

The Role of Statics Application in the Imaging of Sub-Surface in Fold Belt Areas*

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Abstract

Static corrections to seismic data compensate for velocity and thickness variations within the weathered zone. An uncompensated weathered layer thickness can distort the spectrum of the signal and result in aberrations on final stacked data. Static corrections because of weathered and sub-weathered zones are the most fundamental unsolved problem in reflection seismic survey from the standpoint of practical operating techniques. Shallow seismic reflection surveys with special processing efforts can be of great help to build a Near Surface Model. Deep upholes may assist in calibration of velocities and thickness of layers in near surface. Static corrections computed from this Near Surface Model and applied to conventional/deep reflection survey data may improve the seismic stack quality. This method though in its early stage of development will go a long way in easing imaging problem in fold belt areas to some extent.

Introduction

Generally, fold belt areas have complicated terrain with very large and rapid undulations ([Figure 1](#)), so the first consideration is application of precise static correction. The tomographic inversion static method uses iterative process that starts with a Near Surface Model (NSM) composed of different but constant velocity units. The error between first break from forward modeling and first break from real travel time is minimized iteratively by updating velocities in NSM in every iteration. The improvement in stack quality is seen in [Figure 2](#). The deliberate efforts in precise static correction helps improve imaging in fold belt areas. Large scope lies in precision static correction application to meet subsurface quality imaging need of interpretation challenge in these areas.

The transition from structural reservoirs to stratigraphic reservoirs then stratigraphic reservoirs is taking place world over. The change warrants precision on imaging issues of subsurface geology. The widely prevalent technique providing detailed image of subsurface is conventional / deep seismic reflection. Now time has arrived to sharpen this technique by focusing on static issues to clear aberration from imaging seismic panels. Shallow seismic reflection may help address static issues of deep seismic reflection technique to improve imaging in particular in fold belt areas where field static problems are rampant.

In the last 15 years, shallow seismic reflection (SSR) imaging is widely used to identify and characterize near-surface tectonic deformation in areas concerned with earthquake hazards. Because of the societal importance related to the results of these studies, considerable attention is required in acquiring, processing, and interpreting the data. An understanding of the characteristics of neotectonic deformation in an area, coupled with sufficient field testing (utilizing various seismic energy sources, receivers, and field geometries), helps support the collection of high-quality seismic reflection data. It is apparent that variations in geologic setting require changes to data acquisition parameters.

The contrast in the acoustic impedance of the two layers determines the amplitude of the reflected signal. The reflected signal is detected on surface using high frequency geophones. Seismic energy is provided by a 'shot' on surface. For shallow seismics, this will normally comprise a hammer and plate, weight drop or explosive charge. SSR method can give "engineer-related" information about the elastic properties of materials, such density and porosity. It can detect geologic structures in fault zones, find shallow, soft layers of underground earth materials, reduce mapping uncertainties and can greatly reduce the investigation costs of engineering projects. It is used to determine:

- Bedrock quality, profile, and depth
- Degree of alteration and thickness of overburden
- Fractured and faulted areas
- Water table level and continuity
- Elastic moduli values for soils and bedrock

The instant paper looks into the possibility of SSR processed data in building Near Surface Model (NSM) for computation of static corrections for further application on a conventional / deep seismic reflection data. The paper is a conceptualized idea to alleviate static correction problems blurring imaging in conventional / deep seismic reflection data in undulated terrain of fold belt areas. It also deals the intricacies of SSR data and its handling so that it is amenable to building NSM. D.W. Steeples, R.D. Miller and R.A. Black

initiated the idea on their paper “Static corrections from shallow-reflection surveys” in 1990. However, in their paper the static corrections so drawn from SSR were used on synthetic seismic data to test the role of intra-array statics of geophones in a group.

Methodology

The conventional/deep seismic data is acquired from ground level, so are the two-way travel times. It requires static corrections to two-way travel times to measure them from datum. Therefore, the information of weathered layers between datum and ground level their thicknesses, velocities, and spatial distribution is of utmost importance. Accomplishment of this task is to be carried out precisely. SSR comes as befitting technique to help achieve the precision in this task.

Shallow Seismic Reflection survey

Source

The ideal sources for shallow reflection applications are those that generate high frequency and low-energy waves. Such sources greatly improve the resolution and minimize the generation of the ground roll and the air-coupled energy. The projectile sources are one of the best to achieve these requirements but they are not recommended and even are prohibited in urban areas due to safety reasons or the presence of pavements. Therefore, among the non-invasive sources, the impact of the sledgehammer on a plate is almost the only remaining choice and furthermore it is the simplest and cheapest source. Moreover, Ghose et al. (1998) found that it is easier to generate high frequencies on hard ground, like asphalt, than on soft soil, because the former has greater radiation impedance. Again, the choice depends on depth of investigation, logistics, environmental issues, near surface rocks, intensity of surface and body waves and air-coupled waves. Vibrators, mini vibrators, thumpers, explosive, detonators and rifles have been stated to be frequently used in this survey. R.D. Miller, S.E. Pullan, D.W. Steeples and J.A. Hunter have discussed the efficacy of sources in their paper “Field comparison of shallow seismic sources near Chino, California” in 1992.

