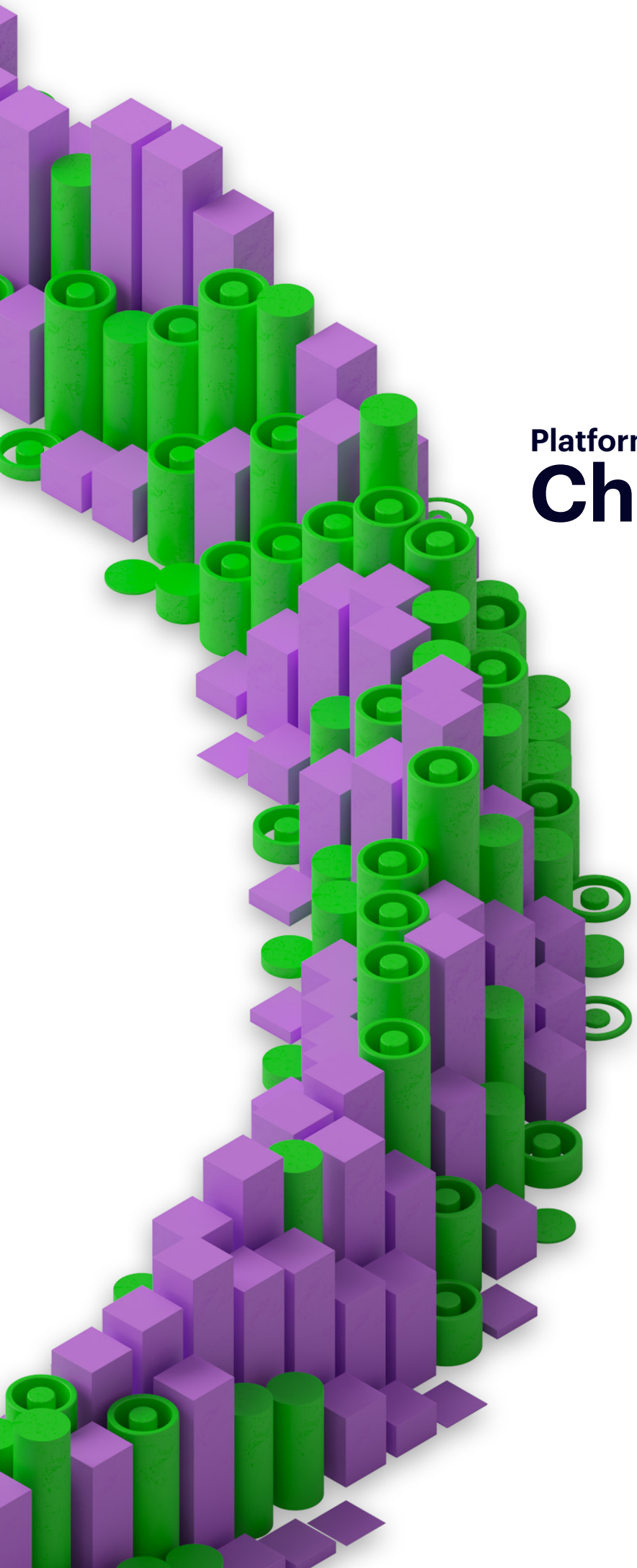
TGT



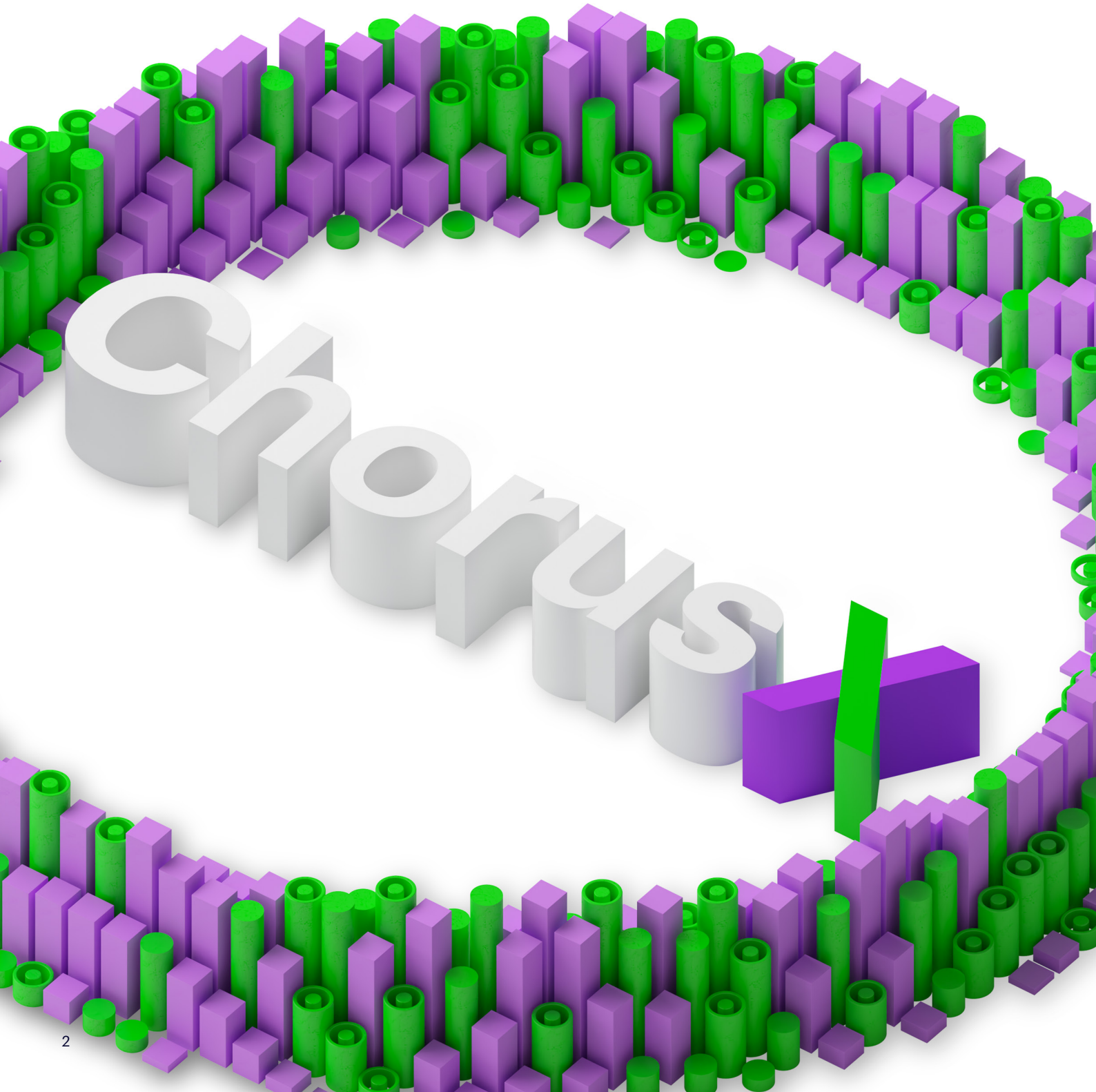
Platform

ChorusX

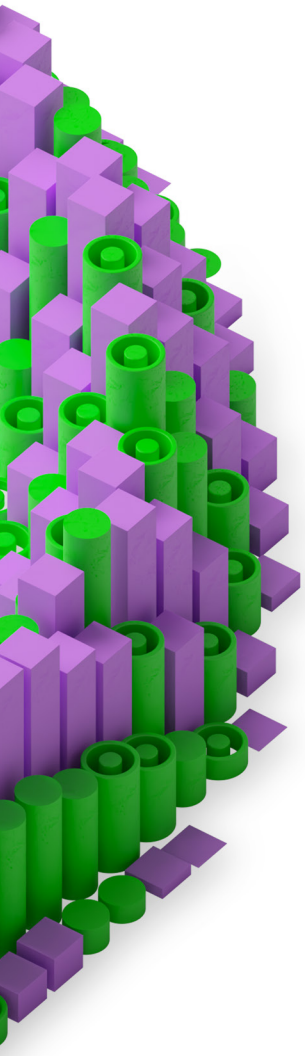
tgtdiagnostics.com

Redefining flow diagnostics

#FindYourFlow



Platform
ChorusX



Find your flow

A flowing well is full of sound encoded with information about the flow that created it. This, and the fact that sound energy penetrates through well and reservoir materials, is why acoustics has become a powerful diagnostic technique for locating and characterising flow. However, the fidelity and resolution of the sound recording, and the effectiveness of processing and analysis technologies all have a direct bearing on the accuracy and certainty of the diagnosis and resulting decisions.

The well-reservoir system is a challenging environment for capturing and analysing the high-fidelity sound required for precise diagnostics. There is a combination of materials and fluids with different acoustic properties, multiple boundaries and mechanical noise that act together to create a complex spectrum of acoustic energy. Decoding the sound and extracting useful flow information from this cacophony requires a special combination of technology, expertise and experience.

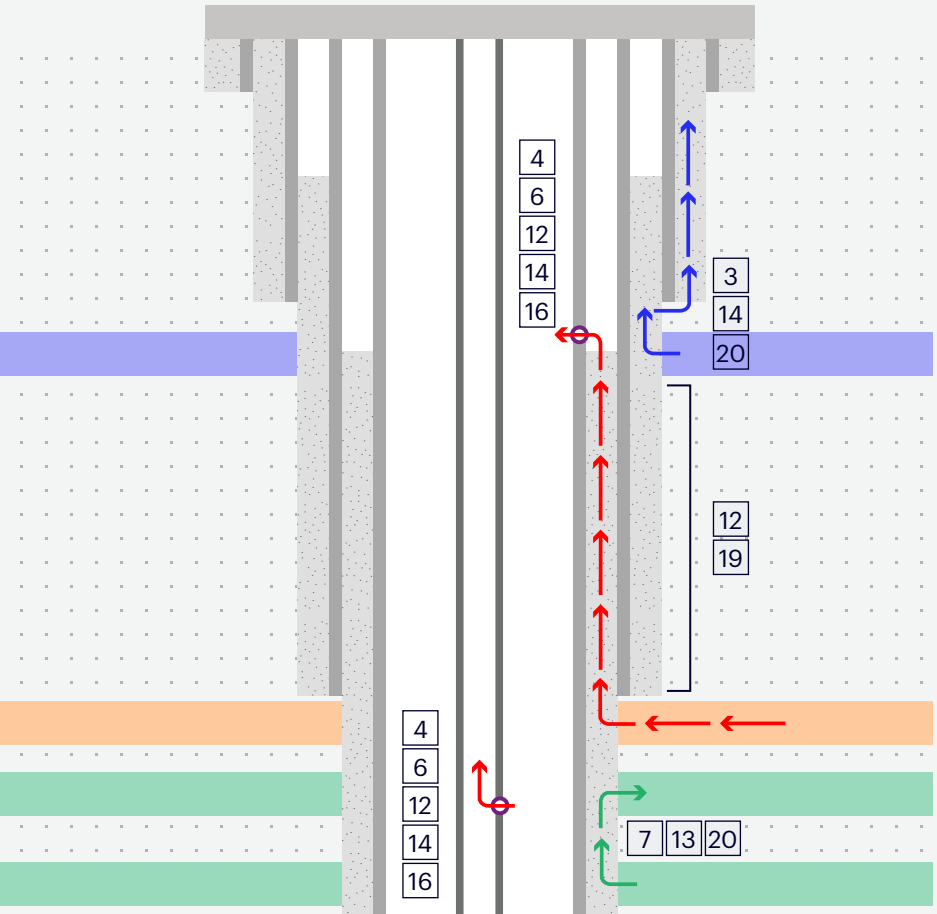
TGT has been advancing the use of acoustics to locate and characterise flow in the well system for two decades. The Chorus brand is already recognised for its sensitivity and dynamic range when capturing high-fidelity flow sounds. Our new generation ChorusX platform takes this capability to a whole new level to deliver exceptional precision, clarity and certainty.

ChorusX has been designed to overcome the limitations of conventional acoustic technology and combines exceptional reach, recognition and locating power to provide production, integrity and reservoir engineers with the ultimate flow analysis resource. Enhanced sensitivity gives ChorusX the