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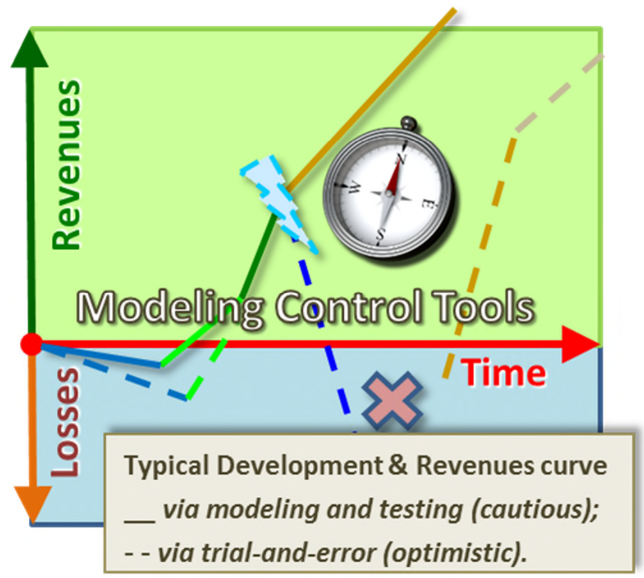
Multiparameter Numerical Medium
for Seismic Modeling, Planning,
Imaging & Interpretation
Worldwide

Tesseral Geo Modeling

Modeling in Seismic

Ray-tracing, and especially, ***finite-difference*** numerical modeling allow accurately simulate all seismic wave effects of the seismic wave-field propagation in geologically realistic multiparameter numerical models. Accuracy of modeling is limited only by complexity approximation of ***wave equation*** and the technical perfection of employed calculation schemes used.

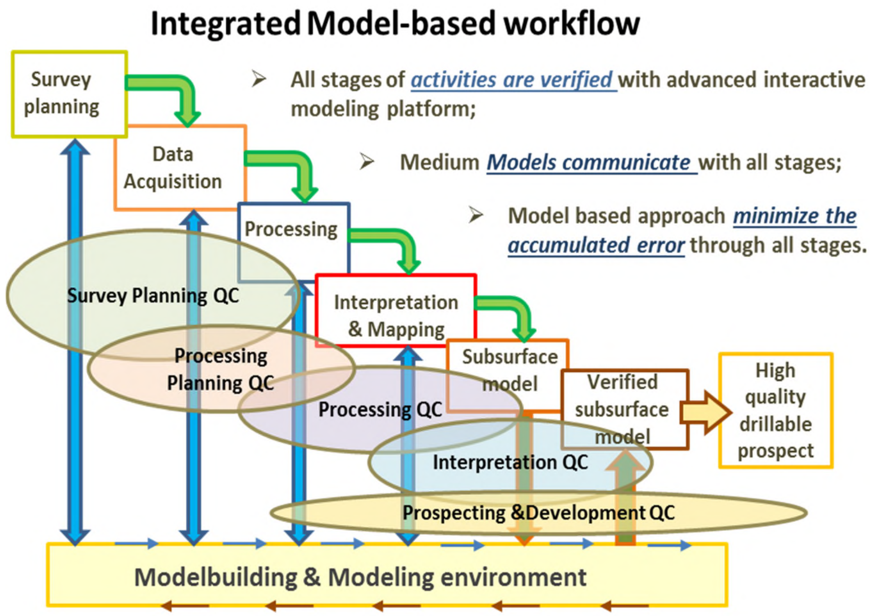


Capability to compute 2D-2C and 3D-3C gathers Enables Geo-scientists to make:

- ✓ Recommendations for the survey planning basing on evaluation of resolving capability of the seismic method for any given geologic scenario and acquisition geometry.
- ✓ Endorsement for seismic data processing workflow basing on modeling of any type of seismic recording such as conventional surface seismic, micro-seismic, VSP, and high frequency well log simulation.
- ✓ Verification of robustness of any given seismic interpretation for reality of the reflected discontinuities and structural elements;
- ✓ Identification of potential processing artefacts not tied with the medium model structure that may lead to interpretive errors.
- ✓ Estimation of horizon illumination under lateral heterogeneities using ray-tracing approach.
- ✓ AVO-modeling or anisotropic, porous, fluid saturated, visco-elastic, thin layered media, and curved boundaries complicated by changing physical properties both vertically and laterally.
- ✓ Sample data sets for geophysical software evaluation and development. Allowing the user to fully understand the strengths and weaknesses of the new technologies so that the adoption cycle time may be greatly reduced.
- ✓ Presentation (report, training course) enabling a clear understanding of the complexities of seismic signal mode conversion, multiples, the creation of surface related noise, etc.

