2.2 Milestone Report: VEMP Tool Reconditioning and Testing

Due to its age and the design of electronic circuits at the time of manufacture, the VEMP system needed an update before it could be declared field ready in the high temperature environment at FORGE (Moore et al, 2020). This included a revamp of the data acquisition circuits, replacement of temperature sensitive parts and thorough testing.

This short report details the upgrade project and provides some local field data from earlier this year.

The VEMP system

The Vertical Electromagnetic Profiling system or VEMP was designed and built at Electromagnetic Instruments, Inc (EMI) with the Japanese company GERD in 1995. The receive tool was intended for high temperature borehole deployment and subsurface imaging especially in geothermal wells, but also for mining applications (Muira et al., 1996).

Tool Characteristics

The VEMP system features separate transmitter and receiver sections for surface to borehole or crosshole logging in a high temperature environment. The system operated with separate stations logging independently, but linked by a system clock

The transmitter develops square wave signals in the range from 4 - 128 Hz at the surface linked to a transmitter/ motor generator and provides them to a surface electric (bipole) or magnetic coil antenna. The high current output is provided by a commercial transmitter generator, which is coupled to the system clock. The VEMP surface station measures the current signal from a shunt resistor on the transmitter, synchronously with the receiver.

The downhole receiver measures the vector magnetic field using a 3-component induction sensor, it also has a vector fluxgate magnetometer for sensor orientation. These are both linked to a digital data acquisition system (Figure 1). The signals are averaged, sampled, and Fourier transformed within the tool and sent to the surface using a long-haul modem telemetry. On the surface the data are collected by and stored on a laptop computer

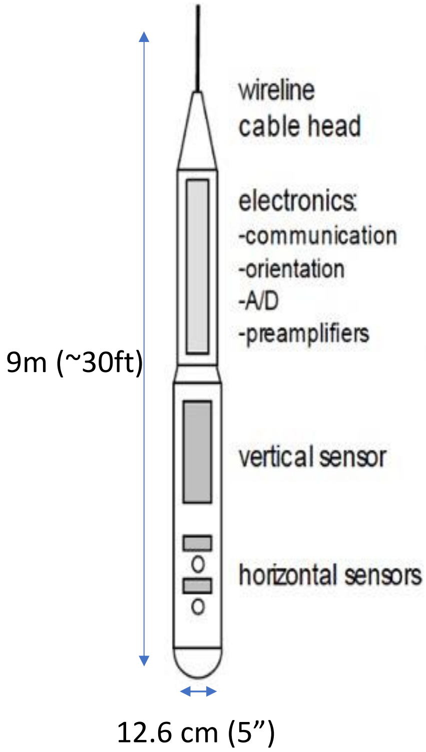

Figure 1 Schematic of the VEMP borehole receiver.

The tool’s magnetic induction coil sensors were quite advanced for their time and are likely still state of the art. The axial sensor is 1.5m long with a 1 cm core of mu metal. It is wrapped with 50,000 turns or wire and connected to a down hole amplifier in a feedback configuration. It has excellent sensitivity from 0.5-1000 Hz. The horizontal components are measured by a trans-axial orthogonal sensor pair. This consists of a series of 2.5” coils connected in series/ parallel. These coils provide impressive sensitivity in a small package.

The digital data acquisition system on the other hand is now quite obsolete, being designed and built in 1994. The acquisition system was based on a 16 Bit A/D with analog electronics and data transmission via a long-haul low-speed modem. Data is averaged downhole and a fast- Fourier Transform (FFT) performed prior to sending data packets to the surface.

The system operates by initially synchronizing the clock and then deploying the source and receiver stations separately. The file and logging characteristics are all recorded by user input and data is collected at the receiver end using a wheel type digital encoder for depth control and manually moving the tool between specified or manually input depths.

Although cumbersome to operate, the tool was ahead of its time for sensitivity and temperature and pressure tolerance. Below is a sample plot from a successful high temperature logging test in Dixie Valley, Nevada. In that test the tool logged 300m of open hole and 200m of cased hole at temperatures up to 215 ^{0}C (Mallan et al., 2001).

