Seismic Imaging is in the mind and at the fingertips: The future of the Seismic Imaging Business.

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Summary

Among the several sources of value in Seismic Imaging, the Model is perhaps the single most important factor to guarantee the best processing results. While the other two sources of value, Capacity and Algorithm, are commodities, Model Building relies on human knowledge and judgment and these abilities are not commodities. Increasing processing speeds, due to more powerful computers and increasingly efficient algorithms, accentuates the commoditization of the Capacity-Algorithm duality versus the Model. While Service Companies are the specialists to monetize commodity value, the Operating Oil Companies maximize monetization of non-commodity value. Will it affect the future of the Seismic Imaging Business?.

Introduction

The increased exploration and development focus on complex deepwater targets worldwide is giving rise to new challenges for subsalt seismic imaging. For example, the rich oil reserves of the Gulf of Mexico are buried in deep and ultradeep waters up to 30,000 feet from the surface, below massive salt bodies and canopies. The U.S. Minerals Management Service estimates that the Gulf holds 37 billion barrels of “undiscovered, conventionally recoverable” oil, which at $100 a barrel, would be worth $3.7 trillion.

Technological advances in seismic imaging not only represent an opportunity to overcome new exploration challenges but also open a substantial business niche to Service Companies because the “prize” for Operating Oil Companies is very high.

These new technologies (like Reverse Time Migration or Waveform Inversion) are compute-intensive, not only because of high-fidelity algorithms that are being employed to meet the imaging challenges but also because of the increased data volumes of data (e.g. wide-azimuth marine acquisition).

These new seismic imaging technologies are becoming more and more commercially viable because in the recent and near-future development of new generations of hardware like FPG’s, GPU’s or Cell /BE Processors. Tailoring of processing algorithms to these new platforms are reducing cycle times by more of one order of magnitude, which constitutes a quantum leap in our industry.

Such a leap lead us to question if this is a culmination of a trend started in the late 90’s, where hardware capacity was a major limitation, technically and economically, or if it is the beginning of a new era where no longer we have to worry about compute capacity or algorithm performance. In this case, Where is the value added in Seismic Imaging?, and, Who will add more value?. The answer to these questions is key for the future of the Seismic Imaging Business.

The Sources of Value in Seismic Imaging.

Subsurface Seismic Imaging consists on determining simultaneously the Structure and the Velocity Field from a single seismic experiment. Since there are two unknown variables, Structure and Velocity Field and a single experiment, the solution to the problem is indeterminate. The only way to solve it is by iterating from an initial Velocity Model that somehow has to be guessed before the process start. Paradoxically the estimation of this initial guess is highly interpretive and depends largely on human knowledge and judgment.

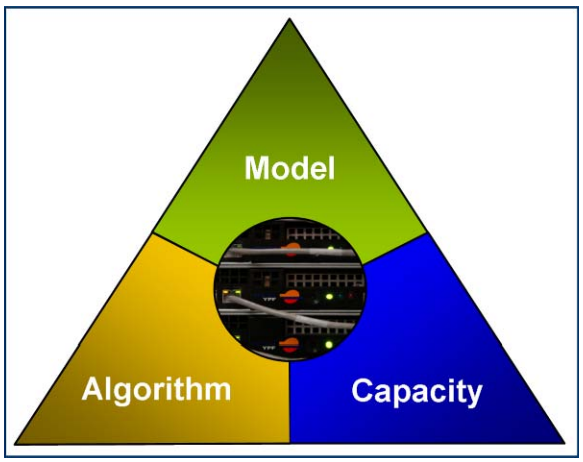

Figure 1: Sources of Value in Seismic Imaging.

There are three Sources of Value in Seismic Imaging (Figure 1): Velocity Model, Algorithms used in the iterations, and the Capacity of the computers used to iterate.

Velocity Model. Focusing seismic energy in Seismic Imaging is exactly the same process as focusing light in Optics. The Velocity Model in Seismic Imaging plays the same role of a lens. The greatest value added during the Seismic Imaging process comes from the time spent "crafting" this lens, i.e., building the Velocity Model. Moreover, as clearer subsalt images are provided by new algorithms, there is still the problem of spatially accurate images, resolvable only with a detailed velocity model.

The Velocity Model Building may be improved with the development of tools that reduce the need for subjective and sometimes inconsistent human interaction, and at the same time, increasing turnaround for large, dense 3D seismic datasets. However, these aids never will eliminate the human interaction to "craft a perfect lens".

