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Preliminary determination of *in-situ* stress orientation and magnitude at the Cornell University Borehole Observatory (CUBO) geothermal well, Ithaca NY

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ABSTRACT

Understanding the *in-situ* stress regime is vital for two central challenges of geothermal projects that rely on permeable fracture zones: to predict the preferential fracture orientation for the design of a future stimulation plan and to mitigate induced seismicity. Here, we present a preliminary wellbore *in-situ* stress analysis for the Cornell University Borehole Observatory (CUBO), a deep geothermal exploration well drilled on Cornell's campus in Ithaca, NY in 2022. The objective of this analysis is to guide the development of the next step, a doublet to produce geothermal heat for direct use in the university's district heating system.

Four-arm caliper surveys (Power Positioning Caliper), hydraulic fracturing stress tests, and repeated borehole acoustic and micro-resistivity image logs (BHI) were carried out in CUBO and used to constrain the orientation and magnitude of *in-situ* stresses. The caliper logs and BHI reveal borehole breakouts (BBOs) and tensile fractures that mark the orientation of the main stresses. Only the four-arm caliper data are available for the three cased-well sections between the surface and 7800 ft. These data indicate that the minimum horizontal principal stress orientation is ~148° on average. In the open section of the well between 7800 ft and 9790 ft, caliper and image logs differentiate borehole breakouts with a preferential orientation of ~125° in the shallower sedimentary formations and somewhat rotated to 146° in the basal formations and crystalline basement. Notwithstanding the subtle change in orientation, the main direction of the maximum horizontal stress for CUBO is northeast, following the regional trend reported in historical data.

An estimation of the magnitude of principal stresses is possible for at least two depth intervals where minifrac tests were conducted with a dual-packer system. The minimum horizontal principal stress (S_{hmin}) and the Vertical stress (S_v) are obtained from the minifrac test and density logs, respectively. The approximation of the S_{hmin} was determined from fracture Closure Pressure (CP). The maximum horizontal main stress magnitude was estimated with a theoretical elastic equation and yielded values from 74.3 MPa at 7885 ft to 96.2 MPa at 9360 ft. The magnitudes of the main horizontal stresses relative to the overburden stress indicate a strike-slip regime at depths below 6000 ft per the general geological regime in the region.

1.BACKGROUND AND MOTIVATION

Stress field interpretation is a critical parameter in reservoir engineering for Enhanced Geothermal Systems (EGS). A clear comprehension of the magnitude and orientation of *in-situ* stress is essential to address several engineering challenges in the geothermal development stage: the stabilities and trajectories of deep development wells, the orientation in which hydraulic fractures propagate, the injection pressure required to activate stimulation, and, to mitigate the risk of induced seismicity in the area (Min *et al.*, 2020).

The Cornell University Borehole Observatory (CUBO) is the exploratory geothermal well step of the Earth Source Heat (ESH) project for heating Cornell's campus. In summer, 2022, the well was drilled to 3 km (TD = 9790.5 ft.). The well was completed in five sections: a 36-inch conductor section with 30-inch casing to 110 feet; a 26-inch surface section with 20-inch casing to 789 feet; a 17.5-inch first intermediate section with 13.375-inch casing to 4,256 feet; a 12.5-inch second intermediate section with 9.625-inch hung liner to 7,809 feet; and an 8.5-inch open hole section to 9,790 feet. The main objective of CUBO is to provide data vital for making decisions about the prospective Cornell geothermal system (Jordan *et al.*, 2020; Tester *et al.*, 2023).

The initial results for CUBO (whole borehole hydraulic tests, microfrac tests, and geophysical logs) show low natural permeability in the prospective geothermal reservoir (Fulcher et al., 2023; Clairmont and Fulton, 2023). A reservoir stimulation alternative becomes relevant for the increase of permeability in the subsequent development stages of ESH. Therefore, the interpretation of the *in-situ* stress is pertinent to direct the next phase of ESH, developing a doublet to produce geothermal heat for direct use in the university's district heating system.

2. METHODOLOGY

Two main stress indicator categories are borehole breakouts (BBOs) and drilling-induced fractures (DIFs). Those are widely used as important indicators of the orientation of the horizontal stresses since in a vertical well like CUBO they are developed approximately parallel and perpendicular to S_{hmin}, respectively (Heidbach et al., 2016). Observations of BBOs and DIFs in CUBO are obtained from image logs and other data sources, including caliper data.