Instrument and Geophones

The main qualities of a recording system are its resolution, which means the number of bits digitized and its dynamic range. The seismographs have 24 bits of analog-to-digital (A/D) converters with sigma – delta technology and dynamic range of 124 dB. With these modern seismographs having capacity of thousands of channels, it is easy to use small group intervals and small sampling intervals. The use of analog low-cut filters can deteriorate the seismic signal, reducing the frequency bandwidth and intensifying the

ringing effect. This was observed in one of the walkway analysis test recorded in a study where 10-Hz and 200-Hz low-cut filters were used. The most recommendable geophones, in order to get high resolution, are those that have a natural frequency in the range of 30 Hz to 100 Hz. The 100 Hz geophones can, sometimes, limit the lower part of the frequency band causing a “ringy” effect in the seismic data. On the other hand, the 30 Hz geophones are more sensitive to urban noises. The geophone-ground coupling is a serious problem in urban areas. Most of the time it is not possible to plant the geophones using their spikes. The problem here is to guarantee that the geophone reproduces as faithfully as possible the ground motion. In order to get a signal with as much high frequency content as possible, a large area of contact is desired. One way to get this is to increase the area of contact using a plate or volume of clay. Planting geophones with clay, instead of metal bases, gives the best results. Self-rotating gimbal-mounted geophones are hassle free as far as geophone planting is concerned.

Field procedure

More geophones and more source points increase markedly the logistical complexity of a SSR survey, which results in increase of time and cost aspect of data acquisition. Recording of such high-resolution data sets requires application of fast and efficient acquisition techniques and systems. Van der Veen and Green (1998) have introduced a land streamer ([Figure 3](#)) concept with the principal goal of decreasing the number of field personnel, time and costs. The land streamer uses self-rotating gimbal-mounted geophones attached to a rubber mat. Moreover, the efficacy of single gimbal type geophone is comparable to using a group of conventional spiking geophones at each receiver station. The SSR survey is carried out on end on mode with predetermined direction of shooting depending on near surface dips. The towing of land streamer by truck/car will depend upon the logistics of terrain, otherwise one may have to deploy geophone spread and conduct roll over of spread to cover the seismic reflection coverage. It requires thorough reconnaissance of the area and experimentation before undertaking such move.

A SSR survey may be designed with acquisition parameters as follows:

- Spread geometry: end on with updip shooting
- No. of channels: 2000
- Sampling interval: 0.125 ms.
- Record length: 500 ms. (subject to target depth)
- Group interval: 1 m
- Source interval: 1 m

- Near offset: 1 m
- Far offset: 1.6 d (target depth in meters, subject to structural dips)

Uphole survey

The uphole survey provides a direct measurement of the seismic energy travel time in the low velocity layers and in the layer immediately below. It is achieved by shooting a series of shots in a hole and recording the results in time. Deep upholes to the depth of datum are necessary to tie SSR data with litho sections of upholes. The time-depth table of upholes also acts as calibration point for velocity picking in SSR data. A tentative velocity model may be generated from uphole hard data by kriging the values, provided reasonable density of upholes is available.

Data processing

The seismic data may be processed in CDP format using the commercial software package. The primary job of processing commences with geometry building and trace editing. The first round of band-pass (70 - 250 Hz.) filtering facilitates rejection of sizeable part of undesired noise. Automatic-gain-control (AGC) scaling is a process regularly used to increase the amplitudes of the data, for display or processing purposes. Here the critical parameter is related to the length of the AGC window, which means the time-band within which the amplitudes are normalized. The highest amplitude within this window will strongly determine the normalization. If the AGC window is too small (close to the dominant period of the data), everything will be changed within this interval, on the other hand if it is very large (close to the record length), no effects will be produced in the amplitude of the data. A good rule of thumb is to approximate its length to 2 times the dominant period of the data and to observe the results. The voluminous traces give way to fast first break picking and computation of refraction statics. The near-surface low velocity layer presents significant lateral variations. These variations affect by similar amounts the refraction first arrivals and reflection travel time, allowing the use of the refraction travel time static shifts. Similar approaches for static correction based on alignment of first break times performed on common shot gathers were proposed by Hatherly et al. (1994) and Pugin and Pullan (2000). This process corrected the variations of medium wavelength (within spread length), and long wavelength (greater than the spread length), due to variations of both near-surface velocity. A method to increase the quality of the seismic data is to remove the noises from the signal, which means muting refractions, airwaves and the ground roll. When the refracted or the airwaves have distinct and dominant phase, spatial filters like f-k can be used to remove them. However, the f-k filter can degrade the data, especially when the airwaves are aliased. Application of this filter in poststack stage often degrades the stack quality. Its application in shot gather is safe and expected to yield positive results. The overwhelming effect of direct, refracted, guided and surface waves plague high-resolution seismic reflection data recorded at many

locations on Earth. This different component of source-generated noise may completely mask reflections at travel times less than 50-100 ms. Conventional processing methods may lead to the misprocessing of source-generated noise (especially guided waves) as reflected events and/or the unintentional removal of important shallow reflections. However, τ -p processing results in the effective separation of reflections from source-generated noise. Shot gathers are transformed into the linear τ -p domain, a τ -p filter so designed eliminates majority of source-generated noise (Figure 4). After noise elimination, we have to revert from τ -p domain to x-t domain and sort the shot gathers into CDP gathers.

