Studying the Relationship of Earthquakes and Groundwater Levels in Long Valley caldera, California: Results from a 3-km Deep Borehole and High-temperature-capable Monitoring Tools

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Goals of our work

Instrumentation Goal:

Develop and test instruments to measure pressure and temperature in hot, deep boreholes over long periods of time (months to years).

Scientific Goal:

Understand the mechanisms of earthquake-induced fluid pressure changes at Long Valley caldera, and use this knowledge to help understand seismic and volcanic processes as well as remotely triggered seismicity.

Reasons to monitor fluid pressure in hot deep wells

Earthquakes nucleate at depths of several km below the earth's surface

Future plans for drilling in seismically active areas include deep boreholes

Hydrothermally active areas may also be good places to study the behavior of fault zones at depth

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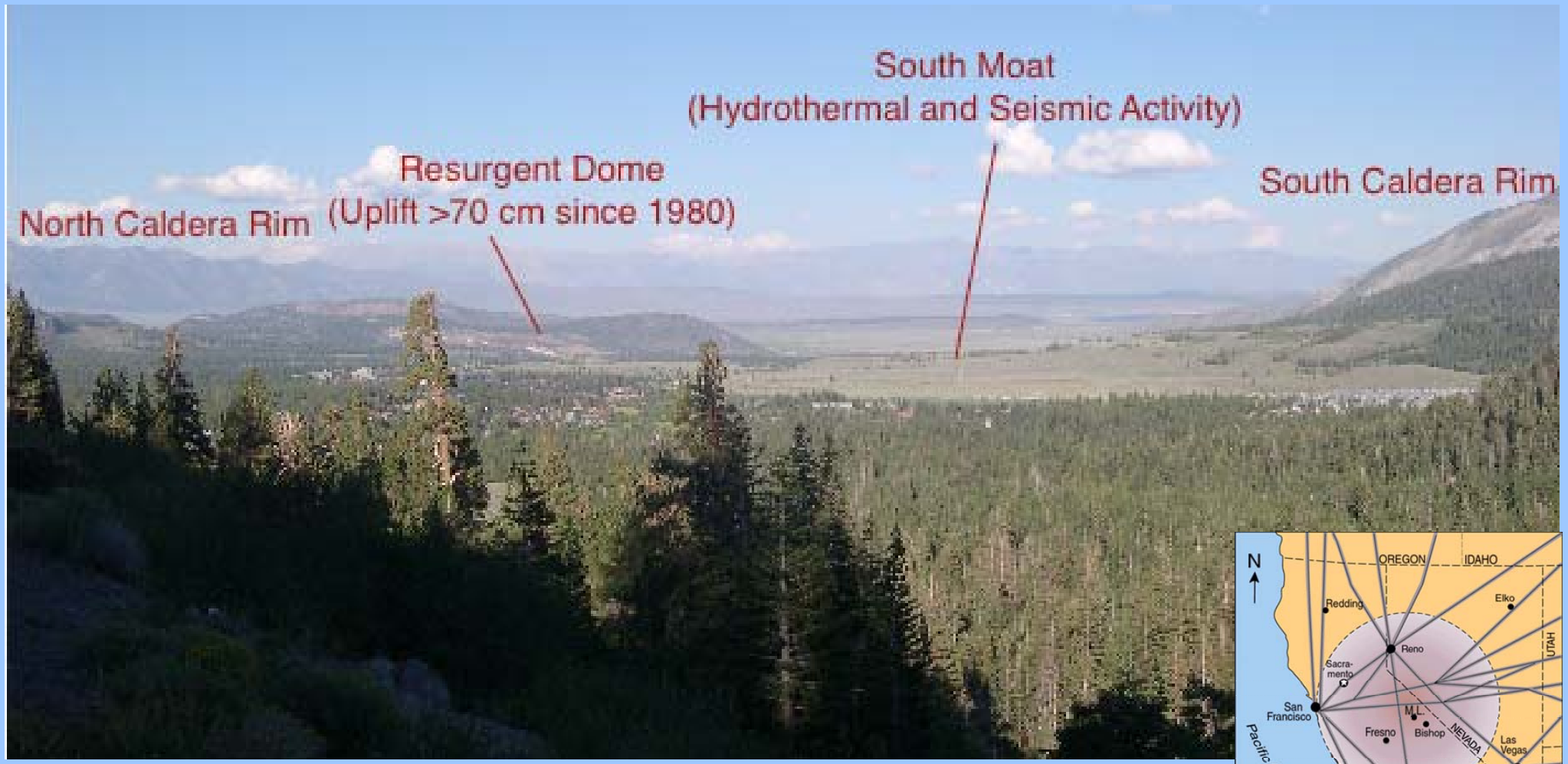
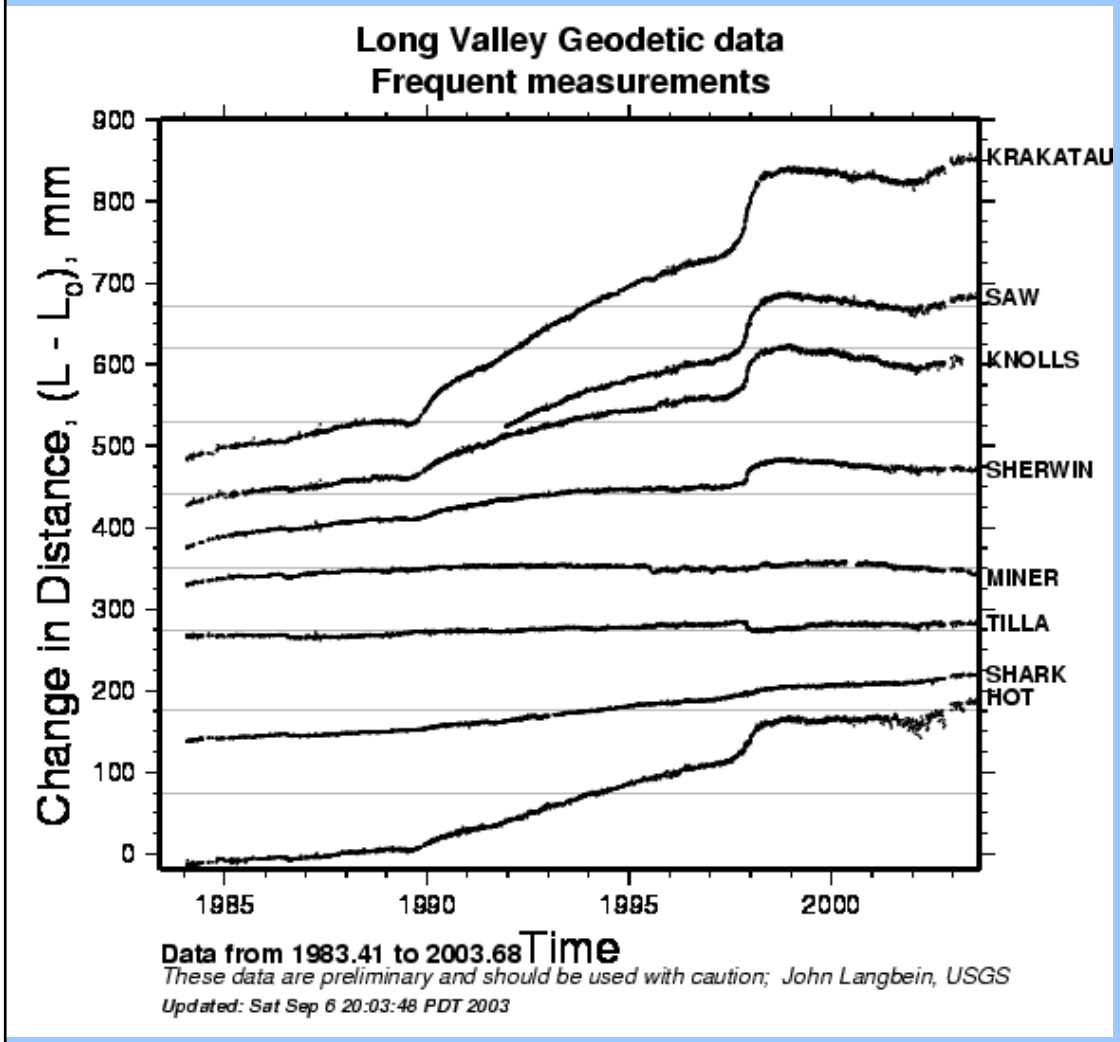
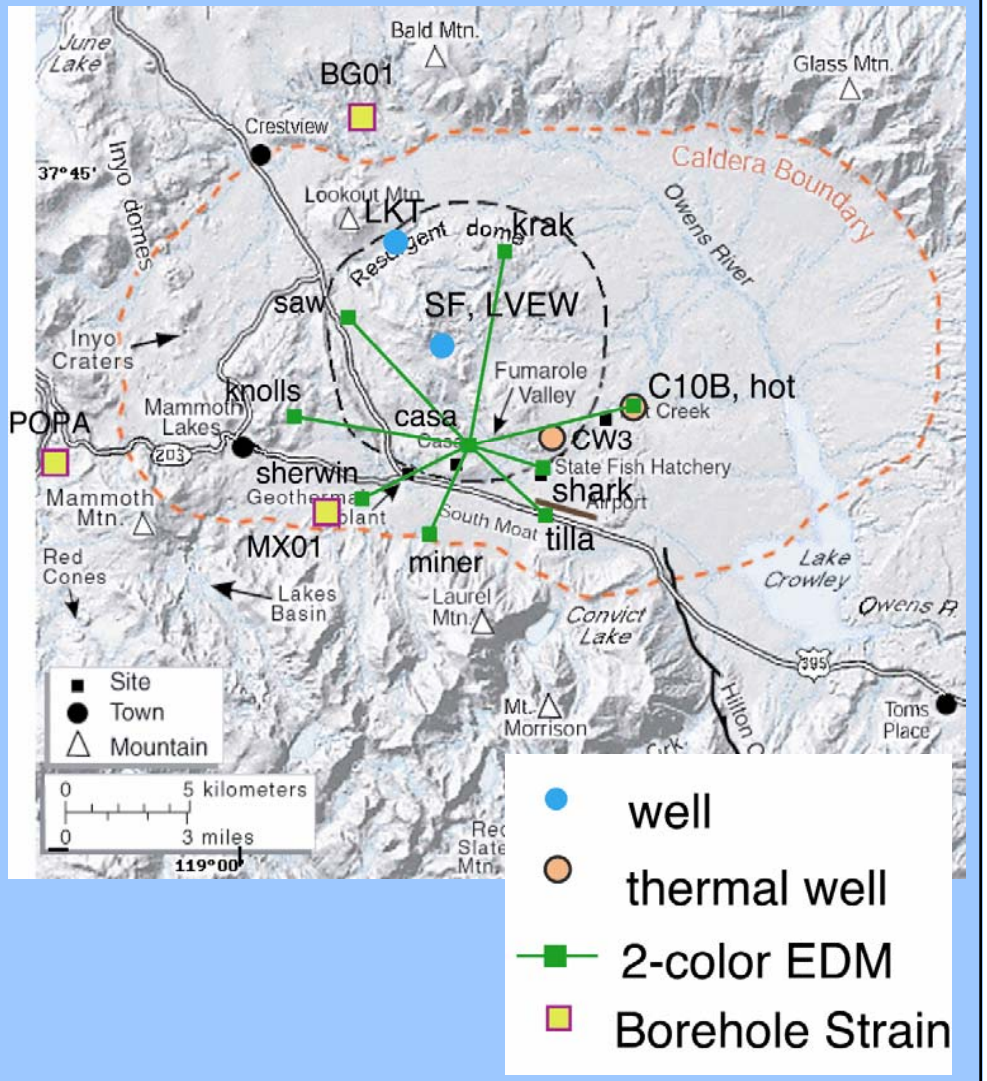
Long Valley Caldera: A Seismically and Volcanically Active Area in Eastern California



