Inversion Technology Application for Reservoir Characterization in Indonesia

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Introduction

Indonesia has been considered as one of the prolific oil & gas province in the world. In addition to large hydrocarbon reserves already found, including some recent giant fields, there are a wide variety of exploration opportunities awaiting for novel technology or creative minds. Appraisal/ development plan is another topic since most of the fields in Indonesia are currently undeveloped. Modern 3D seismic interpretations coupled with detailed geological understanding has been helping oil companies to improve definition of reservoir geometries and hydrocarbon distribution in several fields. However, that is not always the case since reservoirs most of the time can not be easily visualized through seismic. It will be worse in a production mode as a more detailed understanding of reservoir continuity across the field is a high priority for successful and sustained production.

The development of seismic inversion technology offers an alternative solution to the three different stages of hydrocarbon activities mentioned above, exploration, development, and production. 3D seismic data, which proves to be a powerful tool to address spatial issue, can be inverted back to rock properties to enable the interpreters to relate directly with the well data or other geological information. There are several methods in seismic inversion, but firstly we have to define the problems in characterizing the reservoirs or exploration prospects in Indonesia. What are those?

What is seismic inversion?

Before we lay out the problems, it is important to understand the basic philosophy of several advance techniques in seismic inversion.

The principle objective of seismic inversion is to transform seismic reflection data into a quantitative rock property, descriptive of the reservoirs. In its most simple form, acoustic impedance logs are computed at each CMP location. Compared to working with seismic amplitudes, inversion results show higher resolution and support more accurate interpretations. This in turn facilitates better estimations of reservoir properties such as porosity and net pay. An additional benefit is that interpretation efficiency is greatly improved, more than offsetting the time spent in the inversion process.

Seismic inversion has been around as viable exploration tool for about 30 years. In these early days, it had been assumed that each and every sample in a seismic trace represented a unique reflection coefficient, unrelated to any other. This was the so-called recursive method.

The modern era of seismic inversion started in the early 80's when algorithms, which accounted for both wavelet amplitude and phase spectra started to appear. The sophisticated innovation of this algorithm is to arm the technique with incorporating geologic information (constraints) while still honoring the seismic data to a high degree and therefore produces a more continuous and more geologic result.

In mid 90's the development advanced to handle offset seismic to overcome the pitfalls in interpreting AVO/ AVA anomaly. The other branch progressed to resolve the vertical resolution that seismic data has with geo-statistical approach.

Constrained Sparse Spike Inversion (CSSI)

This is the most common inversion algorithm used as the ultimate development of sparse spike method. Geoscientists need to understand precisely what statement the seismic data itself is making about impedance. Sparse Spike is ideally suited for this since, among its other virtues, it produces both a relative version (no low frequencies information from the logs added) and an absolute version (low frequencies added).The separate contributions of the logs and the seismic are then clear.

CSSI is a unique deterministic trace based inversion, unlike the modeling based inversions. This technique transforms seismic data into P-Impedance (Figure 1) using a constrained sparse spike algorithm. The constraint used is not a mathematical constraint but a geological constraint. The resulting output is broadband and optimized to the low frequency model.

Figure 2 is an example of CSSI result from clastic case of Central Sumatra (Latimer et al., 1999). The facies are an alternating sequence of sands and shales. Interpretation is problematic due to the close vertical positioning of contrasting layers within half of a wavelet length. The result is severe interference (tuning) and a general complication of the seismic

