y,z,t)}{\partial z^2}=\frac{1}{V^2(x,y,z)}\frac{\partial^2 P(x,y,z,t)}{\partial t^2}$$

- But to access to the image, the ***velocity model*** **V(x,y,z)** must be defined.

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Migration Methods

- Classes of Migration based on algorithms
  - Kirchhoff Migration (KIRCH)
    - performed by diffraction summation
  - FD Migration (WEMIG)
    - uses the finite difference solution of the wave equation in T-X space
  - FX Migration (FXMIG, GTMIG)
    - uses the finite difference solution of the wave equation in F-X space
  - FK Migration (FKMIG)
    - based on the 2D Fourier Transform

Kirchhoff Migration

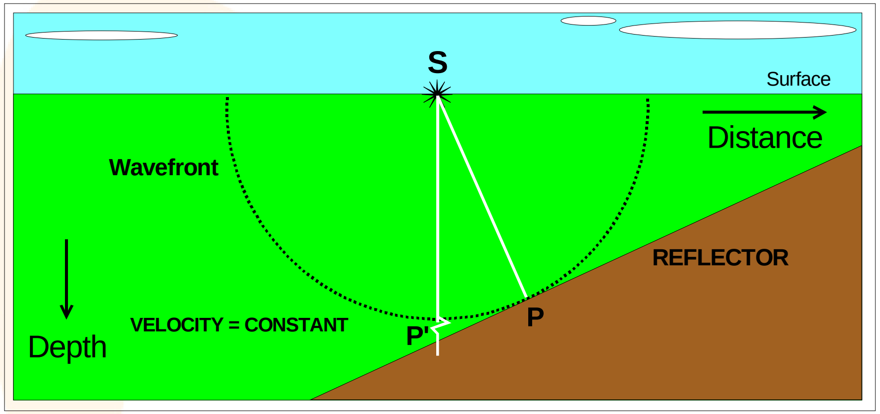
- Kirchhoff migration is performed by summation using either:
  - Wavefront method
  - Diffraction method

- The following is a graphical explanation of the wavefront and diffraction methods

Wavefront Migration - 1

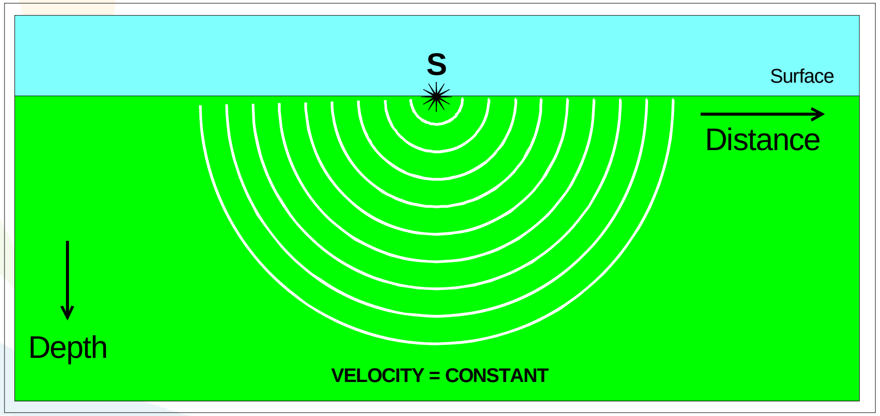
Consider a wavefront impinging upon a dipping reflector.

The actual reflection from P is assumed to be at P'



Both P and P' lie on the same wavefront

Method

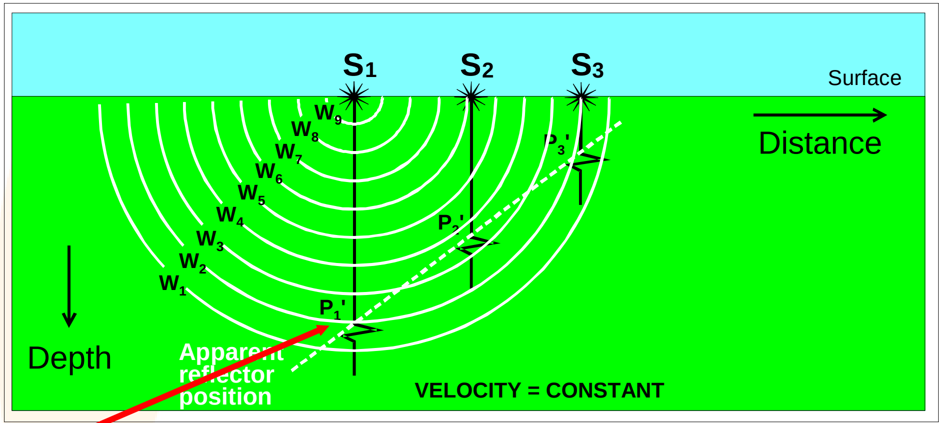


Construct a wavefront chart

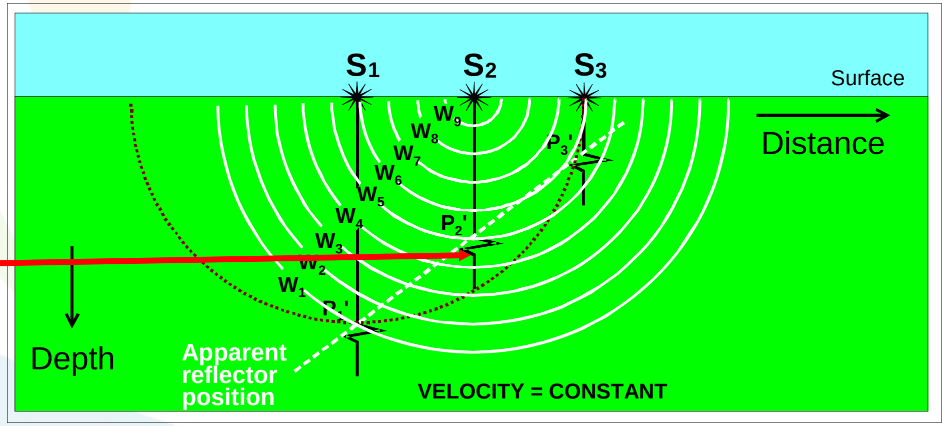
In a constant velocity model the wavefronts are semi-circular

Wavefront Migration - 2

- Use the wavefront Chart in conjunction with a simple reflection model
  - The event is at P_1' on trace S_1
  - The event is at P_2' on trace S_2
  - The event is at P_3' on trace S_3
- Plot the wavefront which overlays reflection point P_1'



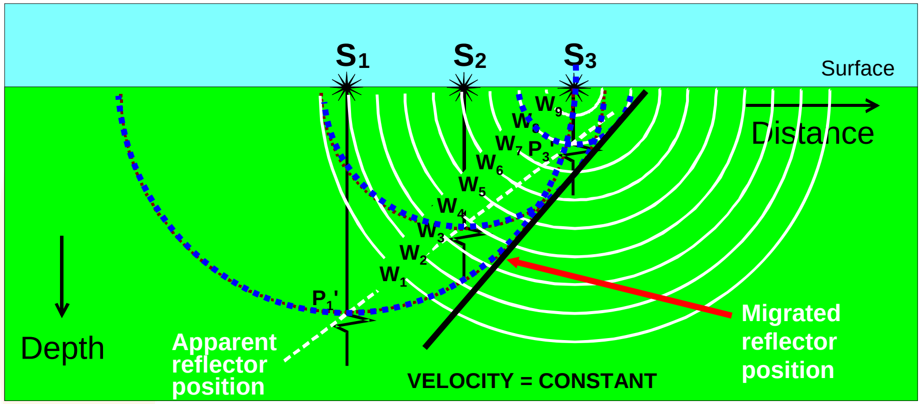
- Move chart to second trace
- Plot the wavefront which overlies point P_2'



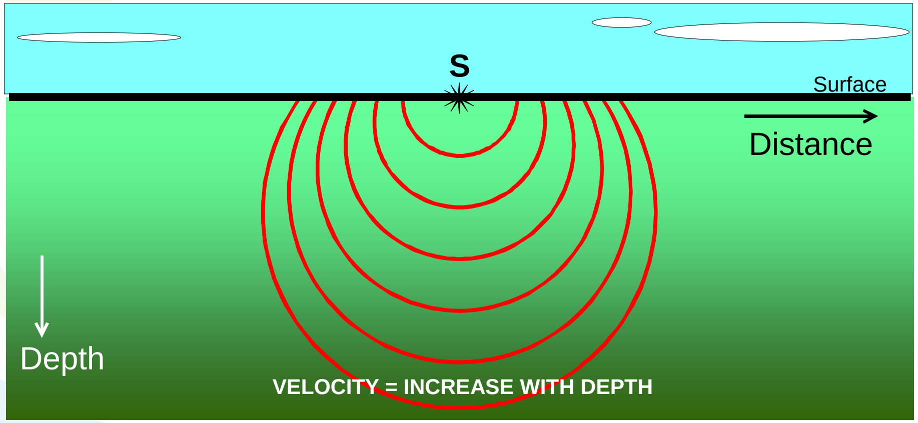
- Repeat for the third trace

Wavefront Migration - 3

- The common tangent to the wavefronts is the true position of the reflector



- A more realistic approach is to assume velocity increases with depth which gives this wavefront characteristic



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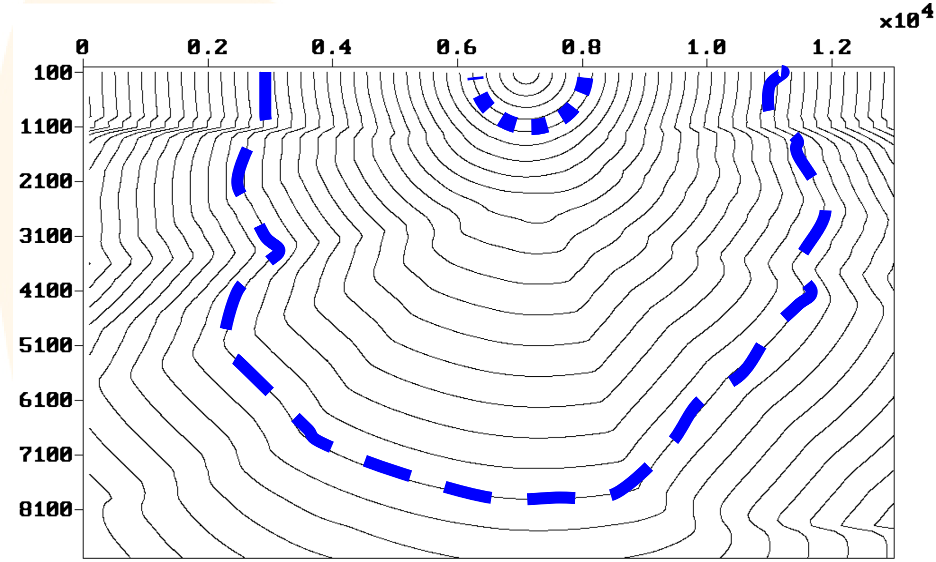
Wavefront Migration - 4

- The wavefront is in fact , an isochron curve

- When velocity increases in depth and changes laterally this isochron curve becomes more and more complex

