

**IESE**  
Institute of  
Earth Science  
and Engineering  
Aotearoa

# BOREHOLE

Instrumentation and Seismic Services

DESIGN | MONITORING | INTERPRETATION

## IESE Overview

The Institute of Earth Science and Engineering (IESE) is a research and development institute of The University of Auckland, New Zealand with affiliation to the Geothermal Institute. The academic home of IESE is with the Faculty of Engineering and the Faculty of Science.

IESE's research interests lie in the study of the crust's active tectonic and hydrothermal systems. The Institute is focused on developing new understanding of such systems, and new data gathering and modelling approaches to achieve this objective. IESE has developed several types of borehole geophysical instruments to aid these studies.

In practical terms, IESE applies the resulting knowledge and technology innovations to geological hazards, energy exploration, resource evaluation, and subsurface monitoring. Currently, in large part, these applications are in geothermal development, and volcano and earthquake hazards. IESE's work is also relevant to water and fossil-fuel resources.

The IESE team brings together experience of more than 30 years in designing borehole networks and deploying instruments in plate boundaries, fault zones and geothermal fields for national governments and industry clients.

IESE works on both public and private concerns, delivering project-relevant research, professional training, and commercial services, and has a strong track record in managing major geothermal and geological projects around the world.



# Borehole Instrumentation

The Institute of Earth Science and Engineering is a premier research institute specialising in innovative borehole instrumentation for microseismic data acquisition and analysis.

As an example of these customised tools, a new cableless, downhole seismometer and data acquisition array has been developed with an industrial partner; where data recording is with each sonde, minimising the data losses due to transmission noise. This new tool is especially well suited to the recording of the faintest of seismic signals, perhaps the smallest ever detected in deep boreholes.

IESE seismometer designs feature passive sensors, which provide long-term reliability for microearthquake monitoring in high-temperature and high-pressure environments.

## CUSTOM SONDES

IESE develops custom designed seismic tools to client specification and for extreme borehole conditions.

### Design features include:

- Downhole 24 bit digitizing
- High temperature 160°C
- High pressure 80 Mpa
- Custom cabling
- Tilt
- Specialised coupling

## STANDARD SONDES

IESE manufactures a standard set of borehole seismometers, which are promptly available and shipped worldwide to order.

### Current model specifications include:



#### Model S21g - 2.0hz/4.5hz

Gimbaled, 3 component seismometer with a maximum tilt tolerance of 18°. For installation in deep boreholes with confining pressures of up to 69Mpa or 5kms, and capable of withstanding high temperatures of up to 160°C. Outer diameter of 89mm.



#### Model S31f - 2.0hz/4.5hz

Fixed axis, 3 component seismometer with a maximum tilt tolerance of 3°. For installation in shallow postholes. Outer diameter of 72mm.



#### Model S31f - 15Hz

Omni directional, 3 component seismometer; high sensitivity and high temperature rating of up to 180°C. Outer diameter of 41mm.

## Seismic Services

IESE is a world leader in borehole seismology and microearthquake studies. IESE's seismic arrays are being utilised for scientific studies, well targeting in geothermal exploration, monitoring of reservoirs and fault zones, and for CO<sub>2</sub> sequestration and hydro-fracturing projects to track the locations of seismic events which relate to fluid production and injection.

IESE provides a complete end-to-end seismic service, from instrument design to scientific analysis, including a team of readily deployable researchers, field technicians, data analysts and machinists for contracted projects.



### Network Design

Borehole and Surface Array Optimisation

### Equipment Fabrication

Custom and Standard Seismometers

### Installation Support

Permanent and Temporary, Real-time Data Solutions

### Data Analysis and Interpretation

#### Standard Techniques

Earthquake Locations; and Simple Velocity Models

#### Advanced Techniques

Seismic Velocity and Tomography; Fracture Density and Orientation; Moment Tensors and Microseismotectonics; and Joint Geophysical Imaging (MT, TDEM, CSAMT, Seismic and MEQ)

### Operation and Maintenance

Training in Network Operation

## Analysis and Interpretation Techniques

IESE offers data processing and advanced analysis, in support of basic and applied geological studies.

