Focused Heat Source Geothermal Potential in Eastern Ohio

Regional public domain geothermal maps of Ohio show uniform subsurface temperatures across Ohio; however, geothermal gradients calculated from oil and gas well log measurements tell a different story. The mean calculated geothermal gradient for all wells is approximately 11°F/1,000 feet, but clusters of wells have geothermal gradients as high as 21°F/1,000 feet. The clustered elevated geothermal gradients indicate a deeper focused heat source that may have its origin in the Precambrian Basement. The fundamental questions are: 1) What is the heat source for the elevated geothermal gradients? 2) How can the heat sources be identified? 3) What is the range of temperatures that could be encountered at the heat source?

Geothermal Data Collection

All available geophysical logs in eastern Ohio were reviewed for Maximum Recorded Temperature (MRT) or Bottom Hole Temperature (BHT) along with the depth of the temperature measurement. Geothermal Gradients were then calculated for each data point. The geothermal gradient dataset was subset into Shallow and Deep Geothermal Gradient subsets. The Shallow Geothermal Gradient subset consist of wells with Total Depths below the Packer Shell, but not deeper than the Queenston Shale. The Deep Geothermal Gradient subset contains wells with Total Depths below the Trenton Limestone and above the Mt. Simon Sandstone. The stratigraphic extents of the Shallow (green shading) and Deep (red shading) Geothermal datasets are shown in Figure 1, the Generalized Column of Bedrock Units in Ohio.

There are 10,676 Shallow Geothermal Gradient data points with a mean geothermal gradient of 11.2°F/1,000 feet and 2,034 Deep Geothermal Gradient data points with a mean geothermal gradient of 10.7°F/1,000 feet. Data distribution of the Shallow and Deep Geothermal Gradients is shown in Figure 2. The lower mean Deep Geothermal Gradient is due to the correlation between cooler Deep Geothermal Gradients and oil and gas production associated with the Post-Knox Unconformity.

Separating the geothermal gradient database into Shallow and Deep Geothermal subsets allows each to be mapped to confirm evidence of geothermal gradient acceleration/deceleration between the two subsets. The comparison of the Shallow and Deep Geothermal Gradients maps helps define upward heat flow pathways, narrows the focused heat source search area, and allows a focused heat source temperature estimate using a Geothermal Gradient Acceleration Model.

Geothermal Gradient Mapping

Regional mapping of the Shallow and Deep Geothermal Gradients provides an aerial view of the clusters of high geothermal gradients. In areas with adequate data distribution, patterns of high geothermal gradients appear to coincide with J1 and J2 joint directions, an example is shown in Figure 3. This indicates that upward heat flow may occur along zones of weakness such as joints and faults.

Figure 4 is the Deep Geothermal Gradient map for the area referred to as the GG Case Study Area. The Deep Geothermal Gradient map has a 15°F/1,000 feet low cut contour. This map indicates that all Deep Geothermal Gradient values inside this contour exceed the mean Deep Geothermal Gradient by more than 4°F/1,000 feet. Also note the tight, linear nature of the high geothermal gradient. This is believed to be due to the fact that the rock type between the heat source and the Deep Geothermal Gradient depths is primarily brittle carbonate which is susceptible to jointing and faulting. Joints and faults in carbonates would provide a linear more direct pathway for heat flow.

Figure 5 is the Shallow Geothermal Gradient map for the GG Case Study Area. The Shallow Geothermal Gradient map has a 12°F/1,000 feet low cut contour, meaning that all Deep Geothermal Gradient values inside this contour exceed the average Deep Geothermal Gradient by more than 1°F/1,000 feet. Note the dispersed nature of the high geothermal gradient values when compared to the Deep Geothermal Gradient. This is due to the rock type between the Deep Geothermal Gradient depths and the Shallow Geothermal Gradients depths being primarily soft, malleable Upper Ordovician shale that is less susceptible to well defined, interconnected jointing and faulting consequently generating a more dispersed heat flow pattern.

Figure 6 is an overlay of the Deep Geothermal Gradient contours onto the Shallow Geothermal Gradient map for the GG Case Study Area. This overlay map provides an insight into upward heat flow between the Deep and Shallow Geothermal horizon. Contour patterns indicate that the upward heat flow between the Deep and Shallow high geothermal gradient anomalies is not vertical and the heat is moving upward along zones of weakness primarily in a northwest direction. This pattern of upward heat flow is observed in many places across eastern Ohio.

Precambrian Heat Source Imaging

Geothermal Gradient mapping indicates that focused heat sources located in the Precambrian exist in Eastern Ohio. 3-D seismic can be used to search for and image the focused heat sources. Figure 7 is a 3-D seismic panel from the GG Case Study Area showing an interpreted hydrothermal vent that breaches the Precambrian Basement unconformity surface. This hydrothermal vent appears to have been active at the end of Precambrian time (Figure 8), and was later buried during Cambrian Mount Simon Sandstone deposition (Figure 9).

The hydrothermal vent identified in Figure 7 is shown in map view relative to the Shallow and Deep Geothermal Gradients on Figure 10. The location of the vent implies a non-vertical heat flow path from the Precambrian Basement vent to the Deep formations and then upward to the Shallow formations in the northwest direction. The upward heat flow along the joints and faults is graphically shown in Figure 11.

A wide-angle view of the hydrothermal vent shown in Figure 12 indicates a larger complex of vents emanating from a deep heat source layer. The heat source layer appears to have a dense roof rock (seismic peak) with a less dense, hotter underlying layer (seismic trough). Hydrothermal vents originating from the heat source layer cut through Precambrian Basement layers as the hydrothermal fluids move upward toward the Precambrian Basement unconformity surface. Several of the hydrothermal vents do not reach the Precambrian Basement surface, but are truncated by horizontal layers below the Precambrian Unconformity. The truncation of the hydrothermal vents by older layers indicates that this hydrothermal system may have been active for more than 500 million years.

Estimated Temperature Ranges at Precambrian Basement

Two methods were used to estimate the temperature at the hydrothermal vent (focused heat source) located at the Precambrian Basement. Each method is based on vertical heat flow, and will provide an estimated range of temperatures at the Precambrian Basement hydrothermal vent.

The first method is a straight projection of the Deep Geothermal Gradient value to the estimated measured depth of the underlying Precambrian Basement. The Deep Geothermal Gradient and estimated Basement measured depth are inserted into the Geothermal Gradient formula then solved for Basement Temperature. The maximum estimated Precambrian Basement temperature calculated using this method for the GG Case Study Area is 228 °F.

The second method uses a Geothermal Gradient Acceleration formula to estimate the Basement temperature. In this Model the acceleration/deceleration between the Deep and Shallow Geothermal Gradients is used to project a Geothermal Gradient at the Precambrian Basement. The projected Basement Geothermal Gradient and estimated Basement Measured Depth are then applied to the Geothermal Gradient formula and solved for Temperature. The maximum estimated Precambrian Basement Temperature calculated with the second method for the GG Case Study Area is 268 °F.

From this, a range of maximum temperatures of 228 °F to 268 °F are estimated for the Precambrian Basement in the GG Case Study Area with all exceeding the boiling point of water.

Mining Heat

The seismic imaging of a focused heat source geothermal vent could identify the path of a directional well to mine the heat (Figure 13). Deep penetration into the vent is believed to be possible due to hydrothermally altered rock being softer than the surrounding rock. Properly placed well bores drilled directly into a hydrothermal vent will allow increased contact time between the circulated fluid and the heat source in a closed loop system (Figure 14). A closed loop system in a cased well bore means no circulated fluids will come in contact Precambrian rock, mining the heat non-invasively.

Summary and Conclusions

Geothermal Gradient mapping and 3-D seismic provide the pathway to defining potential focused heat hydrothermal vents for energy extraction. Several potential areas have already been defined using existing data. Extraction of heat from a hydrothermal vent system that has existed for over 500 million years could provide a long-term, scalable, low maintenance, low profile energy source that is minimally invasive while creating very little waste.

Geothermal Study Highlights

Potential focused heat source areas can be identified using Geothermal Gradient mapping.

Mapped, elevated Deep Geothermal Gradient anomalies are most often linear in the J1 and J2 joint direction when adequate data is available. This is a result of the rocks between the Precambrian heat source and the Deep Geothermal Gradient depth being primarily carbonate.

Mapped, elevated Shallow Geothermal Gradient anomalies are more dispersed than Deep Geothermal Gradient anomalies. This is a result of the rock between the Deep Geothermal Gradient depth and the Shallow Geothermal Gradient depth being primarily shale.

Heat flow from the Precambrian hydrothermal vents is not vertical, but follows zones of weakness such as faults and joints.

Shallow and Deep Geothermal Gradient subsets can be used to estimate a range of temperatures for a focused heat source.

Precambrian Basement temperatures for the GG Case Study Area are estimated to be between 228 and 268 degrees.

3-D seismic can be used to image hydrothermal complexes and vents.

