güralp

MICROSEISMIC MONITORING

FOR THE ENERGY SECTOR

UNDERSTAND
OPTIMISE
PROTECT

PROJECT MANAGEMENT

TURNKEY SOLUTIONS

FIELD SERVICES, INTEGRATION TESTING AND COMMISSIONING

MAINTENANCE AND AFTER-SALES TECHNICAL SUPPORT

INSTRUMENT RENTAL POOL

Est. **1985** PIONEER OF THE MINIATURE FORCE-FEEDBACK BROADBAND SEISMOMETER

35,000 INSTRUMENTS SUPPLIED TO CUSTOMERS ACROSS ALL CONTINENTS

500+ OCEAN BOTTOM SEISMOMETERS DEPLOYED IN ALL MAJOR OCEAN BASINS

Optimise production, comply with regulatory requirements and reduce risk

Güralp Systems is a world leader in the design and manufacture of revolutionary broadband seismic monitoring systems.

Broadband seismic data is critical for the accurate magnitude estimation required for regulatory compliance monitoring of induced seismicity. This is particularly relevant to processes in energy production or carbon sequestration that involve injection into the subsurface.

Our world renowned broadband instrumentation is capable of providing you with the data you need to be confident in your operational activities.

Working with our trusted partners we can offer project management and a complete turnkey service for the full project life cycle. This can include network design, instrumentation supply, installation, system maintenance, data processing and reporting as may be required for regulatory requirements.

Güralp installed arrays have been delivering continuous monitoring to customers for more than twenty years.

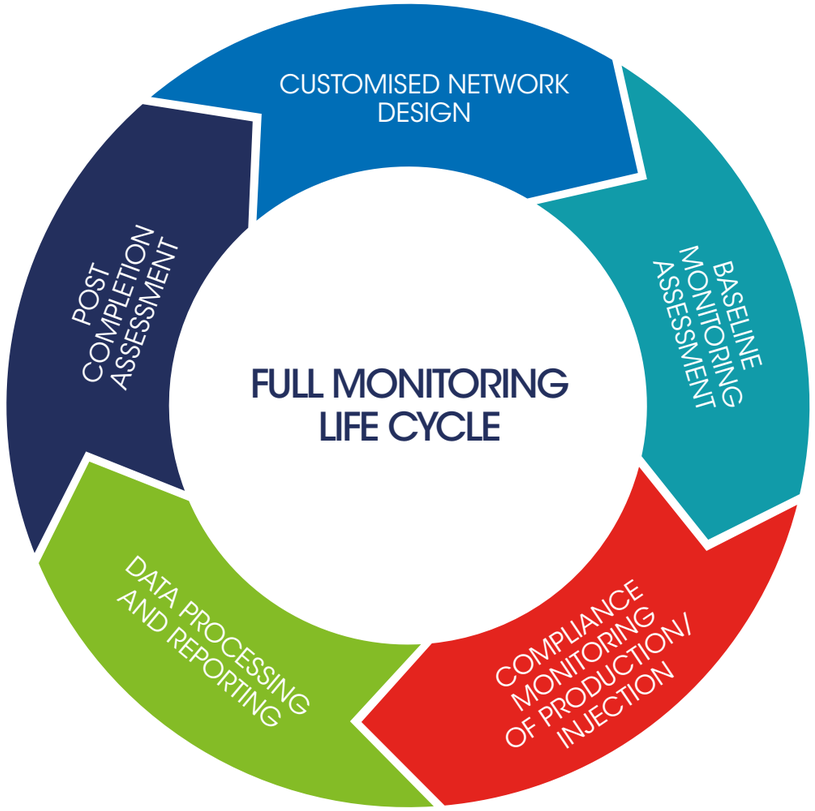


IMAGE 1: HYDRAULIC FRACTURE OPERATIONS, UKRAINE

FRACTURE MONITORING

Governments are increasingly imposing a legal requirement for hydraulic fracturing operations to be monitored for microseismic activity. The area of operation is monitored in real-time so that site injection rates can be adjusted dependent on the observed activity. This is usually done using a traffic light system based on the limits imposed in the jurisdiction of the operations.