spatial reach to capture the furthest and quietest flow sounds from all around the well system. New high-definition acoustic maps can identify the different types of flows that propagate around the well system with exceptional clarity. And the high-resolution sensor array of ChorusX can pinpoint the precise depth of flow activity and its radial proximity to the wellbore.

At the heart of ChorusX is a compact array of eight nano-synchronised sensors that record high-resolution flow sounds across an extreme dynamic range of amplitudes and frequencies. The system also features a unique processing workflow that combines specialised acoustic field modelling with a sophisticated waveform-matching algorithm to bring an important new dimension to acoustics-based flow diagnosis: radial proximity. These advancements underpin four new complementary answer products that analysts and asset teams can use to locate and map flow throughout the well system, easily and accurately.

Analysts and customers can call on four new outputs from ChorusX to resolve complex flow scenarios easily and efficiently. The new high-definition Acoustic Power Spectrum offers increased resolution, greater data density per station, and enhanced visual clarity across a wider range of sound frequencies and amplitudes compared to single-sensor systems. The Acoustic Phase Map can indicate the depth of active flow zones and help determine whether flow is localised or distributed. The Acoustic Radial Map indicates flow source proximity to the well, and the Sound Speed Log provides a qualitative indicator of fluid type in the wellbore.

Understanding flow dynamics in the well system is the key to unlocking better well and reservoir performance. ChorusX technology is available through our comprehensive range of True Flow and True Integrity answer products, to bring a new level of clarity, precision and certainty to well system diagnostics.