Hydrothermal complexes can contain multiple laterally elongate vents that reach the Precambrian Basement surface.

Truncation of hydrothermal vents by older horizontal Precambrian layers indicate that Precambrian hydrothermal complexes may have been active for over 500 million years.

3-D seismic can be used to define targets and assist in developing procedures to mine heat.

Multiple laterally elongate vents in a hydrothermal complex may provide many drillable targets for scalable extraction of energy.

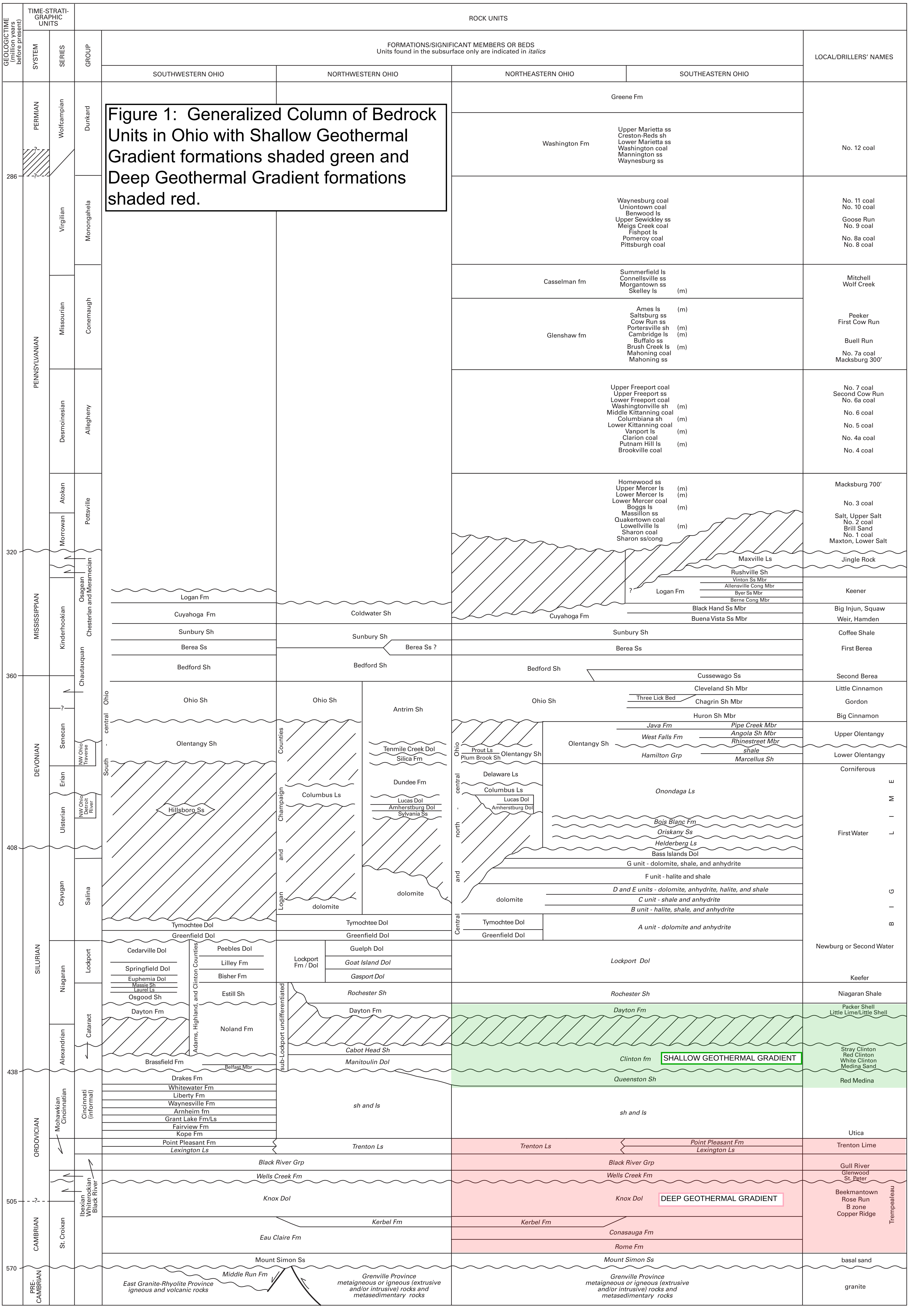
Closed loop heat extraction technology could provide a minimally invasive, long-term, scalable, low profile energy source in a region where existing energy infrastructure exists close to population centers.

GENERALIZED COLUMN OF BEDROCK UNITS IN OHIO

Dennis N. Hull, chief compiler, 1990
revised by Glenn E. Larsen, 2000

STATE OF OHIO
Bob Taft, Governor
DEPARTMENT OF NATURAL RESOURCES
Samuel W. Speck, Director
DIVISION OF GEOLOGICAL SURVEY
Thomas M. Berg, Chief

Figure 1: Generalized Column of Bedrock Units in Ohio with Shallow Geothermal Gradient formations shaded green and Deep Geothermal Gradient formations shaded red.



Sh, sh	shale	Dol, dol	dolomite	Grp, grp	Group		
Ss, ss	sandstone	Cong, cong	conglomerate	Fm, fm	Formation		
Ls, ls	limestone	(m)	Pennsylvanian marine zone	Mbr	Member		

▨ Depositional hiatus or interval removed by erosion
〰 unconformity

Note: lower case lithologic or stratigraphic names indicate informal status of unit

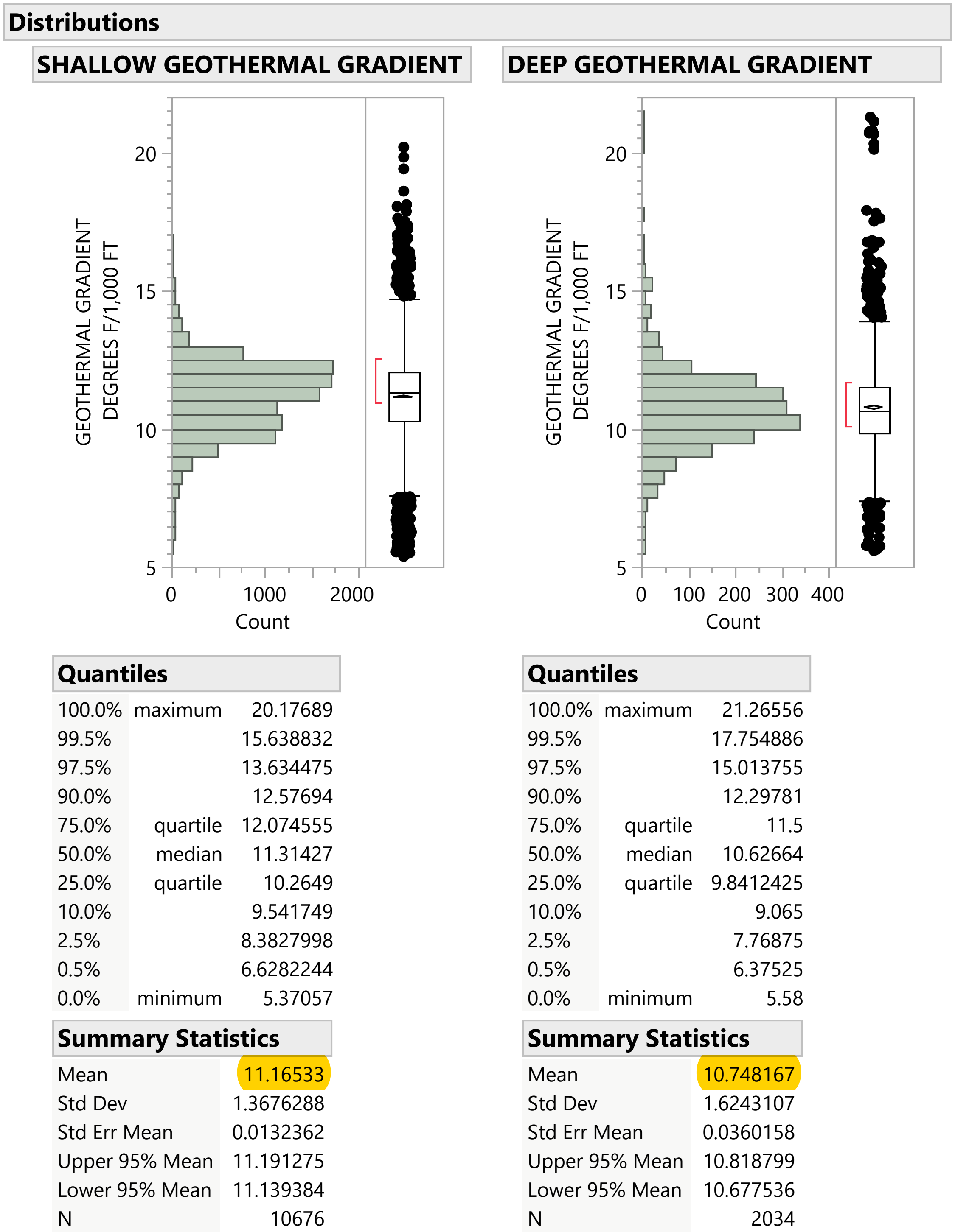
Compilation based on numerous published and unpublished sources and personal communications with the staff of the Division of Geological Survey. Time boundaries from Geological Society of America.

