Integrated Seismic (IS) for Shale Gas Exploration and Management

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SUMMARY

Seismic integration has been a successful accessory in every data interpretation project. For shale gas exploration design, development and implementation, high-resolution seismic data are necessitated. In this context, every exploration project needs multi-disciplinary datasets and their integration that can minimize the ambiguity of the interpretative outcomes. What are the integrated solutions for imaging and interpreting shale gas and how do they impact our shale prospect business? How do we organize and standardize our integrated workflows to address issues of exploration, field development, including drilling campaigns of the unconventional reservoirs? So far, the conventional reservoirs of many worldwide basins did produce even without integrated workflows. With the increase in intricacy in structural and stratigraphic settings, in particular with the fractured shale environments, exploration and field development plans have become multifaceted, complicating the field operations. How do we take on the exploration, development and drilling campaign decisions using the integrated seismic solutions? How do we suggest the "integrated solutions" to our valued operators and service providers? Why are the conventional technologies failures and setbacks? How can we guide and recommend the petroleum companies on appropriate technologies and the reserve computations in shale environments? We come up with an "Integrated Seismic" (IS) strategy, addressing the issues and challenges. The applicability and feasibility of IS in various exploration projects including their execution and implementation in worldwide shale gas basins are discussed. IS has been playing a vital role, making huge impacts on the integrated interpretation projects, especially during prospect identification and risk evaluation stages.

Key words: Shale gas, Integrated Seismic, Exploration, Management, Prospect Generation

INTRODUCTION

The shale gas exploration and development have increased importance worldwide with several TCF of shale reserves are yet to be explored and exploited. Worldwide untapped shale gas resources are in the order of 16,000 tcf and most of them are being exploited in regions other than North America (Nimmagadda and Dreher, 2011). The untapped reservoirs are unconventional and to investigate the resources, special skills and expertise are needed at both exploration and development stages. Besides, the data integration in particular with seismic exploration inputs is a major challenge. Setbacks encountered in shale gas exploration and exploitation are discussed. The purpose and objectives of the current research are to identify: gaps in shale gas technologies, shale gas business opportunities, and shale gas intellectual property (IP) and bridge the gaps through IS solutions. The research covers the topics related to shale gas exploration and production from a wide variety of topics such as basin evaluation, seismic reservoir characterization, fracture analysis techniques, rock physics, micro-seismic, and integration of data types (e.g. core, log, geo-mechanics, hydraulic fracturing). Different technologies, methodologies shale gas exploration, in particular data acquisition design, development and implementation and case studies discussed in the research article are useful for extending the strategies worldwide. Several existing unconventional shale gas case studies are summarized with merits and demerits of the technologies. For all quantitative integrated interpretation projects, it is necessary and essential to integrate all the exploration datasets such as seismic, well-log, petrophysical and rock physics data inputs, for interpretative outcomes that can describe (without any ambiguity) leads and prospects, including risk evaluating the drillable shale prospects. For addressing the existing issues and challenges of data integration in shale gas exploration, we design and develop an integrated methodological framework. The research outcomes obtained from the integrated methodological framework are implemented for fracture identification, fracture density and their orientation analysis, including rock physics and petrophysical properties, besides collaborating other interpretative outcomes in basin evaluation, geophysical data integration and interpretation and seismic reservoir characterization.

Castaneda et al. (2012) describe different workflows for exploring structural and stratigraphic traps, measures taken during exploration and field development plans. They describe various worldwide contexts providing workflow solutions for shale gas development. Anjirwala and Bhatia (2016) compare shale gas scenarios between India and USA including favourable conditions and challenges with logistics of shale gas technology implementations. Padhy et al. (2016) describe various new opportunities of shale oil exploration from Palaeocene – Eocene sequences of the Cambay basin in the Western part of India. Completion qualities have been described providing improved stimulation solutions in the unconventional Eagle Ford Shale of North America. New opportunities and favourable conditions for shale gas prospects are given in Sain et al. (2014). Horizontal drilling techniques that can manage the heterogeneity and tight shales are described in Saurez-Rivera et al. (2011). They provide improved quality completions in good quality reservoirs of the shale basins in the southern parts of the USA. Charsky and Herron (2012) provide quantitative analytic solutions for estimating the kerogen content and shale associated mineralogy using spectroscopic techniques. They demonstrate that quantitative analysis of kerogen, calcite, illite, kaolinite, quartz, dolomite and smectite is possible for cuttings obtained from a well drilled with oil-based mud in a formation in Texas. Chopra et al. (2012) look for new shale play basins in USA. TOC of different shale formations have different properties in terms of maturation, gas-in-place, permeability, and brittleness. They discuss different workflows for characterizing shale formations that involve well log as well as seismic data. Coal bed and associated shale gas reservoirs have been discussed in Jenkins et al. (2008).