- Precise event location and visualization
- Velocity tomography
- Sheer wave analysis and fracture density
- Double difference earthquake location
- Focal mechanisms, moment tensor inversion
- Integration of multiple geophysical techniques for geological interpretation
- Integration of fluid flow modelling and geologic mapping
- Joint Geophysical Imaging

### Joint Geophysical Imaging (JGI)

IESE has developed JGI, a unique technology which involves combining data from seismographs and other geophysical instruments for analysis and interpretation, and takes advantage of signal polarisation effects produced by subsurface fractures. JGI is designed to significantly lessen geothermal development risks, and therefore costs, by locating optimum drilling targets or high permeability zones and therefore significantly increasing well output. JGI improves resolution of reservoir boundaries, upflow, fault and fracture zones, and fracture density and orientation. For developers it offers a way to reduce the risk-against-returns in geothermal exploration.

### Geophysical Observatory and Exploration System (GOES)

GOES is a multi-purpose magnetotelluric, seismic and microseismic recording system that is self-contained, extremely rugged and can be handled like a large geophone. Its innovative design supports the joint geophysical imaging method used by IESE in geothermal exploration and well targeting.



# Project Experience Highlights

## OBSERVATORIES

### The San Andreas Fault Observatory at Depth (SAFOD), USA

32 level, 2.1 km pilot-hole and 3 level, 2.7km main hole seismic observatories in California.

### USGS Volcano Hazards Program, Long Valley Exploration Well Observatory, USA

Installed seismometers and strain meters for a 2.7km main hole seismic instrument string in California.

### Wairakei Geothermal Field Monitoring, New Zealand

Installed a world-class borehole seismic array in New Zealand's oldest operating geothermal field, providing real-time data about the microearthquake activity in the field. Data is used to monitor, manage and possibly expand future operations.

### Coso Geothermal Field Monitoring, USA

Deployment, operation and analysis of a 12 station monitoring network in 100m boreholes, lead to the development of S-wave splitting tomography for locating fractures as drilling targets. Subsequent electromagnetic and drilling studies confirmed the locations and sizes of potential high permeability zones.

### The Borehole Instrument Centre for Eden Park (BICEP), New Zealand

Seismic observation at depths of 400 metres and 25 metres under the South Stand at Eden Park stadium in Auckland. BICEP aims to evaluate how the earth's movement affects the stadium, as well as how building movement affects the earth.

## ENGINEERED GEOTHERMAL SYSTEMS

### Basel Engineered Geothermal System Monitoring, Switzerland

Constructed a 6 station seismometer and accelerometer monitoring network, including instruments at 1.2 and 2.7km deep, followed by the collaborative analysis of induced seismicity.

### Paralana Engineered Geothermal System Monitoring, Australia

Installed a network of 8 borehole stations at a depth of 1.8kms and 4 surface stations, providing real-time feedback on the field during drilling and hydro-fracturing.