3/00

DIVISION OF GEOLOGICAL SURVEY
OHIO DEPARTMENT OF NATURAL RESOURCES

Electronic drafting by Robert L. Stewart, Sr.

For a more detailed stratigraphic chart see Ohio Division of Geological Survey Open-File Report 98-2



SHALLOW GEOTHERMAL GRADIENT

Quantiles

100.0%	maximum	20.17689
99.5%		15.638832
97.5%		13.634475
90.0%		12.57694
75.0%	quartile	12.074555
50.0%	median	11.31427
25.0%	quartile	10.2649
10.0%		9.541749
2.5%		8.3827998
0.5%		6.6282244
0.0%	minimum	5.37057

Summary Statistics

Mean	11.16533
Std Dev	1.3676288
Std Err Mean	0.0132362
Upper 95% Mean	11.191275
Lower 95% Mean	11.139384
N	10676

DEEP GEOTHERMAL GRADIENT

Quantiles

100.0%	maximum	21.26556
99.5%		17.754886
97.5%		15.013755
90.0%		12.29781
75.0%	quartile	11.5
50.0%	median	10.62664
25.0%	quartile	9.8412425
10.0%		9.065
2.5%		7.76875
0.5%		6.37525
0.0%	minimum	5.58

Summary Statistics

Mean	10.748167
Std Dev	1.6243107
Std Err Mean	0.0360158
Upper 95% Mean	10.818799
Lower 95% Mean	10.677536
N	2034

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Figure 2: Shallow and Deep Geothermal Gradient data distributions for Eastern Ohio.

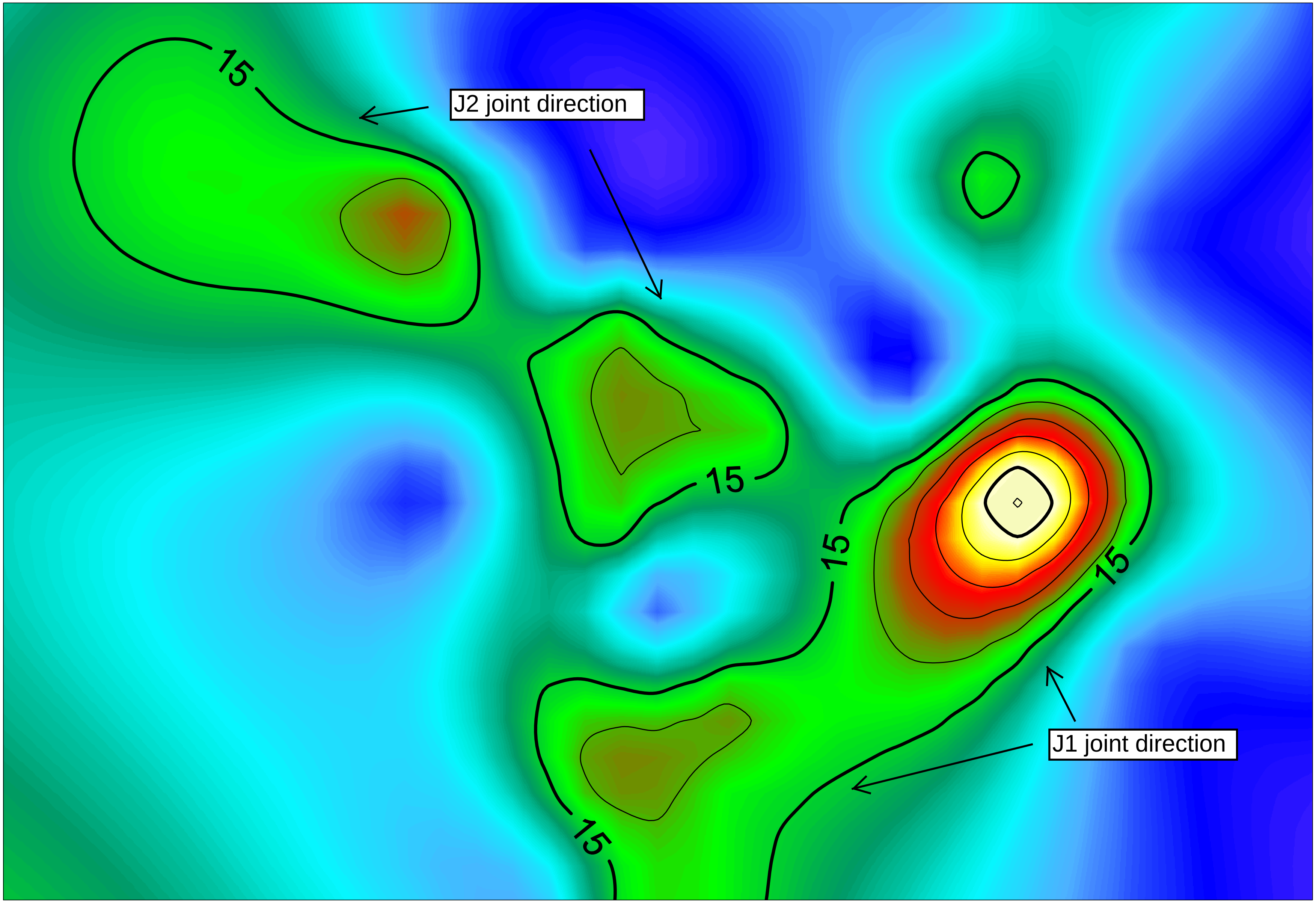


Figure 3: Deep Geothermal Gradient showing high geothermal gradient anomaly orientation along J1 and J2 joints.

