Thesaurus *Seismic Imaging and Resolution*

Contents

1. Seismic migration

By Wikipedia, the free encyclopedia http://en.wikipedia.org/wiki/Seismic_migration

Seismic migration is a one of the standard data processing techniques for reflection-based geophysical methods (seismic reflection and ground-penetrating radar).

Migration moves dipping reflectors to their true subsurface positions and collapses diffractions, resulting in a migrated image that typically has an increased spatial resolution and resolves areas of complex geology much better than non-migrated images. Thereby it is creating a more accurate image of the subsurface. This process is necessary to overcome the limitations of geophysical methods imposed by areas of complex geology, such as: faults, salt bodies, folding, etc. In such cases it can lead to a dramatic uplift in image quality.

Depending on budget, time restrictions and the subsurface geology, there can employed two types of migration algorithms, defined by the domain in which they are applied: time migration and depth migration.

Time Migration

Time Migration is applied to seismic data in time coordinates and therefore doesn’t require a velocity model, simplifying the processing stage and reducing the computer resource time needed. However this type of migration makes the assumption of only mild lateral velocity variations and this breaks down in the presence of laterally changing contrast subsurface structures.

Depth Migration

Depth Migration is applied to seismic data in depth coordinates, which must be calculated from seismic data in time coordinates. This method does therefore require a velocity model, making it resource-intensive because building a seismic velocity model is a long and iterative process. The significant advantage to this migration method is that it can be successfully used in areas with lateral velocity variations, which tend to be the areas that are most interesting to petroleum geologists. Some of the popularly used depth migration algorithms are Kirchhoff depth migration, Reverse Time Migration (RTM), Gaussian Beam Migration and Wave-equation migration.

Resolution

The goal of migration is to ultimately increase spatial resolution and one of the basic assumptions made about the seismic data is that is only shows primary reflections and all noise has been removed. In order to ensure maximum resolution (and therefore maximum uplift in image quality) the data should be sufficiently pre-processed before migration. Noise that may be easy to distinguish pre-migration could be smeared across the entire aperture length during migration, reducing image sharpness and clarity.

Technical Details

Migration of seismic data is the correction of the flat-geological-layer assumption by a numerical, grid-based spatial convolution of the seismic data to account for dipping events (where geological layers are not flat). There are many approaches, such as the popular Kirchhoff migration, but it is generally accepted that processing large spatial sections (apertures) of the data at a time introduces fewer errors, and that depth migration is far superior to time migration with large dips and with complex salt bodies.

Basically, it repositions/moves the energy (seismic data) from the recorded locations to the locations with the correct common midpoint (CMP). While the seismic data is received at the proper locations originally (according to the laws of nature), these locations do not correspond with the assumed CMP for that location. Though stacking the data without the migration corrections yields a somewhat inaccurate picture of the subsurface, migration is preferred for better most imaging recorder to drill and maintain oilfields. This process is a central step in the creation of an image of the subsurface from active source seismic data collected at the surface, seabed, boreholes, etc., and therefore is used on industrial scales by oil and gas companies and their service providers on digital computers.

Explained in another way, this process attempts to account for wave dispersion from dipping reflectors and also for the spatial and directional seismic wave speed (heterogeneity) variations, which cause wavefields (modelled by ray paths) to bend, wave fronts to cross (caustics), and waves to be recorded at positions different from those that would be expected under straight ray or other simplifying assumptions. Finally, this process often attempts to also preserve and extract the formation interface reflectivity information imbedded in the seismic data amplitudes, so that they can be used to reconstruct the elastic properties of the geological formations (amplitude preservation, seismic inversion). There are a variety of migration algorithms, which can be classified by their output domain into the broad categories of Time Migration or Depth Migration, and Pre-Stack Migration or Post-Stack migration (orthogonal) techniques. Depth migration begins with time data converted to depth data by a spatial geological velocity profile. Post-Stack migration begins with seismic data which has already been stacked, and thus already lost valuable velocity analysis information.