Dense surface geophone arrays can be costly and can also underestimate event magnitude (for further information see page 8). Sparse broadband arrays are becoming increasingly popular with operators as they provide a cost-effective monitoring system with higher levels of data confidence. They can also be used to undertake pre-operation baseline studies.

Working with global partners we have successfully provided turnkey monitoring packages to address the requirements of the fluid injection industry.

CASE STUDY 1:

Oklahoma Fracture Monitoring

- A small array of Güralp seismometers monitored a hydraulic fracture stimulation in Oklahoma, U.S.
- Using broadband data and an advanced event location method, we were able to detect five times the number of earthquakes than conventional analyses.
- Our results showed that using advanced event location methods with broadband data is critical for compliance with regulatory traffic light systems that require low frequency magnitude thresholds.

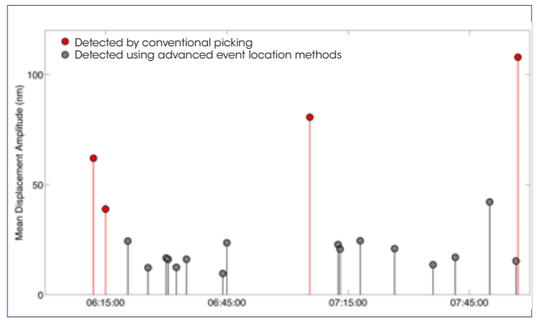


DIAGRAM 1:
MEAN DISPLACEMENT AMPLITUDES OF EVENTS DETECTED DURING TRIALS. THE BROADBAND INSTRUMENTATION DETECTS SMALLER EVENTS MISSED BY CONVENTIONAL ANALYSIS.

DIGITISER FOCUS - **MINIMUS**

The Minimus, either stand-alone or integrated with the sensor, delivers data and instrument management and state-of-the-art communication capabilities.

For microseismic monitoring applications, key Minimus features include:

- Industry standard triggering algorithms (STA/LTA)
- Common Alert Protocol (CAP) enabled to deliver automated messaging if thresholds are breached
- Multi-instrument voting to mitigate false positive alerts
- An ultra-low latency mode for network transmission in 40 milli-seconds - ideal for traffic light warning systems
- Available with either four or eight channels
- Remotely configure response or gain settings on instrumentation in the network

Configuration controls can be accessed via our software application Discovery (or via a standard web browser) providing a simple, user-friendly format for managing the monitoring network.

MINIMUS DIGITISER

EXAMPLE MONITORING THRESHOLDS FOR TRAFFIC LIGHT SYSTEMS

IMAGE 2: KRAFLA GEOTHERMAL POWER PLANT, ICELAND

GEOTHERMAL POWER PLANT MONITORING

Broadband seismometers are used for obtaining accurate hypocentre locations and, using seismic tomography techniques, to image the subsurface and determine the structural features that constitute the geothermal region.

We can also deliver baseline seismicity surveys before, during and after operations with options for real-time data processing and simple traffic light displays for operational feedback. We have installed geothermal monitoring systems that have been in operation for more than fifteen years.

INSTRUMENT FOCUS - BROADBAND SENSORS

1. FORTIS
Fortis is a cost effective, low-noise, force-feedback accelerometer with a large dynamic range, ideal for microseismic applications. Remotely adjustable gain options of 0.5 g - 4 g can be controlled by most seismic digitisers.

2. FORTIMUS
Fortimus combines the Fortis sensor with an internal Minimus digitiser offering all the benefits of both, but in one package. Ultra-low latency alert capabilities make this combination ideal for traffic light monitoring applications.

THE REMOTELY CONFIGURABLE RESPONSE OF THESE INSTRUMENTS DELIVERS FLEXIBILITY AND SIMPLIFIED NETWORK MANAGEMENT

3. CERTIS
The advanced sensor technology of the compact Certis seismometer delivers analogue output with state-of-health parameters. Operational up to 90° from level, Certis' wide frequency response of 120 s - 100 Hz also benefits from a remotely adjustable long-period corner.