These gathers are again subjected to second round of band-pass (120-250 Hz.) filtering to cut coherent and incoherent noise. The CDP gathers are ready for first round of velocity analysis. A velocity model was conceived based on the previously mentioned velocities and picked semblances in velocity spectrum. The velocity analysis was based on two criteria: the best move out alignment of NMO-corrected data, and the best quality of stacked data. One more velocity after residual static correction is advised. The final stacking velocity is used to flatten the events in CDP gathers to obtain NMO corrected gathers. These gathers are stacked after application of manual mute to remove stretching effect. Left over refraction events are removed with the help of refraction muting before poststack migration is effected. Kirchhoff time migration with the smoothed version of stacking velocity may be used for poststack migration. The time-migrated section is converted into depth section using the available velocity field.

The processing flowchart may be as follows:

- (1) Geometry and trace editing
- (2) Band pass filtering (70–250 Hz)
- (3) AGC
- (4) First break picking for static shift calculations
- (5) Static correction
- (6) f–k filtering
- (7) Sorting to CDP gathers
- (8) Band pass filtering (120–250 Hz)
- (9) Velocity analysis
- (10) Residual static correction
- (11) NMO correction
- (12) Stacking
- (13) Refraction muting

- (14) Migration
- (15) Time-to-depth conversion

The processing sequence is not a generalized one, it only emphasizes on issues of source-generated noise (especially guided waves, ground rolls) in near traces in SSR and their handling practices by processors. Usage of GEOTOMO statics, refraction statics and precision statics also find favor in processing flow of conventional seismic survey to improve the data of fold belt areas.

Special Processing

The fast computing machines (tera flops), huge disk space, efficient software and decreasing cost, which historically have been a primary limitation of advanced processing in SSR data may now be used as standard tool in high resolution seismic data. Authors J.H. Bradford , L.M. Liberty , M.W. Lyle , W.P. Clement and S. Hess in their paper “ Imaging complex structure in shallow seismic reflection data using prestack depth migration” in 2006 have used above workflow (Figure 5) . Preprocessing included time varying bandpass filter, automatic gain control (AGC), f-k filtering, top muting the first arrival and inside muting the strongly aliased coherent modes. The processing stream comprises of random and coherent noise suppression, depth - velocity model estimation and prestack depth migration. Velocity model estimation is the most critical step in this workflow. The data are sorted into common image point (CIP) gathers in the post-migrated domain. The flattening of events in the CIP gathers is indicative of correctness of velocity model. Often the velocity model must be updated iteratively to produce good migration result. Layer stripping approach is adopted in some cases where the velocity model is updated layer by layer in a top to bottom sequence. Another approach, we may estimate the model using reflection tomography. This approach has become the preferred method for velocity model building in recent years. Stork presents a method of reflection tomography in the post migration domain. Depth deviations are measured as residual moveout (RMO) in the CIP gathers. The depth deviations are converted to travel time deviations using the velocity above a given reflector. The tomographic inversion is formulated to minimize the travel time deviations along key horizons in the CIP domain with the sensitivity matrix computed via ray tracing. After first iteration of PSDM and reflection tomography using this method the velocity model is edited. The edited velocity model is then subjected to second round of PSDM and tomography. After second round of PSDM and tomography if the RMO is reduced significantly, the velocity model and PSDM are accepted as final results (Figure 6 and Figure 7). Kirchhoff method based on Deregoski’s algorithm is used in this workflow for PSDM. However, for comparison DMO output may be further migrated using poststack Kirchhoff time migration algorithm (PoSTM). The smoothed version of stacking velocity is used in this migration.

Near Surface Model Building

The process of Near Surface Model (NSM) building with the help of Shallow Seismic Reflection (SSR) is a building block towards making of precise NSM. The NSM will comprise of thicknesses of low velocity layers and their velocities. The precise NSM in-turn will be used in computation of precise static correction in conventional (deep) seismic survey. The alignment of events is bound to improve after precise static correction application in conventional seismic survey. The subsequent steps of velocity picking and residual statics will be effectively applied in aligned events resulting into improved velocity model and final PSDM image. The primary purpose of Near Surface Model (NSM) building is to show how corrections for static effects on a conventional/deep seismic reflection survey could be calculated precisely and accurately using near surface velocity model and thicknesses of layers derived from detailed processed SSR data along the same line in 2D or inline in 3D as the case may be. Any velocity or depth and thickness variability uncompensated within the weathered layer can result in static effects that degrade seismic reflection data. SSR surveys have the potential to identify economically the spatial variations in velocity within the weathered layer as well as depth to sub-weathered layer.

Time-depth table of all upholes is already incorporated at the time of calibration during velocity model building in advanced processing. Check shot or VSP data of available deep wells in the area may also be included in this purpose. Normally these data are not available up to the top of the well. In the fold belt area where deep upholes are logistically difficult, VSP may be under-taken up to the top of the well. VSP and Upholes data with lithology is to be overlayed on depth section shown in [Figure 8](#) for completing NSM.

Static Computation

Accurate datum statics correction can be made once an accurate Near Surface Model is in place. The Near Surface Model (Refer: [Figure 8](#)) of the profile is having upholes deep enough in the elevated part to know velocities of the near surface layers down to datum / Mean Sea Level (MSL) . These weathered/sub-weathered velocities of near surface layers ([Figure 9](#)) are essentially required to be substituted in the formulae of static correction given below:

$$\text{Shot correction} = - (ES - D_s - ED) / V_{SW}$$

$$\text{Receiver correction} = - (TUP + (ER - D_s - ED) / V_{SW})$$

$$\text{Uphole time} = DS / V_W$$

Where ES = Elevation of shot station (m)

ER = Elevation of receiver station (m)

ED = Elevation of datum (m)
DS = Shot depth (m)
VSW = Sub-weathered velocity (m/s)
VW = Weathered velocity (m/s)
TUP = Uphole time (s)

Field statics (Shot and Receiver corrections) is computed using above formulae for all shot stations and receiver stations and applied to shot gathers of conventional / deep seismic reflection data before the data is subjected to processing.