Algorithm. Algorithms are crucial for the quality of the final image. Seismic Imaging algorithms have been known even from the sixties, but they were not coded due to the lack of adequate or affordable hardware. During the recent years there has been a race among researchers and software developers to provide with newer and faster algorithms This competition lead to a situation that somebody quoted as "algorithm pollution" referring to the amount of different flavors for the implementation of Seismic Imaging technologies.

Traditionally, imaging algorithms and algorithm implementation have evolved faster than hardware. Particularly in the oil industry, algorithm evolution has concentrated in speeding up existing algorithms trying to optimize the quality/speed tradeoff by making numerous shortcuts, always thinking that someday, who knows when, such tradeoffs will be no longer needed. This time has arrived as we witness nowadays the crossover of the curves representing evolution speed of hardware and software. It is needed, for the oil industry, to accommodate fast to an environment, not seen before, where one of the new questions for the hardware manufacturers is if there will be enough users for the rocket machines they foresee feasible to be built.

	2007	2006	2003
	Reverse Time Migration	Shot Profile Migration	Common Azimuth Migration
Kernel	2-way	1-way	1-way
Dip limitation	None	< 90°	< 90°
Disk per shot (relative)	> 100	1	0.1
Computation time per shot (relative)	> 10	1	0.1

← Better Image

Figure 2: Imaging Algorithms and hardware requirements over time.

Capacity. The need for Capacity is obvious in Seismic Imaging. The amazing price-performance ratio of Linux PC-Clusters made Seismic Imaging Technology a reality from early 00's. The evolution of the algorithms, and the application to exploration in increasingly geologically complex areas is a consequence of the ever increasing performance of PC-Clusters. During the last five years (Figure 2), the need in computing power needed for seismic imaging in the oil industry has increased two orders of magnitude and the storage, and I/O needs, three orders of magnitude. At present time, and considering the new algorithms to come (Waveform Inversion, Plane Wave Reverse Time Migration, ...) there is no indication that this rate will decrease because of the imaging success of these new technologies. For instance, Reverse Time Migration is already a reality and allows better images in areas, like the example in Figure 3, where even Wave Equation algorithms failed.

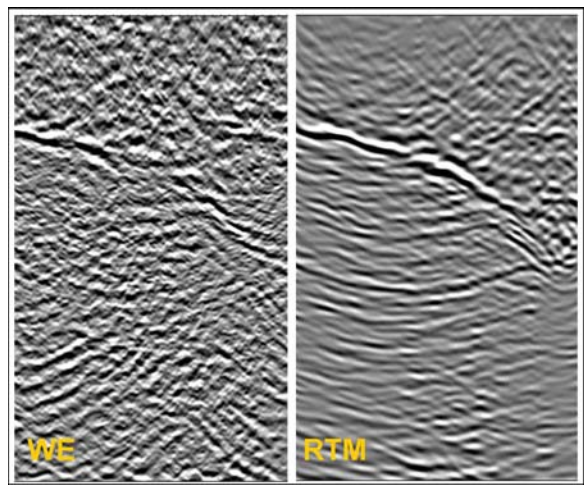

Figure 3: Comparison of Wave Equation, left, with Reverse Time Migration, right.

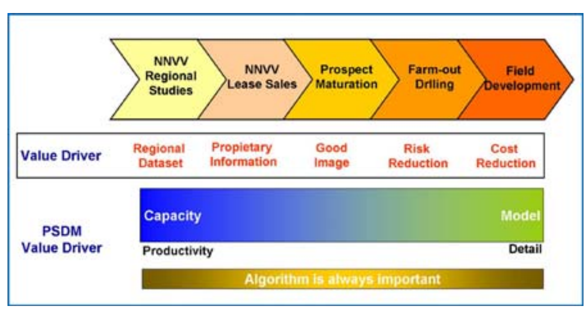

Figure 4: Line up of the Sources of Value in Seismic Imaging with the Value Drivers in the Exploration Cycle.

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Seismic Imaging and Value Drivers in Exploration.

Figure 3 shows the typical Exploration Cycle in the Gulf of Mexico, from New Venture Regional Studies to Field Development. At every stage of the Exploration Cycle the Value Driver for that stage is different. For instance, at the early stages of exploration, the main Value Driver is the possession of a Regional Dataset; during the Lease Sales, Proprietary information is the main Value Driver and at the end of the Cycle, given the costly developments in the deep and ultradeep waters of the Gulf of Mexico, Cost reduction is the main Value Driver for Field Development.

