Geometrical Seismics

Reflection

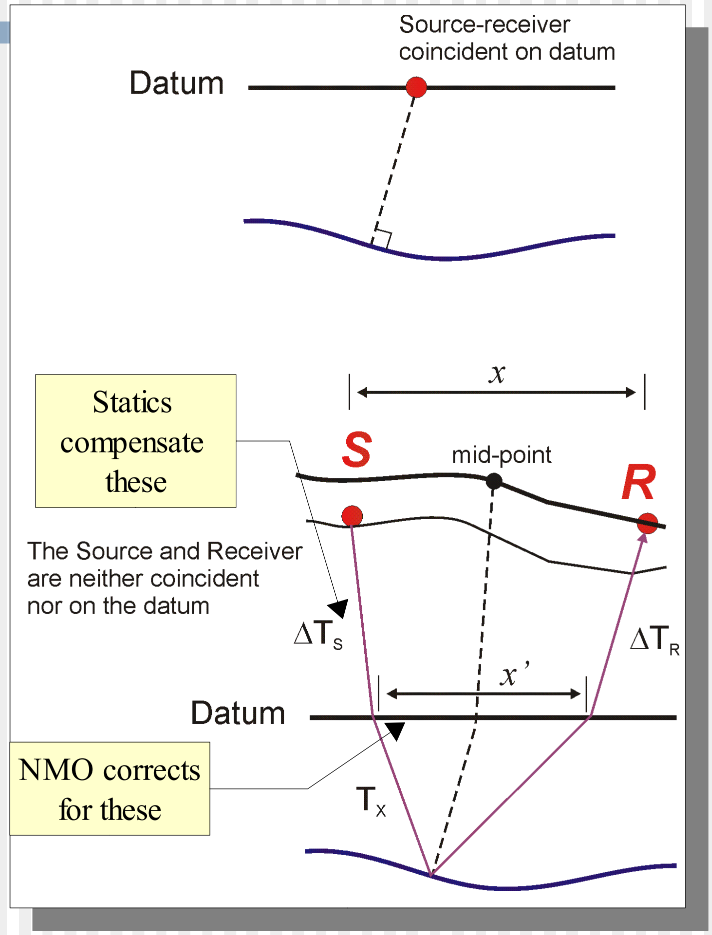
- Normal moveout (NMO)
- Normal moveout correction
- Dip moveout (DMO)

- <u>Reading:</u>
  - Sheriff and Geldart, Chapter 4.1.

Zero-Offset Section

(*The goal of reflection imaging*)

