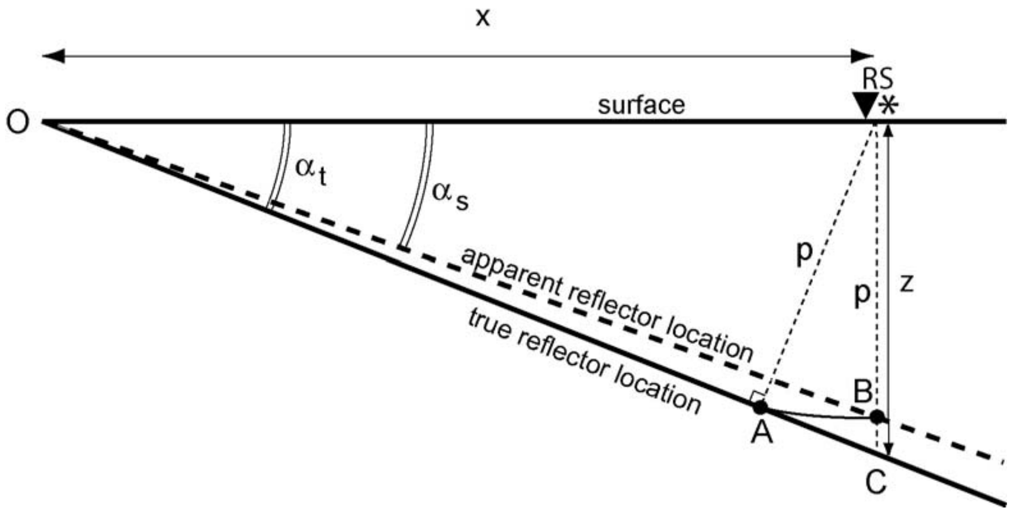
C2.8 Migration of seismic reflection data

C2.8.1 Why is migration needed?

C2.8.1.1 Dipping layers are imaged with an incorrect dip



Consider a shot (S) and receiver (R) that are located close together. A reflector has a true dip angle = α_t and is at a depth *z* below the shot point. Seismic energy that returns to R will reflect at 'A' where the ray path is at 90º to the reflector.

However, in a seismic section, a reflection in plotted as it was **directly below** the shot-receiver point , which in this case is 'B'. Note the line A-B is the arc of a circle, centered at RS. The result is the reflector is imaged by the seismic data with an apparent dip of α_s that is less than the true dip.

From triangle A-C-RS $\quad \cos \alpha_t = p / z$

From triangle O-RS-C $\quad \tan \alpha_t = z / x$

From triangle O-RS-B $\quad \tan \alpha_s = p / x$

Rearranging these equations gives $\quad \sin \alpha_t = \tan \alpha_s$

True dip (α_t)	Apparent dip (α_s)
5º	4.98 º
10 º	9.85 º
20 º	18.88 º
40 º	32.73 º
60 º	40.89 º
80 º	44.56 º

The result is that reflectors appear to have an **apparent dip that is less than the true dip**. The effect is small at shallow angles, but becomes significant when the true dips are greater than 20 º. Note that a vertical reflector will appear at 45 º on a seismic section.

