“Pre-Stack Pro Foundation Project IV”
Consortium Agreement
DRAFT

Hereinafter referred to as “Agreement”.

This Agreement is made and entered into as of the xx of September 2016 by and between

Oil Company XXX

Street Address
Postcode, City
COUNTRY

– hereinafter referred to as »**Industry Partner**« –

and

Sharp Reflections GmbH

BIC KL, Trippstadter Straße 110
67663 Kaiserslautern
GERMANY

– hereinafter referred to as »**SR**« –

In partnership with

Institut fuer Techno- und Wirtschaftsmathematik (Fraunhofer ITWM)
Fraunhofer-Platz , 67663 Kaiserslautern
Germany

– hereinafter referred to as »FhG/Fhl« –

Collectively the entities above may be referred to as “parties”.

Preamble

Enhancements to the Pre-Stack PRO software package are currently under development at Sharp Reflections GmbH, in close collaboration with our research partner Fraunhofer ITWM.

The objective of this consortium is to accelerate the development of Pre-Stack PRO and enhance its capabilities, according to the needs and wishes of the consortium partners.

The Project will be based on cooperation between SR, FhG/FhI, and the Industry Partners, and on a financial contribution by each Industry Partner according to the conditions set forth in this Agreement.

By signing this Agreement, Industry Partner is entitled to participate in the Project and agrees to be bound by all contractual provisions towards SR, as stated in this Agreement.

1 Subject of the Agreement

The subject of the Agreement is the performance of the Pre-Stack PRO Foundation Project IV (hereinafter referred to as FPIV) according to a mutually agreed work program, which specifies a development plan and a delivery schedule. The proposed work program is described in Annex I, and will be refined in discussion with input from actual consortium sponsors.

FP IV shall be initiated in October 2016, and will run until December 31st, 2018.

Subject to success in FPIV, the consortium intends to continue this Project with future Foundation Projects in subsequent years. The duration of future project phases will be two years.

2 Definitions

- Agreement: means this document and the adherent Annex 1 (work package description)
- Confidential Information: shall mean with respect to each Party:

a) any and all Intellectual Property Rights, know-how, information, materials, samples, reports and technical records, data, ideas, product specifications, trade secrets and financial and other business information; and

b) any and all reports, recommendations either preparatory and/or as a results of the Agreement (whether or not technical) communicated between an Industry Partner and SR

- Industry Partner: means the company stated on the first page of this Agreement. Also referred to as sponsors in this Agreement.
- "Background IP": means all Proprietary Information and the IP in it, which either existed or was owned by a party prior to the date of this Agreement or which comes into existence during the term of this Agreement other than as a result of the performance of this Agreement. Each party shall retain all right, title and interest it its background IP.
- "Foreground IP": means any IP that arises or is developed by or on behalf of either party in the course of the project. Foreground IP shall be the property of SR. To the extent that SR subcontracts performance of the project it will ensure that any foreground IP arising from the work of the sub-contractor will be assigned absolutely to it.
- Project: means Pre-Stack Pro Foundation Project IV.
- Proprietary Information: means for the purposes of this Agreement, certain proprietary or confidential business and/or technical information including, but not limited to, technical, financial, commercial, marketing or other business information that the disclosing party desires to protect against unrestricted disclosure or competitive use.
- PSPro-QI means a new standalone software version of Pre-Stack Pro, which includes all functionality currently included in the PsPro-A software module, plus new features to be developed in FPIV.
- Third Party: means any person or entity who is not a party, an affiliate thereof or a co-venturer, or a director, officer, employee (including agency personnel), agent or consultant of a party or any such affiliate or co-Venturer to this Agreement.

3 Participation and Financial Contribution of the Industry Partner

3.1 Each Industry Partner is entitled to join the sponsor group at any stage, subject to payment of the participation fee (see article 3.2). Year one participants may terminate their participation at the end of the first project year for any reason, by notifying SR in writing 30th June 2017.

3.2 The financial contribution of each Industry Partner amounts to:

EUR 50.000,00 (VAT added, if applicable) per year.
(in words: fifty thousand Euros)

The Industry Partner shall make payments upon receipt of an invoice submitted by SR according to the following schedule:

Payments:
- EUR 50 000,- due upon joining[1], or no later than January 15, 2017
- EUR 50,000 by 31 August, 2017.