Resurgent Dome is Actively Uplifting

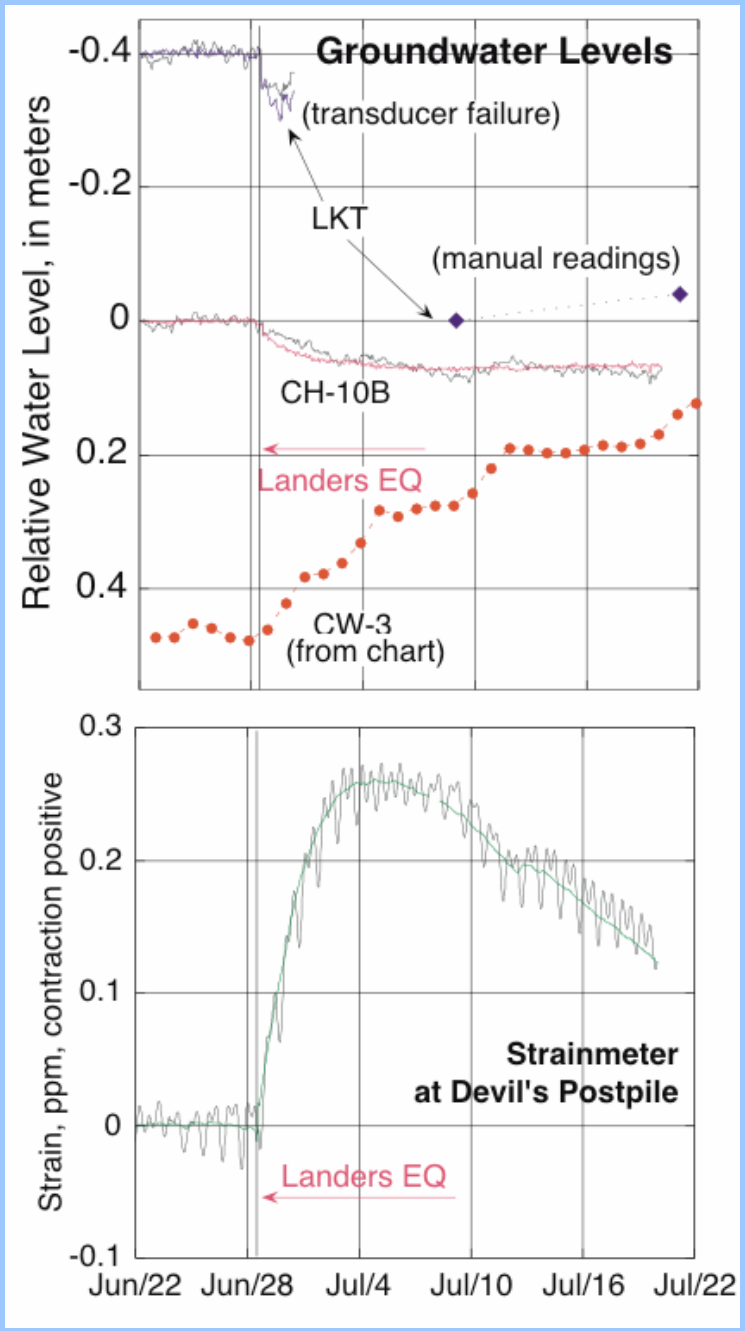




Water Level and Strain Changes Are Triggered by Distant and Local Earthquakes

Persistent water level *drops* occur in non-thermal wells on and north of the caldera's resurgent dome (e.g., LKT)