Discussions

The migration artifacts in the shallow part in poststack time migration (PoSTM) are a result of datuming prior to poststack migration. The PSDM section is migrated from elevation, so the shallow artifacts are minimized. Besides this, artifacts that are present are attenuated through CIP stacking after PSDM. The overall result is that PSDM produces a much clearer image of shallow features than its PoSTM counterpart does. The difference in image quality is particularly evident in zones A and B in [Figure 10](#). Therefore, utilization of PSDM output is much better option than PoSTM output into making of a precise Near Surface Model (NSM).

Conclusions

- Though using SSR for NSM is doubling the efforts of seismic data acquisition, still it makes up for sparse distribution of upholes.
- Special processing like PSDM rather than PoSTM can fetch better results in making NSM.
- Precise NSM holds key of precise static correction computation.
- Precise static correction application to conventional/deep seismic reflection data helps in imaging of subsurface in fold belt areas.

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<http://www.geophys.geos.vt.edu/hole/ccss/spitzerCCSS.pdf>
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Figure 1. Terrain of fold belt area showing variation in elevation.

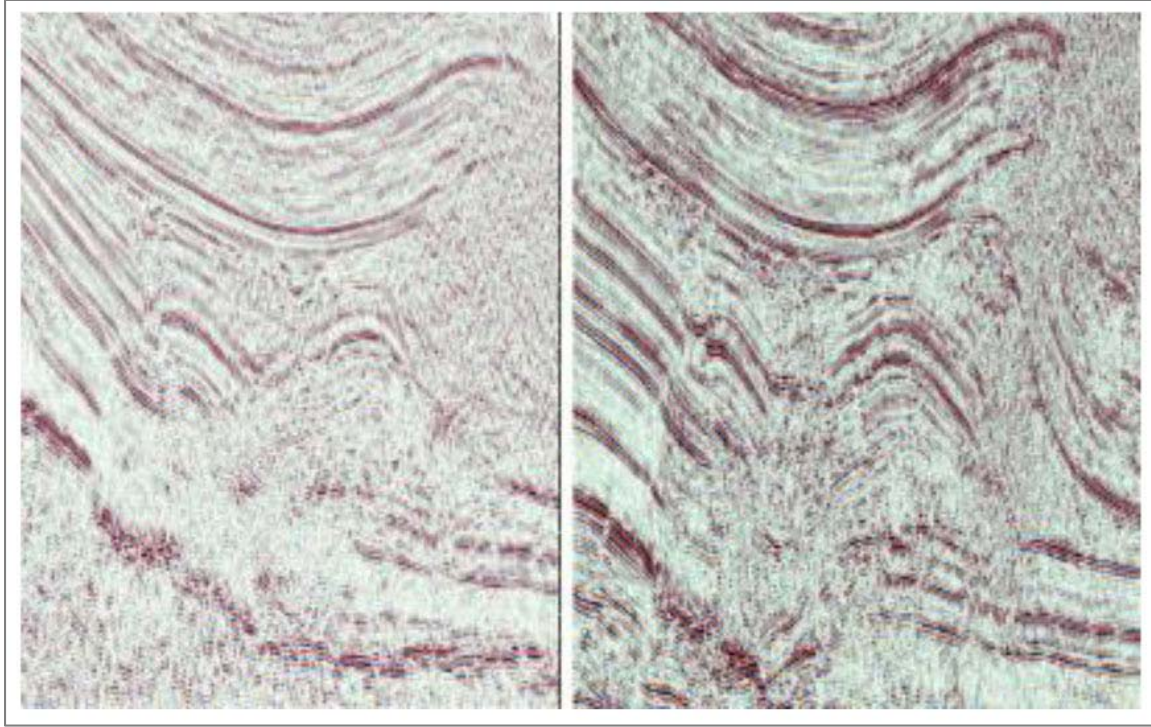


Figure 2. Showing improvement due to tomographic inversion statics in fold belt area.



Figure 3. Land streamer in SSR survey.

