Structural Interpretation of the Dixie Meadows Geothermal Prospect using Joint Modeling of Gravity and Magnetic Data*

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Abstract

The Dixie Meadows geothermal prospect, located ~150 km east of Reno, Nevada, lies within an active, NNE-trending fault zone between the Stillwater Range to the east and Dixie Valley to the west. Geothermal surface expressions consist of advanced argillic alteration, fumaroles, and hot springs. Joint modeling of gravity and magnetic datasets indicates that intersecting faults and splaying normal faults control geothermal fluid flow. Some faults appear to be blind faults with little or no surface expression.

This study incorporates data from 80 aeromagnetic transects flown by the USGS in 2002 and 516 gravity stations acquired in 2010 by Zonge Geosciences, Inc. for Ormat Technologies Inc., covering ~150 square kilometers. Forward modeling of the gravity data, supported by available well data, indicates a basin thickness of ~2 km in the basin center, abruptly decreasing to within 500 m in the intrabasin and a 1-2 km wide zone on the basin margin, adjacent to the rangefront. A reduced-to-pole magnetic map reveals normal fault-bounded magnetic anomalies. The horizontal derivative of the gravity data delineates the strike of normal faults. Joint forward modeling of the gravity and magnetic data, supported by other geothermal exploration methods, indicate the presence of three generations of normal faulting; the oldest, steeply-dipping NW-striking fault is intersected by modern, moderate- to steeply-dipping, NNE-striking faults that are superimposed upon older, steeply-dipping, N-striking, right-stepping faults.

Normal faults primarily strike NNE and dip ESE, orthogonal to regional WNW extension of the northwestern Basin and Range Province. Joint gravity and magnetic modeling reveals tens of meters of total displacement at the rangefront and >1 km of displacement in a blind, sub-parallel piedmont fault, which indicates that the modern rangefront fault developed relatively recently. The NNE-trending rangefront and piedmont faults have N-striking, right-stepping segments inherited from Tertiary faults created by E-W extension. Joint modeling indicates two blind, splaying normal fault segments between the rangefront and piedmont faults, or intrabasin, occur near the hot springs and fumaroles. In addition,

a steep, NW-striking normal fault cuts through the Stillwater Range and into the basin. It is concealed by alluvial cover, but is geophysically delineated and spatially correlates with an abrupt lateral change in shallow (1 m) temperatures and with measured changes of total dissolved solids and pH in spring fluids. The NW-striking fault exhibits stratigraphic offset in the Stillwater Range but does not cut the Quaternary fan surface, and is interpreted to be a remnant of an earlier Tertiary extensional episode.

The interpreted structural model is defined by three generations of extensional faulting. The oldest, NW-striking fault appears to be a hydrologic barrier confining the intrabasin geothermal system. The youngest, NNE-trending rangefront fault and piedmont fault are superimposed upon older, right-stepping, N-striking fault segments. A pair of splaying normal fault segments in the intrabasin spatially correlates with surficial thermal features, suggesting that the splaying faults are hydrothermal conduits. The geophysical approach applied in this investigation delineates blind faults that control hydrothermal fluid flow and provides a testable structural model for further exploration and potential development.

1-2 Structural interpretation of the Dixie Meadows geothermal prospect using joint modeling of gravity and magnetic data

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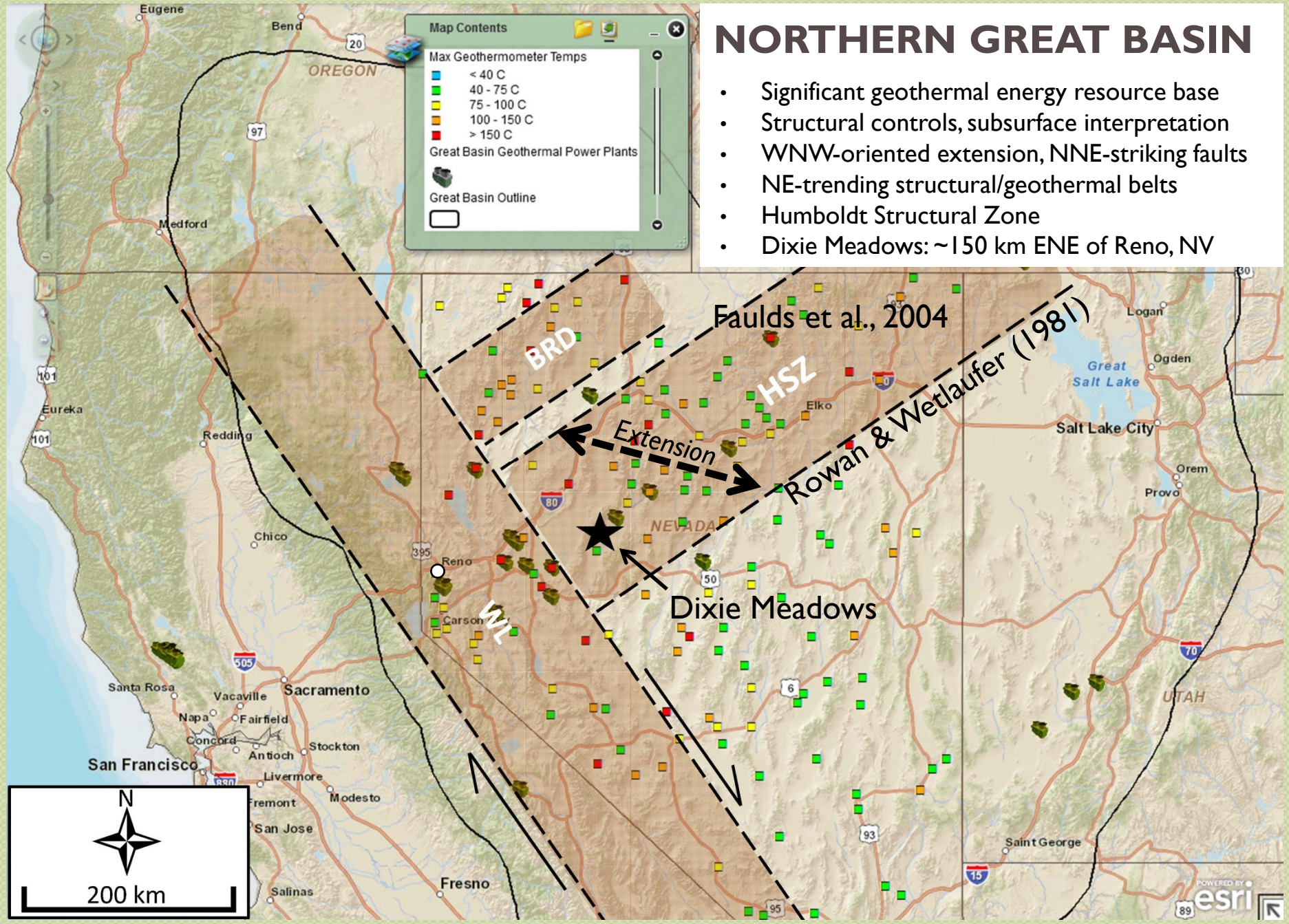
SESSION NO. 1
Geothermal Development in a Changing Energy Landscape
April 22, 2013