[1]Industry Partners are granted two (2) licenses to the software PsPro-QI by making payments as stated above. Licenses will be issued after receipt of first payment.

SR shall submit an initial invoice to the Industry Partner for the payment of the first year annual fee within thirty (30) days after this Agreement becomes effective. For the subsequent year, SR shall provide the Industry Partner with an invoice on or before July 30th, 2017.

Invoices will be due and payable thirty (30) days after the Industry Partner's receipt thereof.

3.3 The price is a fixed price and can only be modified by a written agreement between Industry Partner/s and SR.

3.4 The financial contribution of an Industry Partner does not depend on the number of members of the consortium.

4 Consortium Structure and Benefits to Members

4.1 Steering Committee:

The Steering Committee shall oversee the conduct of the project, and shall include a representative from each Industry Partner, as well as one or more SR and FhG/FhI representatives. The steering committee will meet at least twice per calendar year so that project progress can be monitored. Wherever possible, these meetings will be held in conjunction with Consortium Meetings (4.2). Additional meetings may be held by video conference, at the request of steering committee members. The steering committee will meet at the end of year one to consider and approve the project milestones for year two.

4.2 Consortium meeting:

SR will organize two day-long consortium meetings each year. These consortium meetings will review progress, preview new software features, and provide a forum for knowledge sharing among sponsors.

At one of the two annual consortium meetings, SR will organize a technology transfer workshop for participants. The goal of the technology transfer workshop is to introduce new software capabilities, demonstrate their effective use with actual data examples, and show how they can be combined in a comprehensive analytical workflow.

4.3 Member Benefits

The primary benefit for Industry Partners is acceleration of the development of Pre-Stack PRO according to a plan agreed with SR and approved by the steering committee. Sponsors of Foundation Project IV will also be granted:

- Exclusive participation in the Pre-Stack Pro beta testing program (which provides early access to pre-release software versions).
- Two days per year free coaching (WebEX or in-house) from a Sharp Reflections consultant, to facilitate technology transfer.

All new FP-IV developments will be made available in a PSPro-QI software module, which can be run and licensed independently, or in combination with the existing Processing Toolkit.

- **Sponsors will receive:**

- **Two "seat licenses" for the PsPro-QI software package,** which will include a base license that runs on a single workstation or server. The yearly maintenance fee for each seat license will be set at 8,000 EUR (20% of provisional list price of 40,000 EUR), and is payable from January 2017, or from the date that the license is issued (if this occurs after January 01, 2017).

4.4 Test Datasets

Participants are invited (but not required) to submit a dataset for field testing or use in technology transfer workshops (confidentiality of any such datasets will be maintained by SR and FhG/FhI).
If datasets are submitted to SR for field testing in relation to this Agreement, SR are obligated to sign a confidentiality agreement from Industry Partner.
Datasets will be used to develop and test new modules and verify that they work as required on "real-life" examples. Industry Partners who submit test datasets will receive a "case study" presentation which documents application of specific software modules.

4.5 Reports

In addition to the benefits listed in article 4.3 (and the actual software releases), Industry Partners will receive will receive copies of all presentation material from each consortium meeting, and a short Executive Summary after each meeting that summarizes the milestones achieved in the period. In addition, SR will deliver detailed documentation with each software release, in the form of:

1. New features tutorials that document essential features of any new software modules
2. "Usage Case" examples illustrating the application of new modules to real data
3. Progress reports on modules, features, or research efforts that are in progress, but not complete at the time of reporting.

5 Confidentiality

5.1 Each party shall keep confidential from third parties all information obtained in the course of (or as a result of) this project, except information which the parties have expressly agreed to release. Each party shall ensure that its employees, sub-contractors, co-venturers and customers do not disclose confidential information for any purpose other than the purposes contemplated by this Agreement.

5.2 Each party undertakes that confidential information shall only be made available to such employees, co-venturers, customers and subcontractors as need to know the same for the purposes contemplated in this Agreement. Such employees are bound by their employment agreements, and co-venturers, customers and subcontractors are bound by confidentiality obligations not to use or disclose the confidential information transmitted to them by each party.

5.3 Each party undertakes to take all reasonable precautions within its legal powers in order to prevent the disclosure or use of confidential information and the access of unauthorised persons to the confidential information.

