Geometrical Seismics

Basic concepts of Reflection imaging

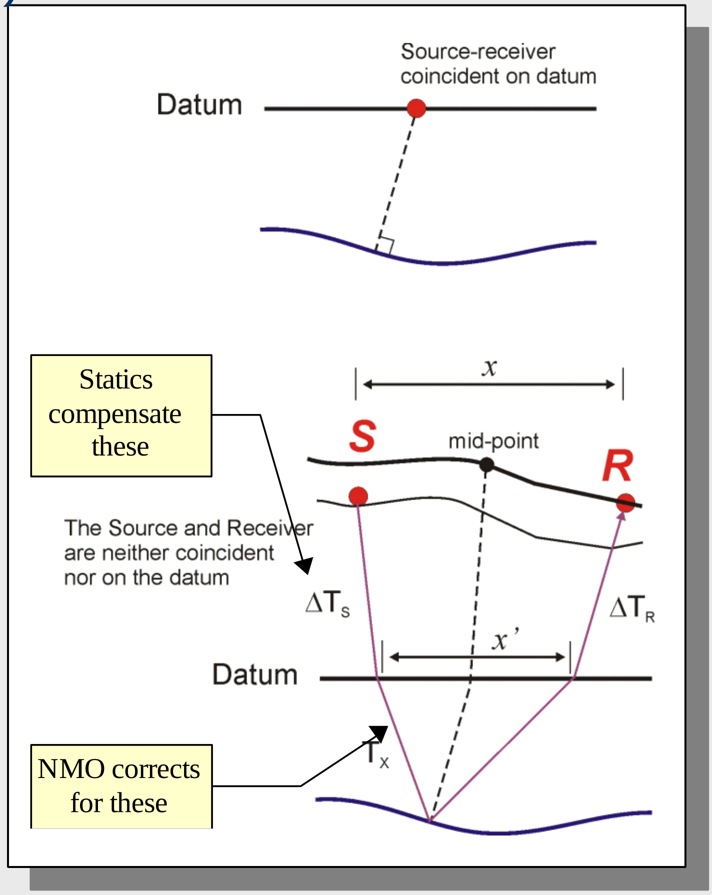
- Normal moveout (NMO)
- Normal moveout correction
- Dip moveout (DMO)

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

Zero-Offset Section

(Ideal picture and of reflection imaging and the goal of "CMP stacking")

- **The Ideal of reflection imaging** (if not talking about AVO) consists in *sources* and receivers *collocated* on a flat horizontal surface ("*datum*")
- However, in reality, we record at finite *source-receiver offsets*, over complex topography, and in complex near-surface structure.