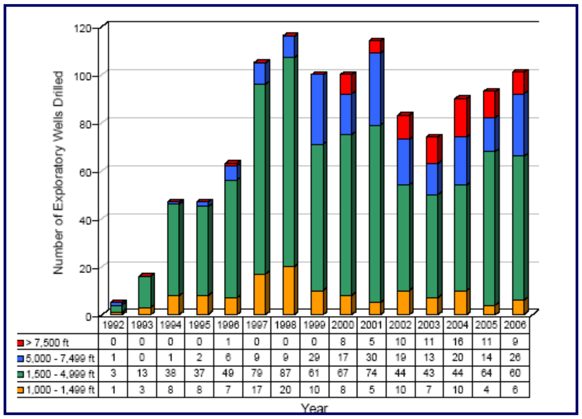
Figure 3 also shows the line up of the three Sources of Value in Seismic Imaging with the Value Drivers in the Exploration Cycle. Summarizing we may say, that in one extreme, at the New Ventures stage of Exploration where Regional Datasets are the Value Drivers, Productivity is demanded from Seismic Imaging, and Productivity mainly is related to Capacity. At the other extreme of the Exploration Cycle, when a field is developed and the Value Driver is Cost reduction, the optimum development requires Detail from Seismic Imaging. Detail is mainly related to quality of the Model. If we think of the Sources of Value in Seismic Imaging, (Model, Capacity and Algorithm) as ingredients of a recipe, we may say that at every stage of the Exploration Cycle, the Seismic Imaging Recipe has to be *different*, aligned to the Value Drivers of the Exploration Cycle at that stage.

However, it rarely happens. Every vendor, every oil company, has a different and peculiar recipe which is applied uniformly to all the cycle. Even more, sometimes it seems that those particular recipes have only two ingredients, Capacity and Algorithm. It is easy to understand because these two ingredients are commodities and do not require man time in production. Man-time is expensive, Man-time will never ever be a commodity. Model building requires the luxury of Man-time. So, Where and How is the lens crafted?.

Discussion. What is the problem?

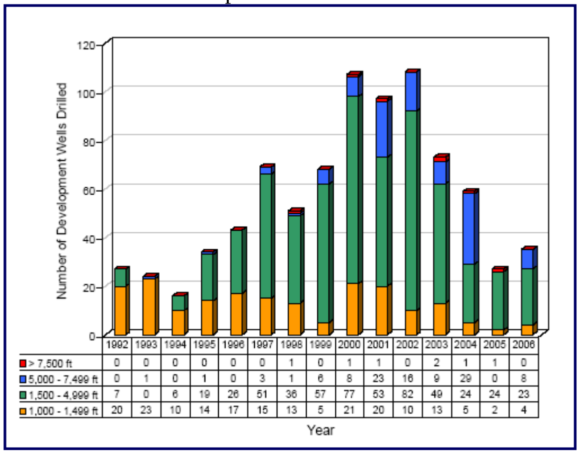
Over the last decade Seismic Imaging technologies have evolved thanks to increasing affordability of computer power and availability of more accurate algorithms. At the same time the evolving technology has created a lucrative business niche for the Processing Contractors offering oil companies products of increasing quality that would eventually decrease significantly the risks associated with the Exploration Cycle.

Having said that, if we review the exploratory results in the deep and ultradeep waters of the Gulf of Mexico something does not match.



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
> 7,500 ft	0	0	0	0	1	0	0	0	8	5	10	11	16	11	9
5,000 - 7,499 ft	1	0	1	2	6	9	9	29	17	30	19	13	20	14	26
1,500 - 4,999 ft	3	13	38	37	49	79	87	61	67	74	44	43	44	64	60
1,000 - 1,499 ft	1	3	8	8	7	17	20	10	8	5	10	7	10	4	6

Figure 5: Exploration wells drilled in the deep and ultradeep waters of the US Gulf of Mexico from 1992 to 2006. Source MMS Report 2007-021.



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
> 7,500 ft	0	0	0	0	0	0	1	0	1	1	0	2	1	1	0
5,000 - 7,499 ft	0	1	0	1	0	3	1	6	8	23	16	9	29	0	8
1,500 - 4,999 ft	7	0	6	19	26	51	36	57	77	53	82	49	24	24	23
1,000 - 1,499 ft	20	23	10	14	17	15	13	5	21	20	10	13	5	2	4

Figure 6: Development wells drilled in the deep and ultradeep waters of the US Gulf of Mexico from 1992 to 2006. Source MMS Report 2007-021.