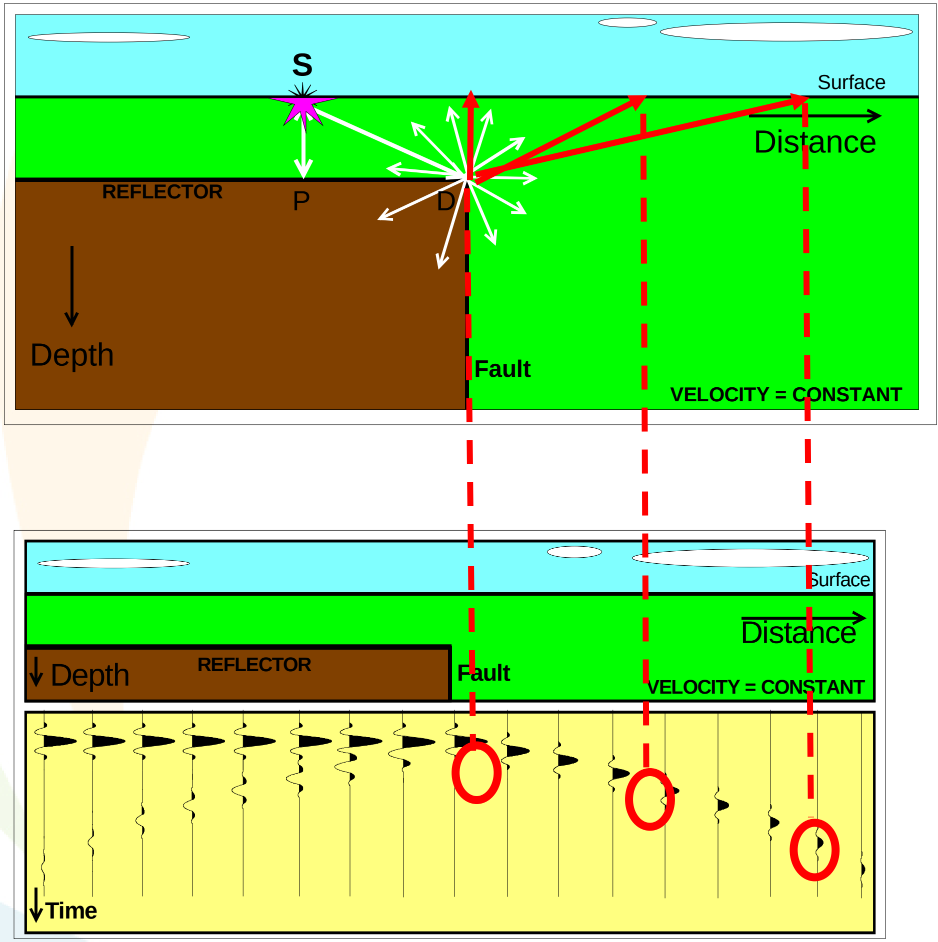
- To take in account these time variations in X,Y domain, we can build a table of travel time for each shot point and each receiver point

This method is in fact used for Pre-stack depth migration only



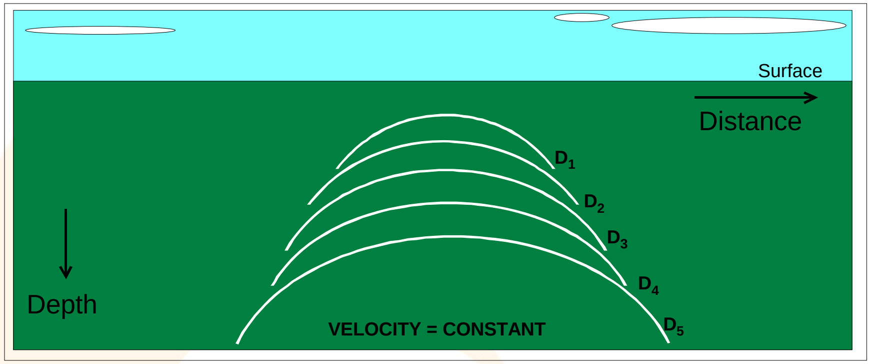
Diffraction Curves Migration

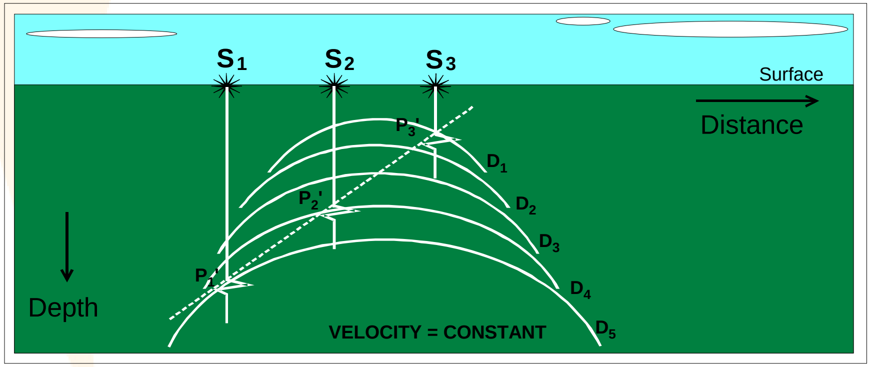
- The diffracting point can be regarded as a new source point at depth



Diffraction Curves - 1

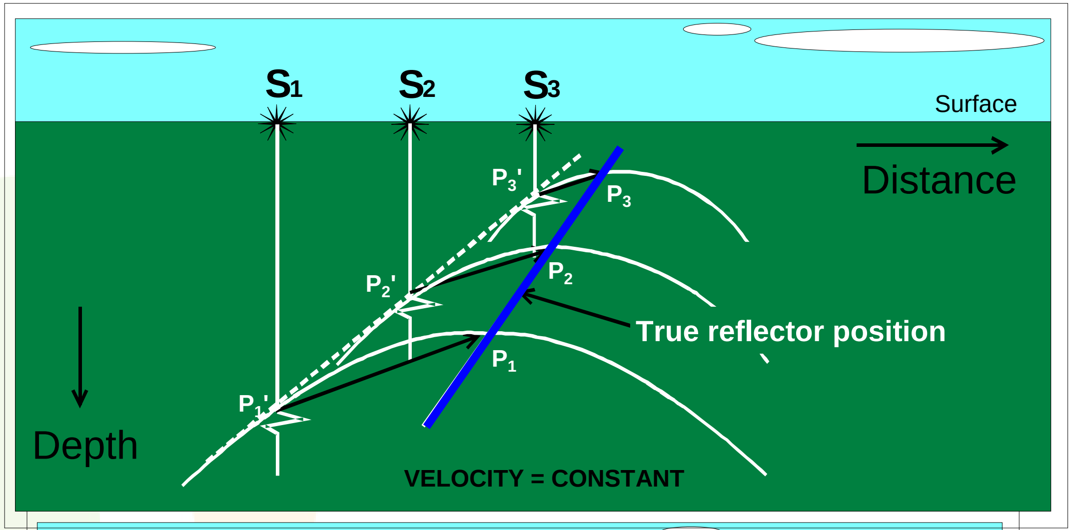
- Construct diffraction curves based on hyperbolic equation
  - Overlay these over the traces with a dipping reflection: slide along until the dipping event is a tangent
  - Note the position of the diffraction curve which is a tangent to the dipping event
  - Repeat for the other traces

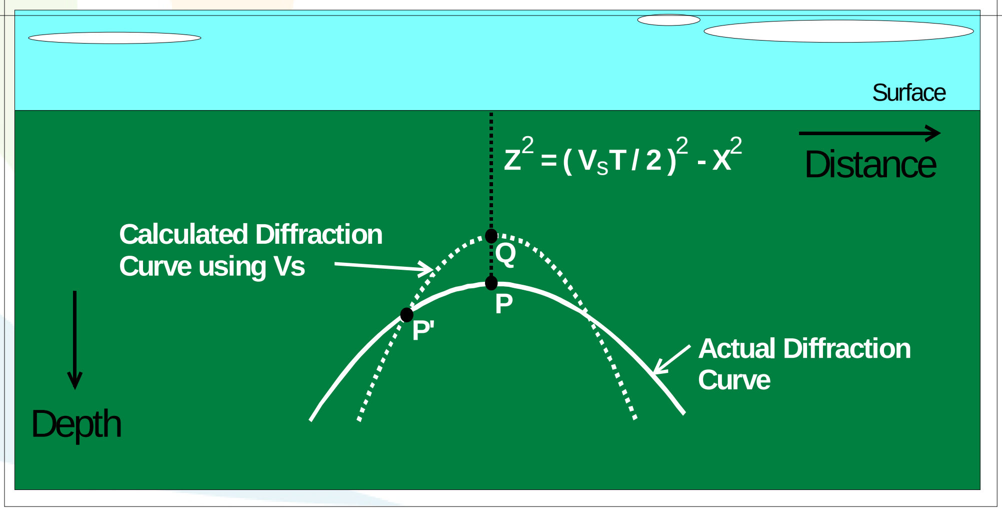




Diffraction Curves - 2

- The line which joins the diffraction curves apex is the true reflector position

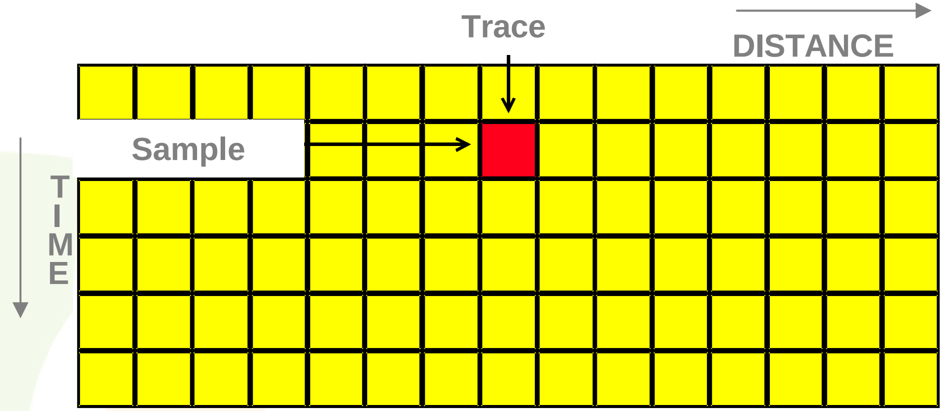




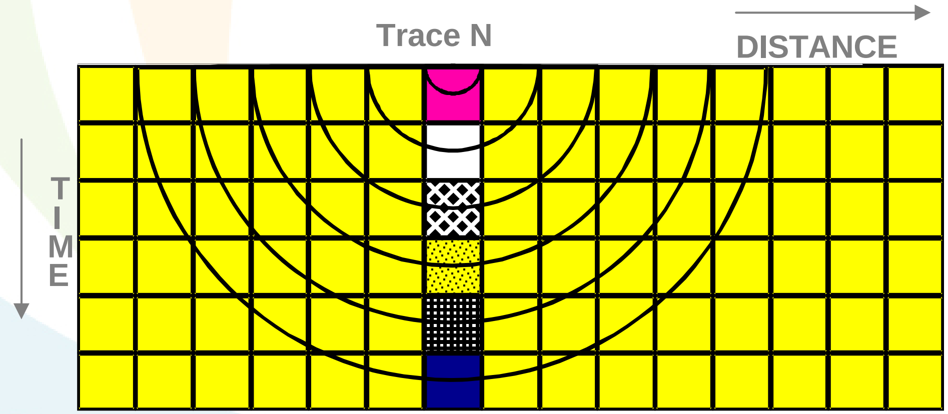
- Note: These curves are sensitive to velocity
- The distance by which an event is spatially shifted is proportional to the SQUARE of the velocity
  - stacking velocity is unlikely to be correct for migration

Migration by Integral methods : Kirchhoff Migration - 1

- Consider the location of each seismic sample to be a 'pigeon hole'



- Superimpose a wavefront chart onto a trace



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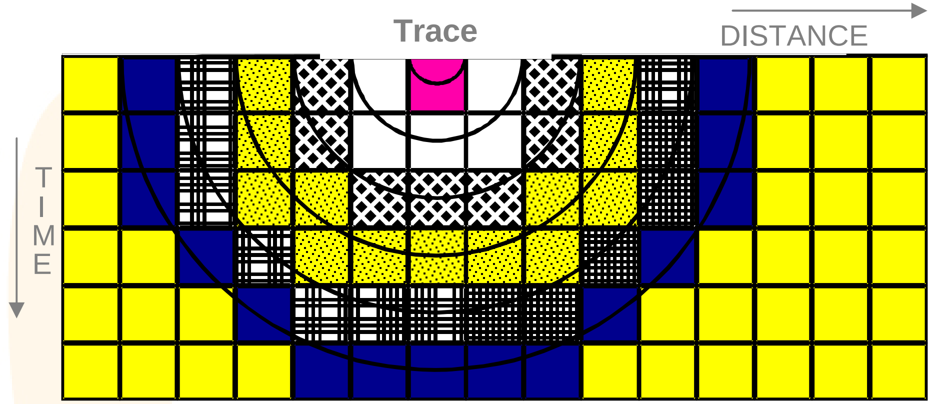
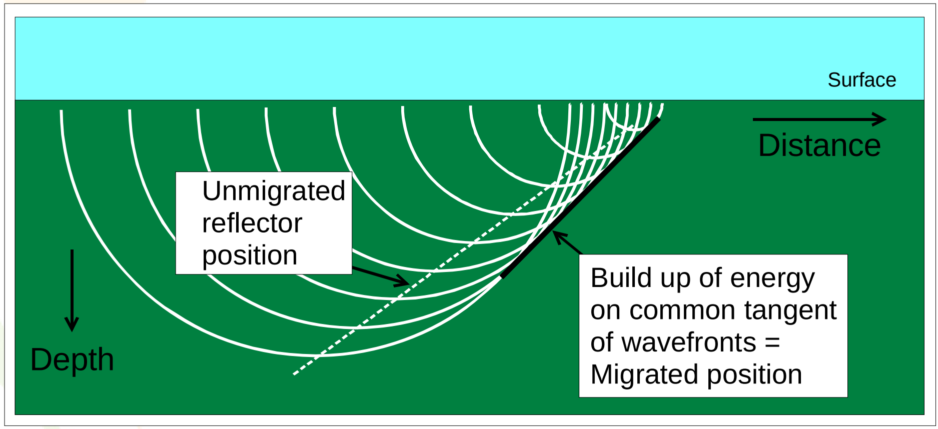
Migration by Integral Methods : Kirchhoff Migration - 2