N

1 inch = 3000 feet

3000 0 3000 ft

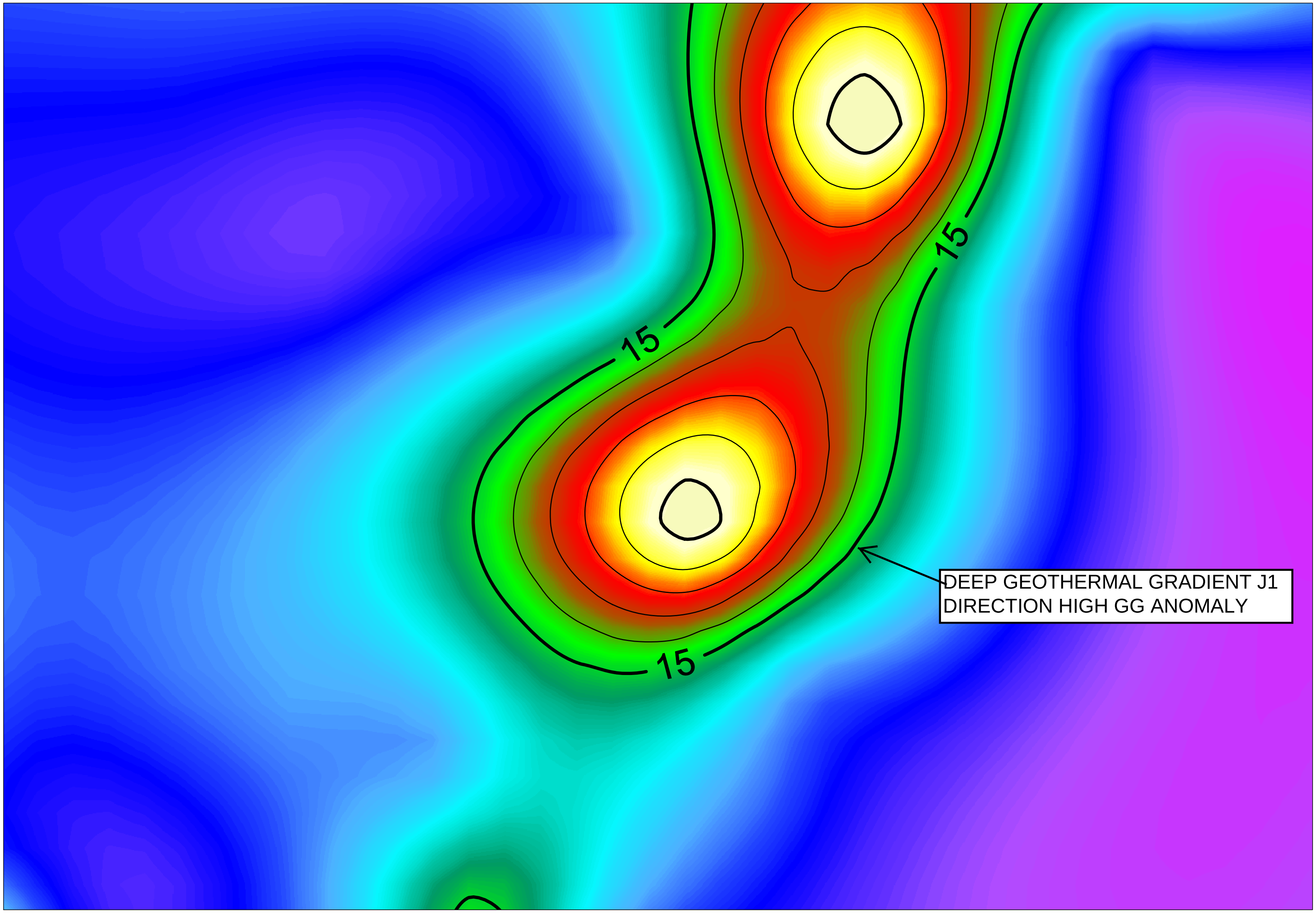
GEOTHERMAL STUDY

J1 AND J2 JOINT EXAMPLE

DEEP GEOTHERMAL GRADIENT

DEEP GG LOW CUT = 15 DEGREES F/1,000 FT

PREPARED BY: EMF GEOSCIENCE	**Scale:** 1 IN = 3,000 FT	**Date:** 12 July, 2023



N

1 inch = 3000 feet

3000 0 3000 ft

Figure 4: Deep Geothermal Gradient map with 15 °F/1000 ft low cut, showing a high geothermal gradient anomaly within the GG Case Study Area.

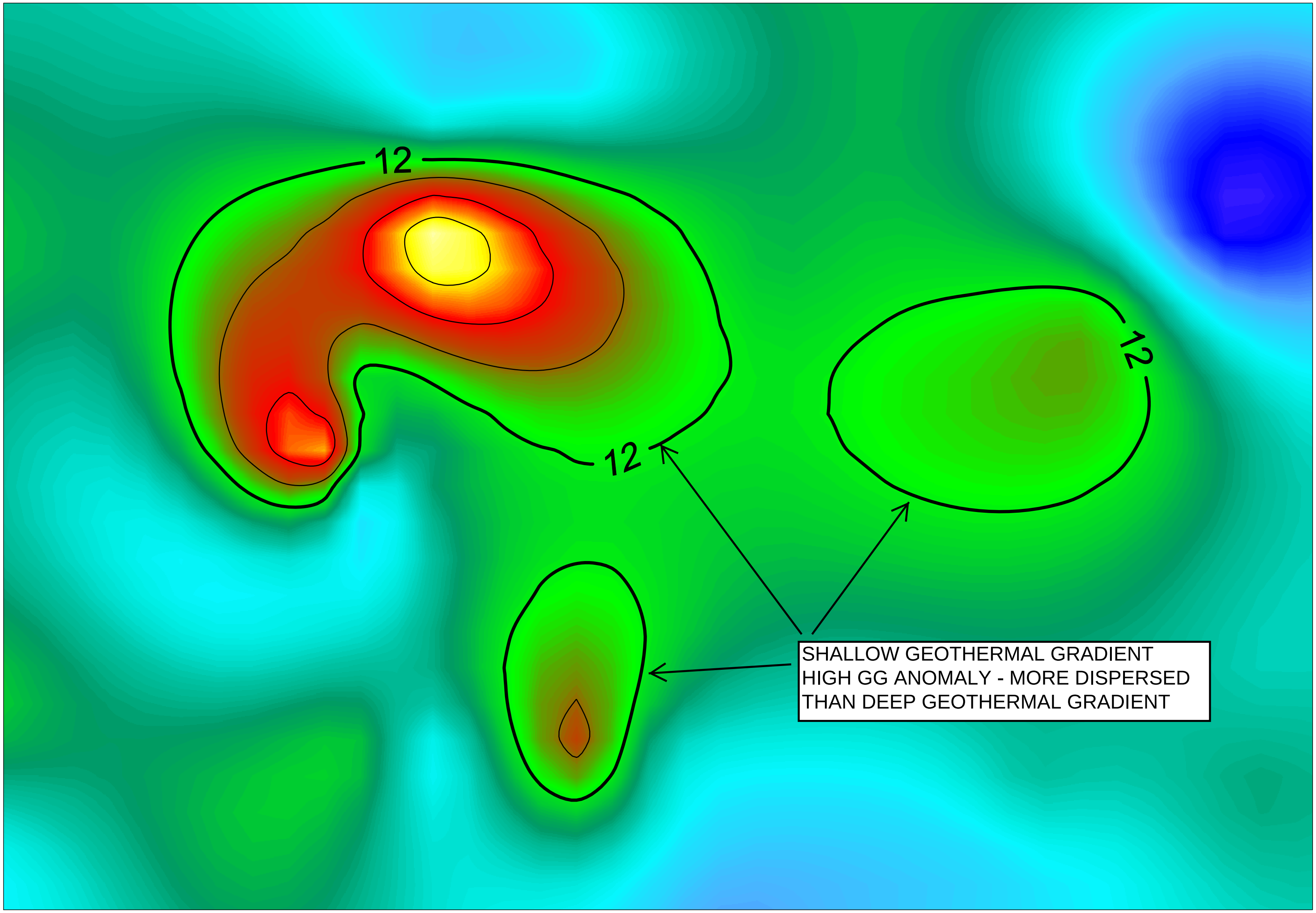
GEOTHERMAL STUDY

GG CASE STUDY AREA

DEEP GEOTHERMAL GRADIENT

DEEP GG LOW CUT = 15 DEGREES F/1,000 FT

PREPARED BY: EMF GEOSCIENCE	**Scale:** 1 IN = 3,000 FT	**Date:** 17 July, 2023



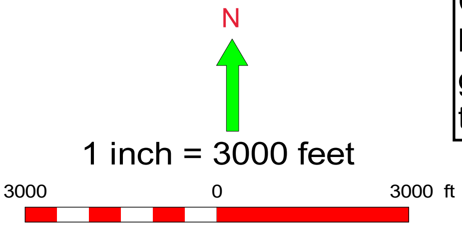


Figure 5: Shallow Geothermal Gradient map with 12 °F/1000 ft low cut, showing a high geothermal gradient area within the GG Case Study Area.

