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SPE Seismic 2017

Addressing seismic challenges on Rosebank through targeted use of technology

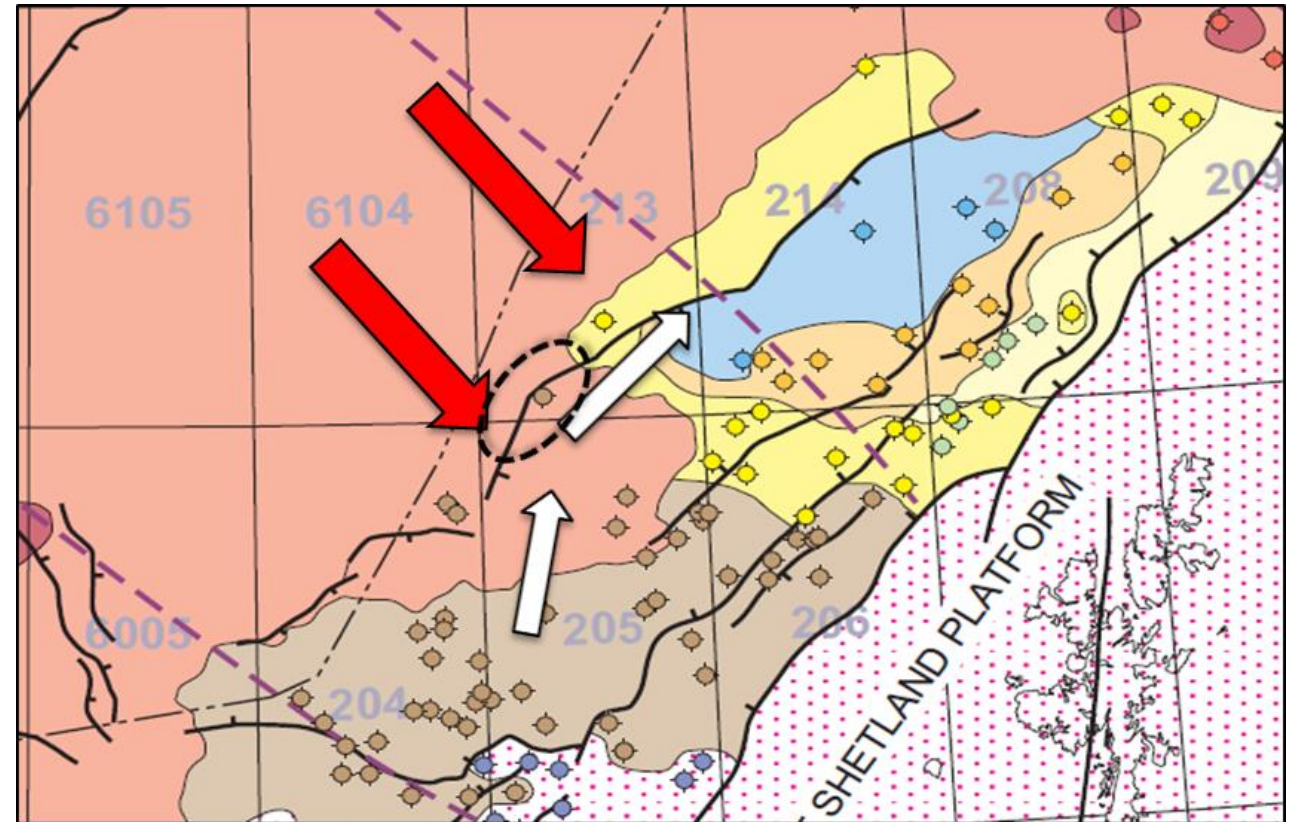
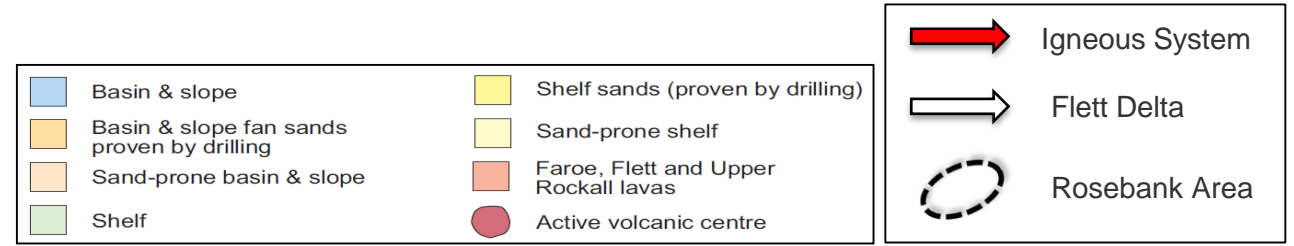
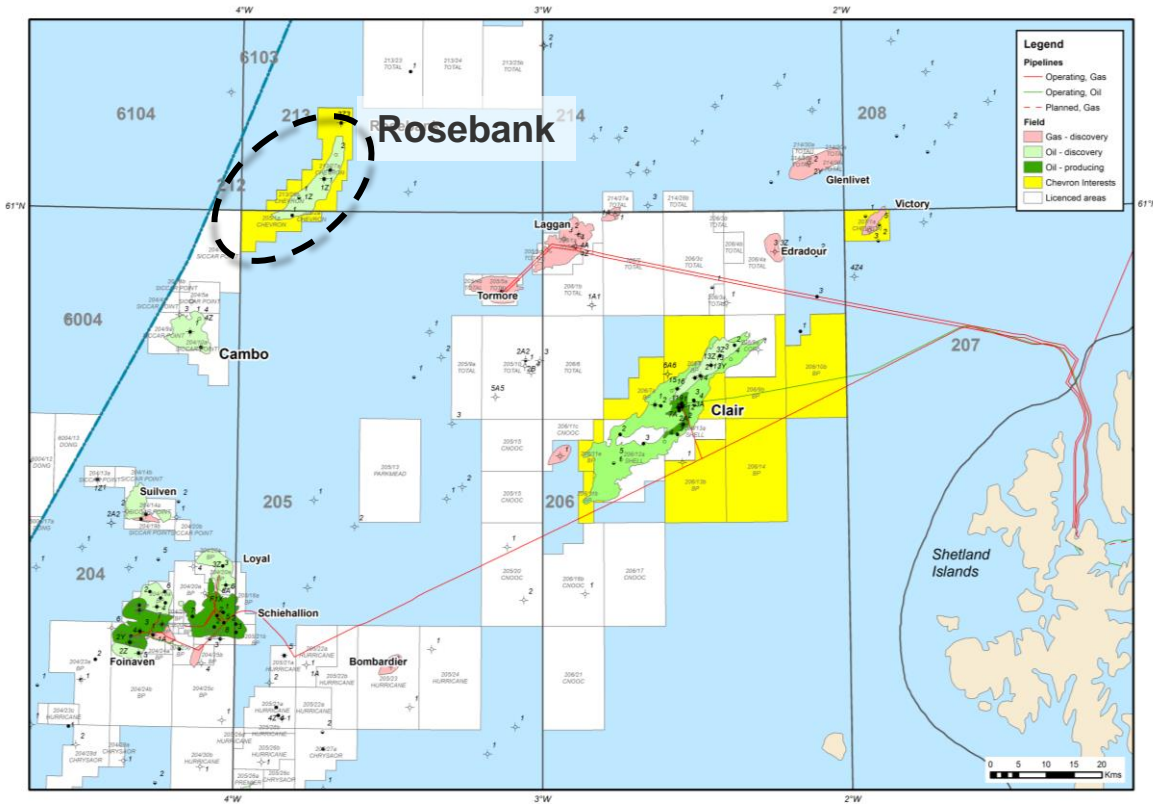
11th May 2017

Outline

- Introduction
- Regional Geology and Play Concept
- Seismic Challenges
- 3D Streamer Data
- Acquisition Modelling
- Ocean Bottom Node Seismic Data
 - Velocity Modelling
 - Spectral Decomposition
 - Spectral Enhancement
 - Inversion
- Conclusions



Rosebank Location - Faroe-Shetland Basin



- Confluence of volcanic and sedimentary systems:
 - Easterly advancing volcanic system of extrusive basalts and volcanoclastics
 - Contemporaneous Flett Delta siliciclastic system to the SSW prograding in a NNE orientation