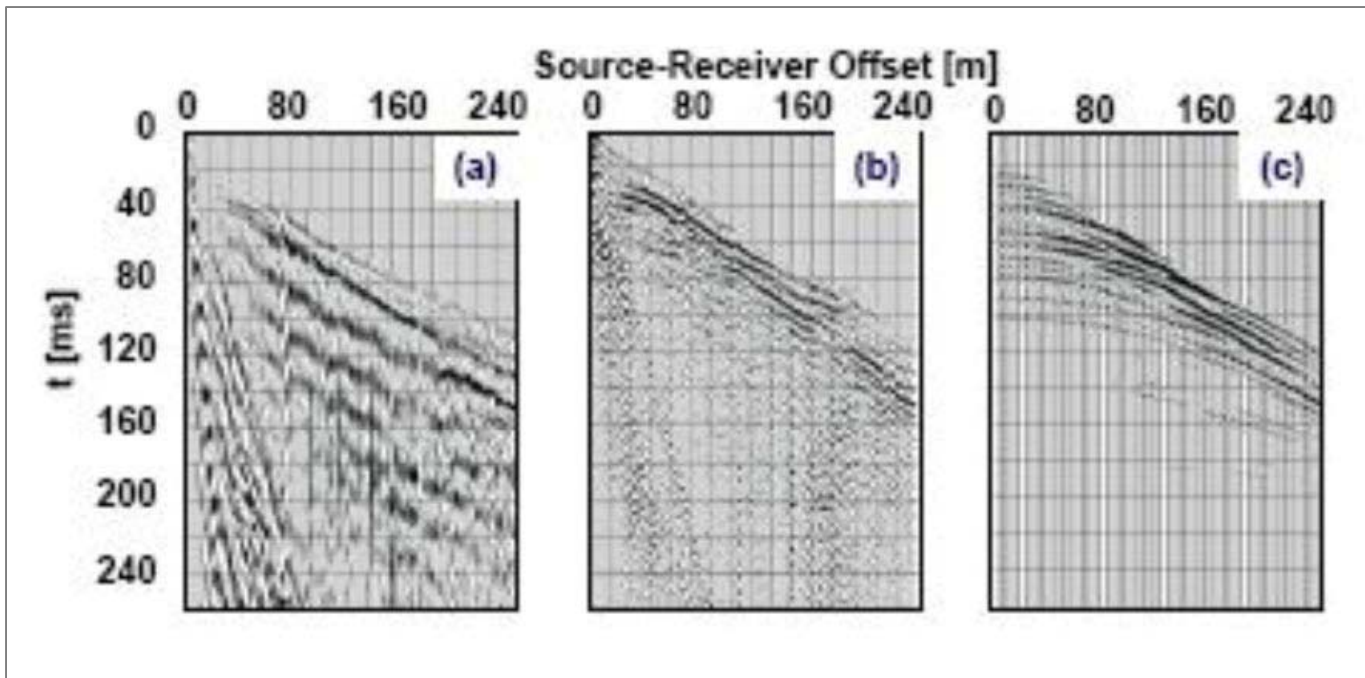


Figure 4. (a) Shot gather with dominance of guided waves; (b) after band pass filter and decon; (c) After filtering noise in τ - p domain.

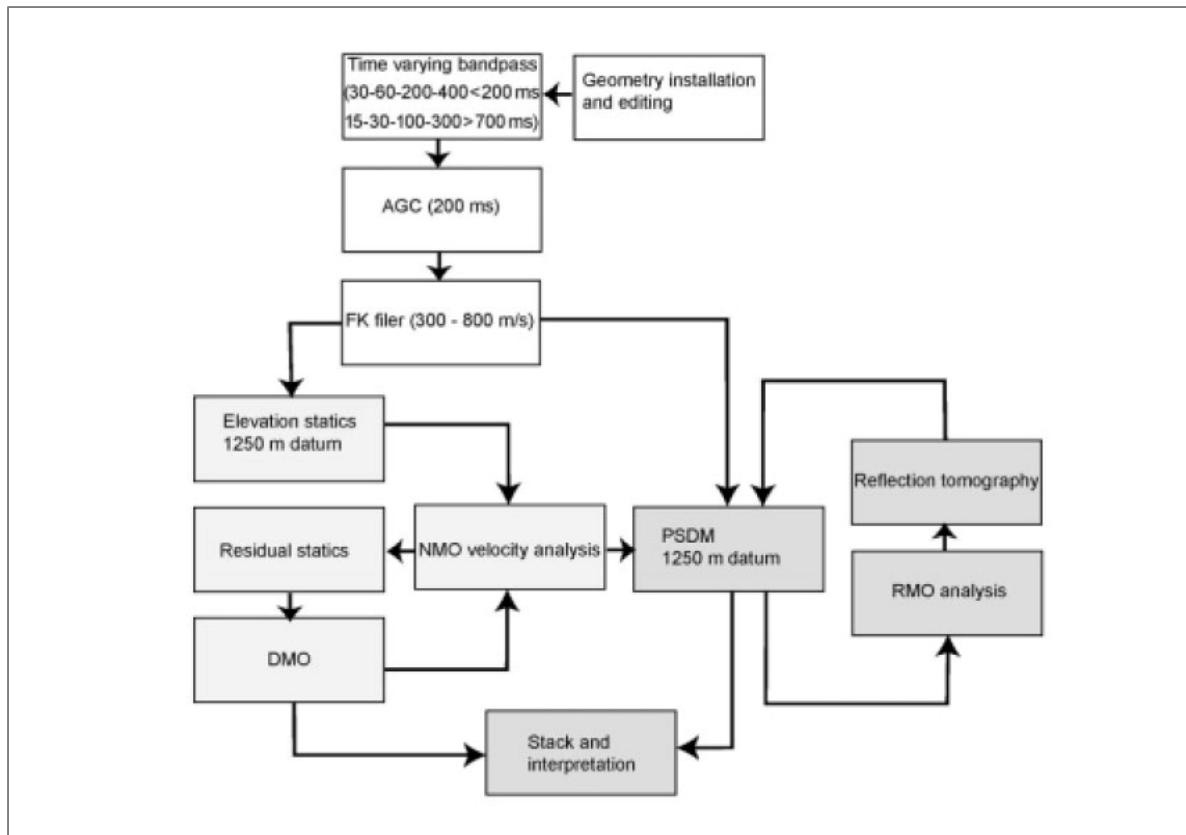


Figure 5. PSDM data processing flow with conventional processing scheme.