Tesseral Geo Modeling

- **Model Builder** allows to quickly build on screen model of geological cross-section incorporating different rock properties and levels of structural complexity. You can integrate well-logs and other available data at interactive Model Building. Practically any kind of geological structure can be simulated and complex patterns of P-wave and S-wave velocities, densities, anisotropy, fracturing and energy absorption can be applied.



- **Computation Engine** allows matching the model complexity with a full selection of accuracy levels of solutions to the wave equation. Scalar, acoustic, elastic, visco-elastic, elastic anisotropic solutions are available depending on the modeling needs and computer power available. The software runs parallelized calculations on a variety of hardware platforms including Windows networks and Linux clusters, employing latest multicore and GPU technologies.

- **Viewer** interactively presents the results of the modeling in a visual format that enables the viewing of wave propagation movies through the geologic model. The movies can be run forward or backward to enable the user to determine the origins of all events and artefacts that are observed on the synthetic shot records. Instantaneous flipping between the vertical, X- and Y-direction and pressure wave records enables a full and rich understanding of the value of multi-component recording.

- **Processing Block** enables the processing of the synthetic data within the Tesseral system. Capabilities include velocity analysis, CDP stacking, pre-stack time and depth migration, time and depth VSP migration, and AVO-modeling.

Input Data

- **Model structure:** scaled cross-section (2D and 2.5D) or cube (3D) with horizons, layers, faults and inclusions supplied with compression and shear (optional) velocity and density parameters.

- **Observation geometry**: position of the source and receiving points (lines) on the model surface or in the well.

- **Seismic signal** form and its peak frequency (or band of frequencies).

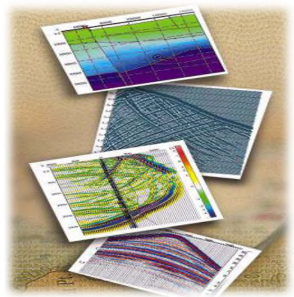
Output Data

- **Multiparameter model** of heterogeneous medium.

- **Synthetic shotgathers, snapshots** and **timefields.**

Software Package Tesseral 2D :

From full-wave modeling of complex structures to pre-stack depth migration

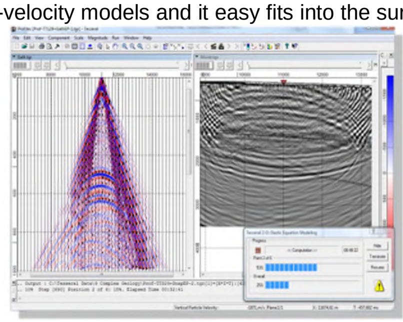


Application allows assigning different seismic acquisition geometries, numerical model building of complex seismic sections **and modeling propagation of seismic waves in heterogeneous medium for the scalar, acoustic, elastic and elastic anisotropic wave equations.**

Algorithms use **fast and accurate computational scheme** based on the finite difference method, which allows effective modeling of arbitrarily complex geological medium, including the combination of solid and liquid state bodies.

Obtained wave fields can be processed, directly within the software, to obtain **seismic images** with the help of different modifications of the **time and depth migration**.

The software package Tesseral 2D is intended for the interactive analysis and examination of depth-velocity models and it easy fits into the survey planning, processing and interpretation of seismic data.



It is widely used as an educational tool in the **study of wavefield propagation phenomena, survey planning, processing and interpretation of seismic data**.

The following software variants are available: **Windows Standalone, Windows Network and Linux Cluster**.