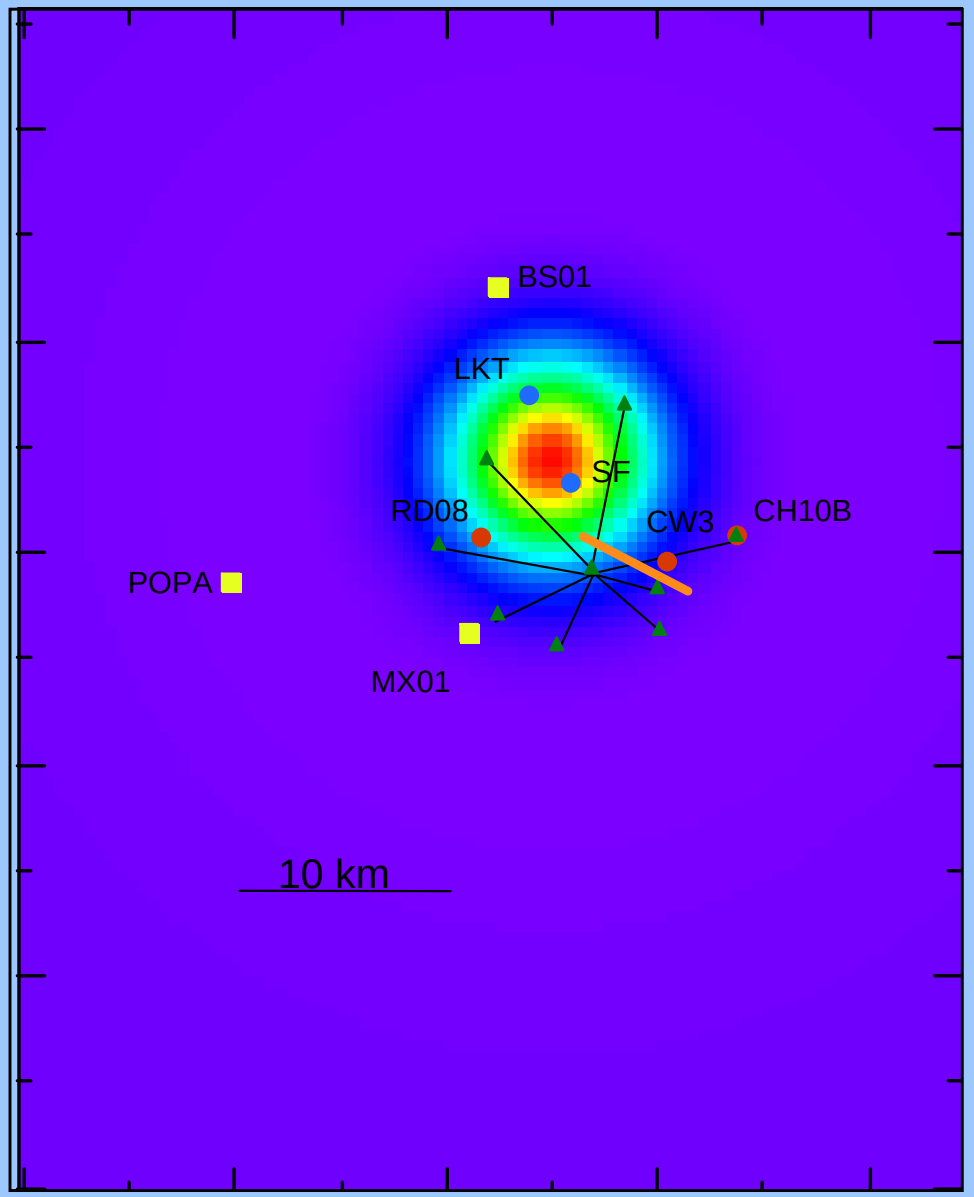
Fluid level *increases* occur in the caldera's hydrothermally active south moat (e.g., CW-3).



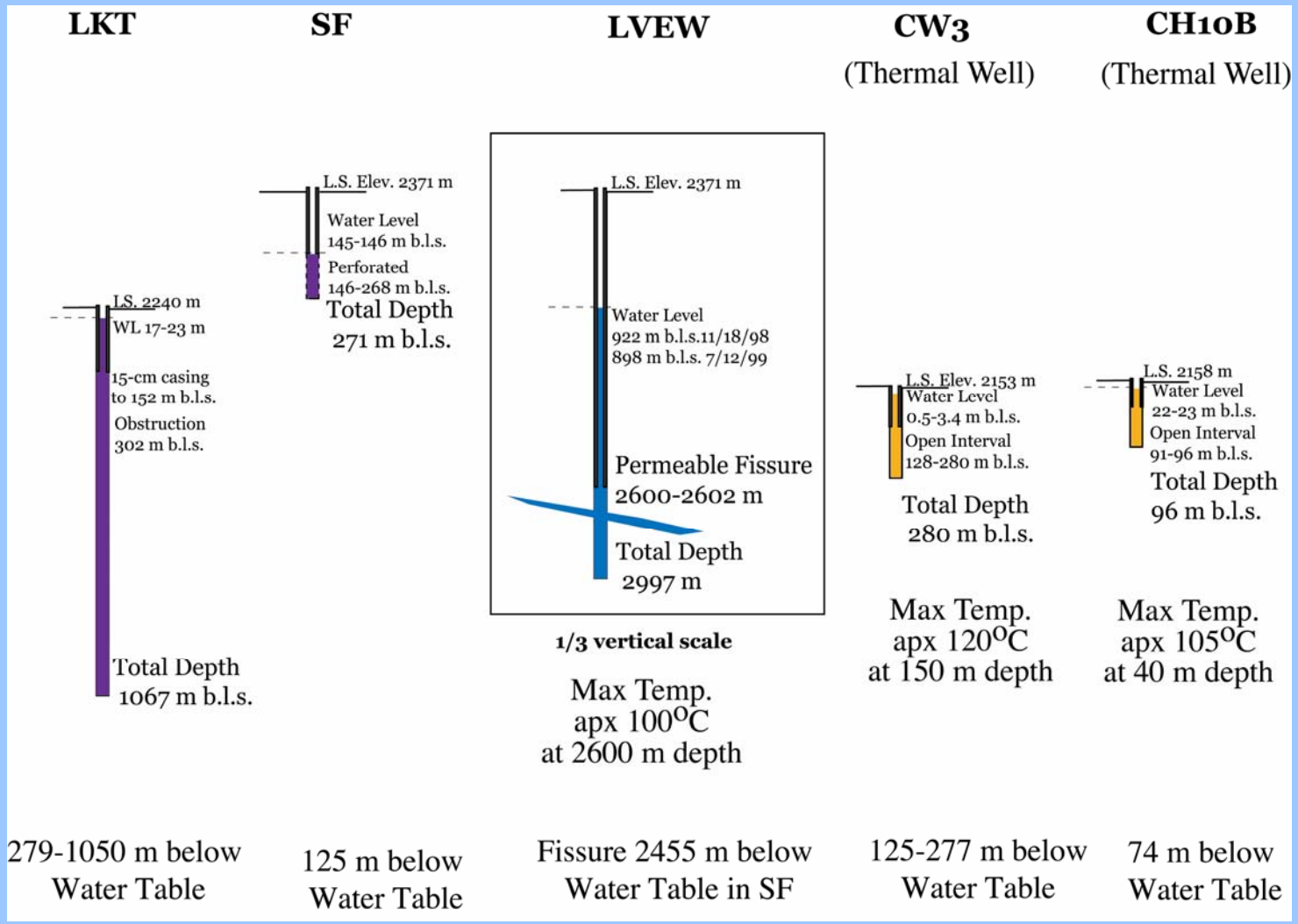
Hypothesis about Causes of Fluid-Pressure Changes:

Earthquake-induced water-level drops on and north of the resurgent dome may be caused by incremental dome inflation

Fluid-pressure increases in thermal wells are due to hot material rising from depth



LVEW: A 3-km Deep Borehole on the Resurgent Dome



High-temperature Capable Pressure-Temperature Monitoring Tools

Utilizes downhole silicon-on-insulator electronics

Designed for T=150 C and P=5000 psi (35 Mpa)

Includes:

- Quartz pressure-temperature transducer
- Strain gage pressure transducer
- RTD temperature sensor