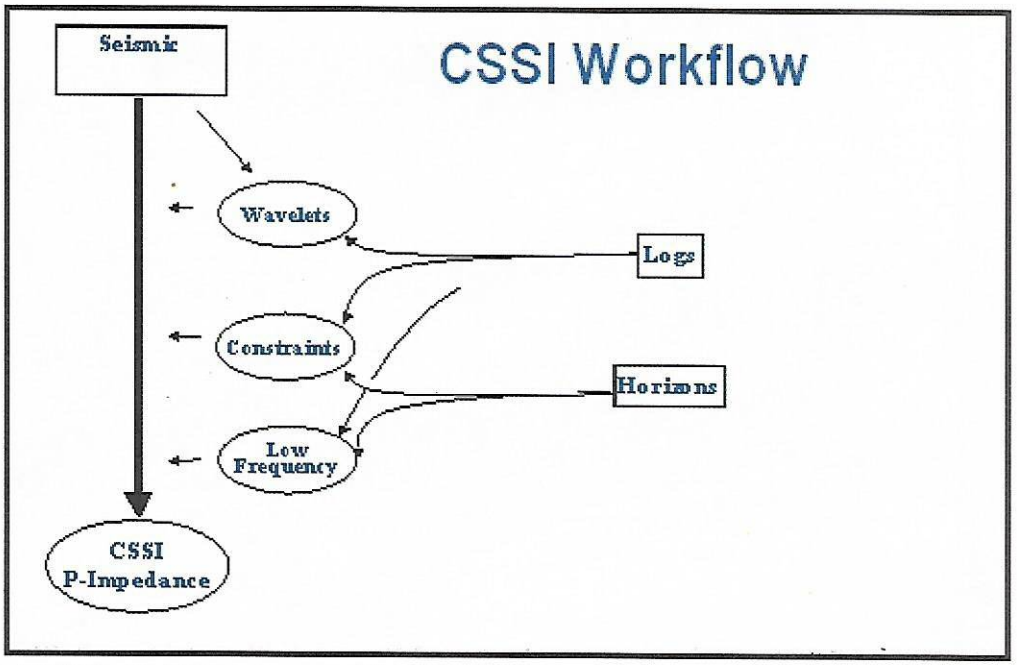


Figure. 1 Common workflow for full-stack inversion. Well data used to derive an accurate wavelet for the target interval whereas combination of well-logs and horizons are used to build low-frequency model to supplement the bandwith that seismic is lacking.

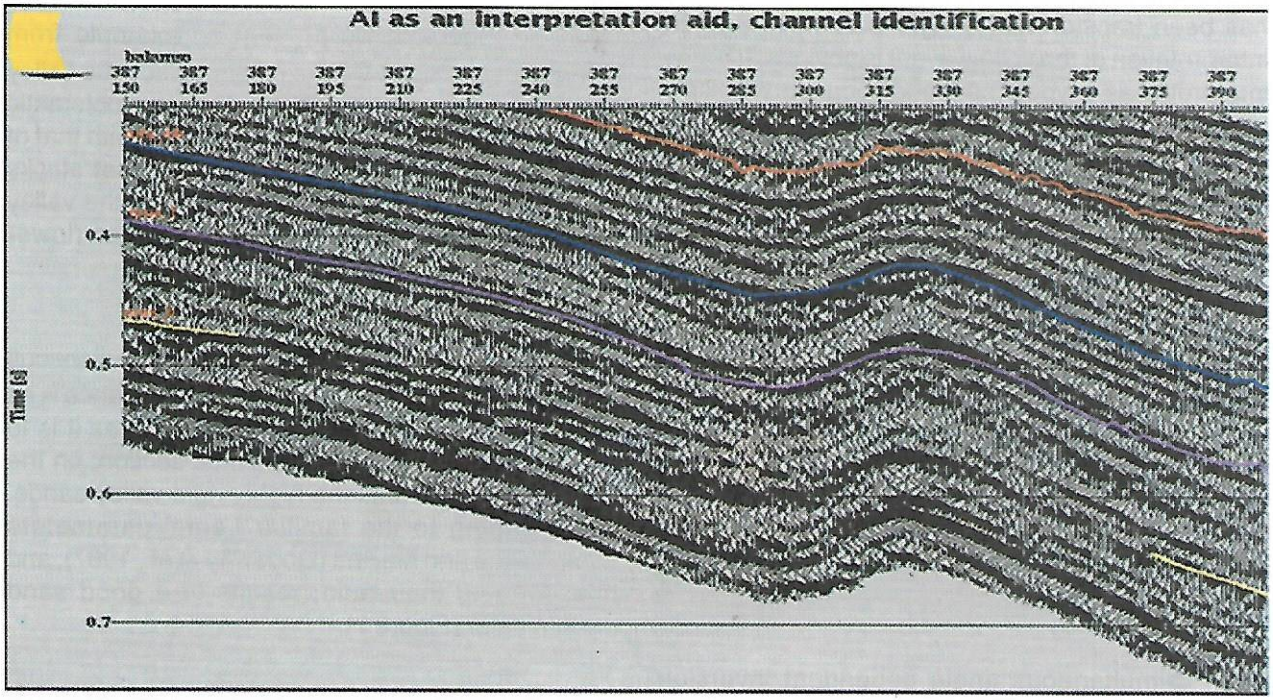


Figure. 2 This seismic section is from southeast Asia and represents a sequence of sands and shales. The Yellow horizon interpretation has not been completed. It is made difficult by the close proximity of events and the structure.

