NIOC's requirements for data processing and interpretation in challenging geological environment

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Abstract

The time for easy oil discovery and production for National Iranian Oil Company (NIOC) is over. This means that the oil is no longer discovered in structurally simple, i.e., almost flat environments like south of Khuzestan province (south west of Iran). This comes along with the fact that Iran's biggest oil reservoirs are in this area, and they are passing half of their life cycle. These giant reservoirs are still producing more than half of oil production in Iran. There is significant uncertainty in future of Iran oil and gas exploration. In fact, the rate of drilling a successful well by NIOC exploration directorate is dramatically reduced in past few decades. The reason is that nowadays NIOC is drilling in structurally complex areas such as Zagros thrust belt mountains with rough topography and complex geology. Uncertainty in the drilling arises mainly from many factors, one of which is the processing tools in NIOC repository that belongs to at least 30 years ago. These tools belong to the time when NIOC used to drill for easy oil. In addition to the processing, other parts such as exploration techniques need to be revised in structurally complex environments. This article briefly looks at processing tools, which are critical to be used by NIOC to be able to significantly improve the drilling success rate.

Keywords: prestack time migration (PSTM), prestack depth migration (PSDM), reverse time migration (RTM), seismic anisotropy, depth calibration

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1 Introduction

Nowadays, the drilling success by National Iranian Oil Company (NIOC) exploration directorate is at all-time low (Iran Oil Ministry Annual Bulletin, 2006). The drilling success according to an unofficial statistic is around 60%. This means that approximately one out of two wells is dry. Considering average cost of an exploration well about20-30 million dollars for land and 50-100 million dollars for marine (Riva and Atwater, 2008; Rigzone), this statistic is mind-blowing.

One of the main reasons is simply not using the proper tools for imaging. The new techniques on seismic imaging emerge more than two decades ago by the introduction of prestack depth migration (PSDM) for complex structures followed by reverse time migration (RTM) in past ten years. Last year, NIOC exploration department finally agreed to put the PSDM sequence in the processing tenders and asked the vendors who are providing PSTM also deliver PSDM. This seems to be a good news but not enough. The PSDM (even RTM) requirement from vendors should be mandatory with every tender. In addition, NIOC expertise should be trained to be able to quality control (QC) the vendor product properly and regularly.

In this paper, three main processing sequences are discussed, which every NOC (National Oil Company)/IOC (International Oil Company) in the world have either in their repository or demanding from a service company to provide them. These sequences are called PSTM, PSDM, and RTM. All these sequences have an anisotropic option, which are briefly looked at it in this paper. NIOC processing expertise spent many years maturing their knowledge on PSTM; however, PSDM and RTM are relatively new for them. In this paper, the most important QC points for depth migration are also briefly touched. At the end, some success stories are shown with an Iranian processing company on some of the most challenging geological environments.

2 Imaging tools

Figure 1 shows the computational demand and seismic depth imaging versus time (Wenes, 2014). As it can be seen, products like PSTM that is currently a conventional processing tool for NIOC exploration department (bottom left of the figure) belong to at least 20 years ago. It seems from this figure that since 1995, Kirchoff depth migration methods emerged in the market, and from around 2007, full wave equation based method (RTM) are in demand of big international companies.

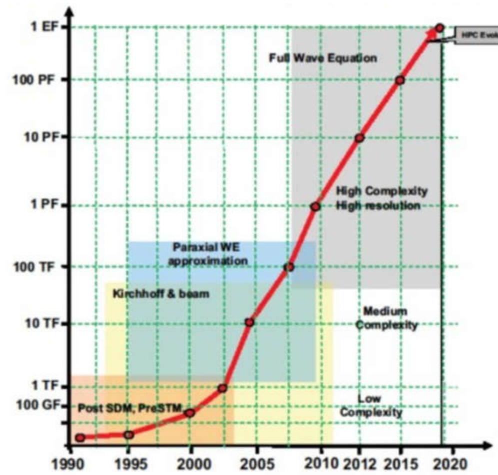

Figure 1. Computational demand versus time for seismic imaging applications, GF, TF,PF, EF are GigaFlops, TeraFlops, PetaFlops, and ExaFlops respectively(Cray computing center, 2014).

Another interesting aspect of Figure 1 is its vertical axis, which is the amount of computational requirement for imaging of a small 3D cube of seismic data. The fastest computer in Iran (National supercomputing center with 164 TFlops peak performance) barely meet the requirements to run a full 3D RTM on seismic data. In Iran, there is not any supercomputer that satisfies the computational need of the state of the artimaging technology; however, with a successful parallel implementation of PSDM on the existing clusters, PSDM for a small 3D survey might be delivered successfully. The need for obtaining a supercomputer, which can handle complex imaging tools such as 3D RTM, already arises and we are striving to purchase such a system soon.