Digital (RS232) output

Sampling interval 2.5 s

Built at Sandia National Laboratories

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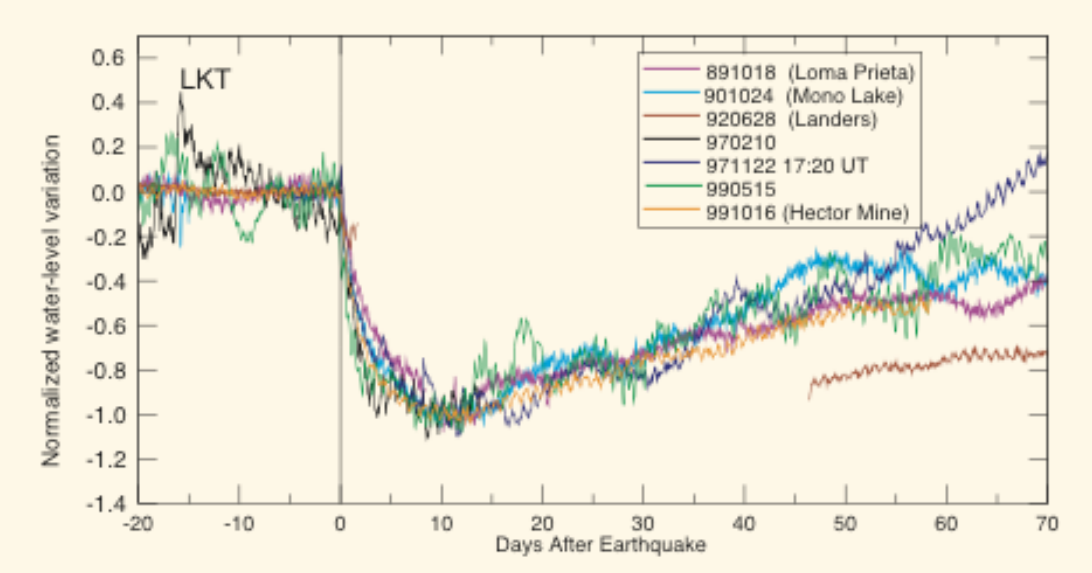
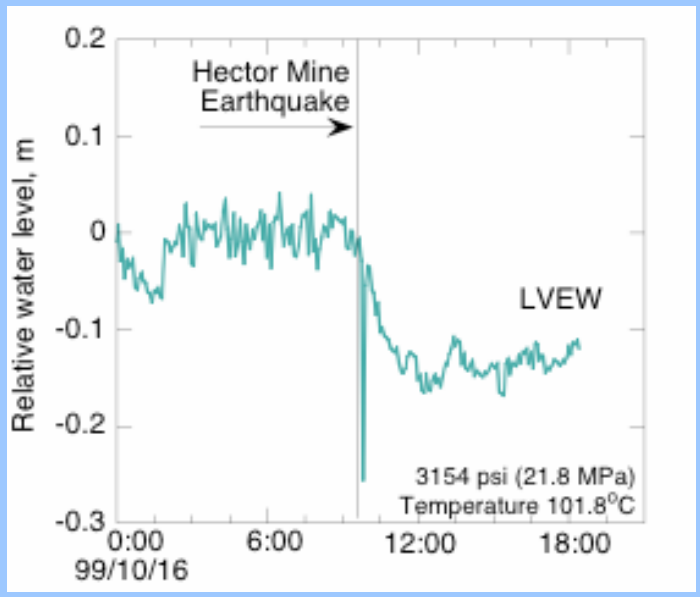
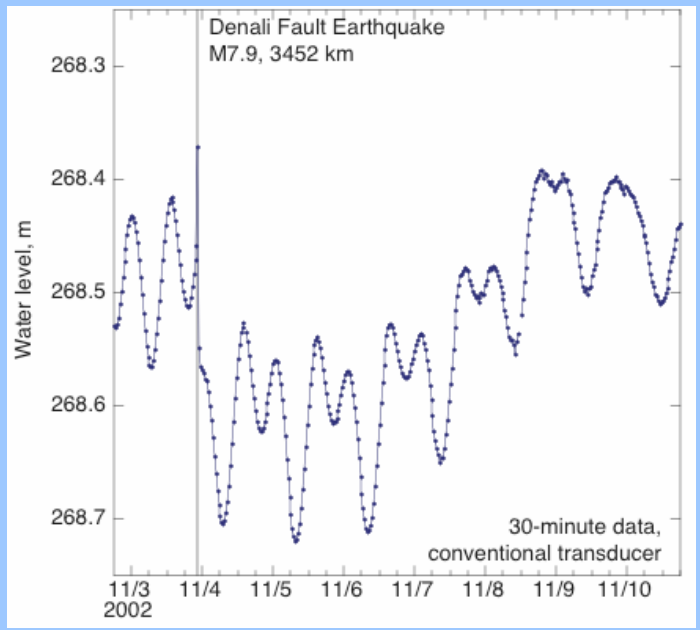
Earthquake-induced pressure drops occur more quickly in LVEW







Minimum water level is reached in 10 days at LKT

In LVEW, time to reach minimum was <6 hours for Hector Mine and about 2 days for the Denali fault earthquake

Shorter time for LVEW is consistent with a source beneath the resurgent dome (closer to LVEW)

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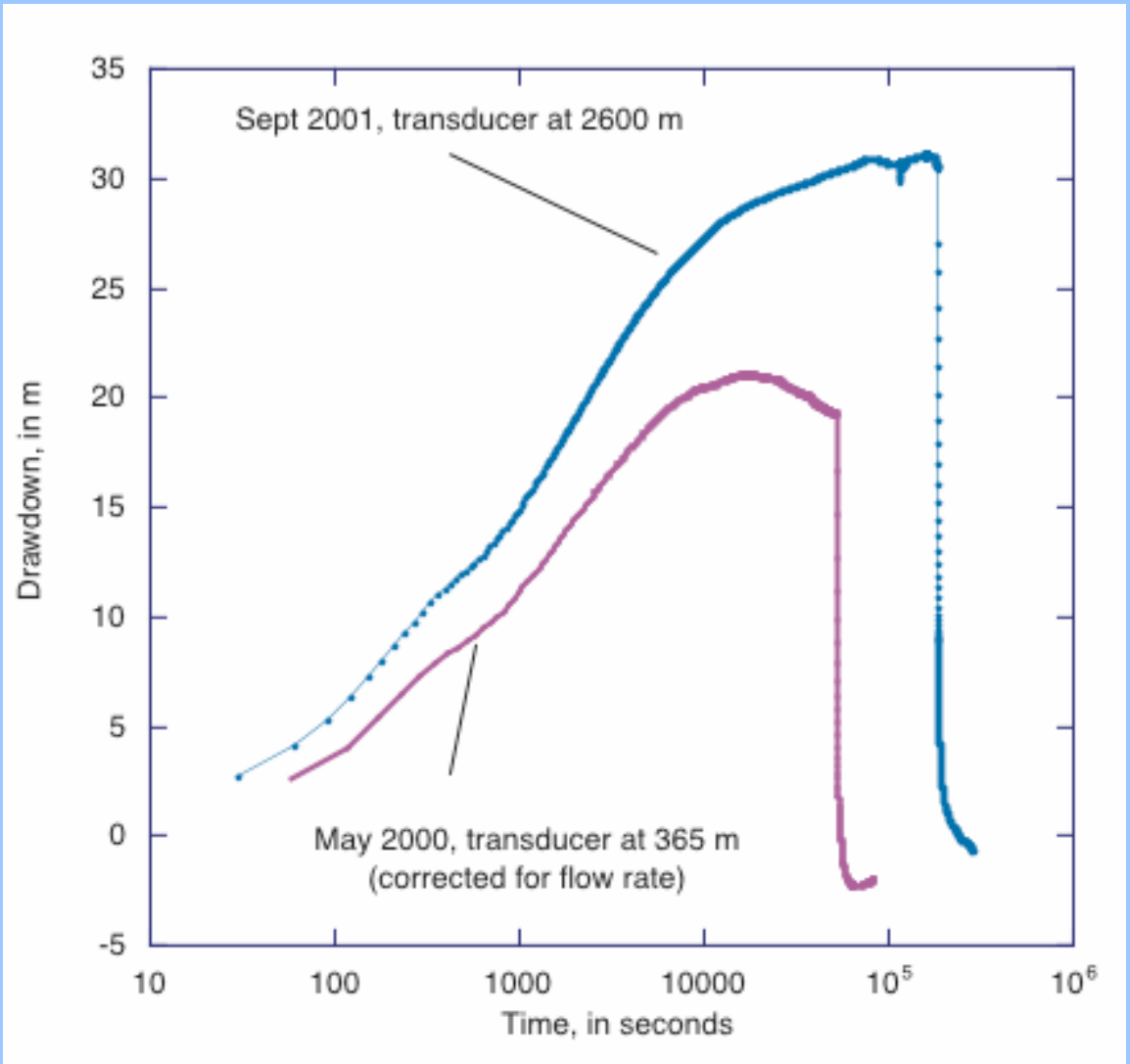
LVEW Pumping Tests



With shallow transducer, drawdown appears to decrease due to temperature changes

Accurate drawdowns are measured with transducer at 2.6 km depth (temperature 102º C, pressure 22.3 MPa).