The magnitudes of the vertical stress (S_v) and minimum horizontal stress (S_{hmin}) can be determined through density logs and hydraulic fracturing tests, respectively. However, the magnitude of maximum horizontal stress (S_{Hmax}) cannot be obtained with a direct method and requires further calculations using published values of key parameters (Heidbach et al., 2016; Zhi Ye et al., 2022). Assuming that vertical (i.e. overburden) stress represents one of the three principal stress directions, then the maximum horizontal stresses are presumed to also reflect principal stresses, denoted by the symbol σ rather than *S*.

2.1 Orientation of Principal Stresses

As reported in the literature, borehole breakout orientations could be determined from two sets of data: caliper logs and borehole image logs (BHI) (Lai et al., 2018; Reinecker et al., 2014). In CUBO, a powered positioning caliper (PPC) was run for all four sections, while borehole acoustic and micro-resistivity image logs (BHI) were acquired in the 8.5-inch open section.

The PPC is a multipurpose, four-arm caliper that delivers accurate dual-axis wellbore diameter measurements (Schlumberger, 2010). Four-arm caliper tools are commonly used to obtain information about the formation (primarily strike and dip of bedding). However, caliper logs can also be used to interpret borehole breakouts.

The criteria described in Table 1 by Reinecker et al. (2014) are used in this work to identify zones of breakouts in CUBO along the four sections of the borehole. Also, some post-processing was done in Geolog 21.0 to obtain an interpretation of zones with breakouts and their azimuth (Figure 1). A breakout cut-off boundary of 10% is used following the criteria in Table 1. In the software, BBOs are interpreted where the minimum caliper reading is close to the bit size, whereas the other caliper pair is larger than the breakout cut-off. Minimum and maximum caliper curves are also created and used to classify the logged interval.

Table 1: Criteria for recognizing a borehole breakout from 4-arm caliper data. After Reinecker *et al*. (2014)

	Criteria for borehole breakout identification
1	Tool rotation must cease in the zone of enlargement.
2	There must be clear tool rotation into and out of the enlargement zone.
3	The smaller caliper reading is close to the bit size. The top and bottom of the breakout should be well-marked.
4	Caliper difference has to exceed bit size by 10 %.
5	The enlargement orientation should not coincide with the high side of the borehole in wells deviated by more than 5°.
6	The length of the enlargement zone must be greater than 1 m.

Borehole image logs (BHI) are a kind of modern log that images the physical property (electrical resistivity or acoustic impedance) of borehole walls. The acoustic imager records the sonic travel time and amplitude of reflected ultra-sonic pulses, whereas electrical imaging tools measure the current around the borehole wall under a constant electrical potential (Lai et al., 2018).
In acoustic image logs, borehole breakouts are typically interpreted as broad zones of increased borehole radius (or travel time) observed on opposite sides of the borehole and often exhibiting caliper enlargement. Drilling-induced fractures (DIFs) appear as narrow zones of low reflectivity separated by 180º and typically sub-parallel or slightly inclined to the borehole axis (Davatzes & Hickman, 2010). In the CUBO open section, three micro-resistivity image logs, FMI (Fullbore Formation MicroImager), and one acoustic log, UBI (Ultrasonic borehole imager), were acquired. BBOs were interpreted on the UBI source following the criteria summarized in Table 2. Twenty-seven (27) BBOs that meet those criteria were identified in the open section. Figure 1 shows one example.

Table 2: Criteria for recognizing a borehole breakout from ultrasonic borehole image data.

	Criteria for borehole breakout identification
1	Increased in borehole radius (or travel time) is 5 ft length or more.
2	The increased travel time is observed on opposite sides of the borehole, separated by 180º.
3	Those increments in travel time are consistent with caliper enlargement.

2.2 Magnitudes of Principal Stresses

The stress state of Earth's upper crust is defined by a stress tensor with six independent components. These can be transformed in a principal axis coordinate system: three orientations and three magnitudes of the principal stresses σ1, σ2, σ3.(Heidbach et al., 2016).

It is assumed that the three principal stresses include one vertical stress (σ_v) and two horizontal (S_{hmin} and S_{Hmax}). In general, the magnitude of the vertical stress (S_v) is obtained by integrating the density logs along the well axis to the depth of interest, and the magnitude of minimum principal horizontal stress (S_{hmin}) can be measured through hydraulic fracturing tests (e.g., DFIT, leak-off test, microfrac test). Finally, the magnitude of maximum horizontal principal stress (S_{Hmax}) is challenging and requires the application of theoretical approaches.(Zhi Ye et al., 2022).