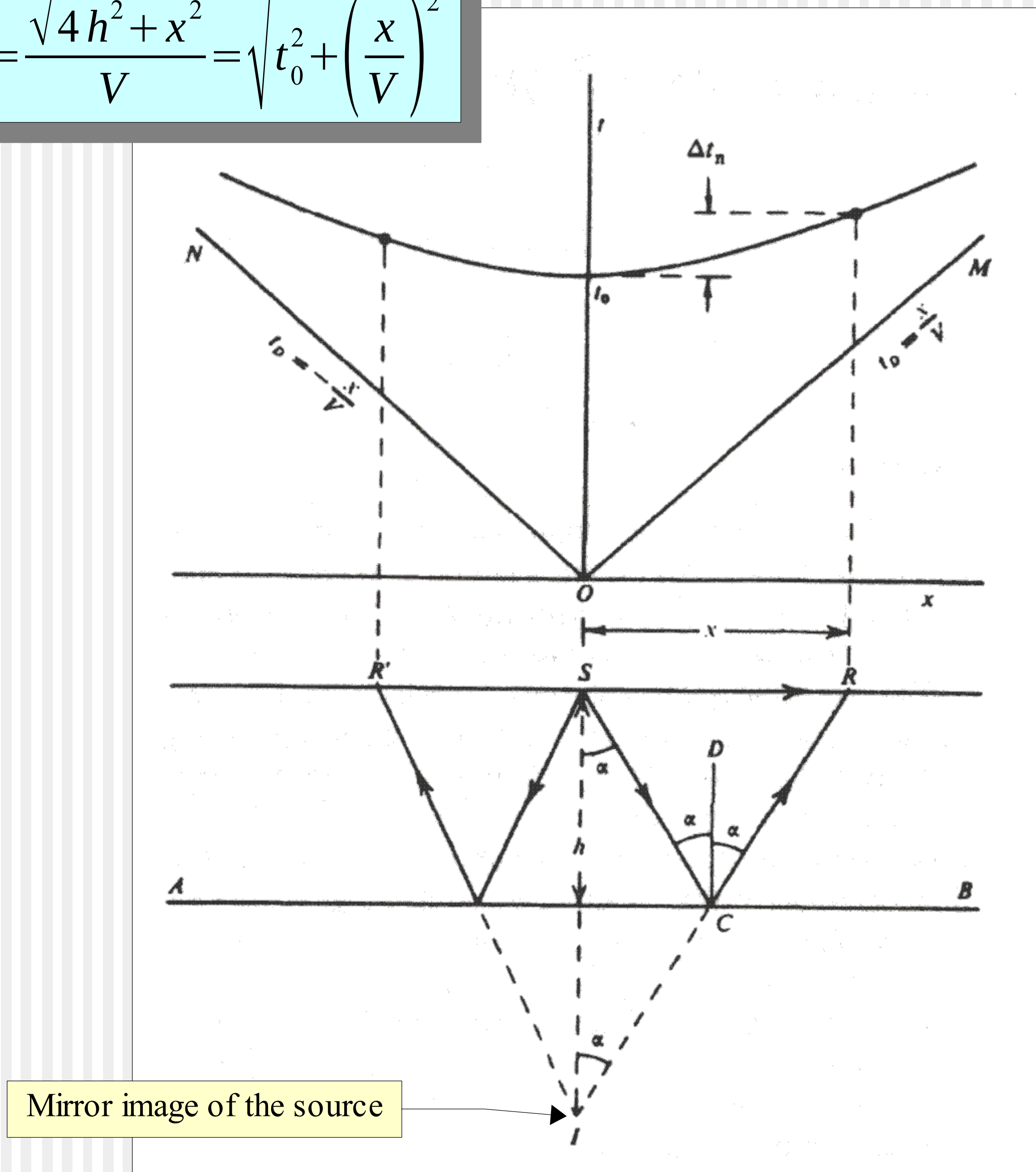
- **The Ideal of reflection imaging** *is sources* and receivers *collocated* on a flat horizontal surface ("*datum*").
- In reality, however, we record at *source-receiver offsets*, and over complex topography.
- **Two types of corrections** are applied to compensate these factors:
    - Statics "place" sources and receivers onto the datum;
    - Normal Moveout Corrections "transforms" the records into as if they were recorded at collocated sources and receivers.
- **As a result** of these corrections (plus stacking to attenuate noise), we obtain a *zero-offset section*.



Normal moveout

- Symmetrical hyperbola
- Reflected rays propagate as if from a source at depth

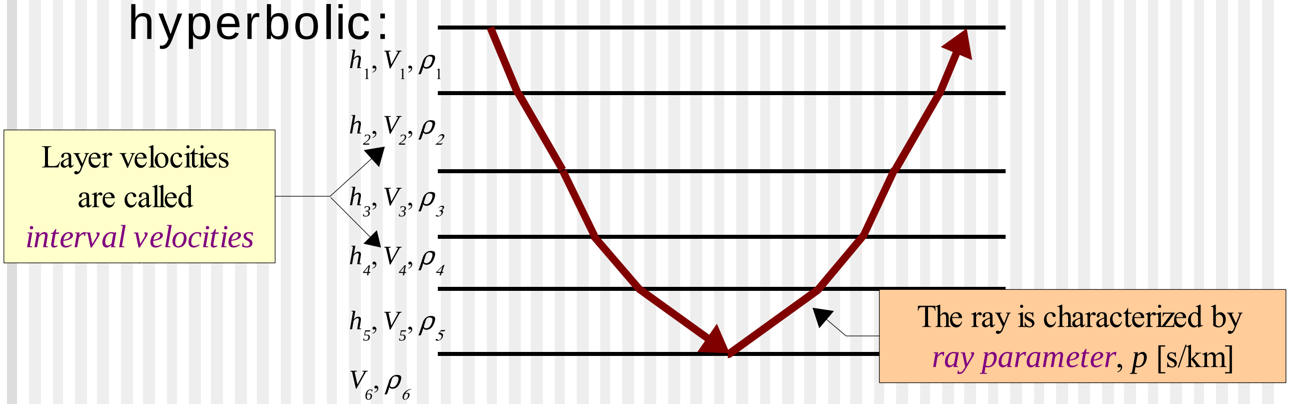
$$t(x) = \frac{\sqrt{4h^2 + x^2}}{V} = \sqrt{t_0^2 + \left(\frac{x}{V}\right)^2}$$