4. CERTIMUS
Certimus is a complete plug-and-play medium-motion seismic station with a ± 90° tilt range for fast and easy installation. As with Fortimus, an internal Minimus digitiser delivers state-of-the-art communication capabilities including event detection and triggered alert capability.

CASE STUDY 2:

Iceland Geothermal Monitoring, University of Cambridge

- Geothermal fields are commonly situated close to the boundaries of the earth's tectonic plates making it difficult to determine whether earthquakes occur due to natural processes or geothermal activities caused by humans.
- A dense array of 24 Güralp seismometers monitored the Krafla volcanic region of Iceland.
- Over 3,000 events were detected in the 14 months of the array's operation.
- Locations of the earthquakes show that most were located beneath the Krafla caldera in the uppermost 2-3 km of the crust.
- Inversion of earthquake focal mechanisms show that many seismic events have complex source mechanics. The presence of some implosive source mechanisms are consistent with fracturing due to fluid migration.
- The majority of earthquakes were interpreted to coincide spatially with the location of the main geothermal field. A small number of events were also associated with drilling of geothermal boreholes. A number of small earthquakes were found to occur along fissure swarms; these events are likely to have been caused by natural tectonic processes.

CASE STUDY 3:

Deep Geothermal Systems, Germany Goethe-University Frankfurt

"The signal to noise ratio is impressively high considering the distance to the array and the relatively small magnitude."

Dr. Philip Hering, Institute for Geosciences, Geophysics Goethe-University Frankfurt

- Rheinland-Pfalz region of Germany is the location of several geothermal power plants. Goethe-University Frankfurt installed a seismic array system to provide large-scale monitoring of seismicity in the region within the framework of a publicly-funded geothermal project.
- The Landau and Insheim geothermal power plants are separated by just 4 km.
- Specific array pattern functions are being developed to detect and identify induced earthquakes in the directional beam of the array.
- Nine Güralp Certimus seimic stations were deployed powered solely by solar panels with no loss of performance, even during darker winter months.
- The array is collecting data to establish a solid data base for classification algorithms.
- If successful, the array may be integrated with the existing conventional seismic networks operated by the regional authorities and the geothermal companies that provide the traffic light warning system for the geothermal plants.

CARBON CAPTURE, UTILISATION AND STORAGE (CCUS)

CCUS is a fast-growing emissions reduction technology involving the capture, transportation, use or permanent storage of CO_2 in an underground geological formation to permanently remove it from the atmosphere. This storage method has been applied previously to aid Enhanced Oil Recovery but it is now being investigated as a long-term solution for carbon storage, both onshore and offshore.

As with other ground injection methods, microseismic monitoring will play an important role in ensuring that CO_2 is injected and stored safely. Since 2008 our instrumentation has been used on a number of projects to monitor seismicity around carbon injection sites in North America and Europe.

We have broadband instruments suitable for monitoring the process for induced seismicity whether for onshore, subsurface, such as for vertical seismic profiling (VSP), or offshore scenarios.

Our instrumentation offers event detection coupled with ultra-low latency data and triggering capability to ensure operations are conducted safely and within pre-determined parameters. For sites located near to other instrastructure, our borehole instruments minimise the impact of surface noise on the seismic response.

Our ocean bottom broadband seismometers have been utilised with both active source and passive imaging. The use of broadband systems for active source imaging can provide greater insights to sub-surface structure at depth.

CASE STUDY 4:

UK Geoenergy Test Bed

- The Radian is currently being utilised by the British Geological Survey as part of the UK GeoEnergy Test Bed (GTB) to monitor and improve understanding of fluid flow through natural subsurface pathways.
- A string of six interconnected Radians provides vertical profiling around the injection site with a maximum of eight units able to join in a single string.
- The Radian will detect and monitor small changes in the subsurface at the GTB as part of the suite of monitoring technologies deployed onsite.