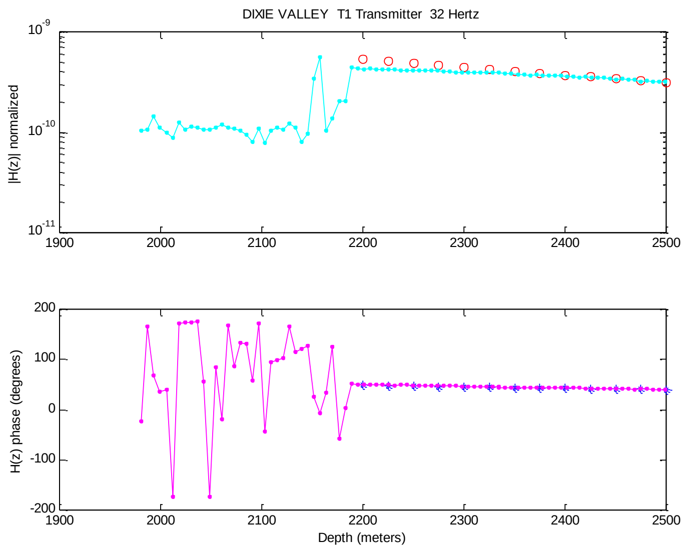

Figure. 2 VEMP vertical magnetic field response from an 800m long surface transmitter bipole. Small symbols and line are collected data, large symbols are from 1 D model**.** Note that the well is cased with steel casing to a depth of approximately 2200m and open hole below this.

Tool status (2024)

This tool had not been used in the US since 1999. It has been carefully stored since then at a GERD facility in Japan. After discussion with GERD they agreed to ship the tool to the US evaluate its status and upgrade and test it if was found to be a viable option for high temperature deep logging. If so they would t loan the tool to LBNL to deploy at FORGE. The tool evaluation and testing was completed in 2021-2 and the following was found:

- VEMP is mechanically sound with the exception of one tool joint which has since been repaired;
- The sensor compartment was intact and the three component sensors were found to be operational within specifications;
- The analog electronics boards were found to be operational and working to specifications;

- The electronics thermal Dewar was found to be intact and subsequent testing found that it had not degraded in holding time;
- The fluxgate sensor used for tool orientation mag was not functional;
- Operational software and computer components were missing;
- There we no system manuals;
- The digital electronics components could not be tested but these were more than 25 years old and obsolete. In addition, no replacement parts were available due to their age.

Due to limited time and financial budgets we modified the data acquisition design to be largely analog with magnetic induction sensor signals traveling up the wireline and processed on the surface with an existing digital (seismic)recording system. Digital circuits were also included for tool orientation and temperature and downhole voltage conditions.

The re-designed system has the following characteristics (Figure 3).

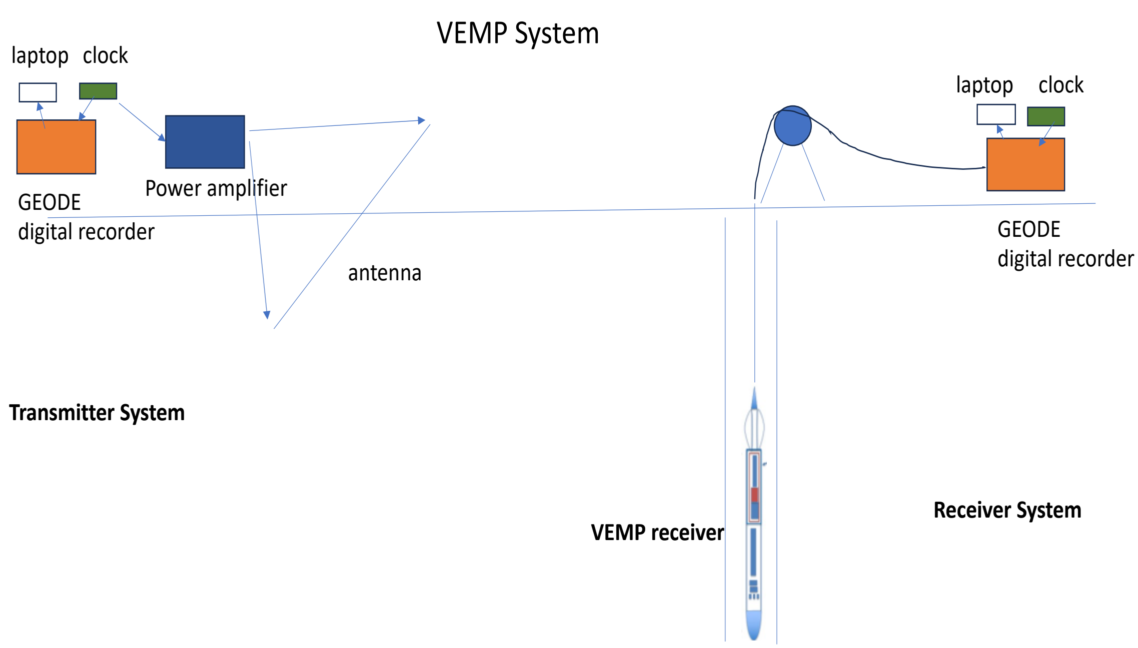

Figure. 3. Re-designed VEMP system.