Application scenarios

Understanding flow dynamics in the well system is the key to keeping wells safe, clean, and productive, and acoustic techniques have become an indispensable means of achieving that goal. ChorusX combines exceptional reach, recognition and locating power to provide production,

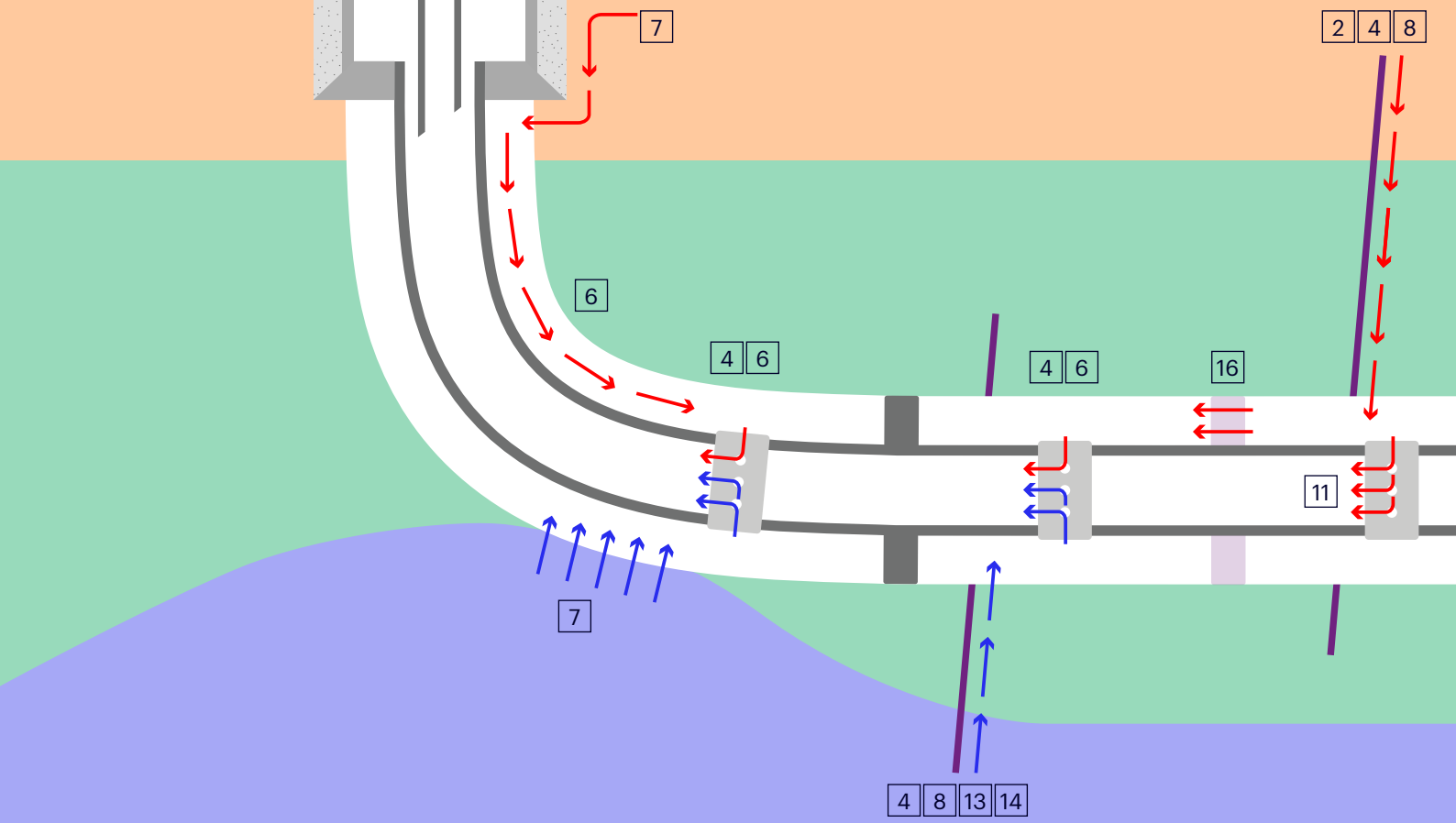
Reach

Ultrahigh sensitivity and extreme dynamic range give ChorusX the spatial and audible reach to record the furthest and quietest flows.

1 Wide spatial scan

2 Intense flows

3 Light flows



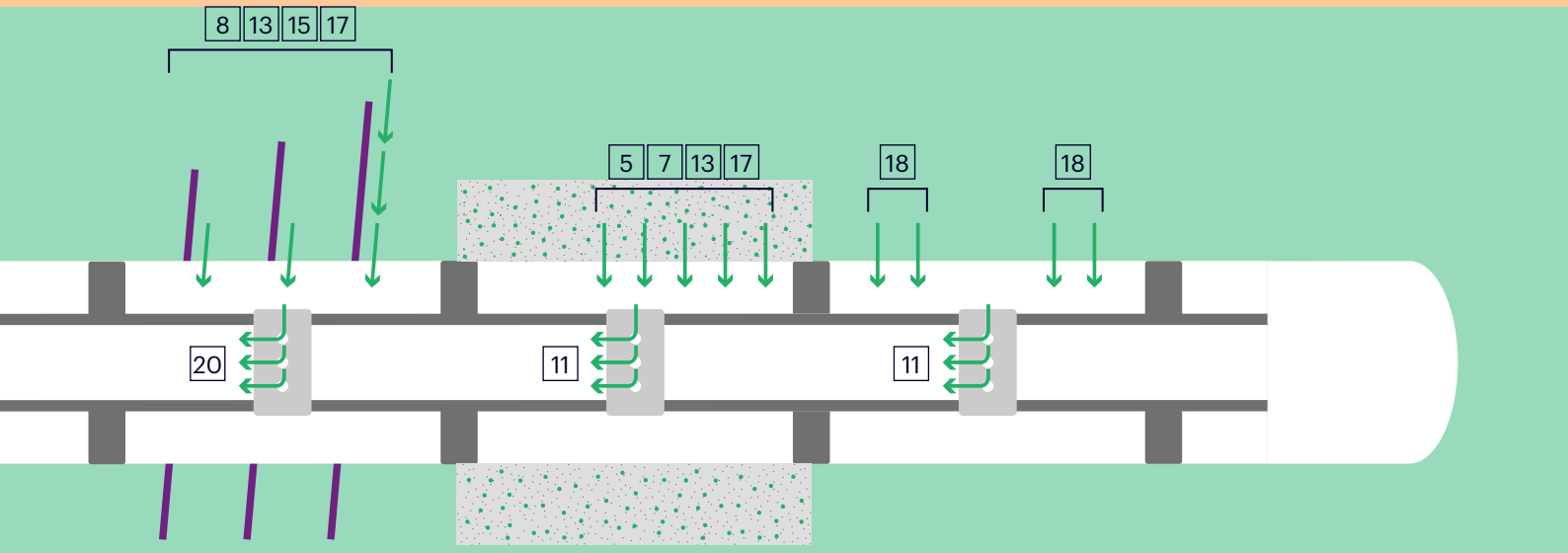
integrity and reservoir engineers with the ultimate flow finding resource. This chart explores a selection of typical flow scenarios and applications found in any well-reservoir system and highlights where ChorusX can help resolve even the most complex diagnostic challenge.

Identify
Four new high-definition acoustic maps enable analysts to recognise and distinguish different types of flow easily and confidently.

- 4 Localised flow
- 5 Distributed flow
- 6 Completion flow
- 7 Reservoir flow
- 8 Fracture flow
- 9 Intense flows
- 10 Light flows
- 11 Fluid type

Locate
Eight high-definition array sensors and a unique phase analysis engine join forces to pinpoint flow sources everywhere in the well system in depth, and radial distance.

- 12 Near flow
- 13 Far flow
- 14 Precise flow depth
- 15 Fractures
- 16 Leak points
- 17 Active stimulated rock interval
- 18 Active producing interval
- 19 Annular flow intervals
- 20 Distinguish depth adjacent flows



ChorusX ingredients
ChorusX is the sum of many parts that work in concert to deliver a range of important benefits to analysts and customers. Each ingredient is special in its own way, but the big gains occur when they are multiplied together.

