A Restated Conceptual Model for the Humboldt House-Rye Patch Geothermal Resource Area, Pershing County, Nevada

Richard Ellis

Keywords

Basin and Range, pull-apart block, VSP, seismic imaging, antithetic faulting, range-front faulting, structural interpretation, upflow, outflow, geothermometer

ABSTRACT

Recent geophysical work in the Rye Patch-Humboldt House geothermal area has occasioned a fundamental revision of the decades-old structural model used in prior development. Gravity, magnetic, LIDAR and recent seismic data have revealed an antithetic system paralleling the range front system that creates a broad zone of dilation and a classic "pull-apart" ("sigmoidal rhombochasm") along the west boundary of the Humboldt Range. To the north, the antithetic and range front fault systems converge and are truncated by the Miocene-age "Midas Transform", a regional, sinistral-slip system which has rotated fault azimuths, the Humboldt Range and the Humboldt River course to the east-northeast. To the south, the block is truncated by the convergence of the Rye Patch and antithetic systems along a newly-identified, parallel transform, again with sinistral-slip motion. This "subbasin" extends eight miles north-to-south and encompasses nearly 8,000 acres of the area of the shallow thermal anomaly. Zones of geothermal outflow and areas of surface alteration occur at several locations in the block. The Range Front Fault controls outflow in the area of the Florida Canyon Mine, while the Rye Patch Fault, a splay off the Range Front Fault system, controls outflow to the south.

Specific targets have been identified using seismic profiling and a revised structural interpretation. A prominent imbricate off the Humboldt City Thrust has created a "high block" which is cut by the Rye Patch Fault or faults in the area of the existing wellfield. The coincidence of the Rye Patch Fault with the imbricate for much of its identified length (nearly four miles) is strongly suggestive of a genetic relationship and may be the principal control for the formation of an active conduit along the Rye Patch Fault. Tests of the deep flow system, projected to carry the high enthalpy fluids predicted from the high chemical temperatures in the system, are designed to target fault intersections with fractured Triassic limestones and volcanic rocks at depths of 7,500 to 8,800 feet.

Numerous drilling targets within the subbasin are anticipated as exploration and development proceeds.

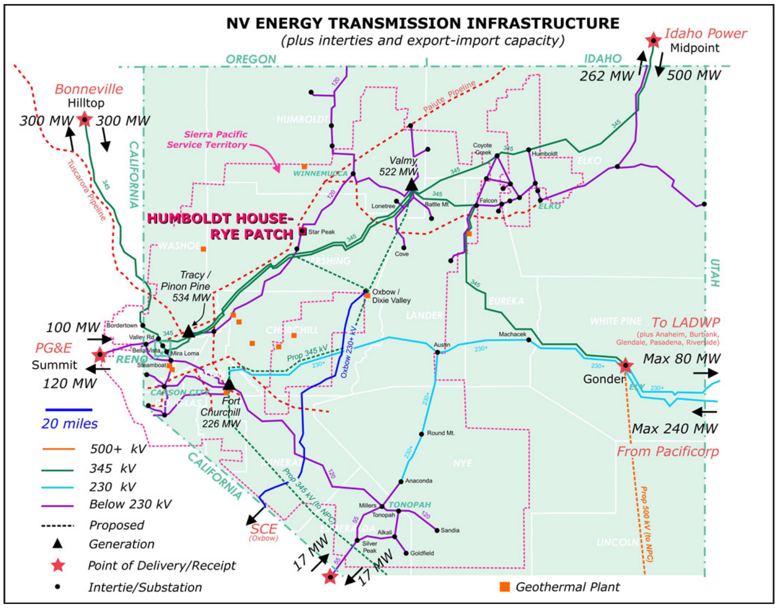

Figure 1.

Introduction

The Humboldt House-Rye Patch Geothermal Resource area (HH-RP) is located in northwest Nevada, approximately 120 miles northeast of Reno (Figure 1). The geothermal resource was originally identified in the 1970s by Phillips Petroleum, and has been explored and drilled with varying degrees of success by others since. The current developer, Presco Energy, purchased the property in 2001, expanded its ownership and commenced an exploration program in the greater resource area. The Project was awarded a DOE "innovative technology" grant in 2009.

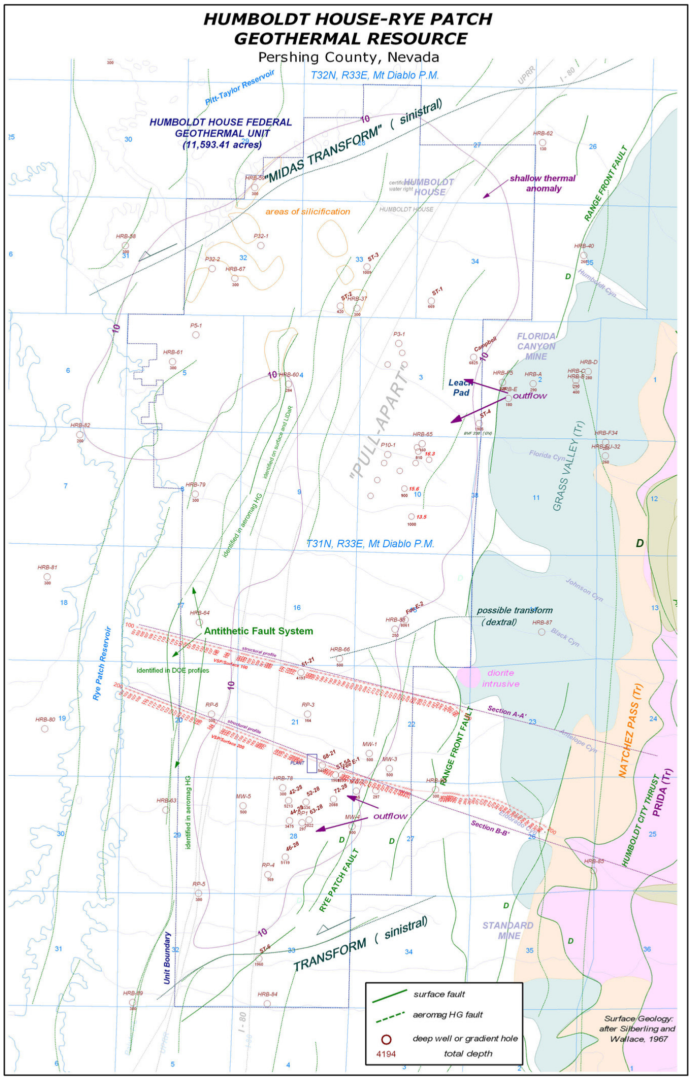

Figure 2.