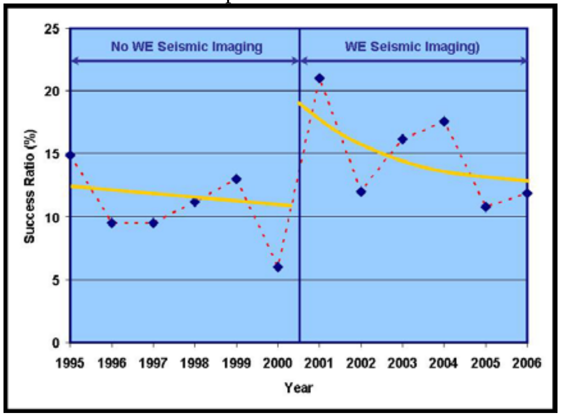


Figure 7: Historic Exploration success rates in the deep and ultradeep waters of the Gulf of Mexico from 1995 to 2006. Source MMS Report 2007-021.

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While the number of exploration wells per year over the decade is more or less constant, the trend of the number of development wells is falling noticeably over the same period of time (Figures 5 and 6). This observation can be explained by the falling trend of exploration success rates during the last eight years (Figure 7).

Figure 7 also shows that there is an abrupt increase in exploration success rates around 2001. This fact, it may be the result of advanced Kirchhoff algorithms for the suprasalt section and the advent of Common Azimuth Wave Equation algorithms for the subsalt section. However, after this initial increase in exploration success ratios decay, almost in an exponential fashion despite the evolution of seismic imaging technology.

The missing ingredient for not seeing as good as promised by evolving Computing Power and Algorithm Accuracy is that there has not been any remarkable evolution on the Model Building technology. We change the computers and the processing algorithms, but we do not improve the lens.

Significant effort has to be dedicated in the near future to "*craft the lens*" if we want to reduce risks and increase exploration success ratios. Paradoxically, the best lens crafter is the explorationist who is the professional with the best knowledge and judgment in the interpretation of the subsurface. At the end of the day, having the right algorithms, and enough capacity available, the best way to maximize the alignment of the Sources of Value for Seismic Imaging and the Value Drivers of the Exploration Cycle, is by changing the degree of Detail of the Velocity Model. An this is the expertise of the explorationist.

We may think of this explorationist as a Pre-Stack Seismic Interpreter, in opposition to the traditional Post-Stack Seismic Interpreters. Given the almost-ready availability of petascale capacity, and fast algorithms, Velocity Model Building will evolve to a more exploration oriented task in the hands of the Pre-Stack Seismic Interpreter. The work flow will include unnumbered near real-time iterations and velocity updates to craft the perfect lens. *Seismic Imaging will be in the mind at the fingertips of the explorationist.*

	Max	Mid	Min
Cell /BE Speed up	10x	9x	8x
Shot Decimation Speed up	5x	4x	3x
Increased Grid Spacing	2.0x	1.6x	1.3x
Total Combined Speed up	100x	58x	31x
Relative time per shot	5'	10'	20'
Days for 100k shots	1.0	1.5	3.0

Table I. Individual and combined performance increases for RTM. Relative time is in minutes and refers to the performance increase normalized per shot compared to an AMD Opteron 270 Dual Core Blade. Duration is in days assuming 500 IBM QS20 Blades.

Ortigosa et al. (2008), Table I, shows that RTM may be accelerated up to two orders of magnitude for Velocity Model Building purposes without any algorithm improvement.

This working scheme will change the way we conceive the Seismic Imaging Business since this Pre-Stack Seismic Interpreter is more on the side of an Oil Operating Company rather than in a Service Company.

Two possibilities:

1. Oil Companies conscious on the value added by the Pre-Stack Seismic Interpreter start developing own algorithms and building in-house petascale computing facilities to be used as tools by the explorationist.

2. Service Companies change their role from processing companies to software vendors and providers of computing on demand for Operating Oil Companies.

In both cases the Value is shifted towards "*crafting the lens*" from "*pure processing*". The first possibility will give more competitive advantages to Operating Oil Companies as they will not share algorithms, although this possibility could be more expensive than the second. However, How much is Cheap or Expensive when the cost of a well is in the order of 150 MMUS$?.

Conclusion.

The trend of Exploration Success Ratios in the GOM is not matching from the expected risk reduction from the evolution of Seismic Imaging technology. One reason may be that only Capacity and Algorithms are over valuated, overlooking the role of Model Building, which is the single more important source of value. Faster hardware and algorithms in near future will result in near real-time turnaround for iterations and velocity updating. Then, man-time "*crafting the lens*" will be the main source of value for Seismic Imaging. With the availability of these near real-time tools Seismic Imaging will be in the mind and at the fingertips of the explorationists in the Operating Oil Companies. This possibility will change the way we conceive the Seismic Imaging Business.

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