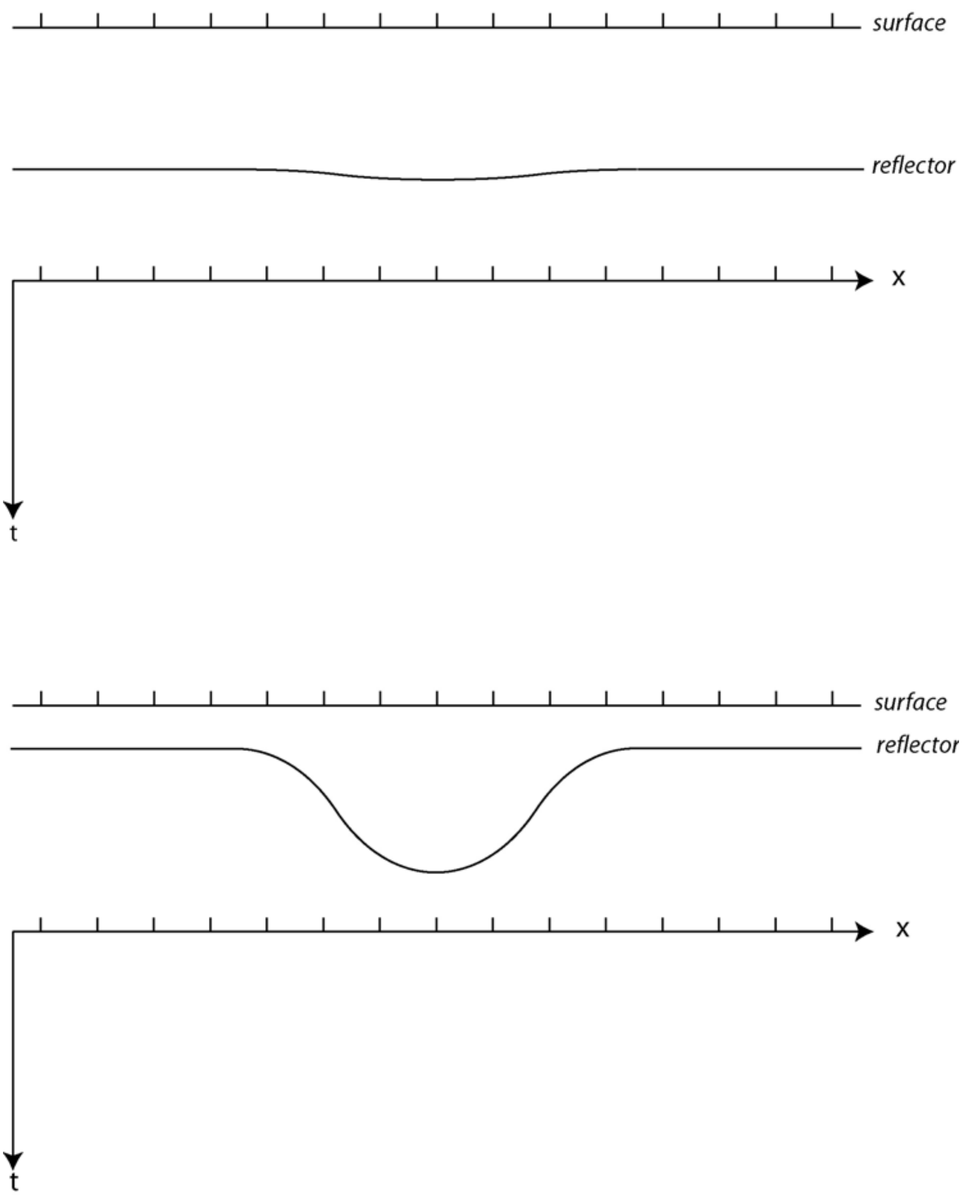
C2.8.1.2 Multiple reflections in same zero offset trace

● When a syncline has very limited topography, only one reflection is observed in each zero offset trace (i.e. shot and receiver are placed very close together and moved along the profile).