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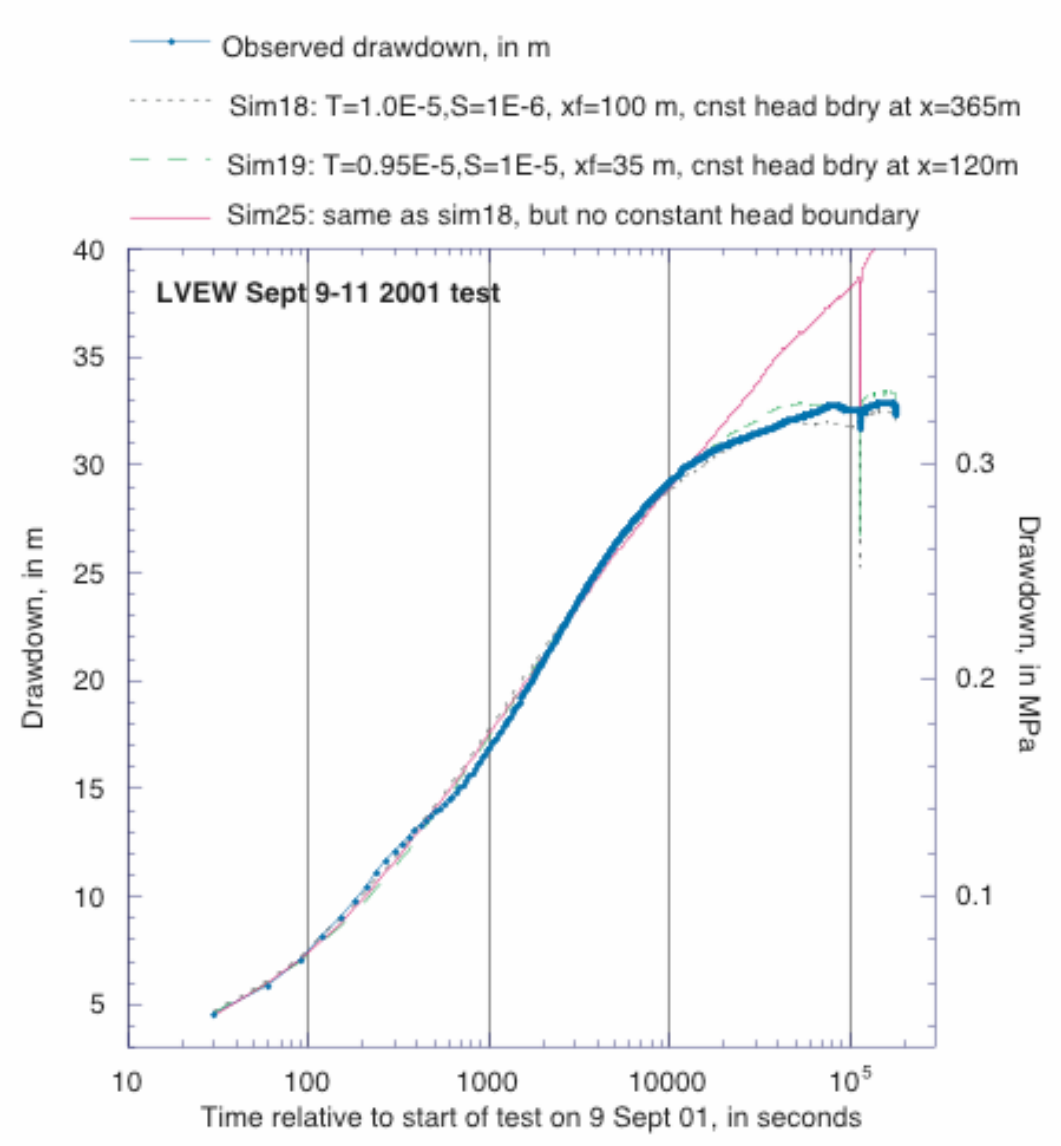
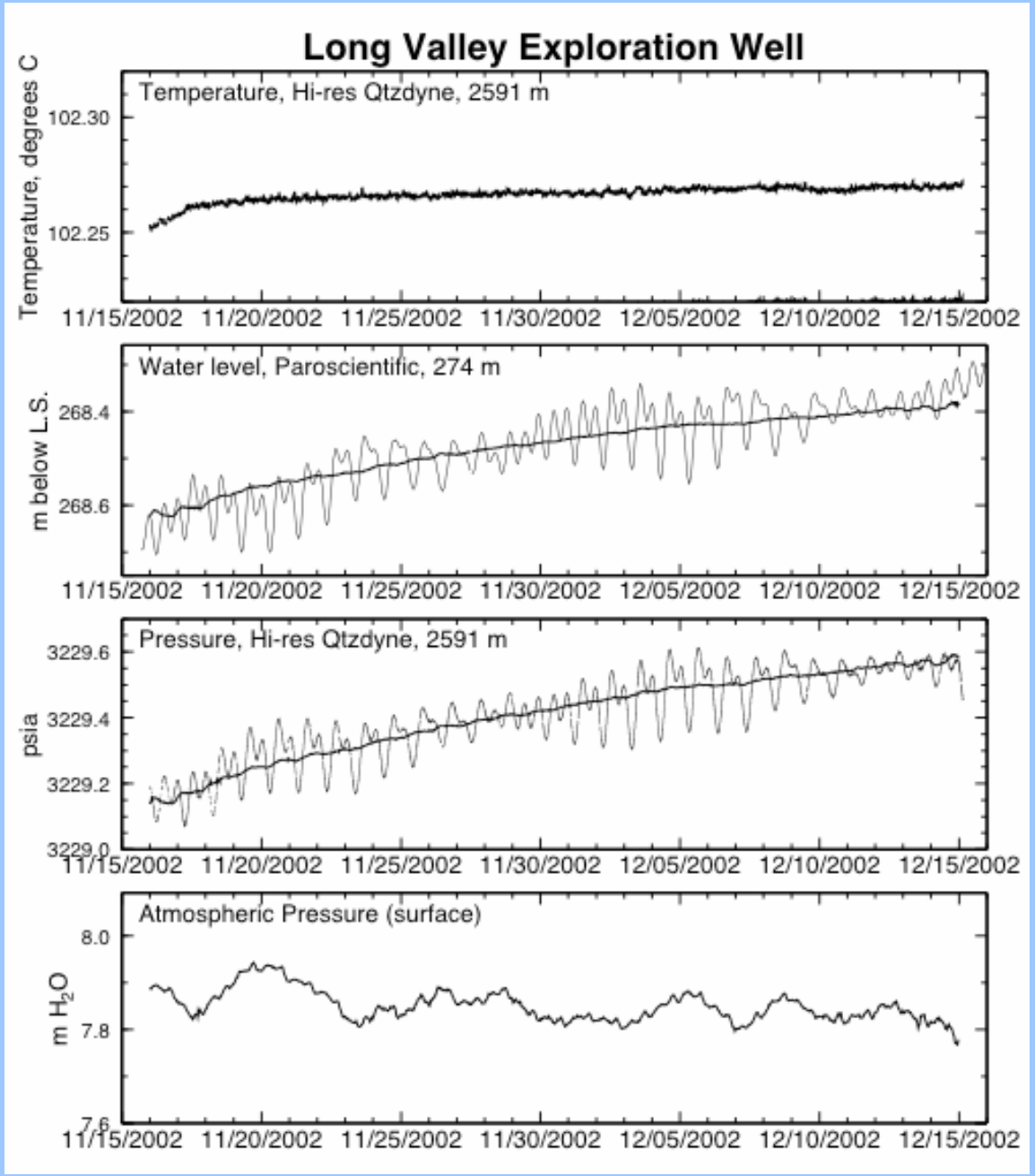
Test modeling using Gringarten fracture solution



Comparison of high-temperature and conventional transducer

Tidal variations are 1.93 kPa peak-to-peak, and ratio of pressure change to strain based on the M_2 earth tide constituent is 30.3 kPa/microstrain.