Magnetic Field data collection

The amplified sensors are now directly wired into the wireline head. The amplified signals can travel up the wireline at low loss. There is also minimal cross-coupling. The downside is that 6 of the 7 wireline ports are now occupied leaving only one port and the system ground to carry all other signals (Figure 4).

On the surface analog signals are connected to a GEODE seismic recording system along with the system GPS clock (Geometrics, 2023). The GEODE accepts the time series, averages together repetitive signals and then calculates the spectral components (amplitude and phase) of the three magnetic field channels. This is controlled by user supplied software.

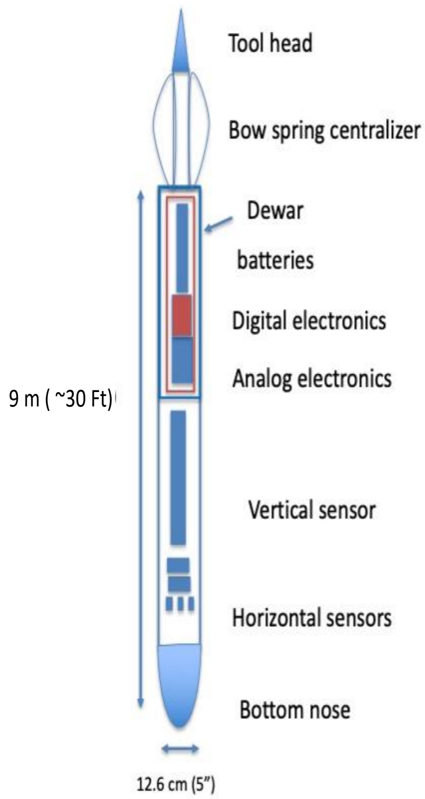

Figure 4. Modified VEMP receiver

Power Supply

The surface and downhole power supply boards have now been replaced by a set of batteries resident in the tool electronics compartment (Figure 4). These are within a confined plug-in packet of six 3.6V lithium batteries than can power the analog and digital electronics up to 30 hours.

The power supply will be real-world tested through the new wirelines to determine the operating lifetime, but we can anticipate at least 16 hours operating time from one set of batteries.

Digital Circuits

The VEMP tool orientation is derived from an on-board three-component fluxgate magnetometer that uses the earth magnetic field to calculate the orientation of the tool. The digital output of the magnetometer is fed into a small circuit board that also measures tool voltages and downhole temperature from several sensors and send a digital stream up the wireline. This input is directly measured on the system laptop.

Transmitter

The previous VEMP transmitter was typically a commercial unit, such as a Zonge GGT-30, with a signal controlled by the system clock. The system also has a circuit within the surface station to measure the transmitter current. Voltage and current measurements are logged with software.

The new transmitter is similar with the exception that the current is measured with an inducive current sensor, a GPS clock and digital circuits are now replaced by a second GEODE system (Figure 3). The new transmitter is a high voltage power amplifier suitable for driving either an inductive source (loop) or grounded source (wire) at frequencies from 0.1 Hz to 10 kHz.

Timing Control and System Clock

The phase reference for both the transmitter and receiver section is a clock, which also provides the square wave signal for the transmitter. This clock was developed at LBNL for a separate project but it is suitable for the VEMP deployment.

System operation—Surface to Borehole

The VEMP system operates by first positioning source and receiver systems and synchronizing the GPS clocks. Data is typically collected in profiles within a well, at fixed station intervals for each transmitter location on the surface. Data is collected while the receiver is stationary and the receiver tool is moved between stations using the wireline system.

The software records the station depth, sensor amplitude and phase readings and input from the digital board. The digital data stream includes vector Earth's magnetic field data from the fluxgate magnetometer, voltage data from the batteries and internal and external temperature data at each depth.

We note that most elements of the system can also be used for high temperature crosshole logging. In that case a down hole transmitter tool would be moved with specified depths (a profile) while the receiver is stationary in a second hole. After each profile the receiver tool is moved until the depth interval is covered in both wells.