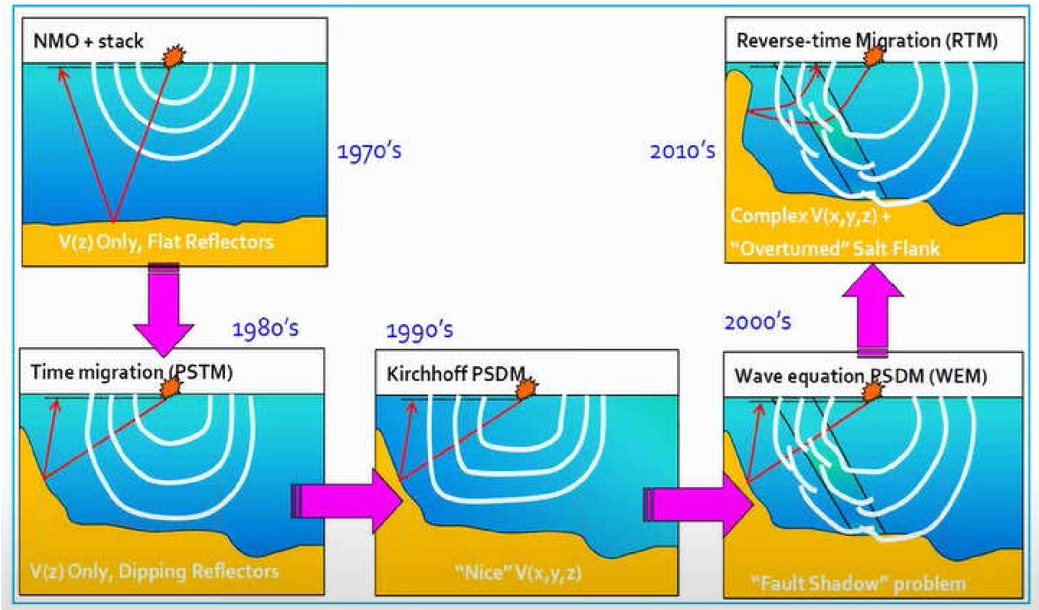

Figure 2. Diagram of the technology trend in the field of imaging.

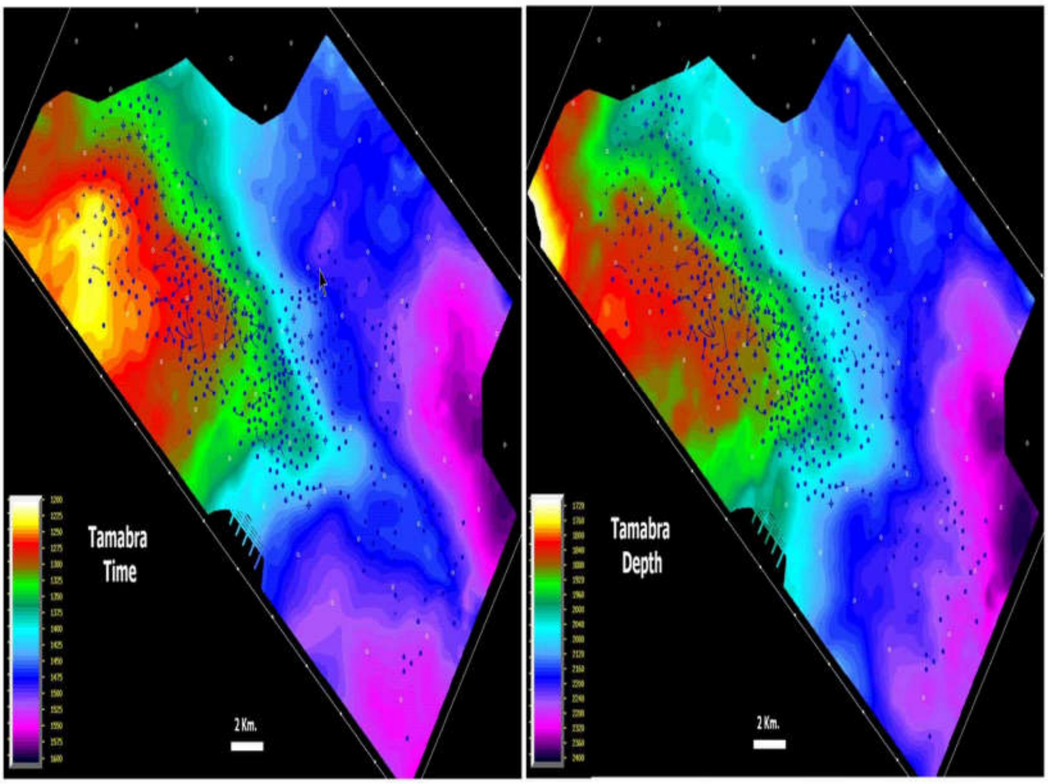

Figure 3. Time horizon (left) versus depth horizon (right) after time to depth conversion for PEMEX mature onshore Tamabra oil field. The dots are well locations. Courtesy of PEMEX.

2.1 NMO+Stack

Standard seismic processing was started with NMO+Stacking in the 1970s (Claerbout, 1971). NMO+ stacking is still in NIOC normal processing sequence day to day need. In some areas with low signal to noise ratio in which the reflectors are barely visible in PSTM sections, processor/interpreter relies on stack sections rather than PSTM sections. The theoretical limitation of stack section is that it assumes that the earth contains horizontal layers (e.g., fails to image properly dipping reflectors), and it also assumes that the velocity model does not change laterally.