8x
Array sensors

The multi-sensor array of nano-synchronised, ultra-sensitive, calibrated sensors and data channels found in ChorusX underpins many of the new benefits delivered by this powerful diagnostic technology. The array enables sophisticated phase-shift computations and new, high-precision flow answers. Simultaneous acquisition of high-resolution data from eight sensors brings significant efficiency and data density gains compared with single-sensor platforms. The multi-sensor array also means that ChorusX has built-in redundancy to ensure that surveys can be conducted as planned.

4x
Answers

ChorusX provides four new ways to resolve complex flow scenarios. The Acoustic Power Spectrum offers 3× the resolution, 4× the data density per station, and sharp visual clarity across a wider range of sound frequencies and amplitudes compared with single-sensor systems. The Acoustic Phase Map indicates the depth of active flow zones and helps determine whether flow is localised or distributed. The Acoustic Radial Map indicates flow source proximity, and the Sound Speed Log provides a qualitative indicator of fluid type in the wellbore.

10x
Sensitivity

The sound waves generated by well system fluid flows vary across a wide range of amplitudes. Low-energy, ‘quiet’ sounds, such as those from flows in the outer reaches of the well system, are challenging to detect. In ChorusX, the dynamic range has been extended from 100 dB – 110 SPL, which represents a tenfold improvement in sensitivity. This has been achieved by improving the dynamic recording range at the low-energy end of the spectrum, thereby enhancing detection capabilities for lower energy flows.

3x
Resolution

Survey resolution drives accuracy, precision and clarity. ChorusX sensors are spaced 30 cm apart, which provides a higher-resolution measurement and higher-density data displays than single-sensor technology. This improvement is reflected in the Acoustic Power Spectrum, the Acoustic Phase Map, and the Acoustic Radial Map. Higher resolution improves the delineation and mapping of active flow zones and flow points. It also helps pinpoint leaks with greater precision and discriminates between multiple flows that are in close proximity.

28x
Phase measurements

The acoustic phase modelling, processing and phase-shift computations used in ChorusX represent a leap forward in acoustic science and the application of acoustics to well system flow diagnostics. Phase-shift calculations are the basis for two new principal answers from ChorusX: the Acoustic Phase Map and Acoustic Radial Map. The calculations are fundamental to the near–far proximity indicator, and the shape of the phase transition curve can be used to infer whether the flow is localised or distributed.

2x
Radial proximity

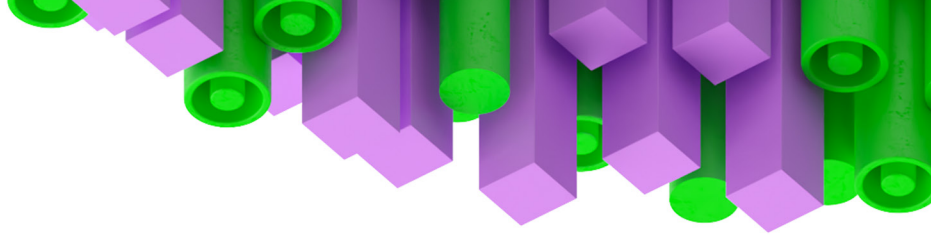
ChorusX determines the radial distance between flow sources and the wellbore with its breakthrough Acoustic Radial Map. Applying a unique and sophisticated phase-shift processing method, the radial map gives a clear indication of near versus far flow sources and a confidence level for the assessment. This removes uncertainties and inefficiencies in the interpretation and decision-making process. The radial map distinguishes between completion flow and reservoir flow, and helps determine whether the flow is localised or distributed.

2x
Frequency range

Well system flows generate sound waves with frequencies ranging from a few hertz to more than 100 kHz. Analysts use frequency data to characterise the flow and its source, so recording systems must record and display sound accurately and with uncompromised fidelity across that frequency range. ChorusX combines high-resolution sensors with eight wideband data channels and two low-frequency channels to capture flow-generated sound from 7 Hz to 120 kHz. This enables analysts to characterise flow and fluid type across a wide range of scenarios.

3x
Efficiency

ChorusX can improve efficiency at all stages from surveying through to implementing an action plan. During the survey phase, ChorusX offers increased data density, reduced survey time or a combination of both. During analysis, ChorusX delivers a range of complementary answers that enable analysts to reach a more accurate interpretation more efficiently. Having a more robust and accurate picture of the well system enables better decisions and means that remediation plans have a greater prospect of first-time success.



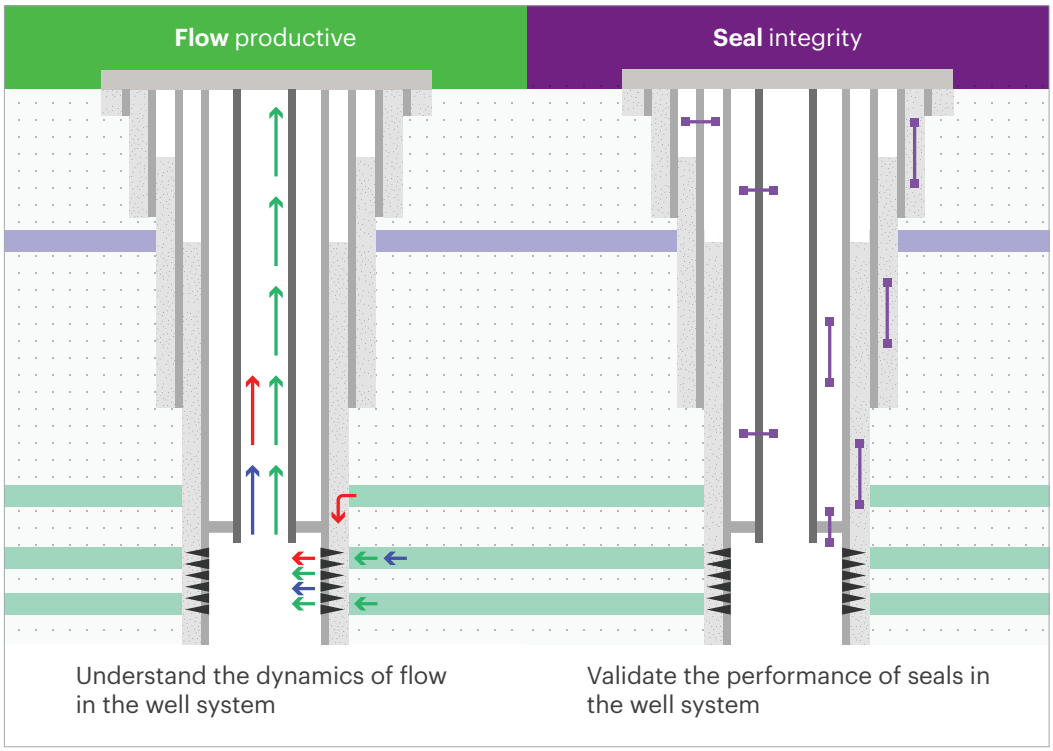
Diagnostic products

Well systems perform by connecting the right fluids to the right places, and mapping flow dynamics downhole is essential to keeping wells safe, clean, and productive. ChorusX provides asset teams with the flow insights they need to manage well and reservoir performance more effectively.

As an integral part of TGT's 'True Flow' and 'True Integrity' diagnostic systems, ChorusX capability is available through a range of application-specific answer products. Through these answer products, ChorusX delivers clear, complementary answers that enable analysts and customers to reach an accurate diagnosis more efficiently. A robust and accurate picture of the well system enables better decisions and positive outcomes. This means that, when remediation plans are being implemented, there is a greater prospect of first-time success.