Prior Model

The conceptual model for the resource area was developed over the past three decades by exploration and drilling programs conducted by several owners. Eleven deep wells and more than 35 gradient holes have been drilled at various points. The preponderance of evidence supports the presence of approximately eight miles of range-front normal faulting carrying geothermal fluids to commercial drilling depths in an area of up to 10,000 acres along the west flank of the Humboldt Range (Figure 2). Three geothermal aquifer systems have been identified in wells drilled to date along or near the Rye Patch and Range Front faults:

1. a shallow outflow zone with temperatures of 150° to 200° F in Valley Fill sediments at depths of several hundred feet,
2. a medium-enthalpy zone (temperatures of 300° to 350° F) at the interface between Triassic "bedrock" and Tertiary volcanic rocks at depths of approximately 1,800 to 2,100 feet, and
3. a high-enthalpy zone with flowing temperatures in excess of 400° F in a "clastic unit" in the Triassic Natchez Pass at a depth of approximately 3,400 feet (44-28 well).

The geochemical data collected over the years at HH-RP were analyzed by Michels (2002), who converged on a set of cations – Li, Cl, B, Na and K – with essentially uniform concentration in all sampled fluids, suggesting a thermally-driven extraction from non-carbonate rocks at a common heat source. Chemical temperatures reveal a source fluid temperature of 500° to 525° F, some 200° F beyond production temperatures. This high-enthalpy target is the focus of all recent geological and geophysical work at the site, including the DOE FOA109 program.

Geophysical surveys and surface mapping have identified the locations of the major faults controlling the resource. An integrated LIDAR and hyperspectral analysis was completed by UC Santa Cruz and the DOE in 2004; the LIDAR data provide excellent illumination of subtle surface faulting in the area, including several faults heretofore unrecognized (Figure 3). High-resolution gravity and magnetic surveys were acquired in 2008. The aeromagnetic survey – 539 line-miles covering 65 square miles – was flown by ultralight at a constant 150m terrain clearance. Depth-filtered, horizontal gradient ("pseudogravity") products were instrumental in the identification of faulting basinward of the Range Front system. Gravity data were acquired over an area of approximately 75 square miles. These data, terrain-corrected and filtered for removal of regional trends, identify several trends which bear on the revised conceptual model.

The recent surveys – LIDAR, hyperspectral, magnetic and gravity – were designed to cover the entire resource area, providing important context for the interpretation of the seismic data acquired in the DOE FOA109 program.

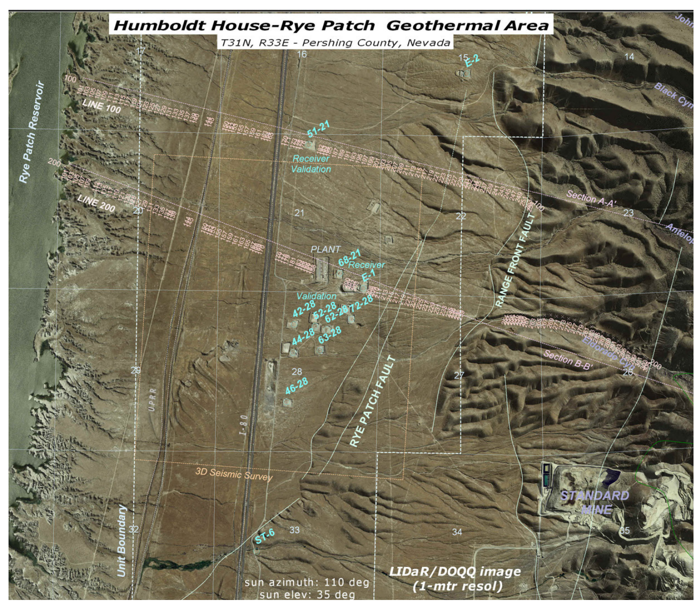

Figure 3.

Seismic Profiling

The DOE program was designed to use a long-aperture, wellbore geophone array and an extended horizontal array of sources to image the structures or zones at depth which are responsible for the active upflow observed in the wellfield. Finite-difference modeling completed prior to design and acquisition suggested a number of potential improvements to traditional surface methods:

- the longer the vertical array or aperture, the better the illumination and resolution of the sub-Valley Fill geometries,
- imaging of acoustic boundaries at high angles was possible, particularly updip of the receiver wells.

Both surface and wellbore seismic acquisition, however, were impacted by various environmental conditions at the site, including the high temperatures at shallow depths in the receiver wells, and a near-surface "Valley Fill" of unconsolidated sands, gravels, boulders and clay that compromised signal recovery and raypath geometries. VSP and surface profiles were acquired through two "receiver wells" (Figure 3), but the wellbore apertures were restricted – geophones were deployed only to depths above the bedrock interface - because of the inability to cool the wellbores below threshold temperature limits (260° F) for the three-component phones. The result was low signal-to-noise, and therefore limited reflectivity, on time- and depth-processed VSP images. The surface seismic was similarly affected, although the extended "live" receiver array was thought to represent a significant opportunity for image enhancement relative to the previous 2D and 3D surveys at the site.

Nevertheless, the profiles uncovered some important features previously unrecognized. The pre-stack, time-migrated (PSTM) surface data, for example, show a pronounced dip reversal to the west: prior interpretations of gravity, magnetic, MT and seismic data suggested continued deepening of the bedrock interface to the west of the existing wellfield, mimicking the topographic change into the (surface) basin. Both surface profiles 100 and 200, in time and depth, show pronounced east dip to the west of the wellfield (Figures 4 and 5). The velocity model and tomography show no changes in the subsurface that could give rise to an erroneous reversal in time and thus both time and depth images provide reliable and conclusive proof of the east dip.

