



SOUR GAS SOLUTIONS

Increasing efficiency and reducing risk through analysis, forecasting and modelling



ASSESSMENT AND MITIGATION **ADDS UP**

SGS H₂S SOLUTIONS

SGS



**ASSESSMENT
AND MITIGATION**

ADDS UP

SGS ADDS VALUE BY INCREASING EFFICIENCY,
IMPROVING QUALITY, REDUCING RISKS AND
BUILDING TRUST

H₂S MITIGATION

WORLDWIDE

INTEGRATED SERVICES

RESERVOIR SOURING

SOUR HYDROCARBON

**UNDERSTANDING
SUBSURFACE AND
SURFACE DISTRIBUTION**

**DATA ACQUISITION AND
LABORATORY ANALYSIS**

**GLOBAL AND MOBILE
LABORATORY CAPACITY**

**ISOTOPE
ANALYSIS**

**SAMPLING, MEASUREMENT
& NORMALISATION**

**CORROSION MONITORING
& PREVENTION**



CORROSION MONITORING

BESPOKE STRATEGY

H₂S DATA REVIEW AND ANALYSIS

INTEGRATED STUDIES

DYNAMIC MODELLING

MODELLING: GENERATION AND MIGRATION

FORECASTING AND PREDICTION

SENSITIVITY ANALYSIS

INTRODUCTION

Accurately monitoring the occurrence and development of sour hydrocarbon accumulations and the contamination of reservoirs with H₂S is critical. Over half of the world's remaining hydrocarbon resources are contaminated with carbon dioxide and/or hydrogen

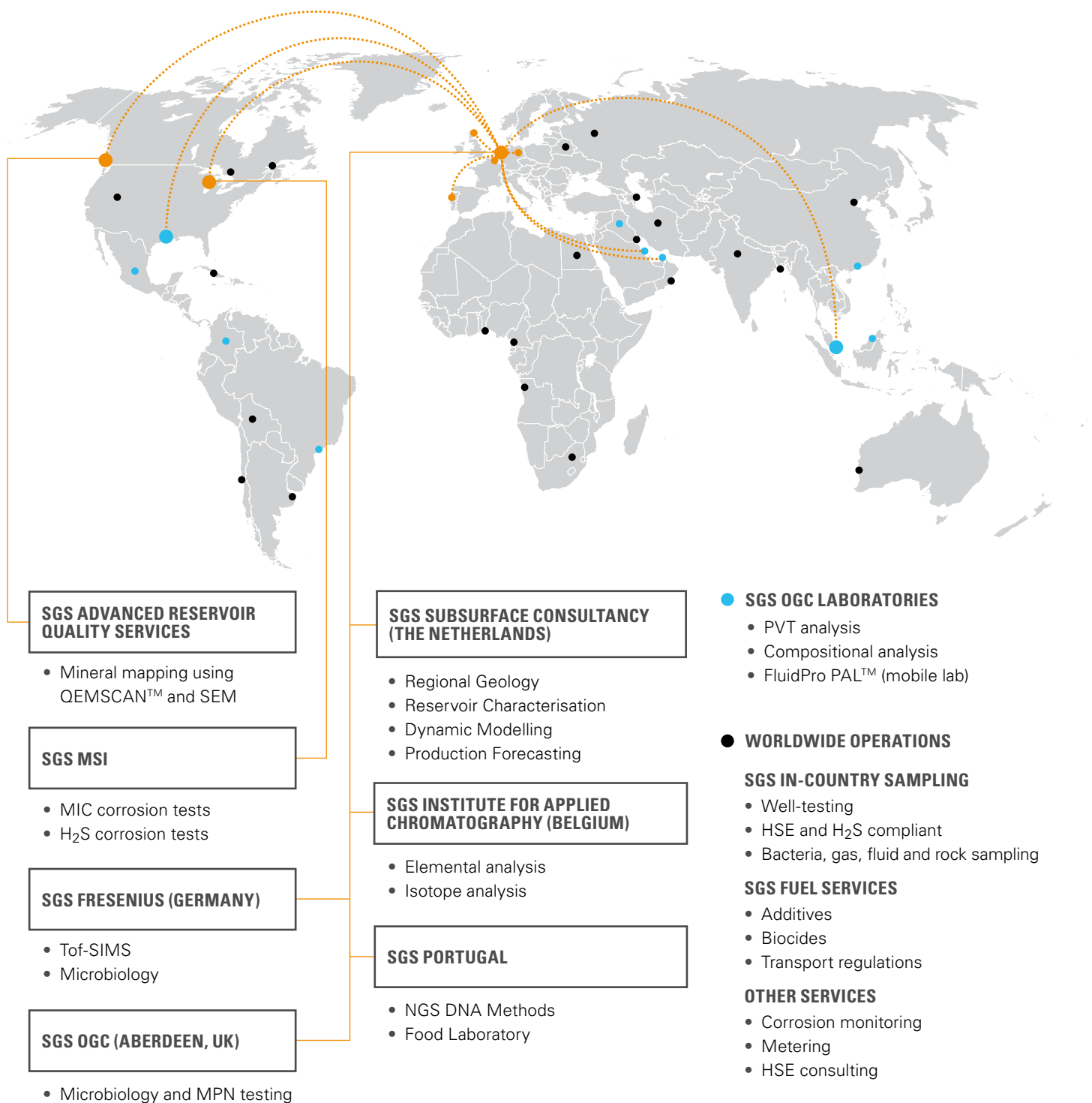
sulphide, and reservoir souring has a significant economic impact.

SGS can help you effectively to mitigate reservoir souring. Combining innovative technology and integrated resources, we provide bespoke mitigation strategies based on

state-of-the-art assessment, forecasting and modelling.