CASE STUDY 5:

Carbon Management Canada (CMC)

- The University of Oxford and the University of Bristol are working on a joint project with CMC to monitor CO_2 injection at the CMC test site using broadband seismometers.
- Research undertaken at the test site is informing authorities seeking to establish safe CO_2 storage monitoring protocols within a regulatory framework, as well as informing industry best practices.
- Seven Güralp seismometers were deployed in 2015 to monitor baseline seismicity one year prior to testing.
- 335 events exceeding M4.5, 556 regional events and no local events were detected during baseline monitoring
- The seismometers remain in situ monitoring injection activities including a week in September, 2021, when nearly a tonne of CO2 was injected. Very few local microseismic events have been detected.
- The Güralp sensors have been invaluable in determining

INSTRUMENT FOCUS - OCEAN BOTTOM SEISMOMETERS

AQUARIUS

For offshore deployments Aquarius offers a flexible solution suitable for both baseline and operational monitoring, without cables, for up to 18 months.

Fully autonomous and highly configurable, Aquarius is also equipped with acoustic data telemetry. For monitoring scenarios, a list of events (detected using using STA/LTA triggers) can be sent to the surface in near real-time. More detailed data can then be retrieved by the operator as desired. Free-fall deployment and acoustic release recovery allow for multiple deployments at different sites.

AQUARIUS AND MARIS ARE BOTH FULLY OPERATIONAL AT ±90 ° TO FACILITATE EASIER DEPLOYMENT ON THE SEAFLOOR

MARIS

For permanent installations, Maris offers the same sensor versatility as Aquarius with the real-time data communication associated with cabled installations.

Maris offers versatile deployment options. If desired, multiple instruments can be strung together via a single cable. Triggered alert data can be sent at ultra-low latency for virtually instantaneous monitoring and alert applications, achieving network transmission in as little as 40 milli-seconds.