Cable Problems

After one month, problems developed with the data from the LVEW, because the cable developed a leak and a short circuit formed.

The instrument itself was at high temperature (100C) and pressure (22 Mpa) for 7 months. It is still in good condition and was recently deployed in well 28-34 at Long Valley.

A stainless steel tube with conductors inside is expected to survive better than logging cable at high temperature and pressure and this is currently being tested by Sandia Labs.

Water-Level Rises in CW-3:

Do not appear to be caused by strain:

-well CW-3 has no tidal response, so very large contractional strain would be required to produce observed water-level rises

-CW-3 is on CASA-HOT geodetic line, which is extending, not contracting

Alternate hypothesis:

-seismic waves stimulate localized upward movement of hot, pressurized fluid in vicinity of CW-3

Scientific Questions

Are the fluid pressure increases observed in CW-3 detectable at other sites?

What is the reason for these pressure increases?

Are the pressure increases accompanied by temperature increases?

Are there seismic oscillations that occur before the pressure increases?

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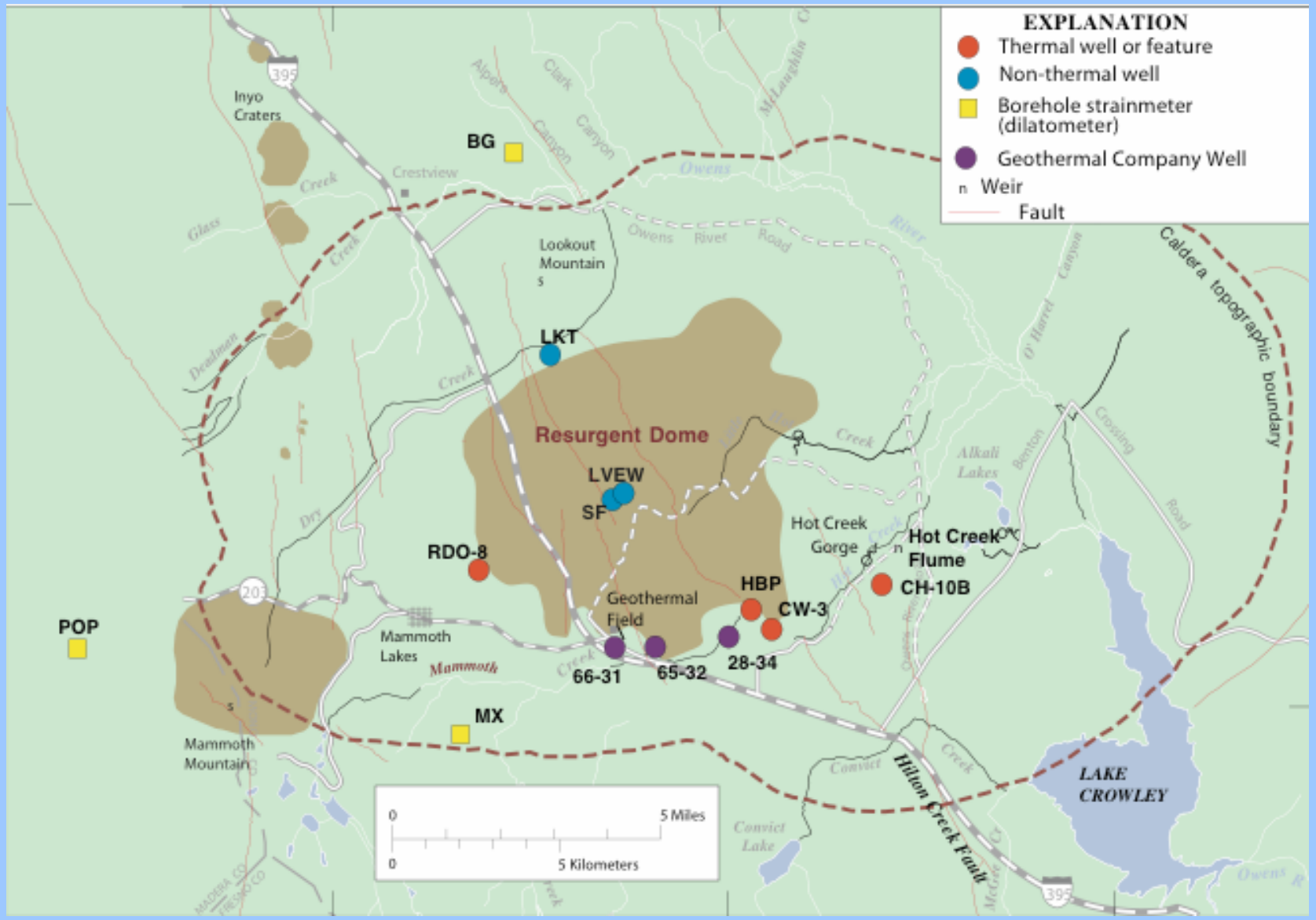
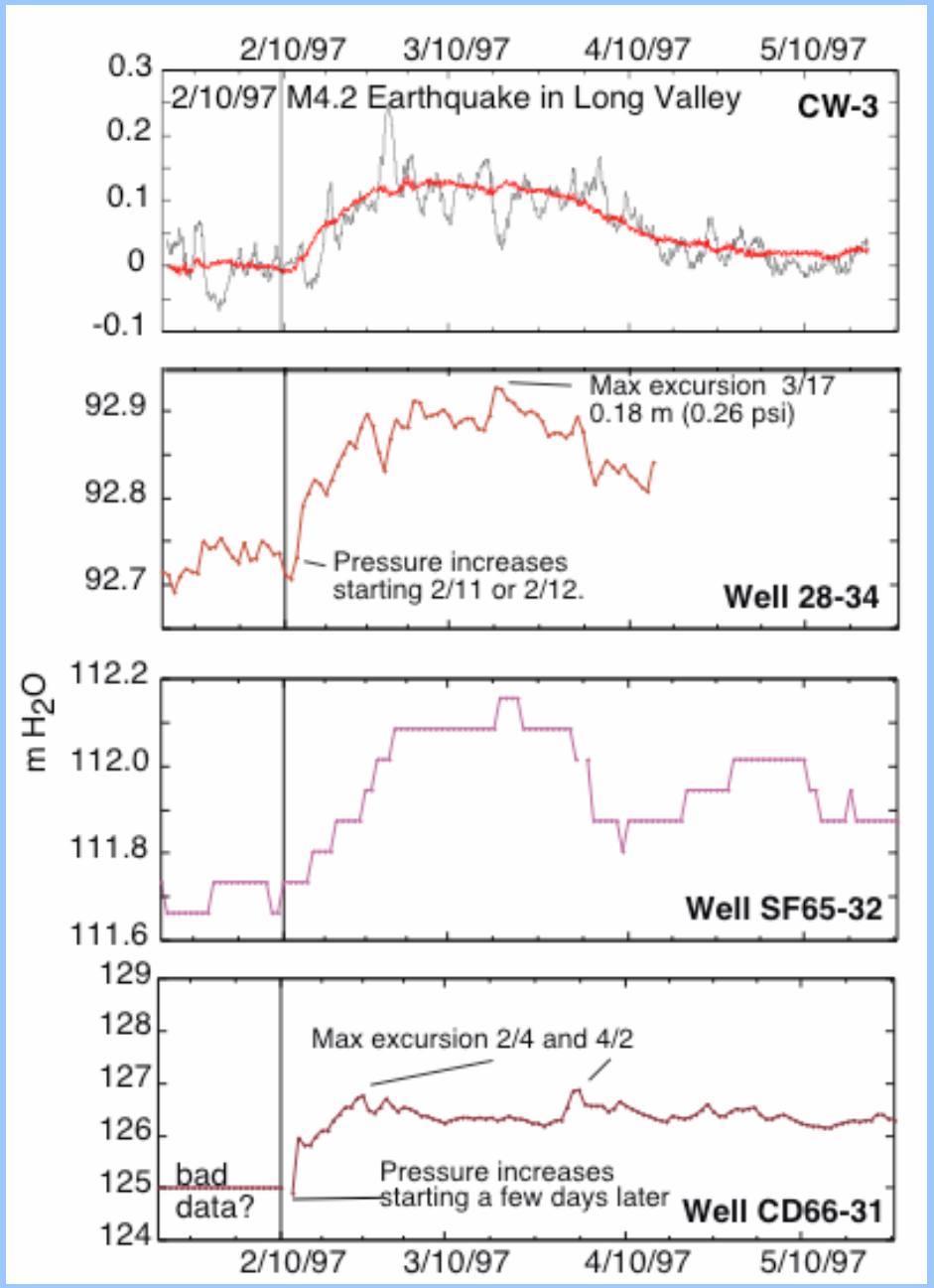
Long Valley Hydrothermal System