This unexpected result is supported by both the gravity and magnetic data. The gravity data show a pronounced "low" aligned NNE along and east of the Rye Patch Reservoir, the present-day topographic low in the Humboldt River Valley (Figure 6). This low is immediately east of a series of faults interpreted in the horizontal gradient of magnetic intensity (Figure 7), and thus the "sense" – down-to-the-east – suggests a major antithetic system to the Rye Patch and Range Front fault system. The antithetic system converges with the Rye Patch Fault at the south boundary of the Federal Unit (Figure 2). The surface trace of the Rye Patch Fault has undergone a pronounced azimuthal change at this location, to WSW, which corresponds with an aeromagnetic fault of the same azimuth interpreted on the horizontal gradient (Figure 7). Both surface and aeromagnetic faults of the antithetic and range front systems are truncated by this fault, which is interpreted, because of the convergence, to be a transform with sinistral-slip motion. To the north, the antithetic and range front fault systems converge and are truncated by the "Midas Transform", a regional, sinistral-slip system which has rotated fault azimuths, the Humboldt Range (Silberling and Wallace, 1967) and the Humboldt River course to ENE (Figure 2).

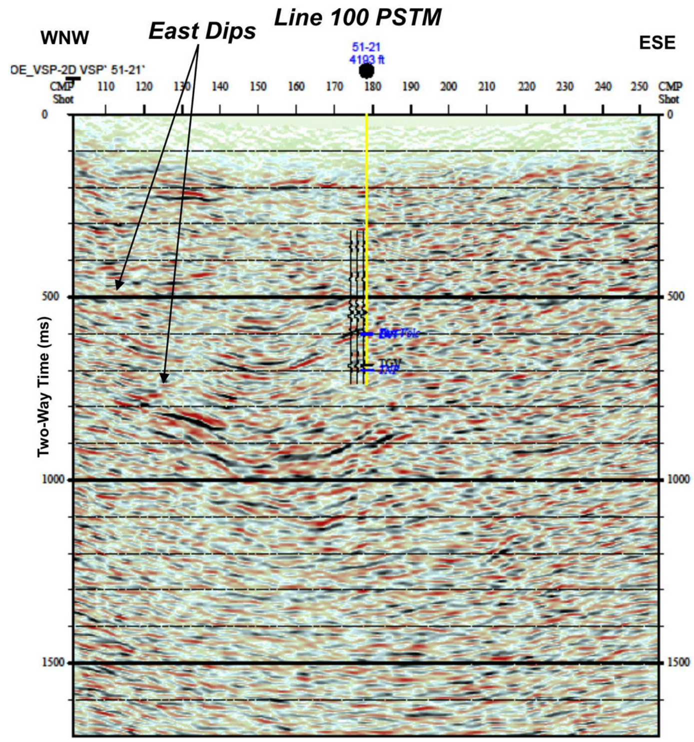

Figure 4.

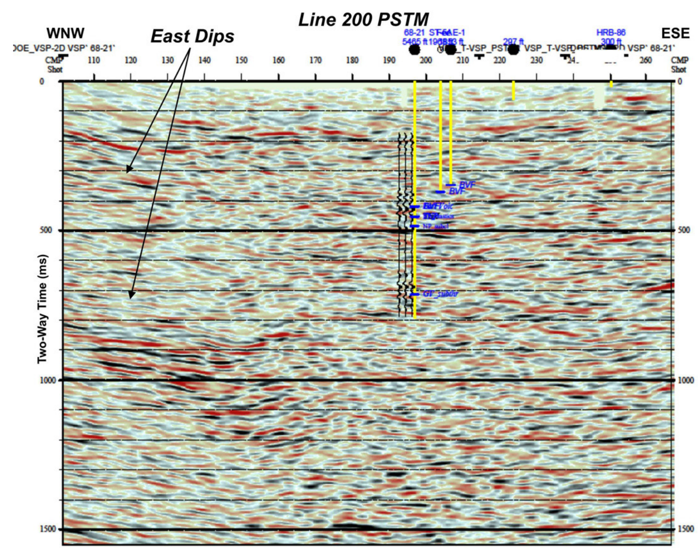

Figure 5.

Structural Interpretation

The downdropped block, truncated and rotated at both ends by transform faulting, has the shape of a classic sigmoidal rhombochasm or "pull apart". This "subbasin" extends nearly eight miles north-to-south and forms a broad zone of dilation, as evidenced by the areas of surface alteration and known geothermal outflow located throughout the block (Figure 2). Of particular interest, the shallow thermal anomaly coincides with the downdropped block over its entire length and breadth, expanding to the west only in the northern portion of the HH-RP