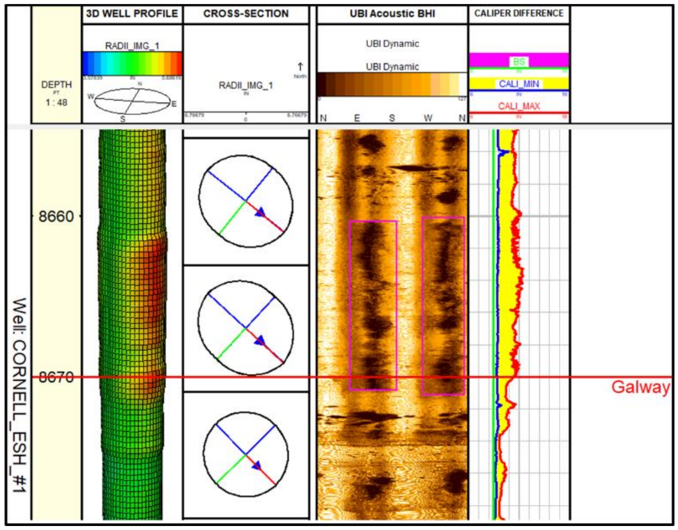

Figure 1: Example of borehole breakout features identified in Borehole Image Logs. From left to right: depths, borehole profile, borehole cross-section, acoustic BHI, caliper difference.

2.2.1 Overburden Stress

The overburden stress, or vertical stress, is caused by the weight of the overlying formations. If the overlying formations have an average density of ρ, then overburden stress, which we assume is a principal stress ($\sigma_v = S_v$), can be calculated as:

$$\sigma_v = \int \rho(z)\ g\ dz \quad (1)$$

where g is the acceleration due to gravity and z is the depth. Bulk densities of the rocks vary with depth, and the vertical stress is calculated by integrating the densities to the depth of interest (Zhang, 2019). For CUBO, density logs from the PEX_MAIN run (triple combo tool) were used in the open section with density values measured every 0.5 ft. For the cased sections, average density values per sequence were used from an offset well in the area. Density values were obtained from the Venice View Dairy well, 30 km north of CUBO. It has complete density log data recorded through most formations reached in CUBO. An average density value was calculated for each geological formation in the reference well. Then those density values for each formation were assigned to the corresponding depth interval for the same formation defined in CUBO. Both sets of density values, CUBO logs and the ones interpolated from the offset well, were integrated to create a density profile.

2.2.2 Minifrac Test

One of the most reliable techniques for determining the least principal stress is the micro-hydraulic fracturing technique (minifrac test). This method determines the minimum stress magnitude by using the pressure response recorded during a hydraulically induced fracture's initiation, propagation, and closure. The fracture trace at the borehole wall can also determine the stress orientation (Schlumberger, 2012).

The stress test analysis involves repeated hydraulic fracturing cycles of pressurization and release of pressure where the following parameters are determined: breakdown pressure (P_b), propagation pressure, Instantaneous Shut-In Pressure (ISIP), Closure Pressure (CP), reopening pressure, and rebound pressure (Figure 2a) (Flemings, 2021; Schlumberger, 2012). Under particular circumstances, the ISIP or the CP better approximates the least principal stress. By evaluating both options, the actual least principal stress at a given depth can be bracketed between plausible maximum and minimum values. The first pressure measurement made after the shut-in is the ISIP. It is widely assumed that the ISIPs recorded by the later cycle during the test, estimates the least principal stress (Zoback, 2007), which is the simplest approximation of the minimum stress, and may be consider its upper boundary. The fracture closure pressure (CP) is interpreted to record when the fracture closes. At some point, as the pressure of the fluid inside the fracture reduces, the stress acting on the fracture (closure stress) will force it to close. When the fluid pressure in the fracture equals the closure stress, the fracture will close completely. This closure stress is assumed to be the most reliable estimation of the minimum *in-situ* stress (Schlumberger, 2012). Closure pressure is an intermediate point in the falloff portion of an experiment and must be interpreted (Figure 2a). Diverse techniques to identify the CP exist: Square root (SQRT), G-function analysis, and timely forced closure. In this work, timely forced closure is used since this value was registered in the minifrac test for both points. This measure is considered the lower bound of least principal stress. The discussion section, below, treats the uncertainty of whether the minimum principal stress measure in the minifrac test corresponds to the minimum horizontal principal horizontal stress or to the overburden stress.