- Each sample value is 'copied' into the pigeon holes through which the wavefront curves pass



- This procedure is repeated on all traces: the net result is a build-up of energy at the migrated position



- Note: Kirchhoff Method may also use Diffraction Curve summation

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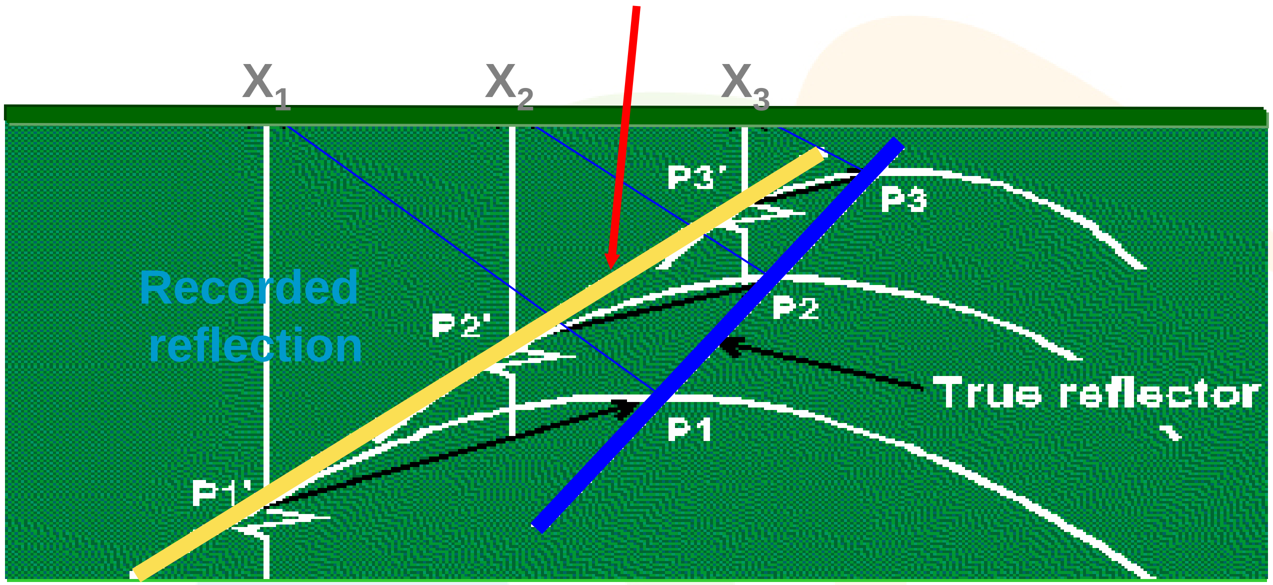
Migration by Integral Methods : Kirchhoff Migration - 3

- Huygen's Principle: Every reflector location is a Secondary Point Source



- Image of Reflector: Integral of diffraction curve
- Recorded Reflection: Tangent to diffraction curves
- Extrapolation: Computation of diffraction curves (travel time)
- Imaging: Integration of the data along the diffraction curves

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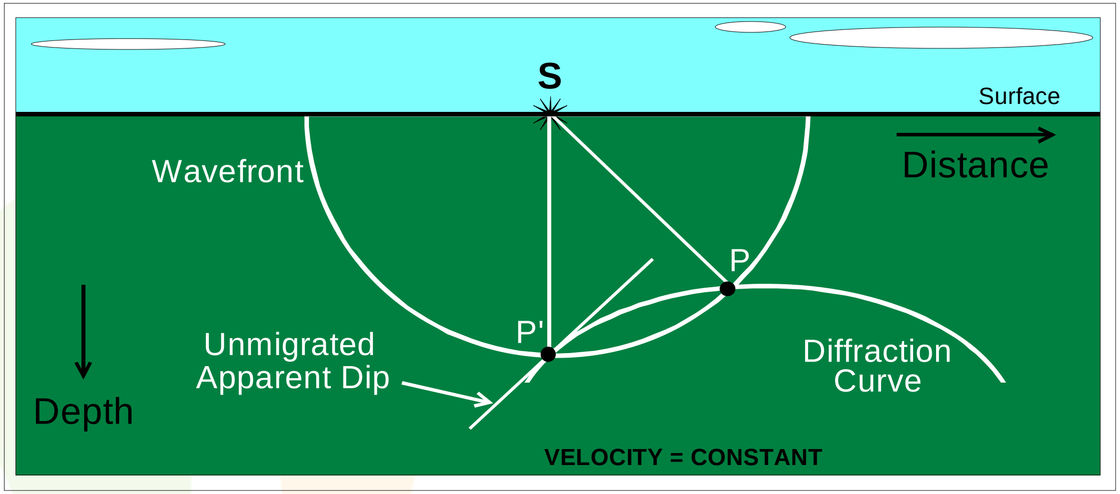
Wavefronts and Diffraction Curves

- Wavefronts and Diffraction curves can be used together
- Migrated position at intersection of the two curves

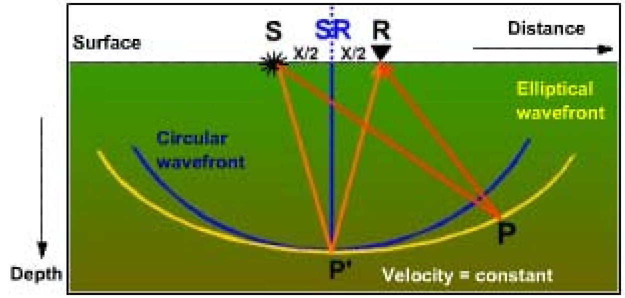


Procedure - 1

1- Apply static corrections

2- Sort traces into common offset gathers

These gathers contain non-zero offset traces.



In the case of non-zero offset traces the wavefronts are ellipses, (not circles as produced by zero offset traces).

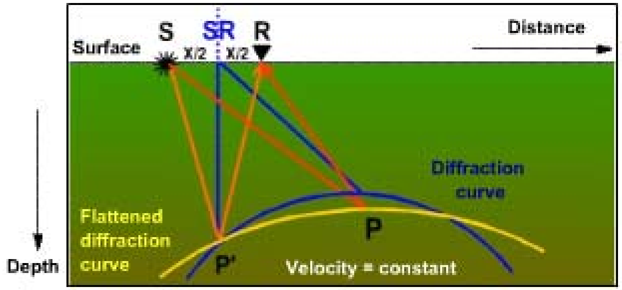
Procedure 2

1- Apply static corrections

2- Sort traces into common offset gathers

These gathers contain non-zero offset traces.

Also the diffraction curves are flattened.



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Procedure 2 bis

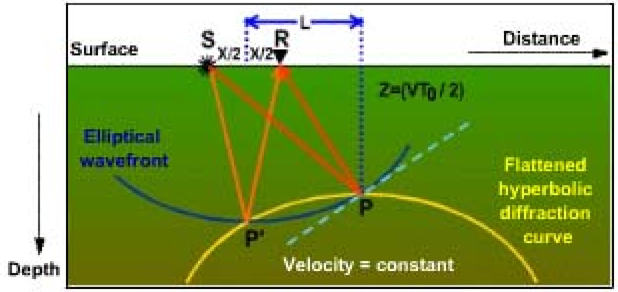
1- Apply static corrections

2- Sort traces into common offset gathers

3- Migration

The apparent reflection point P' migrates along the elliptical wavefront or along the flattened diffraction curve to the true reflection point P.

Each common offset gather is migrated separately.



Procedure 3

1- Apply static corrections

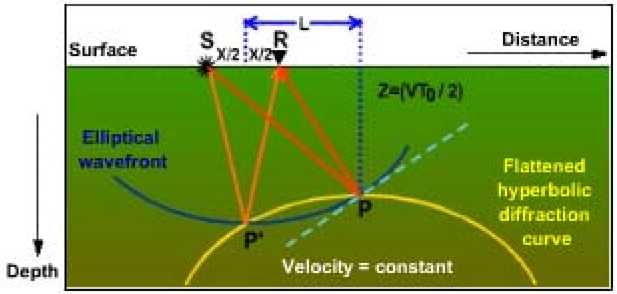
2- Sort traces into common offset gathers

3- Migration

Total travel Time, T is equal to:

Travel time S to P
+
Travel time P to R

For the non-coincident sources and receivers:



Procedure 3 bis

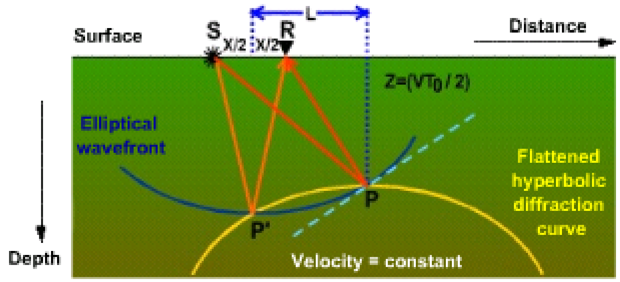
1- Apply static corrections

2- Sort traces into common offset gathers

3- Migration

$$\sqrt{\left[\frac{T_0}{2}\right]^2 + \left[\frac{L + (X/2)}{V}\right]^2} + \sqrt{\left[\frac{T_0}{2}\right]^2 + \left[\frac{L - (X/2)}{V}\right]^2}$$

Therefore, total travel time T is given by the formula below.



Procedure

1- Apply static corrections

2- Sort traces into common offset gathers

3- Migration

4- Resort of traces

The migrated traces are sorted into Common CDP order.

1- Apply static corrections

2- Sort traces into common offset gathers

3- Migration

4- Resort of traces

5- Apply dynamic corrections (NMO)

1- Apply static corrections

2- Sort traces into common offset gathers

3- Migration

4- Resort of traces

5- Apply dynamic corrections (NMO)

6- Stack

Addition of migrated traces.