System testing and calibration

To calibrate the VEMP tool we used the LBNL cross-well transmitter coil as a source and positioned it approximately 30m from the VEMP tool, so that a strong field would be produced but not enough to saturate the receiver. Using this directable transmitter solenoid also proved convenient for calibrating individual field components.

The VEMP system was calibrated against a known standard, a commercial BF6 receiver coil, using an HP spectrum analyzer to measure the relative amplitude and phase over a full spectrum (Figure 6). The source coil was energized using a frequency sweep from 0.1-500 Hz, and the VEMP coil components (X,Y,Z) and the BF6 were measured simultaneously on the spectrum analyzer, where the amplitude ratios and phase differences were recorded. After measurement we then adjusted the data for the response of the BF6 sensor.

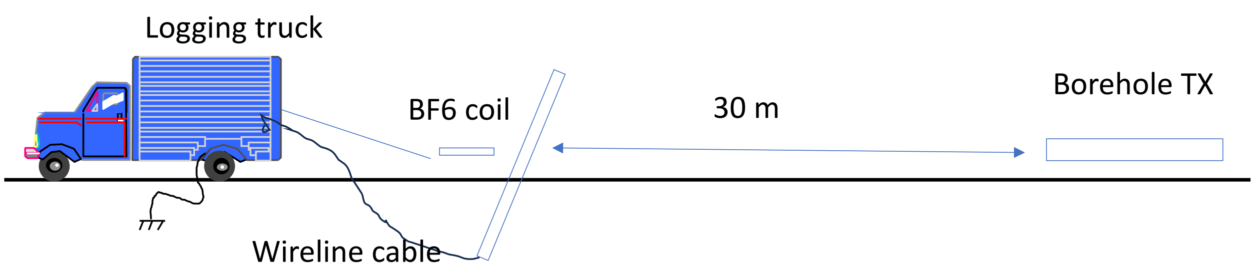

Figure 5 calibration set up

The resulting normalized amplitude calibration for the field components are shown in Figure 6. Note that the VEMP receiver is strongly band limited. That is, the higher frequencies cut out strongly above 100 Hz. Most of this is due to imposed filtering which was necessary due to the original (~1995) data acquisition system, which was quite slow. It is possible in the future to relax the filter and boost the spectral content to above 1000 Hz.

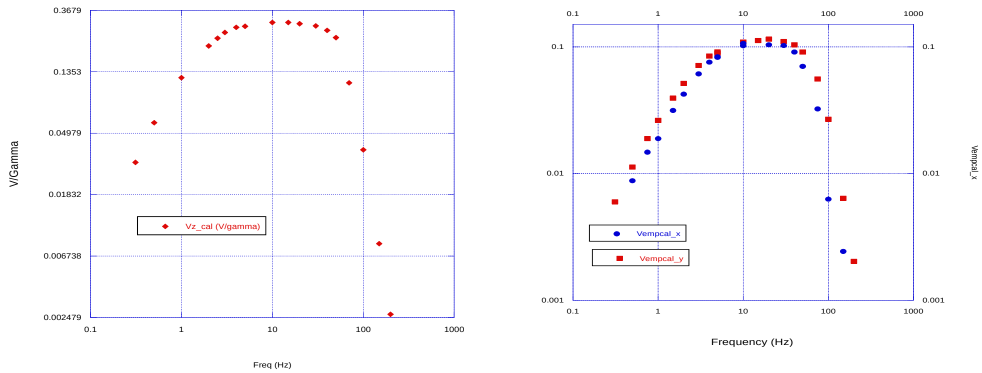

Figure 6 Calibration curves for the VEMP sensor

Tool Deployment

The 3-component VEMP system is 10m long and weighs approximately 200 kg. It is a very difficult task to maneuver this tool for calibration and even more so for deployment, especially with a small crew.

The LBNL logging vehicle "Bread Van" has an incorporated boom and winch system for deployment of "normal" tools, where the tool can be man-handled into position. For this case however the deployment required a separate sling which was used to lift the tool and position it over the well head using the winch. Once in the well the sling is released and the wireline can hold the weight of the tool (Figure 7).

Figure 7. The VEMP system deployed at Richmond Field station in well EMSW.

The initial profile test was conducted using a spectrum analyzer in parallel with our MATLAB/GEODE data acquisition system. The profile recorded the sensor measurements (X Y and Z) against the transmitter current monitor. The set-up is shown in Figure 8; the results are given in Figure 9.

