Advancing YPFB's Hydrocarbon Exploration Programs in the Bolivian Sedimentary Basins using the leading-edge SFD® airborne geophysical survey method

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With a strategy to expand hydrocarbon exploration in Bolivia, YPFB carried out data acquisition of 9,823 line kilometers using Stress Field Detection (SFD®) technology. This airborne technology uses sensors that respond to subtle gravitational field distortions caused by density and stress contrasts in the subsurface. These contrasts are associated with areas conducive for fluid entrapment within the sedimentary package.

The technology was utilized by YPFB with the following objectives:
- to evaluate the effectiveness of SFD® technology in a blind test over known producing fields.
- to identify, confirm and assess potential traps and reservoir prospects in the subsurface.
- to identify new lead areas for future hydrocarbon exploration programs.

The test was conducted over 12 known producing fields. SFD® successfully identified 11 of them. The unidentified field has a lateral extent of less than 2 km. In addition, two out of three exploratory locations were confirmed by SFD® anomalies in two distinct exploratory areas. Data integration on these prospect areas was utilized to delineate the lead areas and find additional lead areas.

The survey results in Bolivia identified 16 Primary and 92 Secondary SFD® lead areas. More integration of SFD® and subsurface geological and geophysical data is currently being carried out with the purpose of generating and maturating exploration prospects. This process contributes to further secure and manage a sustainable energy flow required to meet national and international demands.

SFD® Survey System

SFD® survey system utilizes Citation 560 series jet aircraft that is fitted with multiple sensors to meet the survey requirements. The surveys are flown at high speed (500 km/hr) and at an altitude of 3,000 meters.

The SFD® Sensors
Three systems of multiple sensors.

DAQ
2,000 samples/second/sensor.

GPS
Tracks flight lines.

What is SFD® ?

✓ SFD® is a mesoscopic transducer that represents a new class of airborne gravity-based geophysical instruments.

✓ Its unique detection mechanism utilizes sensor motion to dynamically interact with the gravity field, making gravity anomaly detection time-dependent and selective.

✓ SFD® responds to subsurface discontinuities where stress and density distribution vary markedly at reservoir scales from the surrounding rocks.

SFD® Survey, YPFB 2015
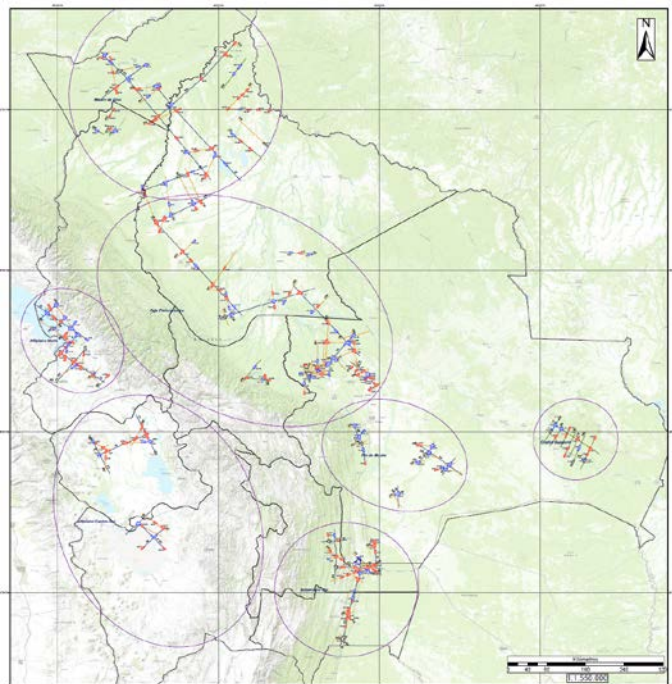

SUMMARY CHART 1ST ORDER SFD® ANOMALIES*				
	SFD® ANOMALY	EXPLORATORY PLAY	FIELD	NO FIELD
1	1.1.1	Altiplano Norte		X
2	2.1.1	Altiplano Centro-Sur		X
3	3.1.1	Subandino Sur	X	
4	3.1.2	Subandino Sur		X
5	3.1.3	Subandino Sur		X
6	4.1.1	Pie de Monte		X
7	4.1.2	Pie de Monte	X	
8	5.1.1	Faja Pericratonica		X
9	5.1.2	Faja Pericratonica		X
10	6.1.1	Madre de Dios		X
11	6.1.3	Madre de Dios		X
12	6.1.2	Madre de Dios		X
13	7.1.1	Craton Guapore		X
14	7.1.2	Craton Guapore		X
15	7.1.3	Craton Guapore		X
16	7.1.4	Craton Guapore		X

- ✓ 9,823 line kilometers of SFD® data acquired.
- ✓ 16 Primary Anomalies identified.
- ✓ Project Timeline 5 months.
- ✓ 7 Exploratory Plays.
- ✓ 14 Prospects identified.
- ✓ 11 of 12 Existing Fields confirmed.