2.2.3 Maximum Principal Stress

The determination of the maximum principal stress magnitude is non-trivial, and its estimation is commonly based on theoretical considerations. Therefore, considering the complete stress tensor, the calculation of the maximum horizontal stress magnitude is the component with most uncertainty (Schmitt & Zoback, 1989).

To determine the maximum horizontal stress here, we use the Hubbert & Willis, 1957 equation that relates the breakdown pressure P_b, to the horizontal principal stresses S_{hmin} and S_{Hmax}, the formation pore pressure P_p, and the formation tensile strength, T (Equation 2).

$$S_{Hmax} = 3S_{hmin} + T - P_P - P_b \quad (2).$$

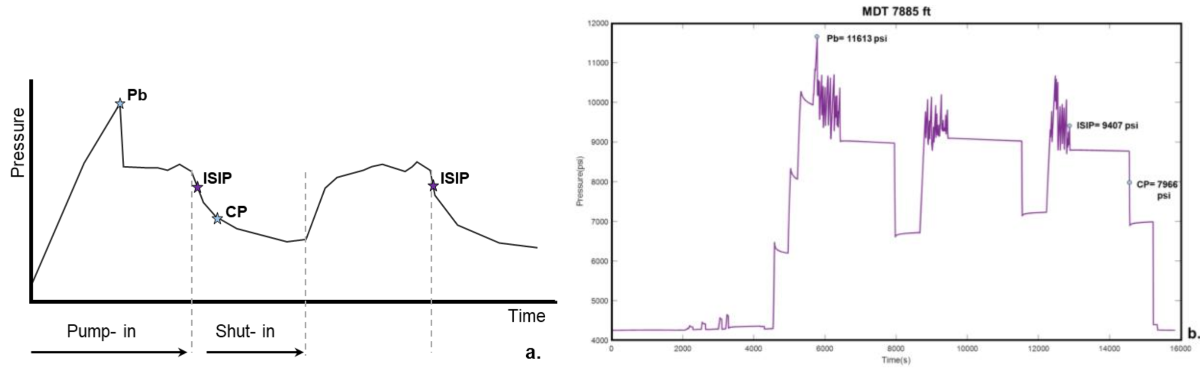

Figure 2. a) Typical Pressure vs Time plot in minifrac test modified from (Flemings, 2021). b) CUBO MDT Station summary at 7885 ft, values used for P_b, ISIP and CP are shown in the graphic.

3. RESULTS

From the interpretation of borehole image logs and caliper logs, borehole breakouts occur through much of CUBO's depth range (Fig. 3a). In the cased borehole interval, 0-7800 ft, BBOs are infrequent except in the Medina Formation. In the open borehole below 7800 ft, abundant breakouts are evident in three main intervals**:** the middle part of Tribes Hill Formation between 7900 ft and 8100 ft, the middle part of the Galway Formation between 9000 ft and 9100, and the basement between 9400 ft and 9650 ft. These intervals are used to constrain the orientation of S_{Hmax} in the open section.

3.1 Stress Orientation Depth Variation

From caliper interpretations and following the classification criteria in Table 1, we observe no BBOs in the upper section from the surface to 800 ft depth. In the 17 ½ in. section, from 800-4256 ft, BBOs were observed primarily within the calcareous Heldeberg Formation and had a preferential orientation of ~145°. Most of the BBOs from the caliper data are distributed in the 12 1/4 in. section, from 4256-7800 ft, where they are well developed in the thick sandy Medina Formation and the calcareous Black River and Tribes Hill Formations. In the borehole between 4256-7800 ft, the BBOs do not greatly vary in orientation, with a mean value of ~148°, which is close to the mean between 800-4256 ft (Figure 3a).

Below 7800 ft, the open-hole section, borehole image logs are interpreted in addition to caliper logs. BBOs have a preferential orientation of ~125° in the shallower sedimentary formations and somewhat rotated to ~146° in the basal formations and crystalline basement (Fig. 3b). Those observations suggest a S_{Hmax} direction between N 38 °E and N 50 °E for the open-hole section, which is consistent with the regional S_{Hmax} reported in historical data.

3.2 Stress Magnitude Measurements

The stress magnitude is obtained at the three depths where complete minifrac tests was performed (7885 ft, 8695 ft, 9360 ft), intervals where there are no breakouts, and the borehole is not elongated. Pressure data used to constrain equation 2, are taken from the minifrac test.

The depth-integrated overburden stress is calculated from the density profile (Fig. 4a, d), as described in the methods section, assuming a gravity value of 9.8 m/s^2 and CUBO depths.

