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So I have a Seismic Image, But what is in that Image?

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Introduction and background

Migration involves repositioning of returned signals in a seismic experiment to show an event (layer boundary or other structure) where it is being hit by the seismic wave rather than where it is picked up. Consequently, a form of migration is one of the standard data processing techniques for all geophysical methods (seismic, ground penetrating radar and electromagnetic sounding, for example). Computational migration needed for large datasets acquired today is extremely demanding on modern computers and the process is very time consuming. This is because the reliability of the migrated image and the properties of the earth model that it samples either directly or indirectly are acutely dependent on the nature of the velocity field and this process (velocity model building) is repetitive. There are many formulations of migrations. Some of the more prominent migration schemes are: Prestack Time Migration (PSTM), Kirchhoff Prestack Depth migration (KPSDM), Reverse Time Migration (RTM), Gaussian Packet Beam Migration (GPM), Wave-equation migration (WEM) and Full Wave Inversion (FWI).

Conventional approaches to build velocity models prior to migration *fail* in several ways: (1) the velocity field often bears no semblance to *True Earth or Rock Velocity* (especially, prior to drilling a well), (2) even with a well data, it is difficult to build a 3D velocity model, since the velocity function from the well samples the velocity field only in one dimension (vertical), and that (3) these velocity fields are not made to obey the geology of the area where mixture of different rock types exist. As a result, the images produced after migration (migrated image) is often at wrong depths, and the structures are not clear. Further, the final velocity fields often cannot be used for deriving *True Earth properties* such as pore pressure without further conditioning of the velocity that has just gone through an elaborate and expensive process of migration. These limitations are particularly acute for subsurface imaging in complex geologic areas such as highly faulted areas, and areas with salt and basalt where there is a lack of signal and coherent events.

The current approach generally relates to processing and application of seismic data and particularly to estimation of seismic velocities that uses Rock Physics as a guide to build velocity models which in turn drives **any** algorithm for Migration of seismic data. For seismic velocities at any depth, velocity conditioning is achieved by creating rock velocities versus depth for a given rock type or a mixture of various rock types based on basic principles of rock physics and geology. When these conditioned (or constrained) velocities are used as a *guide function* to build the final velocity model, for example, using Tomographic velocity inversion and input to a chosen migration algorithm, one obtains a superior migrated image not only at the correct depth but also a velocity field that can be directly used in Earth Property estimation such as pore pressure, fracture pressure, overburden pressure, rock and fluid types, porosity, density and other attributes as a function of either depth or two way time.

Rock Physics Guided Migration (RPGMIG)

This approach is based on a seven- step process as outlined in a recent IP Claim by Dutta et al. In Step 1, a geologic interpretation is made based on the conventional seismic data volume. This yields a description of faults and folds and information on rock types such as salt, basalt, shale, sand, carbonates etc. At this stage, two other pieces of information are also accumulated: (a) an analysis of ages of various rock types from interpretation (for example, chronostratigraphy) of seismic data and (b) estimates of temperature gradients of various geologic strata (for

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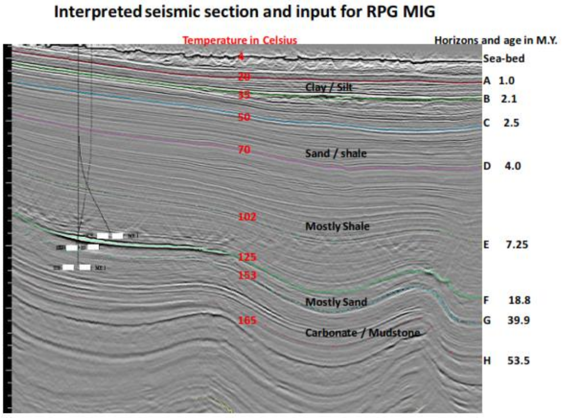
example, from heat flow calculations). An example is given below.



Interpreted seismic section and input for RPG MIG

Input for RPGMIG. A Geologic model is used for Thermal history simulation to obtain effective stress as a function of lithology, porosity and fluids.