2.2 PSTM

With emerge of PSTM in the 1980s (Claerbout, 1985; Lailly, 1984; Fomel, 2003), the limitation of dipping reflector was improved by introducing diffraction hyperbola, but still the major limitation that the velocity model at image point and surrounding should not vary laterally hold (Fowler, 1997; Bancroft et al., 1998). Another characteristic of PSTM is that the velocity model and migrated image are both in the time domain; therefore, there is another time-to-depth conversion process needed to map the time horizons to depth horizons. Figure 3 shows time horizon versus depth horizon for PEMEX (Mexican Petroleums) mature onshore Tamabra oil field in Veracruz, Mexico. Precise depth conversion is a critical step for creating static and dynamic reservoir models that incorporate seismic attributes (Marhx et al., 2004).

2.3 PSDM

In 1990, a new interesting technology emerged that is called prestack depth migration (PSDM) (Versteeg, 1993; Reston et al., 1996). The technology is based on a high-frequency approximation of wave equation and involves the calculation of travel-time maps using ray-tracing methods. PSDM is able to accept lateral velocity changes in the model as well. However, it comes with additional resource costs both human and computing. PSDM in its core needs an iterative tomographic update as well as a processor to pick the gatherings manually, which make the work labor intensive.

Today, it can be firmly assumed that in all geological frameworks, no matter whether it is simple or complicated, a PSDM is needed. The reason is that PSDM offers not only structural simplicity but also much more clear and higher resolution attributes that can be used by interpreter regarding the estimation of net volume, pay zone, fault and fracture maps, etc. Figure 4 shows the result of PSTM and PSDM for a structurally simple (almost flat) in eastern US resource play. By looking at these images, an interpreter might think that although PSDM might resolve some small fault features (which are false complexities created by PSTM), it cannot be justified by the exploration manager to run PSDM for this area considering the time/price cost of PSDM; however, looking at Figure 5 at the amplitude map for reservoir horizon, it surely changes his mind looking at the resolution that PSDM is offering. The PSDM is a rich source of high-resolution attribute information.

2.4 One way wave equation migration

It emerged at the beginning of 20th century as first wave equation based migration method (Stolk and de Hoop, 2005; Stolk and de Hoop, 2006; Flor et al., 2010). It has the advantage of solving the wave equation rather than a high-frequency approximation of wave equation. This means that wave equation migration (WEM) is taking into account the wave propagation mechanism comparing to PSDM, which is only tracking down the wavefronts travel-time.

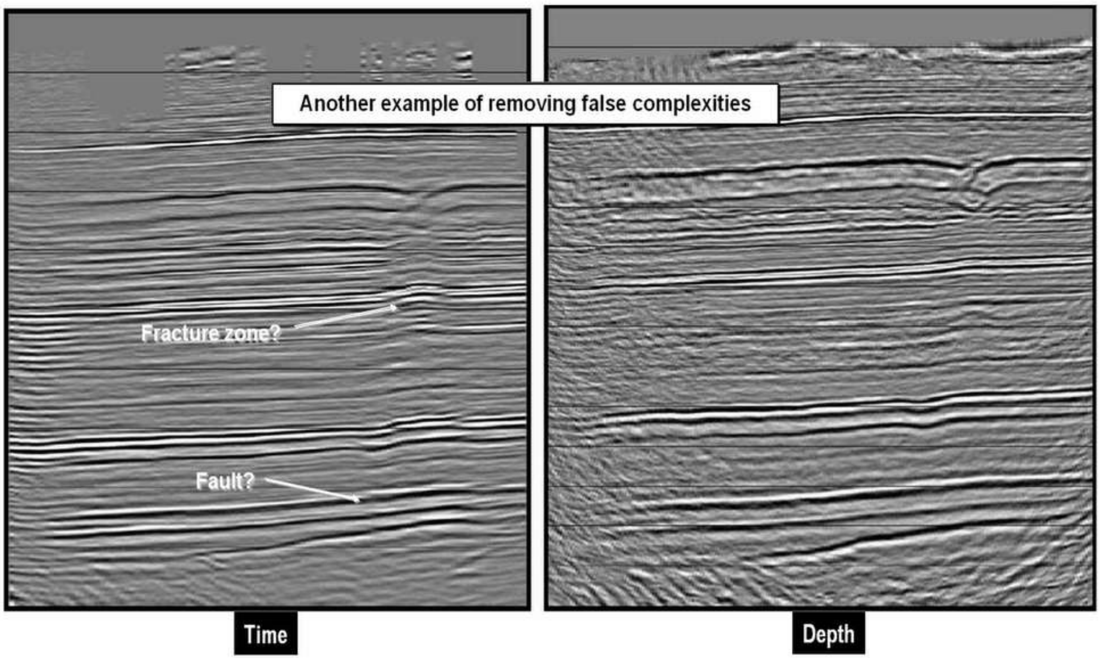

Figure 4. PSTM (left) and PSDM (right) for a structurally simple geology in eastern US resource play. Axes are muted due to confidentiality, courtesy of Trust Belt Imaging (TBI, Calgary).