The minifrac test was performed at 4 depths (7885 ft, 8685 ft, 8695 ft, 9360 ft) (Table 3) (Figure 3a). For three of them, it was possible to run at least three injection cycles with falloff and obtain most of the pressure measurements described in the methods section (Fig. 2a). The intervals selected to perform the analysis were located in sections with no borehole breakouts or natural fractures. At 8685 ft the objective was to measure permeability in a possible drilling-induced fracture, and no injection cycles with falloff were run.

The other three depths were used to estimate the value of the least principal stress, which in all cases we measure in the last injection cycle (Table 3). Four injection cycles with falloff were registered for the station at 9360 ft. The CP is available from only timely forced closure, which is considered a measure of the least principal stress at this point. The next successful station is located at 7884 ft (Figure 2b). During the test, three injection cycles and falloff were registered. Closure pressure (CP) was interpreted from two methods, both square root (SQRT) and timely forced closure. In this station, CP from timely forced closure is used as a measure of the least principal stress. At the last station at 8995ft, a possible drilling-induced fracture was targeted. Because of the additional complexity with this station, we focus the analysis presented here on the other two station results.

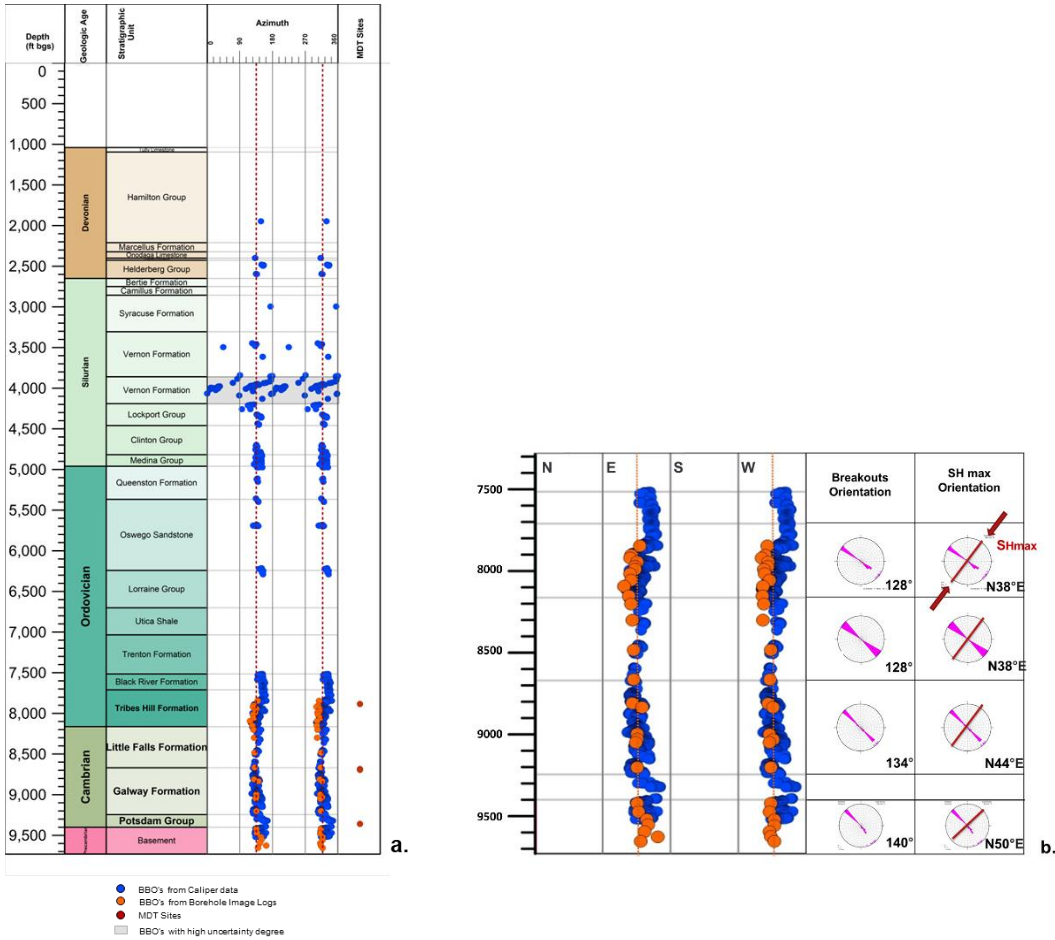

Figure 3. a) Borehole breakouts depth variation in CUBO. Blue dots are BBOs interpreted from caliper logs, orange dots BBOs interpreted from BHI. Dotted line shows the trend of BBOs main orientation, northwest. Right track shows depths of MDT sites (orange dots). b) Borehole breakouts vary slightly with depth in the open section. Interpretation of SHmax orientated northeast.