Critical data needed to appraise the coalbeds and shale gas reservoirs demonstrate the applicability appraisals in worldwide shale basins. Data conditioning is done for seismic structure and attribute analysis for Eagle Ford Shale play in shale basins in USA (Hanning et al. 2010). Zhu et al. (2010) describe hydrocarbon indicators with the responses of TOC and other shale mineralogy. AVO analysis for mineralogical characterizations within shale reservoirs appears promising for pinpointing the shale gas sweet spots. Heterogeneity characterization of shale reservoirs is described with case studies in Li et al. (2012).They suggest the suitability of the well placement in shale reservoirs in the southern parts of the USA. Nimmagadda et al. (2012) present the heterogeneity and multidimensionality of shale reservoirs with data modelling and data storage perspectives. New opportunities in the eastern European contexts have been discussed. Ontologies are described (Nimmagadda and Dreher, 2010) for fracture networks of reservoir ecosystems for borehole management and enhanced oil recovery in the Middle East and Southeast Asian contexts. Nimmagadda and Dreher (2011) present shale gas ontology, a robust modelling methodology for integrating and connecting the fractured reservoir ecosystems in the Latin American contexts. They resolve various issues associated with shale gas production complexities. The seismic volume has been analysed for shale gas reservoirs in South China with an objective of generating shale formation properties related to fracture orientation and intensity in the area (Yu et al. 2015). Shale gas reservoirs exist in South China and integrated studies have been conducted (Yu et al. 2017) involving wide-azimuth 3D seismic for analysing shale formation properties, relevant to fracture orientations and densities. Well data, seismic structure and pre-stack inversion attributes have been integrated in the study area. Elliptic velocity inversions are deployed integrating special seismic attribute interpretation.

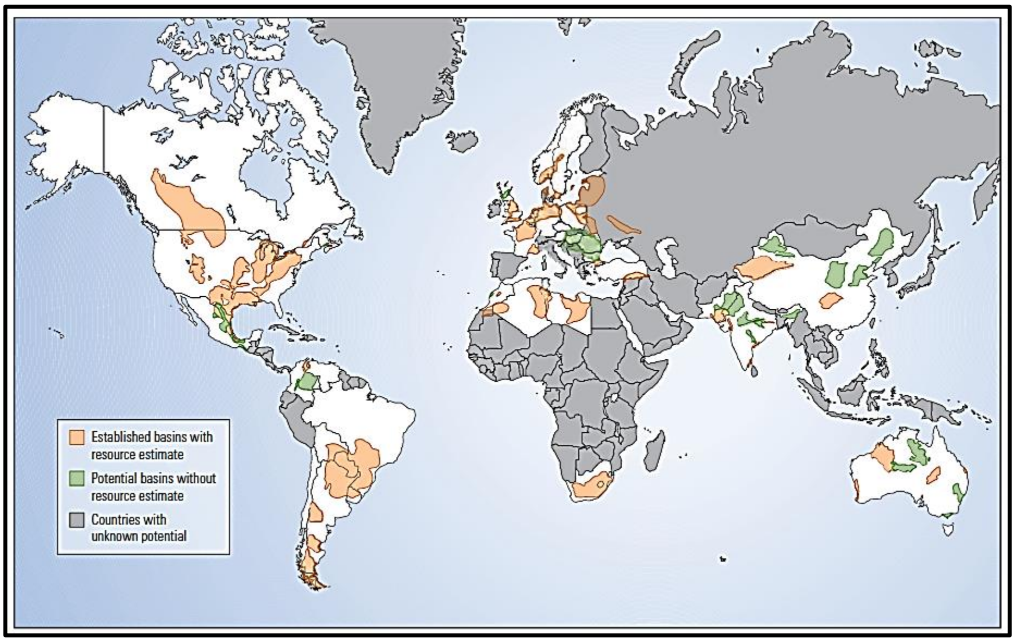

Fig. 1: Shale basins of the world (Boyer et al. 2011)

As shown in Fig. 1, a number of shale basins exists worldwide demonstrating the gas shale production, potential and unknown potential with new opportunities for development (Boyer et al. 2011). The purpose of the current research is to integrate various products of exploration, shale reservoir development and production including data models built at exploration and production stages. The scope of the research is to integrate company DB silos or multi-client unconventional products, which are geographically operated. Integrating different fracture networks of shale reservoirs and establishing their connectivity through information system (IS) solutions are challenging tasks. Most of the shale reservoirs do not exhibit any structural bearing, rather the shale gas production does depend on the fracture orientations and their density. For this purpose, we need special tools and technologies to address the challenges of shale reservoir characteristics. We propose seismic integration in all our workflows and data models. The paper is structured in a couple of sections, data modelling methodologies, implementations and results with summary and conclusions.