GEOTHERMAL STUDY

GG CASE STUDY AREA

SHALLOW GEOTHERMAL GRADIENT

SHALLOW GG LOW CUT = 12 DEGREES F/1,000 FT

PREPARED BY: EMF GEOSCIENCE	**Scale:** 1 IN = 3,000 FT	**Date:** 17 July, 2023

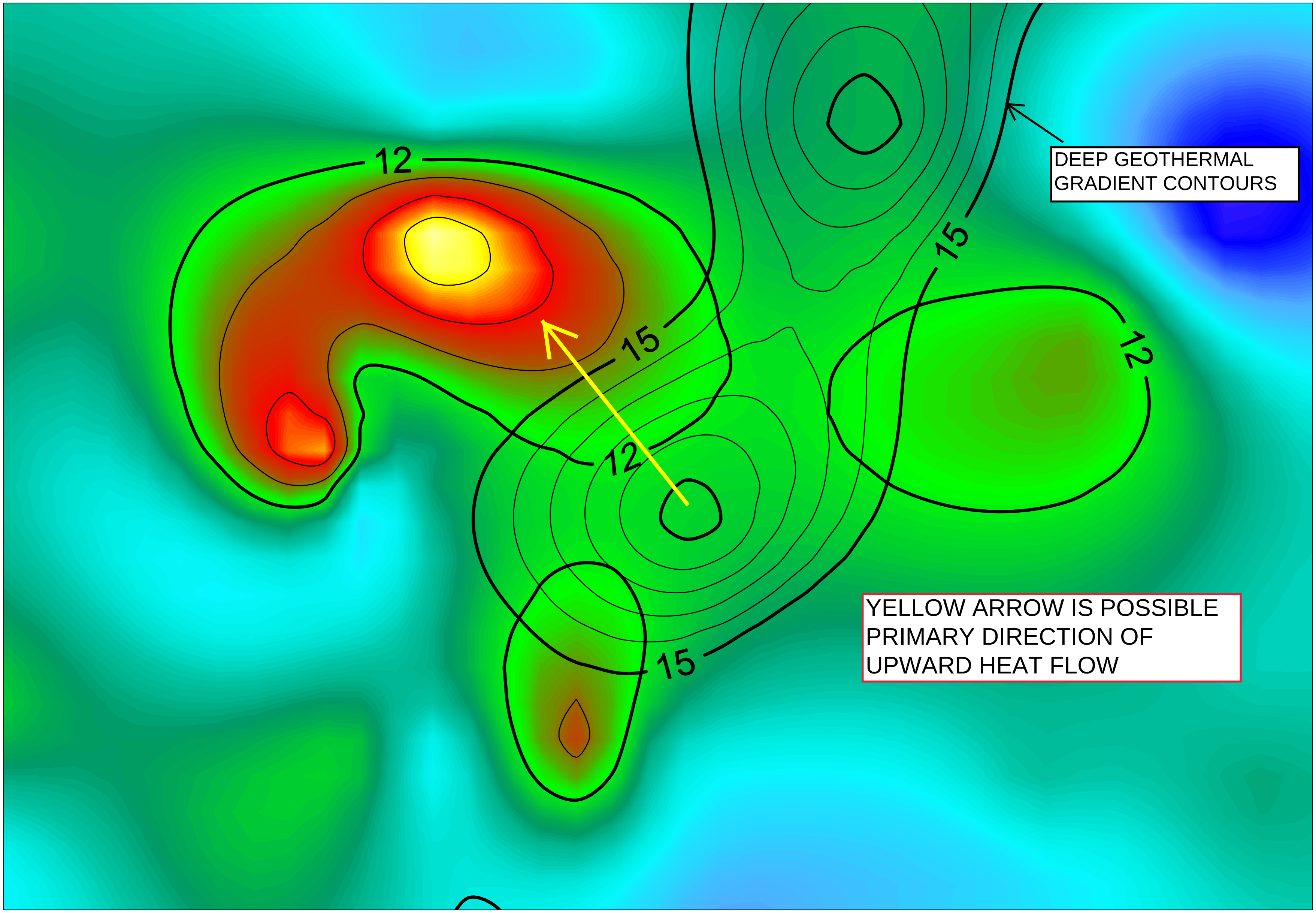


Figure 6: Deep Geothermal Gradient contours overlain on Shallow Geothermal Gradient map to show spatial relationship between the Geothermal Gradient subsets.

GEOTHERMAL STUDY

GG CASE STUDY AREA

SHALLOW GEOTHERMAL GRADIENT WITH
DEEP GEOTERMAL GRADIENT CONTOURS

SHALLOW GG LOW CUT = 12 DEGREES F/1,000 FT
DEEP GG LOW CUT = 15 DEGREES F/1,000 FT

PREPARED BY: EMF GEOSCIENCE	**Scale:** 1 IN = 3,000 FT	**Date:** 17 July, 2023

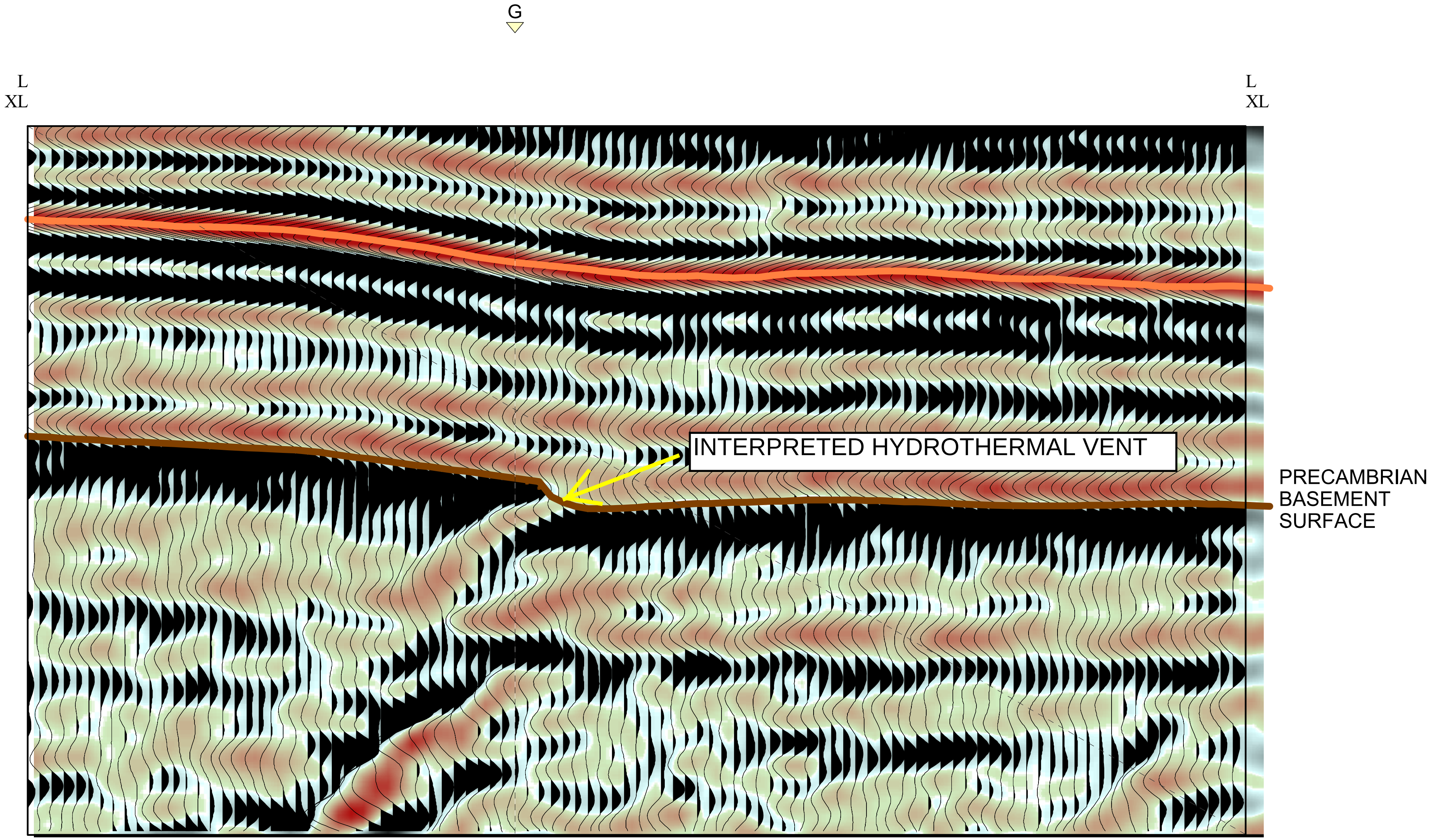


Figure 7: Close-up seismic image of an interpreted hydrothermal vent located inside the GG Case Study Area covered in Figures 4, 5, 6, and 10.