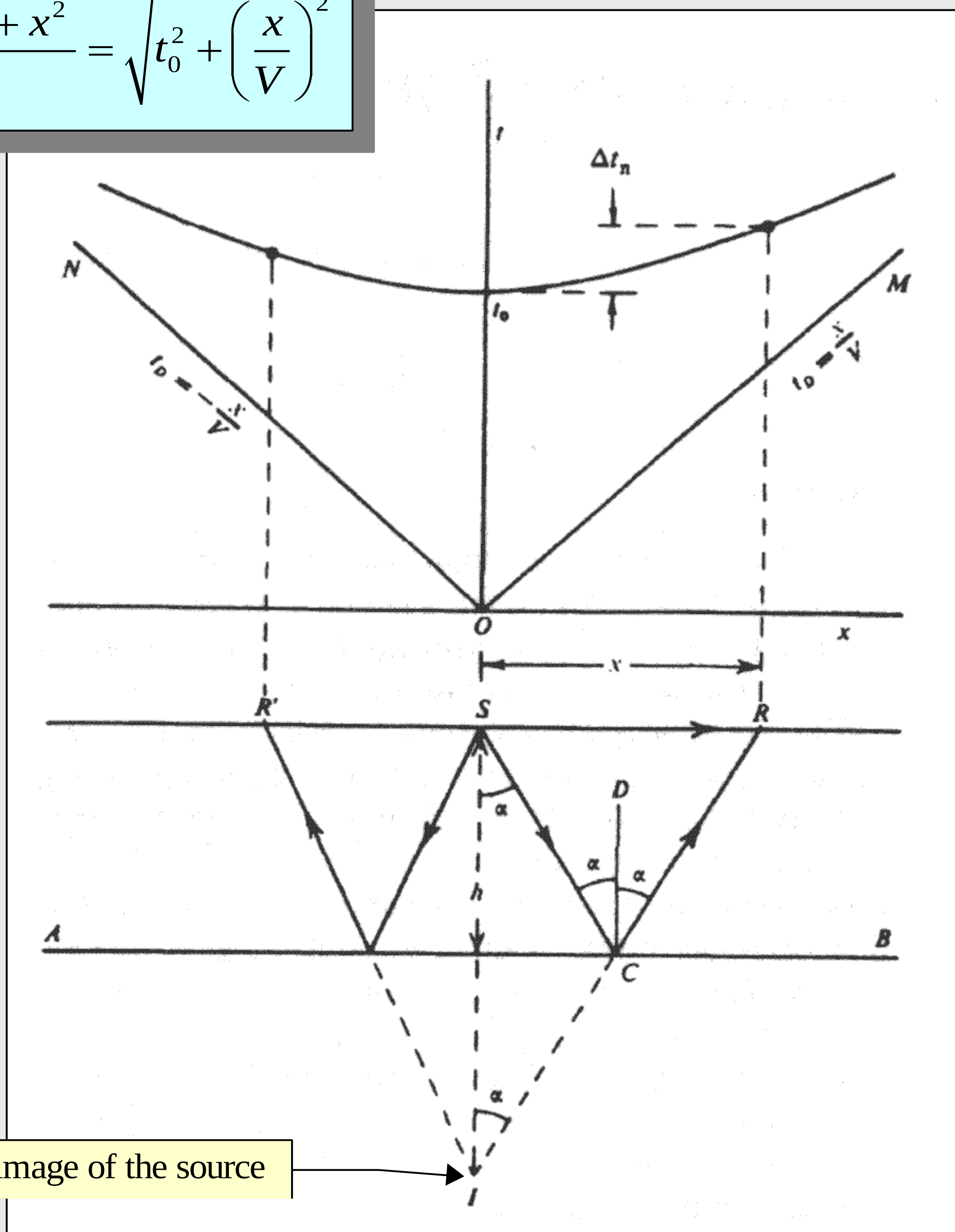
- In the "CMP stacking"-type imaging, **two types of corrections** are applied to compensate these factors:
  - Statics "place" sources and receivers onto the datum;
  - Normal Moveout Corrections "transforms" the records into as if they were recorded at collocated sources and receivers.
- **As a result** of these corrections (plus stacking to attenuate noise), we obtain a stacked *zero-offset section*
- Another type of imaging is "pre-stack", which obtains the final image directly from the full source-receiver geometry

New!

Normal moveout

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

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



New!

Normal moveout

- The NMO hyperbola can be approximated by a parabola
  - Works for small reflection angles (up to about 30°):

$$t(x) = \sqrt{t_0^2 + \left(\frac{x}{V}\right)^2} = t_0\sqrt{1 + \left(\frac{x}{t_0 V}\right)^2} \approx t_0\left[1 + \frac{1}{2}\left(\frac{x}{t_0 V}\right)^2\right] = t_0 + \frac{1}{2t_0}\frac{x^2}{V^2}$$

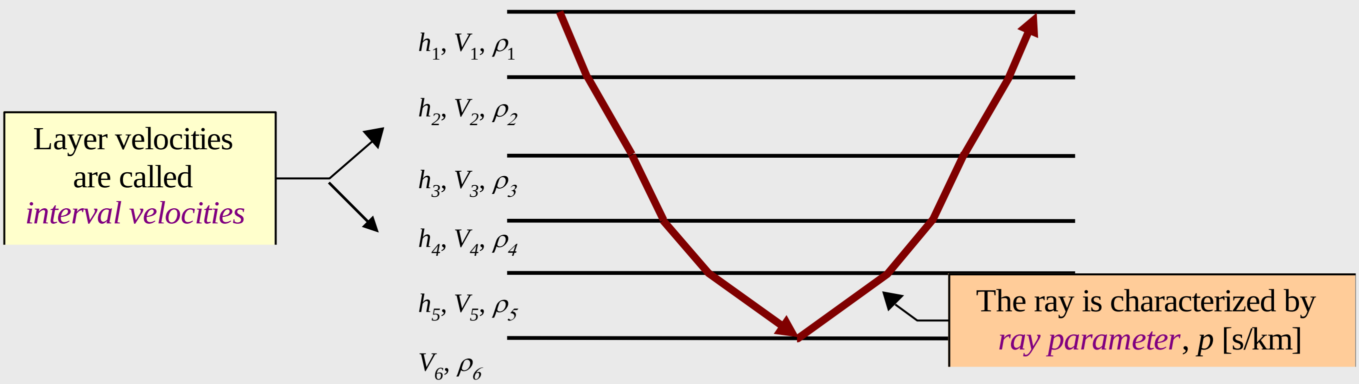
Quadratic function -> parabola in the (x,t) plane