True Flow products help asset teams to understand flow dynamics between the reservoir formations and the well completion. Notably, these answer products reveal flow where it matters most—at the reservoir. Some of the distinct True Flow applications and benefits brought by ChorusX include fracture assessment, delineating active formations, and distinguishing between reservoir flow and completion flow.

True Integrity / Seal Integrity products help asset teams to validate the performance of seals and barriers throughout the well system, including packers, cemented annuli, tubulars, and valves. Typical applications for ChorusX include revealing low-rate leaks, tracing the source of B and C annulus pressure, and resolving leaks in close proximity to each other.



Application categories	**True Flow** applications	**Seal Integrity** applications
Products 	Total Flow Reservoir Flow Fracture Flow Horizontal Flow Dual String Flow Stimulate Flow	Multi Seal Integrity Cement Seal Integrity
General 	Production flow assurance Assess uncemented completions Investigate injection compliance Investigate high gas-oil ratio Pre-and post-fracture assessment Pre-and post-stimulation assessment Decarbonise operations	Integrity assurance Assess complex completions Pre- and post-P&A assessment Optimise P&A operations Finding source of methane leaks Resolving sustained annulus pressure Decarbonise operations
Resolution 	Delineate active formations Identify flow boundaries precisely	Evaluate complex completion elements Distinguish leaks in close poximity
Sensitivity 	Reveal low-rate reservoir flows	Reveal low-rate leaks & annulus flow Resolve source of outer SAP Resolve source of emerging SAP
Proximity 	Distinguish reservoir flow vs completion flow	Distinguish completion leak vs reservoir flow
Clarity 	Distinguish point source vs distributed Locate active fractures Define Active Fracture Interval (AFI) Characterise Fracture vs Matrix flow	Distinguish point source vs distributed Trace leaks and annular flow paths
Efficiency 	Survey longer sections in less time Rapid, higher-confidence analysis Reach correct decisions more quickly Implement actions with higher success	Survey longer sections in less time Rapid, higher-confidence analysis Reach correct decisions more quickly Implement actions with higher success

Case study#1
New acoustic array platform finds elusive low-rate leak source in active well

Challenge
Leaks observed in an active well in the Netherlands forced the operator Nederlandse Aardolie Maatschappij (NAM) to suspend the well. An initial examination indicated that the integrity breach could be located in the tubing, casing or any of the completion elements within or beyond the A-annulus envelope. A pressure test confirmed that the leak rate was small, just 0.25 bar per day, but this was sufficient to pose a health, safety and environmental risk and trigger suspension of the well.

Leaks in the well system are a serious issue, and well integrity engineers want to understand precisely how and where the leaks originate so they can be repaired. The combination of many potential leak points spanning the length of the completion coupled with a small leak rate made this a challenge to investigate.

The operator needed diagnostics technology that had a large radial reach and was both sensitive and accurate enough to scan for leak points and help steer a repair programme.

Solution
The operator selected TGT's Multi Seal Integrity answer product, upgraded with the new ChorusX acoustic array platform to meet the three-part challenge of sensitivity, accuracy and reach. ChorusX combines an array of eight nano-synchronised acoustic sensors with advanced processing to deliver a dynamic recording range that is ten times wider than in previous Chorus technology, specifically at the 'quiet' low-amplitude end of the Acoustic Power Spectrum.

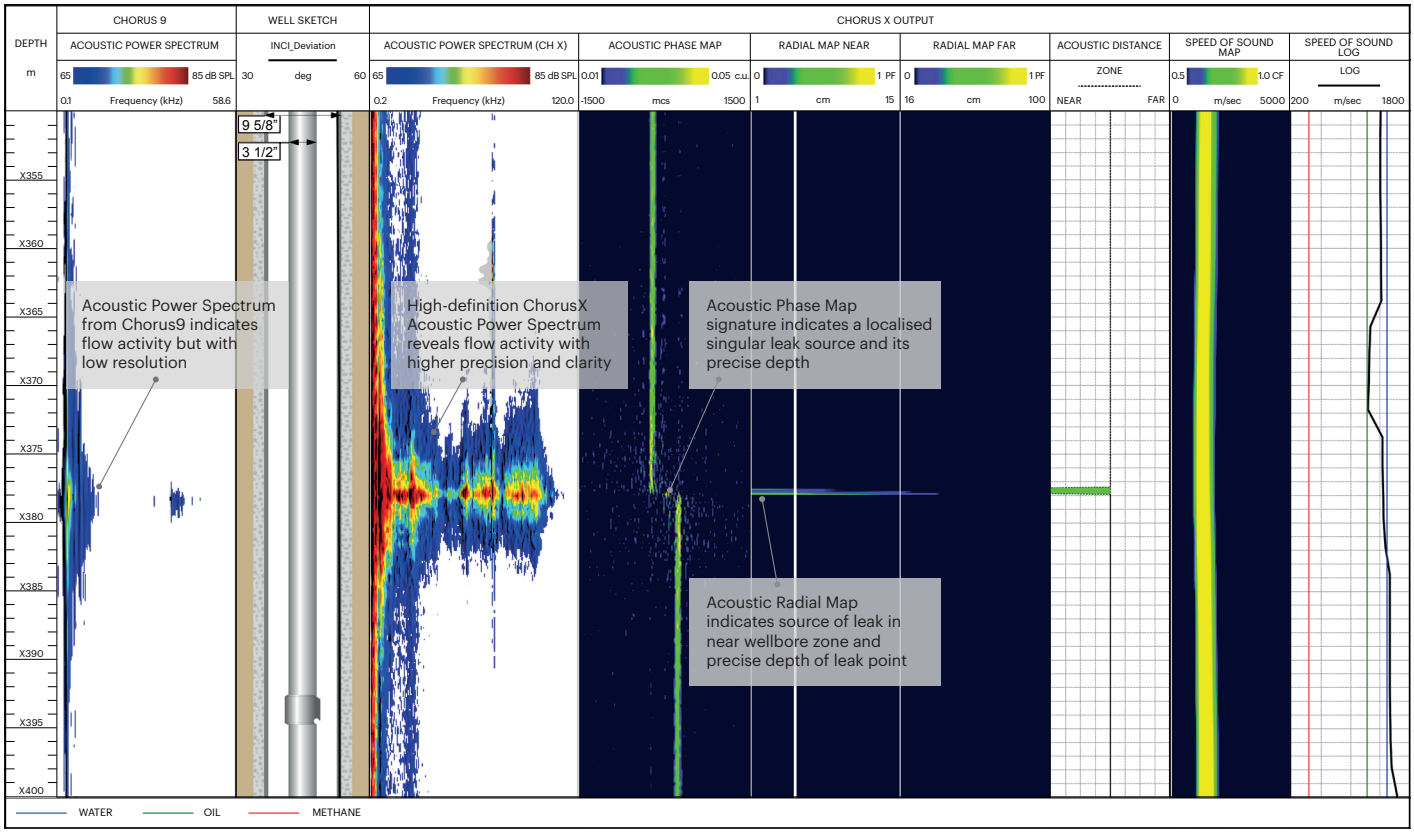
The higher-resolution measurements from the ChorusX array reveal flow activity with increased definition and clarity, and TGT's unique 'near–far' phase shift processing helps analysts distinguish between flow events near the wellbore, in the completion, and far from the wellbore, in the reservoir. This enables operators to target remedial actions with greater precision and implement them with higher confidence. The operator also chose to include Chorus9 technology in the survey programme to make a technical comparison between the two platforms.