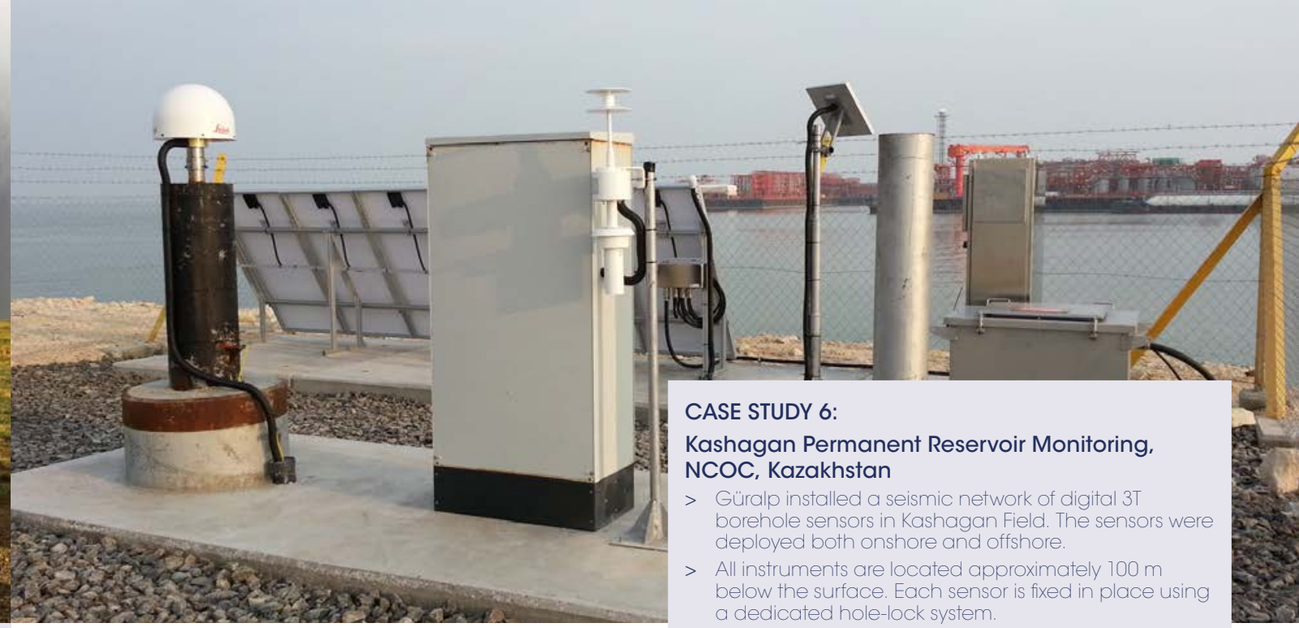


IMAGE 3: STATION INSTALLATION IN KASHAGAN

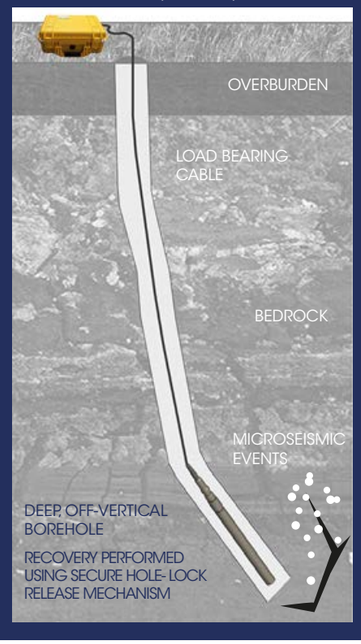
PERMANENT RESERVOIR MONITORING (PRM)

Suitable for both active or passive sources, our broadband systems can deliver insight into cap rock integrity and wellbore stability as part of a reservoir integrity management plan to maximise production and safeguard assets.

Passive seismic imaging is a proven and cost-effective method for PRM to quantify changes in the area of interest, helping to optimise production and safely manage future reservoir development.

INSTRUMENT FOCUS - RADIAN

PRM can benefit from sensors located at depth in order to assess changes in the fields. This slimline borehole seismometer is operational at any angle, making it an economical choice for installation in non-vertical boreholes to depths of up to 2000 m.



CASE STUDY 6:

Kashagan Permanent Reservoir Monitoring, NCOC, Kazakhstan

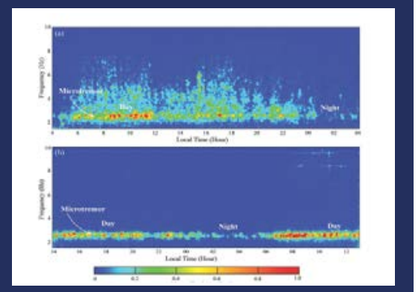
- Güralp installed a seismic network of digital 3T borehole sensors in Kashagan Field. The sensors were deployed both onshore and offshore.
- All instruments are located approximately 100 m below the surface. Each sensor is fixed in place using a dedicated hole-lock system.
- Due to the very high surface noise resulting from the working marine environment, borehole sensors were selected to ensure data with very high signal to noise ratio, leading to better quality waveforms.
- The monitoring was established to satisfy Kasak regulatory requirements.
- Güralp delivered a full turnkey solution to NCOC that consisted of:
  - Recorded data was processed to determine seismic event locations and magnitudes.
  - Automated daily email alerts.
  - Regular detailed reports about the operational status of the network and detected events.

3T/5T Borehole

The Güralp 3T/5T combines our renowned 3T broadband seismometer with the proven 5T strong motion accelerometer. This allows for simultaneous monitoring of both weak and distant seismic events, and near-field, high intensity shaking, in a single instrument.

The 3T is the instrument of choice for an extensive number of nuclear test ban treaty monitoring arrays around the world, with thousands of systems deployed over the past thirty five years.

- Total realised dynamic range of over 200 dB
- Exceptionally low noise floor
- Digital and analogue systems available



WE CAN PROVIDE DETAILED REPORTS OF DETECTED EVENTS AND THE OPERATIONAL STATUS OF THE ARRAY

The importance of broadband.