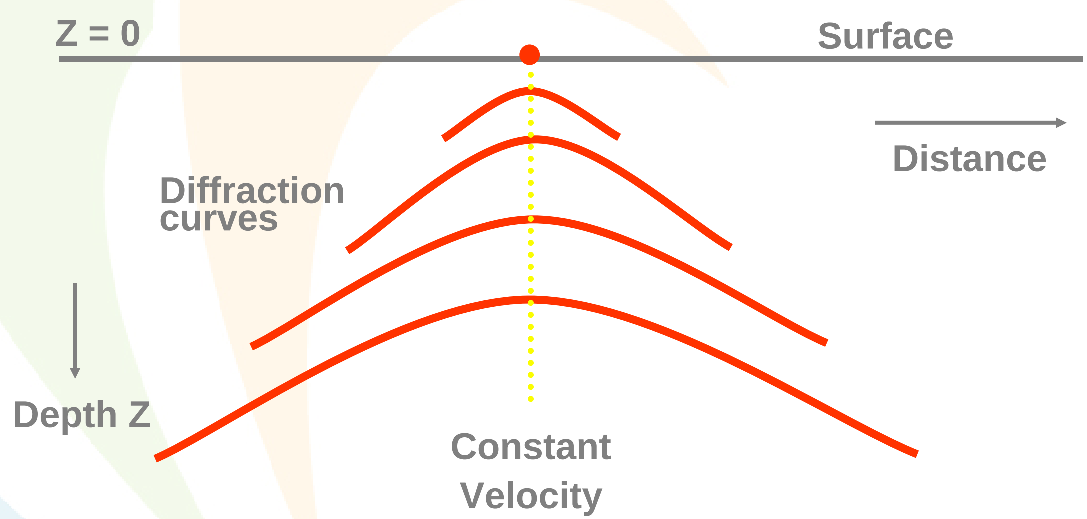
Finite Difference Migration - 1

Implemented in:

- t-x domain (WEMIG)
- f-x domain (FXMIG)

Consider how the shape of a diffraction curve changes with depth in a constant velocity depth model

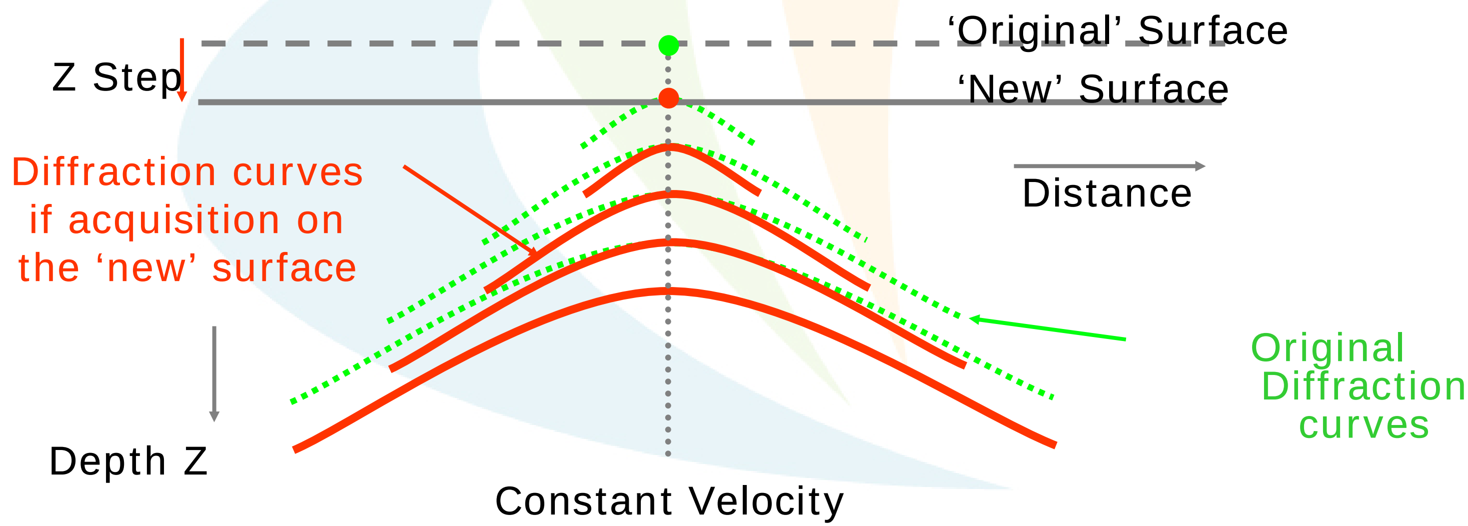
At the surface (z = 0) the curve is collapsed into a point



$$Z_n = (v_0 T_n)/2$$

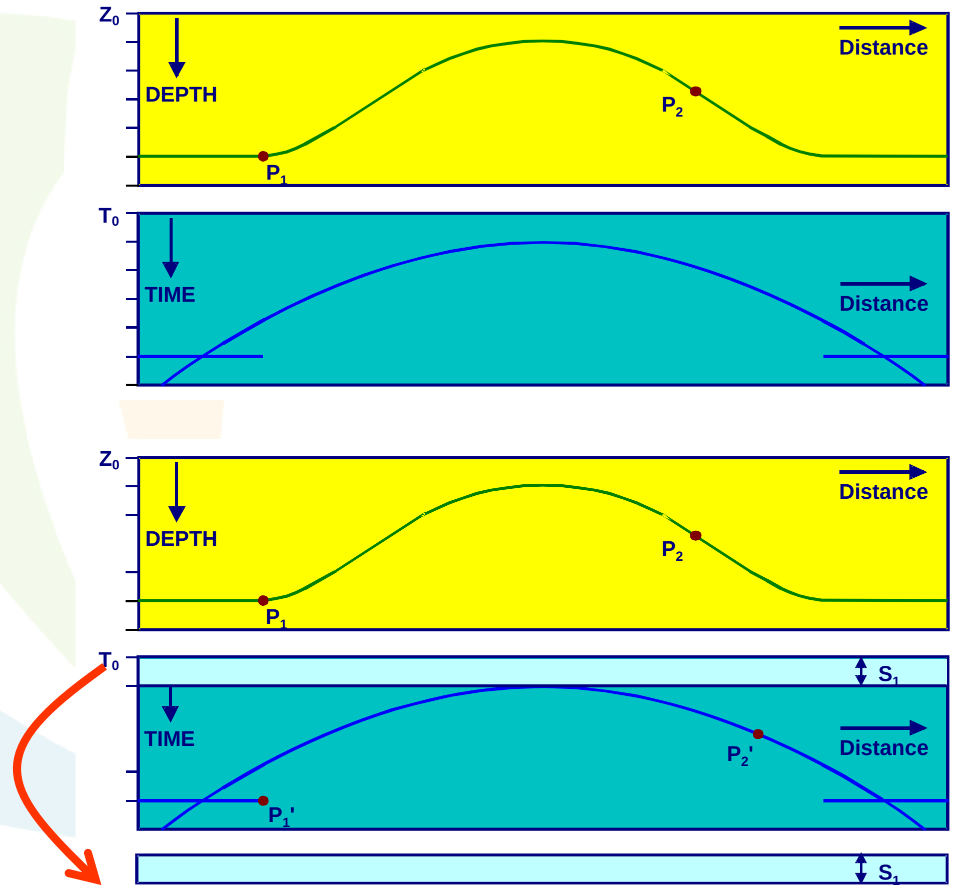
Finite Difference Migration - 2

- If all diffraction origin points could be placed at the surface then seismic energy is concentrated only at their points of origin (the apex of the curves) - the data is therefore migrated!
- The finite difference method uses a wave equation to 'strip off' layers of the earth (z steps) effectively projecting the source and receivers down to each successive layer



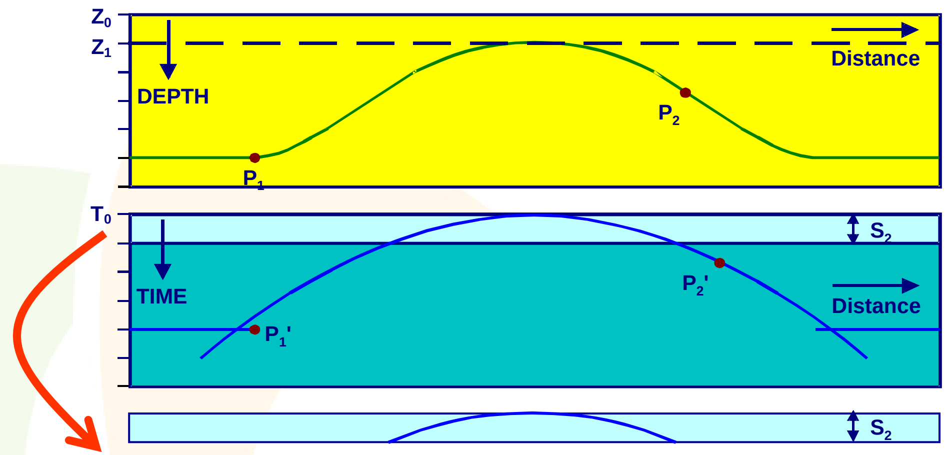
Finite Difference Migration - 3

- Consider a simple anticlinal model in depth and time
  - Points P_1 and P_2 are used as reference points to check how the migration is progressing
  - Starting at T=0 the first layer S_1 is stripped from the section and stored

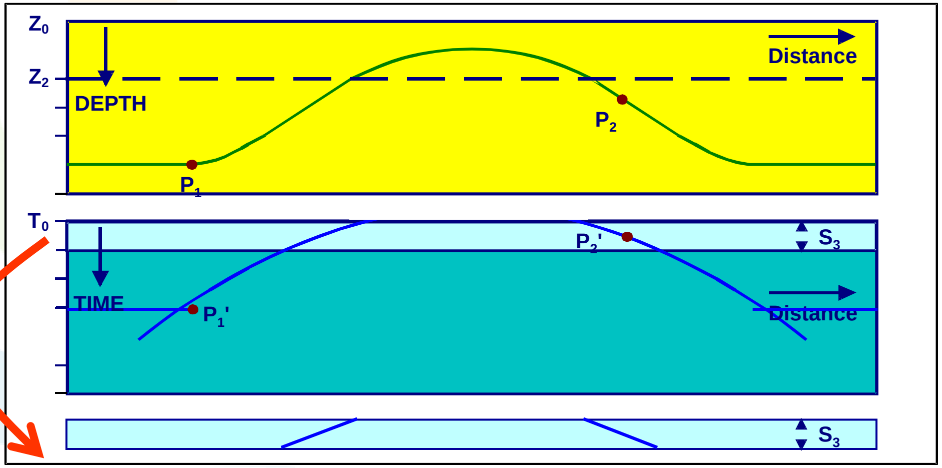


Finite Difference Migration - 4

- The receivers are next placed at depth Z_1 and the wavefield is recalculated: layer S_2 is then removed and stored

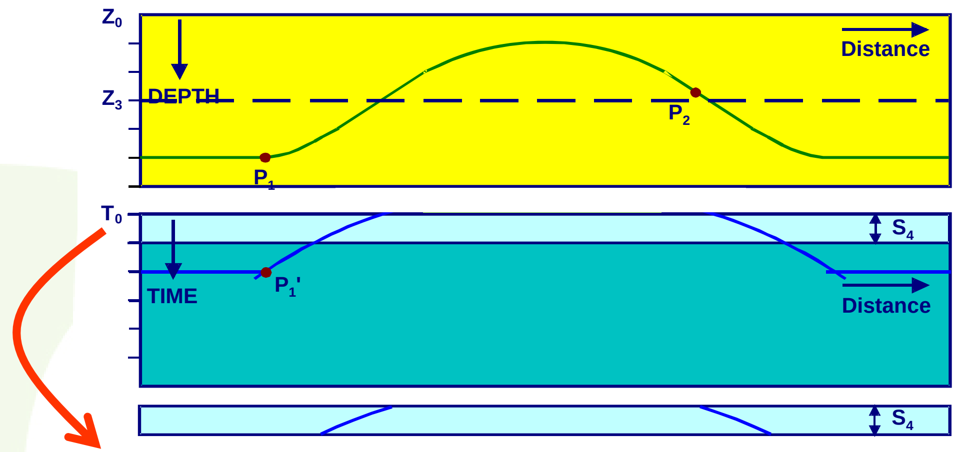


- The receivers are placed at depth Z_2 and the wavefield recalculated: layer S_3 is then removed and stored

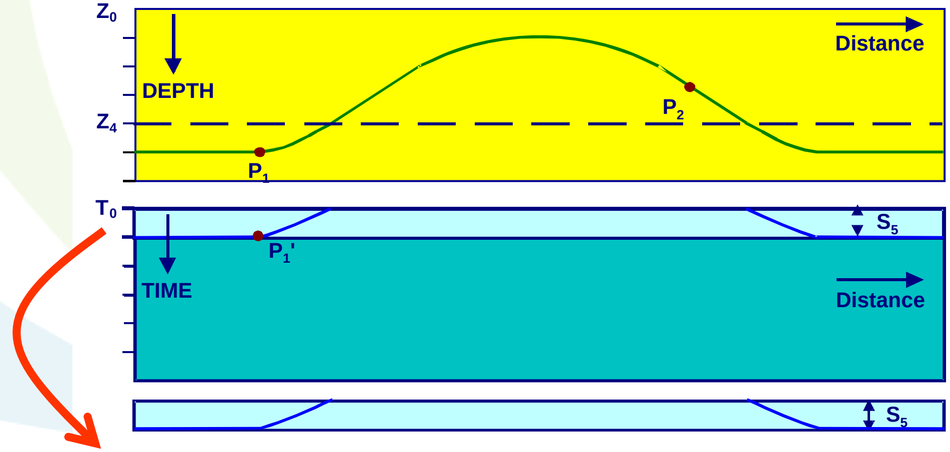


Finite Difference Migration - 5

- Repeat for depth Z_3 and layer S_4 ...