SFD® Integration – YPFB Projects
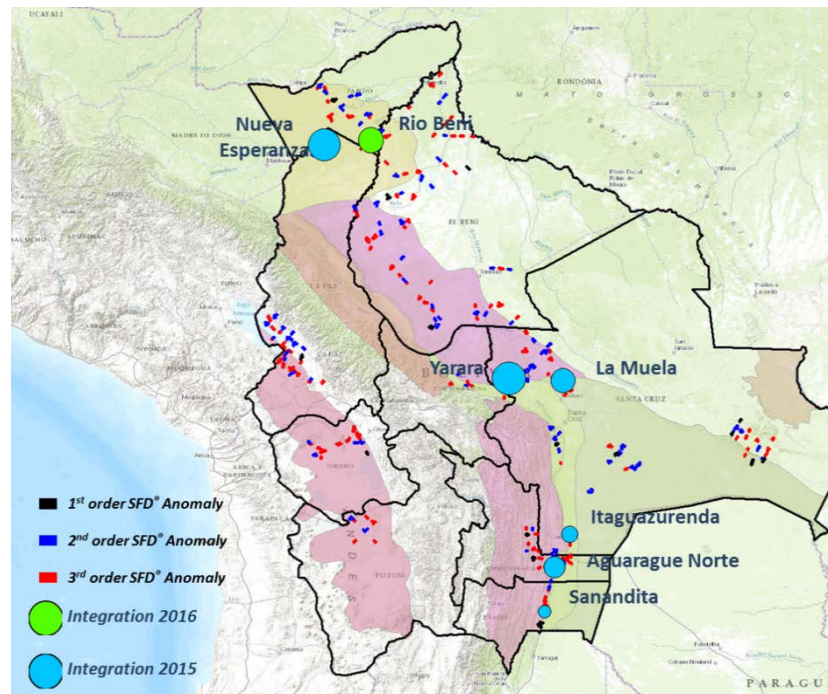
Multidisciplinary integration sessions where held to comprehend and maximize the indications SFD® results from:

1. Individual 1st Order Anomalies.
2. Closely looking to secondary and tertiary order SFD® trends and combine with existing Exploration Portfolio Prospects.

Overall Results

- ✓ Propose New Exploration Leads.
- ✓ Rank Exploration Areas from SFD® Results.
- ✓ Propose Alternative interpretation to known prospects.
- ✓ Provide information on New Exploratory areas.
- ✓ Focus ongoing and new Seismic Acquisition projects.
- ✓ Focus interpretation and Reprocessing efforts: 2D & 3D Seismic Reprocessing, AVO

Yarará - Integration of SFD® and G&G data
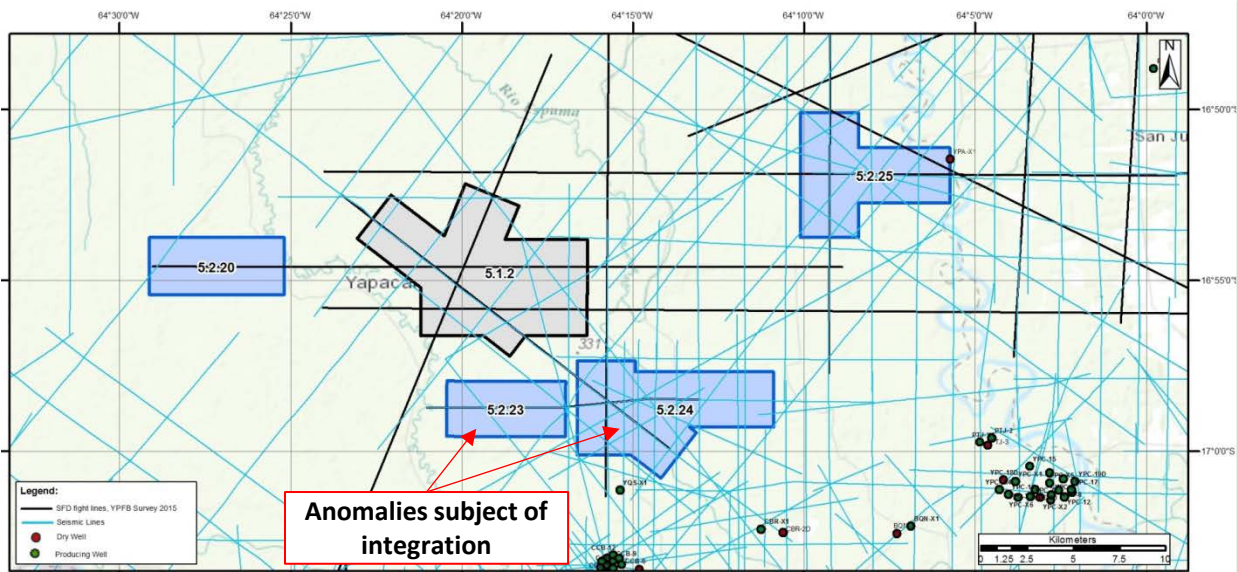
1st Order Anomalies:
1. 1st order anomalies are identified in locations where the SFD® signal shows good/excellent trap and reservoir responses. The SFD® data does not necessarily differentiate between the type of trap (structural or stratigraphic), nor does it necessarily differentiate between the type of fluid(oil, gas, or water).
2. The primary SFD® anomalies exhibit strong signal attribute development indicative of trap integrity and fluid presence.
3. Recommended for further geological and geophysical as to create exploration ready lead areas.
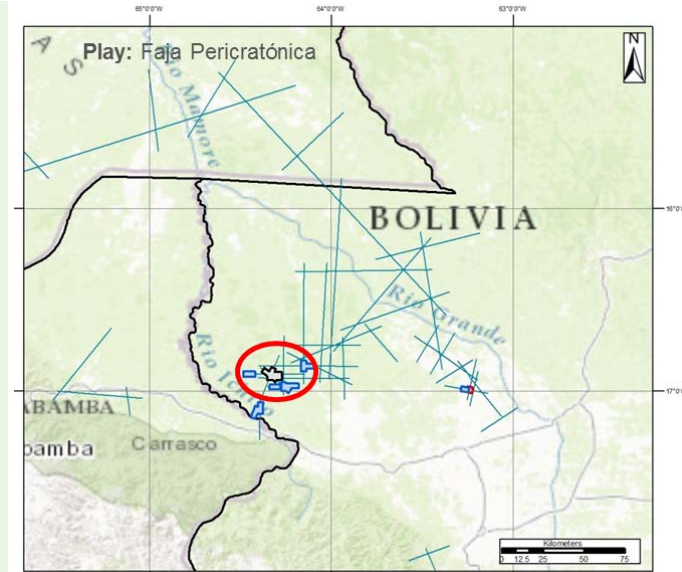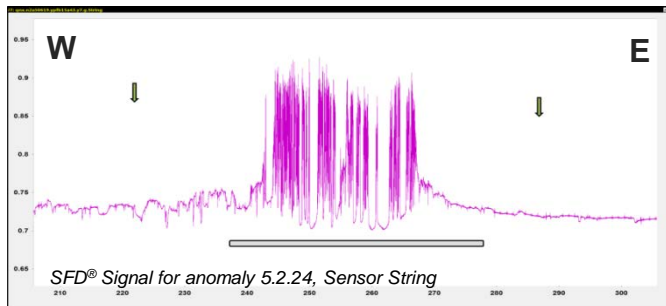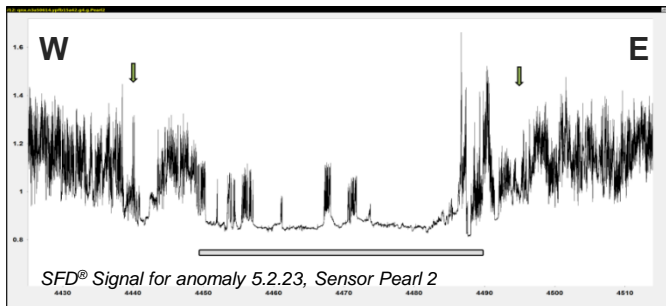
2nd Order Anomalies:
1. Other G&G information supports a sub-optimal azimuth of the original line, which might create a case for additional SFD line crossings in order to confirm reservoir quality.