- To understand this and other formulas below, not that for small $\alpha << 1$:

$$(1+\alpha)^n \approx 1 + n\alpha$$

Reflection travel-times
(*Multiple layers*)

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



- For practical applications (near-vertical incidence, $pV_i \ll 1$), $t(x)$ 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:

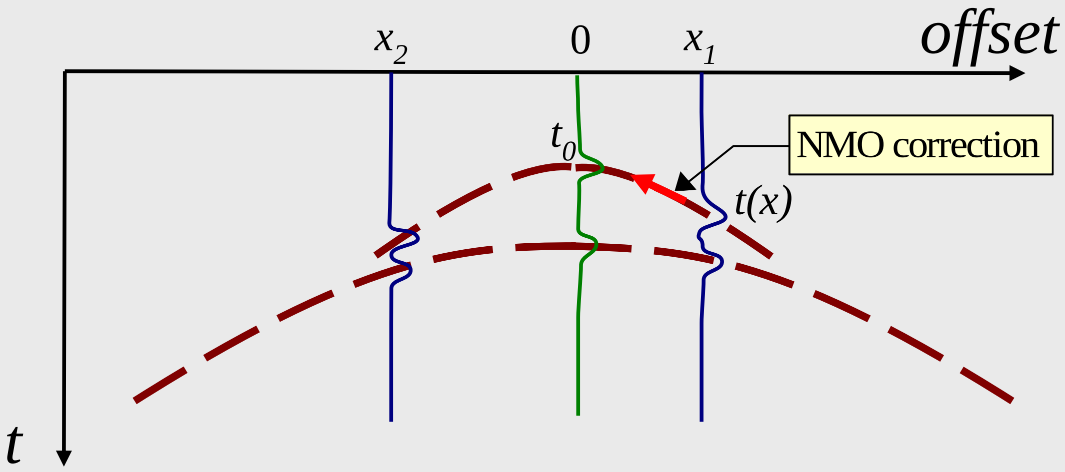
$$V_{RMS} = \sqrt{\frac{\sum_{i=1}^{n} h_i V_i}{t_0}} = \sqrt{\frac{\sum_{i=1}^{n} t_i V_i^2}{\sum_{i=1}^{n} t_i}}$$

Normal Moveout (NMO) correction

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

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

"*Stacking velocity*"