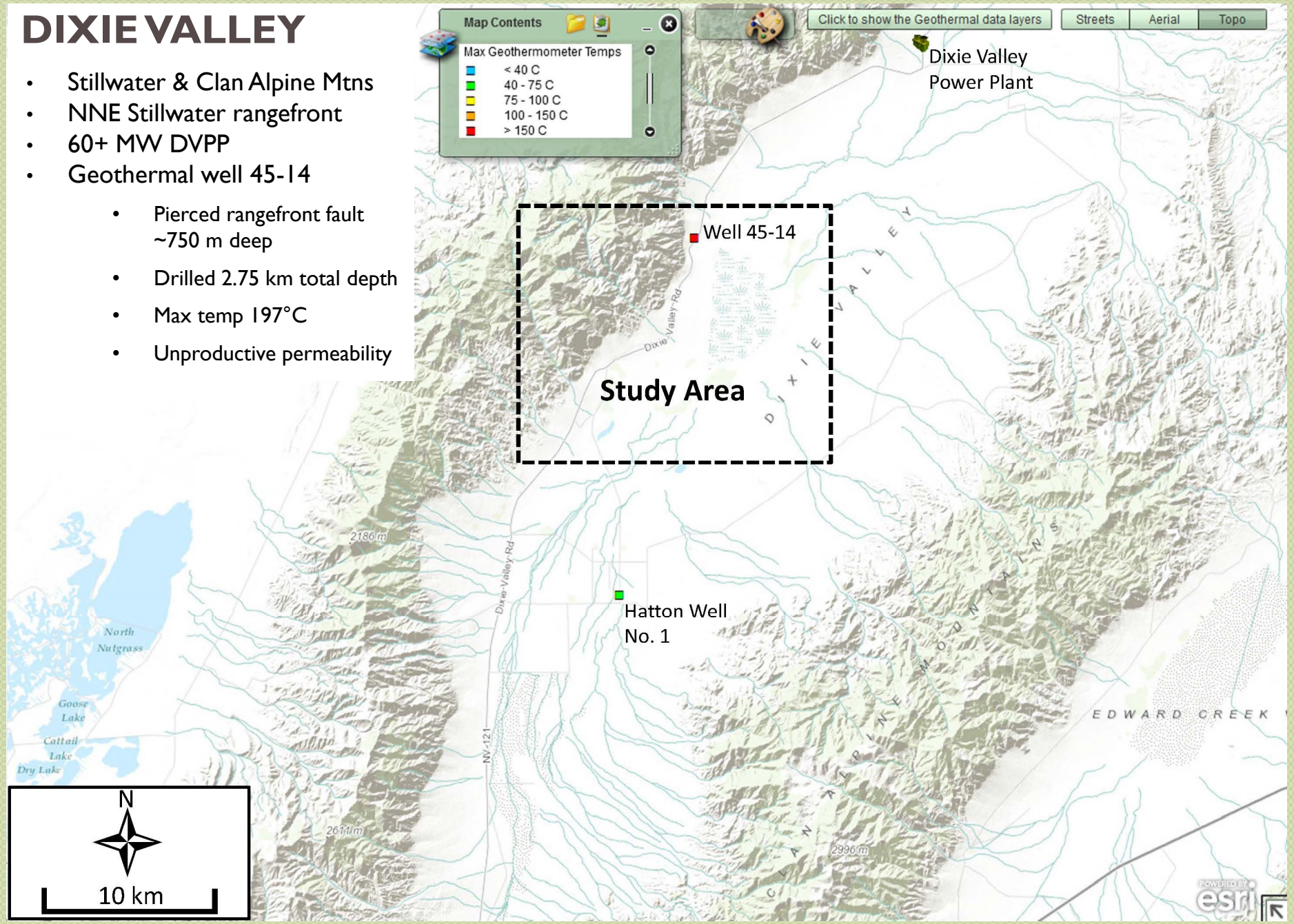
NORTHERN GREAT BASIN

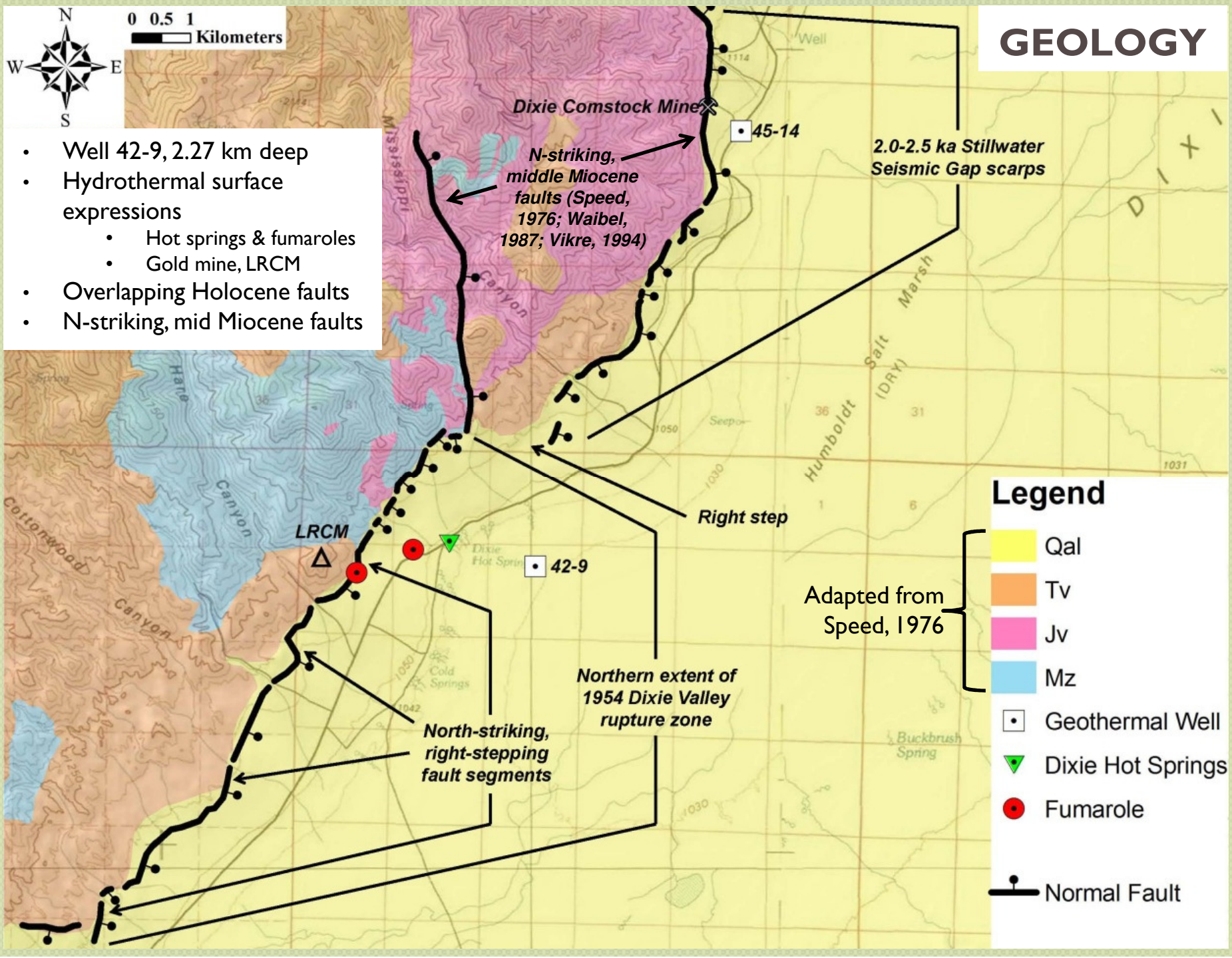
- Significant geothermal energy resource base
- Structural controls, subsurface interpretation
- WNW-oriented extension, NNE-striking faults
- NE-trending structural/geothermal belts
- Humboldt Structural Zone
- Dixie Meadows: ~150 km ENE of Reno, NV



DIXIE VALLEY

- Stillwater & Clan Alpine Mtns
- NNE Stillwater rangefront
- 60+ MW DVPP
- Geothermal well 45-14
  - Pierced rangefront fault ~750 m deep
  - Drilled 2.75 km total depth
  - Max temp 197°C
  - Unproductive permeability