5.4 The confidentiality obligation does not apply to data or information

- that is already known by the receiving party otherwise than by virtue of communication under this Consortium Agreement
- that is or becomes publicly known through no fault of the receiving party, or
- that is disclosed to the receiving party by a third party entitled to disclose it as shown by relevant evidence.

5.5 The obligations in this section of the Agreement shall continue to be effective for a period of 2 years following the termination of this Agreement.

6 Background and Foreground Intellectual Property

6.1 Industry Partner hereby grants to SR a non-exclusive, royalty-free, worldwide right and license to use Background IP of the Industry partner to the extent the same is required in the reasonable opinion of

the partner, for delivery of the Scope of Project. SR will be permitted to transfer the same to FhG/FhI for the sole purpose of this Agreement.

6.2 For the avoidance of doubt, nothing in this Agreement shall be construed as granting SR or FhG/FhI rights, title or license in any Background IP other than that defined in 6.1. Furthermore, it should not be construed as a license to use the trademarks or trade names (whether registered or not) of a project partner or its affiliates, and any goodwill, reputation or common law rights associated therewith, in relation to any products or services offered by SR, FhG/FhI, or their affiliates, without the express written consent of the Industry Partner.

6.3 SR warrants that all works and materials developed, written or prepared in anticipation of or in the course of performing the Project shall:

(a) be original works of authorship to the extent that they do not originate from the Industry Partner or FhG/FhI; and

(b) not infringe the Intellectual Property, proprietary or contractual rights of any Third Party.

SR shall be solely responsible for ensuring that any materials provided by it for use by the Industry Partner pursuant to this Agreement satisfy this requirement.

7 Third Party Intellectual Property Rights

SR shall immediately notify the Industry Partners of any third party intellectual property rights of which it becomes aware during the Project performance and which could infringe upon the agreed use according to this Project Agreement. SR and the Industry Partners shall decide unanimously on how such intellectual property rights shall be taken into consideration in the further Project performance. SR is not liable for any infringement of third party intellectual property rights by use of the Pre-Stack PRO software by the Industry Partners and partners shall not be liable for any possible infringements caused by SR's or FhG/FhI's use of Pre-Stack PRO.

8 Liability and Termination and Withdrawal

8.1 Industry partner uses the Pre-Stack PRO Software exclusively at its own risk and thus there is no warranty obligation of SR of any kind except for cases based on intentional acts. For the avoidance of doubt SR is under no warranty obligation including, but not limited to, implied warranties of merchantability, fitness for a particular purpose or non-infringement of third-party intellectual property rights.

8.2 This Agreement commits the Industry partner to participate for the current Foundation IV project only. The Industry Partner has the right to terminate the project in the case of any alleged material defects. Any further claims for reason of material defects are excluded.

8.3 Notwithstanding Art. 8.1 and 8.2 above, the liability of **SR**, its legal representatives and agents in the case of breach of obligations and tort shall - as far as legally possible with regard to mandatory law - be limited to damages caused intentionally or by gross negligence and to direct damages.

8.4 The Industry Partner has the right to terminate the Agreement at any time during the project with 6 months notice. In case of a termination, payments done in advance of the termination will not be refunded from SR.

8.5 Withdrawal: In case SR cannot meet the milestones specified in the year one work program, and the agreed delivery in the first project year is delayed by more than 6 months, Industry Partners have the option to withdraw from the Project and also be reimbursed of their payments for the second project year. In effect, the Agreement terminates if the Industry Partner withdraws.

9 Statutes of Limitation

The claims of the Industry Partner for violation of obligations and tort shall be statute-barred within 12 months. This shall not apply where legislation prescribes longer periods of time or where SR is liable due to intent or gross negligence or due to injury to life, body or health.

10 Publication, Advertising

Results obtained from the Project exclusive of the delivered software PSPro-QI are and shall remain the property of participating Industry Partners. SR and FhG/FhI shall be entitled to publish results obtained using the newly-developed software tools, without restriction. SR is permitted to list the participants of FP-IV by displaying their company logos on its website or at industry trade shows. Any other advertising material that contains the name of any Industry Partner must be approved by such Industry Partner/s. SR will seek such approval by sending an e-mail request to the relevant Steering Committee member(s) of each Industry Partner.