Reflection travel-times

(*Multiple layers*)

- For multiple layers, $t(x)$ is no longer hyperbolic:



- For practical applications (near-vertical incidence, $pV_i << 1$), $t(x)$ still can be approximated as:

$$x_n(p) = \sum_{i=1}^{n} \frac{h_i p V_i}{\sqrt{1-(pV_i)^2}} \approx p \sum_{i=1}^{n} h_i V_i \left[1 + \frac{1}{2}(pV_i)^2\right] \approx p \sum_{i=1}^{n} h_i V_i ,$$

hence: $$p = \frac{x_n(p)}{\sum_{i=1}^{n} h_i V_i},$$

$$t_n(p) = \sum_{i=1}^{n} \frac{h_i}{V_i \sqrt{1-(pV_i)^2}} \approx \sum_{i=1}^{n} \frac{h_i}{V_i}\left[1 + \frac{1}{2}(pV_i)^2\right] = t_0 + \frac{1}{2} p^2 \sum_{i=1}^{n} h_i V_i$$

$$t_n(x) \approx t_0 + \frac{1}{2t_0}\left(\frac{x}{V_{RMS}}\right)^2$$

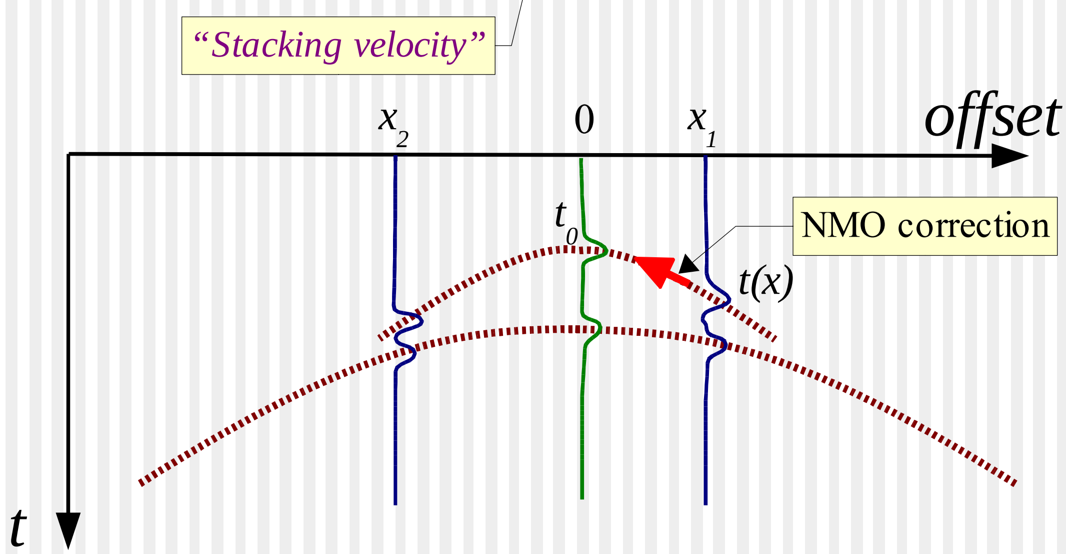
- here, V_{RMS} is the RMS (root-mean-square) velocity:

$$V_{RMS} = \sqrt{\frac{\sum_{i=1}^{n} h_i V_i}{t_0}} = \sqrt{\frac{\sum_{i=1}^{n} t_i V_i^2}{\sum_{i=1}^{n} t_i}}.$$

Normal Moveout (NMO) correction

- NMO correction transforms a reflection record at offset *x* into a normal-incidence (*x*=0) record:

$$t(x) \rightarrow t_0 = \sqrt{t^2(x) - \left(\frac{x}{V}\right)^2} \approx t(x) - \frac{1}{2t(x)}\left(\frac{x}{V}\right)^2$$