In Step 2, a set of compaction curves are generated that relates porosity (void space in the rock that is filled with fluid) or some function relating to porosity to effective stress, temperature, burial history (geologic time) and rock type. Here the effective stress is defined as the difference between the overburden pressure due to all the rock / fluid layers above a layer of rock and the pressure exerted by the pore fluid that is within that layer of the rock. At this stage a burial history simulation of each rock type is carried out to account for the effect of geologic time and temperature on the porosity (or a function of porosity) of a given rock layer. This is intended to account for various diagenetic processes that impact porosity. An example is the burial metamorphism of shale resulting from conversion of Smectite to Illite (Dutta; 1987; Dutta; 1986). A second example is the cementation of sands due to transport of various minerals and subsequent aggregation on rock grains that reduces porosity over geologic time. Yet, a third example is the reduction or buildup of porosity (secondary porosity) in carbonate rocks due to various chemical processes (solution or dissolution).

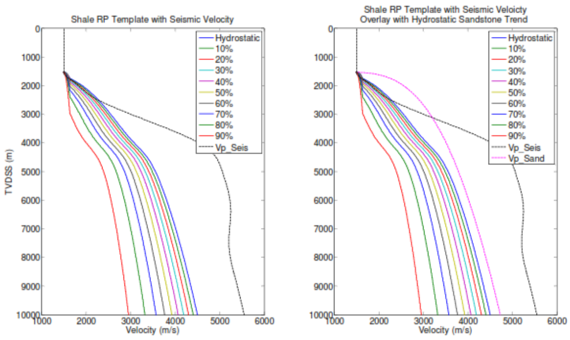
In Step 3, a set of Acoustic Formation Factor curves for each rock types as identified in Step 1 are generated. These curves typically relate either rock velocity or “slowness” (inverse of rock velocity) to porosity or some functions related to porosity, such as void ratio (ratio of pore volume to rock volume) for each rock type (Raiga-Clemenceau et al, 1988). The model proposed by Raiga- Clemenceau et al (1988) is used here but with one important modification: This model is not valid for porosities larger than the Critical porosity (defined as that porosity at which a mixture of sand, silt, clays, etc. and water are compacted and starts to bear the load of the overburden). Therefore, we modified and extended it to porosities greater than the “critical porosity.

In Step 4, Curves from Step 2 and Step 3 above are combined to yield a set of new curves that relate rock velocity or “slowness” to effective stress and temperature for each rock type. In addition, the porosity from Step 3 is used to compute bulk density from seismic velocity and the local geology as defined in Step 1. Upon integration, an overburden versus depth relationship is obtained

In Step 5, Terazaghis Principle is used to derive pore pressure that is the difference between the Overburden pressure and Effective Pressure. We use Biots consolidation coefficient as unity; however, this is not a restriction on the current exposition. The relationships from Steps 4 and 5 suggest that given a temperature profile of a rock type (and its burial history (Dutta; 1987; 1986), one can associate a rock velocity with its effective stress, and hence the pore pressure state. This is the basis of pore pressure analysis using velocity data in this approach. This is Step 6.

In the present workflow, we turn the relationship from Step 6 “backwards”: namely, given a temperature and its effective pressure state of a rock, we recognize that we can predict the velocity of that rock. This is the basis of the Rock Physics based approach. This is the final step in the process; Step 7, in which a set of depth dependent velocity and bulk density curves are generated for each rock type, given the temperature versus depth at a location on the 3D geologic space.

An example is given for shale and sandstones in the figure below.

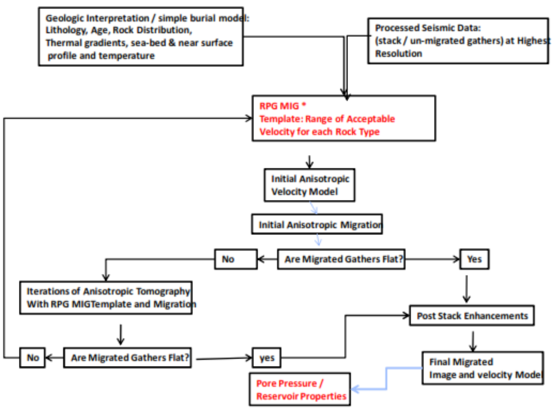


RP Template as percent of overburden

Anisotropic Depth Migration using RPG MIG

Below we provide a workflow for Anisotropic Migration using RPG MIG concept.