- ... and finally for depth Z_4 and layer S_5



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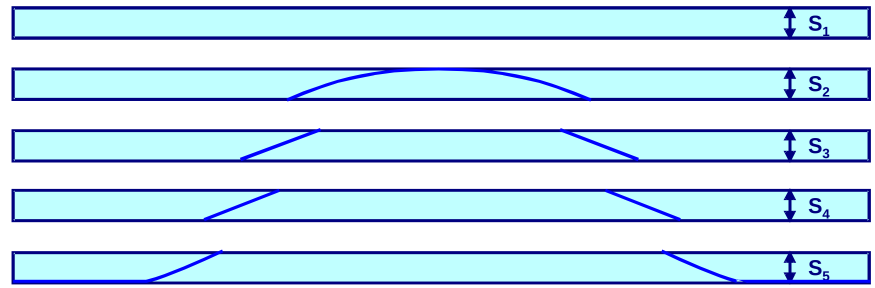
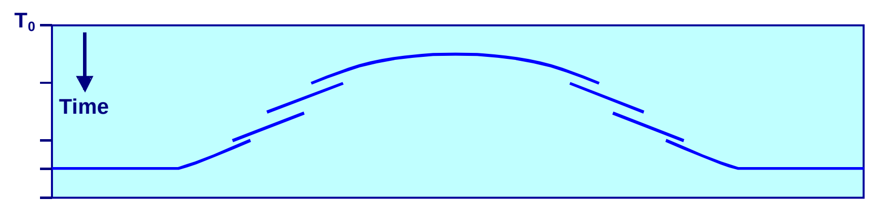
Finite Difference Migration - 6

- Collect together the time slices S_1, S_2, S_3, S_4, S_5 together…



- … and combine to form the migrated section

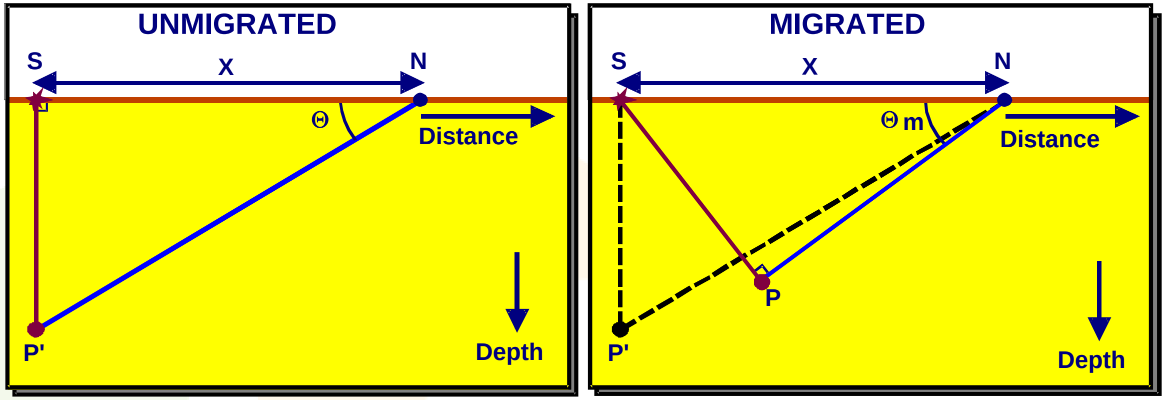


Frequency-Wavenumber (f-k) Migration

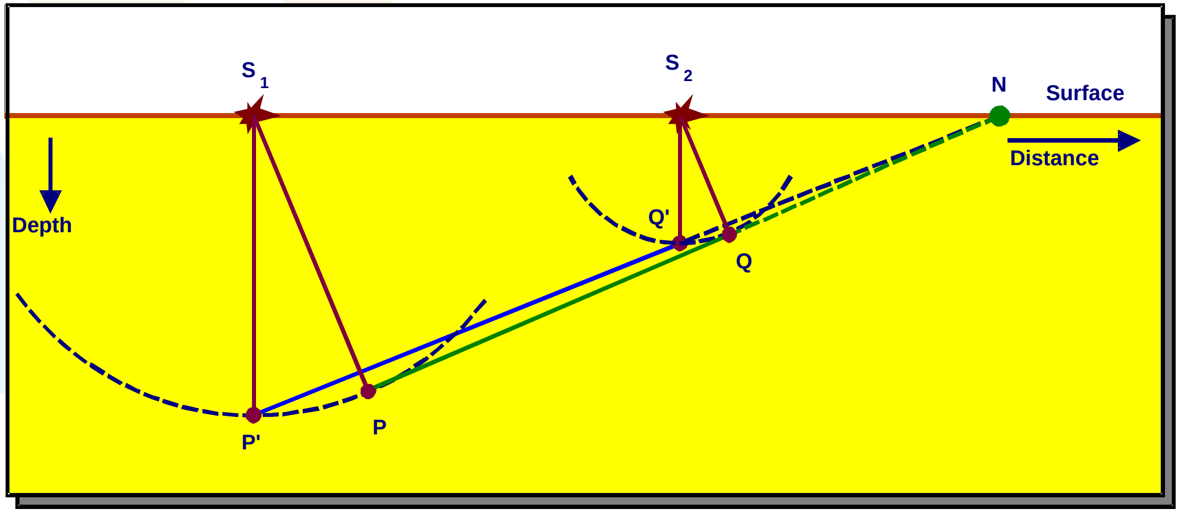
- f-k migration is based on the 2-D Fourier transform
- Migration performed in f-k space

Remapping the f-k Spectrum -

- Consider two time sections with the position of a dipping event pre- and post- migration
  - It can be shown that $\tan\theta = \sin\theta_m$



V = Velocity (Constant)



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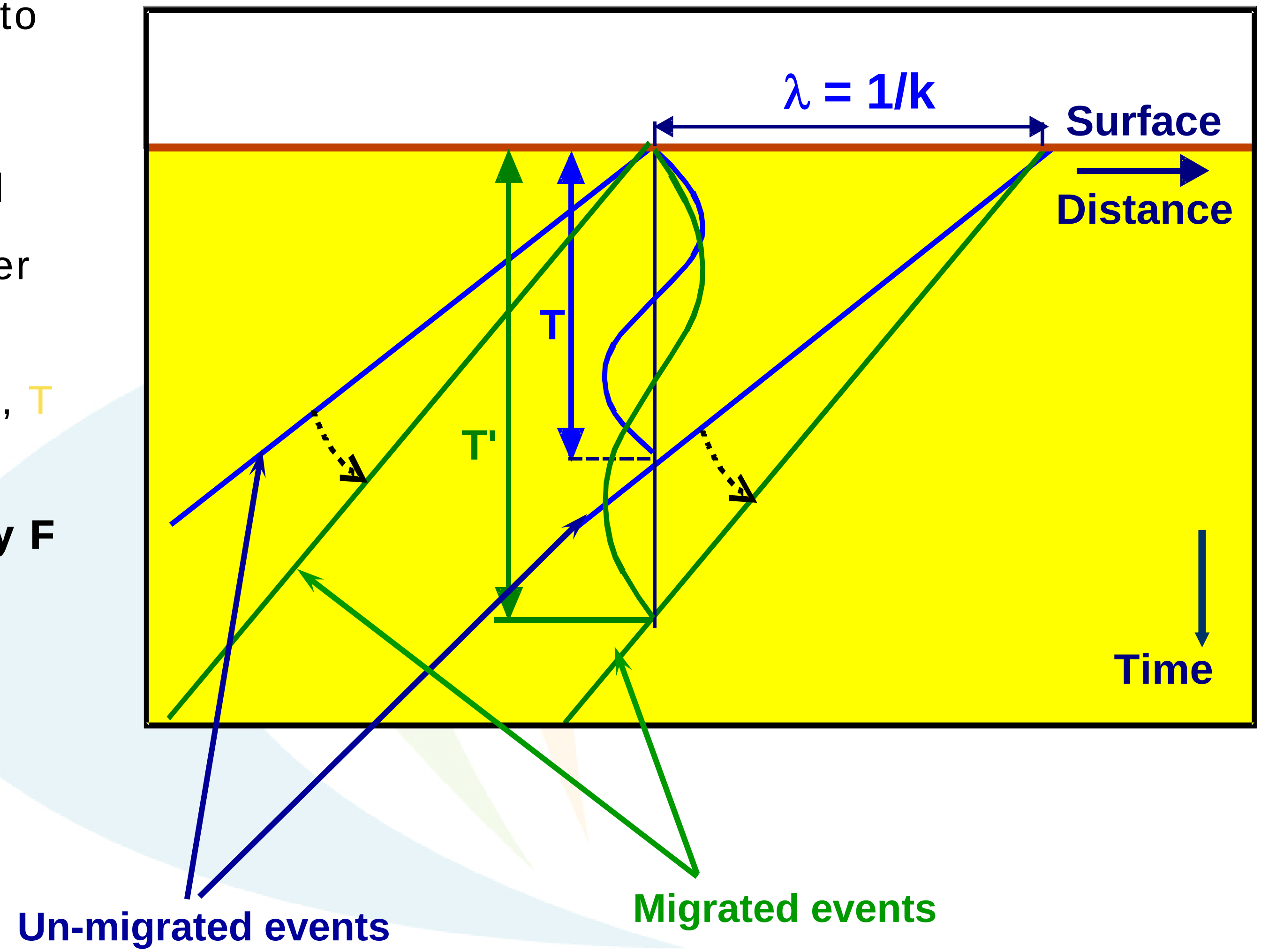
Remapping the f-k Spectrum - 3

- Consider what happens to the period of a wavelet during migration:
  - The apparent spatial wavelength λ (and thus the wavenumber k) is unchanged
  - The temporal period, T is increased to T’,
  - **thus the frequency F is reduced**



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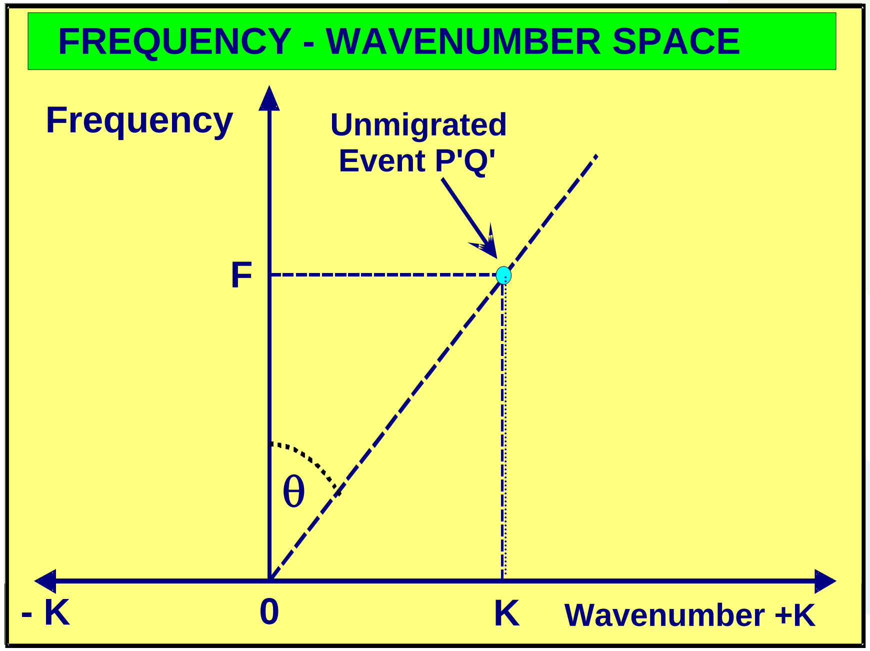
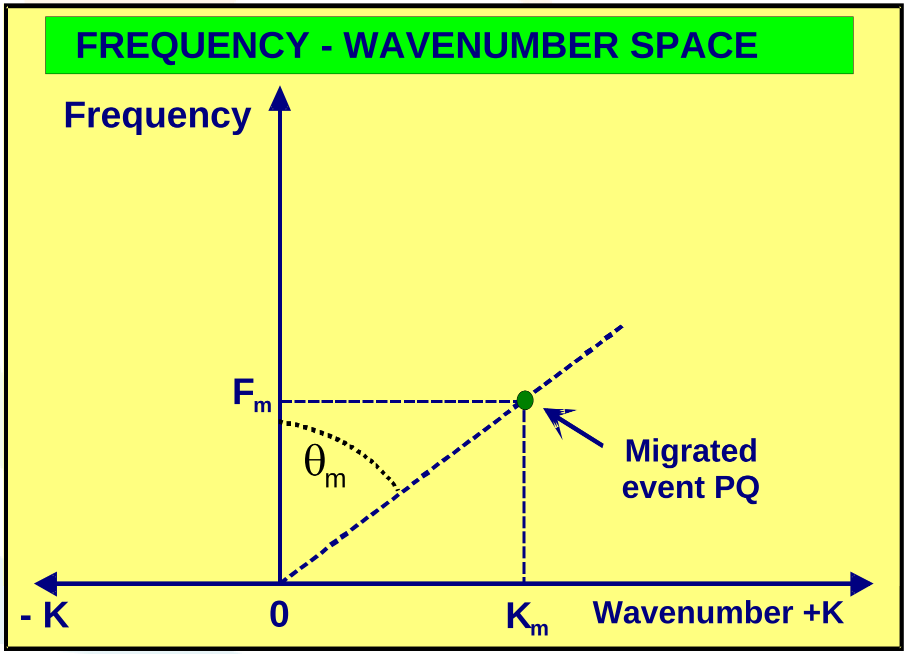
Remapping the f-k Spectrum - 4