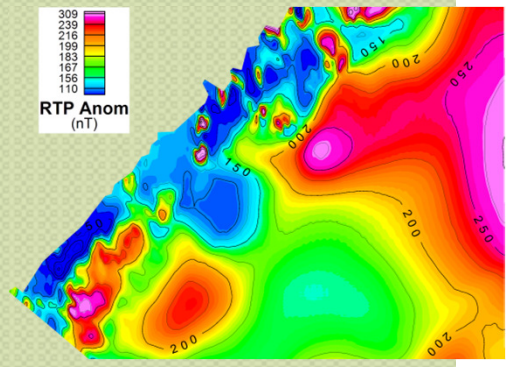



GEOLOGY
N
S
E
W
0 0.5 1
Kilometers
Well 42-9, 2.27 km deep
Hydrothermal surface expressions
Hot springs & fumaroles
Gold mine, LRCM
Overlapping Holocene faults
N-striking, mid Miocene faults
Dixie Comstock Mine
45-14
N-striking, middle Miocene faults (Speed, 1976; Waibel, 1987; Vikre, 1994)
2.0-2.5 ka Stillwater Seismic Gap scarps
Right step
LRCM
42-9
Northern extent of 1954 Dixie Valley rupture zone
North-striking, right-stepping fault segments
Legend
Qal
Tv
Jv
Mz
Adapted from Speed, 1976
Geothermal Well
Dixie Hot Springs
Fumarole
Normal Fault

GOALS

- **Interpretation and 2D joint modeling of gravity and aeromagnetic data**
- **Gain understanding of subsurface basin geometry and fault architecture**
- **Infer likely structural controls and chronology at the geothermal prospect**

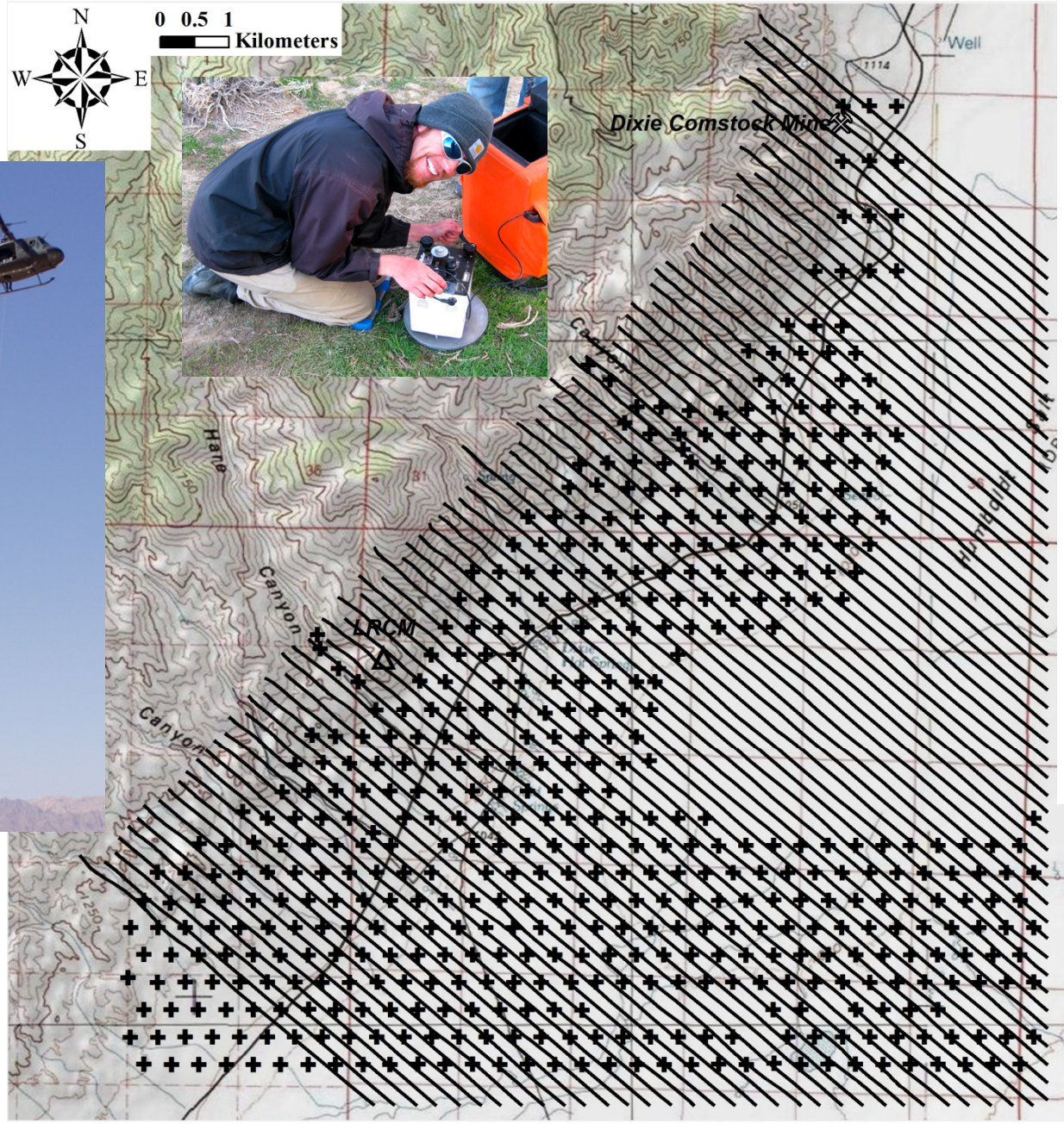
METHODS



- Reconnaissance-level characterization of geothermal surface expressions
  - Spring fluid & fumarole analyses
  - Near-surface temperatures
- Geologic reconnaissance
  - Cenozoic units and faults
  - Drill cuttings