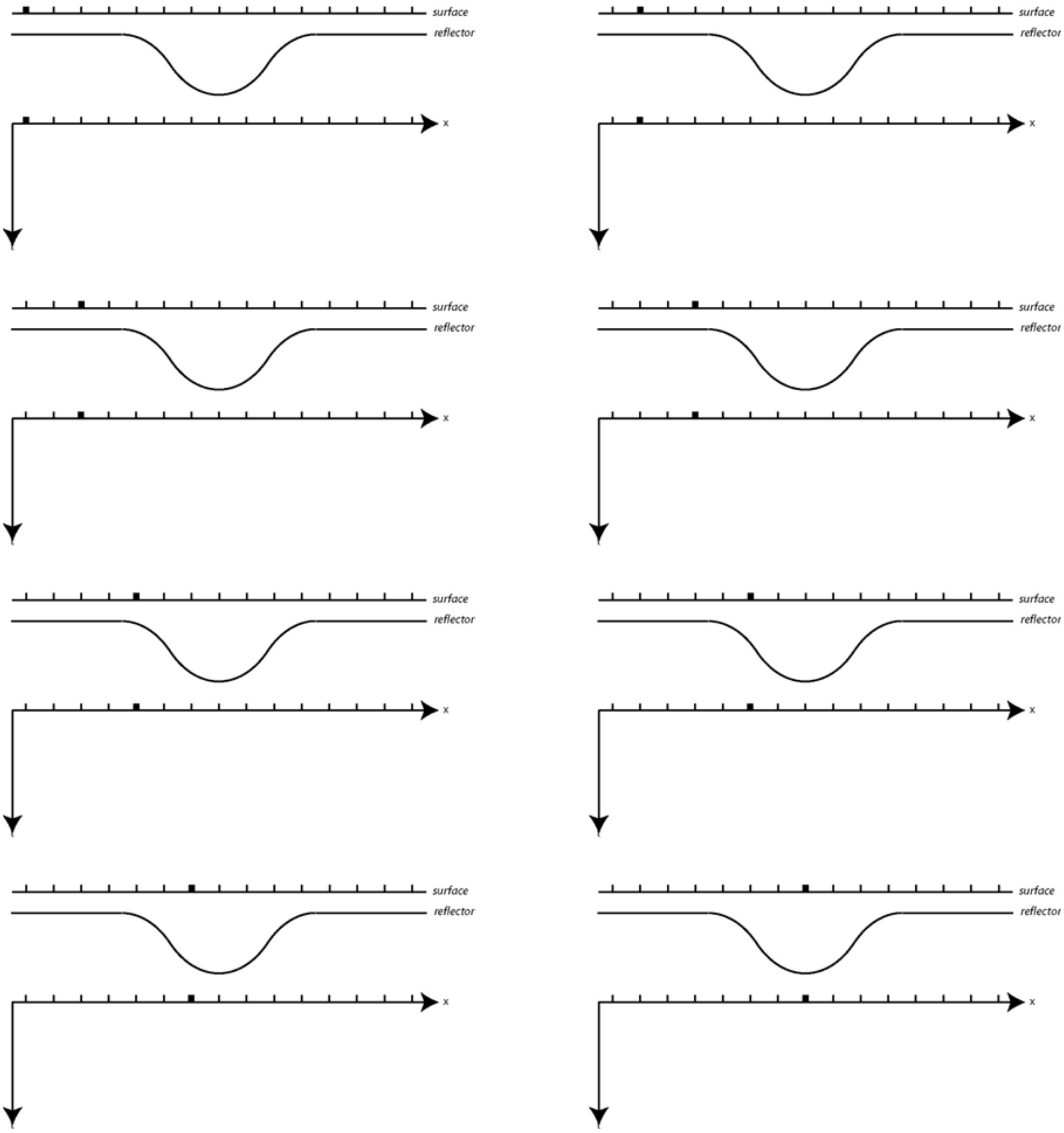
As shown in the previous section, the dip will not be measured correctly. However, the overall geometry in the seismic record section will be very similar to the reflector geometry. Note that reflections occur at right angles to the surface.

● With more rugged topography, a normal reflection will occur at three locations when the source and receiver are above the syncline. This produces the characteristic "*bow tie*" in the travel times.