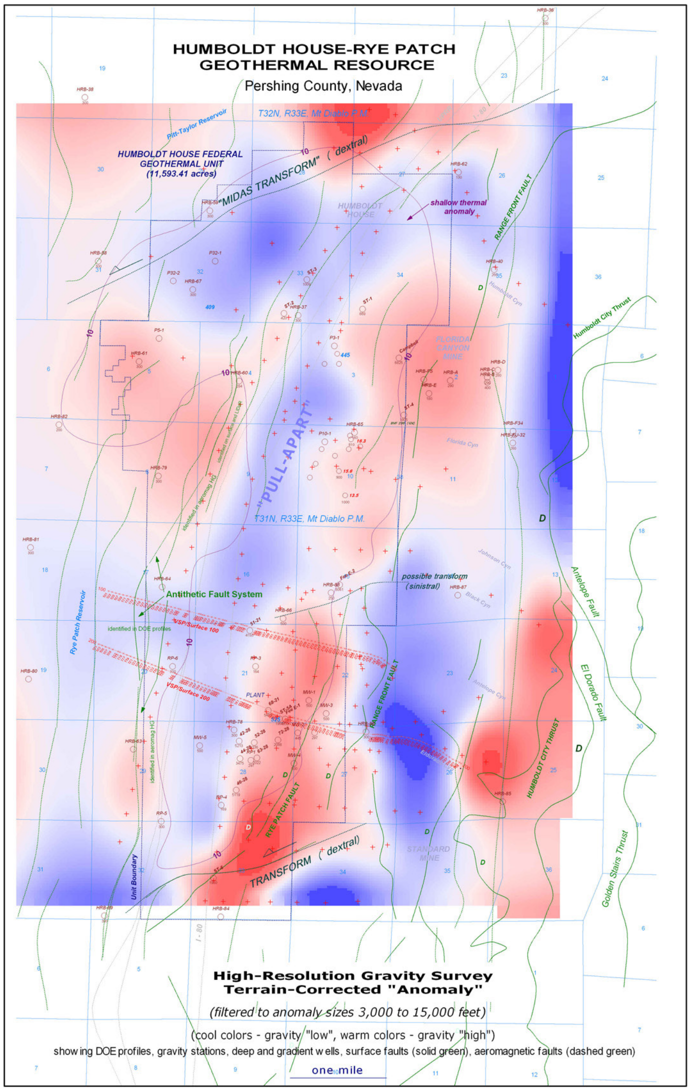

Figure 6.

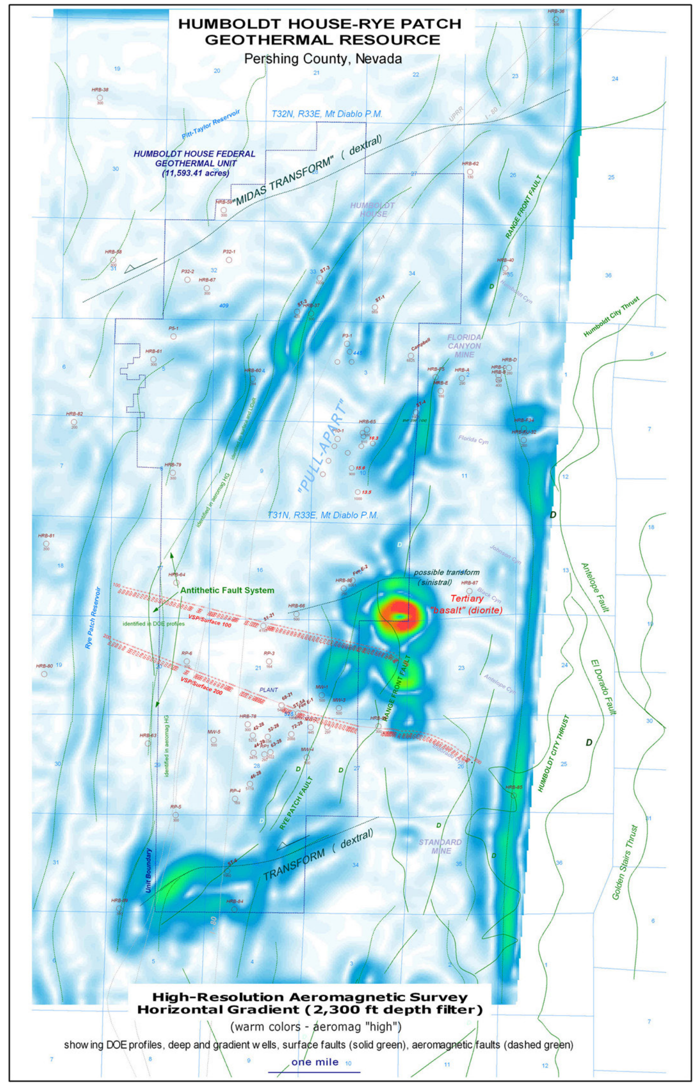

Figure 7.

resource area where it is truncated by the Midas system. While the antithetic system is undrilled, surface mapping of hydrothermal minerals along its northern reaches in 2005 revealed surface flow in the recent past (e.g. prominent vertical zonation of hydrothermal minerals occurs along the surface trace of the antithetic system – the "Pumphouse Fault" - in Section 4, T31N, R33E; Figure 2), and thus it could provide future exploration targets as development proceeds.

When placed in the larger geological and geophysical context, then, the VSP and surface seismic profiles provide confirmation of a mechanism limiting the distribution of deep targets in the greater resource area, and suggest local targets in the area of the existing wellfield. Structural sections were prepared to incorporate the new data from the seismic with the prior geophysical surveys, well and surface data. Both sections represent a significant departure from prior interpretations. Section A-A' (Figure 8) occupies a position along Profile 100, extending an additional 9,000 feet into the foothills of the Humboldt Range (Figures 2 and 3). Section B-B' (Figure 9) occupies a similar position and traverse along Profile 200, extending an additional 5,500 feet into the Range. The east dip and antithetic faulting west of the wellfield area figure prominently in the intrablock geometry, and require significant adjustments in the structural form along the range front faults. The lithologic and geophysical data from

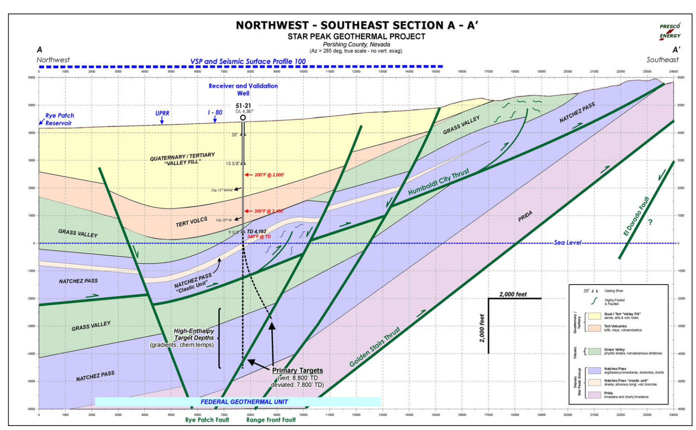

Figure 8.