METHOD AND RESULTS

Different data dimensions of exploration, drilling and production of shale gas, with both technology and case-study perspectives are identified. Within exploration, several sub-type data dimensions are discussed, such as geology, seismic, well log, reservoir, petrophysics and rock physics. The art of integrating multiple dimensions (for shale-gas exploration and development) is key highlight of the research contribution. New methodologies are developed, building innovative data models how they impact the current shale gas business with IS contexts. Integration of the geographically spread different DB silos is another feature of the study. For identifying various dimensions and their attributes for dimensional data modelling, we describe various entities as examined in the following sections.

Study/improve our methods to capture stress/anisotropy parameters: Extract anisotropy from seismic with appropriate PR, epsilon, gamma and estimate delta. Rock physics is exploited to describe the right PR. Pre-stack seismic inversion uses to describe PI, SI, estimate delta, for which check shot at least in the vicinity of shale, by defining workflow with rock physics young's modulus. Since gamma is related to epsilon, it is obtained from gamma and delta from the sonic scanner data. We examine the delta and gamma, if they can be reliably derived from PSDM and thus estimate Young's horizontal and vertical parameters. Shear information is obtained from seismic guided AVO. For density estimations, long offsets (>45Deg incident) are needed, indicating open fractures. Reservoir models are used to obtain anisotropy stress, while integrating with other information. We propose new modules and develop case studies for new methods, such as AVO vs. azimuth and frequency attenuation.

More tests are needed on shale basin data: We consider how we should approach the seismic analyses, extracting anisotropy attributes. For assessing the frackability, horizontal components are necessary for which an azimuthal study is important. PR, Young's Modulus, lithology, ants, density, stress components, geo-mechanical parameters can help design wells and fracks judiciously.

Well log and other seismic attributes: We sample well logs at high resolution rates while model is low res, ~50'. An upscale of log to seismic is needed for improvising the model resolution. We corroborate with curvature attributes that indicate stress and fracture complexity. We try to separate the vertical and horizontal resolution in conjunction with Young's Modulus and Poisson's ratio. If combined with check-shot data, the delta c differentiate brine from oil and from gas fill.

Special well-log studies: FMI is useful, but not as useful as sonic scanner, which sees deeper into the rock. The correlation between seismic data and FMI are in the 0.2 to 0.5 range, which is not compelling. Because sonic scanner sees deeper into the formation and hence covers a couple of hundred square feet (in a vertical well) versus seismic 10,000 square feet, it is more likely to agree with the seismic data than is a vertical FMI. RT (resistivity) anisotropy is useful. Micro-seismic is tied with seismic to define healed fractures. We might build pressure for secondary fracture directions. Velocity analysis and velocity models can indicate anisotropy and fracture orientations. Basin modelling that can predict pore pressure should be able to corroborate with seismic velocities and sonic scanner including predicting stress regimes. The characteristic models designed at exploration and production stages are compared in Table 1 for the best performing model, as part of providing quality services in shale gas exploration and appraisals.

Table 1: Comparison of Models in Shale Exploration & Production Mangement

Model1	Model2
Minimum Data Utilized	Collected Optimum Data
Accept statistical variation in Well Performance	Understand the reservoir and completion qualities
Compensate by drilling more wells	Reservoir based well placement
Factory approach to drilling and completion	Utilize technology to improve drilling and completion efficiency
Large Footprint = high rates & large fluid volumes	Reduced equipment footprint and fluid volumes

Good reservoir quality + good completion quality = "Shale Gas" Economic Success

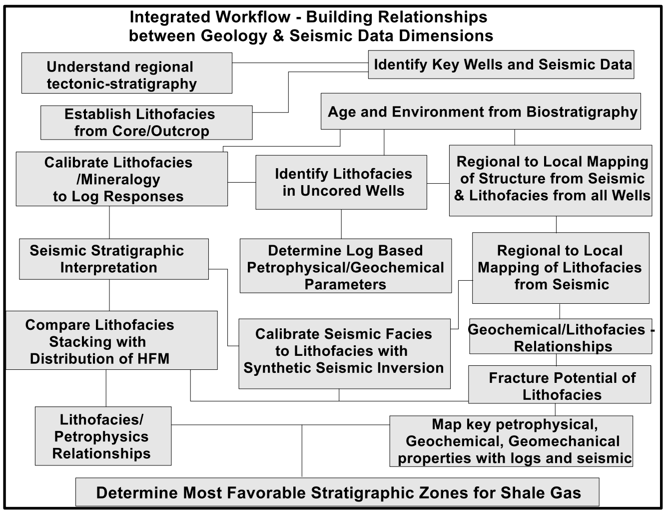

Fig. 2: An integrated workflow - building data relationships through different geology and seismic entities and dimensions