We obtain the magnitude of S_{Hmax} based on Equation 2. This equation assumes a perfectly elastic concentration of effective stresses around a circular borehole (Hickman *et al.*, 1985). For this reason, amongst others, the MDT tests were performed in areas where the borehole is not elongated. Breakdown pressure (P_b) is the pressure at which a hydraulic fracture is created, tensile strength (T) is estimated as the pressure difference between P_b in the first and second test cycle, and pore pressure (P_p) is assumed to be hydrostatic. S_{hmin} stress magnitude is assumed as the (CP), as was explained above. Those parameters and final measurements of stress magnitude are summarized in Table 4. Finally, the maximum shear stress was calculated as $(S_{Hmax} - S_{hmin})/2$.

A graphic representation of S_{Hmax}, S_{hmin}, and S_v, which we interpret as representing the principal stresses σ_{Hmax}, σ_{hmin}, and σ_v, is shown in Figure 4 with a generalized stratigraphic section for CUBO.

4. ANALYSIS AND DISCUSSION

Our results show that the orientation of the maximum horizontal stress at depths below 7800 ft is N 38 °E to N 50 °E.

As seen in Figure 4e, the magnitude of S_{hmin} increases between the shallowest and deepest testing points, 7885 and 9360 ft, from 54.9 MPa to 66.8 MPa, respectively. The magnitude of the middle testing point at 8695 ft is 56.7 MPa which is slightly smaller than the shallowest point and does not follow the linear tendency. This is because this point targeted a preexisting fracture (probably an induced drilling fracture, as shown by the BHI) that does not conform to the stress field of the intact rock. Consequently, the testing points at 7885 and 9360 ft are used to interpret stress magnitude. Absent more data points in the middle, the increase is treated as linear (Fig. 5).

The magnitude of S_{Hmax} also increases linearly from 74.3 MPa to 96.2 MPa over the same depth range and is also assumed to be a linear trend. Correspondingly, the maximum shear stress increases with depth from 9.7 MPa to 14.6 MPa (Table 4).

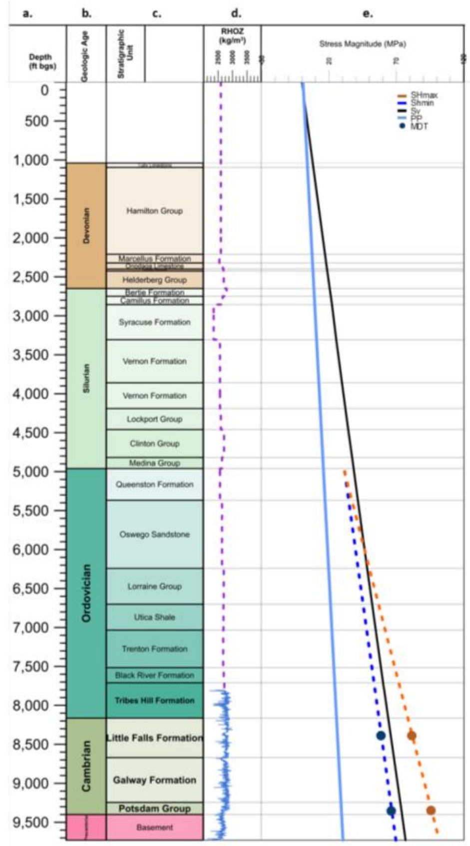

Figure 4. a) depth; b) geological age; c) formation; d) density values utilized. The purple line is the density profile built from average density values per formation in an offset well, and the blue line is the density values obtained from CUBO density logs.; e) the calculated overburden stress (black), horizontal stresses (orange and dark blue) calculated, and Pore Pressure (light blue). MDT test depths used to derive S_{Hmax} are marked by blue circles.

Table 3. Summary of MDT stations

MDT Station	Depth (ft)	Formation	Lithology	Notes	Closure Pressure (MPa)	Pressure Data Available
Point 1	9360	Potsdam	Sandstone	Good measure	66.8	*ISIP and CP*
Point 2	7885	Tribes Hill	Dol. Limestone	Good measure	54.9	*ISIP and CP*
Point 3	8695	Galway	Dol. Sandstone	Possible Fracture re-opening	--	*ISIP and CP*
Point 4	8685	Galway	Dol. Sandstone	Test for Pore Pressure- No able to Flow	--	*NA*

Table 4. Summary of Stress measurements in CUBO, assuming that S_{hmin} is represented by closure pressure and that pore pressure is hydrostatic.