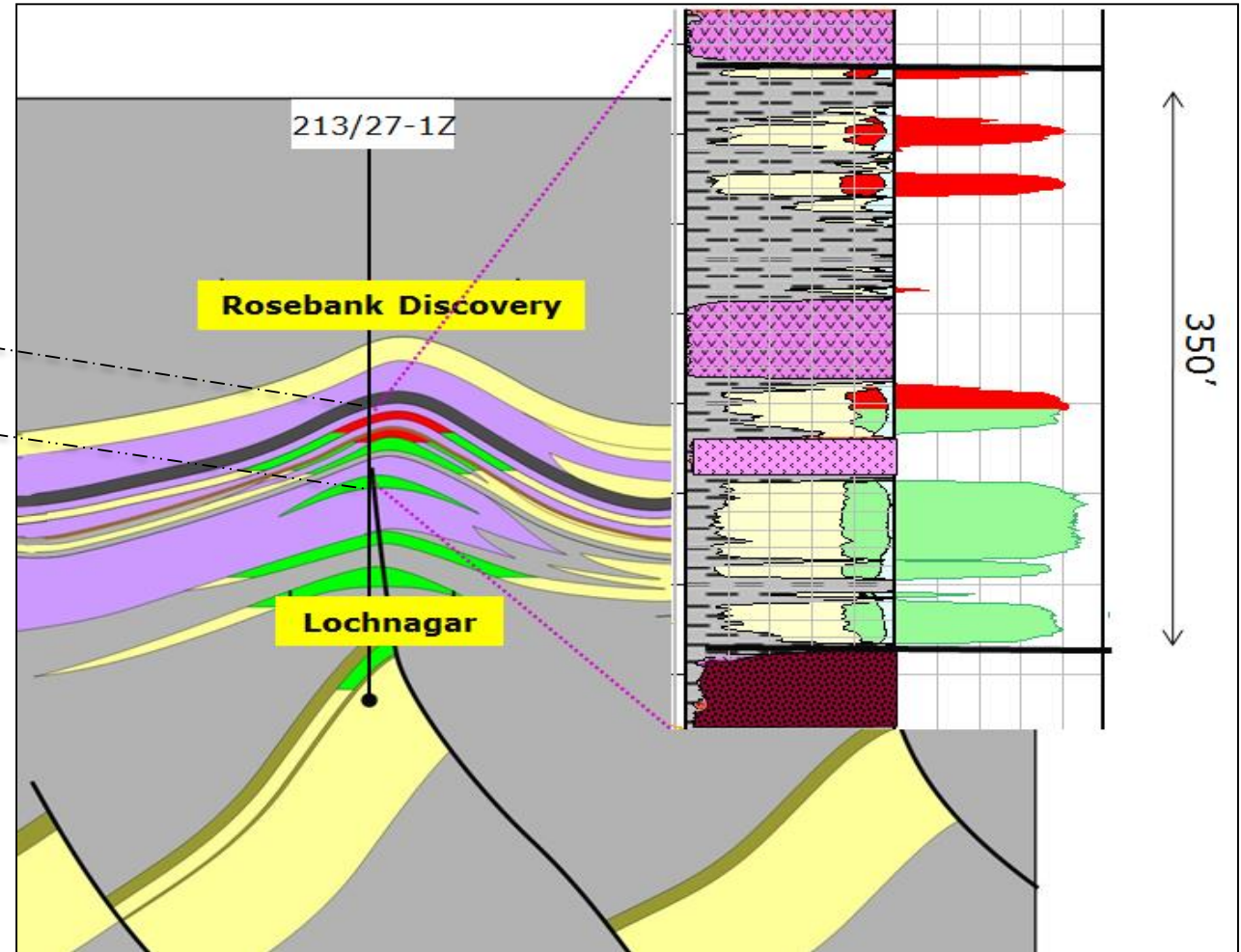
After Ternan, 2009



Faroes Shetland Stratigraphy: Intra- and Sub-Volcanic Reservoirs

Time (Ma)	Series	Stage	Uplift Event	Corona High Q213/214	Judd Basin Q204/205	Flett Basin Q206/214/208	Rona High Q206/207	BGS Lithostrat	BP Sequence	Stratigraphic Surface	North Sea Stratigraphic Sequence	Maine Biostrat Interval	
54.3	LOWER EOCENE	YPRESIAN	Basal Eoc Transgr	Balder Tuff	Balder Sst	Balder Tuff	Balder Tuff	HORDA FM	e2		FRIGG	dracodinium	
54.9			Base Balder	Hildasay Sst Mbr	Upper Flett Sst	Hildasay Sst Mbr		BALDER FM	T50	e1	BALDER	oebisfeldensis	
55.1			Flett Lavas	U Colsay Sst Mbr	Lower Flett Sst	Upper Colsay Sst Mbr	Upper Colsay Sst Mbr	FLETT FM	T45	e0	DORNOCH	wardensis	
55.2			Near Top Palaeocene	Flett Lavas	Lower Flett Sst	Upper Colsay Sst Mbr	Upper Colsay Sst Mbr	FLETT FM	T40		FORTIES II	apetodinium	
55.8	UPPER PALAEOCENE	THANETIAN	Intra-U Thanetian	L Colsay Sst Mbr	Upper Lamba Mdst	Upper Lamba Mdst	Upper Lamba Mdst	LAMBDA FORMATION			FORTIEST	limpov agglutus	
56.1				Upper Lamba Sst	Upper Lamba Mdst	Upper Lamba Mdst				p8	LISTA IIIb		
57.0				U Lamba Tuff	U Lamba Sst	U Lamba Sst	Upper Lamba Mdst			T38	p7	LISTA IIIa	gippingensis
58.1				Upper Lamba Mdst	L Lamba Tuff	Lower Lamba Sst	Lower Lamba Sst			T36	p6	LISTA II	
58.4	UPPER PALAEOCENE	SELANDIAN	Mid Palaeocene	Lower Lamba Sst	Kettla Tuff	Lower Lamba Sst	Lower Lamba Sst	VAILA FORMATION	T35 & T34		LISTA Ib	pyrophorum	
58.7				Upper Vaila Mdst	Upper Vaila Mdst	Upper Vaila Mdst			T33 to T31	p5	LISTA Ia		
58.8				Upper Vaila Sst	Upper Vaila Sst	Upper Vaila Sst				p4	LISTA Ib		
59.2				Upper Vaila Sst	Upper Vaila Sst	Upper Vaila Sst				p3	LISTA Ia		
60.2	UPPER PALAEOCENE	SELANDIAN		Lower Vaila Sst	Lower Vaila Sst	Lower Vaila Sst	Lower Vaila Sst	VAILA FORMATION	T20		MAUREEN II	delicata	
61.2				Lower Vaila Sst	Lower Vaila Sst	Lower Vaila Sst	Lower Vaila Sst			p2	MAUREEN II		
61.5				Lower Vaila Sst	Lower Vaila Sst	Lower Vaila Sst	Lower Vaila Sst				p1	MAUREEN I	planktonics
61.7				Lower Vaila Sst	Lower Vaila Sst	Lower Vaila Sst	Lower Vaila Sst				p1	EKOFISK II	inornata
62.7	LOWER PALAEOCENE	DANIAN	Near Top Danian	Sullom Sst	Upper Sullom Mdst	Upper Sullom Mdst	Upper Sullom Mdst	SULLOM FORMATION	T10		EKOFISK II	inornata	
63.3				Intra-Danian	Ockran Sst Fm	Lower Sullom Mdst	Lower Sullom Mdst				p1	EKOFISK I	delitense
64.3				Near Base Tertiary	Man. Mdst	Manumiella Mdst	Manumiella Mdst				p0	JORSALFARE FM	
65.5				KTBE	Man. Mdst	Manumiella Mdst	Manumiella Mdst				p0	JORSALFARE FM	