Integrate work from different company silos: As shown in Fig. 2, we identify dimensions from geology and seismic entities and to make connections among unconventional resources data. Our idea is to integrate data structures (schemas) and or products of the unconventional resources development in various geographic dimensions. A global consortium is needed to take the concepts and contexts from US unconventional lessons' learnt. Various dimensions and their associated attributes of the unconventional coal and shale gas development are provided in Table 2, recommending seismic, geology, rock physics, drilling, and fracking and production entities. Gas content (Gas_Content), Rock evaluation pyrolysis (Rock_Eval_Pyro), TOC (total organic content), Gas composition (Gas_Composit), core description (Core_Descri), sorption isotherm (Sorption_Isothm), proximate analysis (Proxim_Analytic), mineralogical analysis (Mineral_Analytic), vitinite reflectance (Vitrinite_Reflect), calorific value (Calorific_Value), marceral analysis (Maceral_Analytic), bulk density (Bulk_Density), conventional logs (Conven_Logs), special logs (Special_Logs), pressure transients (Pressure_Trans) and 3D seismic (3D_Seismic) are the dimensions considered in the schema designs.

Table 2: Dimensions and their attributes used for integrated data models for unconventional resources development

Dimensions	Facts	AttributeDim_ID	Fact_ID
Gas_Content	Volume, Coal Samples	VolumeDim_ID (1), CoalSeamDim_ID (2)	GC_Fact_ID (F1)

	Residual Gas, Lost Gas and In-situ gas content	ResidualDimGas_ID (3), LostGasDim_ID (4) In-situGas_ID (5)	
Rock_Eval_Pyro	Petroleum Gen Potential, Thermal Maturity, Fraction of Organic Matter, Total Amt of Hydrocarbons	Petro_Gen_PoDim_ID (1) Therm_MatuDim_ID (2) Frac_OrgaMatrDim_ID (3) Amt_HydrcarbDim_ID (4)	REP_Fact_ID (F2)
TOC	Total Amt of Carbon, Amt of Kerogen, Source Rock Potentiality,	AmtCarbonDim_ID (1) AmtKerogenDim_ID (2) SourcePotentDim_ID (3)	TOC_Fact_ID (F3)
Gas_Composit	Percentage of Methane, CO2, Nitrogen, Ethane, Gas Purity, Composite Desorption Isotherms	PecentMethaneDim_ID (1) CO2Dim_ID (2) NitrogenDim_ID (3) GasPurityDim_ID (4) CompDespIsothDim_ID (5)	GasComp_Fact_ID (F4)
Core_Descri	Coal Brightness, Banding, Cleat Spacing, Mineralogy, Coal Thickness, Composition, Permeability, Heterogeneity of Coal Seam	CoalBrightDim_ID (1) BandingDim_ID (2) CleatSpacingDim_ID (3) MineralogyDim_ID (4) CoreThickDim_ID (5) CompositionDim_ID (6) PermeabilityDim_ID (7) HeterogeneityDim_ID (8)	CoreDes_Fact_ID (F5)
Sorption_Isothm	Vol of Gas, Pressure, Amt of Gas in a Coal Seam, Amt of Gas liberated	VolGasDim_ID (1) PressureDim_ID (2) GasCoalSeamDim_ID (3) GasLiberatedDim_ID (4)	SorpIsoth_Fact_ID (F6)
Proxim_Analytic	Percentage of Ash, Moisture, Fixed Carbon, Volatile Matter, Gas content, Sorption Isotherm of Moisture, maturity of high ranking coal	PercentAshDim_ID (1) MoistureDim_ID (2) FixedCarbonDim_ID (3) VolatileMatterDim_ID (4) SorpIsoMoistDim_ID (5) MatHiRankCoalDim_ID (6)	ProxiAnaly_Fact_ID (F7)
Mineral_Analytic	Bulk mineralogy, Clay mineralogy,	BulkMineralDim_ID (1) ClayMineralDim_ID (2)	MineralAnaly_Fact_ID (F8)
Vitrinite_Reflect	Coal Maturity, Ranking of Coal, Amt of Incident light by vitrinite maceral	CoalMatureDim_ID (1) CoalRankDim_ID (2) AmtIncLightVitDim_ID (3)	VitriniReflect_Fact_ID (F9)
Calorific_Value	Heat Prod, Combustion of Coal, Coal Maturity, Coal Ranking	HeatProdDim_ID (1) CompustonCoalDim_ID (2) CoalMatureDim_ID (3) CoalRankDim_ID (4)	CaloriVal_Fact_ID (F10)
Maceral_Analytic	Spatial Relationship, Gas Sorption Capacity, Brittleness, Gas Content, Permeability	SpatialDim_ID (1) GasSorpCapaDim_ID (2) BrittlenessDim_ID (3) GasContentDim_ID (4) PermeabilityDim_ID (5)	MacerAnaly_Fact_ID (F11)
Bulk_Density	Ash content, gas content, Coal Count, Shale Thickness	PercentAshDim_ID (1) GasContentDim_ID (2) Coal/ShaleThickDim_ID (3) CoalCountDim_ID (4)	BulkDens_Fact_ID (F12)
Conven_Logs	SP, Gamma, Shallow & Deep Resistivity Microlog, Caliper, Density, Neutron, Sonic, Identify Coals/Shales, Porosity, Saturation	SPDim_ID (1) ShDeepResisDim_ID (2) MicrologDim_ID (3) CaliperDim_ID (4) DensityDim_ID (5) NeutronDim_ID (6)	ConvenLogs_Fact_ID (F13)