- **Geophysical interpretation and modeling**
  - **2D maps**
  - **2D joint model profiles (i.e., cross-sections)**

Geophysical Surveys



Gravity

- Zonge Geosciences Inc. under contract to Ormat, 2010 – Dixie Meadows
- L&R gravimeters
- 516 stations
- ~400 m spacing

Aeromag

- Pearson, deRidder, & Johnson Inc. under contract to USGS, 2002 – n. Dixie Valley
- Helicopter-borne, cesium-vapor magnetometer
- 80 transects over Dixie Meadows prospect
- 200 m line spacing
- Avg. sensor height ~120 m

~150 km² of data coverage

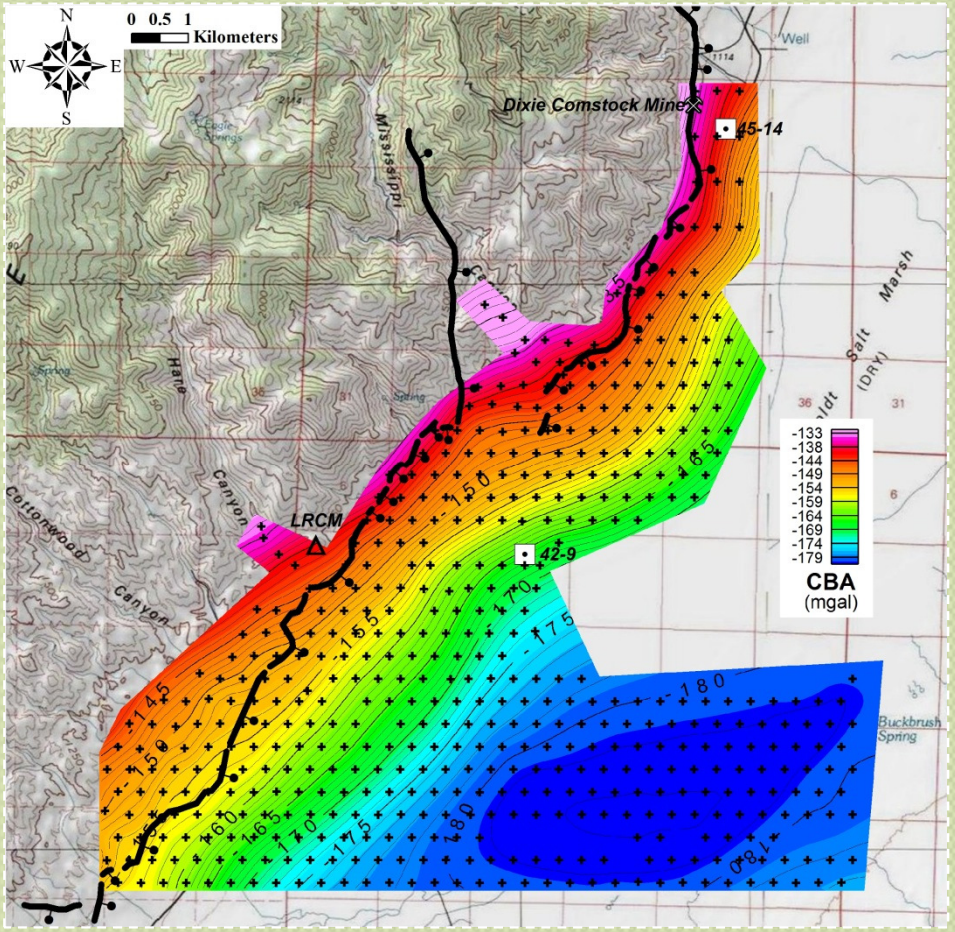
Legend

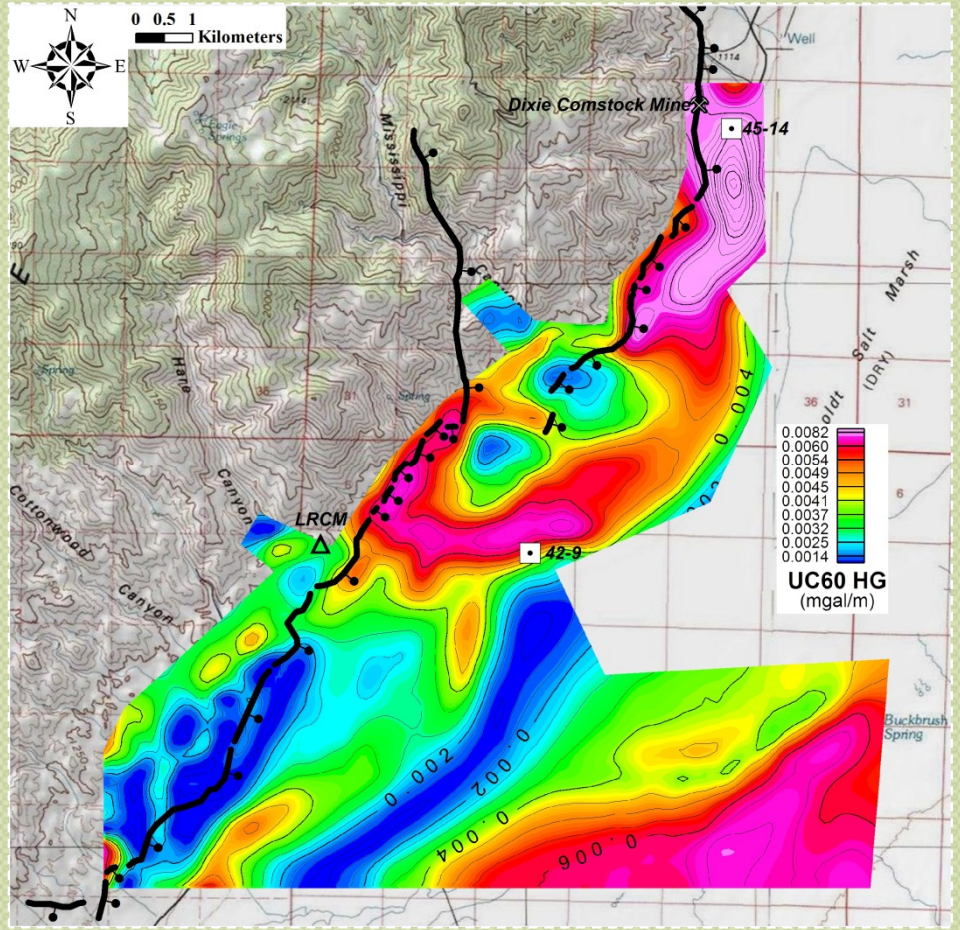
+ Gravity Station

Aeromagnetic Line

Minimum-curvature gridded complete Bouguer anomaly (CBA) @ 2.35 g/cc, overlain by gravity station coverage

Horizontal gradient of the CBA, upward-continued 60 m. Linear horizontal gradient maxima generally delineate strike of faults in this study.