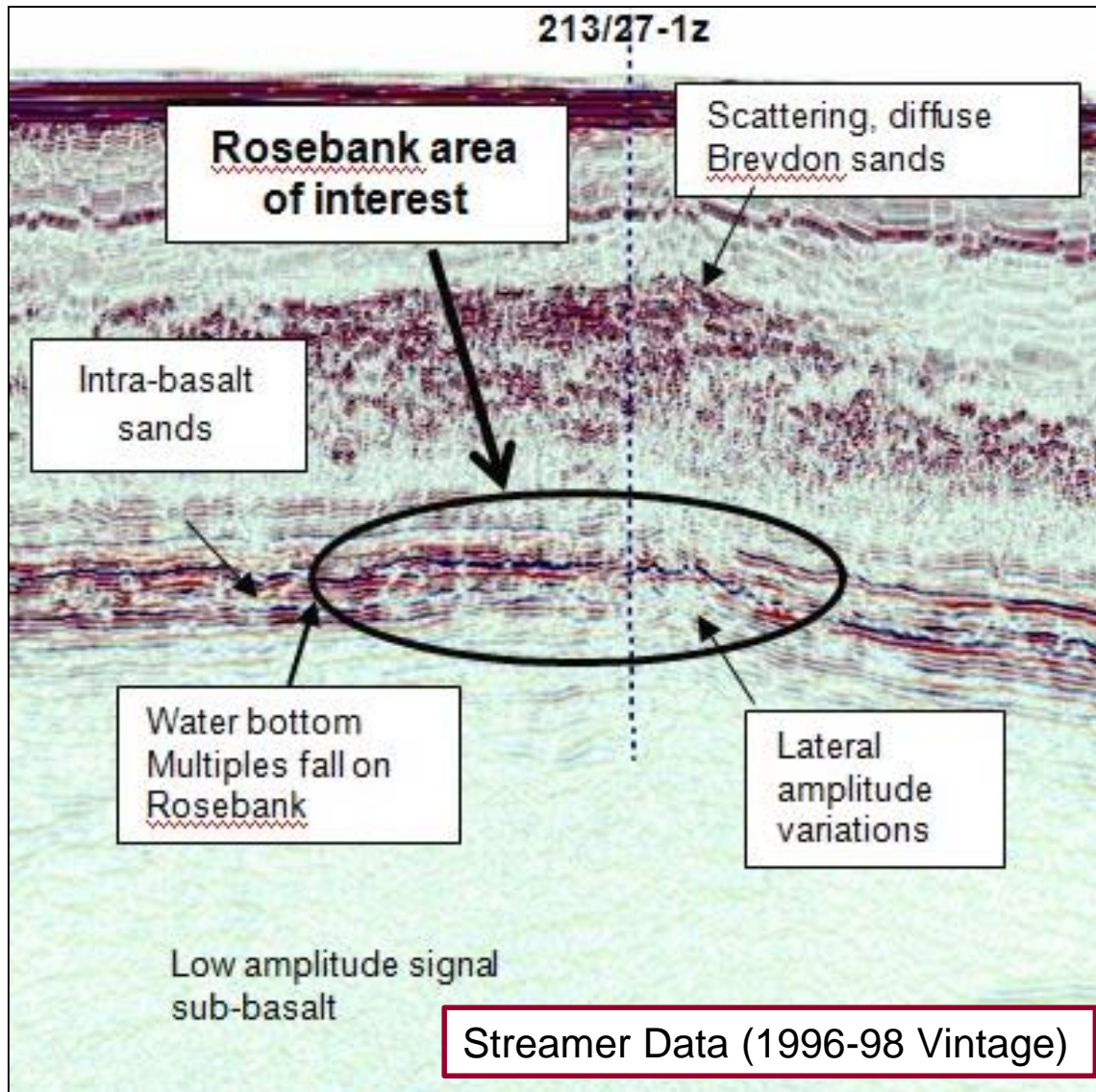
(Holdaway et al., 2009)



After, Duncan, Helland-Hansen & Dennehy, 2009



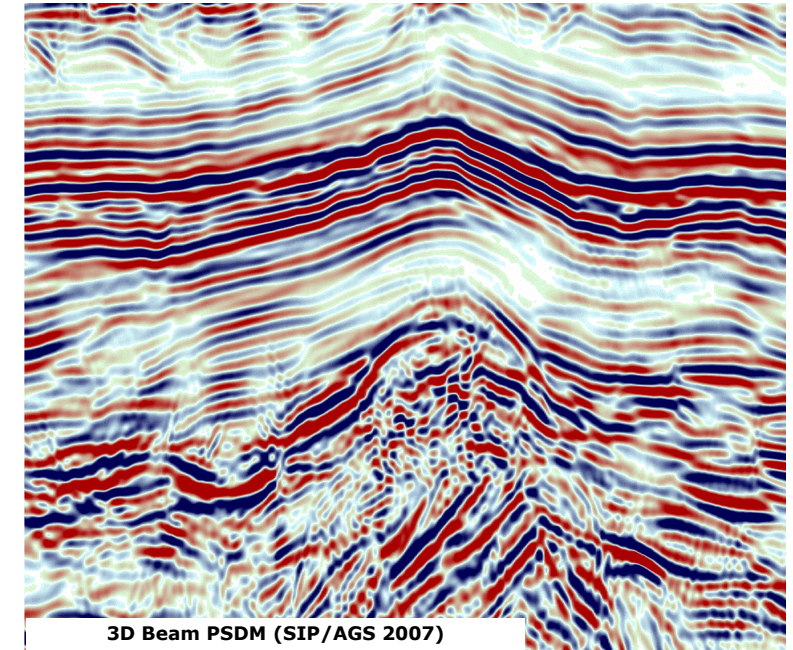
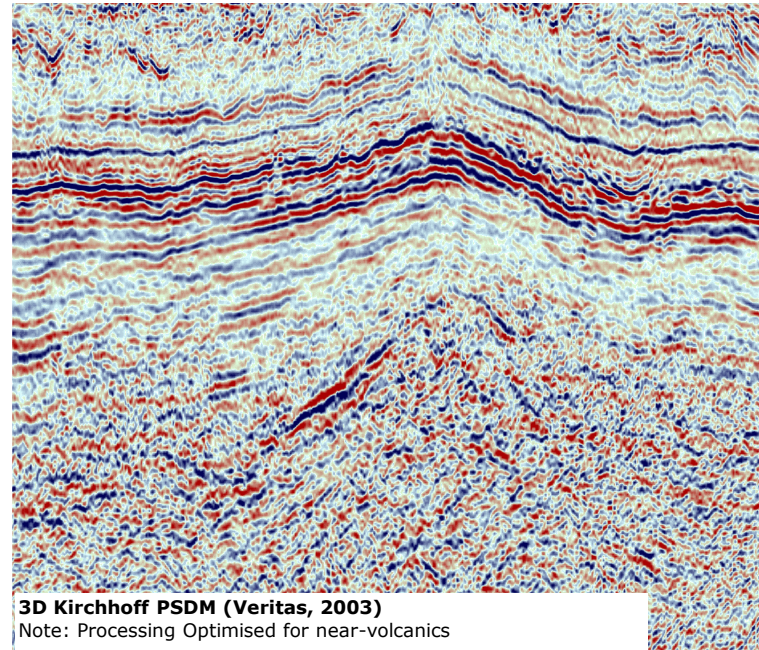
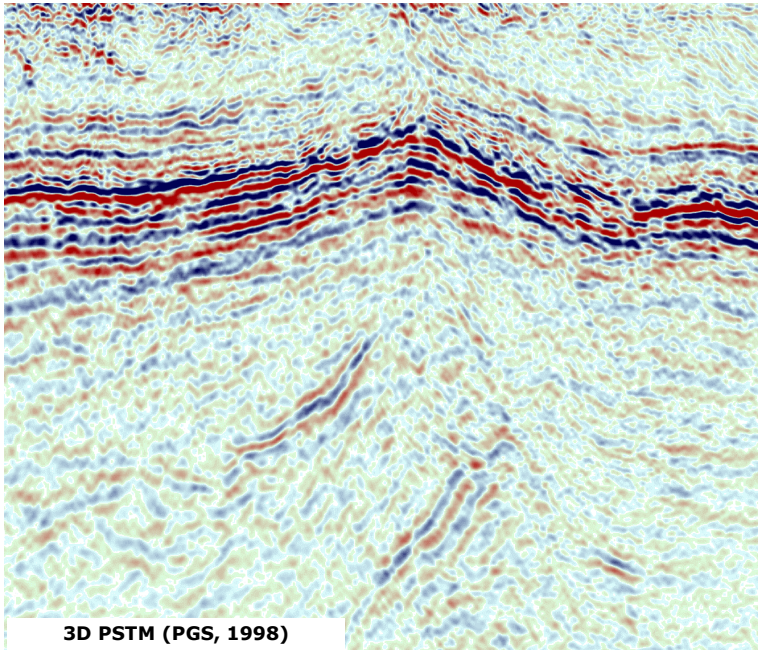
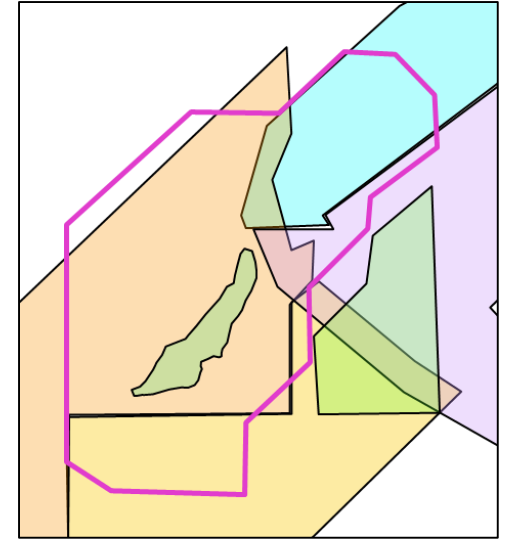
Rosebank Seismic Challenges