- An un-migrated event in the f-k domain will plot thus:

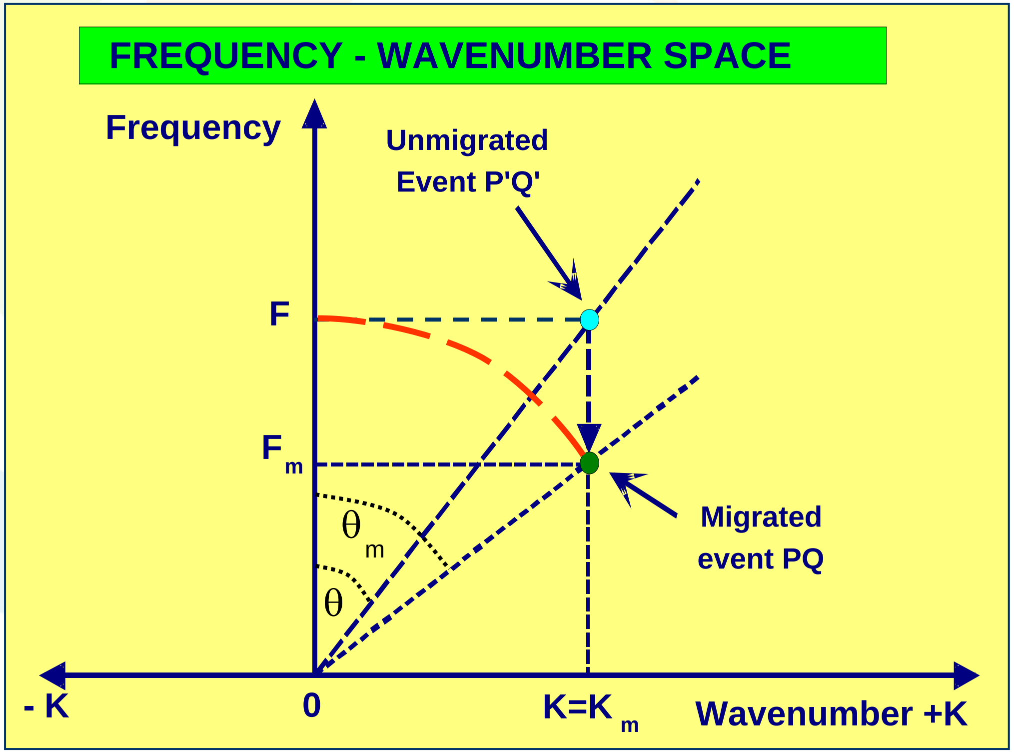


- After migration, the event will plot thus:

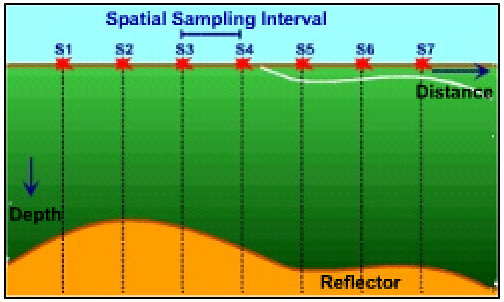


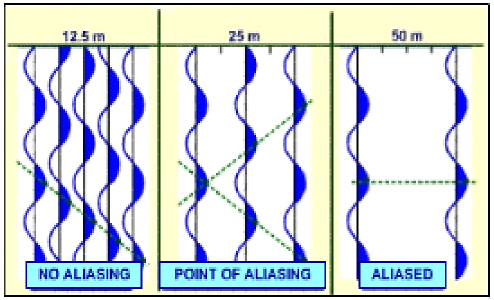
Remapping the f-k Spectrum - 5

- Migration in the f-k domain is a downwards vertical frequency shift



Aliasing and migration



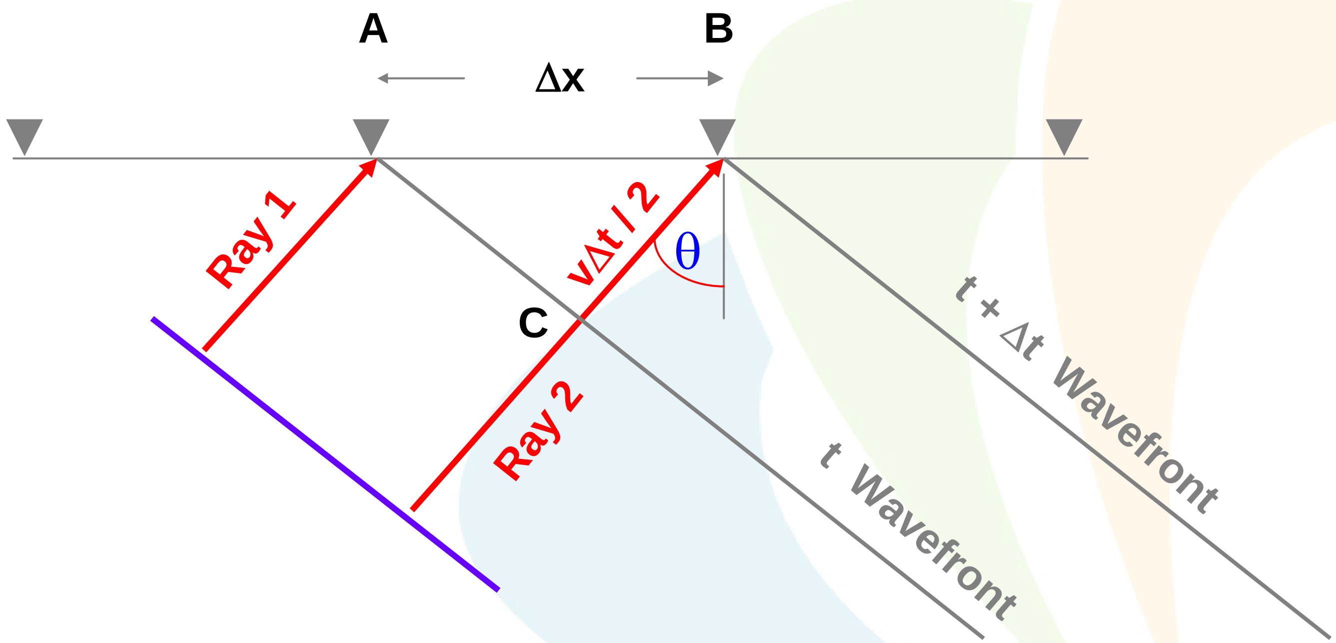


In this example , if the trace spacing is equal to or greater than 25 metres, both humans and machines would migrate some energy incorrectly.

At least 2CMPs within the apparent wavelength of the emerging wavefield

Spatial Aliasing - 1

- Consider the following emerging wavefield at surface:



sin θ = $v\Delta t / 2\Delta x$

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Spatial Aliasing - 2

At the alias point, the distance BC corresponds to half the alias period T_a

$BC = v\Delta t \,/\, 2$

$\Delta t = T_a/2$

$\sin\theta = v\Delta t \,/\, 2\Delta x$
$\quad\;\;\, = vT \,/\, 4\Delta x$

since $f_{max} = 1 \,/\, T_a$

$\sin\theta = v \,/\, 4\, f_{max}\, \Delta x$

therefore:

$f_{max} = v \,/\, 4\Delta x \sin\theta$

To avoid spatial aliasing:

$$\mathbf{2\Delta X < v\,/\,2 \sin\theta\, f_{max}}$$

Horizontally stratified media

Travel times of reflection move out on CMP gathers can be expressed as (Taner and Koehler 1969) :

$$t^2(x) = C_0 + C_1\, x^2 + C_2\, x^4 + \ldots + C_k\, x^{2k} + \ldots$$

With x offset and

$$C_1 = 1/v_{rms}^{\,2}$$

$$t^2(x) = t^2_0 + x^2/v^2_{rms}$$

If x << depth

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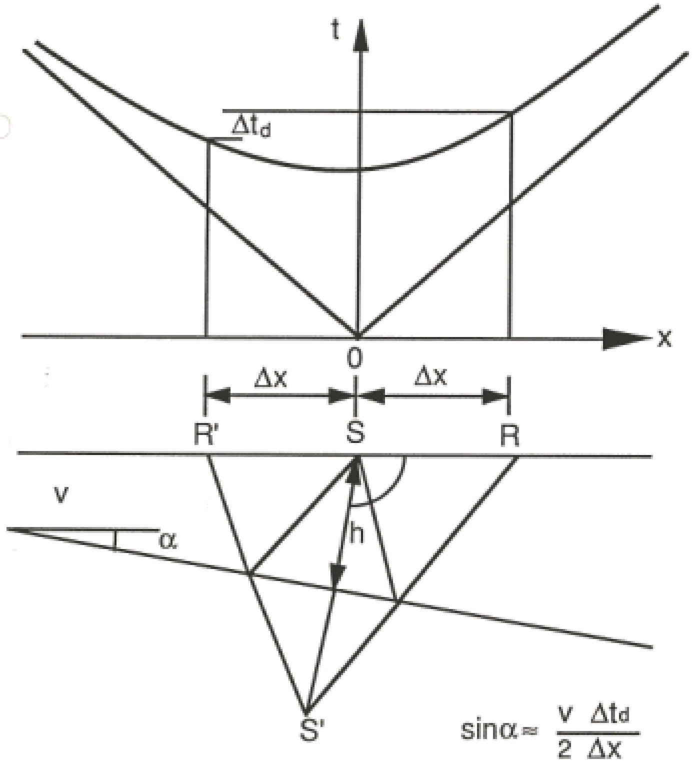
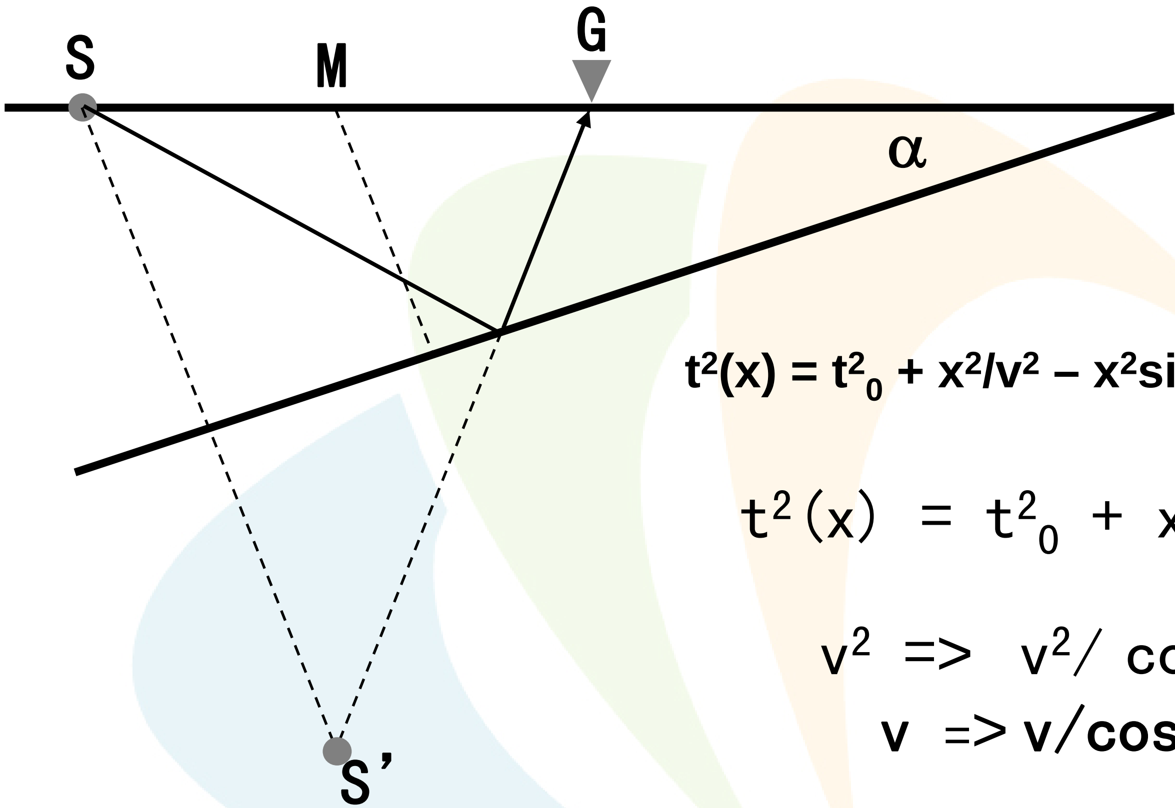
Dipping interface