11 Health, Security and Ethics

11.1 General Management: SR shall plan and run the Project in a manner that ensures that the Project can be performed without loss of life or harm to health, without damage to plant and/or equipment, without unplanned emissions or discharges to the environment, and in such a way that production or processes are not unexpectedly halted.

11.2 Security: SR shall at all times have implemented security measures which protect the members of the Project consortium against relevant threats of harm related to the Project and members' operations and property. Such threats can include, but are not limited to:

- loss, theft or misuse of the Project and a member's property, including information and equipment,
- sabotage, damage or vandalism against the Project and a member's property,
- other actions or omissions by SR and FhG/FhI personnel (or third parties employed by either) which are performed with intent to harm a member's personnel, activities or reputation.

11.3 Ethics, anti-corruption, human rights etc.. SR shall have guidelines for ethics and conflicts of interest in its own business. These guidelines must reflect a clear commitment on the part of management, and describe routines and requirements relating to relevant ethical issues.

12 Force Majeure

No failure or omission by either party to Agreement to carry out or observe any of the stipulations, conditions or obligations to be performed hereunder shall, except as herein expressly agreed to the contrary, give rise to any claim against such party or be deemed to be a breach of the Agreement, if any such failure or omission arises from a cause reasonably beyond the control of the party affected, provided that such party could not reasonably have foreseen such occurrence at the time of entering into the Agreement and could not reasonably have avoided or overcome it or its consequences.

13 Miscellaneous

13.1 Ancillary understandings, amendments and supplements hereto must be made in writing.

13.2 Place of performance for SR shall be Kaiserslautern, Germany. Place of performance for payments by Industry Partner shall be the invoice address.

13.3 The Laws of the Federal Republic of Germany, under exclusion of the United Nations Convention on the International Sale of Goods (CISG) and the German International Private Law regulations, shall apply.

13.4 For all controversies arising out of this Project Agreement, the District Court Munich shall have jurisdiction.

13.5 Should one or more provisions of this Agreement or the appendices hereto be or become fully or partially invalidated by operation of the law or otherwise, the provision or part will to that extent be deemed omitted and the remainder of the Agreement and any appendices thereto will remain in full force and effect. Should this case arise the parties agree that such invalidated provision or part thereof shall be replaced by a mutually agreed and legally valid provision which is a close as possible in commercial effect to the invalidated provision or part thereof.

13.6 This Agreement may not be amended unless specifically expressed in writing to be so amended and signed by the duly authorised representatives of all parties to this Agreement.

13.7 The provisions of clause 6, 7 and this clause 13 subsections (13.4) and (13.7) shall survive termination of this Agreement and remain in full effect between the Parties.

In consideration of the foregoing terms and conditions, Industry Partner and SR have executed this Agreement in duplicate, originals of which shall be of equal dignity.

Industry Partner

Company:

By:_____

Print Name: _____

Date: _____

Location:_____

Sharp Reflections GmbH

…… .

By:_____ _____

Print Name: Dr. William T. Shea

Title: ___CEO_____

Date: _____

Location: Stavanger, Norway.

Program Description

BACKGROUND FOR FOUNDATION PROJECT IV

Pre-stack seismic provides richer and more detailed information than the derived stacks, but presents a big data challenge. Typical datasets range from 1-10 terrabytes in size, and traditional software architectures and infrastructures are inadequate to deal with them. Pre-Stack Pro is the byproduct of 8 years of dedicated R&D to develop a modern, highly-interactive software platform built for "Big Data" and offering real-time processing and quantitative interpretation of 3D pre-stack gathers.

The Pre-Stack Pro Foundation Project was initiated as a long-term R&D consortium to accelerate development of leading-edge geophysical tools for this new software architecture in a cost-effective way. Development costs have been shared among partners, and results to date have delivered a very high return on each company's individual investment. Foundation Projects 1-3 established the processing and interpretation cornerstones of today's software, and were all delivered on time and on schedule.

Sharp Reflections proposes to continue the successful R&D collaboration with its industry partners with a new consortium, Foundation Project IV. The proposed technical program will strengthen the tools for quantitative seismic interpretation, with four work packages designed to better calibrate seismic to well information and improve prediction of reservoir rock distribution using pre-stack data.