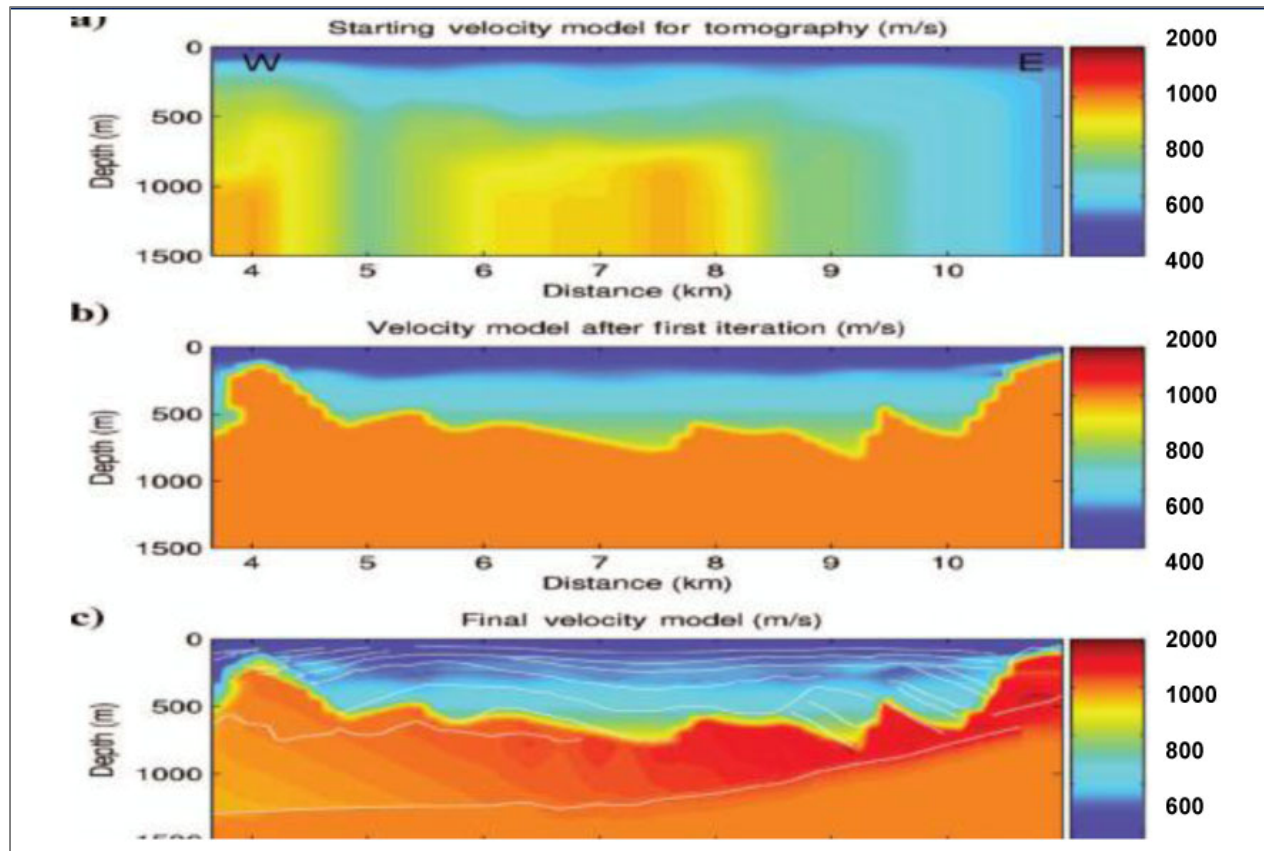


Figure 6. Changes in the migration-velocity model, as it is refined through Reflection tomography. (a) The smoothed stacking velocity model; (b) the model after one round of tomography and editing; and (c) the final velocity model.