Move Out for a Dipping Layer



$t^2(x) = t^2_0 + x^2/v^2 - x^2\sin^2\alpha/v^2$

$t^2(x) = t^2_0 + x^2 \cos^2\alpha/v^2$

$v^2 \Rightarrow v^2/\cos^2\alpha$

$v \Rightarrow v/\cos\alpha$

If more than 1 layer:

$V_{stack} = V_{rms}/\cos\alpha$

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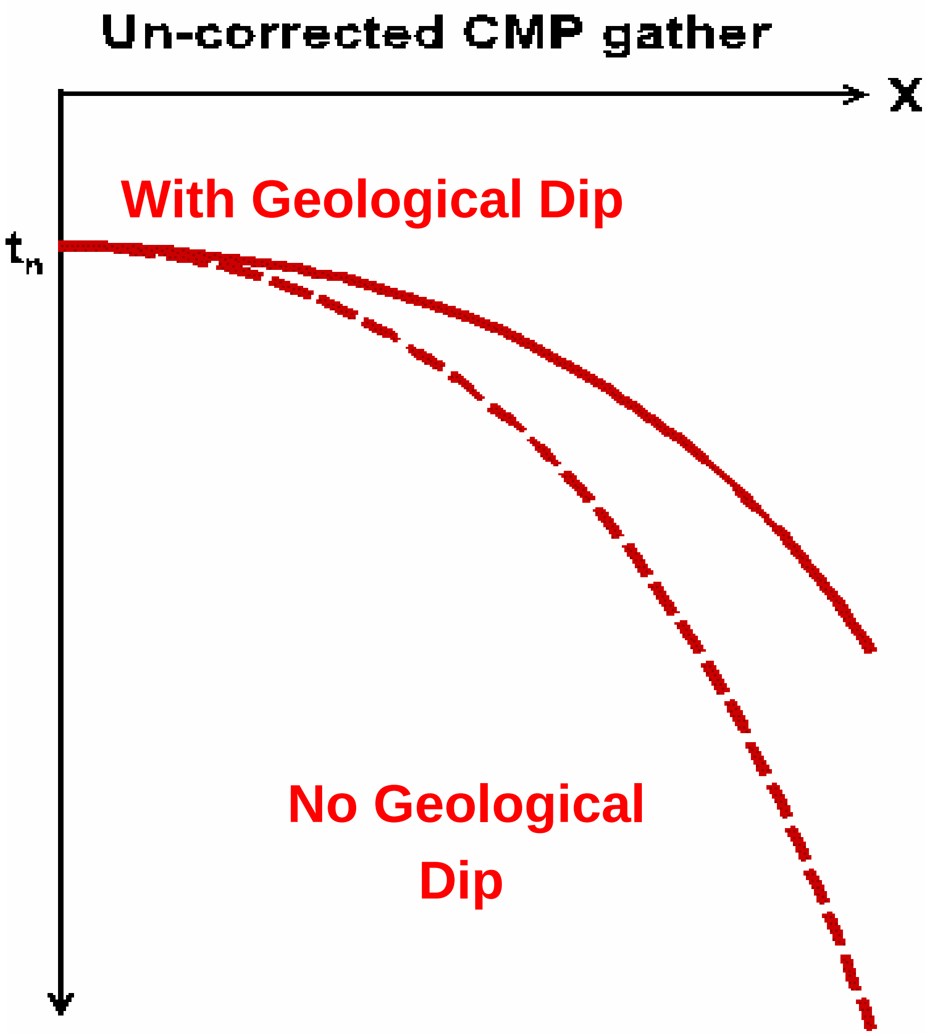
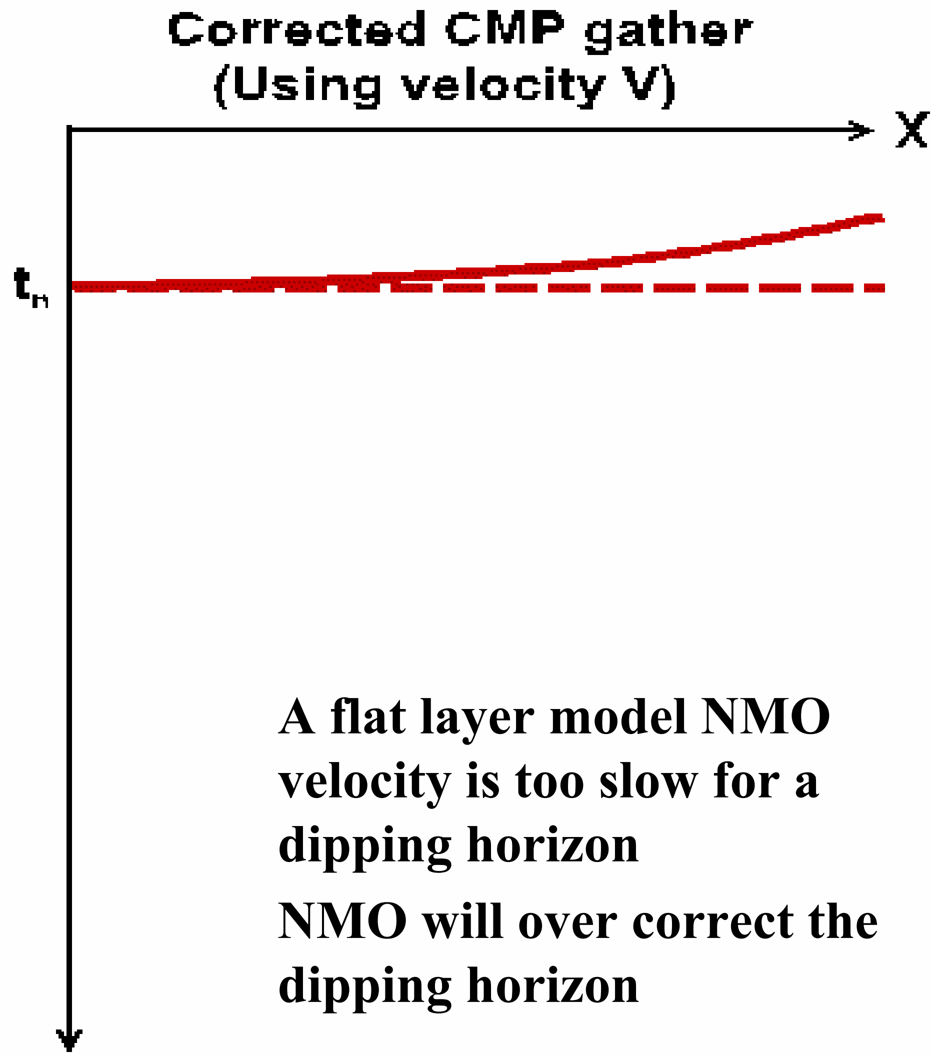
Normal Move Out without dip correction





A flat layer model NMO velocity is too slow for a dipping horizon

NMO will over correct the dipping horizon

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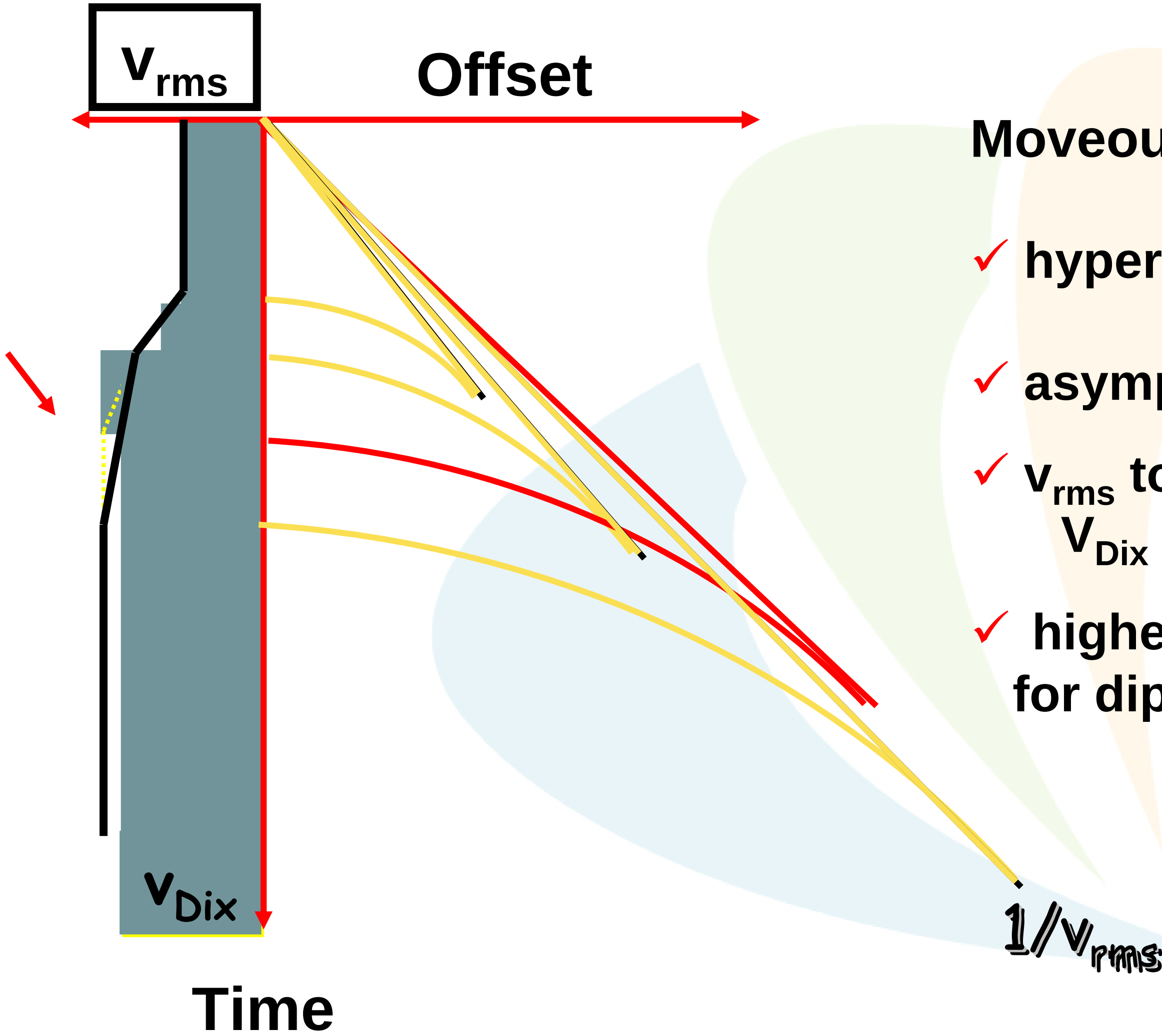
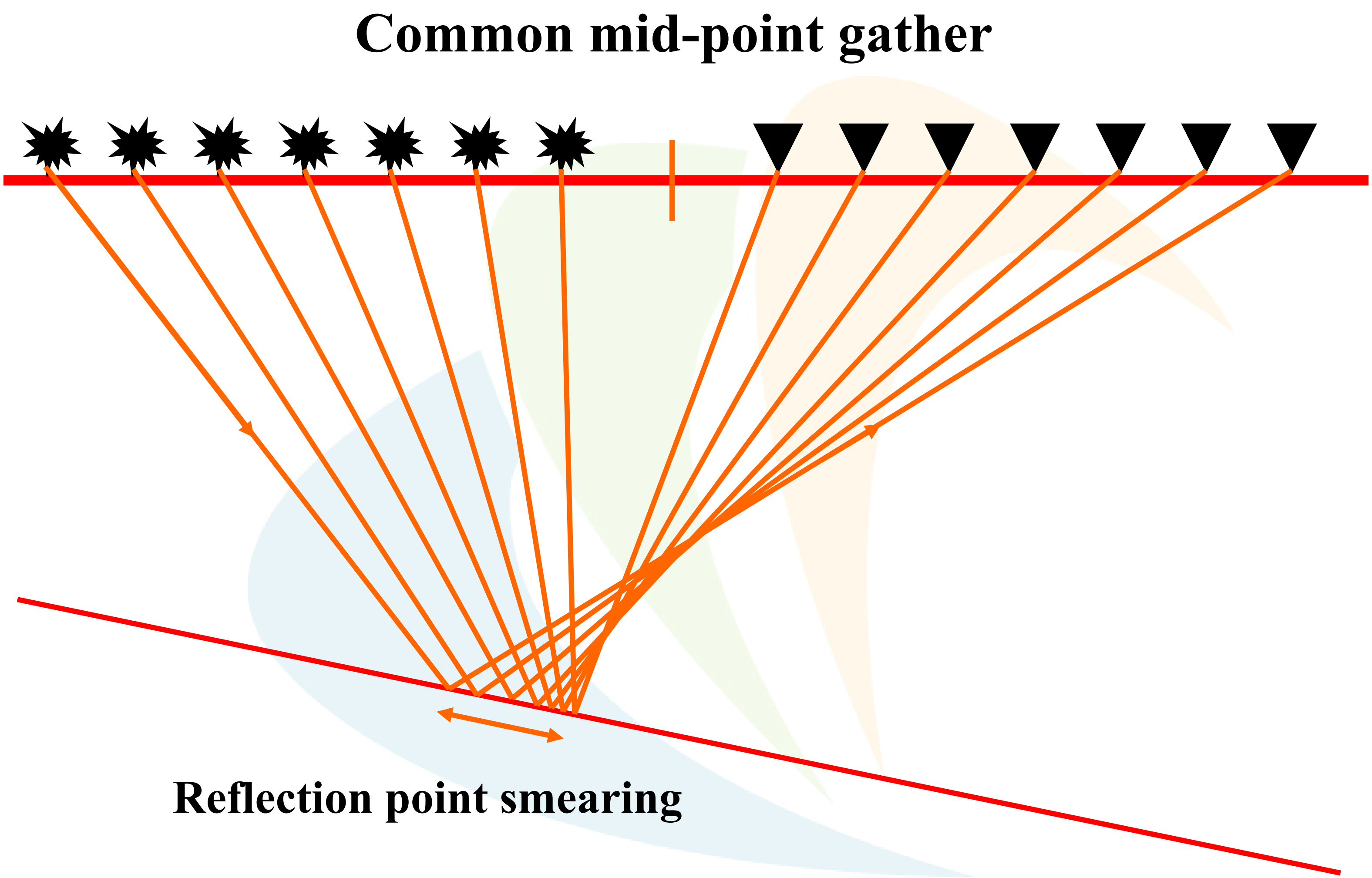
Effect of dip on Move Out