References

1. Yilmaz, Ö. 2001. Seismic data analysis. Society of Exploration Geophysicists
2. Sheriff, R. E., Geldart, L. P., (1995), 2nd Edition. Exploration Seismology. Cambridge University Press.
3. Sheriff, R. E., Geldart, L. P., (1995), 2nd Edition. Exploration Seismology. Cambridge University Press.
4. http://www.cggveritas.com/default.aspx?cid=4-11-2358 Reverse Time Migration. CGG Veritas. 2012.
5. http://www.cggveritas.com/default.aspx?cid=1133&lang=1 Gaussian Beam Migration. CGG Veritas. 2012.
6. http://www.pgs.com/upload/31213/data.pdf Long, A., What is Wave Equation Pre-Stack Depth Migration? An Overview. , PGS Technology. 2004.
7. Sheriff, R. E., Geldart, L. P., (1995), 2nd Edition. Exploration Seismology. Cambridge University Press.

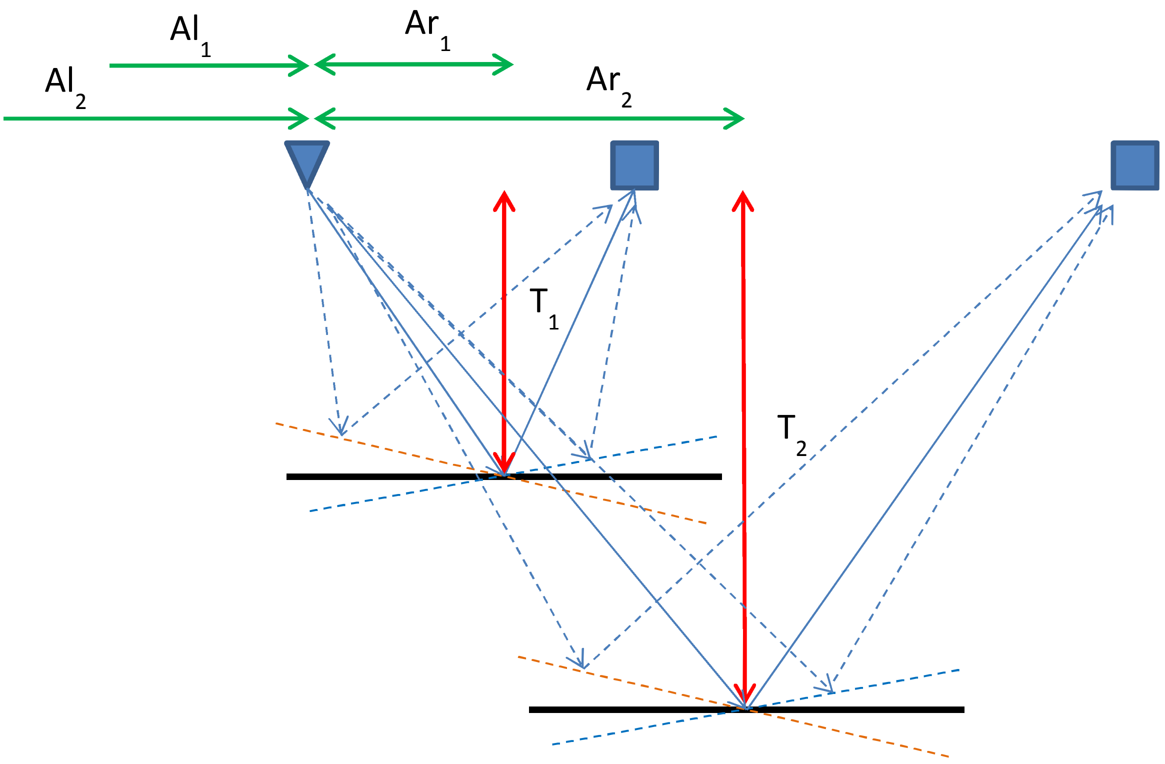
2. Migration Apertures

Aperture is an important parameter of the migration transformation. The migration aperture values relate to the midpoint between source and receiver at particular depth in time T scale (as T_0 – time for seismic wave to travel vertically to this midpoint). There must be indicated sets (1, 2, …) of three values:

- ***T*** – time (ms),
- ***Al*** – left aperture (m),
- ***Ar*** – right aperture (m).
  - Sum of apertures to the left and right in each node point must be non-negative. Aperture size can be approximately determined from expression:

    $L = Z * \mathrm{tg}\,\alpha$,

    where L – aperture size, Z – depth of target boundary, α – inclination angle of target boundary. Processing time is proportional to the aperture size.



3. Spatial Aliasing and Nyquist Rate

Temporal and spatial aliasing occurs at recording of incoming signal when receivers are placed too sparse (***spatial aliasing***) or sampling rate at recording (by receiver) is too big (***temporal aliasing***).

Usually minimal requirement for ***a quality recording is 2 samples per wavelength*** *Wl_min/2* (in case of receiver spacing) or wave period Wt_*min/2* (in case of recording by a receiver). It is called ***Nyquist rate***.

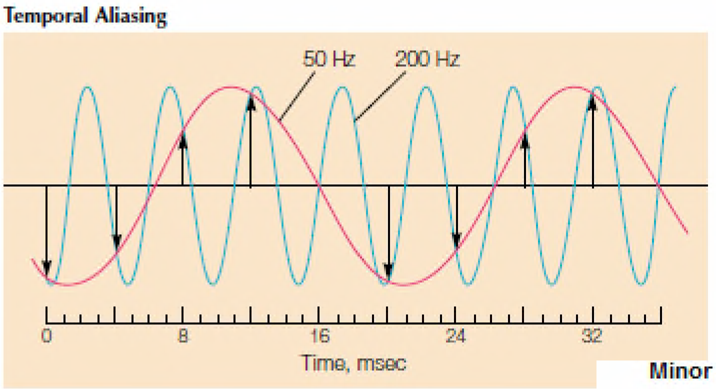
Taking into account that maximal signal frequency is *Sf_max*=1/*Wt_min*. Then

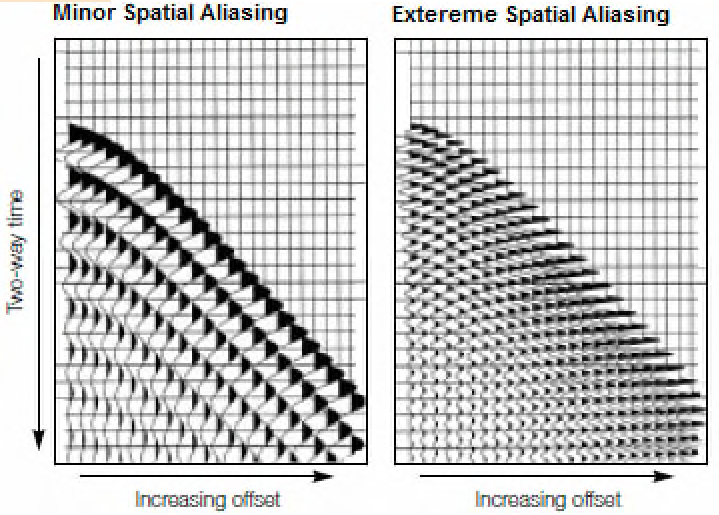
- ✓ *Nf=2*Sf_max* – is a maximal (expected) frequency of the recorded signal – ***Nyquist frequency*** *(Nf)*.