RESEARCH OBJECTIVES

New approaches to horizon interpretation, seismic-well tie, and seismically-derived volumetric estimation will be developed during the Foundation IV Project. In addition, well-established algorithms for seismic spectral decomposition will be adapted to exploit Pre-Stack Pro's unique 5-D seismic data model to allow for one-click computation of frequency spectra for multiple partial stack volumes, to allow for easy investigation of AVO- related effects.

Pre-Stack Well Tie. We will develop a new seismic-to-well tie solution for pre-stack data, to complement Pre-Stack Pro's strong gather modeling toolkit. Vp, Vs, and density logs will be used to generate synthetic gathers that can be tied to real data at wells, to simplify calibration of AVO data. Implementation will require tools for check-shot calibration, wavelet estimation, and statistical comparison of real to synthetic gathers, as well as options to tie all wells with individual wavelets or a single common wavelet. We will also develop new routines to assess goodness-of-fit between real and synthetic AVO curves on individual reflections, to improve assessment of amplitude integrity.

Manual Horizon Picking/Manual Gridding. Pre-Stack Pro now offers an accurate, interactive 3D horizon auto-tracker, which works extremely well on strong amplitude events. However, detailed quantitative interpretation workflows often require targeted infill interpretation of weaker reflections in intervals with low signal-to-noise (e.g. top or base of brine-filled sands). We will develop a new 2D viewer interface specifically for horizon interpretation, which includes interactive noise filtering tools which can be applied to improve manual tracking. In addition, new picks will be interactively gridded and flexed to the data to generate an accurate surface with minimal manual work.

Pre-Stack Spectral Decomposition. Wavelet based Spectral Decomposition is effective at isolating seismic responses in different frequency bands whilst providing good levels of spatial resolution. Combined with RGB blending it can significantly enhance the visibility of features in seismic. We will develop an interactive solution in Pre-Stack Pro, which precomputes "frequency gathers" for all seismic traces in one or more volumes, to allow "on-the-fly" blending of frequency bands. New color blending options will be developed for rapid exploration of data along and between horizons. Finally, spectral analysis tools will be added to the 3D Parametric Modeler and synthetic modeler to improve understanding of color-blended images.

Seismic Volumetrics. Pre-Stack Pro contains now contains most of the baseline tools and seismic attributes that are required to investigate tuning, estimate seismic net pay, and discriminate fluid and lithology effects using AVO cross-plots. We will develop tools to calibrate seismic to well properties, derive multi-variate statistics for seismic property

prediction, and integrate properties between horizons to give net property maps with associated uncertainties. This development will allow routine calculation of volumetric maps that can be used to refine prospect size estimation and plan new wells.

NEW SOFTWARE MODULE – PSPRO-QI

All developments for Foundation Project IV will be offered in a new standalone software module PsPro-QI, which will replace the optional Amplitude Analysis Toolkit (PsPro-A, which currently requires the core processing license). PsPro-QI will include all existing features of PsPro-A, as well as all new modules developed in Foundation Project IV.

DELIVERY DATES AND KEY MILESTONES

Project Plan

A kickoff workshop will be held in late September 2016, at the annual Sharp Reflections User Meeting in Kassel, Germany. Detailed plans for of content, milestones and project scheduling will be finalized with 14 days of the initial kickoff meeting, in order to best match the needs and priorities of the actual participants.

Deliveries

The project will be divided into four periods of 6 month duration. One software release is planned for each of the four periods, beginning with Pre-Stack Pro 5.0.

Semi-Annual Deliveries

In addition to the software deliveries, SR will conduct two semi-annual meetings per year that highlight the R&D results achieved during each of the four project periods. Sponsors will receive copies of all presentation material, and a short Executive Summary after each meeting that summarizes the milestones achieved in the period.

ANNEX 1. DEVELOPMENT PROGRAM, 2016-2018

WP 1- Pre-Stack Well Tie

Purpose/Objectives

Well-seismic ties allow well data, measured in units of depth, to be compared to seismic data, measured in units of time or "imaged" depth, which may be different from true vertical depth. Accurate well ties are required for quantitative seismic interpretation, particular when wavelet estimates are needed for seismic inversion. Where Vp, Vs, and density logs are available, it's possible to develop a well tie module based on comparison of real and synthetic pre-stack gathers.