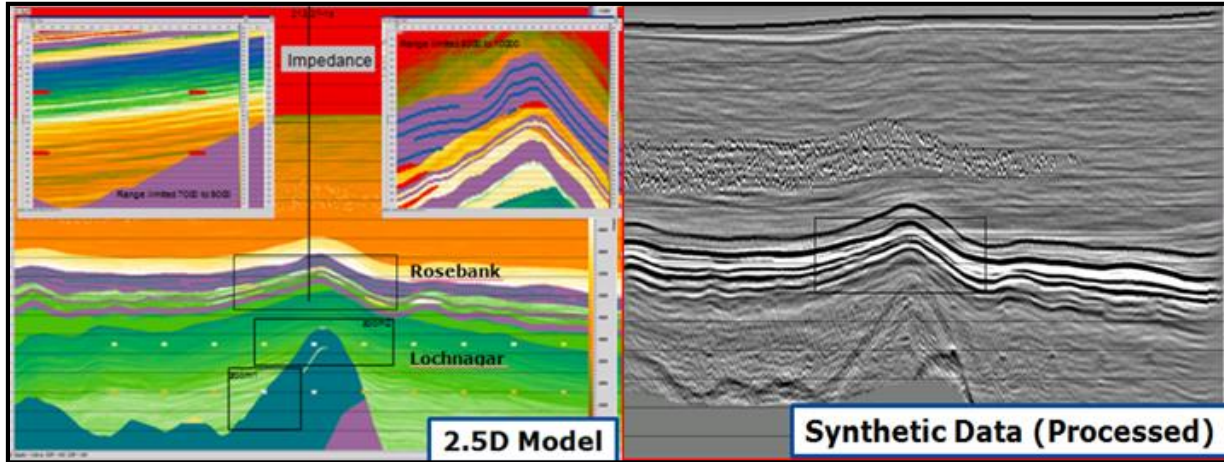
- Complex overburden
 - WB and near WB multiple noise train over target
 - Scattering due to sand injectites
- Sub and Intra basalt imaging
 - Heterogeneous volcanics interval (scattering and intrinsic attenuation)
 - Poor seismic penetration sub-basalt
- Reservoir thickness at edge of detectability
- Difficult to separate seismic response of sands/shales/volcaniclastics

1996-2008 - 3D Streamer Data

- Numerous efforts to reprocess the data were undertaken prior to and after the discovery well
- Lead to an improved image but were limited by the difficulties of merging several surveys and sub-optimal acquisition parameters for intra and sub-basalt imaging

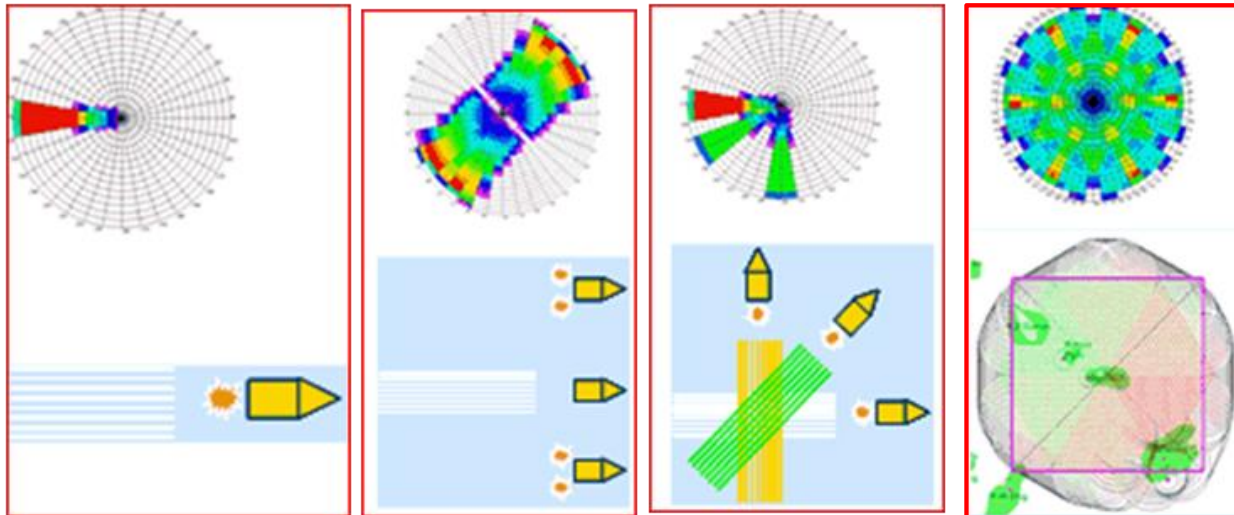


2008-9 Seismic Modelling & Feasibility Studies



- Conducted feasibility studies to enable technology selection
 - 2.5D Finite Difference Modelling and Processing (CGGVeritas) used to assess different acquisition methods
 - Extensive 4D Study; Rock Physics; Core Analysis, etc.

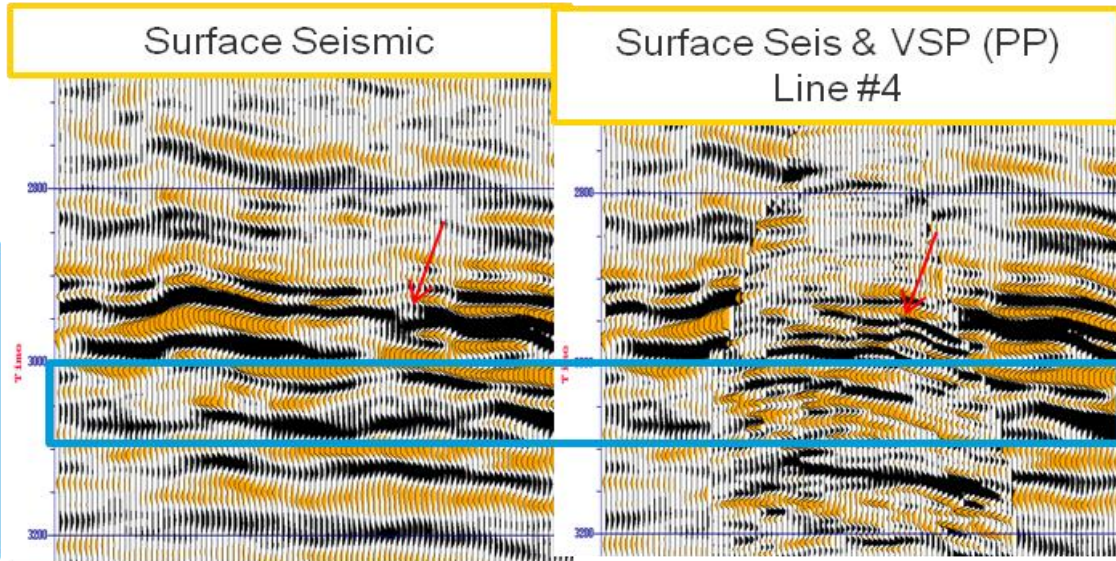
- OBN technology showed best results and was chosen as the preferred method.
 - Best Structural Image
 - Highest Bandwidth
 - Optimal Multiple Attenuation
 - Rich Azimuths & Best Illumination
 - Converted waves for Reservoir Characterisation
 - Best 4D Baseline (best repeatability)



Example survey types: Single, Multi-, Wide and Rich Azimuth



2009 VSP Program Multi-Azimuth Walk-Away VSP



Reservoir Zone

Objectives:

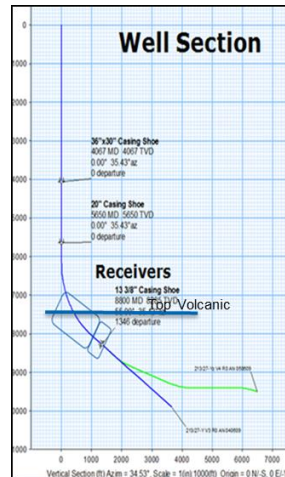
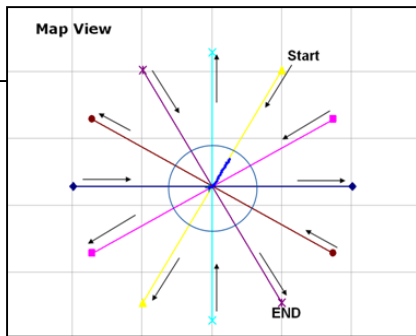
- Determine anisotropy for future processing
- Investigate azimuthal variation
- Increase resolution in target interval
- Include learning's for survey planning

Key Results:

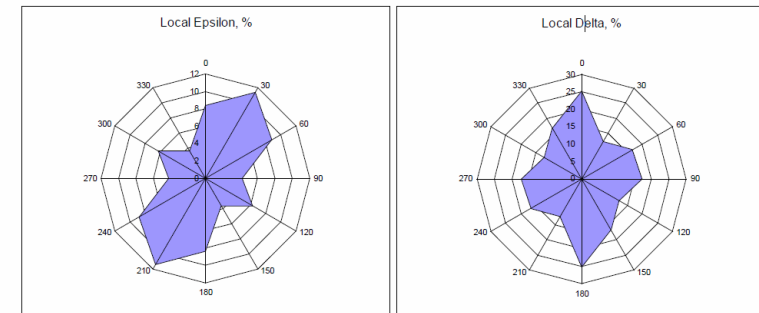
- Acquired 6x10km Walk-away VSP lines, Vertical Incidence VSP and Walk-around VSP
- Higher frequencies & azimuthal dependence
- Anisotropy available for processing of new OBN
- Results supported OBN decision



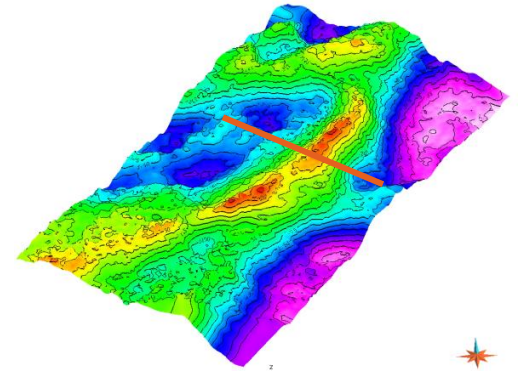
Clockwise: Pattern of VSP lines, Source boat seen from Stena Carron, Well section showing receivers



Local Anisotropy



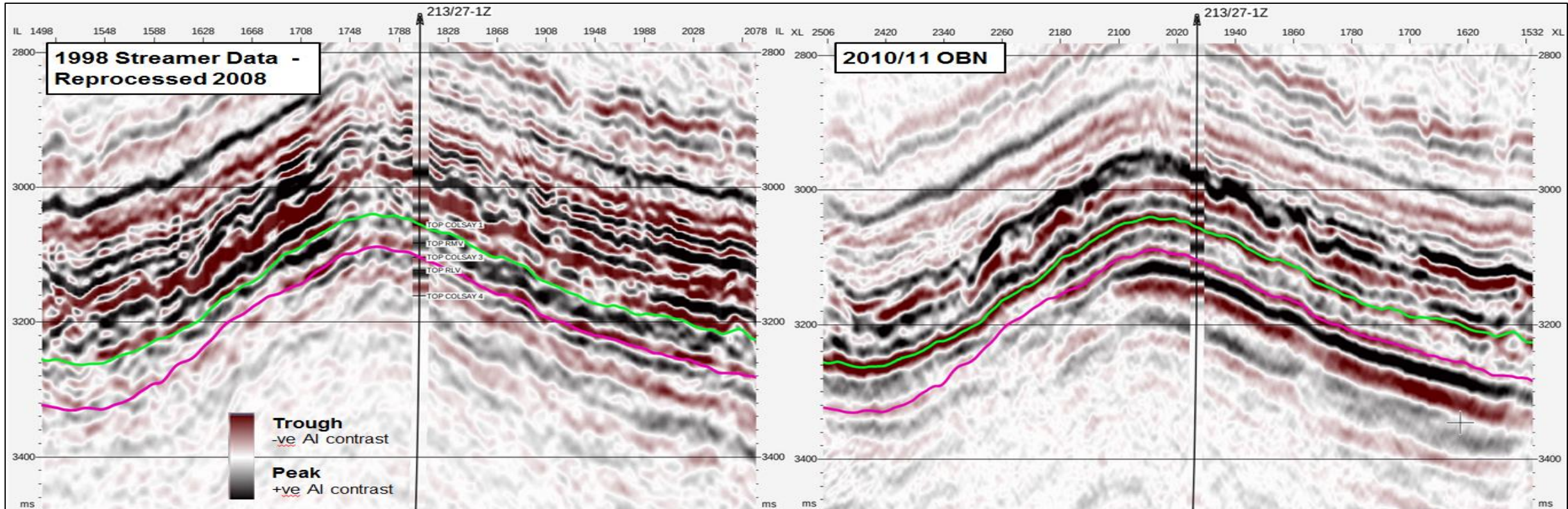
2010 and 2011: Stage 1 and 2 OBN Surveys



- Two stage acquisition approach to confirm benefits of OBN technology

- Stage 1 – May-Aug 2010 - 65 km² node 260 km² shot area
- Stage 2 – Apr-Aug 2011 - 109 km² node 335 km² shot area

- The improved demultiple, full azimuth illumination, and increased low frequency content have all helped to increase the S/N level at the target with a much improved tie to the well synthetics



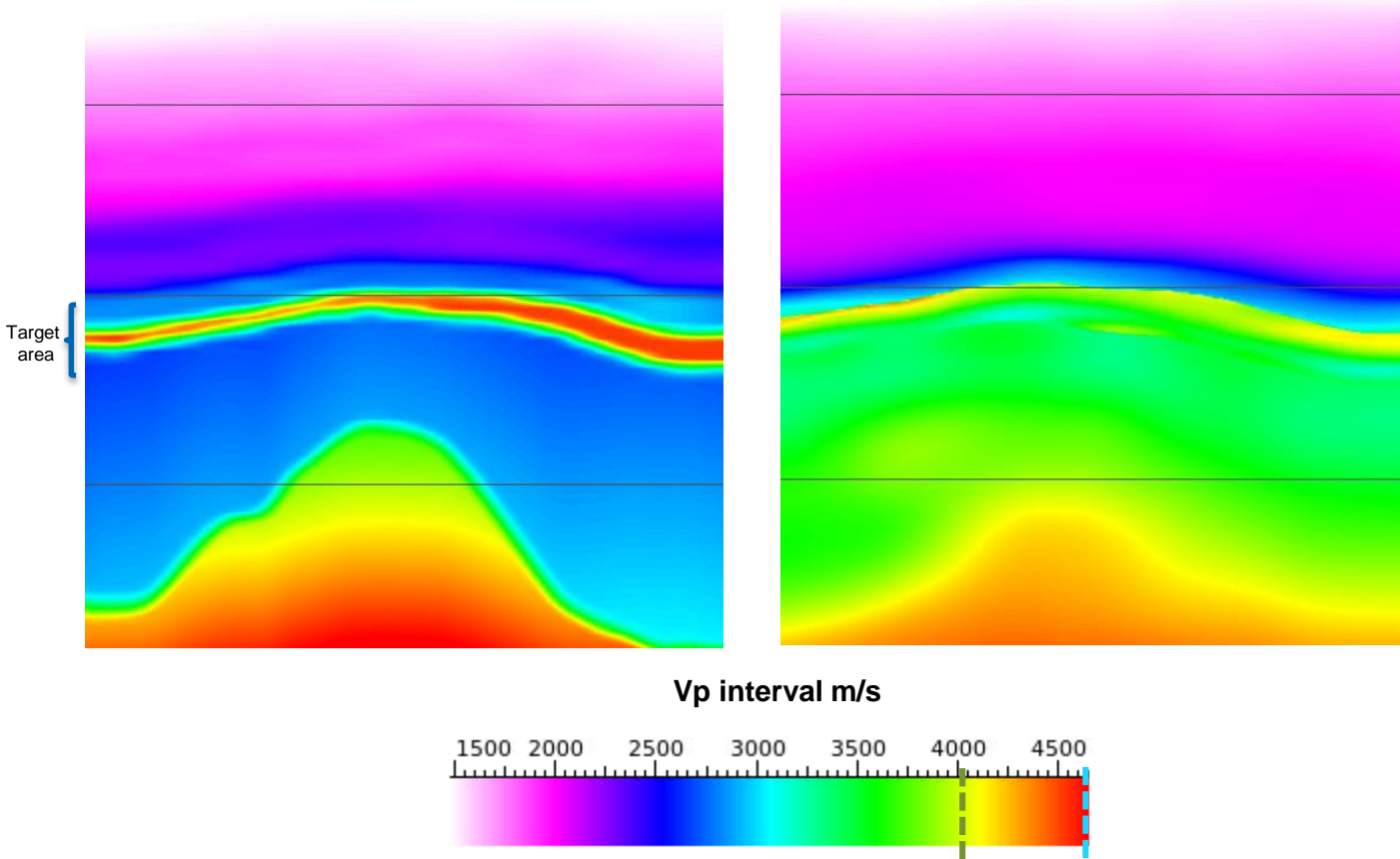
Proprietary to the Rosebank Joint Venture