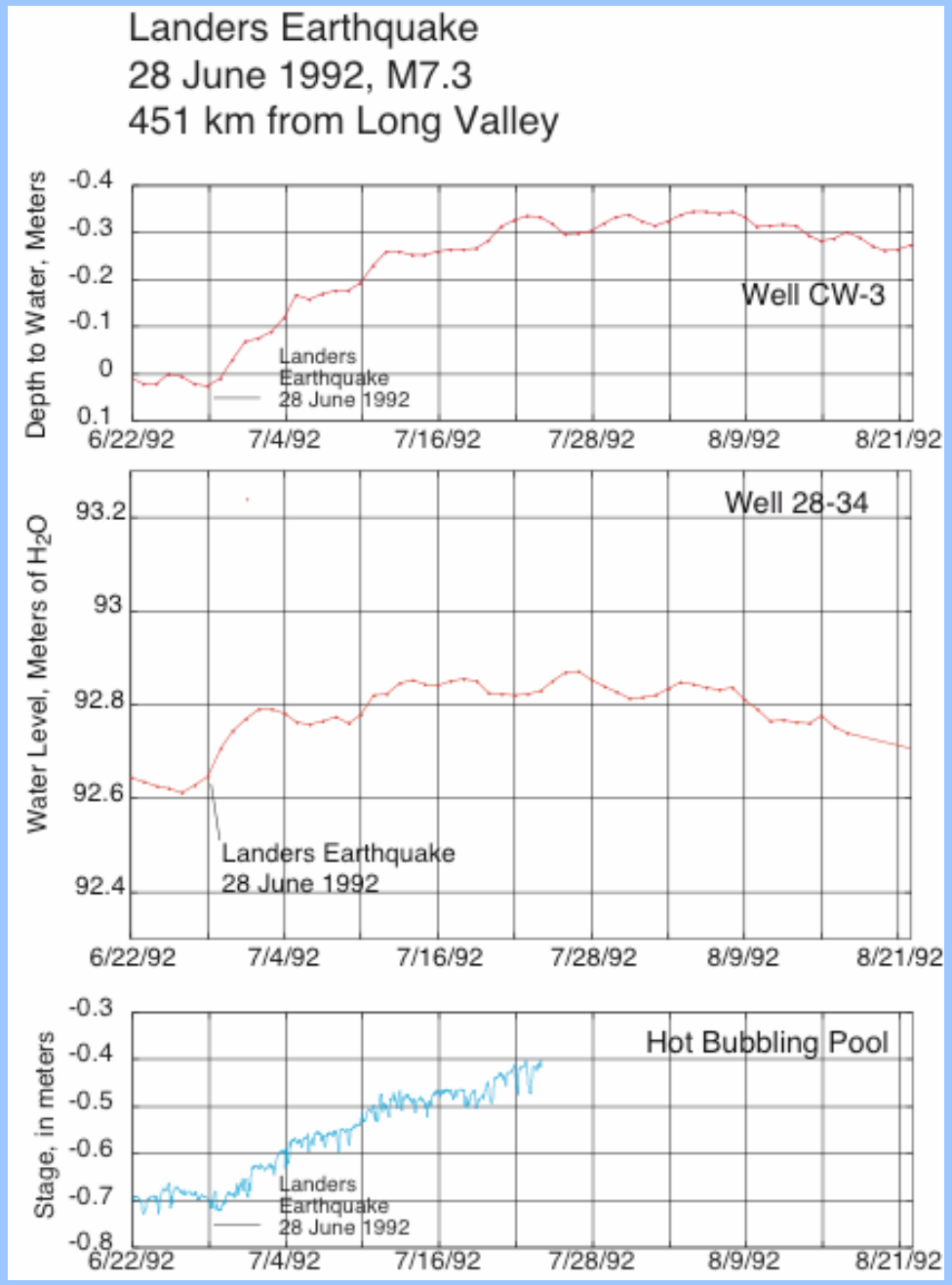
Geothermal observation well 28-34 near CW-3 also exhibits very similar fluid pressure increases caused by earthquakes

Wells further west do not show the pressure increases…so we believe the pressure increase is localized between CW-3 and 28-34 (the "Fumarole Valley" area)



Pressure Increases Caused by Landers Earthquake

Increases occurred in wells CW-3 and 28-34 , and stage rose in the Hot Bubbling Pool about 100m from CW-3.