Well tie functionality will make it possible to reliably quantify the goodness-of-fit between real and synthetic seismic data. The tools may be used throughout the data conditioning process to validate both phase and AVA behavior. Furthermore, direct implementation of well tie tools in Pre-Stack Pro will allow users to quickly and efficiently determine whether and how much well ties improve after specific gather conditioning filters are applied.

Proposed Workflow

The workflow described here is typical, but there are many variations. The well-tie module will be flexible enough to accommodate these.

1. Load and QC check-shots. If there is no check-shot at a well, use the matching of tops and seismic horizons as a crude first pass.
2. Extract seismic data parallel to well (for deviated wells).
3. Apply check-shot correction, create zero phase synthetics using statistical wavelet, edit check-shots as necessary.
4. Extract first wavelet(s).
    a. Optionally, update time-depth curve by bulk shifting, stretch and squeeze, or further check-shot editing.
5. Scan for best match around well location.
6. Iterate with updated time-depth curve, update wavelets, best match location.

Planned Functionality

- Interactive check-shot editing with sonic log calibration.
- Interactive stretch and squeeze to tie unambiguous events.
- Extracting pre-stack and post-stack seismic data parallel to well paths.
- Creating pre-stack or post-stack synthetics with geometry matching the seismic data
- Wavelet extraction: statistical wavelet from seismic data, optimal zero-phase wavelet, optimal constant phase rotation, Roy White method. Particular care will be taken with low frequencies for broadband data. Options for one wavelet per angle or a single wavelet for all angles. Options to optimise the wavelet at a single well, or across a number of wells.
- Pre-stack spatial scanning for best match location.
- QC tools including pre-stack cross-correlations, plots of spectra, seismic residuals, optionally inversion at the well location.
- Cross-validation methods at single wells and between wells will be investigated as a means of estimating phase and for wavelet QC.

WP 2- Data-Adaptive Horizon Picking and Surface Gridding

Purpose/Objectives

Pre-Stack Pro currently contains an accurate, highly interactive auto-tracker for 3D horizon interpretation on stack or gather data. This tool can generate high-resolution surfaces for strong, consistent events from very few seed points. However, where reflections are weak or masked by noise, many more seed points are normally required to guide the tracker, and interpretation efficiency drops. We propose to improve the horizon picking capability in Pre-Stack Pro by implementing good manual picking solutions, to generate interpretation from a composite of auto-tracked areas and manually digitized areas, as dictated by data quality and signal strength.

Manual horizon picking is commonly a baseline tool in traditional seismic interpretation packages, and technology has not advanced dramatically in the past decade. We propose to improve manual picking efficiency in two important ways, by developing:

- new "data adaptive" picking algorithm that follows a bandwidth-filtered version of the seismic suitable for defining gross structural trends, but not all details.
- New data adaptive gridding algorithm that automatically adjusts to the same bandwidth-filtered data between picks, so interpreters can easily determine where greater pick density is needed.

Proposed Workflow

1. Digitize coarse inline/crossline grid of manual points, and automatically decimate to generate an initial set of tracking seeds.
2. Auto-track and QC to narrow the areas that require manual infill
3. Generate initial surface grid to fill all tracking gaps … to guide infill strategy
4. Add manual picks
    a. Digitize individual picks on one line direction (inline or crossline), with adaptive pick refinement to bandpass filtered version of the data.
    b. Automatically grow picks on orthogonal lines, overriding and re-picking as needed to ensure accuracy
5. Repeat as needed, updating the surface grid as new picks are needed
6. Include imported fault surfaces in final grid, by deleting all picks in near vicinity of faults and projecting the gridded horizon back to the fault surface to generate clean "fault gaps"

Planned Functionality

- New 2D viewer for horizon picking with linked and synchronized inline and crossline views and map view to display picked horizon.
- Manual horizon picking controls with options for data adaptive fitting of digitized points to "live filtered" version of the seismic
- Metadata solution to record and store pick origin as a parameter for all CDP locations (seed point, auto-tracked, manual, gridded) for each horizon
- Data-adaptive gridding algorithm that updates as picks are added
- Method to create faulted horizon grids using imported fault surfaces or gridded fault "sticks"