Result

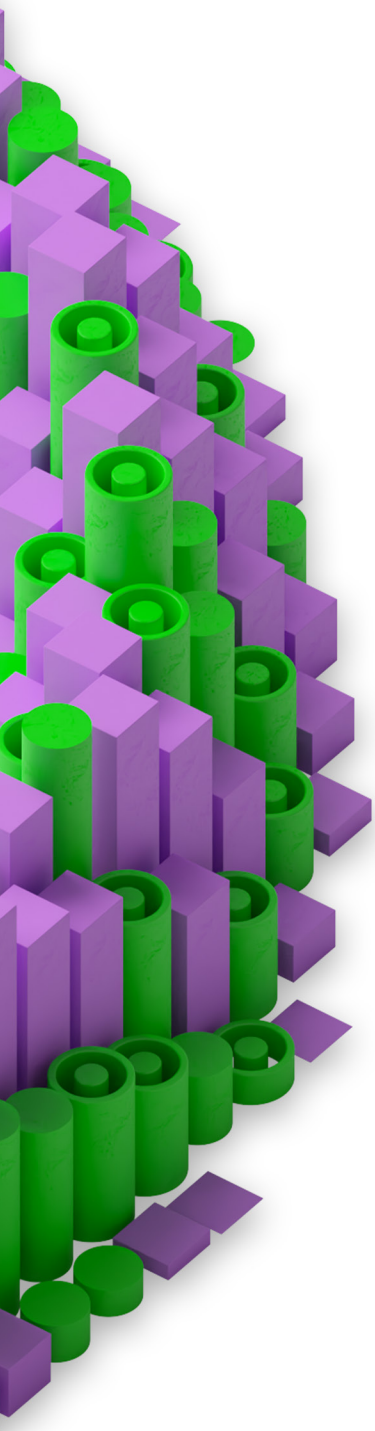
The Multi Seal Integrity survey was performed while applying pressure in the A-annulus and observing a pressure drop of 0.25 bar per day, confirming the very low leak-rate. The Chorus9 and ChorusX platforms both recorded acoustic signals at X378 m, but the Acoustic Power Spectrum (APS) of ChorusX was far more detailed and informative (Figure 1).

The sharp change in polarity of the phase shift data, as seen in the Acoustic Phase Map, indicated a localised 'singular' leak point and its precise depth. The location and character of the data signature in the 'near' panel of the Acoustic Radial Map indicated that the source of flow was near the wellbore within the completion, and not in the reservoir. The precise nature of the radial map data signature further confirmed the exact depth of the leak source.

The combination of independent and complementary acoustic indicators enabled analysts and the operator to isolate the integrity breach to a single location in terms of depth, extent and radial distance from the wellbore. This enabled a highly targeted approach to remediation planning and implementation.



Multi Seal Integrity answer product using ChorusX. The Chorus9 acoustic power spectrum (left) indicates the approximate depth of the leak, but multiple indicators from ChorusX (right) combine to indicate the type, depth, radial proximity and extent of the integrity breach with much greater precision and clarity.



Case study#2
New array acoustics system enables operator to locate fractures and streamline completion strategy

Challenge
Gas is often produced from tight formations using a combination of horizontal wells, multi-zone completions and multi-stage hydraulic fracturing. The wells are typically completed using a cemented liner or an uncemented liner equipped with sliding sleeve valves/ports and external packers to isolate each zone during multi-stage fracturing and prevent inter-zonal communication during production so that each zone can be monitored and produced independently.

The operator of a deep high-pressure low-permeability gas field wanted to assess the feasibility and effectiveness of completing a horizontal well with an uncemented liner that had 10 sliding sleeve valves/ports but, unusually, no isolation packers.

Isolation packers add considerable cost and complexity in terms of mechanical assembly, running of the completion and potential seal failures during the well's operating life. Completed in the standard way, this well would require 10 packers. A successful strategy for removal of the packers would lower completion costs, increase installation efficiency, and reduce future maintenance challenges. These savings and efficiencies would multiply substantially for field-wide application.

The chief concerns about the new strategy were that a lack of isolation during fracturing might prevent sufficient fracture force being focused on each target zone and whether the result would be one large fracture rather than multiple distributed fractures. Another challenge was to evaluate the success of the strategy by identifying and locating the fractures to establish their extent along the wellbore and assess the performance of each fracture group.

Conventional production diagnostics could only assess flow entering the wellbore at each port and would therefore not reveal fracture location or distribution, or even distinguish reservoir flow from port flow. Sophisticated post-fracture assessment was needed to determine whether the technique had been successful, and to fine-tune future operations.

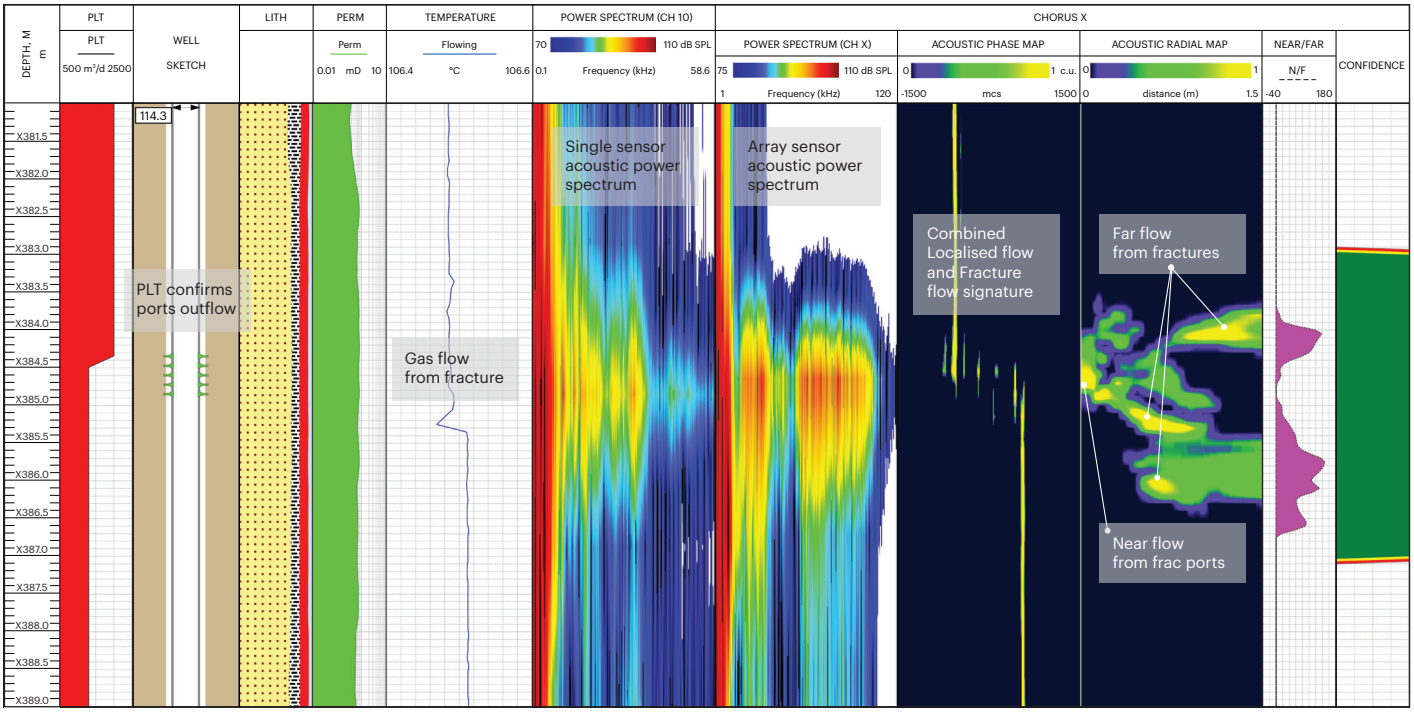
Solution
TGT's Fracture Flow diagnostics product is used to evaluate the effectiveness of hydraulic fracturing operations. In this well, the new ChorusX acoustic array platform was included in the survey programme to bring a wide range of additional benefits and fracture performance insights.