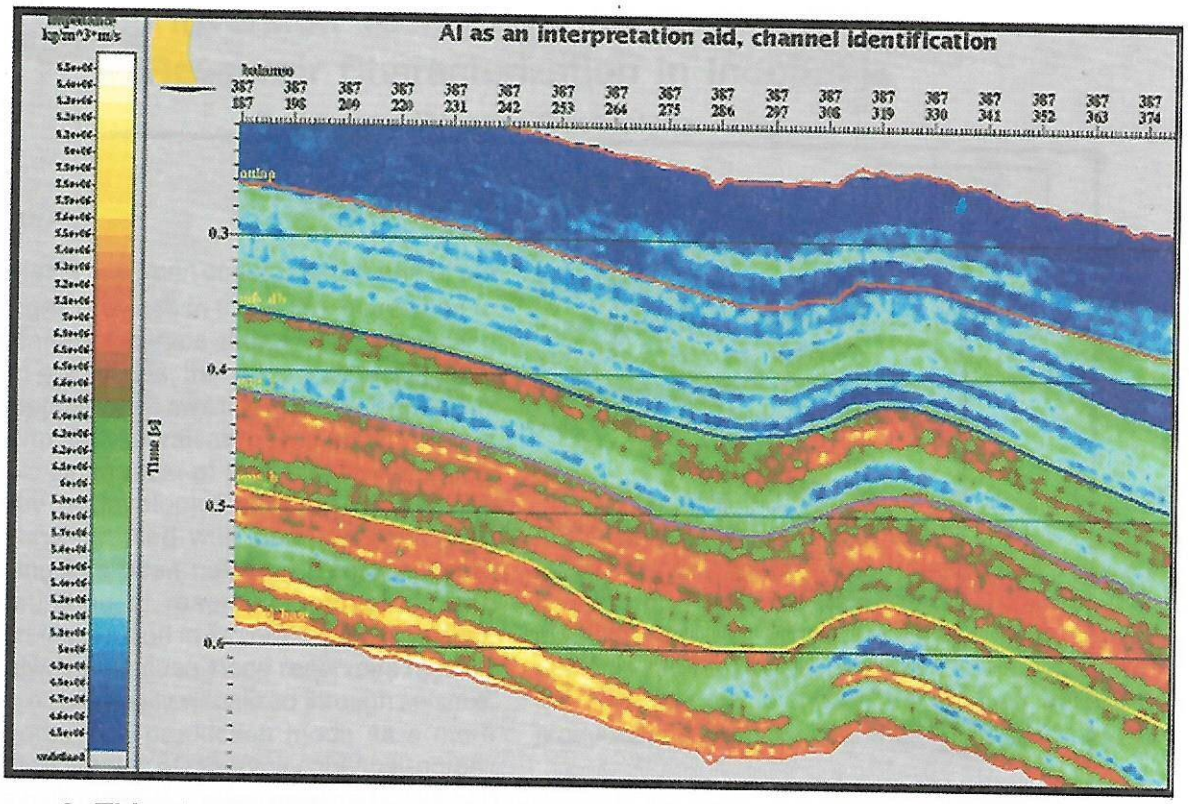


Figure 3: This shows the constrained sparse spike inversion of the data in Figure 2. It is a much simpler section due to the attenuation of wavelet sidelobes. The completion of the Yellow horizon is now easy. The low impedance region above the Yellow, in the middle of the figure has been interpreted to be a valley fill.

section. The interpretation of the yellow horizon is particularly difficult. Figure 3 shows the inversion result. It is generally more simple since the seismic has been transformed to layer properties and the interpretation of the yellow event is obvious. It is now interpreted as a type-1 sequence boundary which is indicated by a deep incision over a more distal facies.

Simultaneous Angle Dependent Inversion (SADI)

The development of elastic impedance inversion leads to simultaneous inversion of angle or offset-limited sub-stacks. SADI is therefore another unique deterministic trace based inversion for offset angle stack seismic data. This procedure brings all the benefits of inversion to bear upon problems encountered in traditional seismic weighted stacking approaches to AVO analysis. The outcomes are inversion volumes of P-impedance, S-impedance and density (Figure 4).

Simultaneous angle dependent inversion transforms multiple partial stack seismic data to rock property models of lithotype (lithology + fluid) and porosity. As an initial product acoustic and shear impedance volumes and a density volume are generated. These products are input to the lithology and porosity estimation modules, and are also useful in their own right for such things as direct estimation of other elastic rock properties, such as Lamé petrophysical parameters, LambdaRho, and MuRho.

In Figure 5, we present an example from Pendrel et al., 2000. Detection of Cretaceous valley sands in the Blackfoot, Alberta area is problematic due to the similarity of their P impedance with that of shales. In Figure 5, the near and far offset stacks have been inverted separately. Note that the valley sands indicated by the arrows are softer (lower impedance) at the far offset.

Figure 6 shows the results of the simultaneous inversion for the Upper Valley. The P-impedance is as much responsive to the off-valley shales as it is to the valley sands. The S-impedance section, on the other hand, highlights the highly-rigid valley sands. Transforming to the familiar Lame' parameters LambdaRho and MuRho (Goodway et al., 1997), and then forming their ratio, results in a good sand discriminator (Figure 7).

To sum up, the primary benefit of SADI compared to CSSI is SADI can handle overlapping properties in P-impedance with incorporation of S-impedance information from P-P seismic data. In most cases, the combination of P-impedance and S-impedance can better delineate the hydrocarbon reservoirs, both in clastic and carbonate cases.