				Hydrofracturing Data				Principal Stresses			
MDT	Depth	Depth	Pore Pressure	Breakdown Pressure	In Situ Tensile Strength	Shut-In Pumping Pressure (ISIP)	Fracture Closure Pressure FCP	Minimum Horizontal Stress	Maximum Horizontal Stress	Vertical Stress	Max. Shear Stress
	ft	*m*	*MPa*	*MPa*	*MPa*	*MPa*	*MPa*	*MPa*	*MPa*	*MPa*	*MPa*
Point 1	7885	2403.4	24.1	80.1	13.8	64.9	54.9	54.9	74.3	62.4	9.7
Point 2	9360	2852	28.7	75.7	---	76.4	66.8	66.8	96.2	74.6	14.7

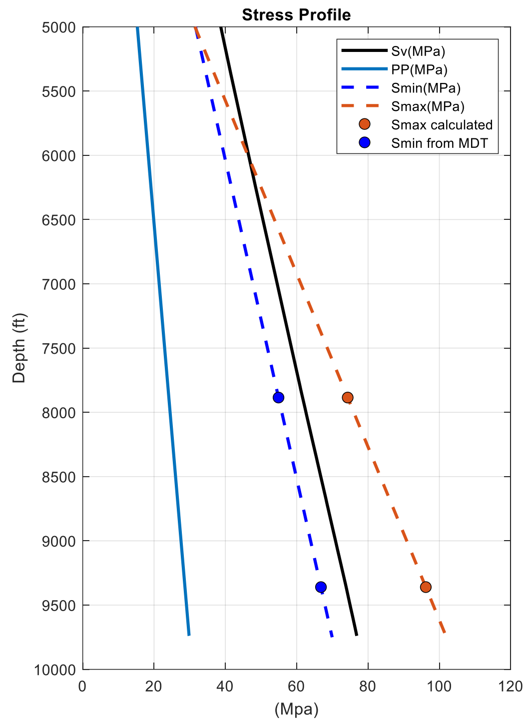

Figure 5. *In-situ* stress profile of CUBO well established based on the observed breakouts.

4.1 Uncertainty in Magnitude Calculation and Least Principal Stress Interpretation

The primary source of uncertainty for the stress magnitude calculation is the estimation of S_{hmin} from the minifrac test. As described in the methods section, there are three different ways to calculate the closure pressure, which is the closest value to the S_{hmin} magnitude. Some authors also refer to the instantaneous shut-in pressure (ISIP) as the closest value to S_{hmin} (Figure 2a) (Zoback, Hickmann).

In the full length of the CUBO borehole, the stress regime transitions from S_v maximum from 0-6000 ft, a normal regime, to either strike-slip or thrust-fault below. Using the closure pressure obtain $S_{hmin,}$ (Table 4), the CUBO stress values for S_{hmin} and overburden stress are close in magnitude, with less than 8 MPa of difference (Figure 5), with overburden exceeding the least principal horizontal stress. This analysis indicates that below 6000 ft depth $S_{Hmax}>S_v>S_{hmin}$. This relation suggests a strike-slip regime.

If instead ISIP is assumed to be S_{hmin}, the relation between the principal stresses would change to $S_{Hmax}> S_{hmin} >S_v$, *a* relation that would indicate a thrust-faulting regime for the open section of the borehole.

There is another important source of uncertainty related to the least principal stress measurements in the minifrac test. The BHI data image well bedding surfaces in the zones in which minifrac tests were conducted, and those beds are mostly horizontal. Bedding surfaces are known to be planes of weakness. In light of the interpretation that the stress values in CUBO for S_{hmin} and S_v are close in magnitude, one possible scenario is the minifrac test reopened some of the bedding surfaces instead of creating new fractures. If so, then the MDT test measured the overburden stress rather than the minimum horizontal stress. If that were true, then Sh_{min} is not constrained by our current analysis.

5.2 Regional Data comparison

The stress field indicators in the Northeast area of the U.S. are compiled in the World Stress Map (WSM) catalog (Figure 6).

Most of the stress measurements in the northeast and southeast parts of New York state are from focal mechanisms, while in the state's central area they are measurements from boreholes. The S_{Hmax} orientation for those measurements in the Appalachian Basin is mainly northeast, like the S_{Hmax} orientation for CUBO.