## GEOHERMAL EXPLORATION

### Krafla Volcanic Field Well Targeting, Iceland

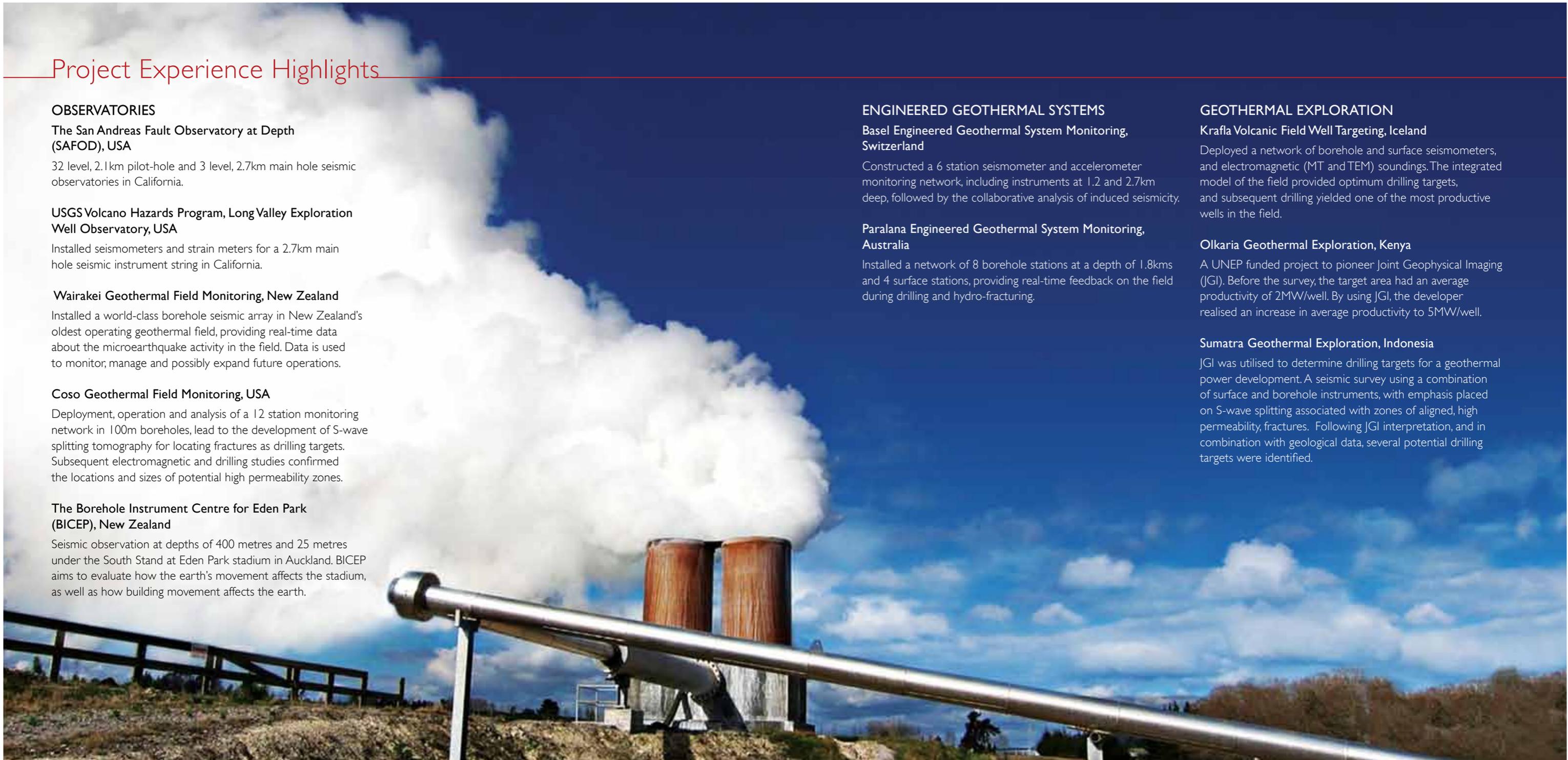
Deployed a network of borehole and surface seismometers, and electromagnetic (MT and TEM) soundings. The integrated model of the field provided optimum drilling targets, and subsequent drilling yielded one of the most productive wells in the field.

### Olkaria Geothermal Exploration, Kenya

A UNEP funded project to pioneer Joint Geophysical Imaging (JGI). Before the survey, the target area had an average productivity of 2MW/well. By using JGI, the developer realised an increase in average productivity to 5MW/well.

### Sumatra Geothermal Exploration, Indonesia

JGI was utilised to determine drilling targets for a geothermal power development. A seismic survey using a combination of surface and borehole instruments, with emphasis placed on S-wave splitting associated with zones of aligned, high permeability, fractures. Following JGI interpretation, and in combination with geological data, several potential drilling targets were identified.