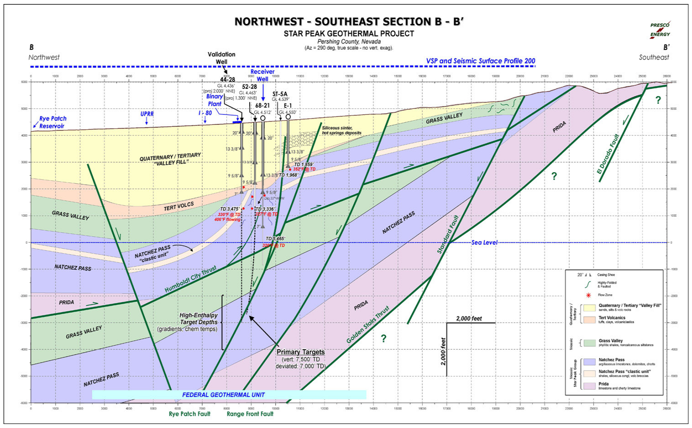

Figure 9.

well 51-21, for example, show a thick section of Tertiary tuffs and volcaniclastics – nearly 1,100 feet in thickness – capping a sliver of Triassic Grass Valley phyllitic shale ("non-reservoir") over Natchez Pass limestones ("reservoir") (Figure 10). The

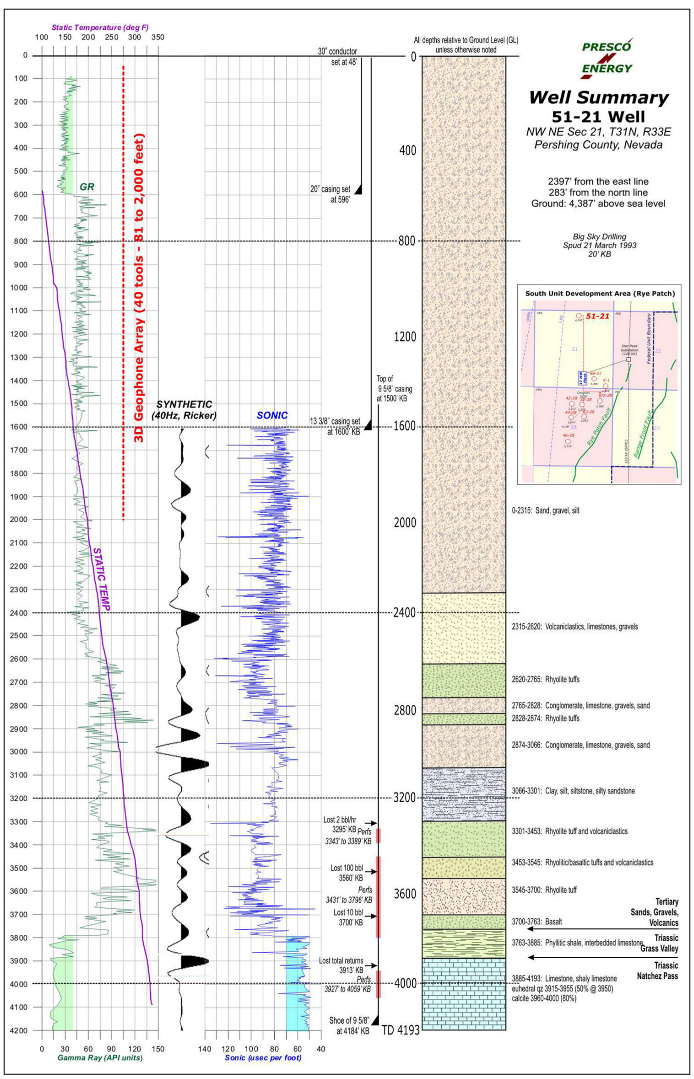

Figure 10.

same Tertiary tuff and volcaniclastic section in well 68-21 is approximately 4-500 feet thick and caps a steeply-dipping lower Natchez Pass section (Figure 11).

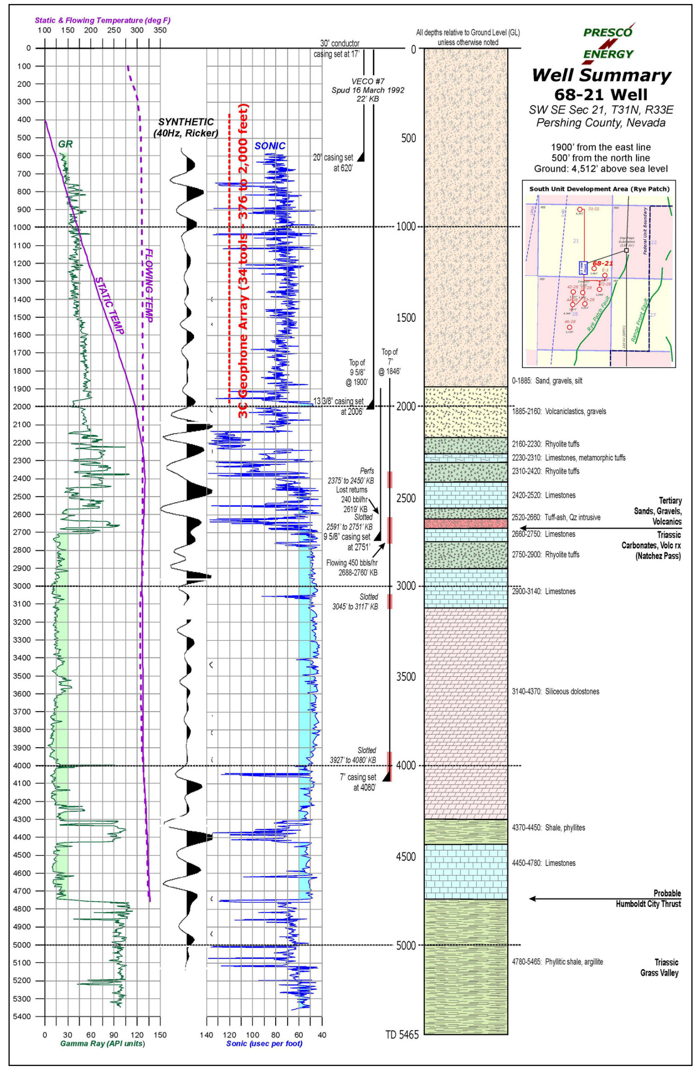

Figure 11.