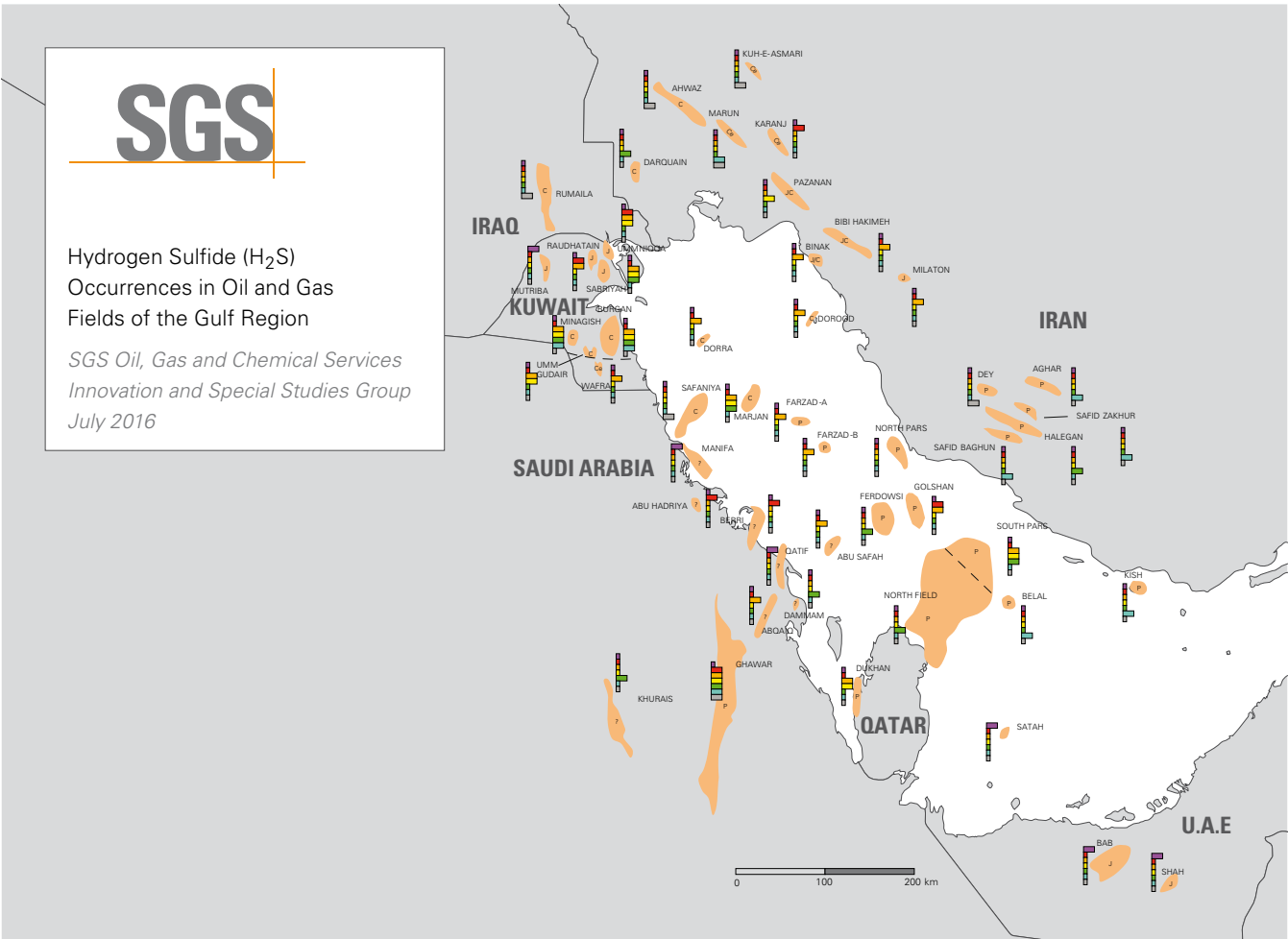
Trust the world's leading inspection, testing, verification and certification company to assess and mitigate your reservoir souring, and improve your efficiency, reduce your risk and maximise your output.

SGS H₂S SERVICE GROUPS & LABORATORIES



SGS H₂S MITIGATION SERVICES

THE H₂S PROBLEM



More than 50% of the world's remaining hydrocarbon resources are significantly contaminated with carbon dioxide and/or hydrogen sulphide. Sour hydrocarbon accumulations are very common in the Middle East, Canada, Northern Europe, Kazakhstan and China.

H₂S occurs in carbonate and clastic reservoirs, and the cost of mitigating the impact of this souring can have a significant impact on field economics. In order to safely and economically develop a sour hydrocarbon field, the origin of the H₂S and the souring

process must be understood. A reliable and accurate forecasting of H₂S development is crucial for the implementation of an effective mitigation strategy.

THE ORIGIN OF H₂S

The origin of H₂S is linked to chemical reactions in reservoirs, hydrocarbon source rocks and the migration of fluid

into traps. In addition, certain minerals in rocks have a scavenging or catalytic effect. There are six processes of H₂S

generation, each of which can produce different concentrations of H₂S.

BSR	TSR	Thermal Cracking of Organic Sulfur Compounds (OSC)	Mineral Dissolution	(Re-) Migration	H ₂ S Injection or Disposal
Bacterial Sulfate Reduction in reservoirs occurs only at low temperatures (< 80 °C)	Thermochemical Sulfate Reduction in reservoirs at high temperature and pressure conditions in the presence of sulfate	During the maturation process the organic sulfur compounds of the kerogen and the oils are thermally cracked and form H ₂ S	$\text{FeS} + 2\text{H}^+ \Rightarrow \text{H}_2\text{S} + \text{Fe}^{2+}$ generate low H ₂ S concentrations	Lateral or vertical migration from deeper H ₂ S bearing horizons	Infection during field operations using contaminated fluids or gasses
< 6% H ₂ S	up to 98% H ₂ S	< 6% H ₂ S	< 50 ppm H ₂ S	up to 98% H ₂ S	up to 98% H ₂ S

H₂S ANALYSIS

Our H₂S mitigation services comprise metering, monitoring and sampling in fields or at facilities, laboratory analysis, data interpretation and forecasting modelling. Our technology provides H₂S mitigation at the subsurface level and during surface transportation, storage and shipment.

Using cutting-edge systems, which integrate structural geology, mineralogical and lithological data, geochemical and compositional data and reservoir data, our experts deliver highly accurate souring assessments and create models for the H₂S generation, propagation and development within reservoirs, wells and surface facilities.