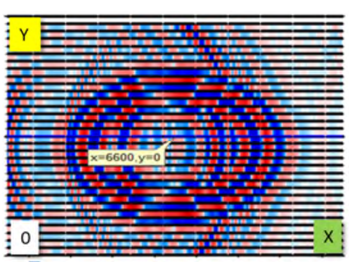
Parallel computation engine Tesseral 2.5D-3C :

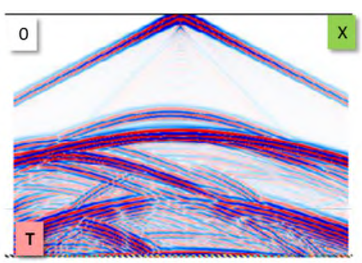
Modeling of the 3D seismic wavefield propagation effects

In contrast to the 2D modeling, waves in 2.5D modeling propagate in a 3D medium and are described with 3D equations. In this case, the dynamic of the wavefield is preserved and creates the possibility to **model 3D-3C areal gathers for surface seismic and VSP**.

2.5D-3C modeling enables to specify **true elastic model;** consider the **thin-layering effects (quasi-anisotropy, dispersion and dependence of wave propagation velocity on frequency), fracturing and anisotropy**.

2.5D-3C modeling allows considering complex geological conditions, but in contrast with the full 3D modeling, it requires some simplification of the 3D medium model: the **medium parameters are assumed to be constant along Y axis (usually oriented along structural strike).** However the anisotropy can be arbitrary and take into account several fracture systems with different spatial orientations.



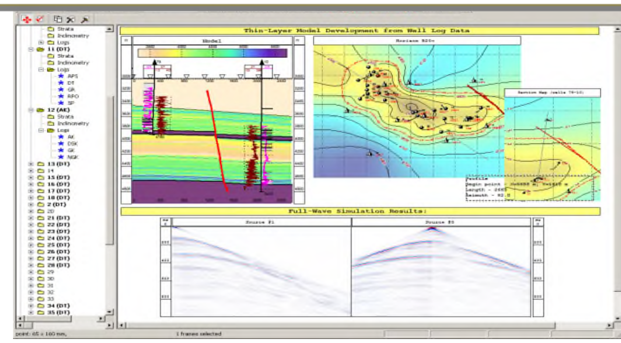


Software Package Tesseral Pro

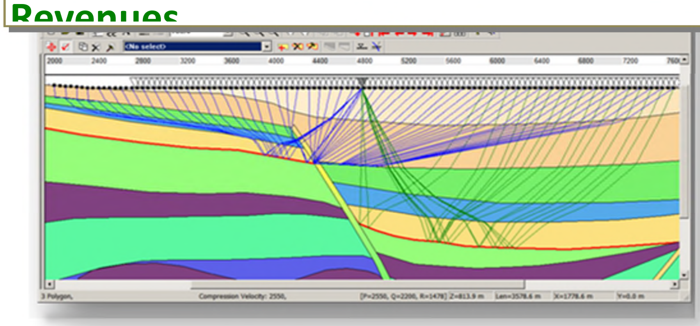
Full wave modeling & ray-tracing for oil and gas fields

Tesseral Pro is a new software implementation based on the Tesseral 2D package. It includes additional tools such as ray tracing and it is intended to be used for the **interactive analysis and examination of depth-velocity models of oil and gas fields by using geological - geophysical data bases**.

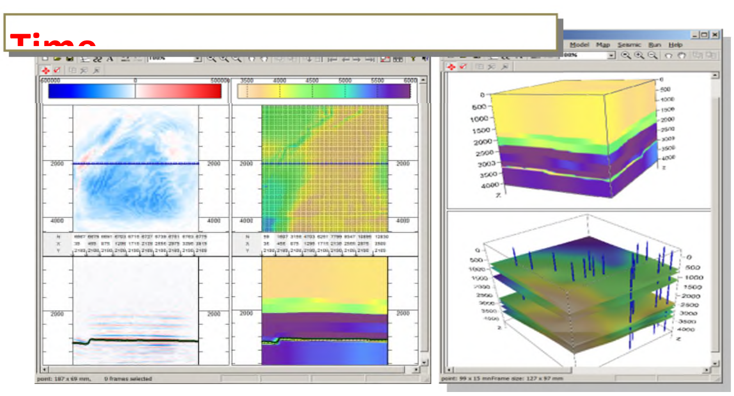
The software allows creating depth velocity **models from well log data, maps of geological surfaces, 2D and 3D seismic velocity models**, for the calculation of synthetic data from 2D built models and as well as the preparation of the 2.5D calculation assignment.