Using ChorusX, analysts located the precise depth and distribution of induced fractures and evaluated the relative contribution from each fracture along the entire reservoir section. ChorusX can distinguish between flow from fractures and flow through the sliding sleeve valves, even when the fractures are located at the same depth interval as the valves. This breakthrough enables the operator to distinguish between port flow and fracture flow, thus giving greater clarity and certainty to evaluations.

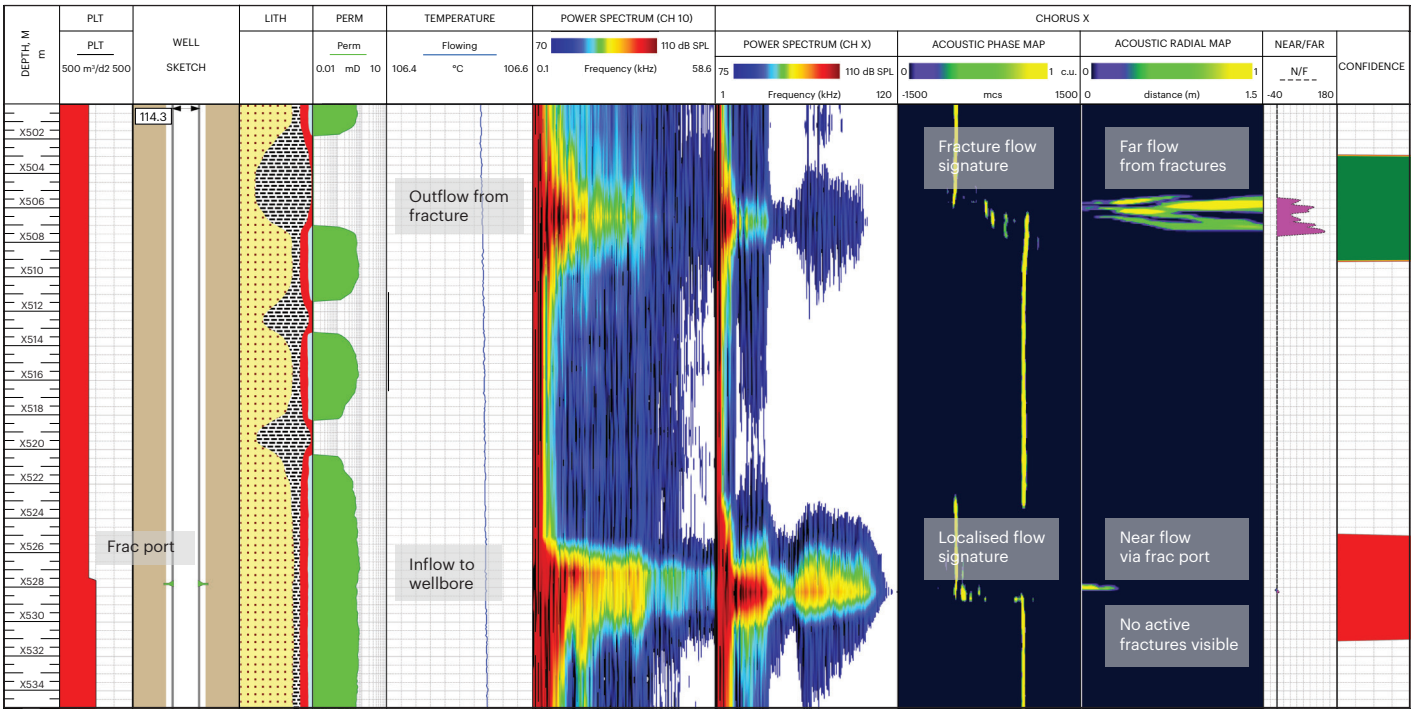
Result
TGT analysts used ChorusX data to identify and precisely locate fractures right along the reservoir section. The survey also provided an accurate flow geometry that displays the relative contribution that each fracture makes to production.

The Acoustic Radial Map serves as a high-resolution, near–far indicator for flow and can distinguish between port flow and reservoir fractures in the immediate vicinity of the ports. These innovative features are unavailable in even the most advanced single-sensor acoustics systems.

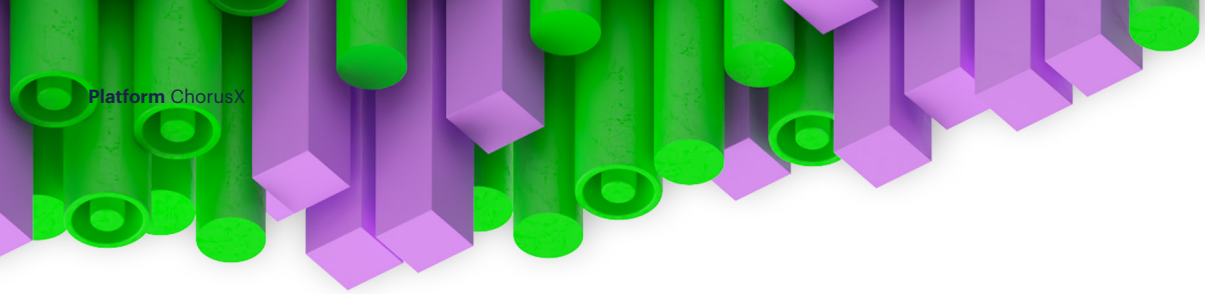
The Fracture Flow product with ChorusX technology proved the effectiveness and viability of the new, ultra-efficient completion technique in this geological setting. The results provided the operator with valuable insights that will enable them to optimise the fracturing parameters and the completion design for field-wide roll-out. This will deliver enormous savings in time, cost and resources, thereby helping operators access 'hard to recover' reserves in a more efficient and economic way.



New ChorusX answers transform the professional workflow, enabling analysts to diagnose well systems flows with greater ease and confidence. In this complex scenario, the Phase Map and Radial Map reveal the location of active fractures directly behind the frac ports. Conventional diagnostics would be unable to deliver this level of clarity and certainty.



Analysts can call on new ChorusX answers to resolve even the most complex flow scenarios. The Phase Map and Radial Map bring valuable insights that complement other measurements, leading to a more confident diagnosis. The top section of this ChorusX answer product identifies and locates active fractures, whereas the lower section confirms that no active fractures are present.