2. The anomaly confidence factor is high – as in the secondary anomaly is confirmed on at least two different azimuths.
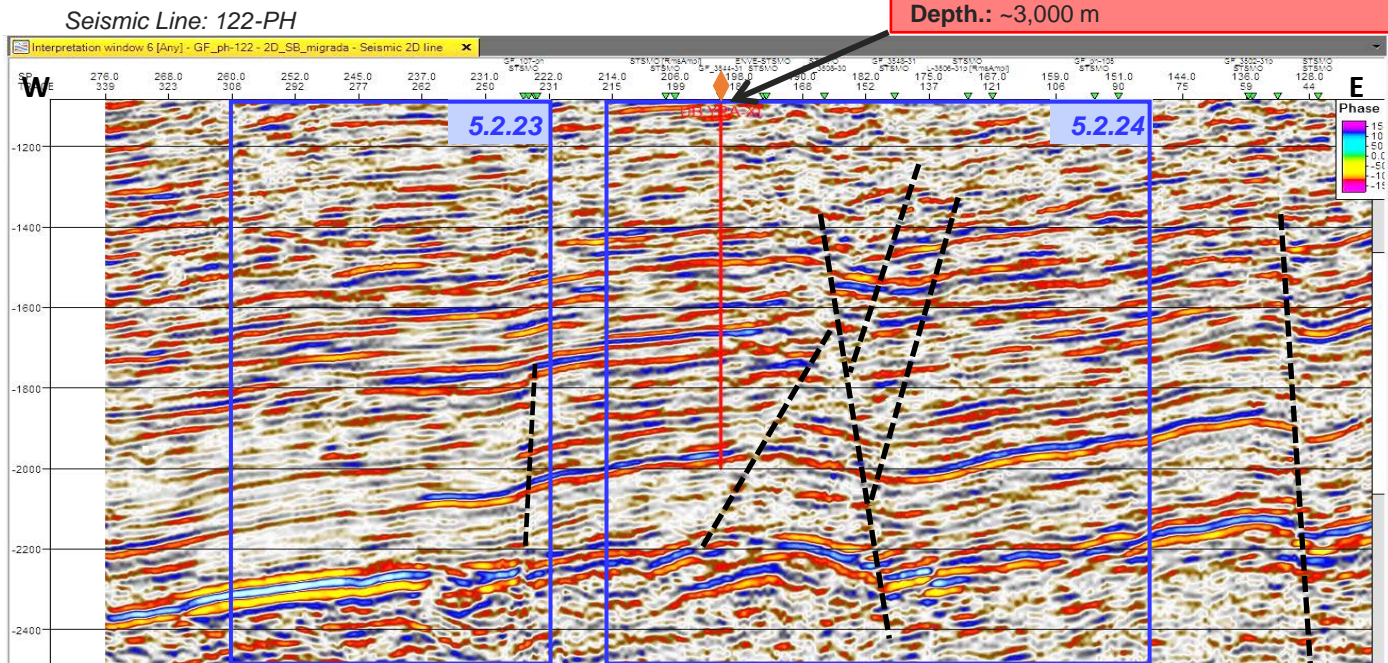
Trap Indicators		Reservoir Indicators	
2+	Excellent trap potential	A+	Exceptional reservoir potential
2	Very Good trap potential	A	Excellent reservoir potential
1+	Good trap potential	B+	Very Good reservoir potential
1	Moderate trap potential	B	Good reservoir potential
		B-	Moderate reservoir potential
		C+	Low reservoir potential