Tesseral Pro enables the creation of **thin-layered models capable of high precision and modeling feasibility**. Along with well log data, the user can enter additional data such as: well's coordinates and inclinometry, stratigraphic arrangements, fault information, horizon maps etc.

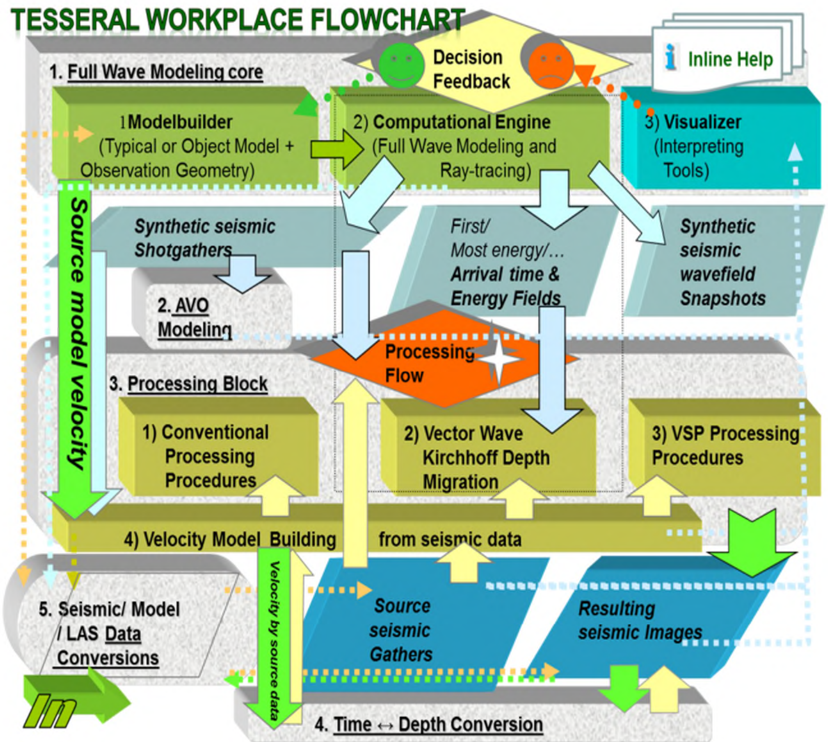


WYSIWYG approach enables **combining maps, cross-sections**, **2D and 3D drawings**, multi-parameter models, seismic cross-sections and cubes, pictures and text strings to create high quality plots. **Overlay and controlled transparency of fields** is supported. Composite documents can be printed or exported in multiple file formats.



You can

... produce synthetic gathers, snapshots of the wave field, time field of the incident waves, time cross-sections and other seismic images, AVO-dependencies for:



- ***Models of virtually arbitrary complexity*** *including* the ones with strong lateral velocity contrast, steep boundaries, compartmentalization, and caustic zones, producing the waves of complex ray-path including those reflected from the vertical boundaries etc.
- Models with ***complex topography and various near-surface conditions,*** including the situation when source/receivers are on different elevations, traps, permafrost, low-velocity zone of variable thickness (by correctly taking into account kinematics and dynamics of ***surface waves, satellite waves, refractions, etc.****)*.
- ***Thin-layered*** models that are built on the basis of the ***acoustic and density well-logs****.*
- ***Transversally isotropic media*** models with the tilted symmetry axis, which may be complicated by tilted ***fracturing systems****.*
- Models with ***visco-elastic properties (Q-factor)*** additionally allowing simulating the ***absorption of seismic energy*** and such wave effects as ***velocity dispersion***.
- Models for ***porous fluid-saturated media*** *(Gasman approximation);*

… using different tools of (numerical) **Seismic Modeling** and **prebuilt models** allowing smoothly **start evaluation and working with the package.**

The source and resulting ***data in popular file formats*** can be ***used or output*** for further analysis and processing in other packages.