The Grass Valley is typically 1,500 to 2,000 feet in thickness in the northern Humboldt and East ranges (Silberling and Wallace, 1969), and although it is highly-contorted and shows exaggerated thicknesses in outcrops to the east, it most likely reaches true formation thickness basinward. This, and the lack of Grass Valley in the wellfield to the south, suggest a prominent "high" in the hanging wall of the Humboldt City Thrust immediately west of the Rye Patch Fault. As depicted in the gravity, this "high" extends south-southwest along the Rye Patch Fault for nearly four miles (Figure 6), and is here interpreted as an imbricate off the thrust plane.

Well control for the imbricate is provided by deep well 68-21 and shallow wells E-1 and ST-5A (Figure 9). The strong west dip in the sub-Tertiary Natchez Pass limestones in 68-21 – 55 to 70 degrees, west-dipping, below the unconformity - argue for the presence of the imbricate, as a "ramp" in the main thrust plane would be unlikely to attain such an attitude without a significant

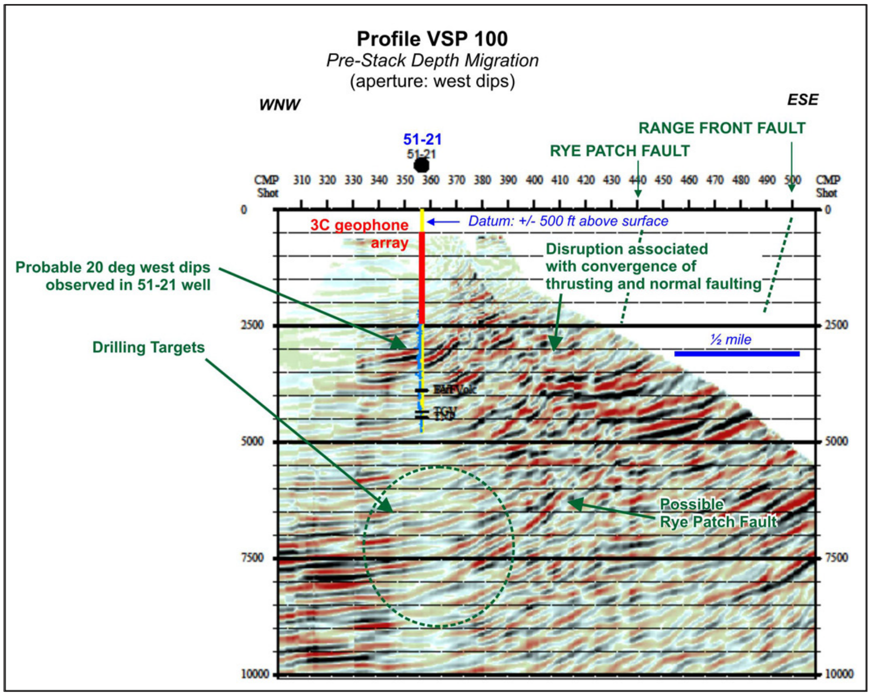

Figure 12.

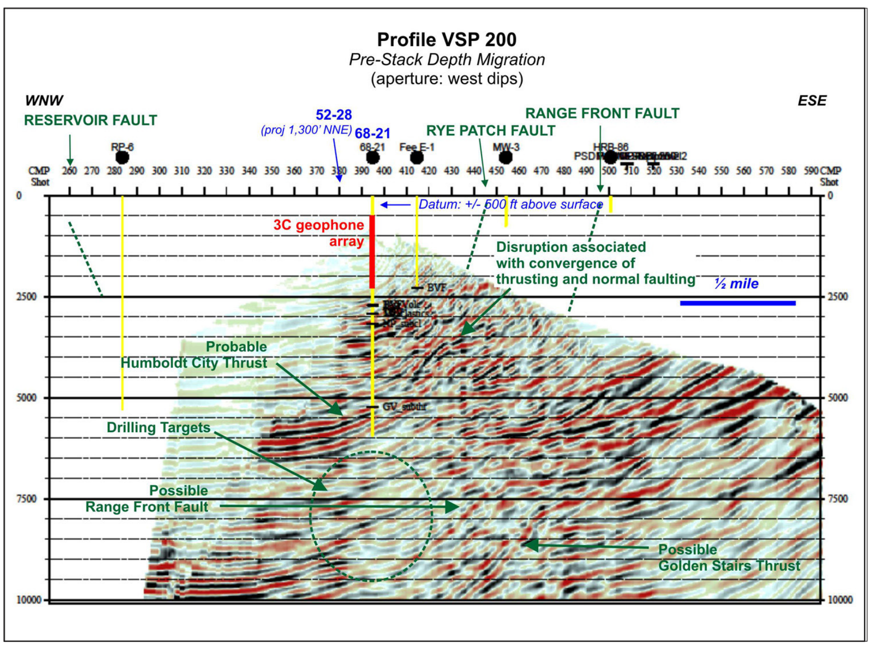

Figure 13.

buttress or ramp below, the evidence for which does not exist. The shallow wells, immediately east of the 68-21 and direct offsets to each other, appear to define a (normal fault) splay off the Rye Patch Fault, as the Tertiary-Triassic unconformity and younger siliceous sinter deposits in both wells are offset 150 feet or more.

Both structural sections incorporate the subthrust formation dip encountered in the dipmeter data of 68-21: 25 to 35 degrees to the west. In addition, well 68-21 encountered approximately 700 feet of Grass Valley below the Thrust (Figure 11), and thus both interpretations carry a full or nearly-full section of Grass Valley west of the Rye Patch Fault. Because the Grass Valley phyllitic shales typically behave plastically under stress (witness the severe disruption and repetition in the low foothills to the east), these rocks are considered "non-reservoir", and thus targeting anticipates the need to drill through a significant subthrust thickness of Grass Valley to reach the brittle limestones, cherts and siliceous dolomites of the (reservoir) Natchez Pass and Prida formations.