For example, if expected maximal frequency of incoming signal is Sf_max, and (minimal) *apparent velocity* of incoming wave can be estimated as Vp_min then:

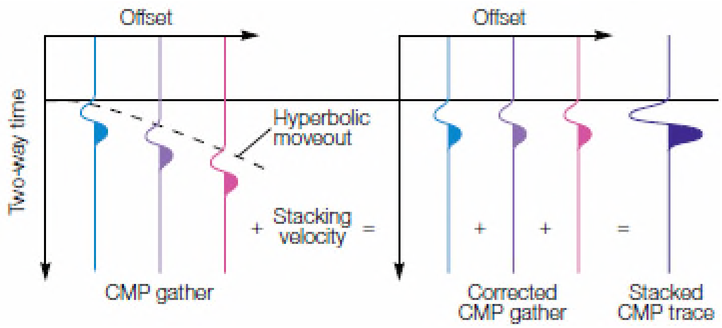
- ✓ ***Interval between receivers*** *(spatial)* must be not bigger than *Vp_min/Wf_max*;
- ✓ and recording (by receiver) ***sampling rate****(temporal)* must be not bigger than *1/(2*Wf_max);*

- ❖ **Temporal aliasing** (top) occurs when insufficient sampling renders a 50-Hz signal and a 200-Hz signal indistinguishable (arrows represent sample points). The 50-Hz signal is adequately sampled, but not the 200-Hz [adapted from *Sheriff*].





❖ **Spatial aliasing** occurs when receiver spacing is more than half the spatial wavelength. With minor aliasing left) arrivals can be tracked at near offsets as time increases, but become difficult to follow at far offsets. With extreme aliasing (right) arrivals even appear to be traveling backwards toward near offsets as time increases [adapted from *Claerbout*].

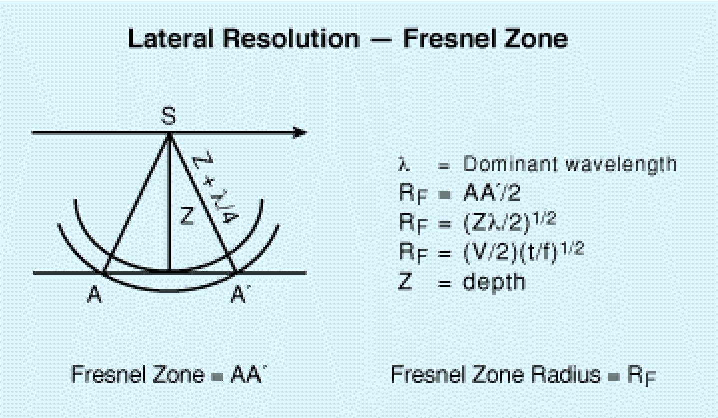


- Reflection arrival times from different offsets are assumed to follow a hyperbola.
- The shape of the hyperbola is computed from the arrivals.
- Traces are aligned by flattening the best-fitting hyperbola into a straight line, then summed, or stacked.
- Perfect alignment should yield maximum signal amplitude at the time corresponding to zero offset.

❖ **A wide range of evenly spaced offsets gives a better fitting hyperbola, and so a better stack**.

4. Fresnel zone

By Schlumberger Oilfield Glossary http://www.glossary.oilfield.slb.com/



named for French physicist Augustin-Jean Fresnel (1788 to 1827)

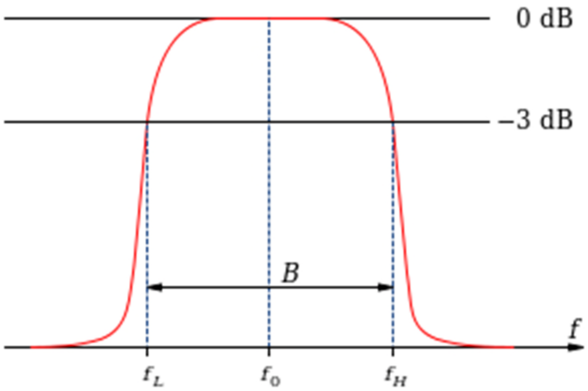
Spherical divergence and attenuation of seismic waves causes a Fresnel zone, shown in this 2D sketch as length A-A'. In 3D seismic, the Fresnel zone is a circular and has diameter A-A'. The size of the Fresnel zone can be calculated to help interpreters determine the minimum size feature that can be resolved.