Anisotropic Migration Workflow: RPGMIG*

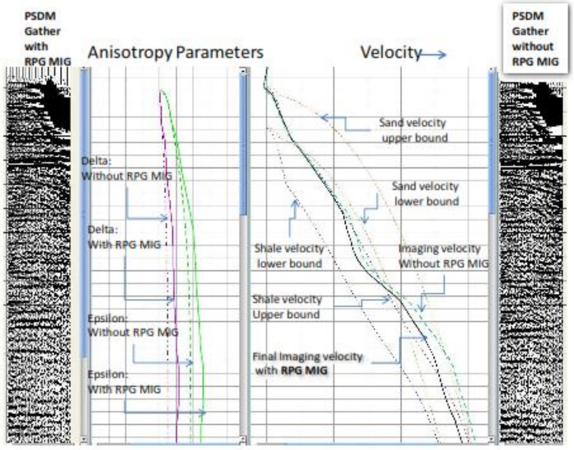


Here anisotropic parameters are calculated using basic principles of rock physics, geology and seismic gathers. The key is to create an acceptable range of anisotropic parameters that are "reasonable" (for example, known ranges of these parameters for various rock types) and to use these parameters in conjunction with the Rock Physics template to constrain the velocity field prior to tomography and migration. Further, at each stage of the tomography, the ensuing velocity fields are always constrained by these templates. Once the convergence criterion is met, we exit the iteration loop for tomography and inversion and carryout post stack enhancements. The final product would be a structurally consistent image that also guarantees a velocity field that is suitable for predicting beyond imaging products such as pore pressure.

Our experience shows that the use of RPG MIG in the migration process actually enhances the structural image quality. This is because the RPG MIG constrained velocity field is reflective of the True Earth Velocity (or Rock Velocity) and thus the seismic energy is focused appropriately to add clarity to a migrated image.

How to use The Rock Physics Template to build a Velocity Model Prior to Tomography and Migration

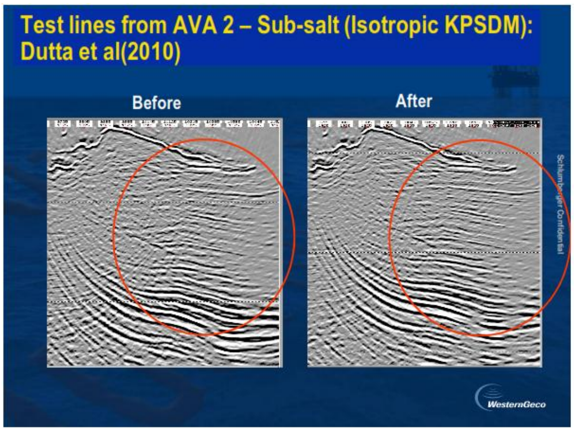
An example is given in the Figure below that shows how the template is used to guide the velocity model. We illustrate the application using the anisotropic depth migration (VTI KPSDM) workflow as an example for a particular basin where there was no well control. On the extreme right hand side, we show a PSDM gather prior to using RPG MIG approach. The velocity problems are clearly visible. On the extreme left side, we show the same PSDM gather that has gone through the RPG MIG approach. The gathers are "flatter" indicating a better velocity model. This improvement is achieved by using the middle two panels that involve RPG MIG approach to condition the velocity (the second panel from right) and the anisotropy parameters- epsilon and delta, on the third panel from right. In the velocity panel (second panel from right), there are four curves that is a result of applications of Rock Physics templates that were built as explained earlier – these are the guide functions. Shown are four guide functions: lower and upper bounds on velocities for sand and similar bounds for shale. We also show the "final velocity function" as a result of Tomography that used these bounds during the inversion process and a comparison is made with the imaging velocity that used no such bound (conventional anisotropic depth migration). In the third panel on right, traditional anisotropic parameters (epsilon and delta) are shown for both cases: with and without RPG MIG. The improvement in the velocity function after Tomographic inversion (second panel from right) is substantial and yields not only a better image but also a better velocity field for pore pressure.