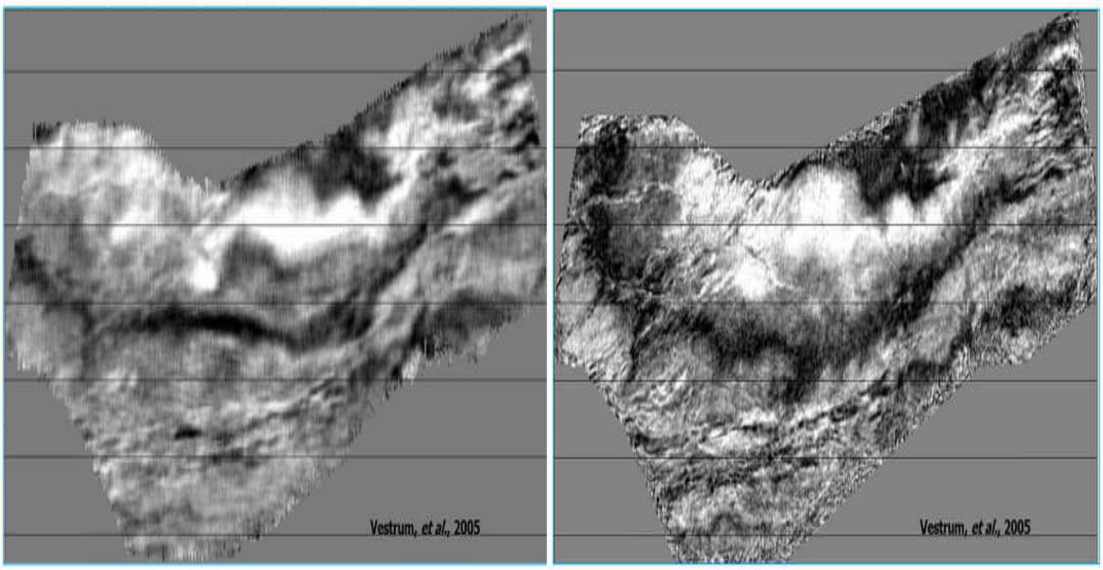

Figure 5. Amplitude map on reservoir horizon surface, PSTM (left) and PSDM (right), look at the resolution which PSDM offering at reservoir level. Axes are muted due to confidentiality, courtesy of Trust Belt Imaging (TBI, Calgary).

This adds additional computational cost of an order of magnitude. There have not been many applications of WEM in an international service company. Probably with the commercialization of RTM, this product was almost abandoned.

2.5 Reverse time migration

Reverse time migration is the high-end imaging method chosen for rapid spatial velocity variations (Baysal et al., 1983; Farmer, 2006). Since the reverse time migration solves the full form of the acoustic wave equation, no dip limitations suffer the method, and superior images for overturned reflections are produced. RTM algorithm generates accurate images of the subsurface. Despite all these benefits, RTM has a major limitation and it is the velocity model. If velocity model for RTM is not very accurate the image deviates from truth significantly. To overcome this challenge in standard processing, the velocity model for RTM is obtained from PSDM with suitable iterations of tomography.

I had been involved in software development of RTM in a company called Acceleware Ltd., a Calgary based Canadian software company (McGarry et al., 2008; Foltinek et al., 2009). Today, seismic processing centers are more comfortable running RTM on marine data, and they generally decline to run it on land data unless it is structurally simple with very mild topography. When you are asking a seismic processing shop to run RTM on rough topography land data, they generally decline to doit or bring some excuses, e.g., for velocity uncertainty is too high, the static problem is destroying the image and so on. Even with all the efforts made to obtain an accurate velocity model, there have been very little applications of RTM on land data with rough topography. This can be due to the static problem and removal of the weathering layer from data that creates near-surface inaccuracy for velocity model hence generates problem for RTM that relies on very accurate near-surface velocity model.

The first application of RTM on rough topography land data has been done with cooperation and support of CadCam Iran, a small processing shop in Tehran. The result of this research is presented in this year's EAGE Conference in Paris (Jamaly and Moghaddam, 2017). Figure 6 shows the result of the RTM research.