DATA REVIEW & ANALYSIS

- Structural Geology
- Mineralogy & Lithology
- Geochemistry
- Thermal History & Maturation
- Fluid & Rock Properties
- Reservoir Conditions



DATA ACQUISITION & LABORATORY ANALYSIS

- Fluid Sampling
- Mobile On-Site GC Laboratory
- Fluid Compositional Analysis
- Rock Samples
- S-Isotope Analysis & CSIA



INTEGRATE INFORMATION

- Establish Dependencies
- Compilation DataBase
- Trend & Correlation Analysis
- Data Normalisation at Reference Conditions
- Identify Scavengers
- Dynamic Modelling & History Match



DELIVERABLES

- H₂S Generation Model
- H₂S Risk Profile & Maps
- Calibrated Field Scale Sour Gas Dynamic Models
- Predict H₂S Development & Production
- Evaluate Mitigation Techniques

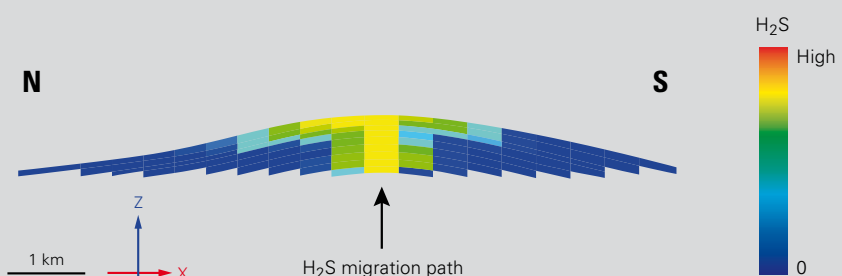
We use commercial modelling software in combination with proprietary workflows to forecast H₂S generation on geological and field production timescales.

Our clients receive H₂S mitigation options tailored to their field development. Each comprehensive study comprises multiple modelling projections in order to allow for the uncertainties of H₂S generation and migration.

The H₂S modelling includes geological, geochemical, lithological and rock properties, as well as thermal and maturation history, fluid regions, pressure regimes and reservoir properties.

Forecasts are presented in plots, maps and tables and digital 3D model format. Based on the simulation results the appropriate H₂S mitigation technique can be identified.

H₂S GENERATION AND MIGRATION FORECASTING MODEL



LABORATORY SERVICES

We have chemical laboratory and sour gas expertise centres in the United Arab Emirates, Malaysia, Belgium, Germany, the USA and the Netherlands that carry out advanced analysis relating to reservoir souring.

This expertise includes GC-MS, ICP-OES, Isotopes, CSIA, TOF-SIMS and biomarkers analysis, and DNA analysis of H₂S producing bacteria.

Furthermore, our laboratory facilities can carry out:

- Core flooding experiments
- Scaling and corrosion studies
- Mineralogy (QEMSCAN™, SEM and XRD) analysis
- Mechanical rock property (nano-indentation) analysis
- High-resolution CT scans



EXAMPLE A: ISOTOPE ANALYSIS

Sulfur has 25 known isotopes, of which four are stable. The ratio of the two most common isotopes, ³²S and ³⁴S, is compared to the Vienna Canyon Diablo Troilite (VCDT) standard. Sulfur isotopes are expressed in their deviation of ³⁴S from this standard in ‰ VCDT.

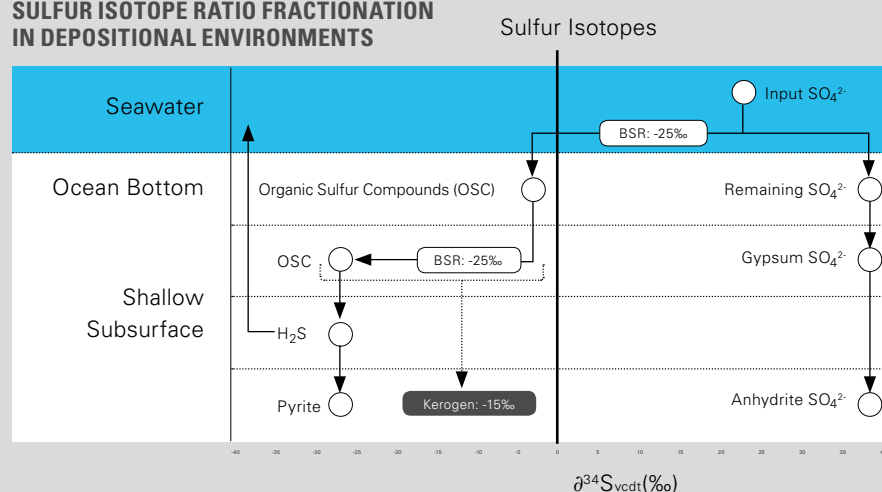
The sulfur isotope ratio allows the distinction between sulfur species derived from biogenic processes and those derived from thermogenic processes. This process relies chiefly on the fact that biogenic processes prefer

consumption of ³²S over ³⁴S, leading to sulfur 'fractionation'.

To assess the origin of H₂S in reservoirs it is important to compare the sulfur isotope ratios of the following:

- Rocks (core or cuttings of anhydrite, source rock and pyrite)
- Formation and injection water
- Organic bound sulfur in oil
- H₂S in gas
- Carbon isotopes in the gas

SULFUR ISOTOPE RATIO FRACTIONATION IN DEPOSITIONAL ENVIRONMENTS



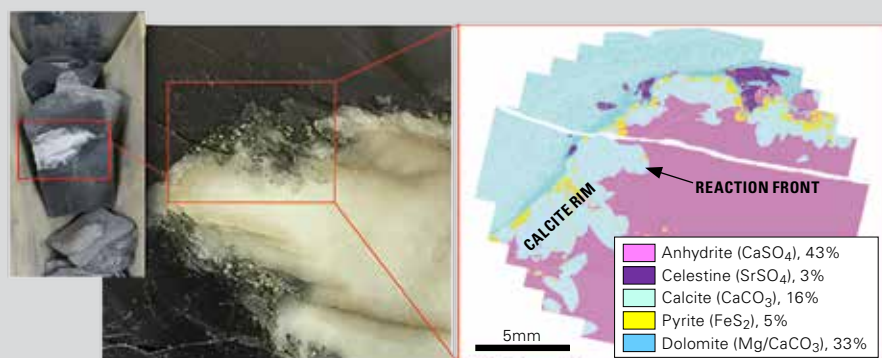
EXAMPLE B: MINERALOGY

H₂S generation from different sources affects the crystallography of by-product minerals. For example, the generation of calcite macrocrystal during the biogenic process and the creation of calcite rim and pyrite during the thermogenic process.