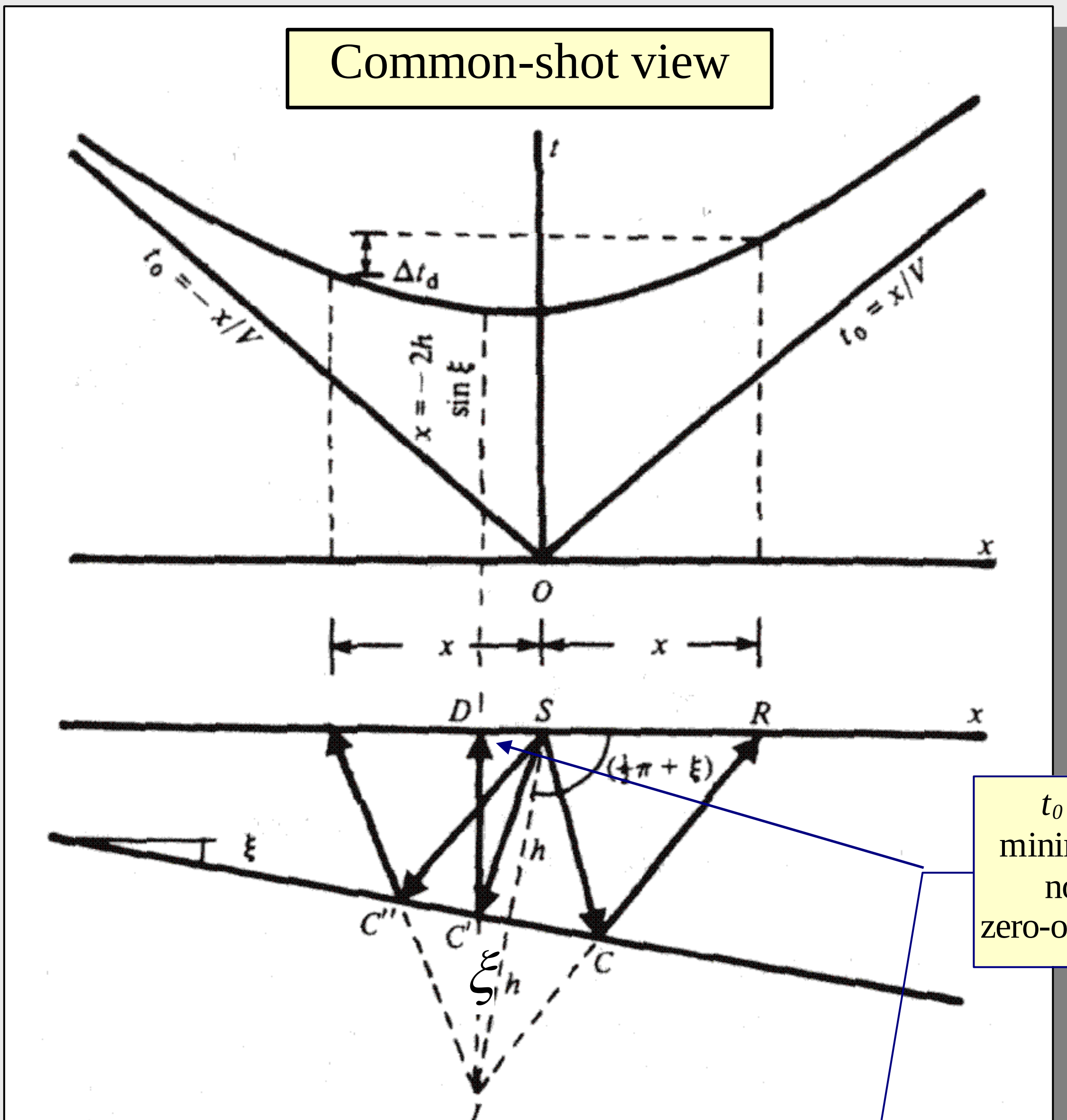


- *Stacking velocity* is determined from the data, as a parameter of the reflection hyperbola that is best aligned with the reflection event
- Note that NMO correction affects the shallower and slower reflections stronger
  - This is called "*NMO stretching*"

New!

Dipping reflector

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



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

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

New!