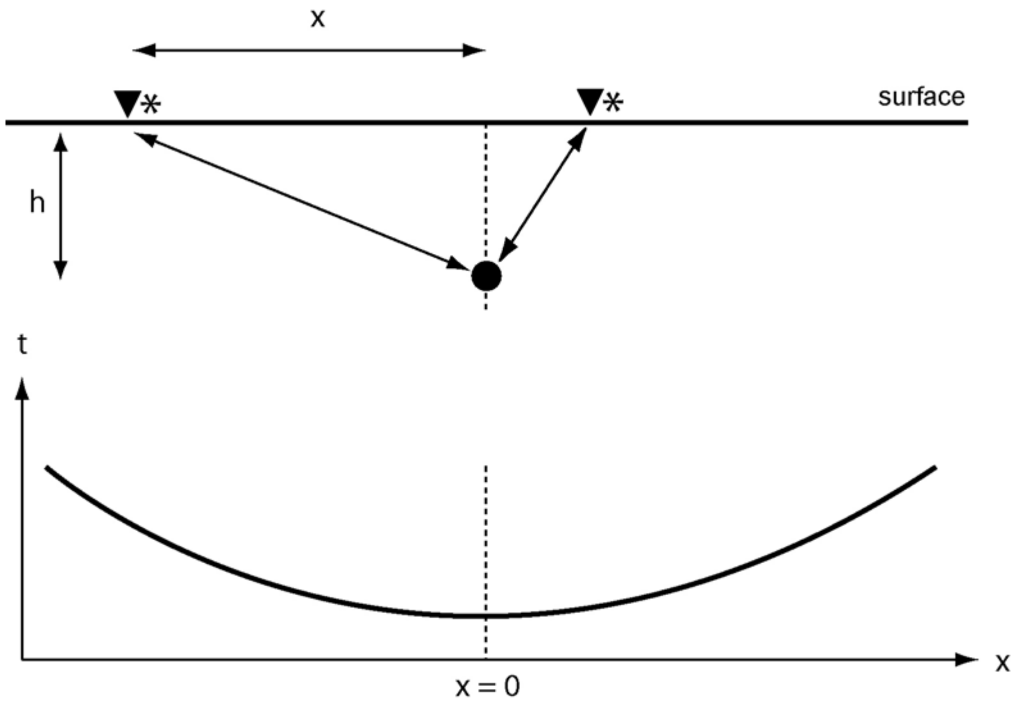
C2.8 Why migration is needed -part 1



C2.8 Why migration is needed -part 2



C2.8.1.3 Diffractions



- Diffractions occur from point reflectors and corners. The figure above shows a small sphere that is diffracting seismic waves. The diffractor has the property that it scatters energy in all directions. Some of this energy returns to the location of the shot (*) along the same path (like a boomerang).

- When the shot-receiver array is moved along the profile with zero-offset, the travel time curve above has a travel time $t_{diff} = \frac{2\sqrt{x^2 + h^2}}{v_1}$ which plots as a hyperbola.

- A hyperbola will also result when the shot-receiver offset is varied (*e.g.* a shot gather or CMP gather). In this case the move out rate will be half that observed from a plane reflector

C2.8.2 Migration methods

Migration in geophysics has nothing to do with birds flying south in winter. It is mathematical process that attempts to reconstruct the reflector geometry from measurements of the reflected seismic energy. A wide range of methods have been developed.

The simplest technique works by assuming that from the travel time, we know that the reflection point must lie somewhere on a hemispherical surface. By migrating several points this allows us reconstruct the reflector surface.

If applied to a diffraction, this will **collapse the hyperbola to a point**. The diffraction hyperbola is the steepest dipping even that can be recorded on a seismic record section.

Some commonly used methods of migration include:

- diffraction migration
- wave equation migration
- Kirchoff migration

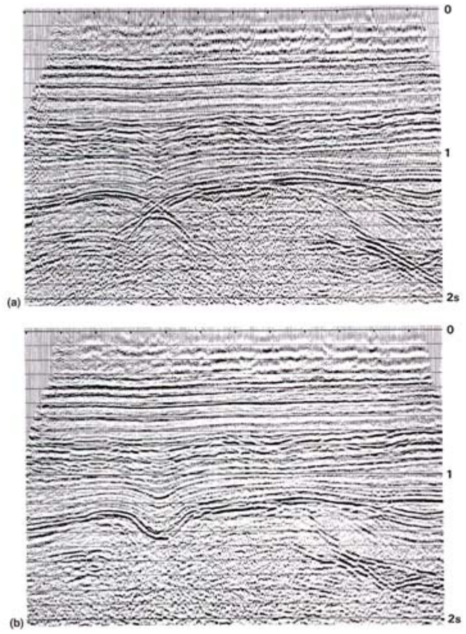
More details and references for these methods are given by Kearey in chapter 4. Each migration technique can be further divided into **time** and **depth** migration

- *time migration*: the vertical axis on the migrated section is still time.
- *depth migration*: estimates of velocity are used to convert time to depth during migration. Even rough estimates of velocity (*e.g.* from computing the stacking velocity for each CDP gather) can greatly improve the quality of the migration.