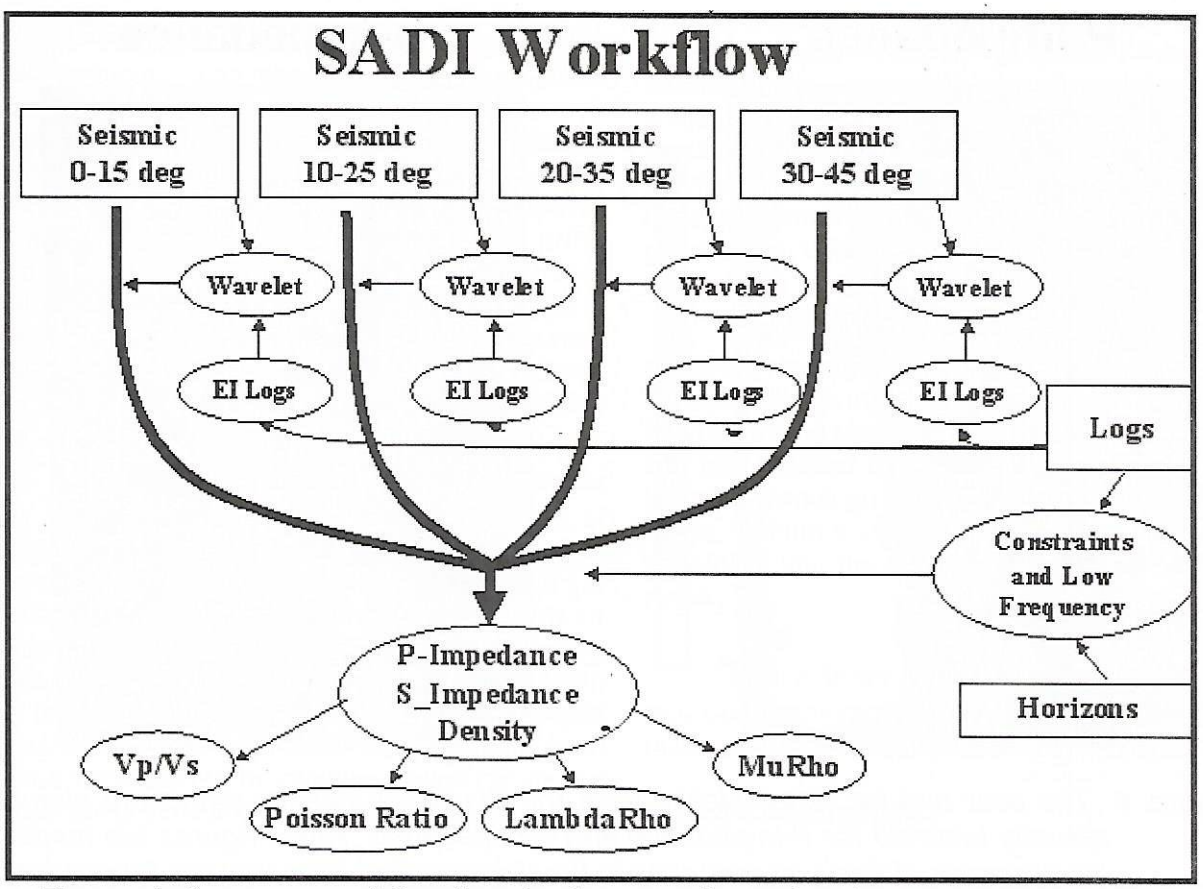


Figure. 4 Common workflow for simultaneous inversion. In contrast with CSSI, the input seismic is in the form of angle-stacks. S-impedance and higher resolution P-impedance can be derived from PP seismic data.