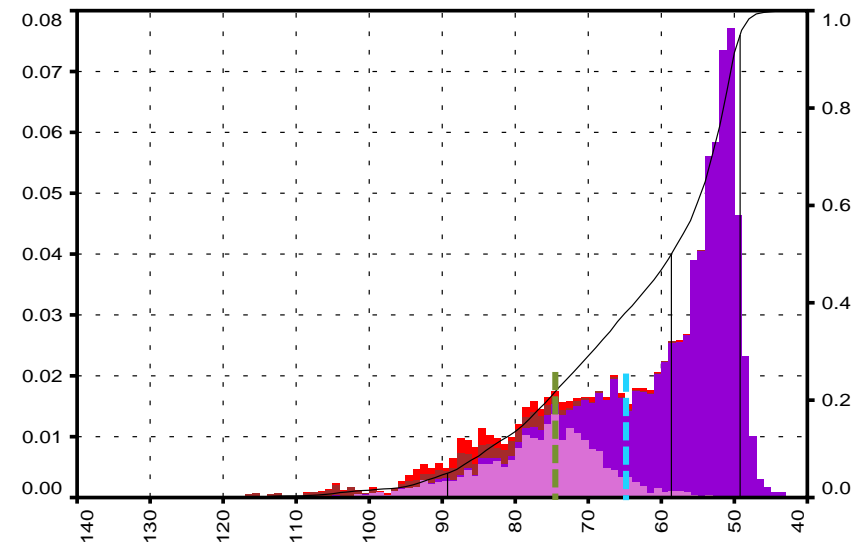
OBN Seismic Imaging: Velocity Modelling - Volcanic velocities

Best Technical Imaging
Velocities Pre-OBN

OBN Imaging
Velocities



Well Velocities From Sonic Logs

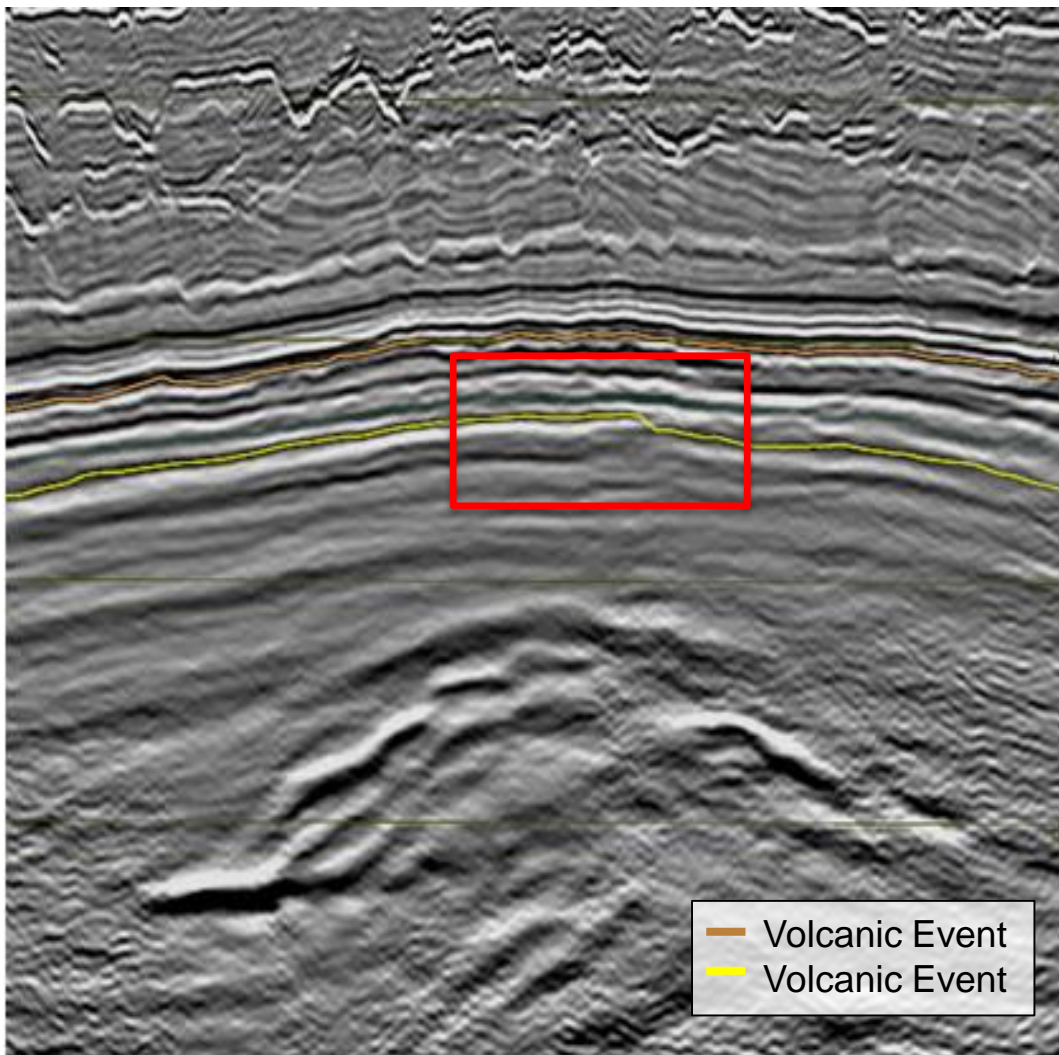


LOG FACIES	DESCRIPTION
	Coarse-grained Volcaniclastic Sandstones
	Fine-grained Volcaniclastic Siltstones
	Vesicular Basalts
	Basalts