		CoalShaleDim_ID (7) PorosityDim_ID (8) SaturationDim_ID (9) PeriodDim_ID (10)	
Special_Logs	Image Logs Wireline –Spectrometry In-situ Gas Content	ImageLogDim_ID (1) SpectrometryDim_ID (2) InSituGasDim_ID (3) PeriodDim_ID (4)	SpecialLogs_Fact_ID (F14)
Pressure_Trans	Pressure Build up, Reservoir Pressure, Permeability, Skin Factor, Fracture Behaviour	PressureBuildDim_ID (1) ReservoirPresDim_ID (2) PermeabilityDim_ID (3) SkinFactorDim_ID (4) FractBehaviourDim_ID (5)	PressureTrans_Fact_ID (F15)
3D_Seismic	Survey Geography, Survey Name, Fault Location, Reservoir Depth, Coal/Shale Properties, Shale/Coal Thickness, Areal Extent, Period	GeographyDim_ID (1) SurveyNameDim_ID (2) FaultLocDim_ID (3) ReserDepthDim_ID (4) Coal/shalePropDim_ID (5) Shale/CoalThickDim_ID (6) ArealExtentDim_ID (7) PeriodDim_ID (8)	3DSeismic_Fact_ID (F16)

Data usage and company preferences: Many companies store large amount of data, but they do not know how to use them**.** They prefer to reduce costs and seismic specialists show their expertise where to put wells and where to frack. This can save large number of resources by reducing the number of wells and fracks. As an example, Denver Shale project (Pope at el. 2012) where seismic anisotropy analysis was done on the overburden help explorers understand deeper targets, for which additional reprocessing could have been worthwhile. Integrating the pre-stack seismic data, well logs, microseismic and cross well seismic based tomography modelling including sonic scanner is valuable in many shale basins to meet company preferences and demands. Different companies' silos are calibrated to provide and corroborate significant products including case studies. The dimensions and their attributes documented in Table 2 are used in the star schemas (data structures) as demonstrated in Figs. 3a and 3b for integrating them in the warehouse schemas.

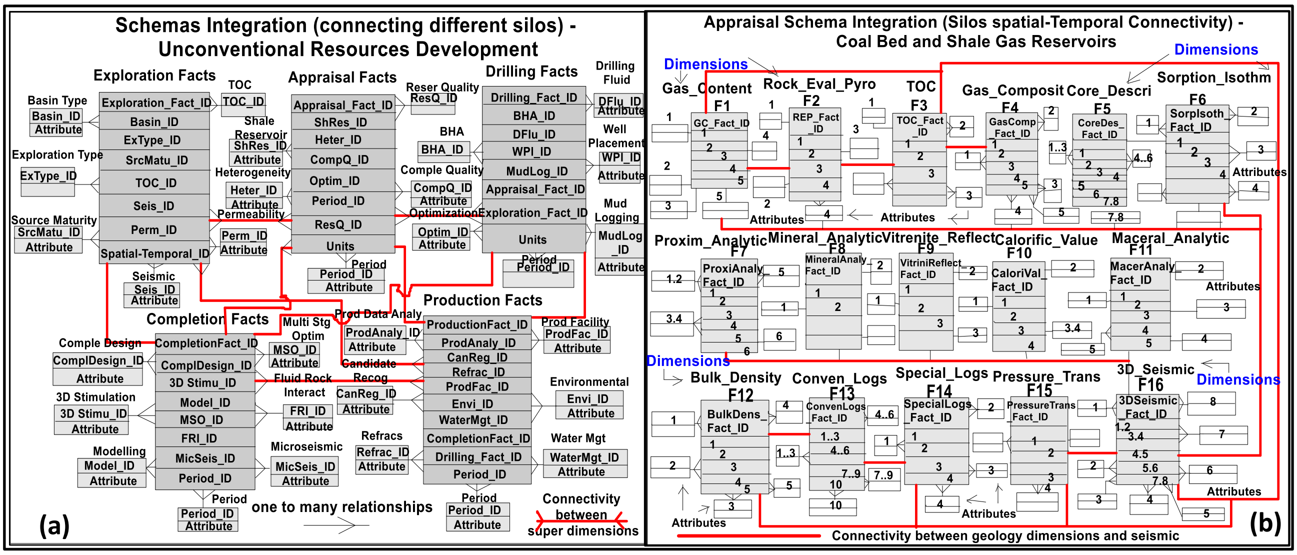

Fig. 3: (a) Data schemas and their integration in the unconventional resources development; (b) Schema integration of appraisal data – coal and shale gas reservoirs focus (Table 2)