The software runs ***parallelized calculations*** on a ***variety of hardware platforms*** including *Windows* networks and *Linux* clusters, employing latest ***multicore and GPU technologies***.

More ... about the method

- The ***wave propagation*** depends on the ambient medium ***static*** (not changing with time) properties changing in space (***heterogeneous medium***), such as:
  - ✓ ***velocity*** of wave propagation ***Vc*** (compressional waves),***Vs*** (shear waves)***, density D*** and other for more complex approximations, such ***as anisotropy –*** $\varepsilon\ \delta\ \gamma$ ***Thompsen's parameters, absorption – Q-factor,*** etc;
- The ***wave field*** is described by ***variable*** (changing with computations) parameters, such as***:***
  - ✓ ***instant particle velocity, pressure*** or ***stresses***, etc.
- Data relationships may be described in ***differential wave equations***, which can be translated into the ***computer program*** and then simulated ***closely to the real process***. Oscillating change of variables with computations is equivalent to their variation with time, which is regarded as the wave propagation.
- For digital modeling of the processes developing in the continuous heterogeneous medium special logical discrete structures and algorithms are used.
- Computer program treats data as a set of medium properties and wave field variables distributed on logical discrete structure. Depending on such structure computational methods are divided into two categories: ***finite elements*** and ***finite differences***. First represents some non-uniform distribution of areas - *finite elements*, latter is using a set of uniform *rectangular (orthogonal) grids* oriented along X, Y, Z directions in Cartesian co-ordinate system.
- For modeling of wavefield additionally must be defined ***source(s)*** – its position and parameters of generated signal, such as its form (***wavelet***), main (***peak***) ***frequency*** and intensity (***amplitude***).
- ***Full-wave*** modeling allows simulating all (including frequency depending) effects of wave propagating in heterogeneous medium, which is generated from the source with particular signal.
- Asymptotic approximation of wave equation in assumption of infinite frequency is called ***Eikonal equation***, and corresponding method of modeling – ***ray-tracing***.

Seismic Surveys, seismic Imaging and geophysical Research

Full wave modeling may also be applied at different stages of ***seismic survey planning and QC***:

- ■ Conventional *seismic surveys* consist in detecting seismic waves using a line (*2D seismic survey*) or a grid (*3D seismic survey*) of *receivers* placed on or near the surface of a geological zone of interest. Shotgathers for all available sources and corresponding observation geometry represent the *survey data*.
- □ At this stage full-wave modeling may be used for survey planning and quality control (*QC*) monitoring. Produced gathers can be analysed in different ways, like real ones (***pre-stack level*** of interpretation).

Full wave modeling may also be used for ***seismic data processing planning and QC****:*

- ■ Seismic data *processing procedure* input the survey data (usually after some necessary upgrading – *pre-processing*) and then generates seismic images revealing geological boundaries or interfaces at different times (*time scale images*) or depths (*depth scale images*).
- □ At this stage full-wave modeling may be used for planning of processing flow (sequence of processing procedures and their parameters) and QC of the produced seismic images (***post-stack level*** of interpretation).

Full-wave modeling in seismic may be used in different ***geophysical research applications***:

- □ Creating of synthetic datasets for development and testing of seismic processing algorithms, analysis of seismic records for typical for region of interest geological conditions, etc.