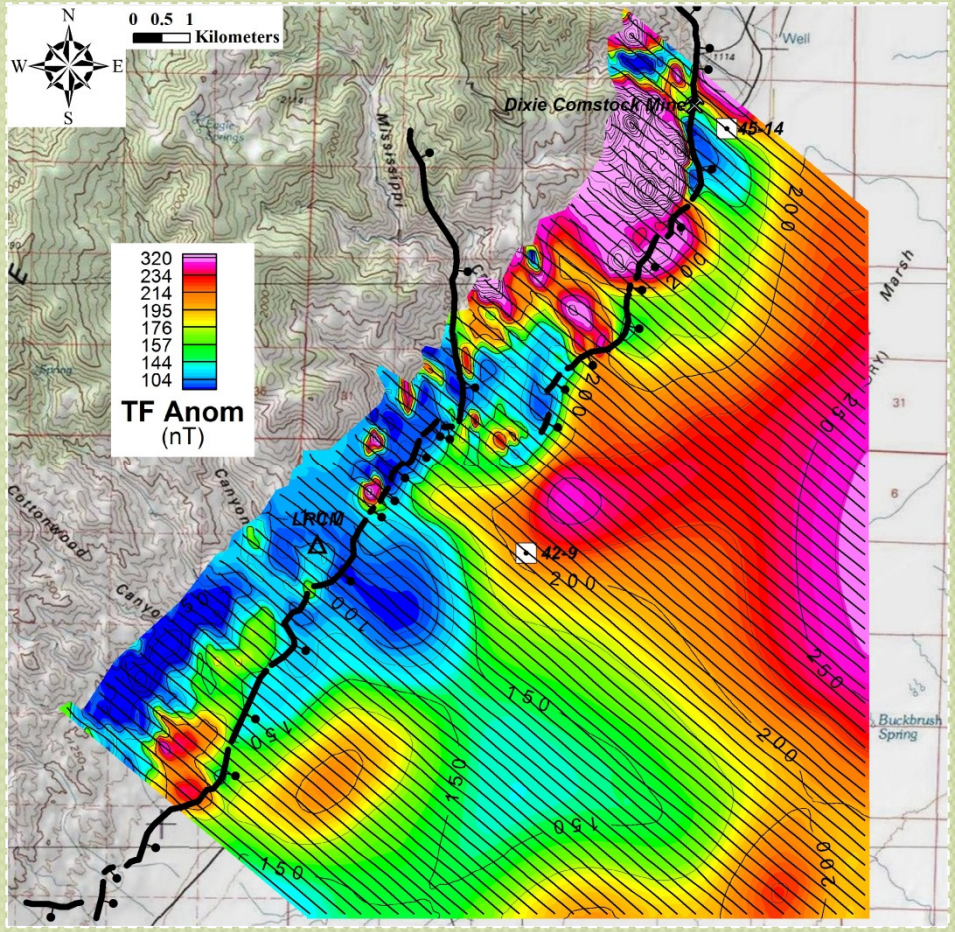


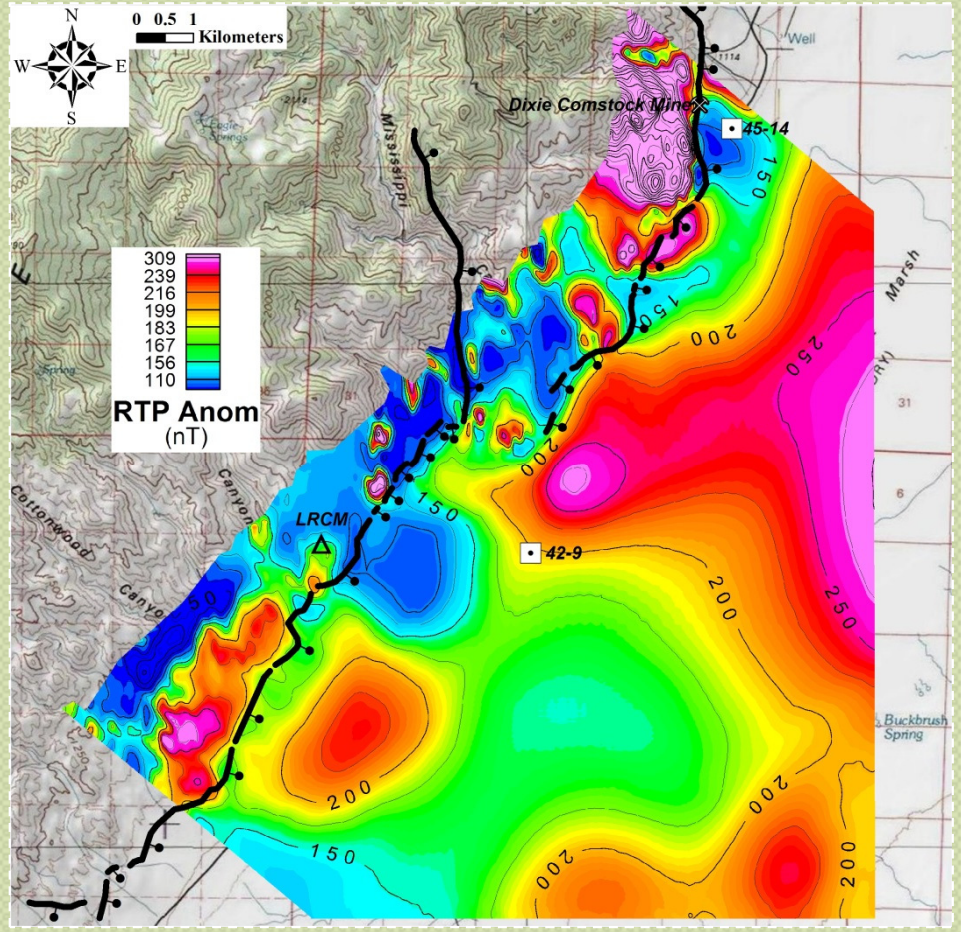


Gravity Maps

Bi-directionally gridded total field (TF) magnetic data (Grauch, 2002), overlain by transect coverage.