YARARA	
Anomaly	**Combined Rank**
5.1.2	2B- — 1st Order
5.2.23	1+B- — 2nd Order
5.2.24	1+B- — 2nd Order

Yarará - Integration of SFD® and G&G data

SFD® Signal for anomaly 5.2.23, Sensor Pearl 2

SFD® Signal for anomaly 5.2.24, Sensor String
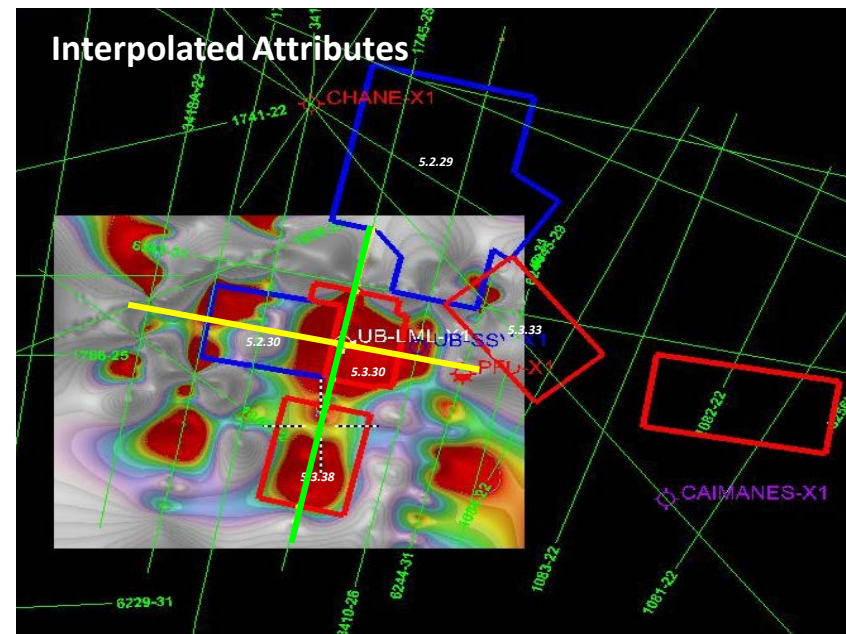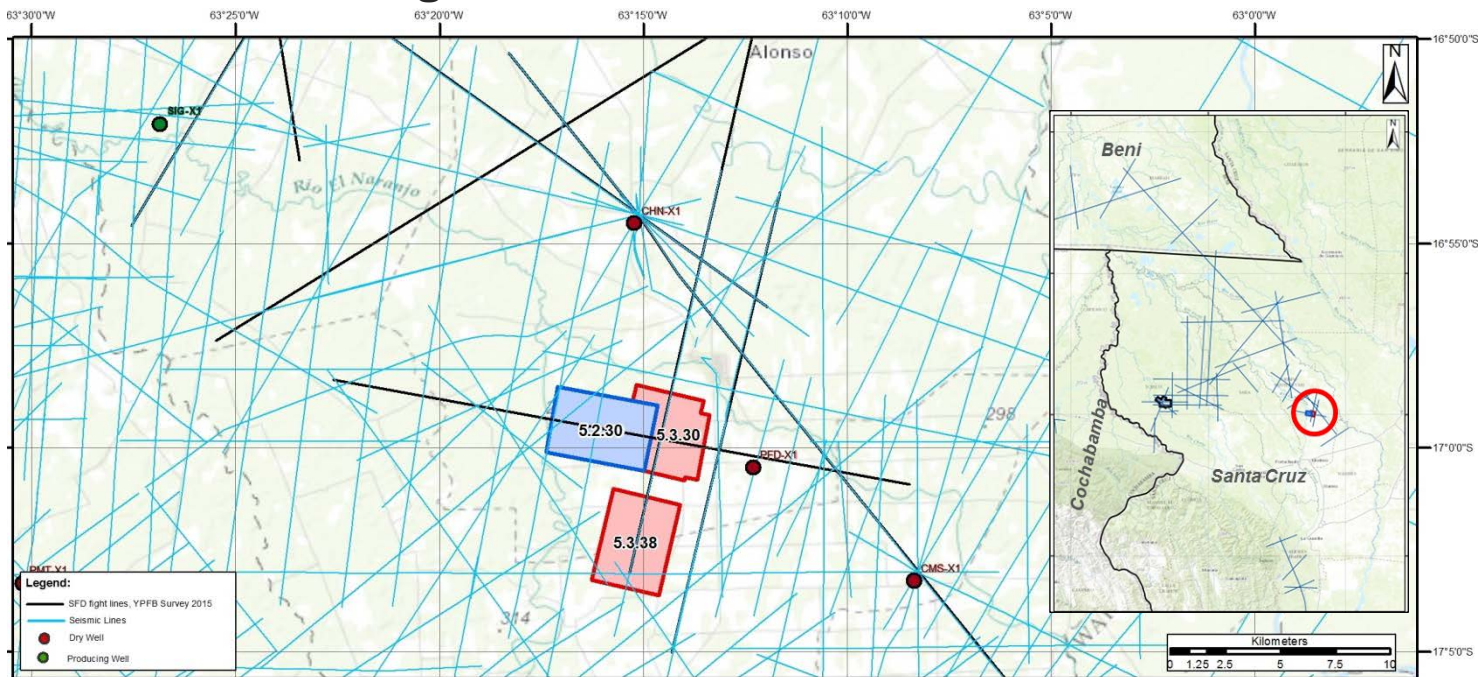
Preliminary results showing (5.2.23) and (5.2.24) anomalies interpreted as secondary with good trap potential and moderate fluid entrapment 1+B-.