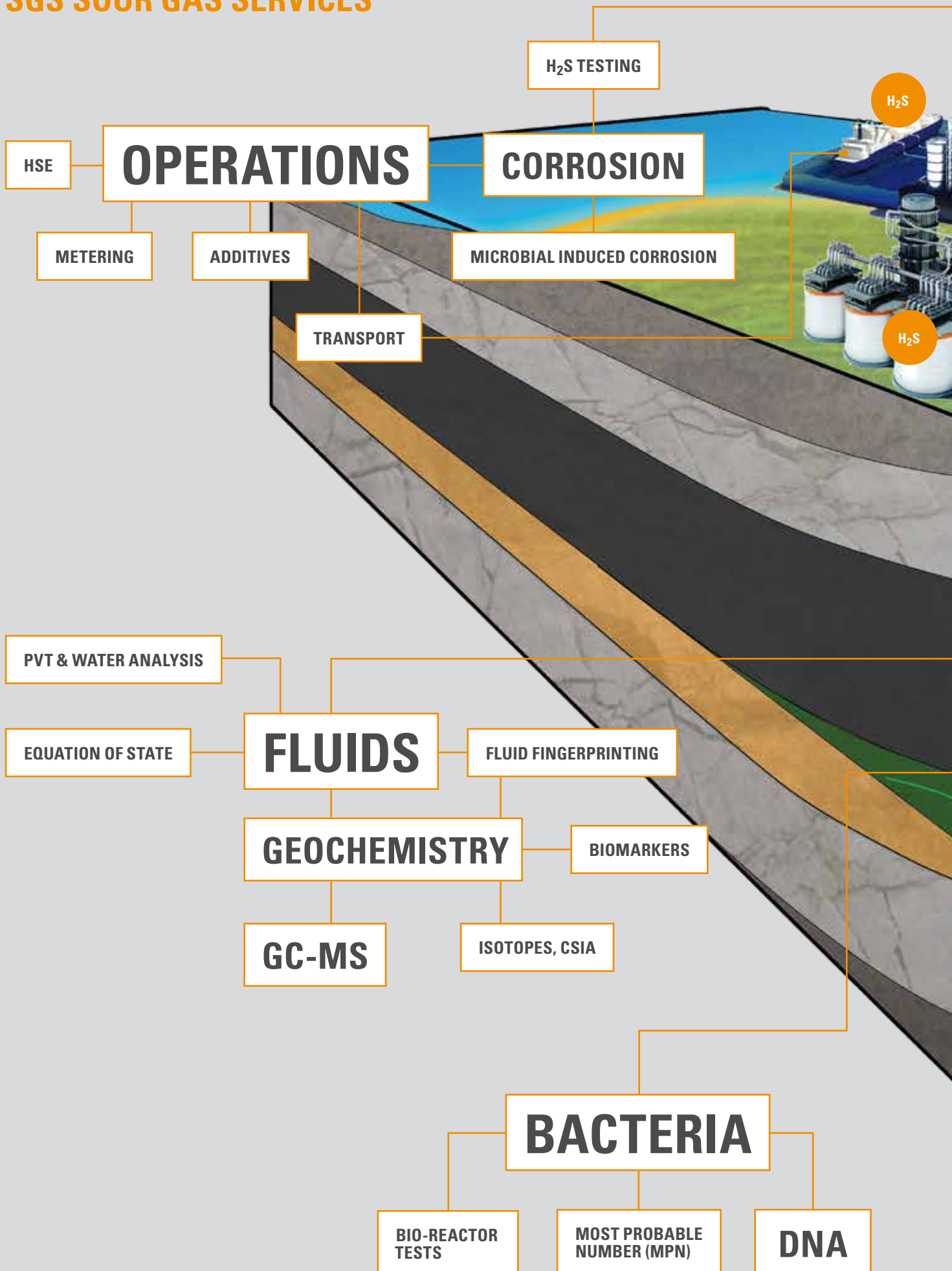
Certain minerals that are naturally present in reservoirs are capable of scavenging considerable amounts of H₂S through the formation of metal sulfides. Common scavenging minerals are siderite, magnetite, glauconite and clay-phase chlorite.

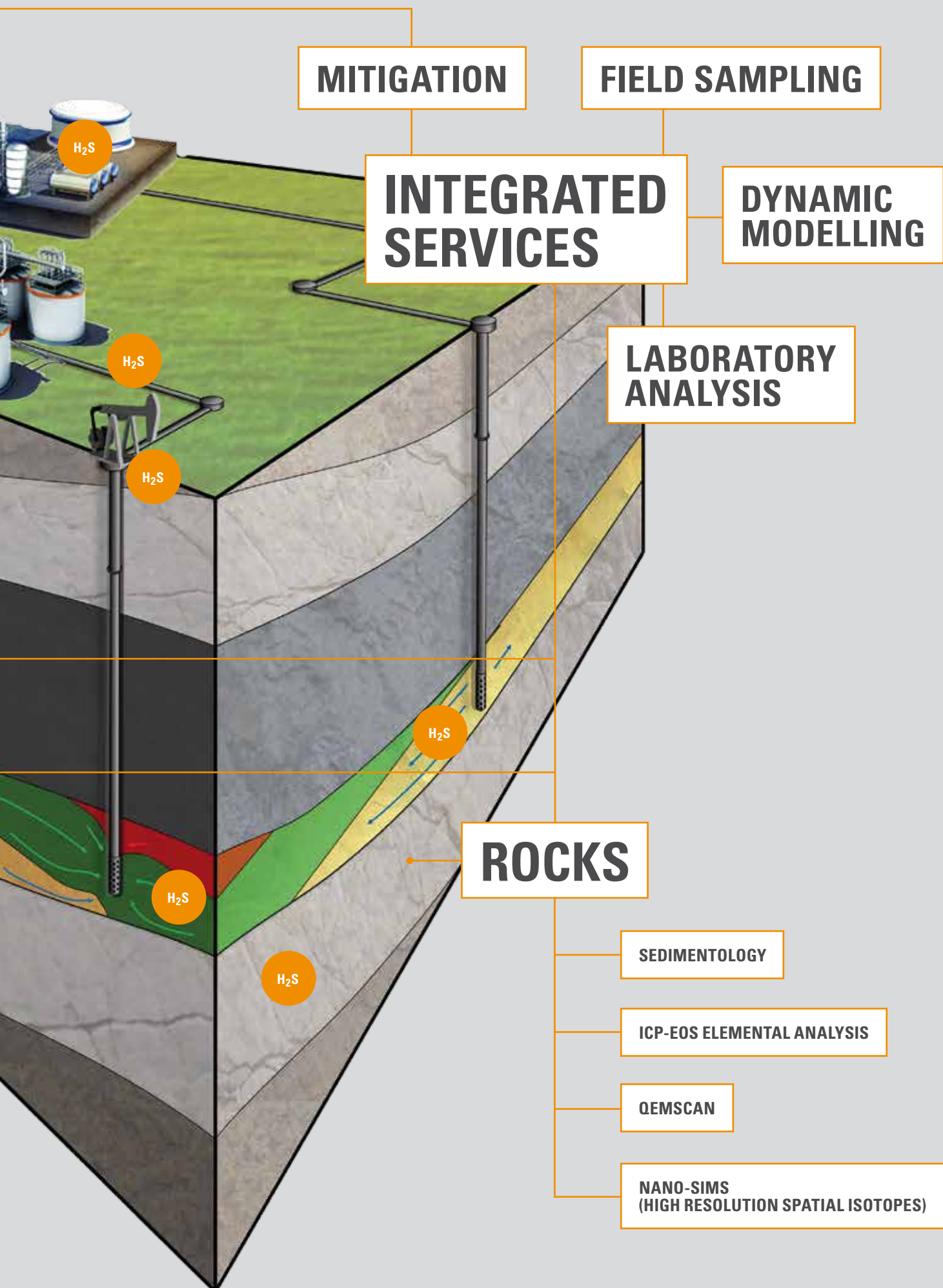
We apply a combination of CT scan, QEMSCAN™ and SEM technology to carry out mineralogical, lithological and petrographical analysis and interpretation. These technologies allow:

- The identification of the origin of the H₂S
- The description of the induced mineralisation processes
- The understanding of the natural scavenging effects

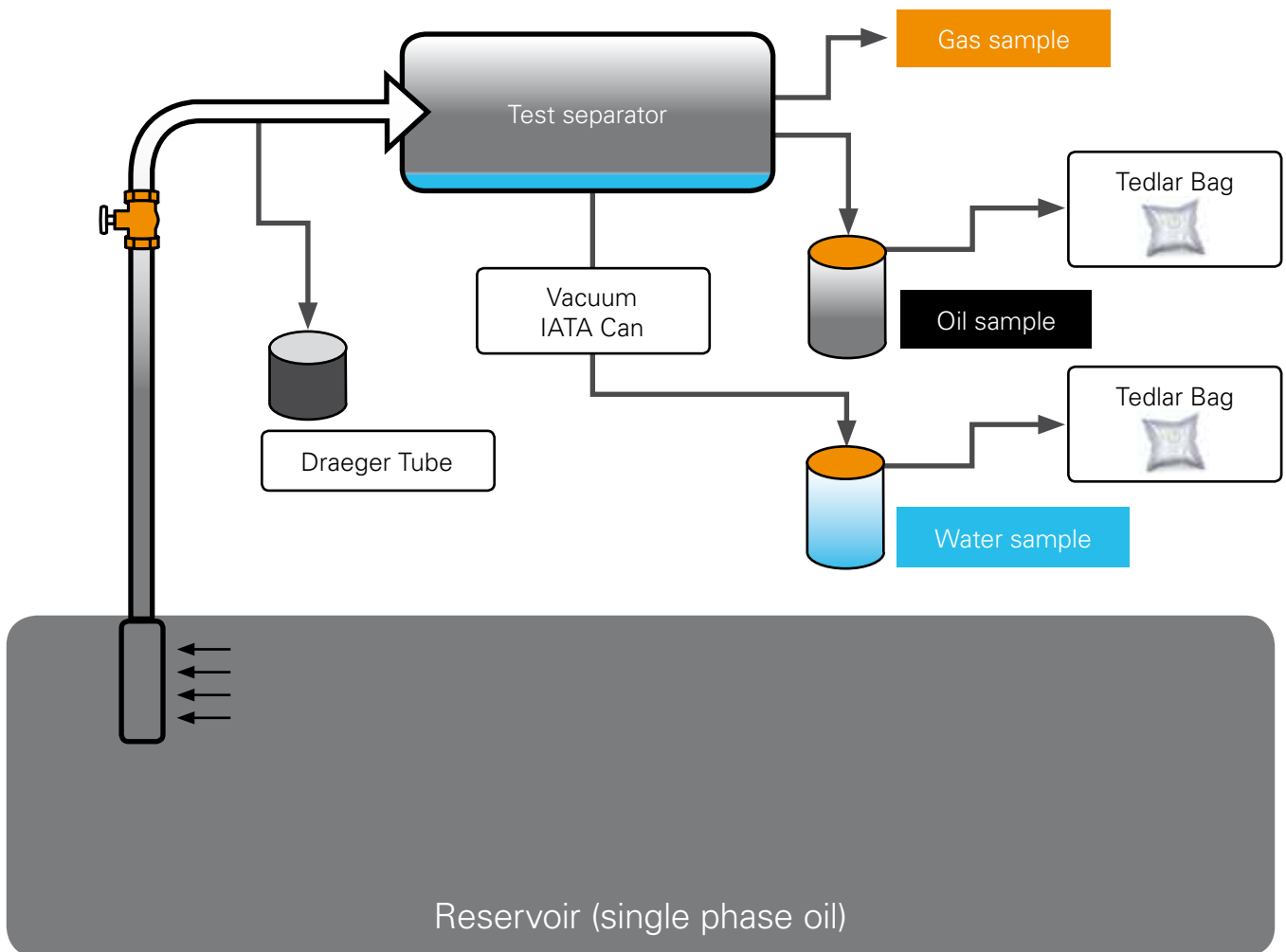


SGS SOUR GAS SERVICES





H₂S SAMPLING AND MEASURING



We have developed our own sampling protocol, which improves the accuracy of the H₂S sampling and measurements in a multi-phase flow environment.

H₂S concentrations in oil, gas and water are sampled at various stages of the production process:

- Downhole
- Well head
- Test separator
- Gathering stations
- Pipeline inlet/outlet
- Processing facilities

The common measuring technologies are:

- Stain tube
- Gas chromatography
- Titration of gas

Each one has its limitations in terms of accuracy.

The measured H₂S concentration in fluid and gasses depends acutely on the pressure at which the sampling and analysis is performed, and to a lesser extent on the temperature. For example, the same gas shows significant variations of H₂S concentration depending on the pressure conditions of the sampling and analysis.

SGS has developed its own sampling protocol to collect representative fluid and gas samples at the well test separator, in order to acquire reliable measurements of H₂S concentration.