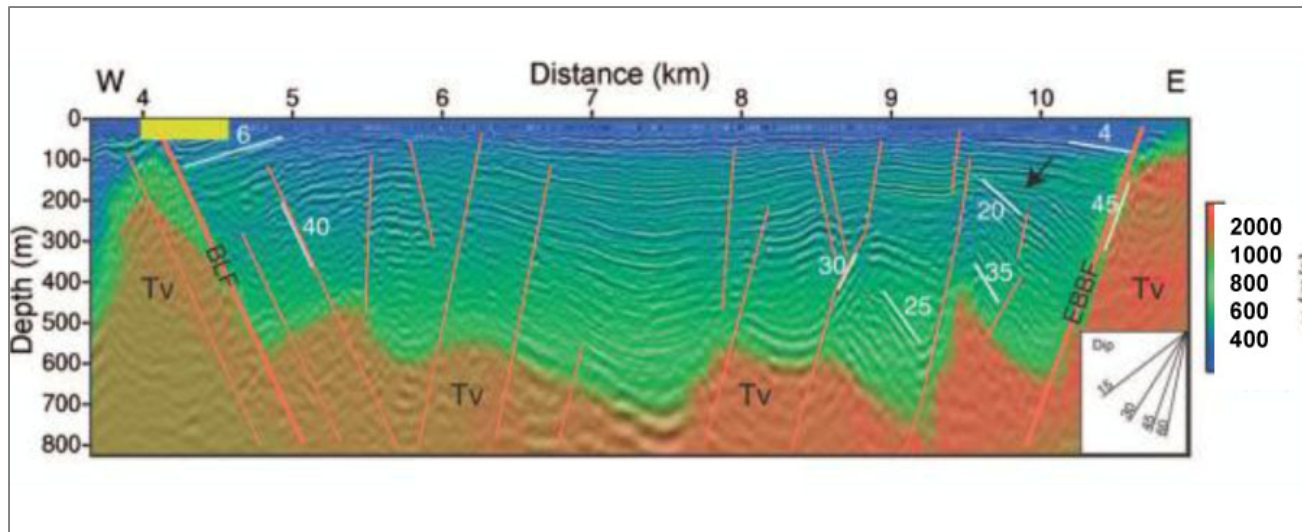


Figure 7. PSDM section with final velocity overlay.

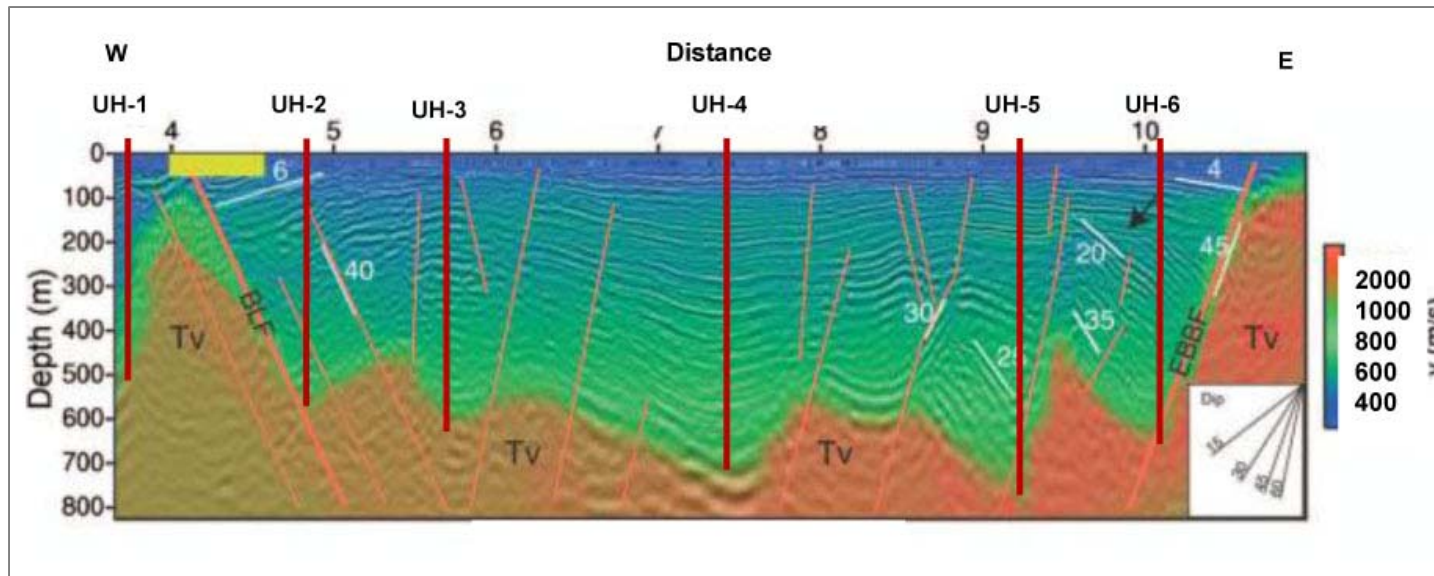


Figure 8. Near Surface Model (NSM) with final velocity and uphole overlay.