More integration is recommended and focus and comparison with 1st order anomaly 5.1.2.
(work in progress)

Seismic Line: 122-PH

YRA-X1 - Initial Proposed Well location
Depth.: ~3,000 m

La Muela - Integration of SFD® and G&G data

Interpolated Attributes

Trap Indicators / Reservoir Indicators

Trap Indicators		Reservoir Indicators	
2+	Excellent trap potential	A+	Exceptional reservoir potential
2	Very Good trap potential	A	Excellent reservoir potential
1+	Good trap potential	B+	Very Good reservoir potential
1	Moderate trap potential	B	Good reservoir potential
		B-	Moderate reservoir potential
		C+	Low reservoir potential

La Muela

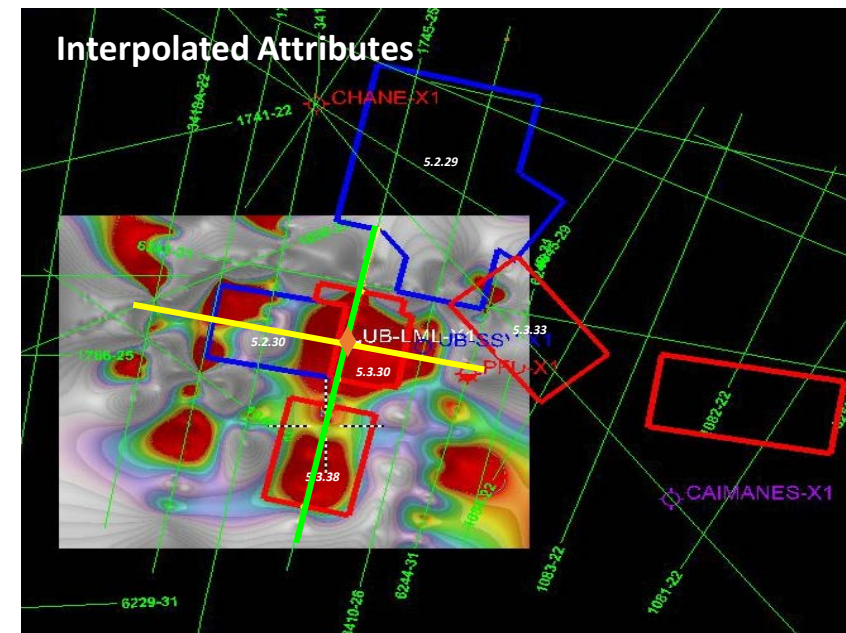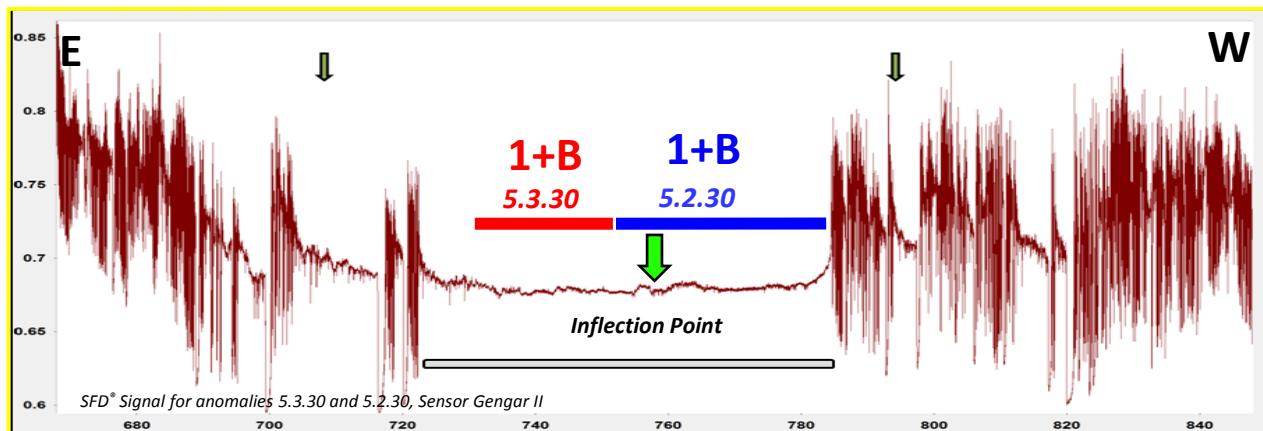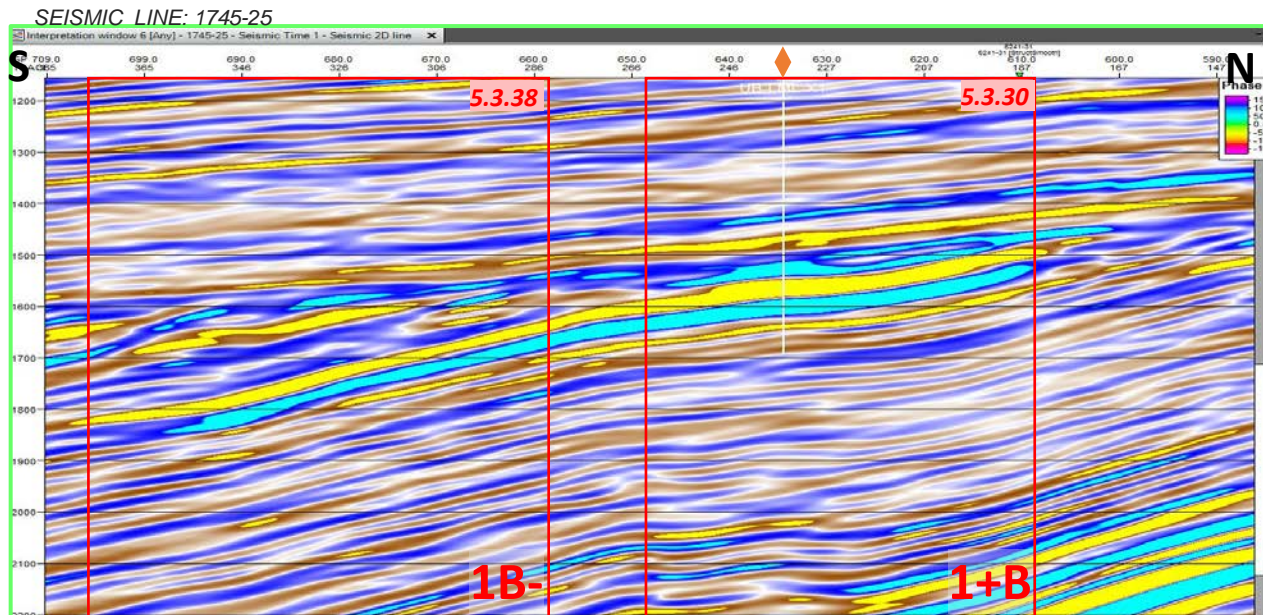| Anomaly	Combined Rank	
5.2.30	1+B	2nd Order
5.3.30	1+B	3rd Order
5.3.38	1B-	3rd Order