Dip moveout

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

Note: $2h = t_0 V$

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

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

Apex ≈ Zero-offset time

Normal moveout term

Dip moveout term

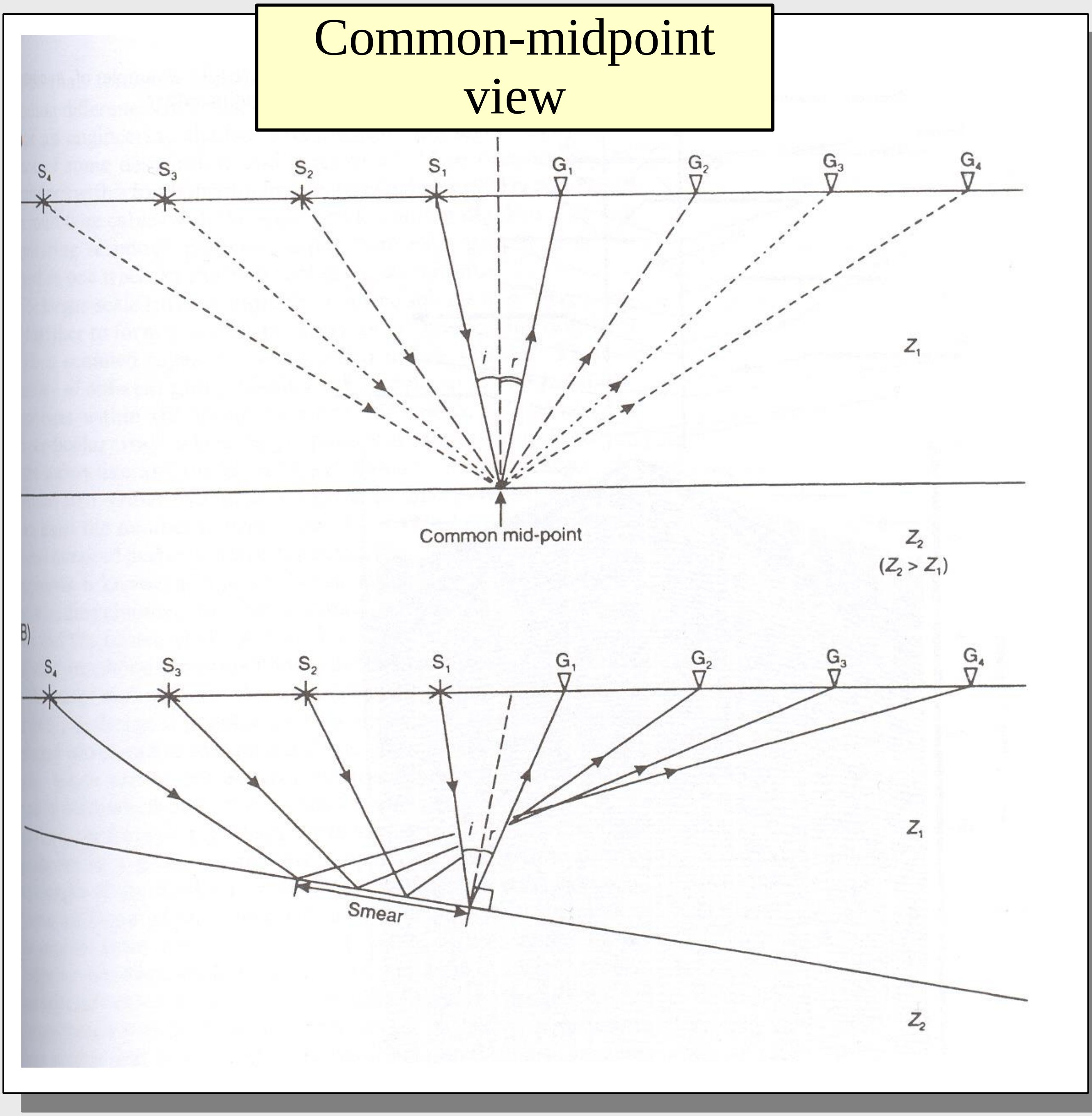
- Reflector dip ξ can be measured from the *dip moveout*:

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

This ratio is also called *Dip Moveout*

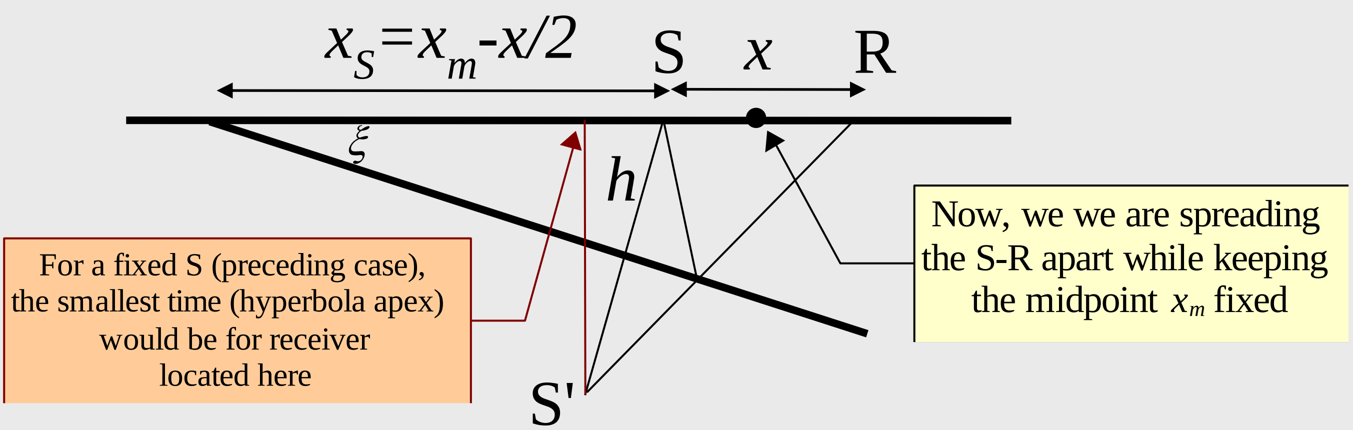
Dip moveout in CMP gathers

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



New!

Stacking velocity in the presence of dip



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

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

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

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

continued...

New!

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

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

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

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 hyperbola)
- As a result, reflectors with conflicting dips cannot be NMO-corrected and stacked accurately.
  - Processing step called ***DMO*** (dip moveout correction) corrects this problem. We will talk about this method in the next lectures