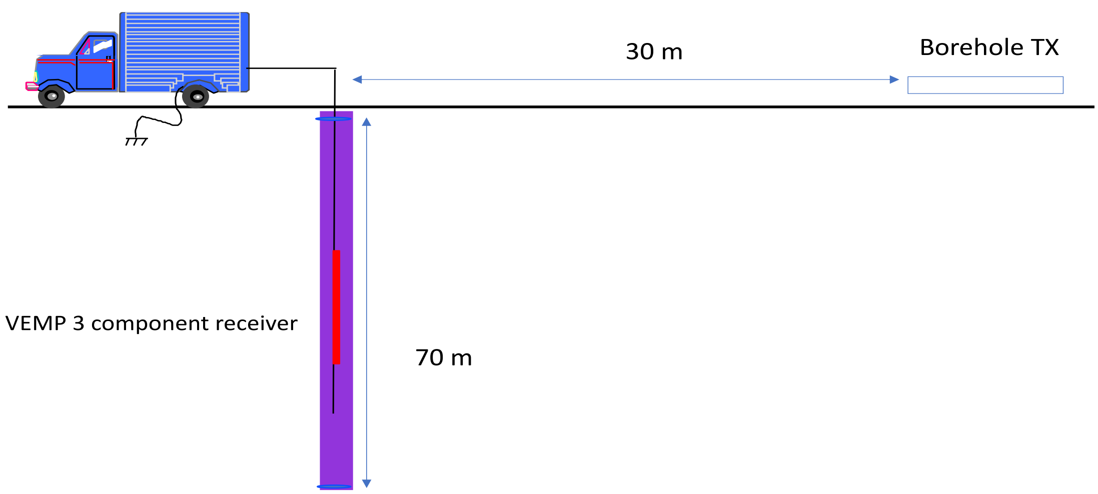

Figure 8 Profile data acquisition set up

These results are preliminary and we did not take great care in depth control or system isolation. We simply wanted to see if the system was working and the results seem to show that it is. We note that this is the first VEMP profile since 1997.

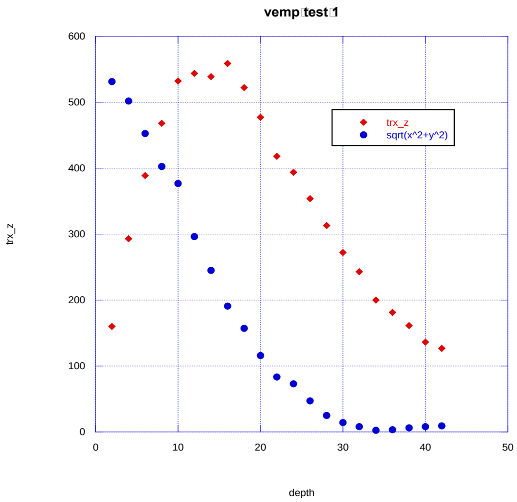

Figure 9. Amplitude profile for the vertical and horizontal fields at Richmond Field Station

Tool hardening

Prior to deployment at FORGE we have begun to harden the VEMP tool by updating remaining solder joints and connectors to high temperature versions, draining and refilling the pressure oil compensation system. This process will continue until February, 2024.

Logging Conveyance and cables.

VEMP will be deployed at FORGE using 2 LBNL logging trucks (Figure 10). The full size truck will hold up to 5,000 m of wireline cable and it has been recently fitted with a high temperature cable that can log up to 300^{0}C. The "Bread Van" has a maximum reach of approximately 1400m. It has recently been fitted with a 250 ^{0}C logging cable and head.

Figure 10 LBNL full size logging truck, right (left) , LBNL "bread van" shallow to medium depth logging truck (right).

Software development

Data collection for VEMP will use a MATLAB based data acquisition system tied to the GEODE seismic recording system. We are presently using a beta version and will have a final one testing for the final calibration and profile measurements.

Final Calibration.

After completion of some final tasks for tool preparation we will do a final system calibration and repeat the shallow profile data collection. In this case we will fit the data to a numerical 1D model using the known resistivity structure at Richmond.

References

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Miura, Y., Osato, K., Takasugi, S., Muraoka, H., and Yasukawa, K., 1996. Development of the Vertical Electro Magnetic Profiling (VEMP) method. Journal of applied Geophysics, 35(2-3), pp.191-197.

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