# Major Seismic Monitoring Projects

## PERMANENT OBSERVATORIES

Borehole and Surface Stations: Standalone and Real Time

|                    |  |
|--------------------|--|
| <b>Australia</b>   | Paralana Geothermal prospect / hydrofrac monitoring: 12 borehole stations at 0.1 and 1.8kms, plus 4 surface stations |
| <b>Australia</b>   | LaTrobe Valley—exploration & monitoring: 2 stations at 0m and 1.7km  |
| <b>Iceland</b>     | Krafla Volcanic Field: 6 stations at 100m  |
| <b>Indonesia</b>   | Muara Laboh Geothermal Prospect: 10 stations, 3 borehole and 7 surface   |
| <b>Italy</b>       | Institute of Geophysics & Volcanology central Italy seismic zone: 3 stations at 250m                                 |
| <b>Japan</b>       | Nankai Non-Volcanic Tremor Monitoring Network: 4 stations at 250m  |
| <b>Monsterrat</b>  | Volcanic Field monitoring: 4 station seismometer and strainmeter network at 250m                                     |
| <b>New Zealand</b> | Alpine Fault, Franz Joseph & Fox Glacier 'SAMBA': 12 stations, 2 at 100m and 10 at 5m post holes                     |
| <b>New Zealand</b> | Wairakei Geothermal Field monitoring: 10 borehole stations at 200m   |
| <b>New Zealand</b> | BICEP—Eden Park stadium tremor & engineering: 3 level at 400m, 30m, 0m   |
| <b>New Zealand</b> | GeoNet: 6 stations; 4 in Auckland, 1 each in Ruapehu and Taranaki at 100m to 400m                                    |

## PERMANENT OBSERVATORIES

Borehole and Surface Stations: Standalone and Real Time

|                    |   |
|--------------------|---|
| <b>Norway</b>      | CO <sub>2</sub> Sequestration: 5 level array at 300m, plus 3 sensors in postholes at 15ms         |
| <b>Switzerland</b> | Geopower Basel HDR Project monitoring: 6 seismometer and accelerometer network at 0.4 and 2.7km   |
| <b>Switzerland</b> | 8 autonomous seismic data loggers for installation up to 3km                                      |
| <b>USA</b>         | Puna Geothermal Field, Hawaii monitoring: 8 station network at 30m                                |
| <b>USA</b>         | USGS Volcanic Hazards Program: 2 seismometers at 2.2km and 2.7km                                  |
| <b>USA</b>         | Western Plate Boundary Observatory: 113 boreholes at 250m   |
| <b>USA</b>         | Parkfield: 12 station at 250m continuous since 1985   |
| <b>USA</b>         | San Andreas Fault Observatory at Depth: 32 level in 2.1km pilot, 3 level & MT array in 2.7km main |
| <b>USA</b>         | Coso Geothermal Field: 12 station network in 100m boreholes                                       |
| <b>USA</b>         | Parkfield Varian: VSP array, 42 level at .7kms  |

## TEMPORARY OBSERVATORIES

Borehole and Surface Stations: Standalone and Real Time

|                    |   |
|--------------------|---|
| <b>Australia</b>   | Olympic Dam Mine Hydrofrac: 6 surface stations  |
| <b>Kenya</b>       | Olkaria Kenyan Rift Valley Geothermal study: 60 surface stations  |
| <b>Kenya</b>       | Olkaria / Domes Geothermal Field Seismic Study: 20 'geowatch' instruments                                   |
| <b>New Zealand</b> | Autonomous Building Vibration study, CBD, Auckland: 3 stations  |
| <b>Iceland</b>     | Krafla Geothermal Field Exploration: 40 surface stations  |
| <b>Spain</b>       | Tunnel Boring Seismic Look-Ahead Experiment: 16 level, 3-C seismometer string in horizontal 150m drill hole |
| <b>USA</b>         | Kill Van Kull Dredge Blast Monitoring: 8 surface stations   |
| <b>USA</b>         | Mammoth Geothermal Field Micro-earthquake study: 45 surface stations. 10k events recorded in 1997           |
| <b>USA</b>         | Naknek Engineered Geothermal System Site  |
| <b>USA</b>         | Utah Geothermal Exploration: 8 surface stations at Box Elder  |

## TEMPORARY OBSERVATORIES

Borehole and Surface Stations: Standalone and Real Time

|            |   |
|------------|---|
| <b>USA</b> | Nevada Geothermal Exploration: 6 surface stations at Silverpeak |
| <b>USA</b> | Loma Prieta Earthquake Aftershock study: 6 surface stations     |
| <b>USA</b> | Orange Country Quarry Blast Monitoring: 6 surface stations      |
| <b>USA</b> | Wilmington Dredge Blast Monitoring: 4 surface stations          |



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