Detailed velocity modelling from surface to down depth is proposed for at least one well per field, for accurate depthing and drilling. Geo-steering of horizontal wells needs LWD, rather than MWD in which case, it is expensive and boreholes have to be larger. The products, we develop and deliver are simple and easy to use so that drillers can avail the services with comfort. The seismic facies through SeisClass, from which identifying the heterogeneity around wells into inter-well areas is a new opportunity. Coal bed methane in Australia, tight gas in Kuwait show how seismic can indicate good results, defining the fractures and their individual porosity descriptions. Vp, Vs and PR as indicators of stress fields, fracture orientation, lithologies, pore fluids can be derived by pre-stack seismic inversion. But we need to upscale log data to seismic resolution scale, otherwise we can achieve only 4 percent correlation.

Integrate workflow and DB silo strategies: As demonstrated in Fig. 3, an integrated workflow may uniquely be designed, developed and implemented with shale gas perspective. The workflows must be made flexible enough to sustain the geological and economic conditions. Workflows, for example, may be learnt from the existing case studies and analysed for the best for current research.

Integrated workflow should represent the overall exploration & development data integration strategy with rigor of seismic integration. The integrated workflows and their designs are ensured cost effective, attracting worldwide shale gas business contexts. We adjudge the high level to low level workflows. Every project needs different attributes – PR, Ants, or stress direction analysis. We take well data to analyze rock properties, figuring out project objectives – shale gas, tight sand including fractured carbonates. Superior data acquisition designs are made sure to meet the project objectives partly though the processing or reprocessing of the seismic data can achieve the shale gas objectives. Multi-client services with special seismic surveys meet the shale gas objectives. We have new opportunities of using workflows for reanalysing the competitors' data. Many producing and service companies deploy technologies in their joint ventures, such as EOG, Apache, CNOC, Reliance, Statoil, Saudi Aramco including ONGC in India, Santos Energy in Australia and Ecopetrol in Colombia. We focus on integrating their DB silos, which are geographically spread. In another example, the Schlumberger Company has numerous geomarkets and their DB silos and workflows can be integrated for the shale gas exploration and development. Quicklook Petroleum Systems' Modelling (PSQL) that typically include PetroMod, MicroSeis Viewers is used to do basin modelling to leverage models for the life of the shale gas asset. For mature shale basins, the pitch may be with petroleum systems' analysis in which we can standardize the products and services that may have many uncertainties. Consider showing a model and backing out the information to show the need for different types of information and to define what effects different uncertainties can have. Show how the uncertainties affect the economics and what company products can reduce the uncertainties. Basin modelling can predict pore pressure that can corroborate with seismic velocities and sonic scanner that can add finer details. For predicting stress regimes, Visage and PetroMod may reduce time and costs. We provide couple of motivating case studies as demonstrated in Figs. 4a and 4b, where fracture networks have successfully been interpreted using the multidimensional data modelling and warehouse repository technologies.

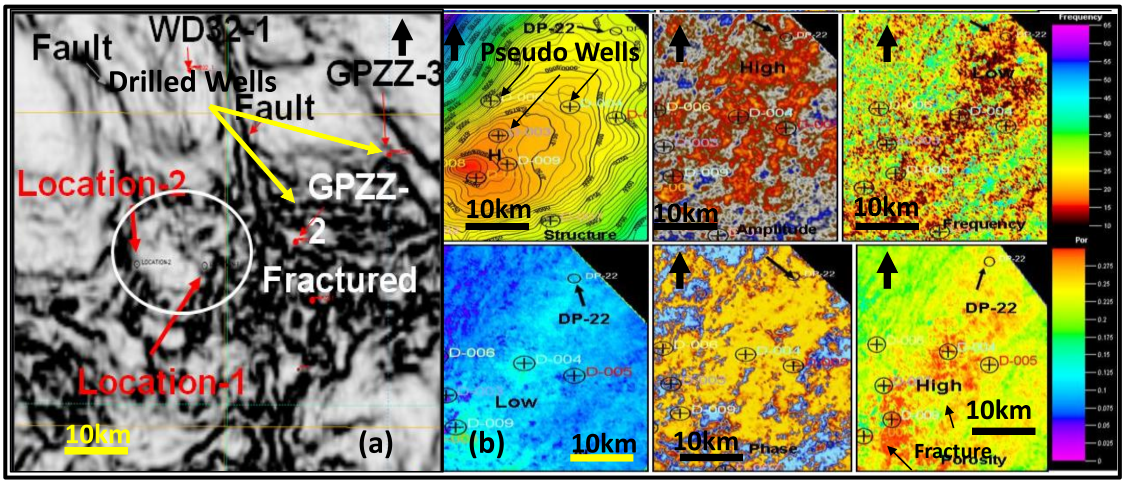

Fig. 4a: Fractures interpreted on seismic attributes (calibrated with drilled locations)

As shown in Figs. 4a and 4b, the drilled wells fall on structural highs, but the recent proposed pseudo wells are interpreted on the flanks of the structures where the fractures are dense within fault compartments. Seismic integration offers good value in these case studies.