Regarding the stress magnitude, the WSM compilation mainly shows a thrust-faulting regime in the northern part of New York state and some isolated locations in the southwest that present a strike-slip regime. The CUBO results indicate some uncertainty in the geological regime, which the current preferred interpretation being a strike-slip faulting regime but also close to a thrust-faulting regime. A detailed analysis of regime depth variations in offset wells must be added to this correlation.

5.3 Implications in the well-design stage

The interpretations presented here, and the uncertainties, would have critical impacts in the subsequent production well-design stage of our project . If the target zone is in a thrust-faulting regime ($S_{Hmax} > S_{hmin} > S_v$), horizontal hydraulic fractures are expected to be developed. For this fracture configuration, vertical doublet wells would probably be more efficient for extracting the geothermal fluids.

If the target zone is in a strike-slip regime ($S_{Hmax} > S_v > S_{hmin}$), vertical hydraulic fractures could be developed. In this scenario, a horizontal well may improve the productivity of fluids extraction.

Efforts continue to define the relative magnitude of the stresses in the target zone more accurately. One set of steps is to use other techniques to constrain the values of the stress measurements in order to decrease the uncertainty of the S_{Hmax} magnitude. Those methods include constraining the S_{Hmax} using the stress polygon (Moos & Zoback, 1990), the borehole breakouts width or the observed DIFs from FMI logs. Another avenue is to learn if stress measurements for the intermediate depth MDT station, excluded here, could be added by back-calculating the magnitude of the minimum horizontal stress (S_{hmin}) despite the fact that test targeted a drilling induced fracture.

Uncertainty in stimulated fracture direction increases when one considers anisotropy in fracture resistance in addition to fracture driving stress directions. The observation of multiple bedding planes within the minifrac zones and of existing fracture sets intersecting CUBO are causes for such uncertainty increase.

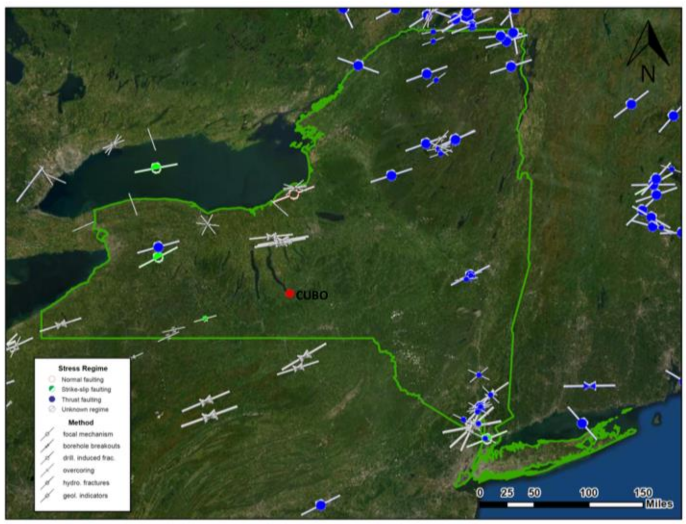

Figure 6. World Stress Map indicators for New York State. Regional orientation of S_{Hmax} is northeast.

5. CONCLUSIONS

Our results, based on observed BBOs from borehole image logs and caliper logs, suggest a S_{Hmax} direction between N 38 °E and N 50 °E for the open-hole section. This is consistent with regional values for S_{Hmax} orientation. Consequently, during a planned follow-on stimulation program of a geothermal target in CUBO, if vertical fractures result from stimulation they would trend in the northeast orientation direction.

This study also reveals the magnitude of S_{Hmax} at the depths of 7884 ft and 9360 ft, using as input the S_{hmin} values obtained in minifrac tests at those depths. We use the Hubbert & Willis equation with the lower bound of S_{hmin} given by the closure pressure obtained with the timely forced closure technique. The magnitude of S_{hmin} increases downward from 54.9 MPa to 66.8 MPa for the tested depths. The calculation of S_{Hmax} also increases from 74.3 MPa to 96.2 MPa over the same depth range. The values calculated for S_v are certainly close to the magnitude of the S_{hmin}. Therefore, there is uncertainty in defining the stress regime for the target section in CUBO, which is in a window between the strike-slip and thrust-faulting regimes. Those preliminary results of the *in-situ* stress in CUBO, will help guide the well design and stimulation plans. In a strike-slip scenario, a horizontal well may improve the productivity of fluids extraction, while in a thrust-faulting regime vertical wells will be more efficient for extracting the geothermal fluids.

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8. DISCLAIMER

The views expressed in this paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

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