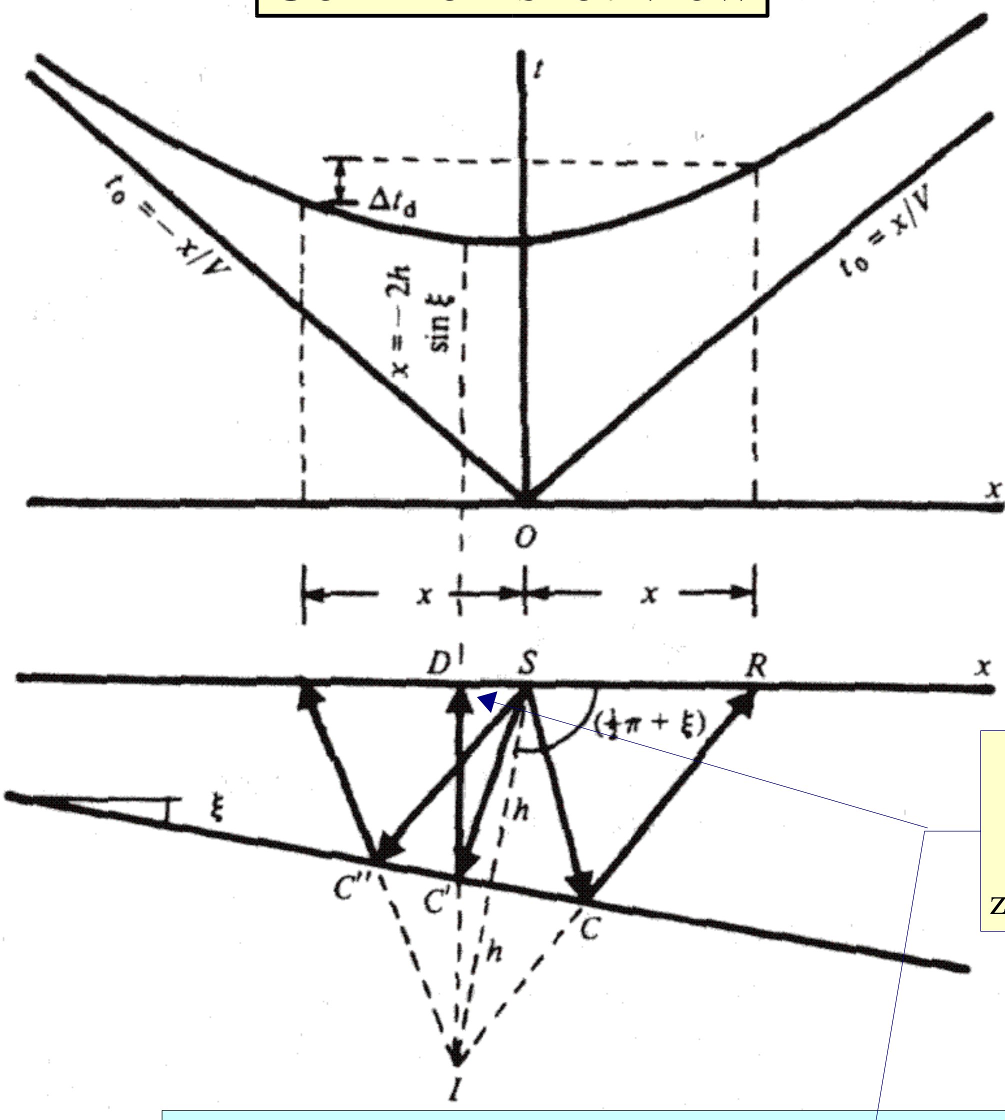


- *Stacking velocity* is determined from the data, as a parameter of the reflection hyperbola that is best aligned with the reflection event
- Note that NMO correction affects the shallower and slower reflections stronger
  - This is called "*NMO stretching*"

Dipping reflector

- Hyperbola of the same shape but with the apex shifted up-dip
- Asymptotically the same moveouts

Common-shot view



t_0 is the minimal time, not the zero-offset time!

$$t(x) = \frac{\sqrt{4h^2 + (x + 2h\sin\xi)^2}}{V} = \sqrt{t_0^2 + \left[\frac{(x + 2h\sin\xi)}{V}\right]^2}$$

Dip moveout

- For small offsets ($x << h$) and dips ($h \sin \xi << x$):