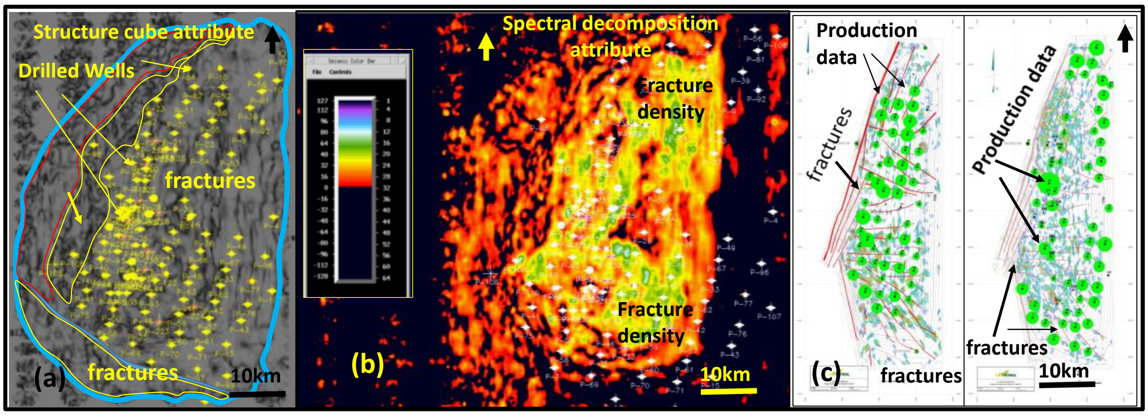

Fig. 4b: Seismically derived fracture signatures in panels (a) and (b) with production data on panel (c)

Drillers often evaluate for lowest cost per foot of frack, though some communities do not consider the heterogeneity of shales and do not want to take risk of missing any zones and resort to factory drill and frack. In such contexts, we should reach high level of decision making to make pitch for the value of seismic and its integration with shale exploration inputs. The costs of running LWD are more and hole sizes can be designed identifying key minimum measurements, for example for sonic, shear and density. Grid blocks in PetroMod are typically in the order of 0.5x3x3km for mechanical properties and for drillers, it may be too large. We need finer details for planning safe drilling in required mud weight windows, which open up another new opportunity of integrated seismic in unconventional shale gas development. As described in Nimmagadda and Dreher (2011), the metadata is created for data mining and visualization (through slicing and dicing) as shown the slices in Figs. 4a and 4b. Several fractures and their networks are interpreted from seismic attributes, such as acoustic impedance, spectral decomposition, structure cube and variance. Fracture porosities are computed providing fracture alignments and orientations as shown in Figs. 4a and Fig 4b. As described in Fig. 4b (c), the bubble plot of production data suggests that production has no structural bearing, instead it depends on the fracture densities and their orientations.

Other seismic studies: Innovative seismic acquisition techniques such as Q are unique. Consider using fracking for source, or ambient noise, or interferometry. Interpretative workstations can be linked with Oracle database; plugins may be used to access stimulation data, hydraulic fracture geometries, and drilling and subsequent production data. Case studies, lessons' learnt and shale gas expert opinions may be incorporated in the databases and data modelling. Present the integrated solutions and case studies with lessons learnt consistently to producing and multinational service companies. The project outcomes, reports of log analysis, seismic analysis, wellbore planning, drilling strategies and completion methods are effective in marketing the successful shale gas stories worldwide.

Development of new technologies proves beneficial: The natural vs. hydraulic fractures, how the seismic integration can detect the difference between these fracture signatures. The natural fractures are often critical to production, but they are not necessarily opened. The pressure tests, production performance and history matching can provide evidence of open natural fractures. This information if combined with seismic data can minimize the ambiguity of fracture interpretation. When natural fractures are 90 degrees to maximum stress, micro-seismic shows very complex results. 30 degrees is needed to a minimum horizontal stress to be able to open with frack job. Seismic data can assess min/max stress orientations.