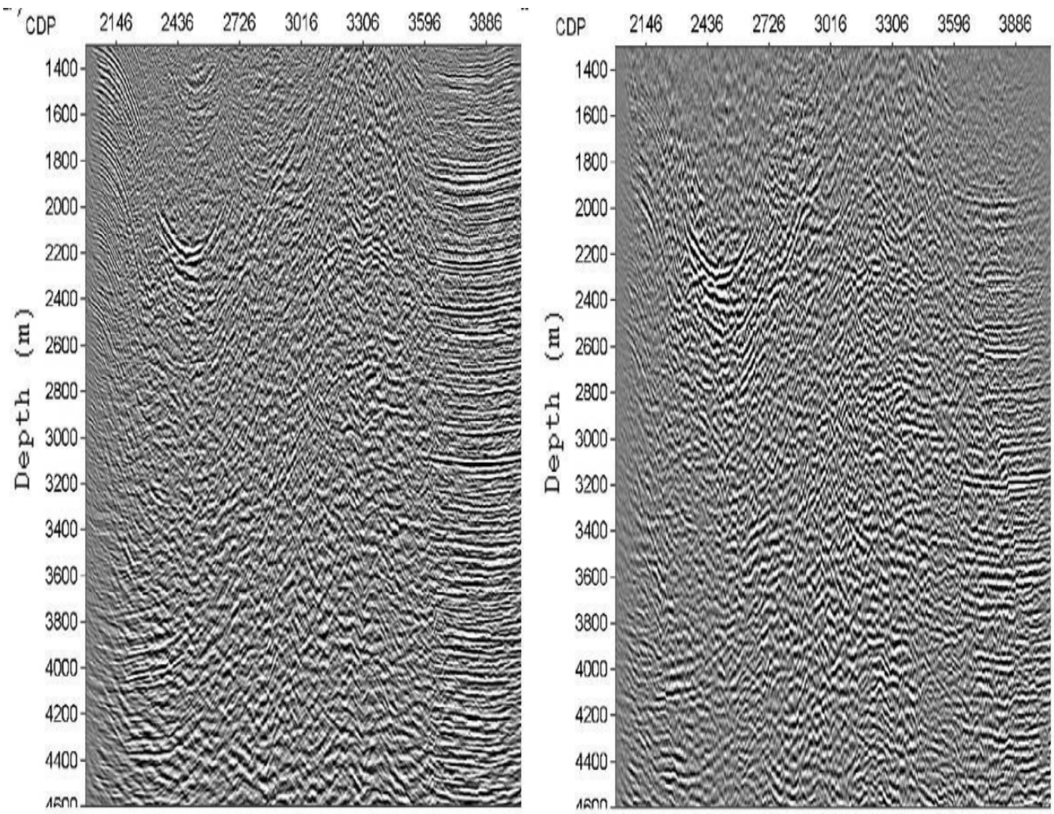

Figure 6. Comparison between PSDM (left) and RTM (right) on rough topography Zagros land dataset (courtesy CadCam Iran).

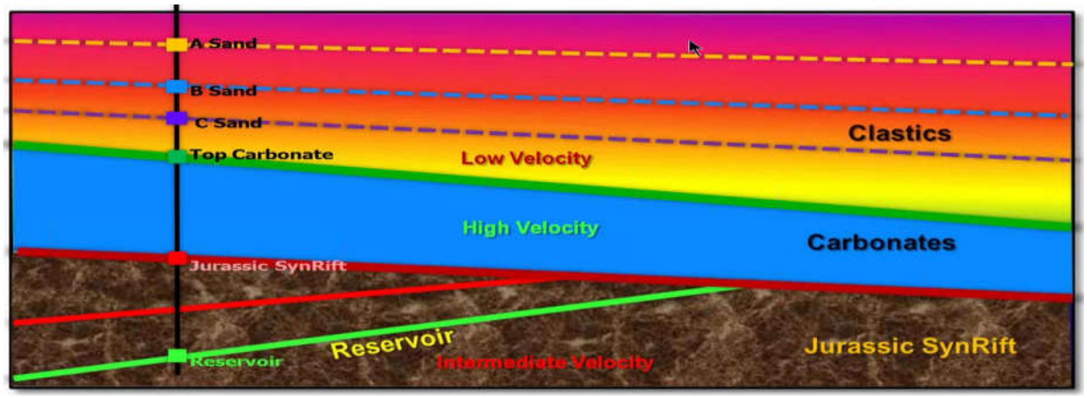

Figure 7. An example of a good model with fairly behaved compaction regiment up to carbonates, the existence of carbonates add complexity in the velocity model lateral variation which directly impacts PSTM time to depth calibration.