3rd Order Anomalies:

3rd order anomalies are identified in locations where the SFD® signal shows minor trap and reservoir responses. This can happen for a number of reasons, some of which are identified below:

- The SFD line is skirting the edge of the anomalous area, which identifies only the weaker part of the anomaly. Stated another way, it is possible that the best part of the area under question, is somewhere in vicinity to the tertiary anomaly.
- The azimuth of the SFD line is not well suited to crossing that particular anomaly .
- The anomaly itself is fairly weak.

Tertiary anomalies are only recommended for investigation if there is some other information available to lend support.

La Muela - Integration of SFD® and G&G data

SEISMIC LINE: 1745-25

Interpolated Attributes

SFD® Signal for anomalies 5.3.30 and 5.2.30, Sensor Gengar II

- ✓ Exploratory location found to be within a third order anomaly (5.3.30) 1+B-.
- ✓ Clear expression of pinch out setting underlying the Limoncito unconformity as primary play in the area.
- ✓ Recommended to investigate further with seismic products the 2nd order anomaly (5.2.30) 1+B.
- ✓ Discussion about the AVO product which was recommended to update with additional and updated seismic data.
  (work in progress)

Rio Beni - Integration of SFD® and G&G data
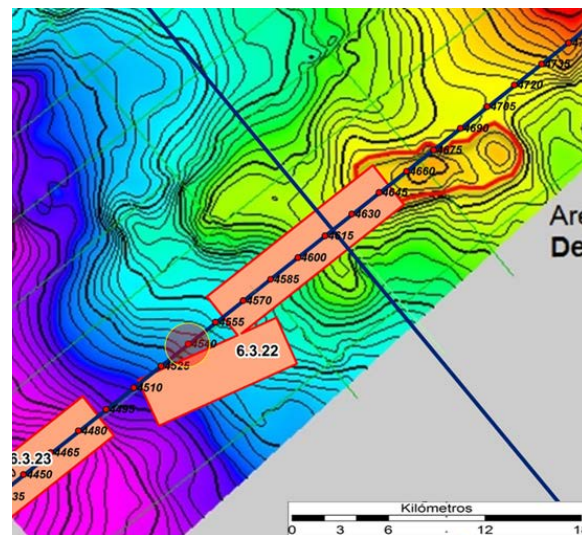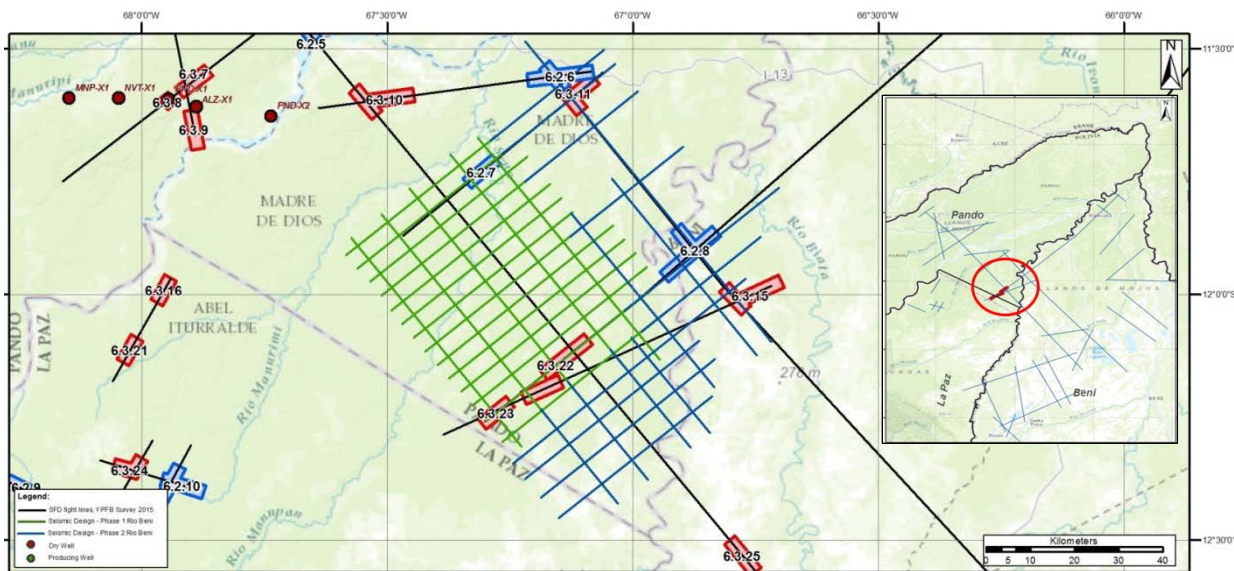
3rd order SFD® Anomaly 6.3.22 Sensor Gengar II