Broadband data is critical for accurate magnitude estimation, which is particularly relevant for compliance monitoring.

The Full Energy Spectrum

The moment magnitude of an earthquake is calculated from ground displacement. The larger the magnitude, the greater the amount of low frequency ground motion that cannot be accurately recorded by traditional high-frequency geophones.

Broadband seismometers can record low frequencies, providing accurate magnitude estimates. Scientific studies have shown that geophones can underestimate seismic event magnitudes by up to 0.6 magnitude units.

Detect and Locate

Locating the earthquake's hypocenter can determine whether an earthquake is natural or related to human activities (e.g. hydraulic fracturing, fluid injection, etc).

Identifying and accurately recording the earthquake's S-waves provides a much more accurate hypocentre location. S-waves appear clearer on broadband data, making it easier to distinguish near-local events from regional events, reducing the risk of data interpretation errors. S-waves are especially vital for microseismic monitoring because the S-wave of a typical fracture event has 5–15 times more energy than its P-wave.

Broadband instruments are the key to recording the full spectrum of seismic events in an area (shallow vs. deep; small vs. large), allowing for the most complete catalogue of events for the prediction of reservoir changes.

Broadband instruments are ideal for baseline monitoring, crucial for constraining the design and event detection capability of a larger seismic network for future drilling activities.

Determine Complex Faulting Behaviour

Earthquakes have complicated rupture mechanics. For example, induced and frack events may have highly non-double couple mechanisms, which can be identified using Moment Tensor inversion. The Moment Tensor must be calculated at the lowest frequencies of the seismic source, in which most energy is released. Broadband seismometers offer the optimum solution for accurate determination of source mechanisms across a wide range of natural and induced events.

True broadband capability is vital to the effective implementation of a traffic light scheme where earthquake magnitudes must be accurately quantified.

Earthquake magnitudes are measured from displacement spectra. Only broadband instruments are capable of capturing the full range of displacement spectra, producing a robust estimate of earthquake magnitude. Industry-standard geophones are limited to high frequencies, resulting in systematic underestimation of magnitudes.

Viegas et al. (2012)* show that using data from geophones rather than broadband sensors can lead to measurement errors of as much as 0.6 magnitude units, crucial when operating in regulated areas.