Migration can also be applied **before** or **after** stacking the CMP gathers:

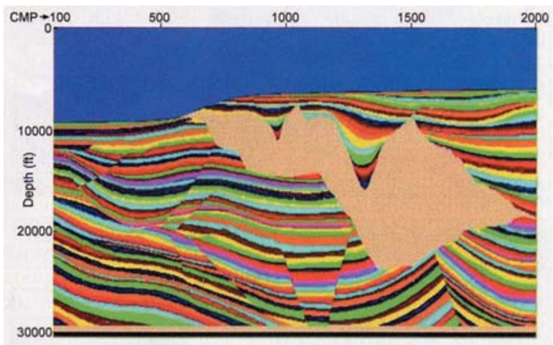
- *Post-stack depth migration* : This was the original migration strategy. The zero offset traces derived from the CMP stacks are migrated. This has the advantage of **lower computer time** and the **higher signal-to-noise ratio** can make the migration more stable. However the process of stacking assumes a relatively flat interfaces. This is valid in geological structures that have sub-horizontal stratigraphy, but is not valid in complex, highly 3-D environments.
- *Pre-stack depth migration:* This migrates individual traces prior to stacking. Requires major amount of computation, but is necessary in complex 3-D environments.

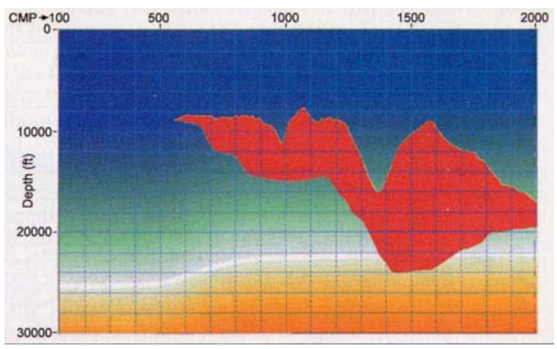
C2.8.3 Examples of migration

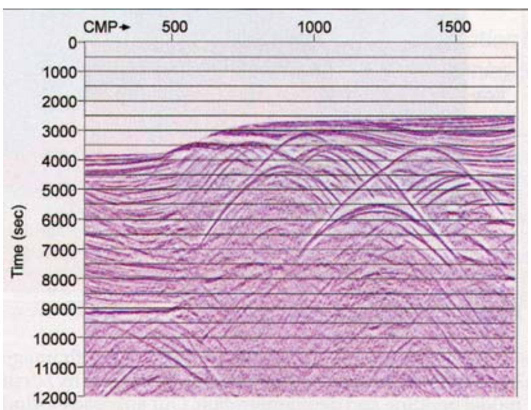


Wave equation migration in a location where structures generally sub-horizontal. Note that bow-ties are essentially removed by the migration (Kearey chapter 4).

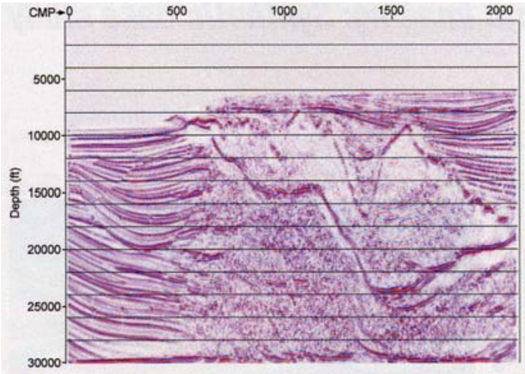
The Sigsbee model was developed to simulate sub-salt seismic imaging in deeper water exploration areas such as the Gulf of Mexico. More details can be found in Integrated approach to sub-salt depth imaging: synthetic case study, *The Leading Edge*, **21**, 1217-1223, December 2002.