Full-wave modeling vs Ray-tracing

	Full-Wave Modeling		Ray-Tracing
1	***Difference**:* Propagating waves are calculated as a distribution of instant and local movements and pressures changing with time for the whole medium model.	1	***Difference**:* Each ray is calculated as a string of points along the time-field gradient. Ray-tracing algorithms emulate the wave propagation nominally, as the infinite-frequency approximation of the wave propagation in relatively smooth heterogeneous media.
2	***Disadvantage**:* Wave fronts cannot be treated separately. Dividing of the waves for analysis may be difficult.	2	***Advantage**:* Rays may be treated separately, for example, for tomography applications. Different ray clusters can be separated for analysis.
	Stable and correct calculations require much more computing resources than ray-tracing.		Takes comparatively short time for calculations. Stability in many cases is not an important issue.
3	***Advantage***: Modeling is the most close to the wave propagation process, which can be easily visualized as the animated series of snapshots. No conceptual restrictions applied.	3	***Disadvantage**:* Modeling is restricted by the geometry optic theory: no diffraction and other effects proper to the wave nature can be exactly simulated. Visualization of the ray-traces does not provide good understanding of wave effects.
	Dynamic parameters are intrinsic to the calculations, and may be determined with high accuracy even for complex models and whole range of angles of incidence.		Require additional operations to assure quality and stability of calculations for complex heterogeneous models and amplitudes of reflected waves for wide incidence angles.
	Complexity of the model does not influence the quality and stability of calculations.		It is difficult to make the uniform and stable ray coverage for the complex model, which produces blind spots and big, unstable gaps between ray traces.
	Reflections and conversions (as well as diffraction and other wave effects) are an integral part of calculation and do not require special control.		Reflection event must be controlled for each discontinuity, and produces a separate cluster of rays, making it difficult to calculate multiple reflections and conversions.

1D, 2D, 2.5D and 3D full-wave modeling cases

Case (Spatial)	Common meaning	Case (Modeling)	Comments
1D	1D modeling for vertical incidence within 2D cross-section	***2D-1C***	2D – cross-section model, 1C – seismic wave propagates along vertical line and recorded within cross-section
2D	2D modeling for express building of T_0-approximation to stack/migrated time cross-section.	***2D-To***	2D – cross-section model, To - seismic wave propagates mostly vertically within cross-section plane using special methods: *Exploding Surface* (wave propagates down from surface) and *Exploding Reflectors* (wave propagates upward from model boundaries) and recorded within cross-section.

2D	2D modeling	***2D-2C***	2D – cross-section model, 2C - seismic wave propagates within cross-section plane and recorded within cross-section
1D	3D modeling for horizontally layered medium	***1D-3C***	1D – horizontally-layered model; 3C – seismic wave propagates within 3D volume and recorded within 3D survey area;
2.5D	3D modeling within cross-section	***2.5D-2C***	2.5D - volume model - same in Y-direction as the basic 2D cross-section; 2C - seismic wave propagates within 3D volume, but recorded within basic cross-section only;
2.5D	3D modeling within cross-section stretch	***2.5D-3C***	2.5D - volume model - same in Y-direction as the basic 2D cross-section; 3C - seismic wave propagates within 3D volume and recorded within 3D survey area;
3D	3D modeling	***3D-3C***	3D - volume model, 3C – seismic wave propagates within 3D volume and recorded within 3D survey area;

- For different applications, where is required comparison of well drilling and logging data with surface seismic surveys, may be useful ***2D-1C full-wave modeling***. In this case seismic waves are modeled as propagating vertically only. Such an assumption does not take into account the dissipation of the seismic energy on 2D elements of the modeled cross-section. As it is well-known, differences in sonic logging frequencies (10-50 kHz) and seismic frequencies (20-100 Hz) require entering for thin-layered medium stratigraphic correction to make comparisons between well-logs and seismic cross-sections, and in this case 2D-1C full-wave modeling allows doing it. Such kind of modeling is relatively fast and also may be used as initial rough approximation before 2D-2C full-wave modeling.

- ***2D-2C full-wave modeling*** allows to produce and analyze 2D-1C (Z- component) and 2D-2C (Z- and X-component) synthetic gathers for modeled seismic profile (2D line). It effectively approximates wave effects of seismic energy propagation in a real geological situation, i.e. can be modeled thin and small-size inclusions, interferential, complex reflected waves from sub-vertical discontinuities, anisotropy and pseudo-anisotropy, etc. It models the wave propagation for complex heterogeneous media in a relative short turnaround time and with good numerical accuracy. This process may provide very accurate modeling for the velocity anisotropy of arbitrary symmetry, longitudinal and transverse fracturing, topography and observation system, thin layering effects, and multiple reflections/refractions. This approach provides enough efficiency without sacrificing numerical accuracy and calculations can be easily done on an average class PC.