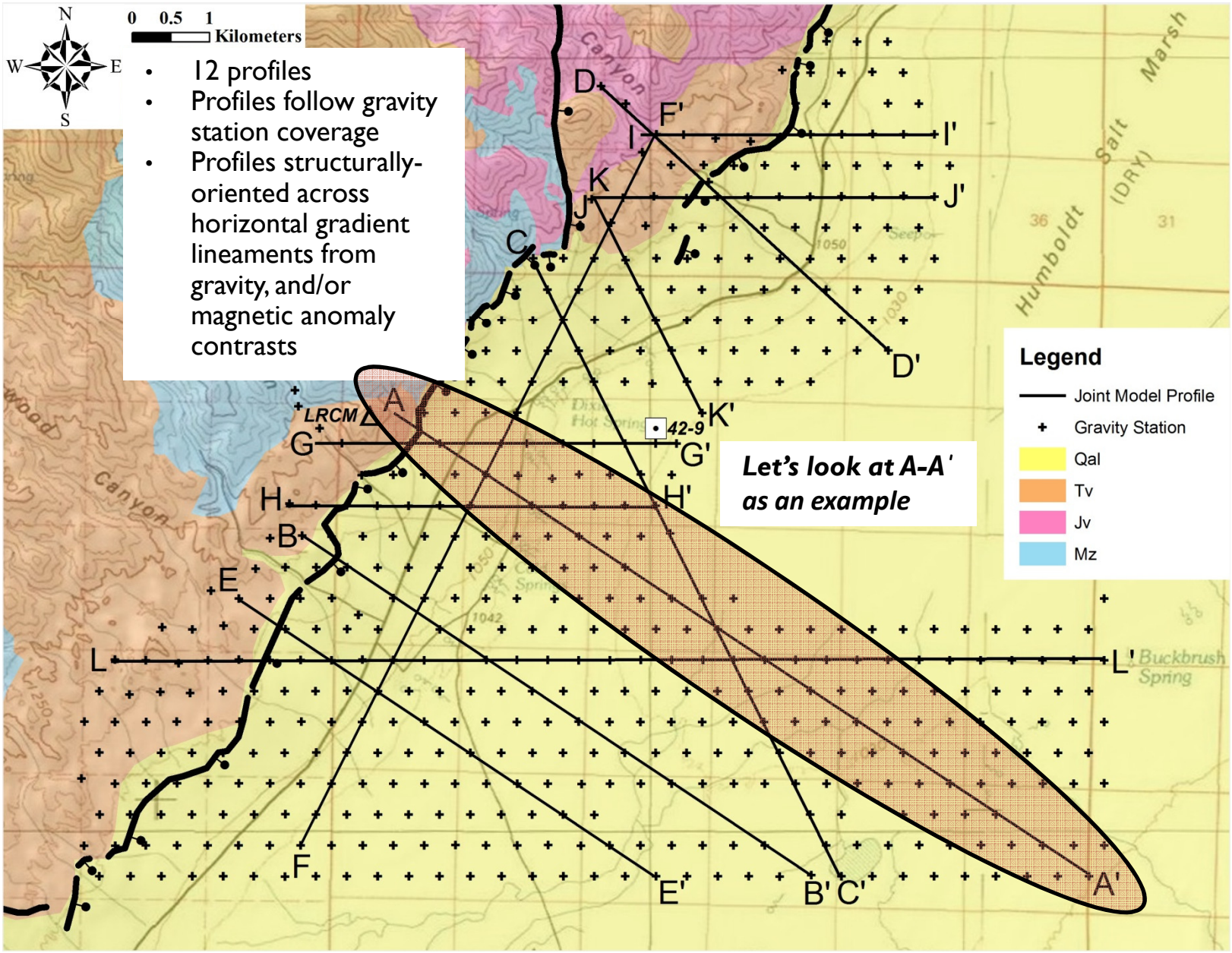
Reduced-to-pole TF data. Magnetic lows often targeted in geothermal exploration; lows may be indicative of hydrothermal demagnetization.