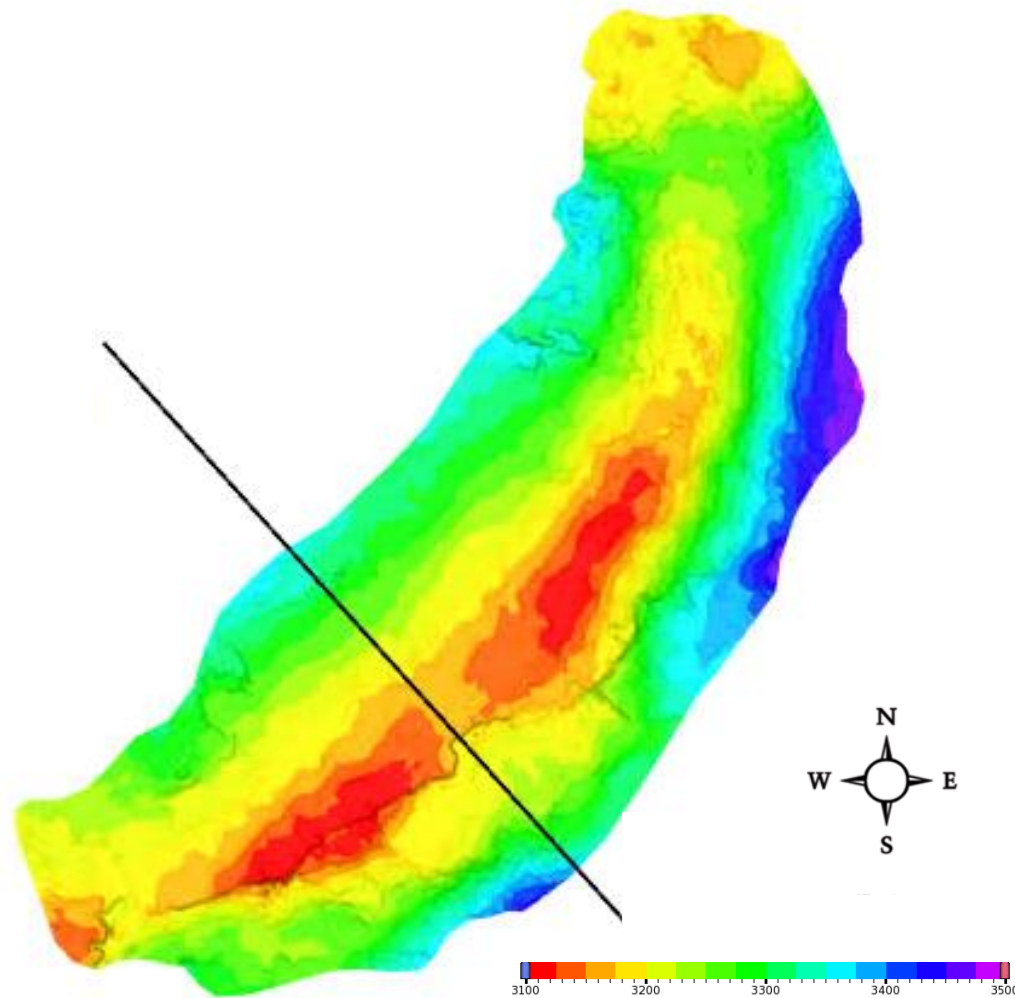
OBN Seismic Imaging

Velocity Modelling – Enhanced structural definition

OBN Inline



Yellow Event - TWT Structure Map



NW

SE

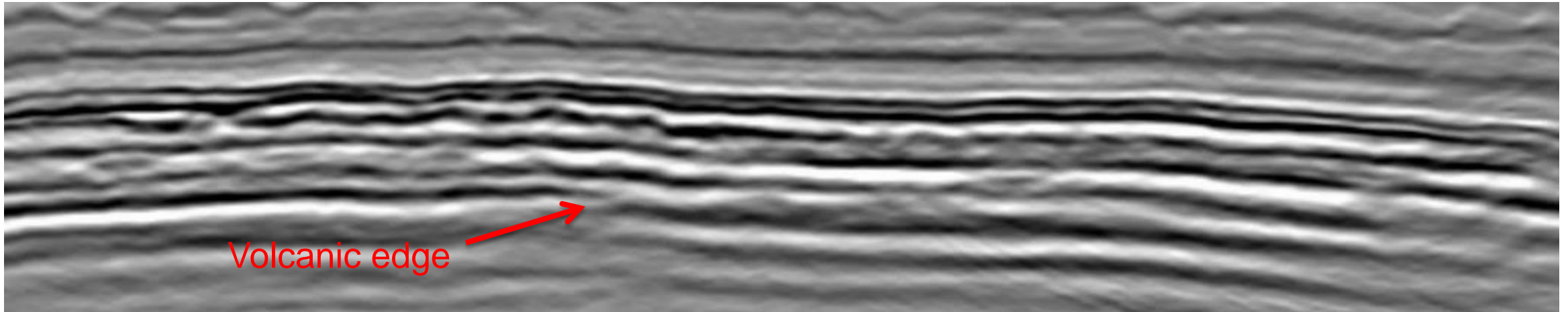
Proprietary to the Rosebank Joint Venture

Peak, Black
+ve AI contrast

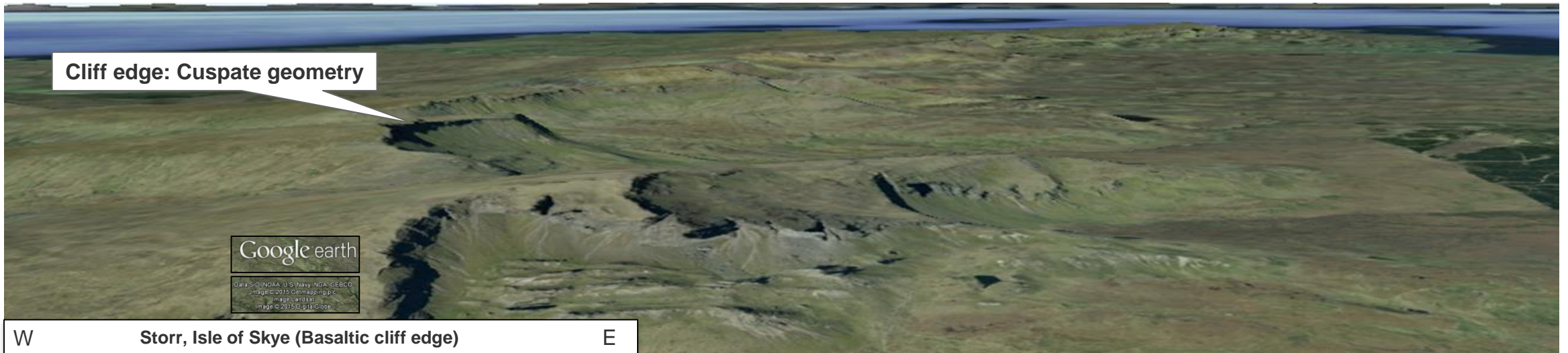


OBN Seismic Imaging

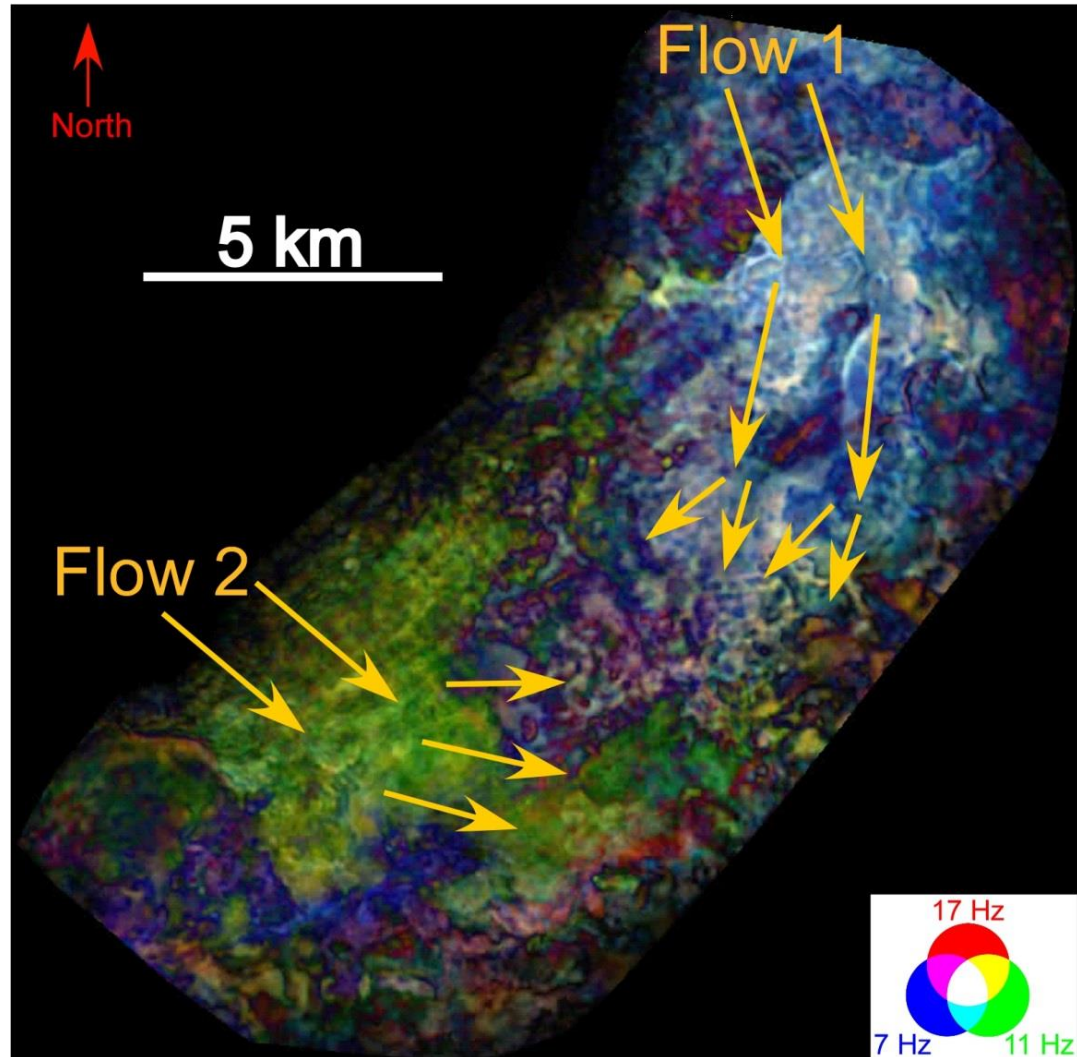
Velocity Modelling – Enhanced structural definition