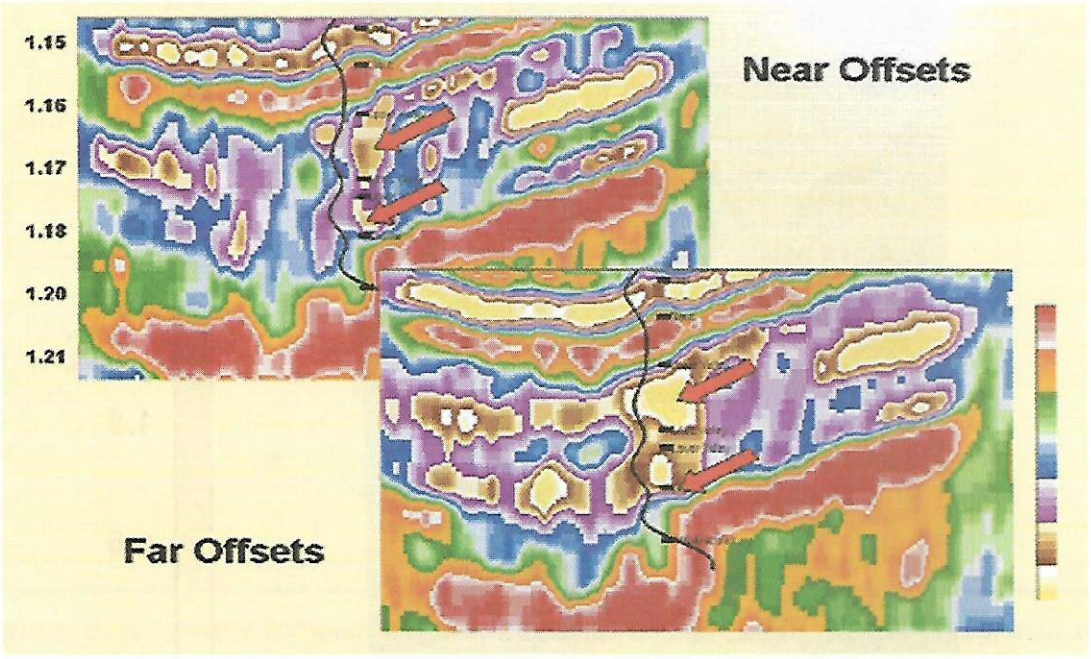


Figure. 5 Independent inversions of near and far offset stacks from the Blackfoot 3D survey. At Blackfoot, Glauconitic sands and shales have similar P-impedance. Note that the valley sands (arrows) appear softer at the far offsets. This is the AVO effect. The estimation of separate wavelets for each inversion means that offset-dependent scaling, phase and tuning have been optimally adressed.

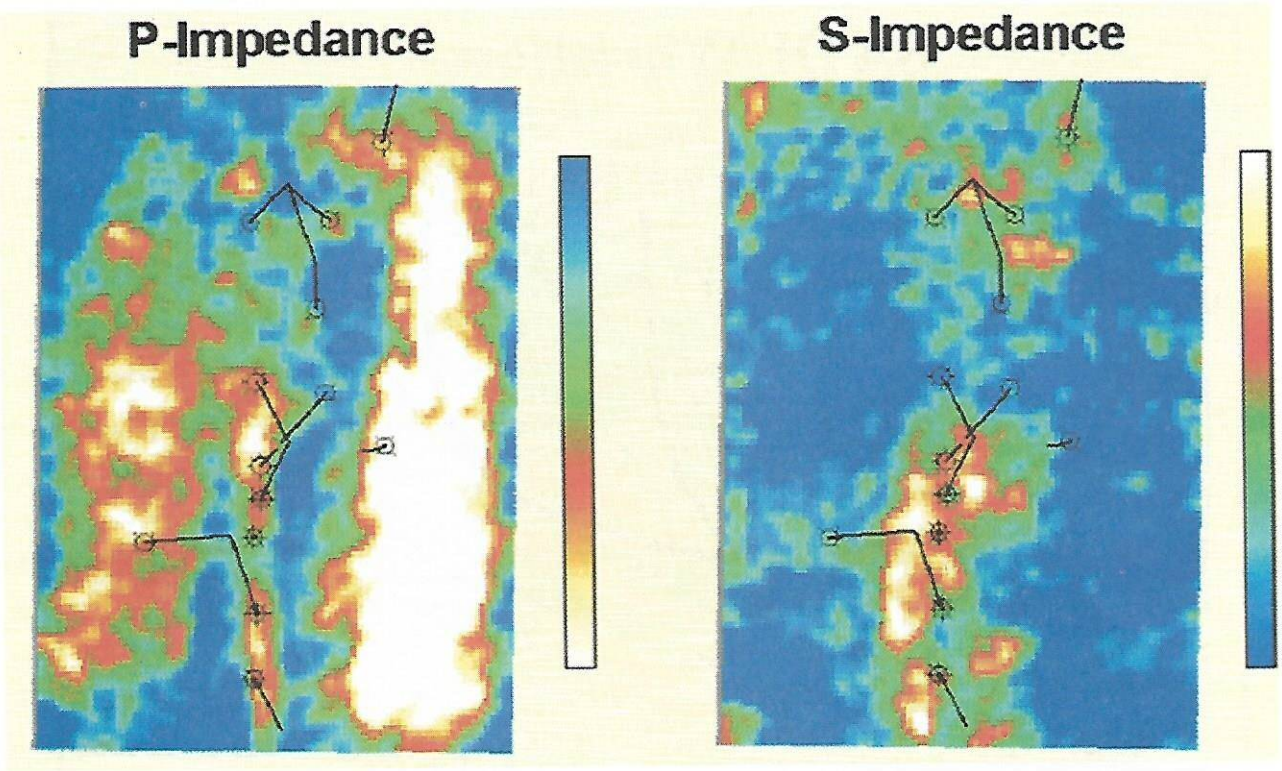


Figure. 6 The near and far offset stacks from the Blackfoot seismic data were simultaneously inverted for P-impedance and S-impedance. These figures are maps of the averages of these impedances in the Upper valley. Note that the S-impedance map shows the rigid sands as relatively high impedances. The P-impedance map is sensitive to both sands and shales.