GengarII shows the signal anomalous region from 4555 to 4645 seconds. Frequency change which is indicative of the presence of entrapped fluid.
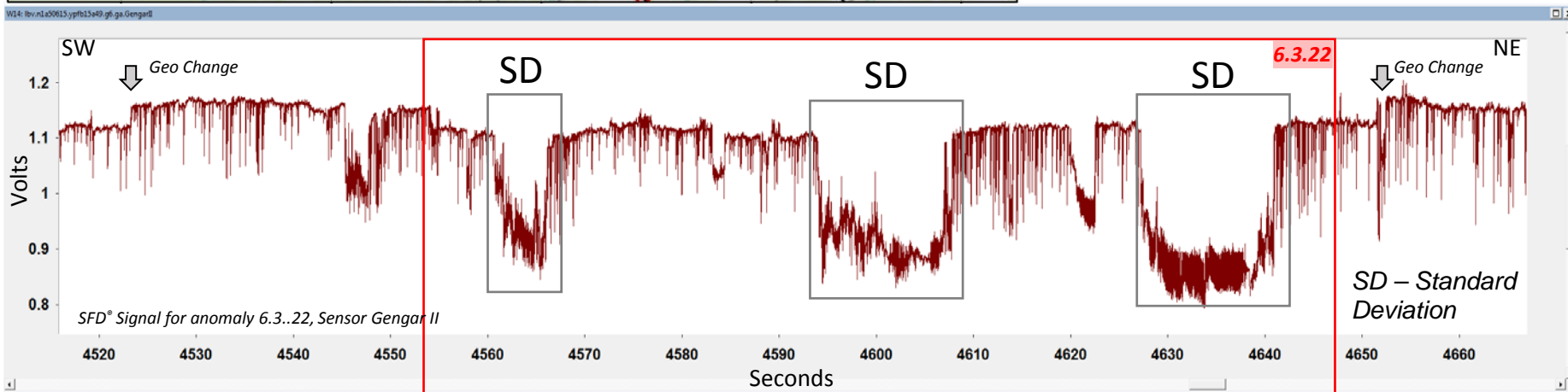
The development of the signal tends to rise in the levels of 4630-4635 seconds with high standard deviation changes combined with lower levels of average amplitude.

Rio Beni - Integration of SFD® and G&G data

By correlating the SFD® 3rd Order anomaly with seismic we observed:

1. Both sensors are anomalous within CDP 1607 – 2807 Gengar II shows an increase in frequency, with optimal response between the CDP 2307- 2700
2. Similarly changes are observed in the sensor String
3. Devonian basal internal interpretation allows to describe the geometry referring it to a possible structure that needs confirmation in the strike direction.
4. The location of the anomaly highlights the possibility of changes in the underlying Basal Devonian section.
5. Because of the low order of the anomaly. It is recommended to do the evaluation of neighboring areas on different azimuths in order to investigate for prospective Leads in the study area.
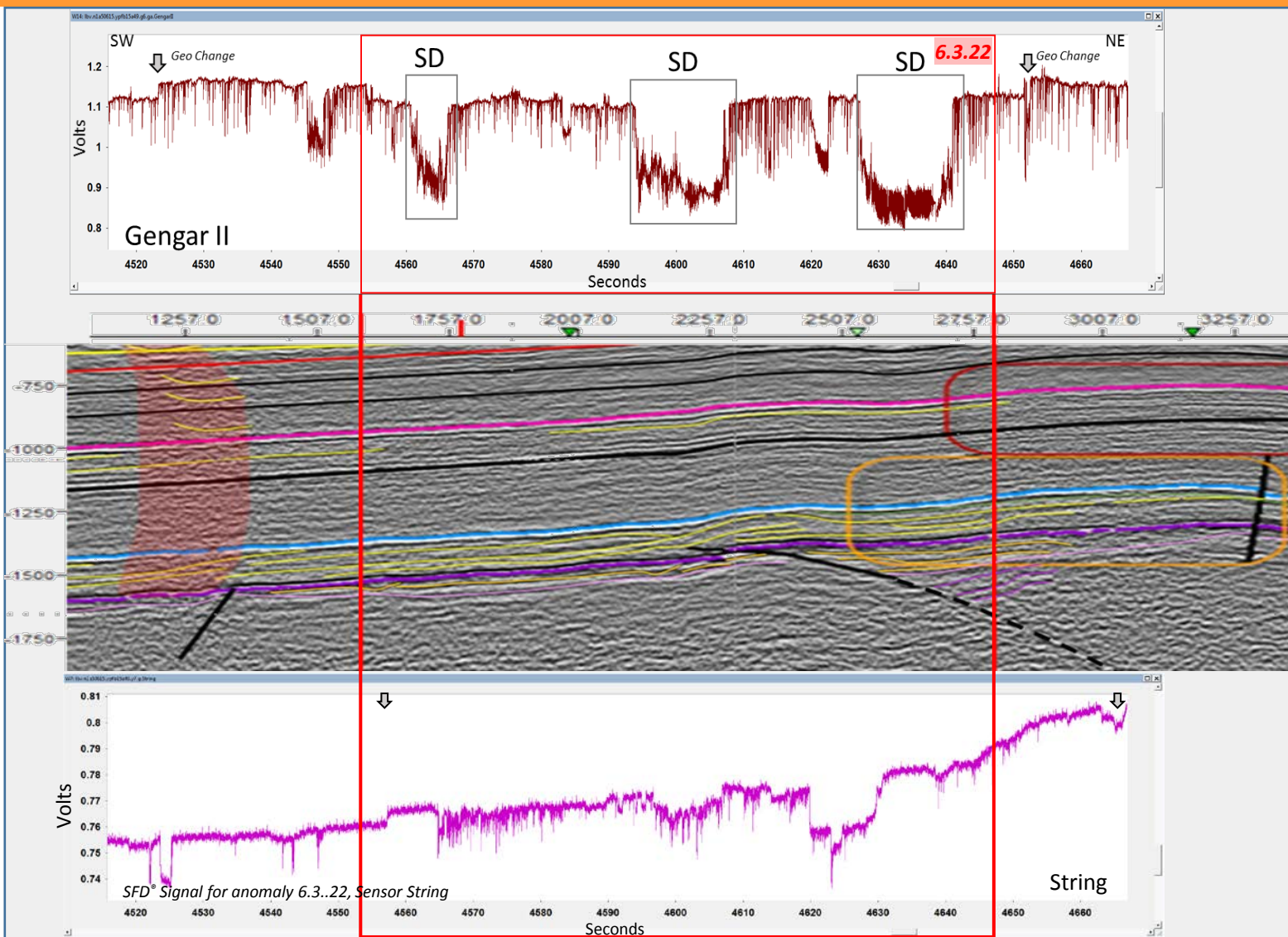
Conclusions:

- ❑ SFD® Results when integrated with Wells and Seismic data, has supported YPFB Exploration Programs in numerous ways:
  - ✓ Provided 14 high ranked Leads ranked distribution of Leads across 7 different geologic provinces.
  - ✓ SFD® Signal Confirmation and Analogs provided by existing Oil and Gas Fields.
  - ✓ Integrated SFD® with seismic and well data with the following conclusions and recommendations:

- ❑ Río Beni:
  - ✓ Third order anomalies show promising match with the structure suggesting the reservoir is within the internal stratigraphy rather than at the top of the unconformable Devonian horizon. More SFD® in different azimuth would be required to confirm upgrade or reject this Lead.
  - ✓ Regional distribution of SFD® anomalies in the Rio Beni area show areas better development of SFD® anomalies (2nd order) North and out of 2D seismic coverage.
  - ✓ New Seismic Acquisition has been designed to continue this evaluation.

- ❑ La Muela:
  - ✓ Exploratory location found to be within a third order anomaly (5.3.30) 1+B-Clear expression of pinch out setting underlying the Limoncito unconformity as primary play in the area.
  - ✓ Here the value recommendation to investigate further with seismic products and focus in the neighboring 2nd order anomaly (5.2.30) 1+B.

Conclusions:

- ❑ Yarara Integration
  - ✓ Structures and length of the 2nd order anomalies where integrated and reviewed, high correlation between prospective area and anomalies was observed.
  - ✓ Preliminary well locations are tested against the SFD® results. YPFB is planning to propose exploratory wells incorporating the SFD® anomaly analysis into the decision making process.
  - ✓ Preliminary results from 2nd order anomalies with good SFD® rank coinciding with exploration prospects. The results suggest additional integration and focus on neighboring 1st order anomalies.

- ❑ Acquisition and integration of SFD® can be applied across the Exploration phases:
  - ✓ When implemented early, it identifies lead focus areas for future exploration and delineation.
  - ✓ When applied after the prospects are identified it indicates and rank the prospect portfolio.
  - ✓ If implemented after discovery it confirms and can provide additional exploration potential by indicating the outline of the entrapped fluid area.

- ➢ **Next Steps:**
  - ✓ Continue the Evaluation of high grade SFD® on Exploration areas via integration with G&G data.
  - ✓ Design additional SFD® acquisition in Bolivia's frontier exploration areas.
  - ✓ Incorporate infill SFD® additional into areas sparsely covered by 2015 survey.