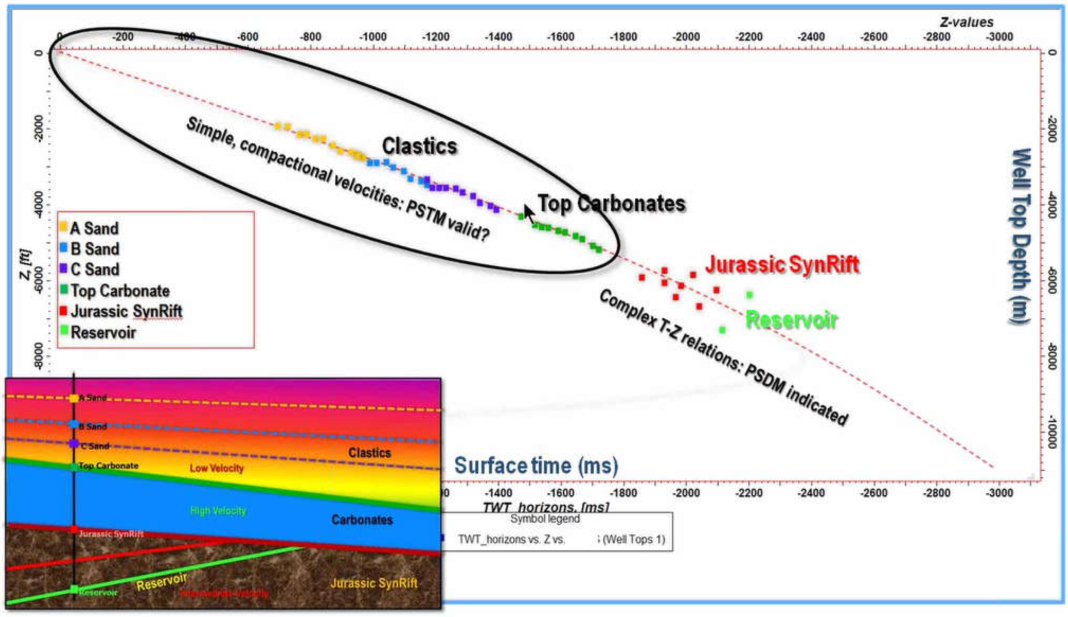

Figure 8. PSTM time to depth indicator, with the vertical axis is the actual value of well-top in meters and the horizontal axis is the corresponding horizon time from PSTM for the same event.

3 When is depth imaging recommended?

Figure 7 shows a fairly well-behaved model controlled by compaction and slow velocity increase, up to the top of carbonate it is expected that time-depth compaction regime would be the linear and no outliers is expected if a good job in time migration is performed. However, in carbonate, there is a jump from a low-velocity to a high-velocity zone that is expected to create complexity down to reservoir level.

Figure 8 shows PSTM time-to-depth indication result in which the vertical axis is the actual value of well-top in meters and the horizontal axis is the corresponding horizon time for the same event. This is an extremely important reality check, on the top circle (up to the top of carbonate) if there is a single point outlier, it can be calibration error, or if there is a large drifting outlier, it can be a well deviation that has not been booked properly. Interpretation job was mostly spent on quality controlling and correcting outliers. In this figure, up to the top carbonate, there is a fairly good result without a big outlier (e.g., drifting from the straight line) following the compaction regime. This means that time migration can be a good candidate for this structure up to the top carbonate. At the reservoir level below Jurassic horizon, it looks like that time depth conversion does not work, which means the time migration failed to properly locate the events. This is because of the large lateral velocity variation at the top carbonate level. This shows to interpreter that a depth imaging is needed.

During the relatively velocity-insensitive process of time imaging (PSTM), the interpreter often relinquishes processing oversight to the processor with little interpretive background. However, as depth imaging grows in importance, it had become clear that it cannot be considered a “product”. Depth imaging is intimately linked with the interpretative process. Therefore, the interpreter must be invested in the QC process and be prepared to guide it. As it will be mentioned in well-calibration section, a PSDM work without well-integration is almost worthless.

Another way of investigating as whether a depth migration is needed or not is shown in Figure 9 when there is no or not enough well information can be integrated. Suppose that depth of the target is about 1500 m, then the migration aperture is about 3000 m. Within one migration aperture at reservoir level (target depth level), there should not be more than 5% of the change in velocity variation. If there is more change than 5%, then the PSTM results cannot be trusted. The risk of relying on PSTM image is significant.

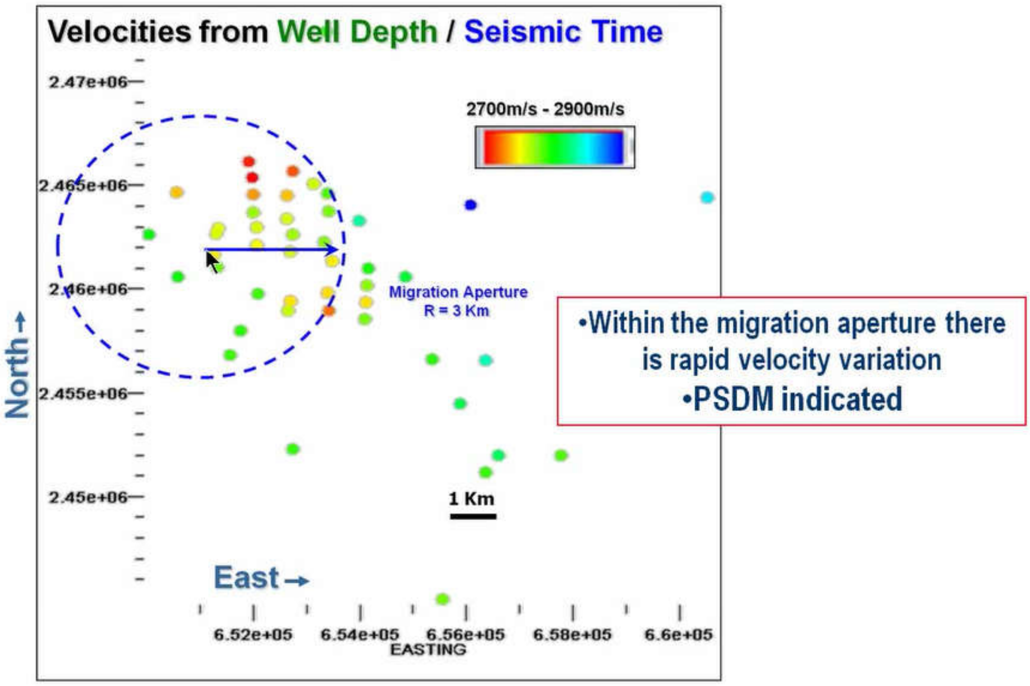

Figure 9. The value of estimated velocity (color coded) on target horizon within one migration aperture, the rapid change in velocity strongly suggest using PSDM.