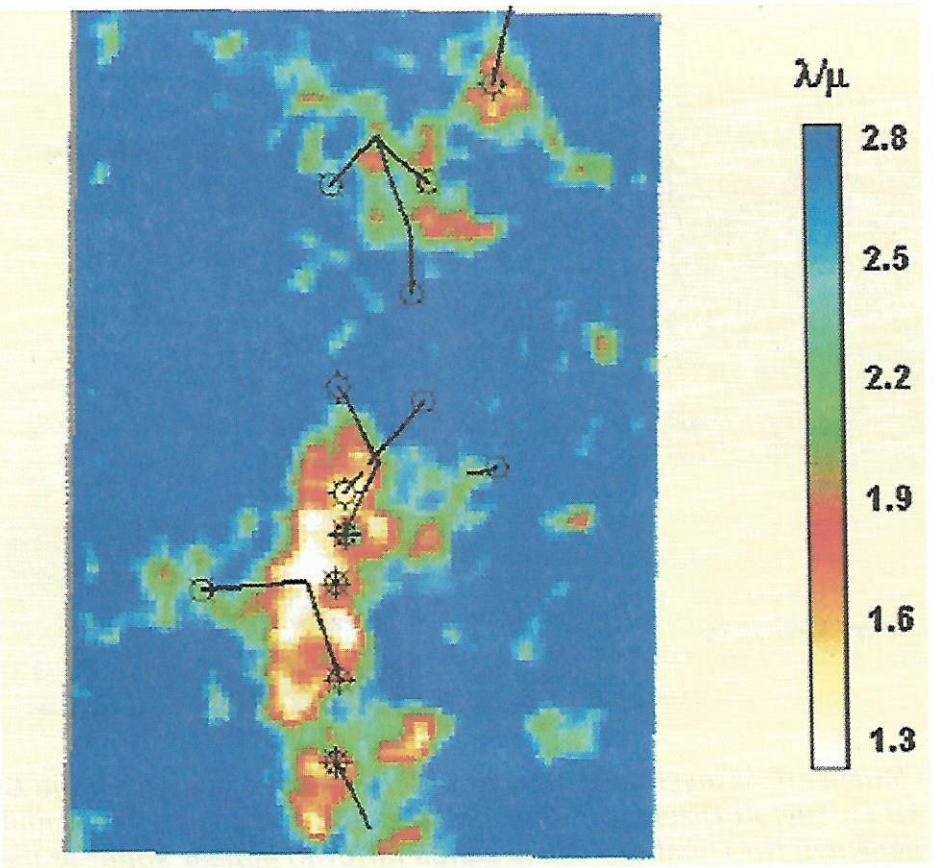


Figure. 7 The P- and S- impedance volumes from simultaneous inversion were transformed to the Lame' constants (Lambda-rho and Mhu-rho). Then a ratio volume was formed by dividing them. The result is a very sensitive valley sand detector.

Geostatistical (Stochastic) Inversion

Geostatistical simulation differs from all of the other methods in one respect. There is no objective function and hence no need for a simplicity term to stabilize it. Rather, property solutions (impedance, porosity, etc.) are drawn from a probability density function (pdf) of possible outcomes. The pdf is defined at each grid point in space and time. A priori information comes from well logs and spatial statistical property and lithology distributions. As in the other model-based methods, the logs are assumed to represent the correct solution at the well locations. It is useful to run a CSSI or SADI first, to establish this.

Historically, away from wells, geostatistics has had problems. It is the inversion aspect of geostatistics which has finally guaranteed its use as a modern inversion tool. The geostatistical (or stochastic) inversion algorithm simply accepts or discards simulations at individual grid points depending upon whether they imply synthetics which agree with the input seismic. The decision to accept or reject simulations can optionally be controlled by a simulated annealing strategy. The inversion option results in a tighter set of simulations, the variation of which can be used to estimate risk or make probability maps. The simulations can be done at arbitrary sample intervals. Close to wells, resolution beyond the seismic band can reasonably be inferred. Away from wells, the absence of a simplicity term in the simulation and the statistical conditioning still hold the possibility of resolution beyond that of traditional inversion methods (see Figure. 8 for detail geostatisical inversion that honored seismic data).

Important end results of 3D Geostatistical modelling are property probability volumes in vertical resolution that is much finer than seismic resolution. A set of volume simulations of porosity, for example, can be modelled as a Normal probability density function at each grid point in time and space. From these, volumes can be constructed giving the probability that the porosity lies within a specified range.

Those three major branches of seismic inversion and its combination basically can overcome reservoir characterization issues in Indonesia. The