WP 3- Pre-Stack Spectral Decomposition

Purpose/Objectives

Spectral decomposition (SD) allows interpreters to utilize the discrete components of the seismic bandwidth to image and understand subtle details of the subsurface stratigraphy. Since the stratigraphy resonates at wavelengths dependent on the bedding thickness, the interpreter can image subtle thickness variations and discontinuities, and utilize the frequency variations to estimate reservoir bed thickness. SD techniques may also contribute to direct hydrocarbon detection, as fluid fill influences often changes the spectral signature observed on frequency gathers.
We propose to implement a high-quality spectral decomposition solution in Pre-Stack Pro, which exploits the already existing 4D (pre-stack) and 5D (full-azimuth pre-stack) seismic data structures in the software. SD will improve the QI workflow by offering new tools to defining reservoir depositional geometries, and aid in the delineation of top/base reservoir events. 4D Time-frequency gathers will be generated for any stack, and a full 5D frequency gather dataset can be quickly calculated from gathers or multiple partial stacks. Once precomputed, these frequency gathers can be manipulated in new ways to enhance reservoir understanding.

Proposed Workflow

1) Apply spectral decomposition (SD) to stacks or pre-stack gathers to create time-frequency (amp/phase) gathers
2) Use Data comparator to display seismic traces, single frequency gather, frequency gathers at specific X/angle traces and AVA/spectra plots and tri-band (rgb) response at any TWT location on the gather.
3) Use frequency blend widget to interactively adjust low-med-high frequency ranges for volumes or specific horizons – rgb ranges will be updated immediately in map viewer. We also propose to extend Pre-Stack Pro's mute function to operate on frequency gathers, so users can design time-varying RGB blends using mute objects.
4) Create polygons from RGB blends to create map-view " Zones of Interest" for other quantitative work

Planned Functionality

1) Spectral decomposition algorithms to perform the decomposition on and output frequency gathers as 4D or 5D volumes. Frequency gathers will be adapted for use throughout Pre-Stack Pro. Gabor-Morlet wavelet transform is already implemented in the spectral balancing algorithm in Pre-Stack Pro, and other methods will be investigated.
2) New RGB blend display for spectral decomposition results in Map, Slice, and Section viewers. Also make available as a general option for blending other multi-volume properties.
3) Add "frequency gather" output option to 3D Parametric Modeler, to enhance understanding of frequency response for thin beds with different fluid fill.

WP 4- Seismic Volumetrics

Purpose/Objectives

Interpreters can choose from a large number of qualitative and QI methods to predict reservoir volumes from seismic data. Most popular methods rely on some combination of tuning curve analysis (for thin beds), bandwidth limited relative impedance attributes (from AVO seismic), or elastic property cubes derived from pre-stack inversion. Seismic results are typically combined with rock physics, geological and petrophysical data to derive a predictive model. Uncertainty can be estimated from statistical analysis of the seismic and derived attributes.
We propose to develop a set of workflows and calculators for volumetric estimation, to delineate reservoir units, estimate the properties within them, and combine units and properties to estimate volumetrics with associated uncertainties.

Proposed Workflow

1) Delineate Units
    a. "In or near tuning" - Track top and base reflections and create difference horizons, to cross-plot horizon thickness versus seismic property, set background level from the scatter observed, and create calibrated wedge model to estimate thickness
    b. Region-growing or other methods will be investigated to isolate units in complex geological settings where accurate horizon picking is not possible.
2) Find Properties
    a. Single-variable regressions: Calibrate properties to seismic by upscaling log curves and cross-plotting logs with any desired seismic attributes, and performing regression analysis (curve fitting) on the cross-plots. Density functions will also be fit to the cross-plots, normalized, and used as probability density functions.
    b. Multi-dimensional regressions/Principal components analysis, to give more fitting ability by combining attributes to predict reservoir properties. All of these methods naturally incorporate uncertainty analysis for property prediction
3) Estimate thickness from units and properties
    a. Reservoir properties can be integrated over thickness to give net property maps. Uncertainties in properties and thickness will be combined to calculate uncertainties in the final result. Where facies probabilities are available, they may be combined via Bayes' theorem and to calculate marginal and conditional probabilities, which allow the construction of P10s and P90s for properties of interest.