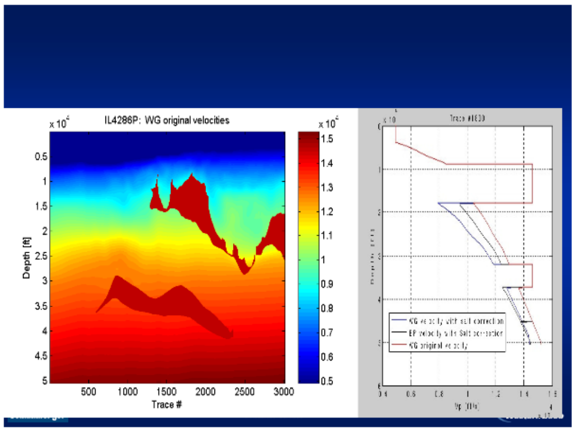


Examples of the use of RPG MIG for creating a guide function for velocity model building. This guide function is used as input to a Tomographic inversion algorithm to obtain the final velocity model (also shown as a1D function at a location taken from the 3D volume). After this, a final migration is carried out.

Once the velocity functions are created that satisfy the bound as provided from the rock physics templates described in the example above, the model is input to a Tomography algorithm to generate a full 3D velocity volume from travel time inversion of the 3D seismic data. The output of that model is a 3D velocity field that is within the rock physics bounds without degrading the structural image. This velocity field is now input to a migration algorithm (such as VTI KPSDM) to produce a final structural image that is now consistent with a velocity field that is also appropriate for beyond imaging products such as pore pressure.

An example of the process of RPGMIG as applied to a data set from the Deepwater Gulf of Mexico (a sub-salt project) is shown below. The data are from our internal library. The salt geometry is shown in the adjoining figure along with the velocity profiles from RPGMIG under the first salt body labeled as "WG velocity with salt correction". PSDM images -both before and after RPGMIG application are also shown. The velocities used to produce the image labeled "after" are appropriate for pore pressure analysis below salt (verified to be of very high pore pressure), while the velocities associated with the image labeled "before" would produce pore pressure below "hydrostatic pressure" – an absurd and unphysical result. This is very common with ALL conventional depth imaging algorithms. That is why, the common practice has been to convert the data to time domain after depth imaging and then do velocity analysis etc. for pore pressure. This extra step is now totally eliminated in the current procedure using RPGMIG. Thus, we not only get a superior image in depth but also ALL 'beyond imaging" products.





Conclusions

Here we propose a very general and a novel approach to build velocity models for subsurface rock strata that accounts for geology rock physics and thus guides the seismic velocity field that is realistic and consistent with expected ranges of plausible velocities. These guide functions help manage the inherent uncertainties and the non-uniqueness of the Tomography and migration process while producing a subsurface image that is not only in conformance with the geology and at the right depth but also capable of delivering beyond imaging products such as pore fluid pressure, overburden pressure and fracture pressure. These guide functions can be built with or without well control as shown and can be used with any migration algorithms (PSTM, PSDM. WEM, RTM, FWI, etc.).

References

Dutta, N. C., et al (2011); "Methods and Devices for Transformation of Collected Data for Improved Visualization Capability", IP Application Number: 13/179461; Filing date: 08 Jul 2011; Priority Application: (PSP) - 08 Jul 2010

Dutta, N. C., (1986); "Shale compaction, burial diagenesis and Geopressure: A dynamic model, solution and some results", In *Thermal Modeling in Sedimentary Basins, J. Burrus, Ed., Editions Technip*, Paris, 149 - 172.

Dutta, N. C., (1987); "Fluid flow in low permeable media", In *Migration of Hydrocarbons in Sedimentary Basins*; *Brigitte Doligez, Ed., Editions Technip*, Paris, 567 - 595.

Raiga-Clemenceau, J., Martin, J. P., and Nicoletis, (1988), "The concept of acoustic formation factor for accurate porosity determination from sonic transit time data"; The Log Analyst; v. 29, p. 54-60.

Eaton, Ben A., (1995), "How to use drilling petrophysical data in prospect evaluation, Part 1"; World Oil, September 1995, p. 69 – 72.

Bowers, G. L., (1995), "Pore pressure Estimation from Velocity Data: Accounting for Overpressure Mechanisms Besides Undercompaction"; SPE Drilling and Completions, June 1995.

Pennebaker, E., S., (1968); "Seismic Data Indicate Depth, Magnitude of Abnormal Pressures"; World Oil; v. 166, No. 7, p.73-78