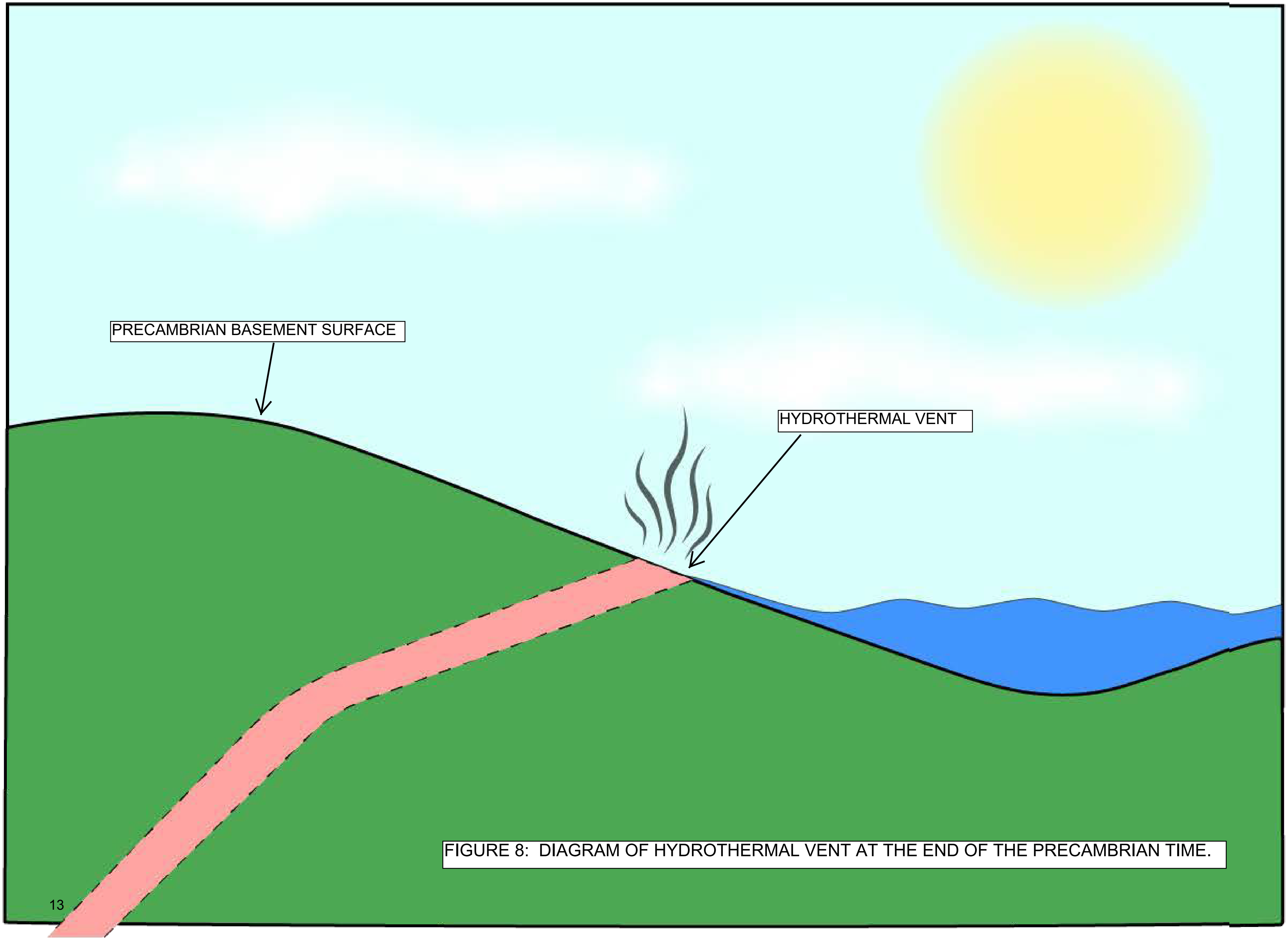


FIGURE 8: DIAGRAM OF HYDROTHERMAL VENT AT THE END OF THE PRECAMBRIAN TIME.

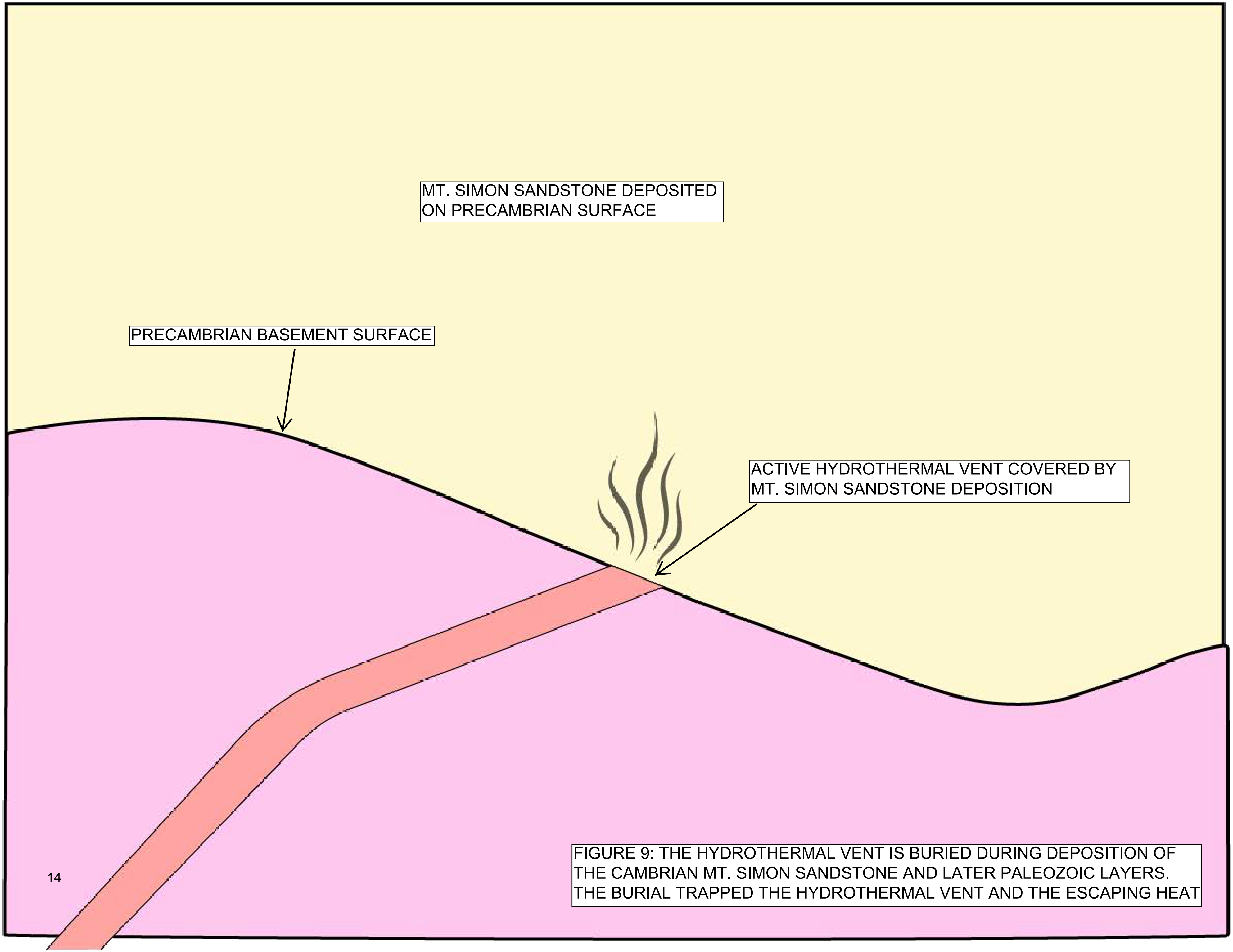
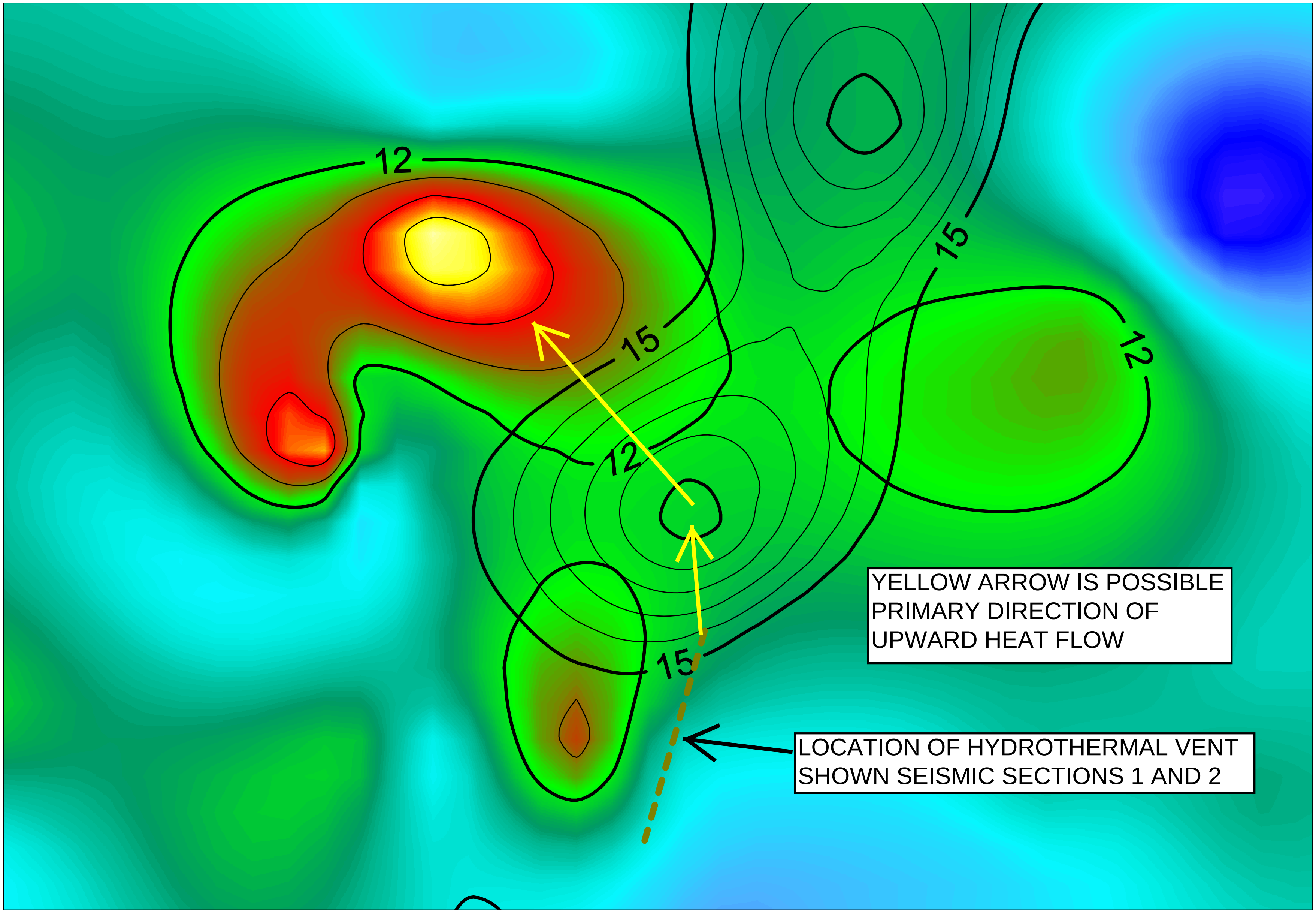


FIGURE 9: THE HYDROTHERMAL VENT IS BURIED DURING DEPOSITION OF THE CAMBRIAN MT. SIMON SANDSTONE AND LATER PALEOZOIC LAYERS. THE BURIAL TRAPPED THE HYDROTHERMAL VENT AND THE ESCAPING HEAT



YELLOW ARROW IS POSSIBLE
PRIMARY DIRECTION OF
UPWARD HEAT FLOW

LOCATION OF HYDROTHERMAL VENT
SHOWN SEISMIC SECTIONS 1 AND 2

N

1 inch = 3000 feet

3000 0 3000 ft

Figure 10: Deep Geothermal Gradient contours overlain on Shallow Geothermal Gradient map with location of hydrothermal vent interpreted on Figure 7 and 12.