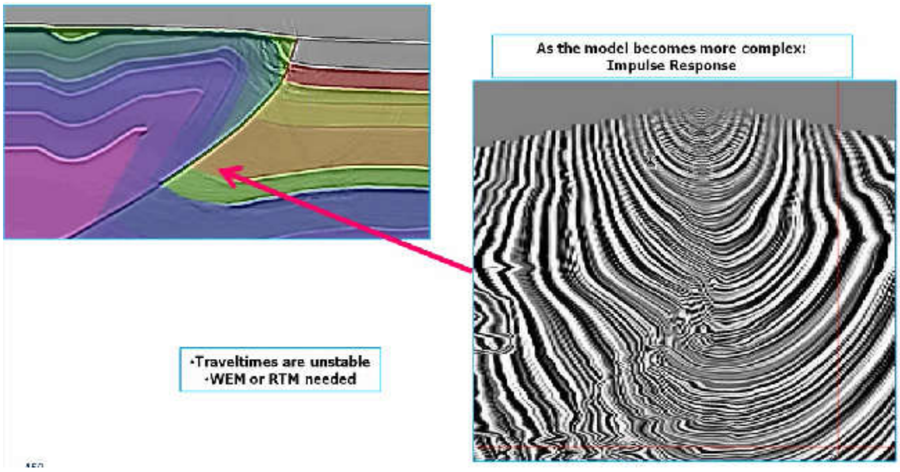

Figure 10. Velocity model (left) and wavefronts associated with PSDM impulse response (right) for this model. This example shows when RTM is recommended (MacKay, 2011).

3.1 When is RTM recommended?

Using RTM especially for deep marine datasets with salt anomalies is well established in the industry. RTM application for shallow marine is a case-by-case problem, and RTM is barely applied to land dataset due to the static problem and the surface velocity uncertainty. Figure 10 shows a case in which the velocity model is too complicated to be handled by PSDM. The right image shows PSDM impulse response for this velocity. When wavefronts cannot be identified in travel time curves due to the velocity complexity, this means that PSDM is going to fail, and RTM is needed. The interpreter can ask the processing shop for impulse response and when there is this kind of travel time behavior, the interpreter will need to make some hard decisions (asking RTM and pay for the price).

4 Seismic anisotropy

Another important processing tool that NIOC completely ignored in past decades is seismic anisotropy (Helbig, 1984; Tsvankin, 1997; Tsvankin, 2001). The isotropic processing of seismic data is simply obsolete more than a decade ago. All major imaging tools, PSTM, PSDM and RTM have anisotropic options in commercial processing software, which needs to be exploited and used properly. The first attempt to tackle anisotropic PSTM processing has been successfully performed by CadCam Iran Service Company. Figure 11 shows the result of isotropic and anisotropic PSTM on the land dataset. As it can be seen in this figure, the anisotropic PSTM image has better continuity along reflections and was able to resolve some parts of image that appeared to be washed out (dimmed) in isotropic PSTM.

Anisotropic PSDM is still in research and exploitation phase in Iran; however, it is routinely used by international seismic vendors. An example of it is shown in Figure 12 for a comparison between isotropic and anisotropic PSDM on Gulf of Mexico deep marine data (courtesy of TGS).

5 Data validation and well calibration

As it is mentioned in the last section, the depth migration is not simply a product similar to PSTM, which NIOC can ask for it from its vendor. The processor needs to data validate its depth imaging workflow with the well data (Rojano et al., 2005). A PSDM work without data validation is a total failure unless there are no wells in the region. In fact, to be able to run an anisotropic PSDM existence of the well top is necessary for the estimation of Thomsen anisotropic parameters (Thomsen, 1986). Figure 13 shows PSDM with well calibration.