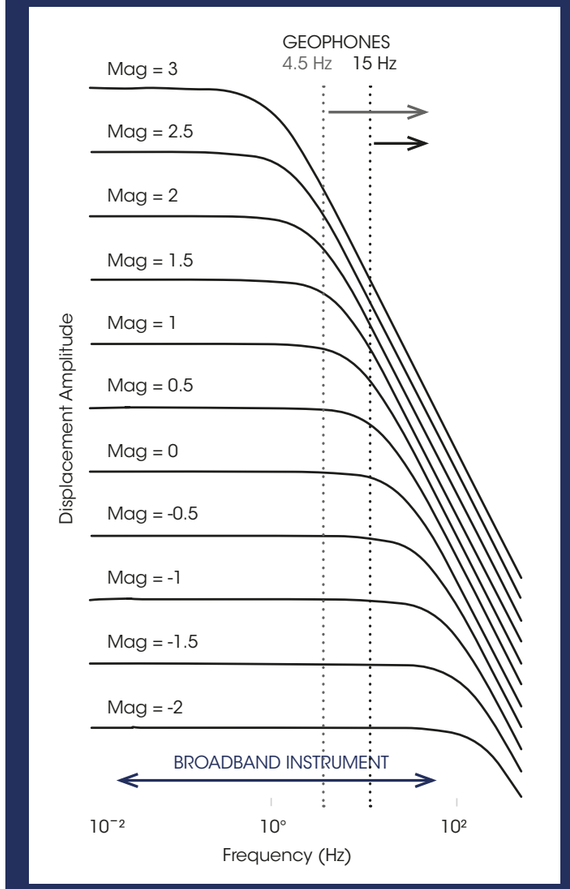
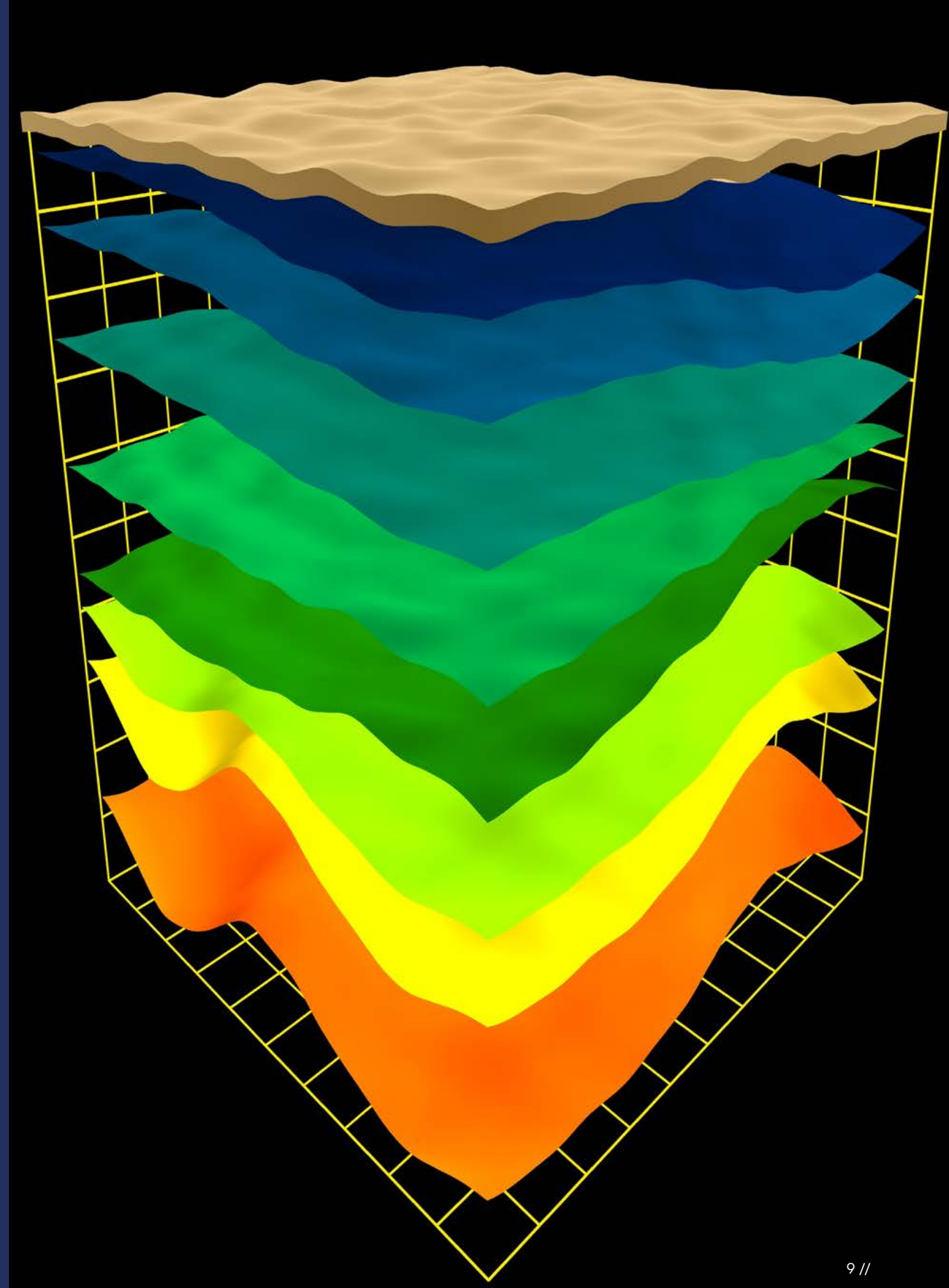