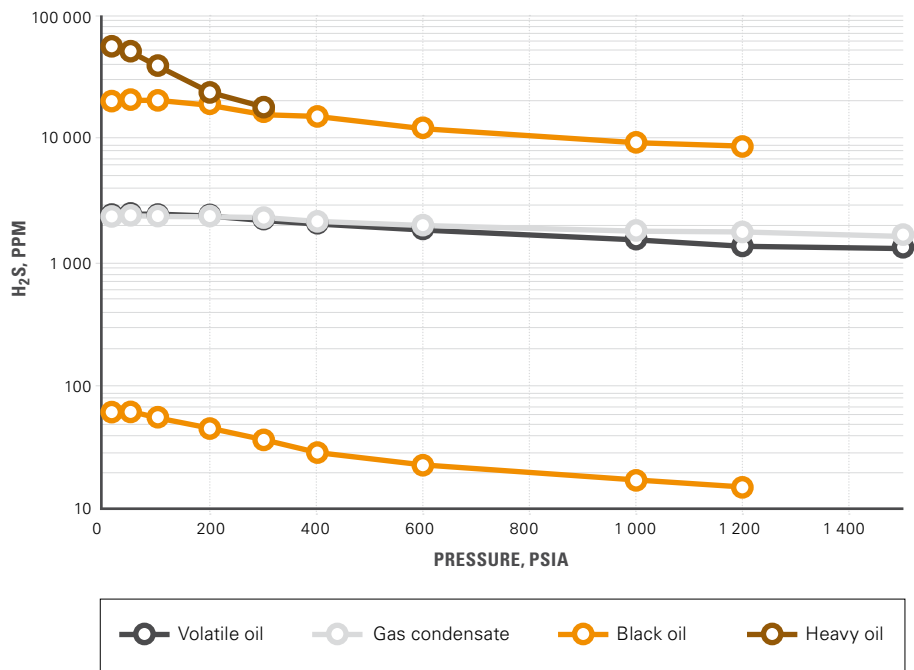
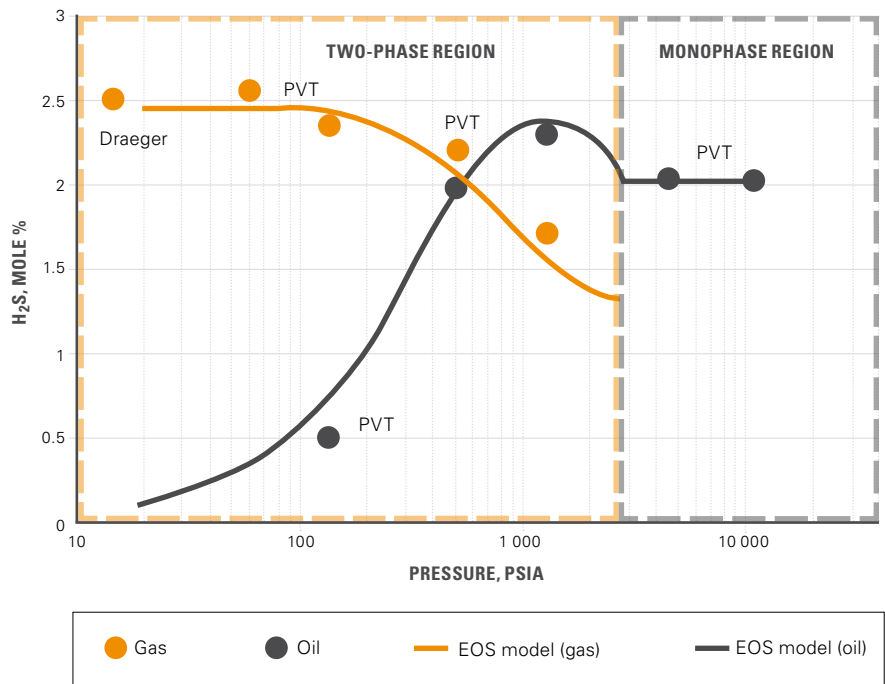
We take multiple measurements during well tests with the objective of capturing H₂S content data for the different phases.

H₂S MEASUREMENT INTEGRATION AND NORMALISATION

SGS developed technologies to normalise H₂S measurements of different sampling points to a common reference level. This allows the reliable mapping and modelling of H₂S concentrations across fields.

Partitioning of mono-phase reservoir fluids into multi-phase fluids (i.e. oil, water and gas) occurs as the fluids moves from the reservoir to the processing facility. The H₂S concentration in the gas and oil changes as the pressure alters.

The physical effect of the H₂S partitioning between the different phases can be calculated using a calibrated Equation of State or from correlations or experimental PVT data. In order to compare H₂S concentrations from the various sources, which are sampled under different pressure and temperature conditions, we have developed technology that normalises data with reference to surface or sub-surface conditions.