Proprietary to the Rosebank Joint Venture



Overburden: Spectral Decomposition

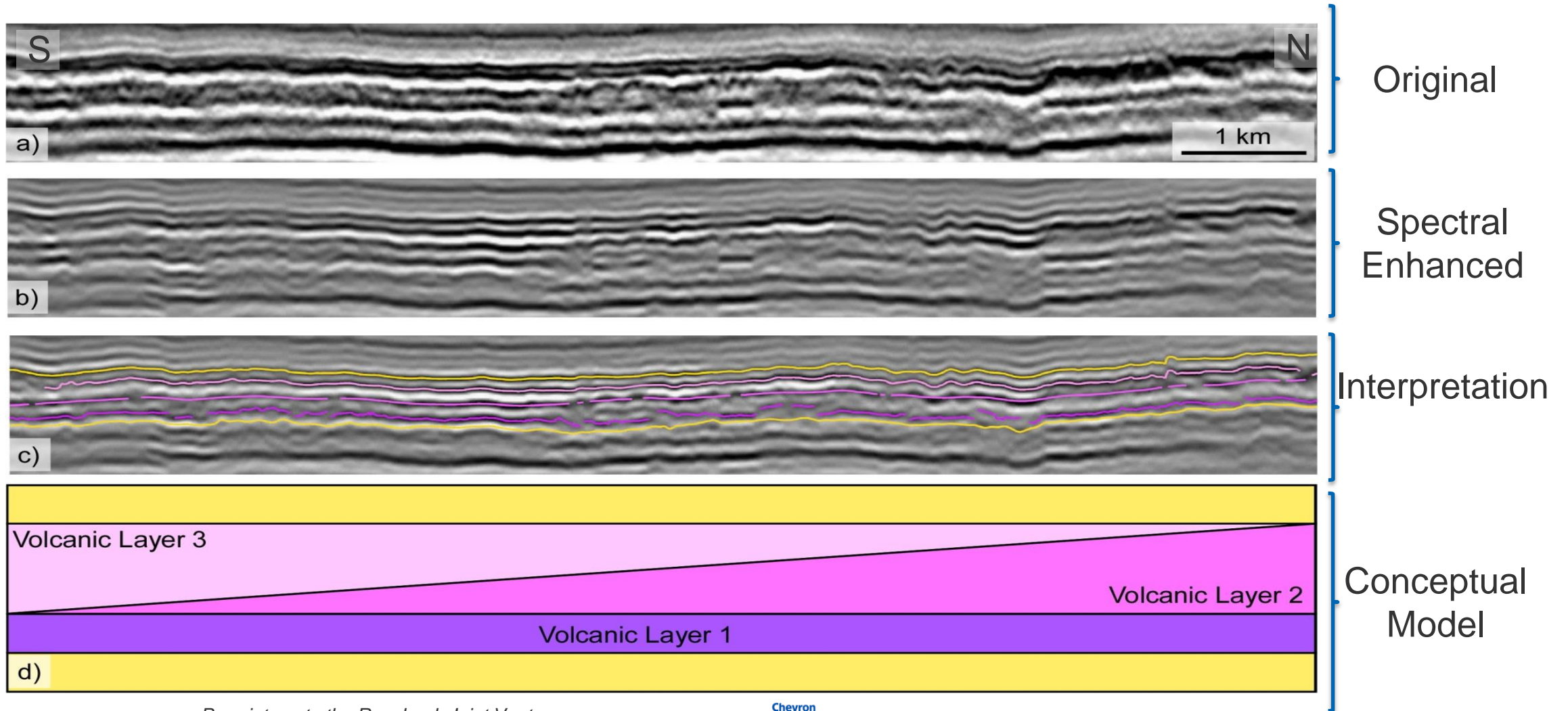


Proprietary to the Rosebank Joint Venture

- RGB (Red-Green-Blue) blend of 3 magnitude volumes (17Hz/11Hz/7Hz)
- Northern area characterized by strong 7 Hz signal (Blue)
- South-western area dominated by 11 Hz signal (Green)
- Central area shows a mixed seismic signal
- Spatial geometry of seismic response point towards individual gross flow packages
- Flow 1 = 75% basaltic, Flow 2 = 75% volcanoclastic



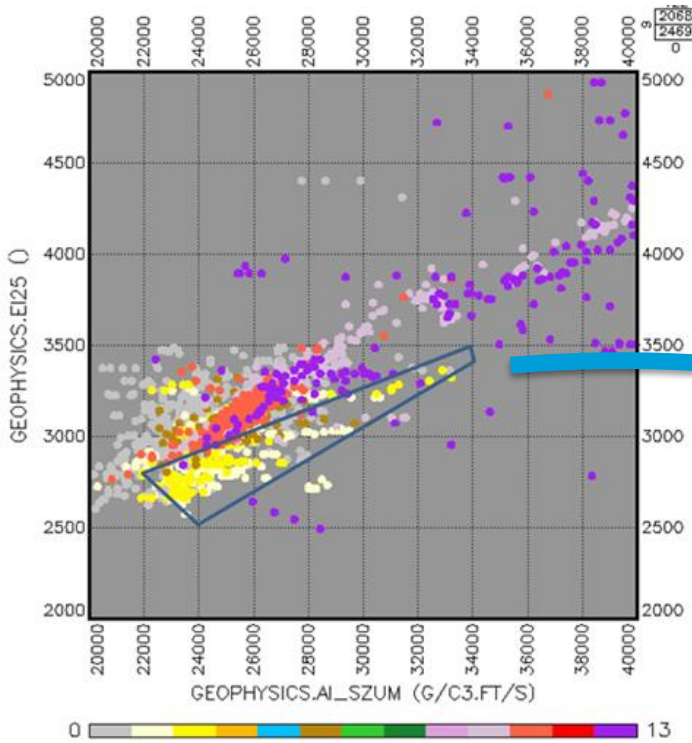
Overburden: Spectral Enhancement



Proprietary to the Rosebank Joint Venture



Reservoir Characterisation: Inversion - interpreting sand vs non-reservoir facies

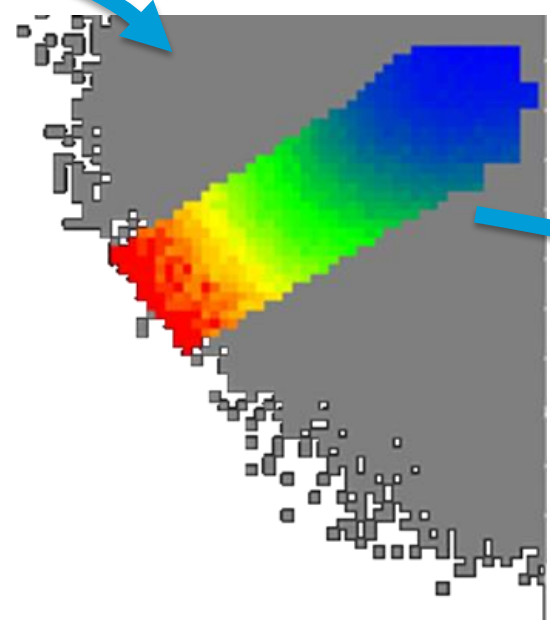


Acoustic vs Elastic Impedance

Well Data Coloured by Facies

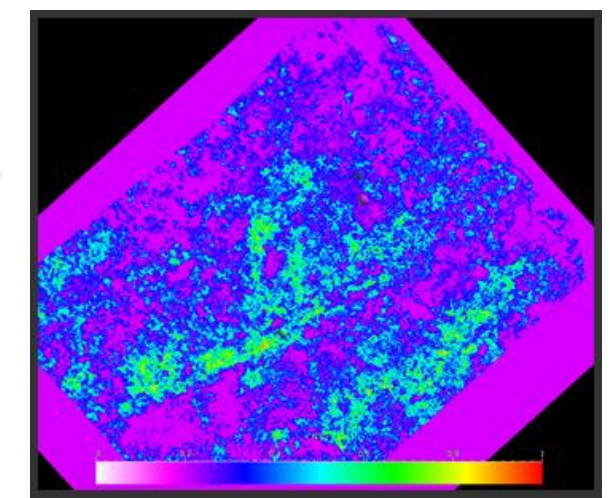
Acoustic vs Elastic Impedance

Seismic Data Coloured by Sample Density



Facies	
Background shale	Grey
Braided sand bars	Yellow
Inter-bar sands	Orange
Mouth Bars	Light Yellow
Overbank	Dark Red
Proximal Pro-delta	Light Green
Distal Pro-delta Silts	Dark Green
Coarse Volcaniclastic	Light Purple
Fine Volcaniclastic	Dark Purple
Coarse Volcanic	Red
Basalt	Magenta

Sand Probability Map



Proprietary to the Rosebank Joint Venture

Conclusions

- Rosebank reservoir unique in subsurface context
 - Significant technical challenges
- Technologies have been screened and selected based on their ability to address these challenges
- Significant image uplift from high quality OBN data acquisition
 - OBN has provided a legacy dataset for the asset
 - Improved structural definition across the Rosebank prospect
 - Quantification of volcanic velocities and improved imaging leading to refined velocity models.
 - Identification of individual basaltic flow units using spectral decomposition techniques.
 - Increased confidence in sand distribution in inter-well space for development planning
- Improve subsurface decision making
 - Better definition of in-place and resource distributions
 - Potential to reduce costs through optimal placement of wells



Acknowledgements

Rosebank Co-Venturers:

- Chevron North Sea Limited
- Suncor Energy UK Limited
- Siccar Point Energy Limited
- DONG E&P (UK) Limited