Of particular interest, outcrop relationships to the east, at the toe of the Thrust in the Humboldt Range, invariably show Natchez Pass in the hanging wall and (older) Triassic Prida in the footwall ("younger over older"), and thus at least 3,000 feet of downcutting (to remove all Grass Valley and Natchez Pass rocks) must occur in a little over three miles, a significant balancing problem. The Humboldt City Thrust appears to be a younger ramp over a preexisting hanging wall, most likely part of the Golden Stairs Thrust complex exhumed in the Range to the east (Figure 9 and Silberling and Wallace, 1967).

Seismic Evidence

The VSP depth images are instructive here. To minimize the effects of noise and artifacts, the depth data were filtered for enhanced resolution of structural attitudes. The hanging wall disruption and possible dip reversal associated with the imbricate is visible on both VSP profiles for apertures restricted to west dips only (Figures 12 and 13). Both aperture products show alignments crossing reflections (or noise) at the projected position of the Rye Patch Fault at depth, and this forms the basis for the interpretation that the fault plane rotates slightly, from 70+ degrees at the surface to 60+ degrees at depth. The aperture product for Profile 200 provides evidence for the attitude of the Humboldt City Thrust at and slightly west of the 68-21 well; the approximate 20-25 degree west dip matches the subthrust attitudes observed in the dipmeter data, and thus the steep hanging wall dips are considered compelling evidence for the presence of the imbricate, as no kinematic thrust model would allow such dramatic cutting downsection (i.e. at high angle) in the direction of transport.

The disruption associated with the convergence of thrusting and normal faulting at the 68-21 well has removed any shallow seismic evidence of the Rye Patch Fault and splay. Alignments at depth are postulated as possible evidence for the Range Front Fault and older Golden Stairs Thrust, both of which are visible on the surface east of the wellfield (Silberling and Wallace, 1967).

3D and 2D Seismic Images

The 2D PSTM surface profiles show little if any intrablock resolution, an artifact of the limited signal and lack of effectiveness of the migration. This troublesome result was explored further: because of the enhanced spatial resolution and effectiveness of migration for typical 3D data, the prior 3D survey (1997 DOE/LBNL three square mile vibroseis) was reprocessed after a detailed geometry review, assessment and editing. Some 33,000 traces with good refraction data and known geometries were processed through migration. Of particular interest is the comparative resolution between 2D and 3D migration products in the intrablock region (Figure 14 - both profiles at the same horizontal and vertical scales). Review of the synthetic response in several field wells suggested much higher potential reflectivity in the Grass Valley phyllitic shales than the massive carbonates of the Natchez Pass (e.g. Figure 11). The packages of higher reflectivity observed in the 3D profile are thus almost certainly attributable to Grass Valley, and thus the general structural form of west-dipping Grass Valley in both the hanging wall and footwall is confirmed. The acoustically "opaque" packages above and below the footwall Grass Valley are most likely the Triassic carbonates (see synthetic in Figure 11), while the opaque package above the hanging wall is likely amorphous or highly-heterogeneous Valley Fill material. Note that this qualitative assessment and distinction is difficult to impossible on the 2D images, and in parts of the 3D survey as well, but can be used with reasonable confidence for general structural/stratigraphic purposes in a fair portion of the Rye Patch 3D. Further processing refinements are underway.

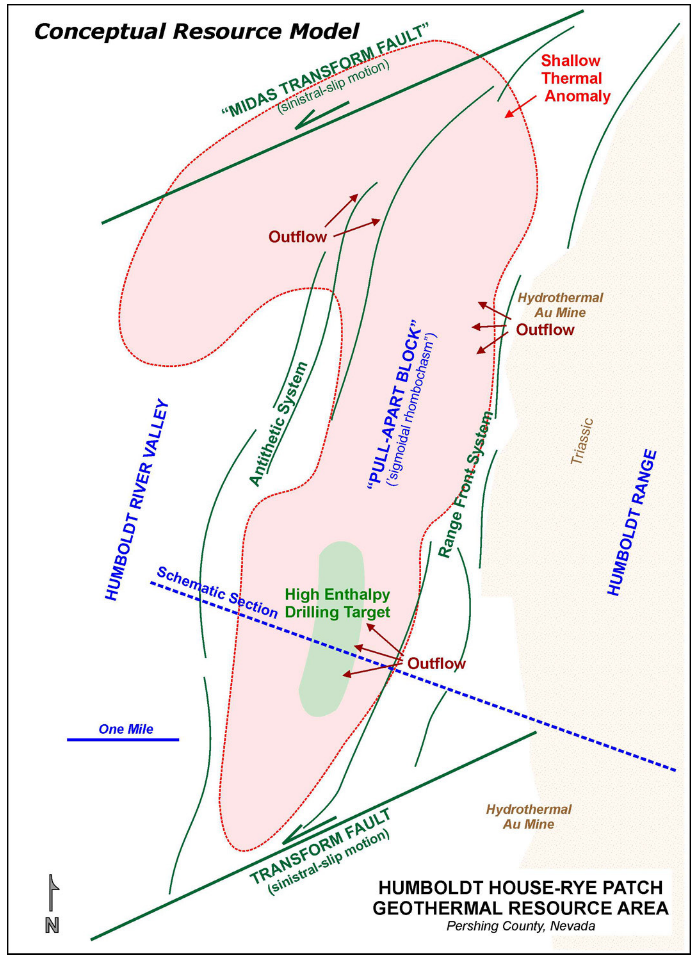

Figure 15.

Summary and Conclusion

The seismic profiling, placed in the larger context of prior geophysical and geological work in the Humboldt House-Rye Patch resource area, has fundamentally altered the understanding of the structural controls and form of the deep geothermal resource area. While image quality is limited, sufficient resolution is present to provide reliable and conclusive evidence of the lateral limits within which commercial resource flow is likely to occur.