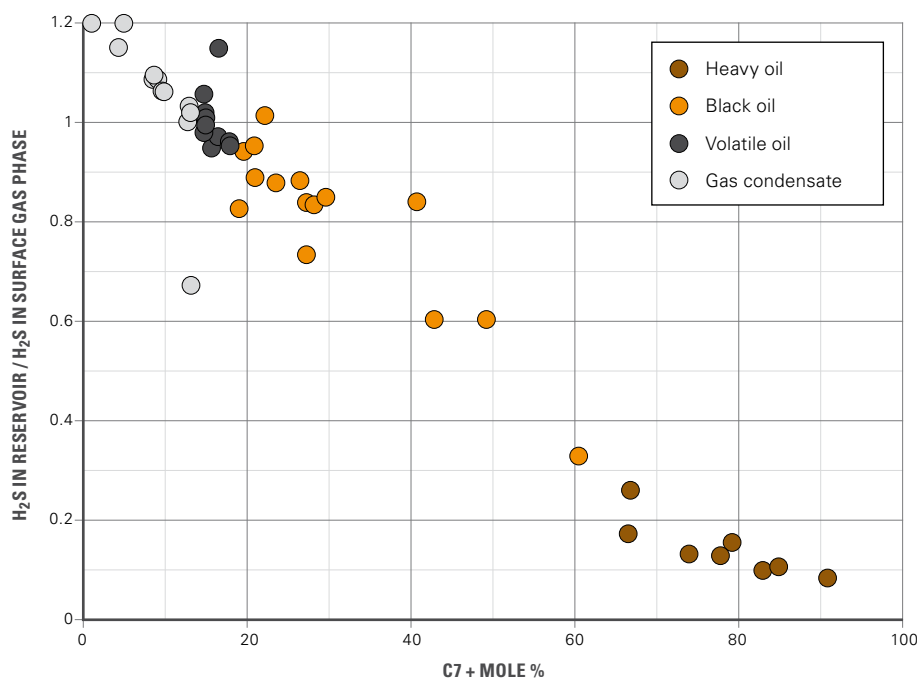
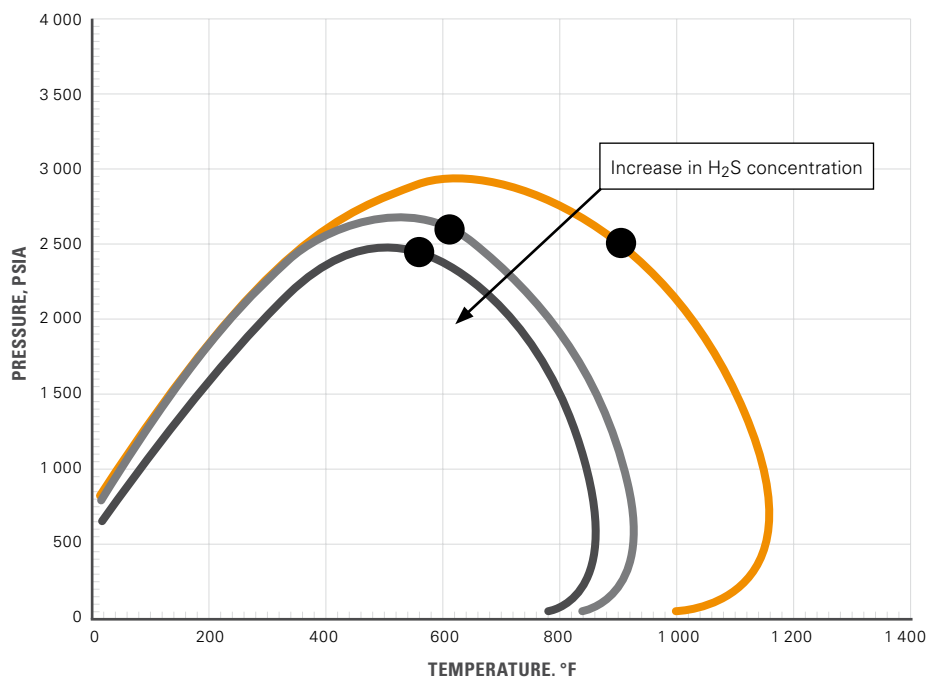


The normalisation is performed separately for each fluid type. The composition and physical properties of the fluids control the slope of the normalisation function.

PHASE BEHAVIOUR AND FLUID COMPOSITION

We are a world leader in the analysis of H_2S development. We use these H_2S data to create highly accurate souring simulation studies.

The generation, migration or injection (for pressure maintenance or enhanced oil recovery purposes) of H_2S into an oil reservoir changes the phase behaviour and the thermodynamic properties of reservoir fluids.



Partitioning of H_2S concentration in three phases of gas, oil and water during the production process from reservoir to surface facilities, is a key aspect of souring studies. Especially in production of hydrocarbons with low GOR the effect can be significant, partitioning leads to much higher H_2S concentration measured in the liberated gas at surface than compared with that measured in the oil at reservoir conditions.

The ratio of H_2S concentration in the hydrocarbon at the reservoir conditions to H_2S concentration in gas phase at ambient conditions is a strong function of hydrocarbon compositions. As the hydrocarbon becomes compositionally lighter the ratio becomes larger and closer to one. SGS established mathematical functions for these conversions and applied in recent souring simulation studies.

SOUR GAS MODELLING AND FORECASTING

Our innovative approach in modelling and forecasting allows for more efficient and cost-effective H₂S mitigation strategy planning.

Prior to any numerical simulations, material balance tools are used to validate multiple scenarios. Our in-house material balance tool takes into account sulfur sources and sinks as well as produced and remaining sulfur in a reservoir. This allows us to determine whether the mechanisms considered in a scenario can produce the observed quantities of H₂S.

Numerical reservoir souring models can be used to validate the origin of H₂S from analytical analyses and

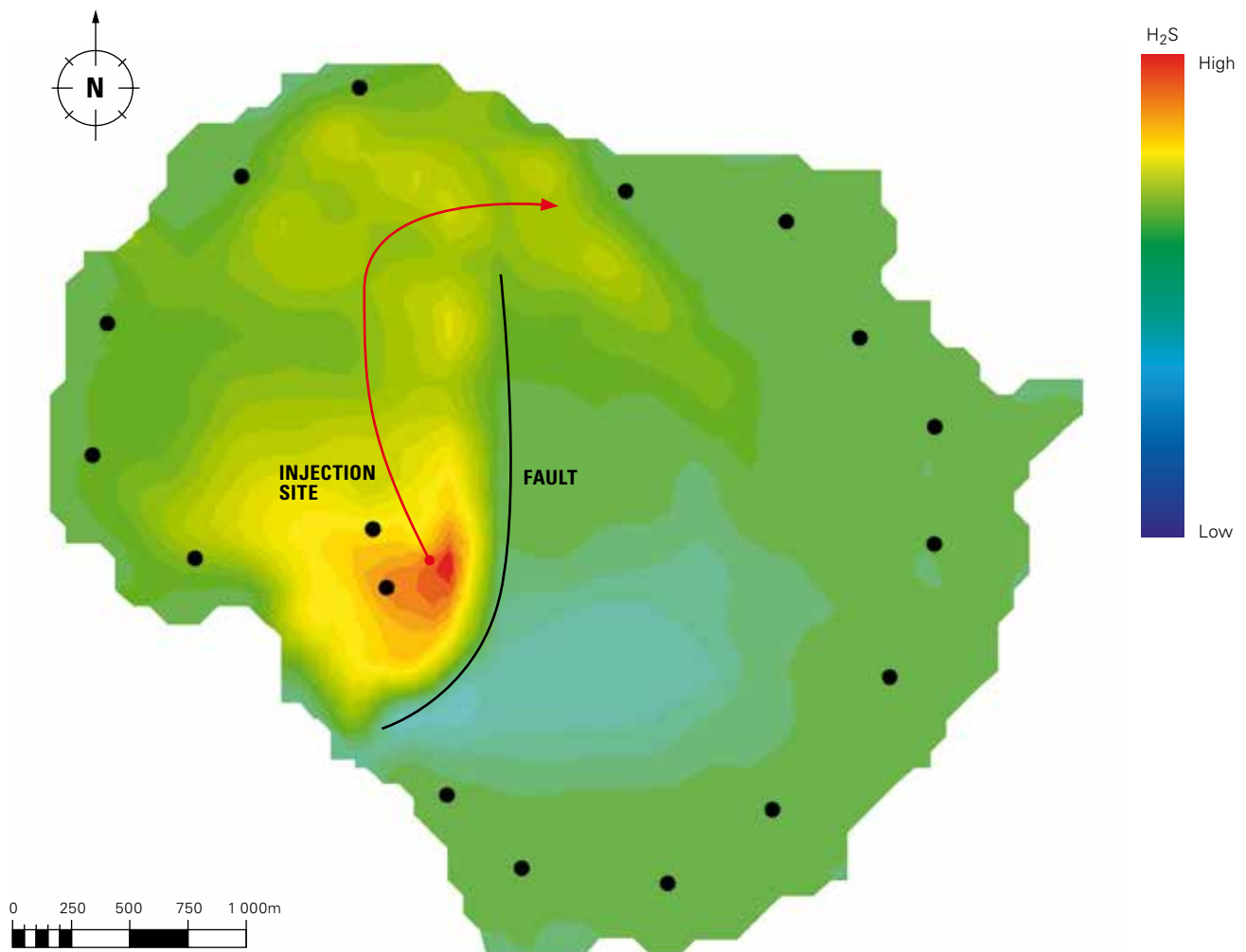
interpretations. Moreover, a calibrated souring model reduces uncertainty in future H₂S production and allows souring mitigation strategies to be developed.