- ***1D-3C modeling for horizontally layered medium*** is a relatively quick way to produce true 3D synthetic wavefield. It has all abilities of 2D-2C and 2.5D-3C (see below) modeling. The only limitation consists in the medium model considered as horizontally layered. In many cases in may be quite good approximation for stratigraphic geological conditions and for practical analysis of influence of thin-layering, fracturing and anisotropy with different dips and azimuths.

- ***2.5D-2C and 2.5D-3C full-wave modeling*** allows the user to build a realistic 3D model including (in addition to mentioned above for 2D):

  ✓ Ability to create multi-component (3D/3C) gathers for both CDP and VSP observations.

2.5D-3C (-2C) modeling (unlike “full” 3D modeling) requires certain simplification of the model of the media. The properties of the media are assumed to be constant along the Y-axis. Nevertheless the symmetry axis of all the anisotropy properties (including the anisotropy that is caused by fracturing) may have arbitrary azimuth within the XY-plane.

However, unlike in 2D modeling, the waves can propagate not only in XZ-plane but in all three dimensions – to put it simply, this kind of forward modeling is true 3D, but the medium properties are the same along Y-direction. For the case of the TTI anisotropy (or tilted fracturing, or its combination), 2.5D-3C modeling allows to simulate both “fast” and “slow” shear waves and takes into account all of their qualities such as wave coupled refraction. More complex approximations (viscoelastic) can take into account Q (the Q-factor or Quality of the medium are re-calculated into “complex” parameters in correspondence of the parameters of the Q-factor for P- and S- waves) and may allow to accurately simulate polarization effects for both surface waves and volume waves.

The properties of the medium along the XZ-plane can have any complexity. Due to this, 2.5D model will provide correct 3D results for locally stretched (up to tens of kilometers) very complex models.

For a great number of models, the results of the 2.5D will provide virtually the same results as the “full” 3D wave equation modeling (regardless of their complexity along XZ-plane). This kind of modeling can be successfully used for of 3D-3C creation datasets for processing algorithms testing, survey planning and 3D-3C data interpretation in order to locate the fractured zones (by using azimuthal AVO method), doing full elastic inversions, etc.

Due to the computational intensity of the method, it would require a multi-processor hardware - such as Linux cluster – to implement. A 2.5D solution lends itself very well to the parallelization on a cluster (since it requires minimum communication among the individual nodes of the cluster). This quality of the 2.5D-3C modeling allows relatively (compared to the full 3D) fast calculations. On average, creation of the 3D synthetic shotgather (using 2.5D method) – running on the 100-processor cluster – would take the same time as producing a 2D shotgather running on a single-processor workstation (with the same length of the observation and signal frequency).

2.5D-3C modeling may be used as an intermediate approximation between 2D and 3D models. It may be a good and viable option for regular applications of full-wave modeling in solving relating problems in seismic.

2.5D-3C modeling can be useful for both processing and interpretational geophysicists for survey planning, interpretation, processing sequence planning, multiple wave and anisotropy studies as well as for EOR (enhanced oil recovery) monitoring and 3D VSP observation planning and processing.

2.5D-3C modeling can work on relatively affordable hardware (as opposed to full 3D modeling) and may provide the modeling results that – in most of the cases – would be not different from the results of full 3D elastic anisotropic modeling.

- ***3D-3C full-wave modeling*** (3DFWM) allows approximating wave propagation in conditions of realistically heterogeneous (in all 3 directions X-,Z- and Y-) medium. This modeling can be applied to the objects like reefs, salt domes or steeply inclined faults etc. in the areas where an accurate reservoir characterization is required. In addition, the parameters an expensive 3D (multi-component) seismic survey can be predicted ahead of the actual field seismic acquisition experiment and used at stage of its planning. Because latest multi-component data acquisition technologies are very expensive, there is a need to predict, process and verify their results with most possible precision before such type of acquisition takes place in the field. 3DFWM is a tool of modeling all types of 3D elastic and anisotropic wave-filed propagation arrivals including free surface conditions.