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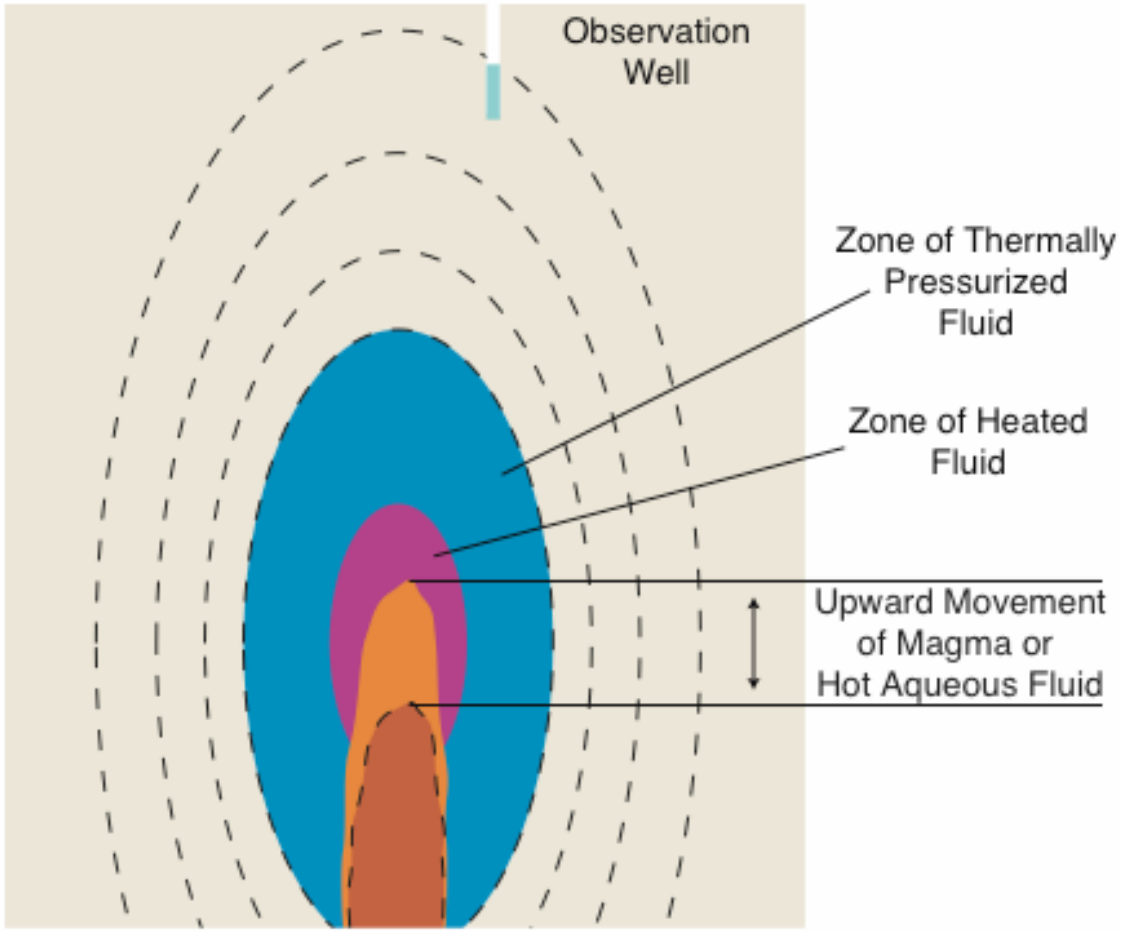
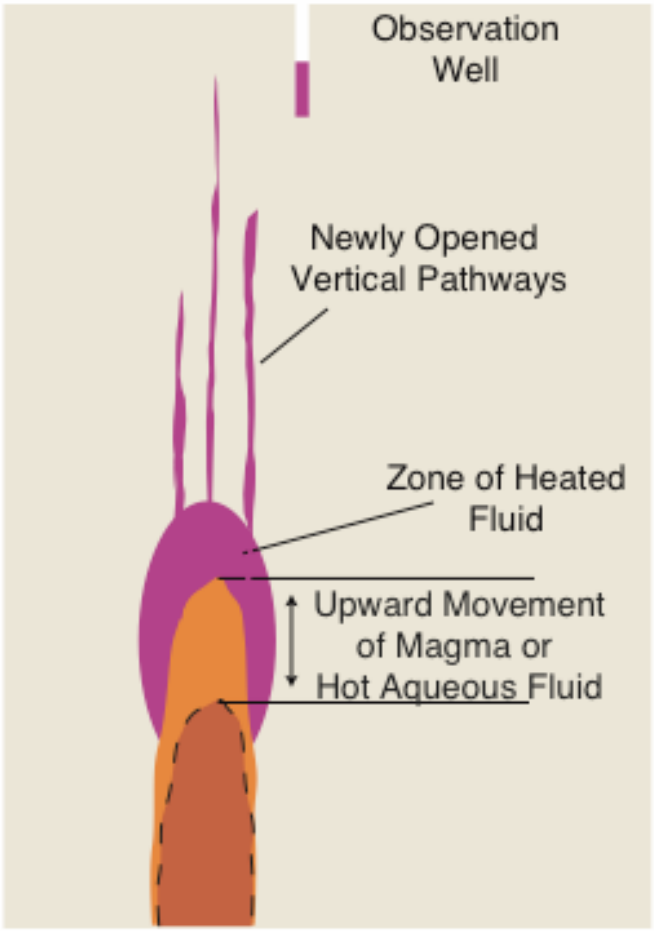
Need for Temperature Measurements

Thermal Pressurization:
Pressure in Observation Well Increases,
Temperature Does Not



Increased Vertical Permeability:
Pressure and Temperature Both
Increase in Observation Well



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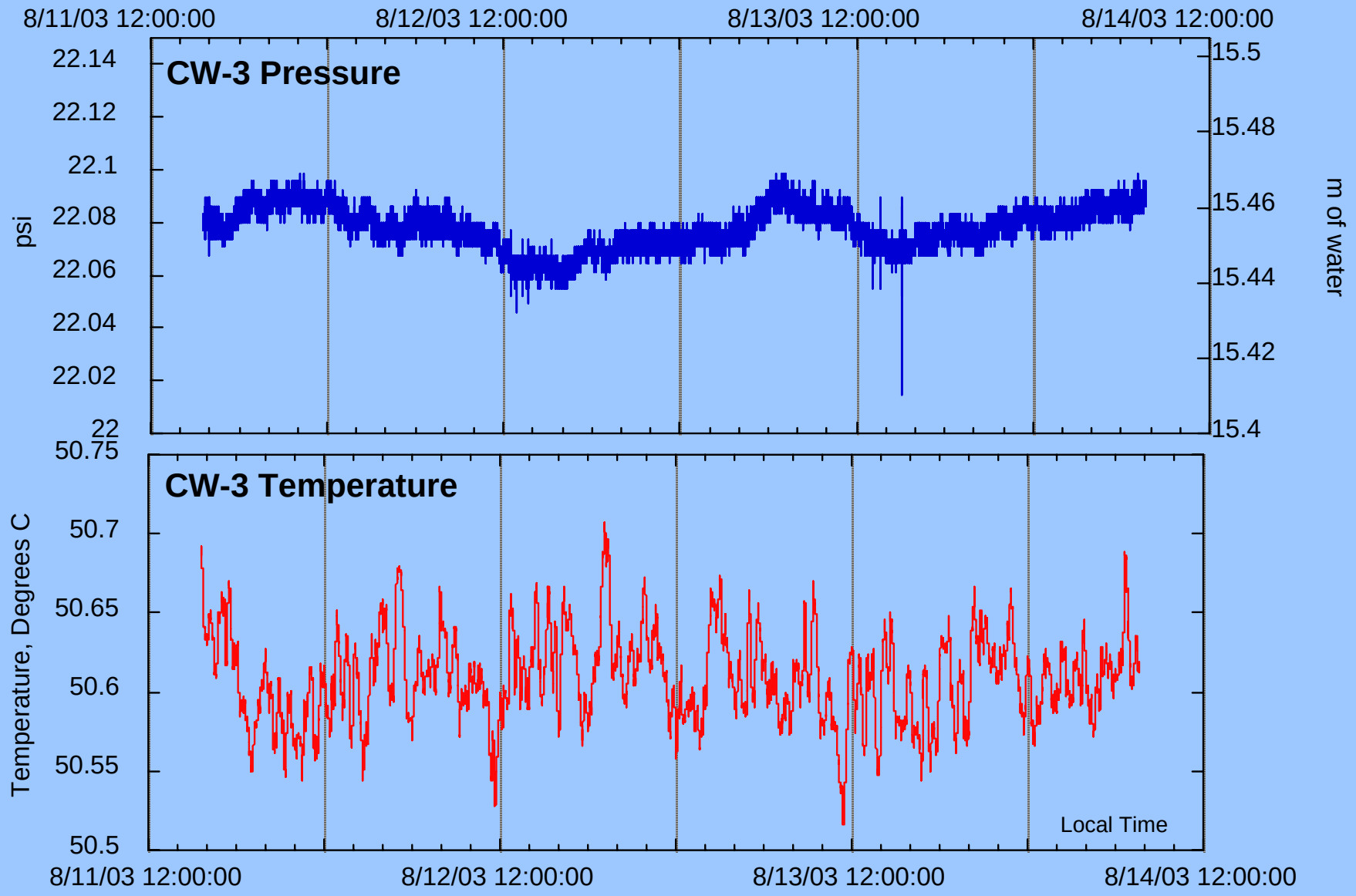
Example of Data



Summary

It is possible to record high-resolution water pressure data at intervals as short as 2.5 s to temperatures as high as 150C and pressures as high as 35 Mpa.

Main challenge is corrosion of the cable, which can probably be avoided using a steel tube to house the conductors.

We characterized the permeability, fracture dimensions, and tidal response of the 3 km deep LVEW to help understand whether earthquake-induced dome inflation is causing post-earthquake water-level drops.

We are recording high-resolution data in two thermal wells in which pressure increases occur following earthquakes.

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