Miocene and younger transform faulting at the north and south boundaries of the project area has created a prominent zone of dilation and a classic "pull-apart" ("sigmoidal rhombochasm") along the west boundary of the Humboldt Range (Figure 15). Zones of outflow have been identified along the east side of the pull-apart block over a distance of nearly eight miles, and surface evidence of recent flow can be identified on the northern end of the antithetic system defining the west boundary of the block. The Range Front Fault controls outflow in the area of the Florida Canyon Mine, with shallow supply wells and the pit containing medium enthalpy fluids. The Rye Patch Fault, a splay off the Range Front Fault system, controls flow from shallow and deep wells to the south. The targeted reservoirs for the deep flow system are

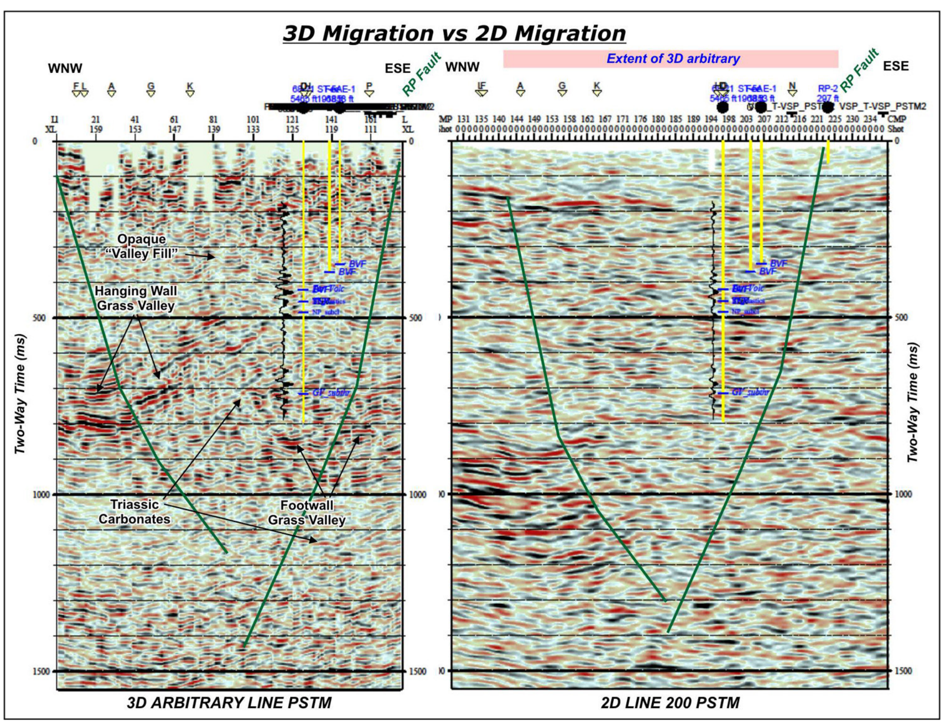

Figure 14.

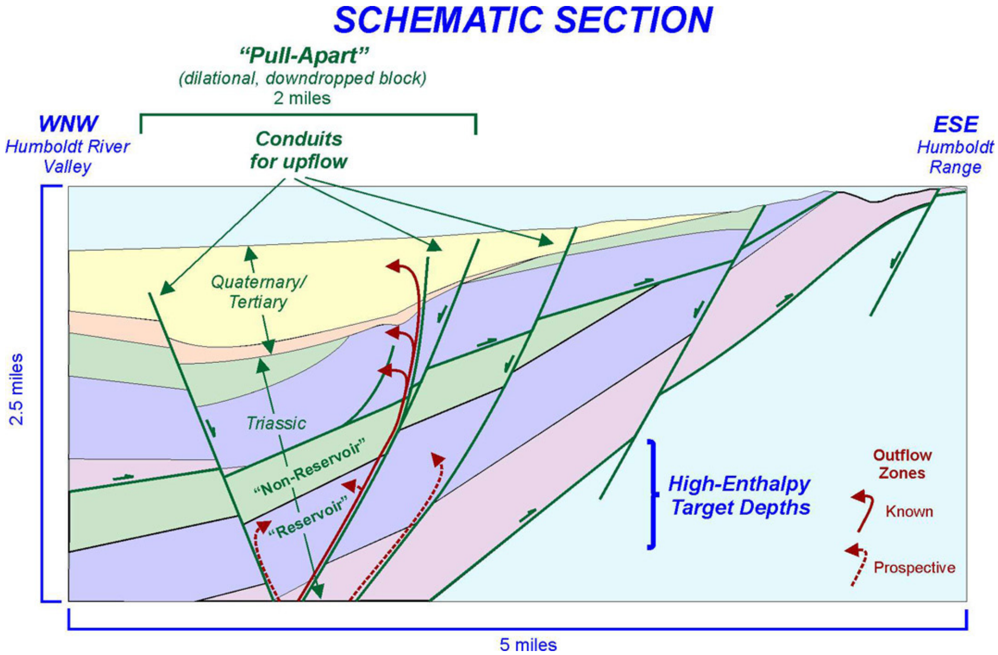

Figure 16.

fault intersections with fractured Triassic limestones and volcanic rocks at depths of 7,500 to 8,800 feet (Figures 8, 9 and 16).

The structural interpretation has identified an imbricate off the Humboldt City Thrust that forms a prominent high block in the existing wellfield which is cut by the Rye Patch Fault (Figure 16). A gravity "high" coincident with the wellfield high block extends some four miles along the Rye Patch Fault to a point of truncation and shift along the southern transform. The coincidence of the Rye Patch Fault with the imbricate for much of its identified length is strongly suggestive of a genetic relationship and may be the principal control for the formation of an active conduit along the Rye Patch Fault.

References

Michels, D., 2002, Rye Patch geothermal development, hydro-chemistry of thermal water applied to resource definition, Report to Presco Energy, 33 pp., 13 figures.

Silberling, N.J., and R.E. Wallace, 1967, Geologic map of the Imlay Quadrangle, Pershing County, Nevada, GQ-666.

Silberling, N.J., and R.E. Wallace, 1969, Stratigraphy of the Star Peak Group (Triassic) and overlying Lower Mesozoic rocks, Humboldt Range, Nevada, Geol. Surv. Prof. paper 592, 49 p.