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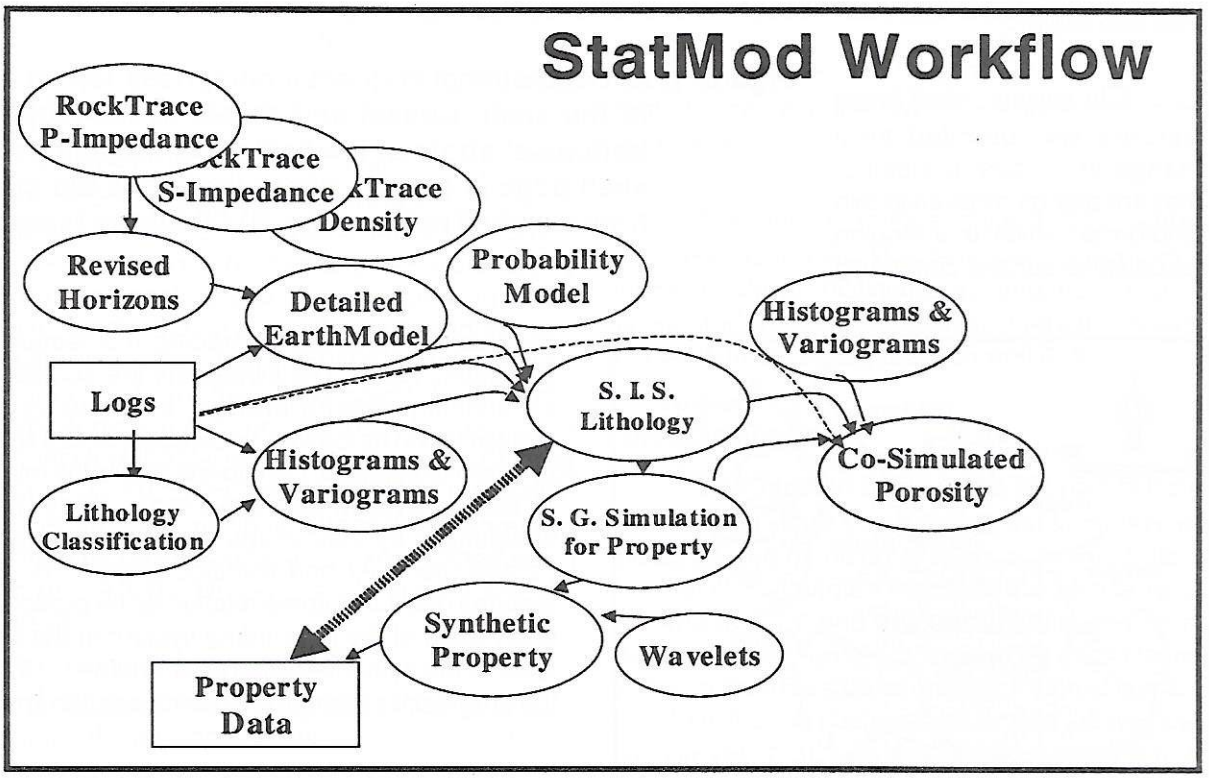


Figure. 8 Workflow for geostatistical inversion. The main discrepancy with other geostatistical application is the functionality to internally validate each point away from the wells with the inversion results (e.g. P-impedance from CSSI or Vp/Vs from SADI). The final results are tighter set of simulations and the variation can be used to better estimate risk and make more accurate probability maps

Editorial Note:

The extended abstract was extracted from unpublished MSc thesis of Deddy Aditya Sebayang submitted to Petroleum Geoscience Department - Universiti Brunei Darussalam)

References

Brami, T.R., Pirmes, C., Archie, C., Heeralal, S., and Holman, K.L., Late Pleistocene deep-water stratigraphy and depositional processes, Offshore Trinidad and Tobago GCSSPEM Foundation 20th Annual Research Conference Deep-Water Reservoir of the World Proceeding, p. 104-115.

Demyttenaere, R., Tromp, J.P., Ibrahim, A., Ward, P.A., and Meckel, T, 2000, Brunei deep water exploration: from sea floor images and shallow seismic analogues to depositional models in slope turbidite setting: GCSSPEM Foundation 20th Annual Research Conference Deep-Water Reservoir of the World Proceeding, p. 304-317.

Fowler. J., Guritno,E., Sherwood, P., Smith, M., 2001, Depositional architectures of Recent Deep Water deposit in the Kutei basin, East Kalimantan: Indonesian Petroleum Association Proceedings, v.28, p.409-422

Mayall, M., and Stewart, I., 2000, The architecture of turbidite slope channels: GCSSPEM Foundation 20th Annual Research Conference Deep-Water Reservoir of the World Proceeding, p.578-586.

Posamentier, H., Interpretation of Transgressive Depositional Elements using 3D Seismic Data: Case Study from Offshore Northwest Java using Stratimagic™ Software, CGG website

Posamentier, H.W., Meizarwin, Wisman, P.S., and Plawman, T., 2000, Deep water depositional system-ultra-deep Makassar Strait, Indonesia: GCSSPEM Foundation 20th Annual Research Conference Deep-Water Reservoir of the World Proceeding, p. 806-816.