SUMMARY & CONCLUSIONS

Different workflows are described for exploration and development of shale gas reservoirs along with stratigraphic characterization, identification of fracture systems on 2D/3D seismic datasets. More emphasis is put on exploration data (seismic and well log) quality through data conditioning, which is the biggest challenge and critical in identifying and extracting new knowledge on fractures. History matching and porosity prediction analysis are narrated from both surface and volume attributes, with special focus on impedance and ant-track attributes. Workflows can make good demonstration and case study of IS for Shale Gas exploration and development. Data conditioning has increased the signal-to-noise ratio, enhanced interpretability of thin events, and the likelihood of successful well landings in thin formations. The structural and stratigraphic methods analyse the seismic expression of structural and stratigraphic features, enabling a better interpretation of shale plays. The fracture analysis provide fracture presence, enabling the generation of a probability map of prospective sweet spots. Excellent case studies have been described on fracture detection, representing appropriate use of seismic, other multiple datasets and their integration. Seismic frequency attributes, including dominant frequency variations/anomalies, analysis of log data with core-descriptions and cross plots with bulk densities and their corresponding porosity attributes have been interpreted, integrating with special attributes derived from acoustic impedance volumes. Based on specific geophysical criteria, workflows designed, are good demonstration of exploration of shale gas plays including shale gas volume accumulations. Fracture maps corroborate with production histories in many study areas, though they do not agree with structural high areas. Integration of frequency attenuation and fracture maps provide good production correlations. Frequency spectra and frequency attenuation anomalies provide good clues of better porosity development areas. Variance and ant-track volumes included in the workflows provide good added value to the integrated interpretation, especially the detection of open fracture systems. In summary, a typical workflow includes wavelet analysis, well to seismic ties, horizon interpretation, frequency spectra analysis, variance & Chaos volume analysis, ant-track volume attributes, isochrons, seismic attribute integrating with azimuthally varying velocity anomalies and AVO attribute analysis. Tight shale gas mapping, using integrated seismic and well log attribute inputs, is another demonstration of successful workflow for mapping heterogeneous reservoirs associated with shale gas prospects. Source rock heterogeneities, core descriptions are described that corroborate with integrated seismic inputs, besides, depositional facies and diagenesis descriptions. Rigor is on pore pressure, rock fluid properties and the transitional well log attributes that are in good guidance for better well completions. Data integration is more comprehensive and it is more than the scope of seismic integration. Any workflow, designed must be part of broader workflow of integrated shale gas exploration and development that can address any field and basin.

An effective data storage and mining methods are presented, which are often stumbling block in the E & P management; different workflows presented along with case studies of fractured reservoirs exploration done in Australia, India, Middle East, North Africa, Colombia and Venezuela are lessons learnt. Volume attributes demonstrating fractured reservoirs, represented in spectral decomposition, variance and ant-track volumes, help investigating fractured structures and reservoirs more rigorously. Anisotropy attributes, such as Young's modulus and Poisson's ratio from seismic data are analyzed, characterizing dense fractured reservoirs and their orientations. Acoustic Impedance volumes, including Poisson's ratios along with density data, can obviously provide not only good reservoir distribution (space domain), but reservoir qualities as well. Young's modulus integrated with Poisson's ratio values, can better describe the frackability that can lead to better well completion qualities. Investigation of reservoir qualities in space domain, so called sweet spot areas, can better be addressed by good quality 2D/3D seismic data acquisition and processing efforts, which are prerequisites for imaging unconventional shale gas reservoirs. Poisson's ratios, Young's modulus and acoustic impedance attributes can together narrate anisotropy associated with shale gas reservoir characterization. Appropriate seismic acquisition designs in the field are paramount for any anisotropy studies with subsequent processing efforts for imaging the shale gas reservoir characterization. All the ideas, relevant to anisotropy, must be included with the integrated workflows that intended for exploration and development of shale gas reservoirs. AVO attributes definitely add value to the fractured reservoir interpretation. Mangrove wire-mesh technique shows improved micro-seismic analysis. Geochemistry of shale reservoirs is complex and unless its complexity is well understood and investigated, it is futile to establish the validity of any workflow and an integrated shale gas model.

More robust, integrated and flexible workflows are needed to design, develop and implement the innovative data models in a broader scale of shale-gas tectonics and basin model. Case studies are used along with *lessons-learned* in terms of, which tool and technique can better address the best geological issue. Integrated solutions, once made more consistent and flexible, may be used to educate the explorers, who are actively involved in shale gas business around the world. Often models are ambiguous, because of variety of geological and even economic situations. Besides, data quality is critical issue that dictates model quality and reservoir. It is important to acquire good quality data for shale-gas, in particular addressing the anisotropy properties, pinpointing fracture densities and their orientations. Reservoir and well-completion qualities are key criteria, based on which technologies and innovative integrated workflows are designed. Integrated seismic solutions facilitate investigations of open fracture systems, feasibility of hydraulic frack and even the horizontal drilling. Integration of different domains' datasets is very significant for successful the shale gas exploration project.

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