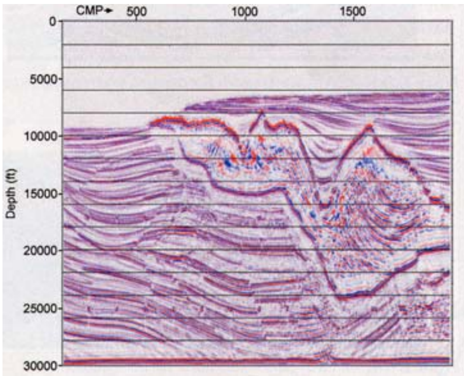






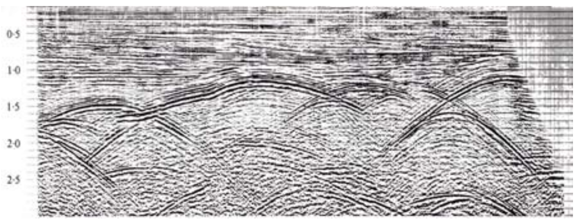
In the zero-offset time section, note the **diffraction hyperbolae** that originate in the sharp corners in the upper surface of the salt sheet. Very few coherent reflectors can be seen beneath the salt.



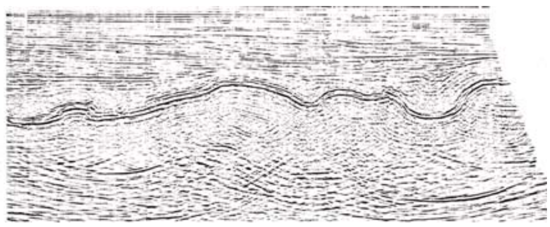


Left : Kirchoff depth migration. Reflectors to the left and above the salt body are well imaged. **Right** : Finite difference Pre-stack depth migration. Coherent reflectors are imaged in the sedimentary sequence beneath the salt body.

Multiples do not migrate correctly and along with other errors in migration this can produce "*smiles*" which are upward directed hyperbolae. This is illustrated in Figure 4.84 from Telford.

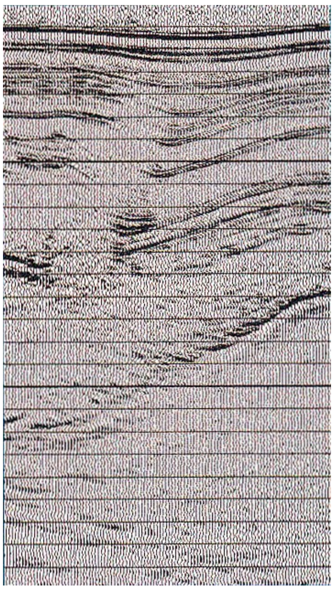


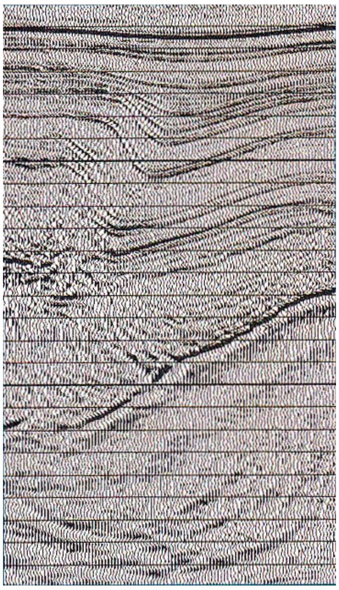
Original time section



Results of time migration

Example below is from a PGS advert in The Leading Edge. Note that structures with steeper dip are imaged more reliably with pre-stack depth migration.


Post-stack depth migration


Pre-stack depth migration