DIAGRAM 2 COMPARISON SHOWING GÜRALP BROADBAND INSTRUMENT AND GEOPHONE RESPONSES

*Viegas G., Baig A., Coulter W., and Urbancic T., 2012: Effective monitoring of reservoir-induced seismicity utilizing integrated surface and downhole seismic networks: First Break 30, 77-81



MADE IN THE UK

WE ACHIEVE GLOBAL REACH THROUGH OUR NETWORK OF TRUSTED INTERNATIONAL DISTRIBUTORS WHO PROVIDE LOCAL EXPERTISE AND SUPPLEMENTARY SERVICES

TRUSTED ALL OVER THE WORLD

OVER MORE THAN THIRTY FIVE YEARS, WE HAVE SUPPLIED THOUSANDS OF INSTRUMENTS AROUND THE WORLD TO CUSTOMERS ACROSS THE PUBLIC AND PRIVATE SECTORS.

ALL OF OUR INSTRUMENTATION IS DESIGNED AND MANUFACTURED IN OUR UK FACILITY BY OUR DEDICATED AND TALENTED TEAM WHOSE DISCIPLINES INCLUDE ENGINEERING, GEOPHYSICS AND MANUFACTURING.

CUSTOMER SERVICE

WE PROVIDE ON-GOING SUPPORT FOR ALL OF OUR INSTRUMENTATION AND SYSTEMS, FROM THE DAY THEY LEAVE THE FACTORY, THROUGHOUT THEIR LIFETIME.

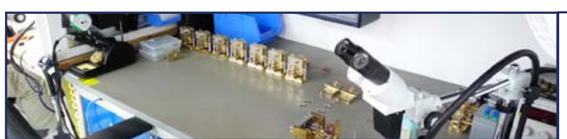
RENTAL POOL

OUR LARGE POOL OF RENTAL EQUIPMENT IS AVAILABLE FOR TEMPORARY MONITORING PROJECTS AND WE CAN PROVIDE ASSISTANCE WITH DESIGN AND INSTALLATION.

EMAIL OUR SALES TEAM FOR MORE INFORMATION: SALES@GURALP.COM

MODERN DESIGN AND MANUFACTURING

WE DESIGN AND MANUFACTURE THE MOST CRITICAL MECHANICAL COMPONENTS IN-HOUSE USING THE LATEST CAD/CAM TECHNOLOGY USING OUR FOUR STATE-OF-THE-ART CNC MILLING MACHINES, INCLUDING THREE ROBOTICALLY TENDED 5-AXIS MACHINES. THIS ALLOWS FOR REDUCED LEAD TIME, TIGHT PROCESS AND QUALITY CONTROL, AND A LEAN DESIGN CYCLE DUE TO OUR ABILITY TO RAPIDLY DEVELOP AND REFINE PRODUCT PROTOTYPES.



QUALITY MANAGEMENT

GÜRALP SENSORS ARE BUILT IN CLEAN, HEPA FILTERED LAMINAR FLOW ENVIRONMENTS WHICH ACHIEVE ISO CLASS 7 CLEANLINESS (EQUIVALENT TO FED CLASS 10,000). ALL INSTRUMENTS ARE THOROUGHLY TESTED AT MULTIPLE STAGES THROUGHOUT THEIR ASSEMBLY.

ISO9001:2015

WE OPERATE A QUALITY MANAGEMENT SYSTEM IN ACCORDANCE WITH ISO 9001:2015 FOR THE SCOPE OF:

"DESIGN AND MANUFACTURE OF LOW-NOISE BROADBAND SEISMOMETERS, ACCELEROMETERS, DIGITIZERS AND NETWORKING EQUIPMENT FOR SCIENCE AND ENGINEERING, AS WELL AS MANAGEMENT OF CUSTOMER OWNED SEISMIC STATIONS".

CERTIFICATION INTERNATIONAL SOCOTEC ISO 9001 UKAS MANAGEMENT SYSTEMS 0063

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