Ideally, the models should encompass all relevant historic observation. This includes conclusions on the source of H₂S, initial concentration and distribution in the reservoir, and historic developments in H₂S concentration.

It should be noted that most commercial souring simulators are basically post-processing steps of reservoir simulation output, such as production profiles or dynamic property grids. Our system is based on a commercial reservoir

simulator adjusted to incorporate nutrient species, bacteria, isotopic fractionation, thermodynamics, fluid flow, reservoir heterogeneities and chemical reactions.

The benefit of the SGS method is that sensitivity analysis can be easily performed and calibrated to specific well configurations and sectors, or to a full-field model. Moreover, reservoir development and management scenarios, such as changes to injection, production rates and patterns, recompletion and surface compression, can easily be evaluated with regard to H₂S development and production.



EVALUATION OF MITIGATION OPTIONS

Our H₂S analysis and assessment capabilities ensure that you benefit from the most-efficient and effective mitigation solution.

We distinguish between H₂S remediation (artificial scavenging) and mitigation. Those strategies that can be used to reduce or scavenge H₂S from production streams are referred to as remediation techniques.

H₂S mitigation refers to strategies that can be employed to reduce the risk of H₂S generation in reservoirs. The most common H₂S mitigation techniques are nitrate injection, biocide injection, sulfate removal units and phosphor removal.

The objective of these H₂S mitigation techniques is to deprive the sulfate reducing bacteria of its nutrients, explicitly (i.e. sulfate and phosphor removal) and/or implicitly, by creating microbial competition (i.e. nitrate injection), or simply to kill sulfate reducing bacteria by applying biocides.

The efficiency and applicability of these mitigation methods varies and are case dependent. Thus, a screening study is required to select an appropriate mitigation strategy for a specific sour reservoir. Without a full understanding of the source of the H₂S (i.e. the location of sulfate reducing bacteria, their

species and their characteristics, the presence of nitrate reducing bacteria and the availability of nutrients), the selection of effective mitigation options is not possible.

Once the origin and source of souring is fully understood, and after calibration of the dynamic souring models based on all relevant measurements and observation, selected mitigation options are simulated and their technical and economical efficiency can be assessed.

H₂S MITIGATION FORECAST – EXAMPLE



MICRO-BIOLOGY AND DNA

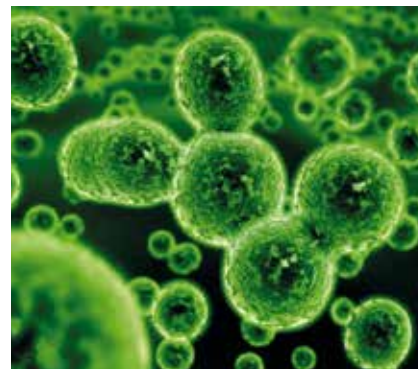
Our microbiology and DNA sampling and analysis expertise assures that you benefit from greater accuracy in terms of H₂S assessment and mitigation.

We have extensive experience of performing microbial analysis via the most probable number method, including for fields and facilities in the North Sea region.

Our microbiology laboratories use special sampling kits to make the distinction between sulfate and

nitrate reducing bacteria and general heterotrophic bacteria. We also carry out DNA analysis of water samples, solid samples and incubated cultures.

DNA technology is used to identify and characterise the bacteria present in a sample. This analysis is done using state-of-the-art Next Generation Sequencing (NGS) techniques.



CORROSION MONITORING AND TESTING



Our unique, cost-saving corrosion management services provide more accurate and more efficient testing of wells, gathering stations and pipelines.

H₂S is highly corrosive and causes significant issues with scaling and residue. For example, the 'Black Powder' phenomenon is a commonly observed scaling product at wells, gathering stations and pipelines. In addition, the bacteria that produce H₂S can often be linked to microbial induced corrosion (MIC).

To combat this, SGS provides a full range of corrosion monitoring and testing services, including bespoke H₂S and microbial induced corrosion management strategies.



SGS **ADDS UP**

SGS is the world’s leading inspection, verification, testing and certification company. Recognised as the global benchmark for quality and integrity, we employ over 85 000 people and operate a network of more than 1 800 offices and laboratories around the world. We are constantly looking beyond customers’ and society’s expectations in order to deliver market-leading services wherever they are needed.

We have a history of undertaking and successfully executing large-scale,

complex international projects. With a presence in every single region around the globe, our people speak the language and understand the culture of the local market and operate globally in a consistent, reliable and effective manner.

We provide innovative services and solutions for every part of the oil, gas and chemicals industry. Our global network of offices and laboratories, alongside our dedicated team, allows us to respond to your needs, when and where they occur. Our reputation

for independence, excellence and innovation has established us as the market leader in providing services that improve efficiency, reduce risk and deliver competitive advantage for you.

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WHEN YOU NEED TO BE SURE