Note: $2h = t_0 V$

$$t(x) = \sqrt{t_0^2 + \left[\frac{(x + 2h\sin\xi)}{V}\right]^2} \approx t_0\left[1 + \frac{x^2 + 4hx\sin\xi}{2(t_0 V)^2}\right].$$

$$t(x) \approx t_0 + \frac{x^2}{2t_0V^2} + \frac{x\sin\xi}{V}.$$

Apex ≈ Zero-offset time

Normal moveout term

Dip moveout term

- Reflector dip ξ can be measured from the *dip moveout*:

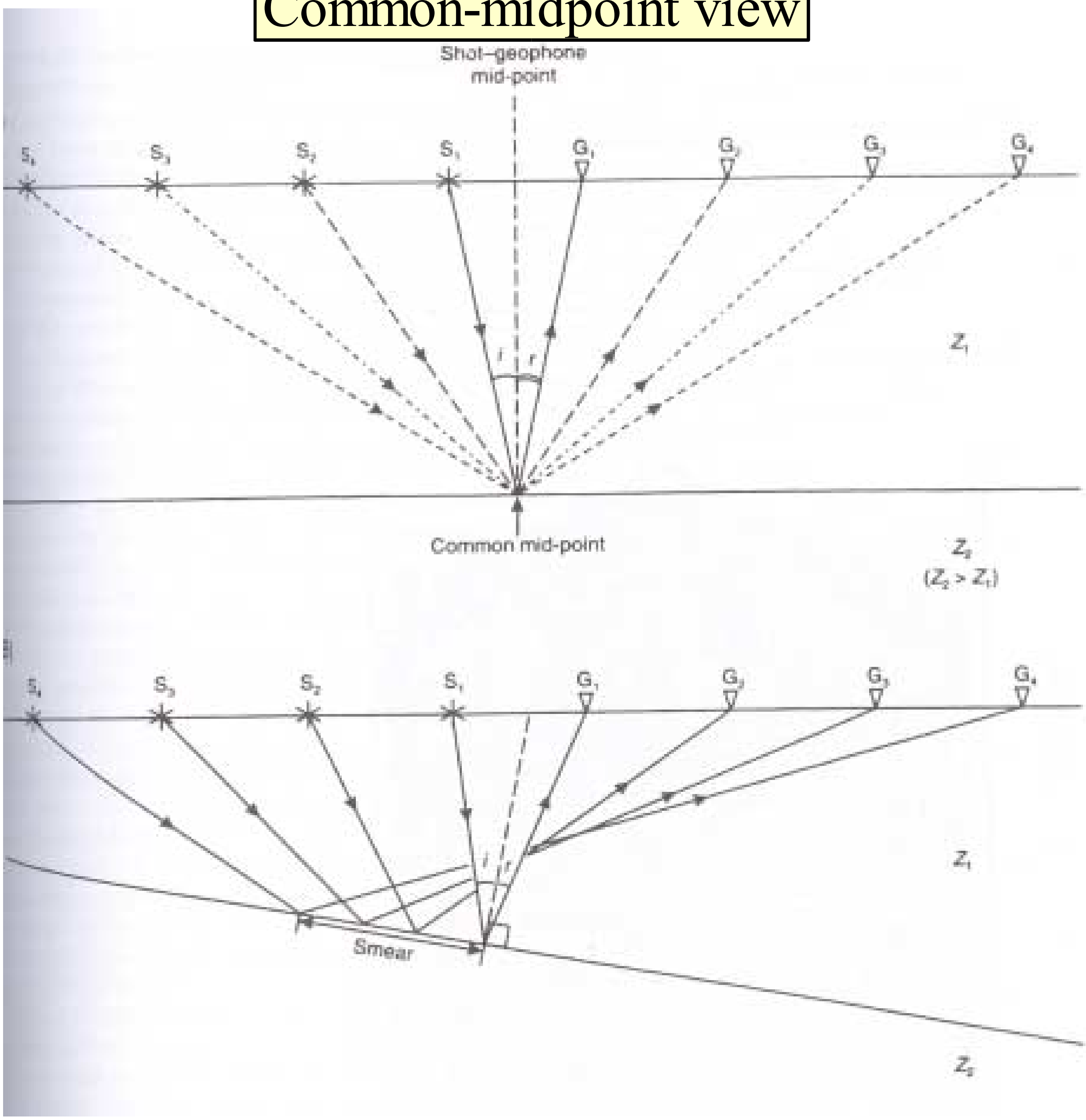
$$\sin\xi \approx \frac{V}{2}\frac{t(x) - t(-x)}{x} \equiv \frac{V}{2}\frac{t_{Downdip} - t_{Updip}}{x}.$$