Poupon, M., New methodology based on seismic facies analysis and litho-seismic modeling, CGG website

Richards, M., 1996, Deep-marine clastic system, in Emery, D., and Myers, K., J., eds., Sequence Stratigraphy, p.178-210

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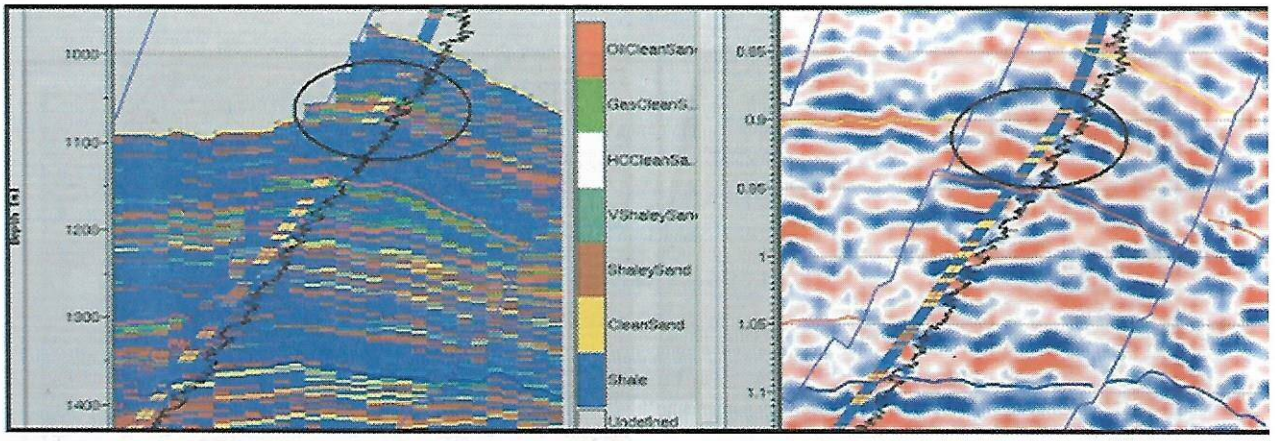


Figure. 9 An example on how stochastic inversion with lithology simulation can resolve the problem of thin sand (Beale, 2001). Left panel shows excellent comparison of lithology predicted in the section with actual lithology and gamma ray of the well track. The panel on the right is seismic from the same section with the well lithologies superimposed along the well path which shows that clearly conventional seismic would not be able to predict several thin sand units highlighted inside the circle since some of the sands are as thin as 3-metre thick.

detail flow on the implementation on a particular area, however, must be determined through a feasibility study, observing the rocks behavior on that field based on the wireline logs.

Conclusions

Interpreters need to consider seismic inversion whenever interpretation is complicated by interference from nearby reflectors or the end result is to be a quantitative reservoir property such as porosity. Output in the format of geologic cross-sections of rock properties (as opposed to seismic reflection amplitudes) is endlessly useful as a means to put geologists, geophysicists, petrophysicists and engineers "on the same page". It is almost always useful to do sparse spike inversion first so that we may be crystal clear about what the seismic is telling us, free from bias from logs.

The days of viewing seismic inversion as an extra processing step or subject of an isolated special study are long gone. Modern inversions are intimately connected to detailed and quantitative reservoir characterization and enhanced interpretation productivity. The process requires and integrates input from all members of the asset team. Horizons should be re-assessed, models re-built, log processing reviewed and inversion steps iterated toward the best result. After drilling, new information should be used to create a "living cube", always up-to-date with all available information. It is this partnership directed to the solution of real reservoir characterization problems

References

Goodway, B., Chen, J., Downton, J., 1997, AVO and Prestack Inversion, CSEG Ann. Mtg. Abs. p. 148

Latimer, R.B., Davison, R., Van Riel, P., 2000, An Interpreter's Guide to Understanding and Working with Seismic-Derived Acoustic Impedance Data, The Leading Edge, 19 #3, p. 242

Pendrel, J., Debye., H. Pedersen-Tatalovic, R., Goodway, B., Dufour, J., Boogards, M., Stewart, R., 2000, Estimation and Interpretation of P and S Impedance Volumes from the Simultaneous Inversion of P-Wave Offset Data, CSEG Ann. Mtg. Abs. Paper AVO 2.5



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Dumestre, M.A. & Carvalho, F.F., 1985, The petroleum geology of the Republic of Guinea Bissau, Oil & Gas Journal, vol. 83, no. 36, p. 180-191

Jackson, M.P.A., Vendeville, B.C. & Schultz-Ela, D.D., 1994, Structural dynamics of salt systems, Annual Review of Earth and Planetary Science, No. 22, p. 93-117

Jones, E.J.W. & Mgbatogu, C.C.S., 1982, The structure and evolution of the West African continental margin off Guinea Bissau, Guinea and Sierra Leone, in Scrutton, R.A. & Talwani, M., The Ocean Floor, John Wiley & Sons, Chichester, p. 165-202

Seibold, E., 1982, The northwest African continental margin - an introduction, in Rad, U von, Hinz, K., Sarnthein, M. & Seibold, E. (eds), Geology of the Northwest African Continental Margin, Springer-Verlag, Berlin, p. 3-20

Tari, G.C., Ashton, P.R., Coterill, K.L., Molnar, J.S., Sorgenfrei, M.C., Thompson, W.A.P., Valasek, D.W. & Fox, J.F., 2002, Are West Africa deepwater salt tectonics analogous to the Gulf of Mexico?, Oil & Gas Journal, vol. 100, no. 9, p. 73-82