With the advent of the new 3C point receiver technology and the already 4C proven Seafloor technology, there is a need in predicting 3D full waveform synthetic seismograms. Since three dimensional (3D), 3C-9C and 4C acquisitions are very expensive, the 3DFWM elastic software will be able to predict the full 3D elastic wavefield and consequently design an optimum 3D acquisition geometry prior to conducting a complex 3C, 4C and/or 9C experiment. In such applications the ability to generate accurate 3D full waveform wavefields in a short turnaround time will be beneficial in terms of economic and technical reasons.

In addition, if ability to run a number of 3D elastic simulations in a feasible turnaround time will be achieved, it will allow generating accurate 3D elastic wavefields, where various seismic data processing technologies can be thoroughly tested and improved.

The practical use of 3DFWM (especially elastic and anisotropic) is restricted by the huge computational resources needed for achieving results in reasonable turnaround timeframe and may be done only on parallel computers. For example, in the case of complex anisotropy the 3DFWM is approximately 10000 times slower than the 2DFWM modeling counterpart. This means days of continuous computations on a cluster of some thousand nodes. Latest advances of GPU cluster technologies make such computations practically feasible.

The ability of ***3D-3C (partially 2.5D-3C) method allows*** to generate accurate synthetic 3D full waveform elastic gathers in a short turnaround time may provide the following benefits:

- ✓ Full Waveform multi-component acquisition planning and verification;
- ✓ Seismic data processing planning and examination;
- ✓ Various 3D acquisition field geometries planning and examination (land, marine, surface and subsurface configurations);
- ✓ Reservoir seismic response and resolution with respect to 3C, 4C and 9C point receivers for 3D & 4D acquisition types;
- ✓ Identification of complex 3D elastic & anisotropic wavefield propagation paths (snapshot movie generation).
- ✓ Step-by-step optimization of 3D multi-component acquisition geometry prior to complex field experiment (vertical and horizontal wave-field components),
- ✓ Estimation of the seismic resolution with respect to the proposed field multi-component sensors and sources configurations
- ✓ Accurate full wavefield synthetic seismograms to clearly identify complex wave-field propagation paths (multiples, turning waves) through complex geological structures,
- ✓ Seismic interpretation verification, detection of false structures resulted from processing time simplifications.
- ✓ Seismic wavefield snapshots and movie generation to facilitate in the interpretation of complex seismic arrivals.

Wave Equation Approximations for Finite-difference Solutions

- ❑ ***Scalar medium model*** – uses the P-wave velocities only and this is the fastest way to model 2-D 2.5-D and 3-D wave propagation.
- ❑ ***Acoustic medium model –*** effectively approximates 2-D 2.5-D and 3-D wave effects of seismic energy propagation in a real geological situation.
- ❑ ***Elastic medium model*** – permits the user to precisely and consistently model 2-D 2.5-D and 3-D seismic energy propagation in the solid medium, including all wave effects appropriate to geological media, such as wave P-S and S-P conversions. In case of marine observations user can model true effects of water-bottom discontinuity.

- ***Vicsoelastic medium model*** – in addition allows to model absorption of the seismic energy by the medium and requires determining of distribution of the Q-factor property(es). It also models such wave effects as velocity dispersion.
- ***Anisotropic medium model*** - is an extension of the elastic wave equation. The difference between physical properties in vertical and horizontal directions (where it is defined) is taken into account. Anisotropy properties are defined using Thompsen's parameters ε,δ and γ in addition three systems of fracturing can be determined.
- Each computational formula may include some additional ***modes*** such as: 1) producing ***time field*** within the medium for incoming waves basing on particular criterion (like first arrivals, maximum energy etc), 2) ***suppressing SV-waves from source*** allows switching on/off surface waves produced directly by the source, etc.
- ***Exploding surface*** and ***Exploding reflectors*** source modes allow the user quickly obtain approximations to the seismic time cross-section.