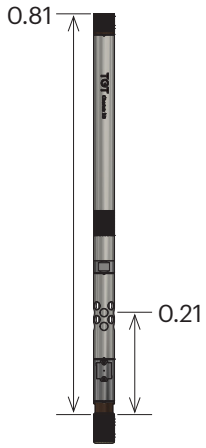


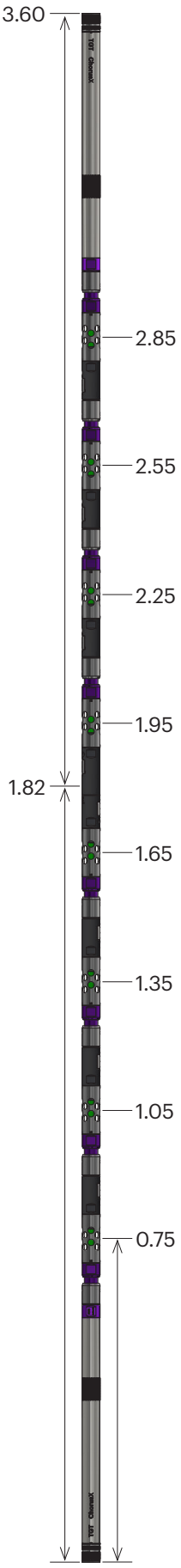
Chorus10
Measurement specifications

Measurement principle	Acoustics
Measurement type	Frequency Amplitude
Sensors	1
Resolution, m	0.8 – 1
Principal outputs	Acoustic Power Spectrum
Recording channels	1x Wideband / 117 Hz – 59 kHz HD mode 1x 512 UHD mode 1x 1024 Full HD mode 1x 4096 [Sand Flow] 1x Lowband / 9.5 Hz – 4.9 kHz HD mode 1x 512 channels UHD mode 1x 1024 channels
Analogue to Digital A2D sampling, kHz	118 16-bit
Frequency range, Hz	9.5 – 60,000
Amplitude range, dB SPL	Wideband 100 Lowband 108
Survey mode	Real time or memory
Station interval, m	1
Station period, s	30
Combinable	Yes

Mechanical specifications

Temperature range, degF [degC]	-4 to 302 [-20 to 150]
Maximum pressure, psi [MPa]	14,500 [100]
Housing material	Titanium
Maximum H_2S content, %	≤30 with TFE/P black duro o-rings
Maximum compression, kgf [lbf]	5,000 [11,023]
Maximum tension, kgf [lbf]	5,000 [11,023]
Outside diameter, in [mm]	1.65 [42]
Tool length, ft [m]	2.65 [0.81]
Tool weight, lb [kg]	11.68 [5.3]
Memory, Gb	2
Recording time, h	140



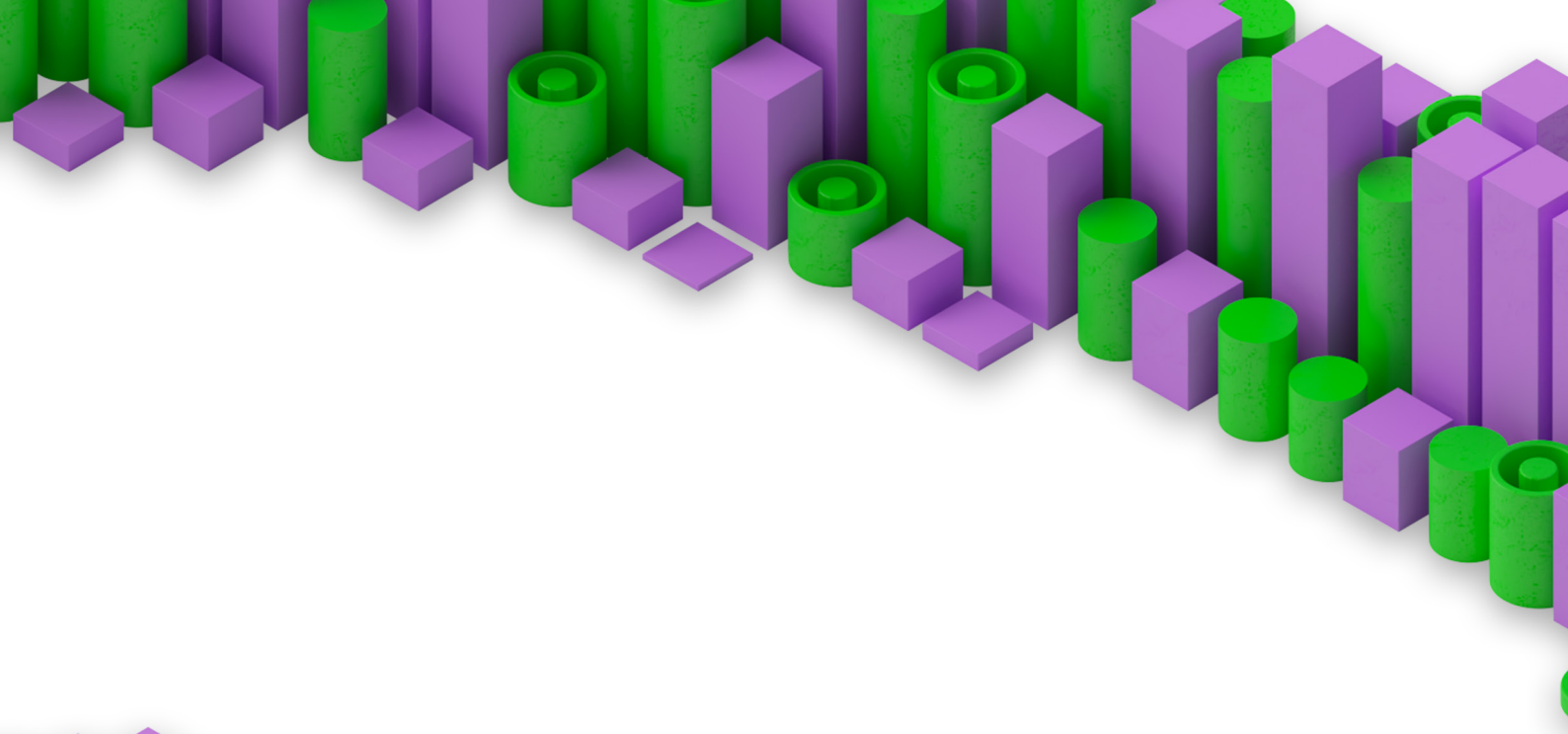


ChorusX
Measurement specifications

Measurement principle	High-definition array acoustics
Measurement type	Frequency Amplitude Phase
Sensors	8
Resolution, m	0.3
Principal outputs	Acoustic Power Spectrum HD Acoustic Phase Map Acoustic Radial Map Sound Speed Map
Recording channels	8x Wideband / 234 Hz – 120 kHz HD mode 8x 512 UHD mode 8x 1024 [Phase] Full HD mode 1x 8192 [Sand Flow] 2x Lowband / 7 Hz – 3.7 kHz HD mode 2x 512 channels UHD mode 2x 1024 channels
Analogue to Digital A2D sampling, kHz	240 16-bit
Frequency range, Hz	7 – 120,000
Amplitude range, dB SPL	Wideband 110 Lowband 110
Survey mode	Real time or memory
Station interval, m	2
Station period, s	30
Combinable	Yes

Mechanical specifications

Temperature range, degF [degC]	-4 to 302 [-20 to 150]
Maximum pressure, psi [MPa]	14,500 [100]
Housing material	Titanium
Maximum H_2S content, %	≤30 with TFE/P black duro o-rings
Maximum compression, kgf [lbf]	5,000 [11,023]
Maximum tension, kgf [lbf]	5,000 [11,023]
Outside diameter, in [mm]	1.65 [42]
Tool length, ft [m]	11.81 [3.6]
Tool weight, lb [kg]	61.72 [28]
Memory, Gb	24
Recording time, h	280 HD / 140 UHD



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