Moveout of reflection events:

- ✓ **hyperbola (offset<depth)**
- ✓ **asymptote $1/v_{rms}$**
- ✓ **v_{rms} to time interval velocity**
  $V_{Dix} = (V_{i+1}t_{i+1} - V_i t_i) / \Delta t$
- ✓ **higher apparent velocity for dipping events**

Dipping Reflectors



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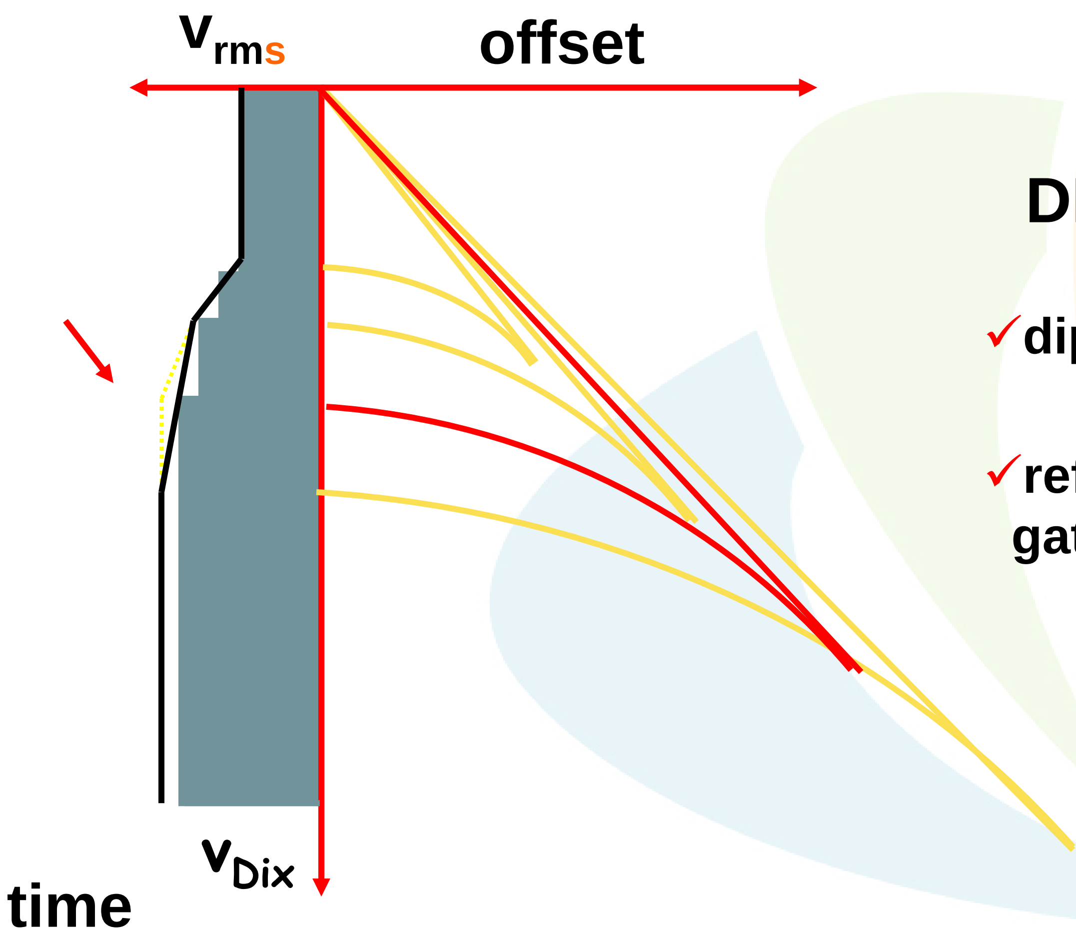
Moveout (NMO+DMO)

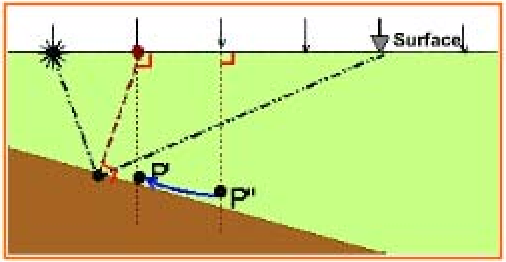


DMO correction removes:

- ✓ dip-dependency in velocity field
- ✓ reflection point smearing in the gather

NMO+DMO corrections transforms non-zero offset data into zero offset data (TZO)

DMO+NMO corrections and post stack migration



D.M.O. is a dynamic correction which takes into account structural dip.

It is a partial migration carried out before stack on groups of constant offset traces.

Dip MoveOut Geometry - 4

It can be shown that...

$$\Delta = \frac{x^2}{D}\cos\phi\sin\phi$$

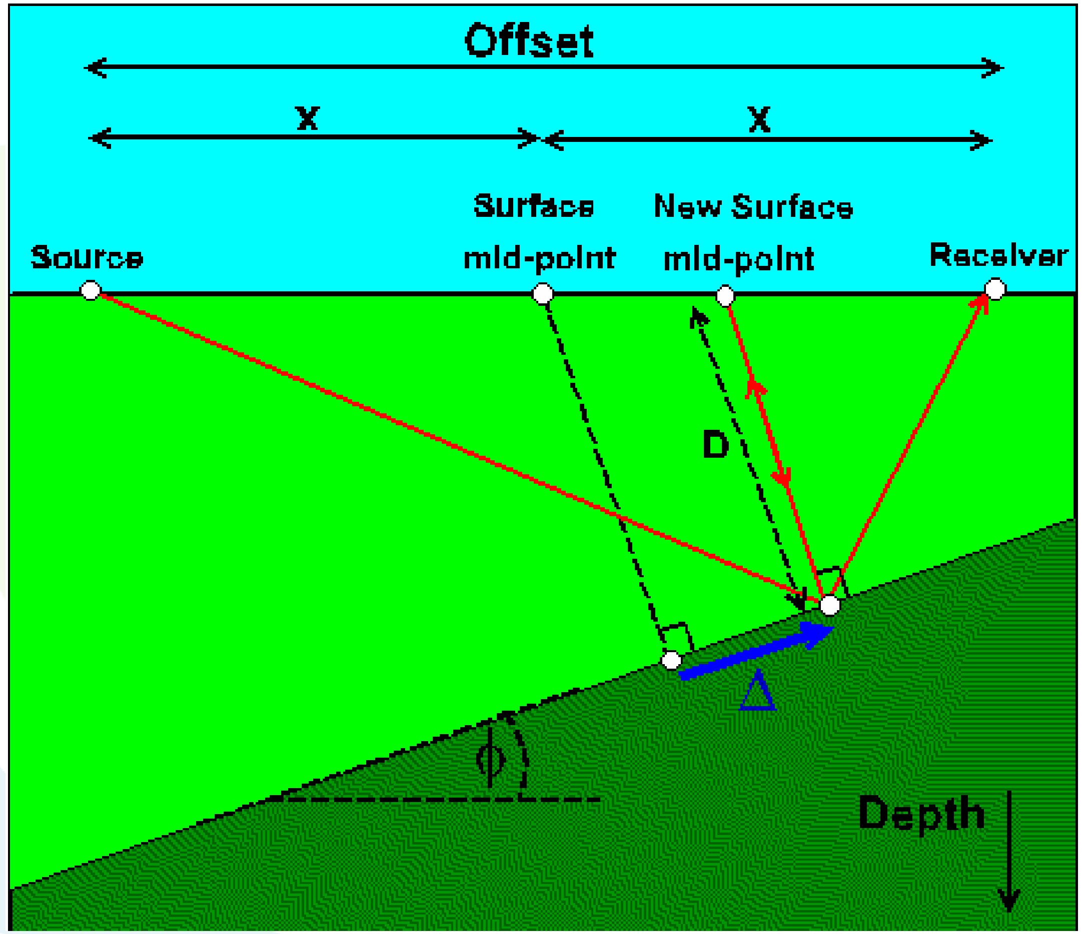
Where...

Δ = moveout up dip

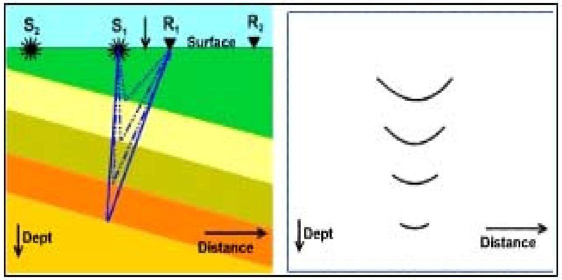
x = half source-receiver offset

D = depth to reflector at the midpoint (along normal)

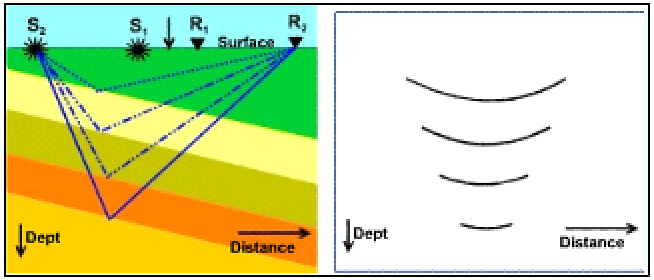
ϕ = local dip of reflector



DMO operator – same dip, different depths



Here is the effect of a DMO operator on the events recorded on a trace with a short offset S1 to R1



And here the effect of a DMO operator on the events recorded on a trace with a long offset S2 to R2.