This ratio is also called *Dip Moveout*

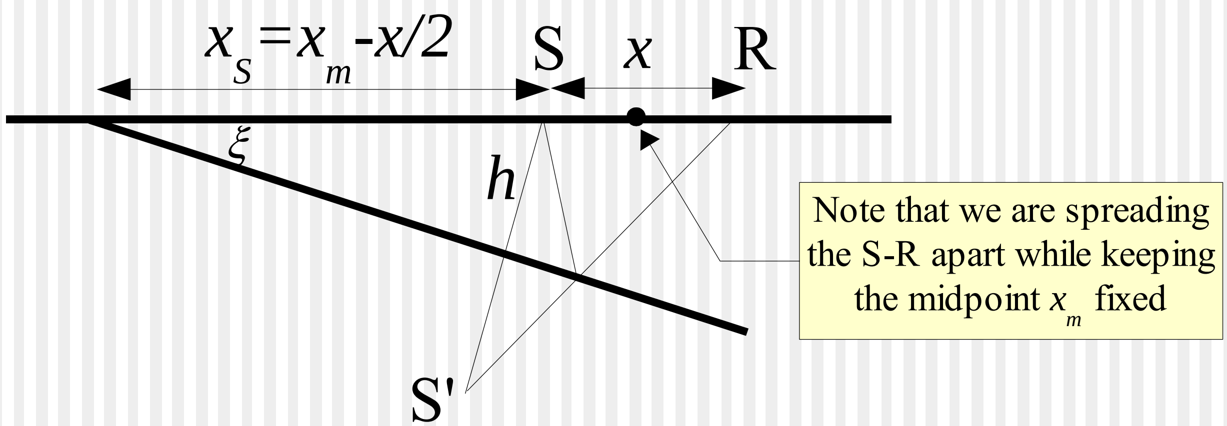
Dip moveout in CMP gathers

- The travel-time hyperbola becomes ***symmetrical***
- Reflection points are ***smeared*** up-dip with increasing offset
- Asymptotic velocities *are* ***greater*** than the true velocity

Common-midpoint view



Stacking velocity in the presence of dip



- If the coordinates are measured from the surface projection of the reflector plane, then the apex time, as a function of the source coordinate, is:

$$t_0(x_S) = \frac{2h(x_S)\cos\xi}{V} = \frac{2x_S\sin\xi}{V} = \frac{2\left(x_m - x/2\right)\sin\xi}{V}.$$

- Therefore, for a fixed x_m, the dependence of the S-R time on the offset x is

$$t(x) = \frac{1}{V}\sqrt{\left(x + 2h\sin\xi\right)^2 + \left(2h\cos\xi\right)^2}$$

$$t(x) = \frac{1}{V}\sqrt{\left[x + (2x_m - x)\sin^2\xi\right]^2 + \left[(2x_m - x)\sin\xi\cos\xi\right]^2}$$

$$t(x) = \frac{1}{V}\sqrt{\left(2x_m\sin\xi\right)^2 + \left(x\cos\xi\right)^2}$$

continued...

CMP Stacking velocity in the presence of dip (*cont.*)

- This equation describes a hyperbola similar to the NMO equation (compare:
  $$t_{NMO}(x) = \sqrt{t_0^2 + \left(\frac{x}{V}\right)^2}$$):

$$t(x) = \frac{1}{V}\sqrt{\left(2x_m \sin\xi\right)^2 + \left(x\cos\xi\right)^2} = \sqrt{\left(\frac{2x_m \sin\xi}{V}\right)^2 + \left(\frac{x\cos\xi}{V}\right)^2}$$

Zero-offset time

Hyperbolic moveout

- Thus, because of the dip, the effective velocity is increased:

$$V_{Dip} = \frac{V}{\cos\xi}.$$

- This means that when stacking velocities are measured from a CMP gather, dipping reflectors will result in higher velocities (flatter reflection hyperbole)
- As a result, reflectors with conflicting dips cannot be NMO-corrected and stacked accurately.
  - Processing step called ***DMO*** corrects this problem.