A frequency- and range-dependent area of a reflector from which most of the energy of a reflection is returned and arrival times differ by less than half a period from the first break. Waves with such arrival times will interfere constructively and so be detected as a single arrival. Subsurface features smaller than the Fresnel zone usually cannot be detected using seismic waves.

5. Bandpass Filter

From Wikipedia http://en.wikipedia.org/wiki/Band-pass_filter

A ***band-pass filter*** passes frequencies within certain range and rejects (attenuates) frequencies outside that range.



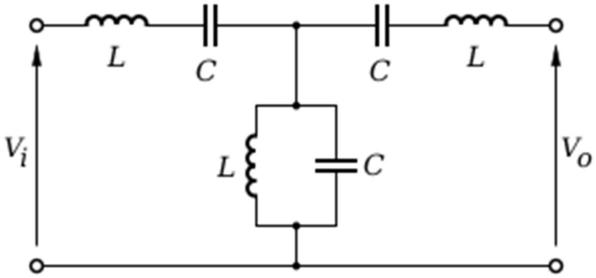
Bandwidth measured at half-power points (gain -3 dB, √2/2, or about 0.707 relative to peak) on a diagram showing magnitude transfer function versus frequency for a band-pass filter.

An example of an analogue electronic band-pass filter is an RLC circuit (a resistor–inductor–capacitor circuit). These filters can also be created by combining a *low-pass filter with a high-pass filter*.

A *bandpass signal* is a signal containing a band of frequencies away from zero frequency, such as a signal that comes out of a bandpass filter.

An *ideal bandpass filter* would have a completely flat *passband* (e.g. with no gain/attenuation throughout) and would completely attenuate all frequencies outside the passband. Additionally, the transition out of the passband would be instantaneous in frequency. In practice, no bandpass filter is ideal. The filter does not attenuate all frequencies outside the desired frequency range completely; in particular, there is a region just outside the intended passband where frequencies are attenuated, but not rejected. This is known as the *filter roll-off*, and it is usually expressed in *dB* of attenuation per octave or decade of frequency. Generally, the design of a filter seeks to make the roll-off as narrow as possible, thus allowing the filter to perform as close as possible to its intended design. Often, this is achieved at the expense of pass-band or stop-band *ripple*.

The bandwidth of the filter is simply the difference between the *upper and lower cutoff frequencies*. The shape factor is the ratio of bandwidths measured using two different attenuation values to determine the cutoff frequency, e.g., a shape factor of 2:1 at 30/3 dB means the bandwidth measured between frequencies at 30 dB attenuation is twice that measured between frequencies at 3 dB attenuation.



A medium-complexity example of a band-pass filter

6. Deconvolution

A step in seismic signal processing to recover high frequencies, attenuate multiples, equalize amplitudes, produce a zero-phase wavelet or for other purposes that generally affect the waveshape. Deconvolution, or inverse filtering, can improve seismic data that were adversely affected by filtering, or convolution that occurs naturally as seismic energy is filtered by the Earth.

The reflectivity series (R)

The seismic wave is sensitive to the sequence of impedance contrasts.

We input a source wavelet (W) which is reflected at each impedance contrast

The seismogram recorded at the surface (S) is the convolution of the two **S = W * R**

Spiking or whitening deconvolution

Reduces the source wavelet to a spike. The filter that best achieves this is called a **Wiener filter.**

Our seismogram **S = R*W** (reflectivity*source);

Deconvolution operator, D, is designed such that **D*W = δ**;

So **D*S = D*R*W = D*W*R = δ*R = R .**

Time-variant deconvolution

D changes with time to account for the different frequency content of energy that has traveled greater distances.

Predictive deconvolution

The arrival times of primary reflections are used to predict the arrival times of multiples which are then removed