Planned Functionality

1) Add rock physics templates to seismic and log cross-plots, to aid estimation of key rock properties (e.g. porosity, HC saturation, dispersed shale content) form their cross-plot response
2) Tuning analysis tool to assist in deriving quantitative thickness estimates from tuning curve response
3) Unified tool to upscale logs, cross-plot, and fit regression curves (with uncertainty) and pdfs.
4) Methods to apply regression curves to seismic volumes, incorporating uncertainties.
5) Rock Volume Calculator to estimate volumes from defined units, property volumes, and HC contact locations, with associated uncertainties to guide estimation of P10, P50, P90 cases.

ANNEX 2. PSPRO-A FEATURES IN NEW PSPRO-QI INTERPRETATION PACKAGE

	Features in GREEN are included in Base Package		
Algo Name	**Processing Package**	**Interpretation Package**	**Special**
	Attibutes Menu		
Volume Calculator	X	X	
Sectral Attributes	X	X	
AVA Attributes	X	X	
Complex Trace Attributes	X	X	
Moving Window Statistics	X	X	
Normalized RMS	X	X	
Auto/Cross Correlation	X	X	
Structural Dip	X	X	
Dip-steered Semblance	X	X	
Extrema	X	X	
Signal to Noise ratio	X	X	
AA RMS Velocity	X	X	
AA Interval Velocity	X	X	
Geometric Properties	X	X	
AVAZ Attributes	X	X	
Gather Attributes	X	X	
Semblance Multi-Input	X	X	
	Processing Menu		
NMO			
Stack/Mute			
Partial Stacking			
Butterworth Filter	X		
Frequency Filter	X		
User Defined Filter	X		
Spatial Smoothing Filter	X		
Destriping	X		
Median Filter	X		
2D ECED Filter	X		
3D ECED Filter	X		
EPS 3D Filter	X		
Gaining	X		
Q-Model	X		
Q-Filter	X		
Radon	X		

Inverse Radon	X			
Tau-P Deconvolution	X			
Adaptive Substraction	X			
RMO	X			
RMO (Timeshifts)	X			
Semblance Optimization	X			
Align 2	X			
Align_tmp_3	X			
Continuous Velocity Analysis	X			X
Velocity Editor	X			
Phase Rotation	X			
Spectral Balance	X			
Bandwidth Extension	X			
Demigration				X
Remigration				X
Fast Fourier Transformation	X			
Inverse Fast Fourier Transformation	X			
Seismic Time Depth Conversion	X			
	X			
Seismic RMS amplitude calculation	X			
Velocity Conversion				
Resample Z Axis	X			
Bulk Time Shift	X			
Trace Interpolation				
Offset Trace Interpolation				
DIP Filter	X		X	
Spatial Amplitude Balancing				
Create Qb Background				
COCA sectorization				

Interpretation Menu				
Offset to Angle				
Angle to Offset				
PCube Model Builder			X	
PCube Inversion			X	
1D Model Builder	X		X	
Generate synthetic gather	X		X	
3D Parametric Synthetic Model			X	
Shuey-Modeled gathers			X	
Chi Angle Volume				
Trace Integration	X		X	
AVO Scaling	X			
Multi Well Scalar	X			
Scult				
Volume flattening				
Volume unflattening				
Create maps				

- Advanced		X
Cross Plot		X
- Plot facies		X
- Plot well logs		X
Horizon Tool		
- Gridding		
- DeSpike		
- 3D Tracking		X
- 4D/5D Tracking		X
Wavelet Tool	X	X
- CI Inversion	X	X
- EEI Inversion	X	X
- Matching Operator	X	X

Utilities Menu		
Volume Calculator	X	X
Create Subvolume		
Create New Volume		
Create Arbitrary Path Volume		
Load 2D lines from SEGY		
Create Pseudo PreStack		
Merge Volumes		
Combine Volumes		
Calculate Statistics	X	X
BaseFileData to Volume		
Manage Wells		
Manage Well Logs		
Manage Log Sets		
Manage Polygon Selections		
Manage Mutes		
Manage Velocity Function		
Manage Facies		
Manage File Groups		
Header Math		
Trace Header Interpolation		
Coordinate Converter		
Unit Converter		

Viewer Menu		
Spectral Analysis	X	X
Data Comparator		
Trace Viewer		
2D Map Viewer		
2D Gather Viewer		
2D Stack Viewer		

2D Top PreStack Viewer
2D Top Stack Viewer
Well Log Viewer
View/Compare Probabilities