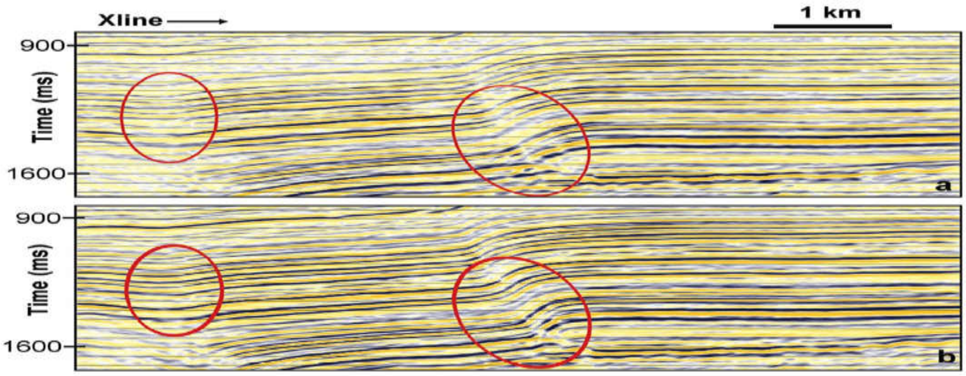

Figure 11. Top: Isotropic PSTM, bottom: anisotropic PSTM for land data (courtesy ION Geophysical).

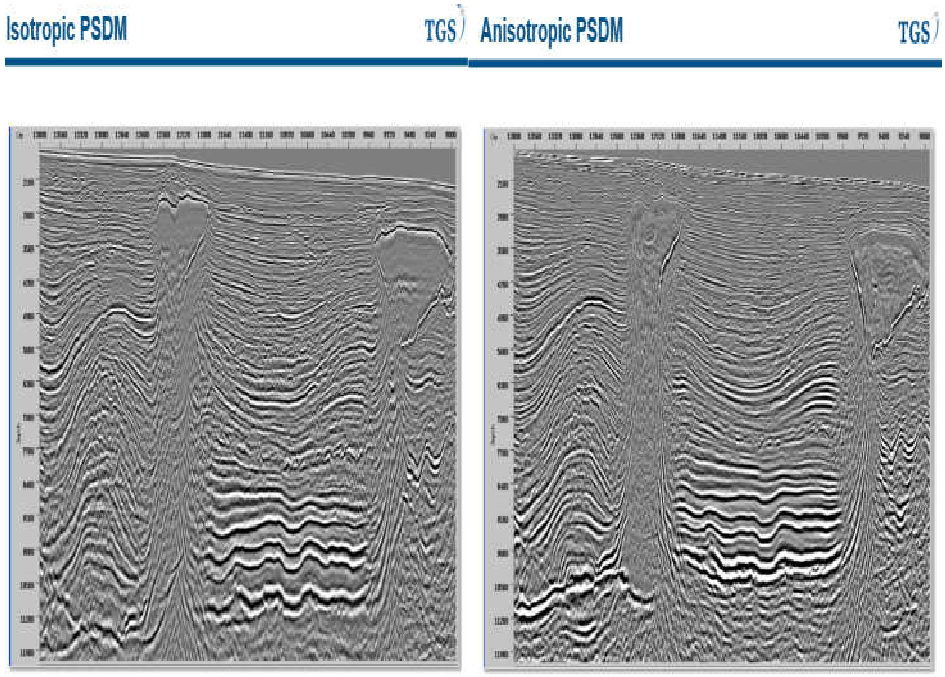

Figure 12. Isotropic and anisotropic PSDM on deep marine data (courtesy of TGS).

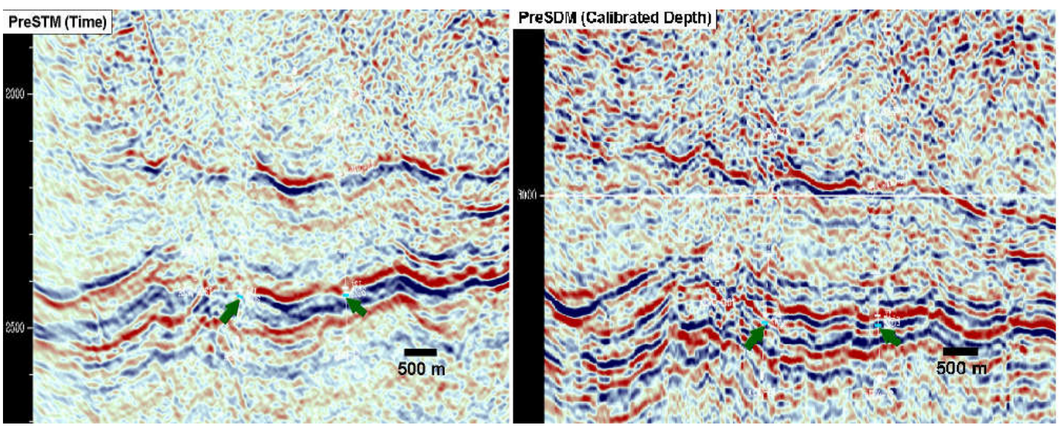

Figure 13. Comparison between PSTM and calibrated PSDM with well tops (Green arrows show the productive zone).

6 Conclusions

Each topic covered above was needed several years of research and development to be mature and be used in industry, and they are all in urgent need of NIOC exploration directorate. Some commercial software supporting most of the above-mentioned imaging tools, but unfortunately, no one paid attention to how to use them with proper quality control and data validation, which generally needs professional training. With this article, it is looking forward to seeing that NIOC would be looking at such an urgent need with the hope that in the next few years, drilling in structurally complicated areas is not performed solely on PSTM images.

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