GEOTHERMAL STUDY
GG CASE STUDY AREA
SHALLOW GEOTHERMAL GRADIENT WITH
DEEP GEOTERMAL GRADIENT CONTOURS
AND INTERPRETED HYDROTHERMAL VENT
SHALLOW GG LOW CUT = 12 DEGREES F/1,000 FT
DEEP GG LOW CUT = 15 DEGREES F/1,000 FT

PREPARED BY: EMF GEOSCIENCE	**Scale:** 1 IN = 3,000 FT	**Date:** 17 July, 2023

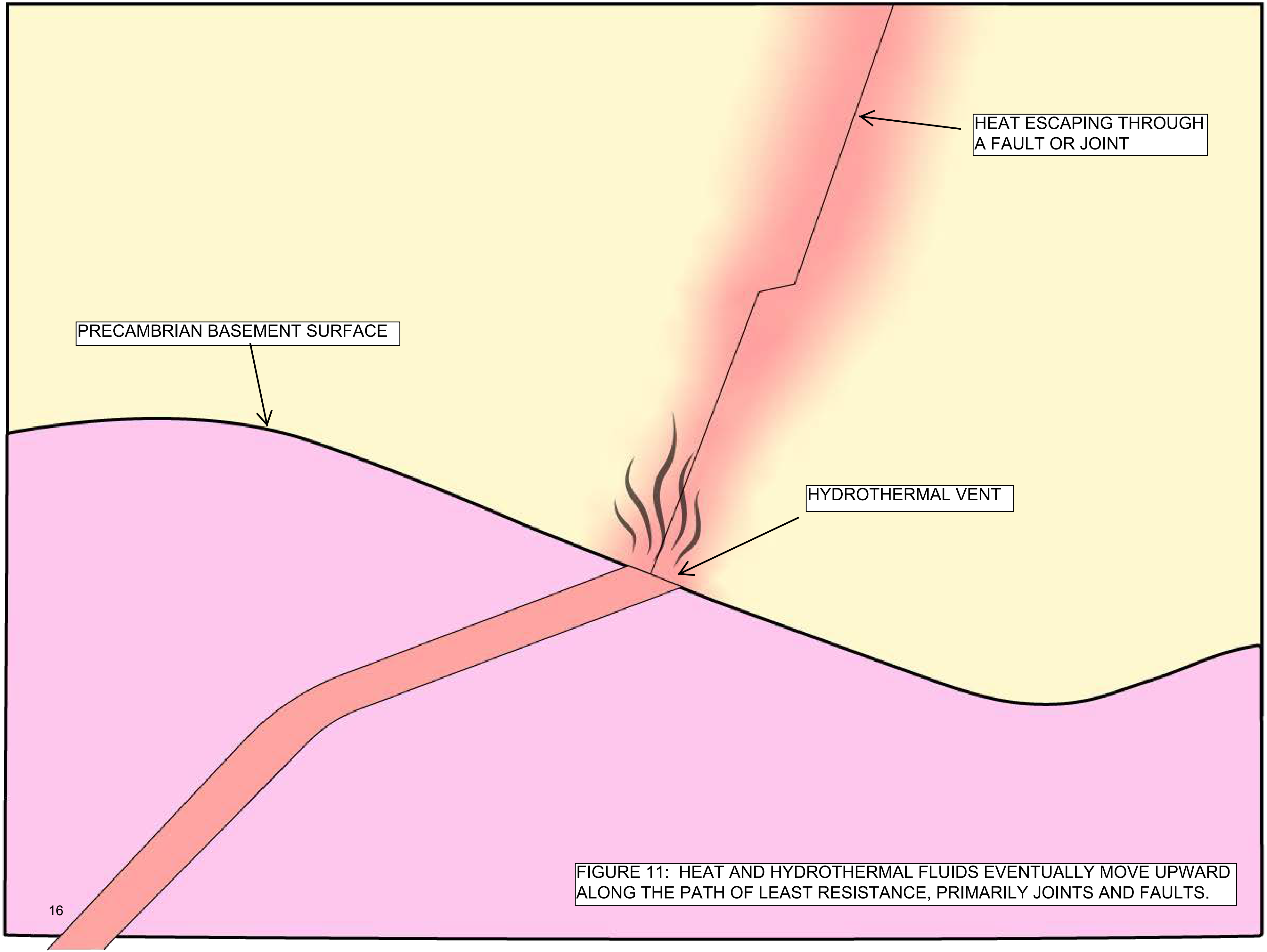


FIGURE 11: HEAT AND HYDROTHERMAL FLUIDS EVENTUALLY MOVE UPWARD ALONG THE PATH OF LEAST RESISTANCE, PRIMARILY JOINTS AND FAULTS.

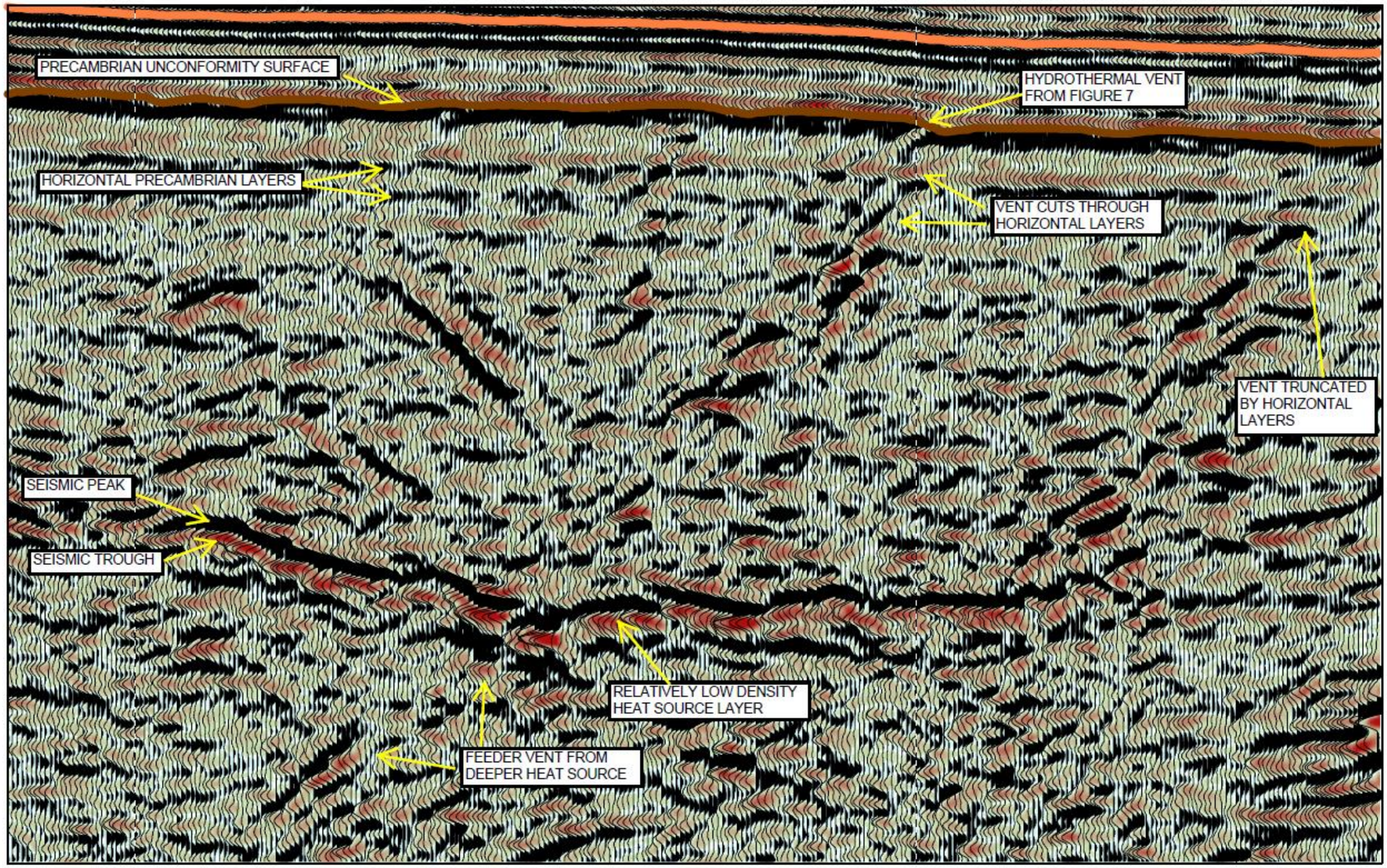


Figure 12: Wide angle view of hydrothermal complex and vents inside the GG Case Study Area.