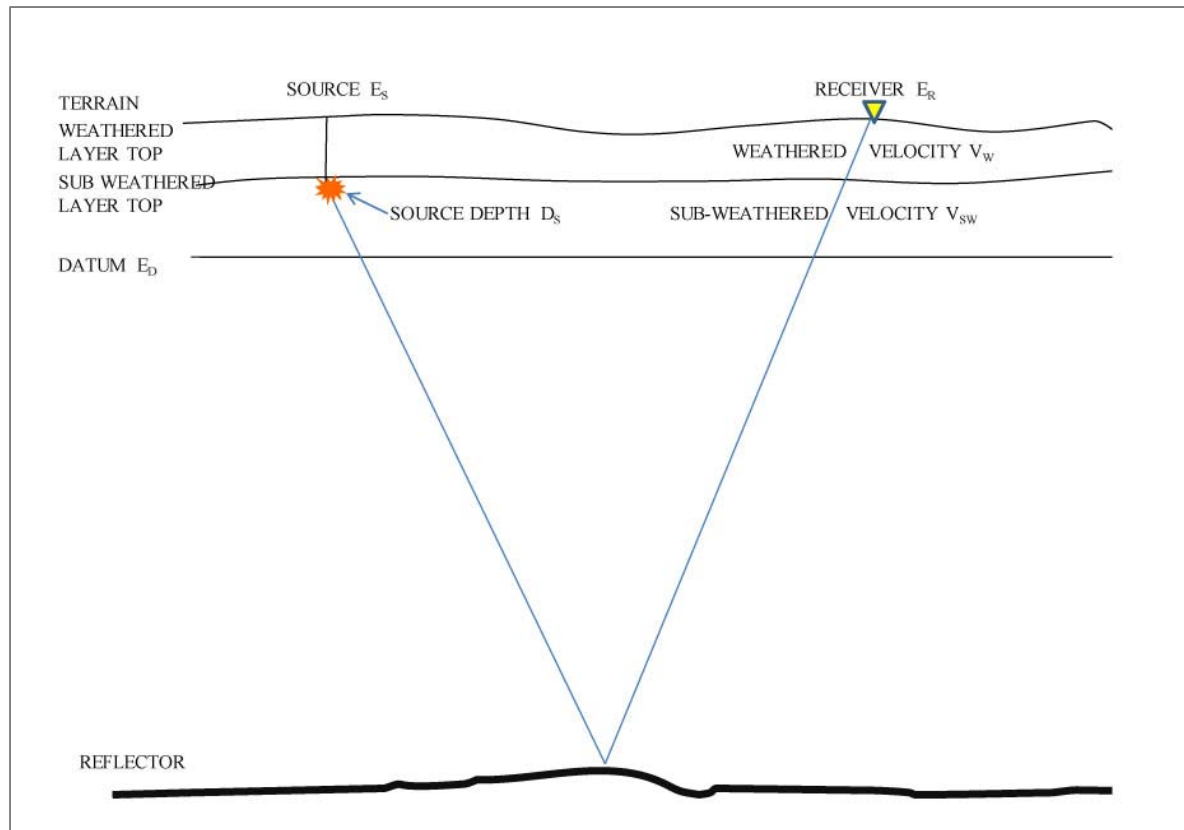


Figure 9. Schematic diagram showing static correction.

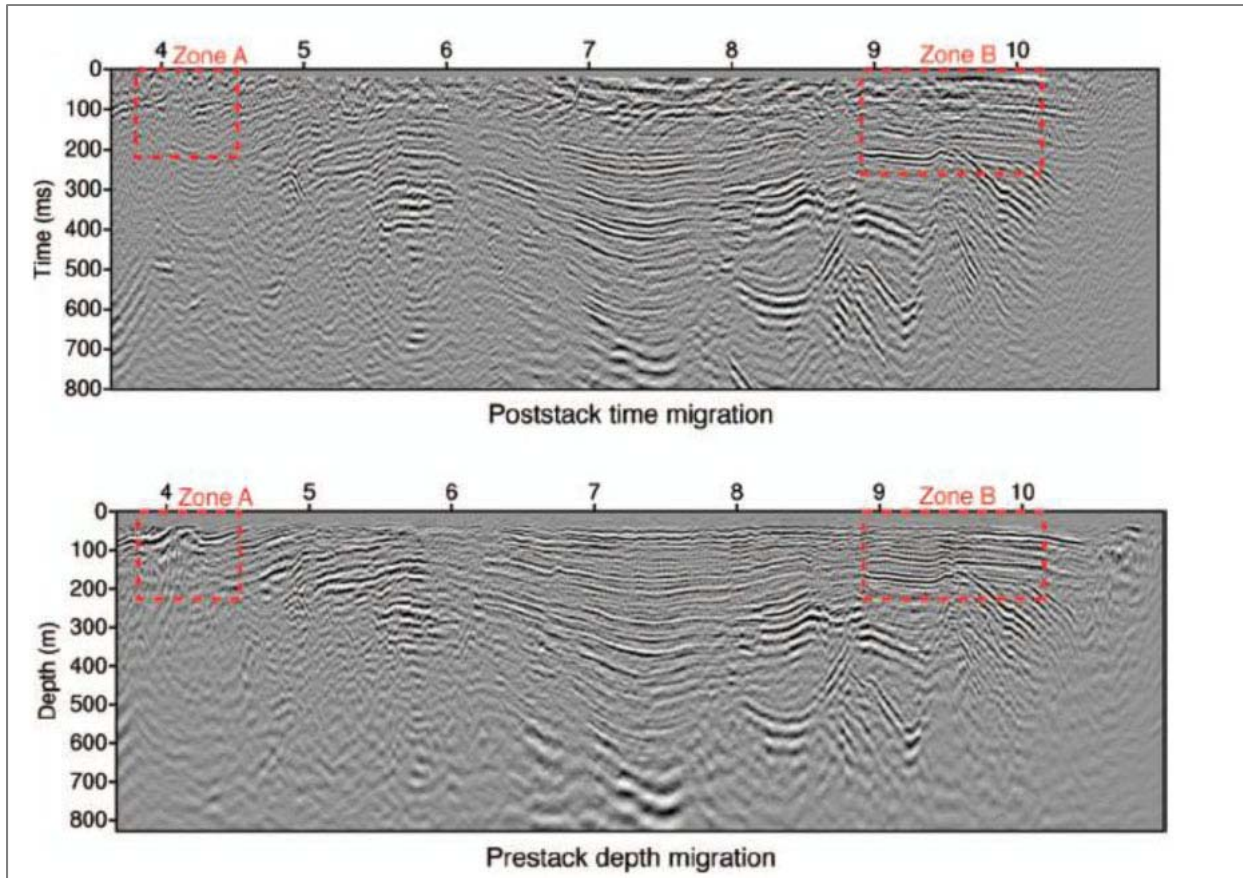


Figure 10. Comparison of imaging in PoSTM and PSDM.