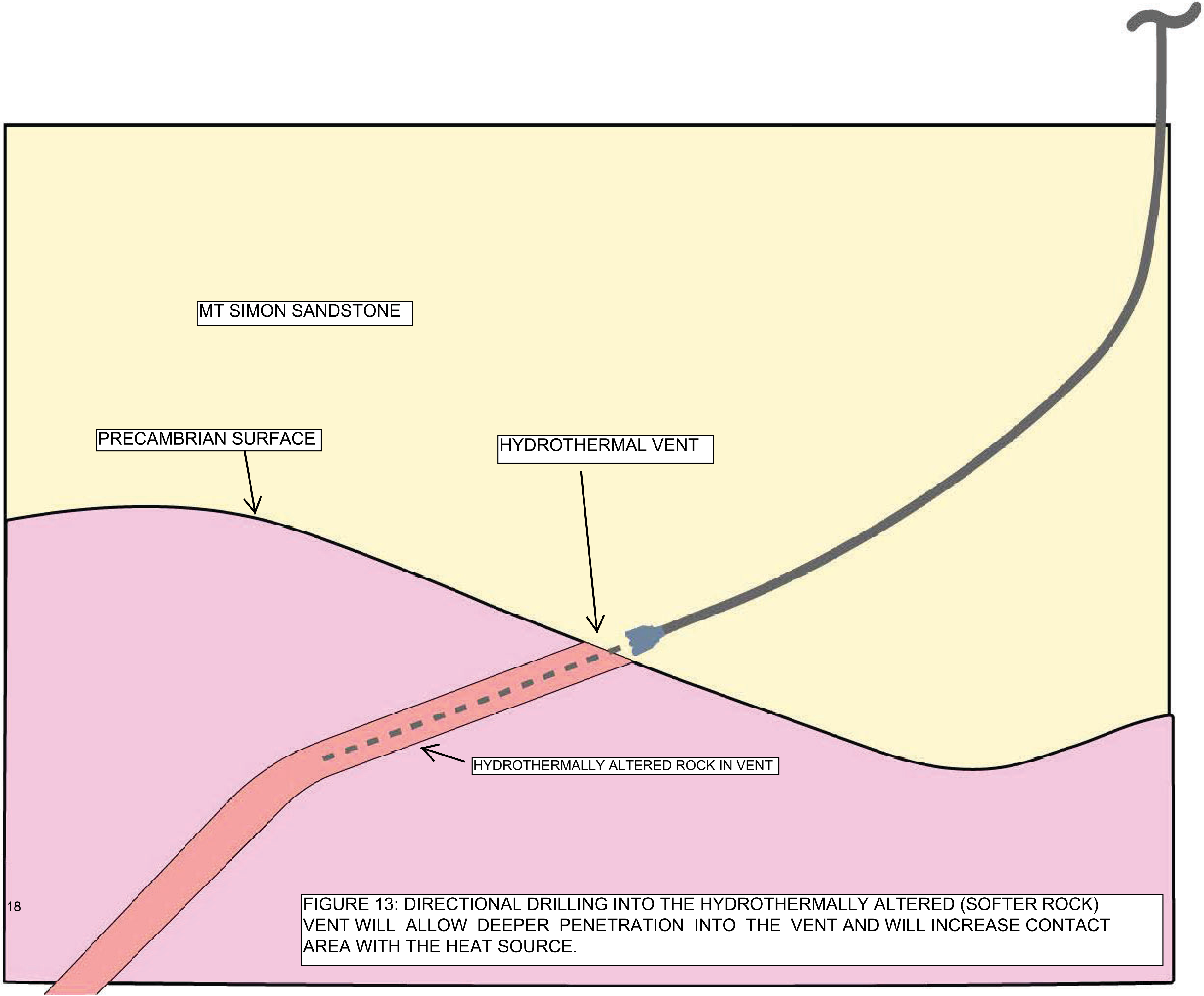


FIGURE 13: DIRECTIONAL DRILLING INTO THE HYDROTHERMALLY ALTERED (SOFTER ROCK) VENT WILL ALLOW DEEPER PENETRATION INTO THE VENT AND WILL INCREASE CONTACT AREA WITH THE HEAT SOURCE.

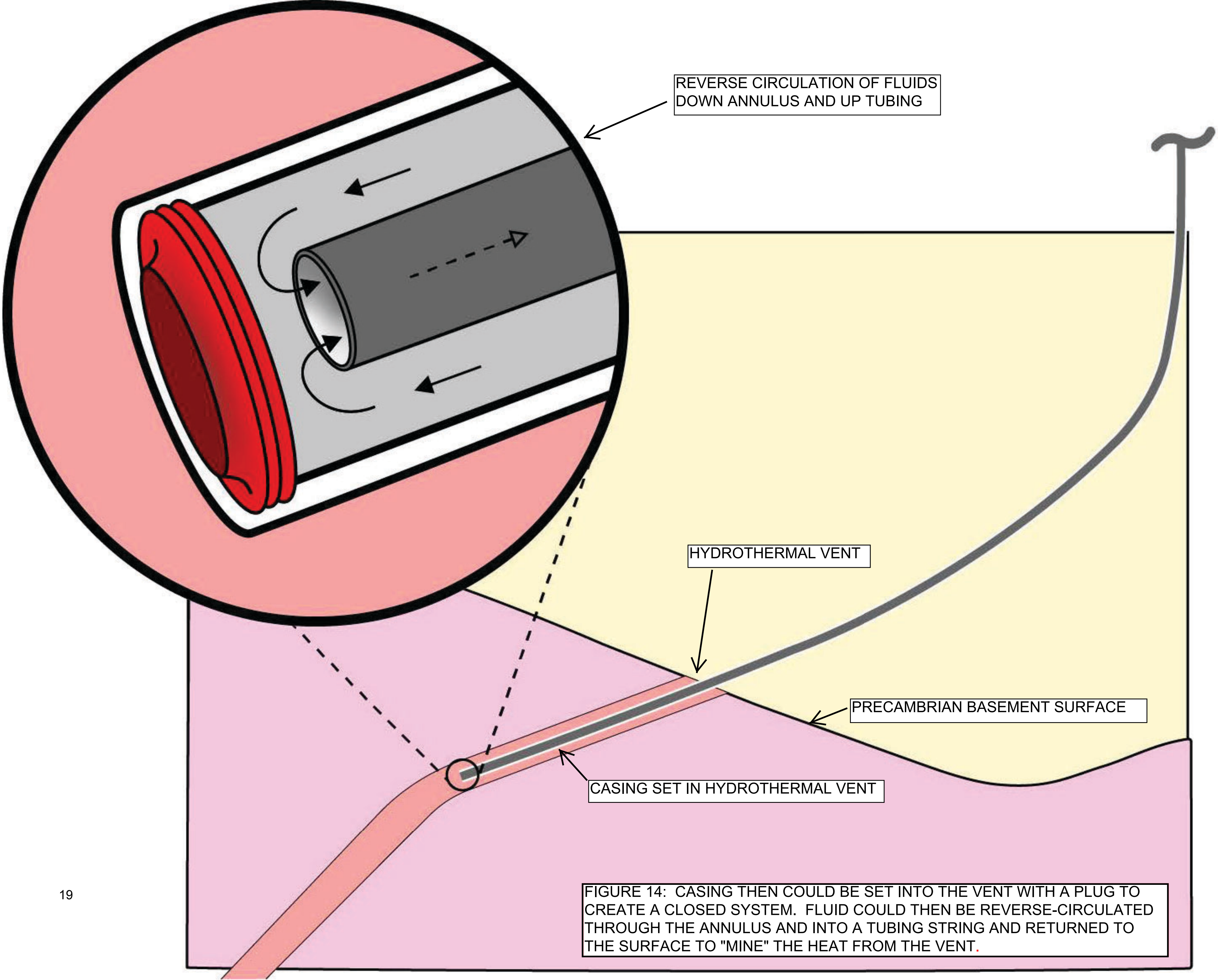


FIGURE 14: CASING THEN COULD BE SET INTO THE VENT WITH A PLUG TO CREATE A CLOSED SYSTEM. FLUID COULD THEN BE REVERSE-CIRCULATED THROUGH THE ANNULUS AND INTO A TUBING STRING AND RETURNED TO THE SURFACE TO "MINE" THE HEAT FROM THE VENT.