Magnetic Maps

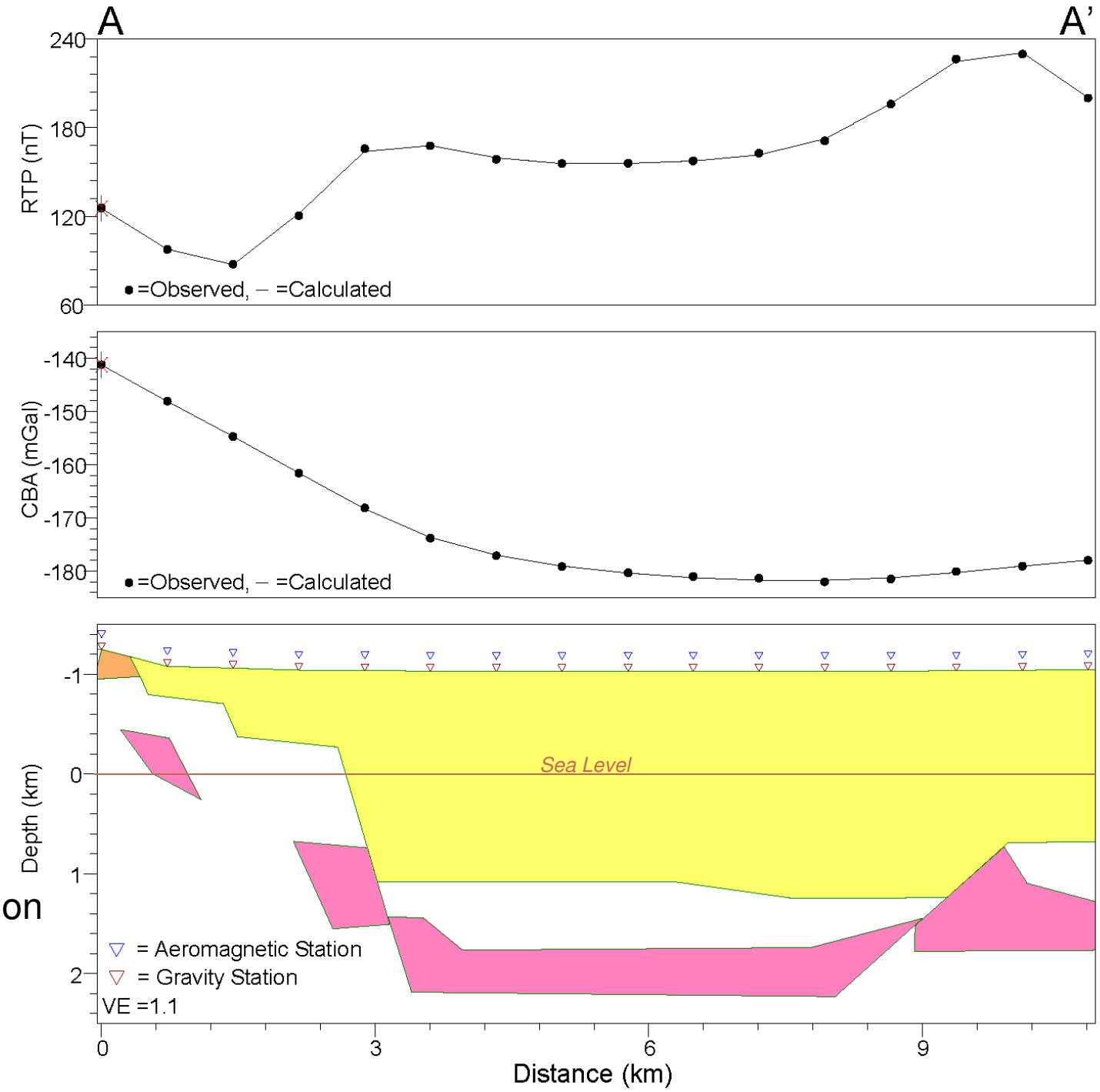
2D Joint Model Profiles



< 2% NRMSD

< 1% NRMSD

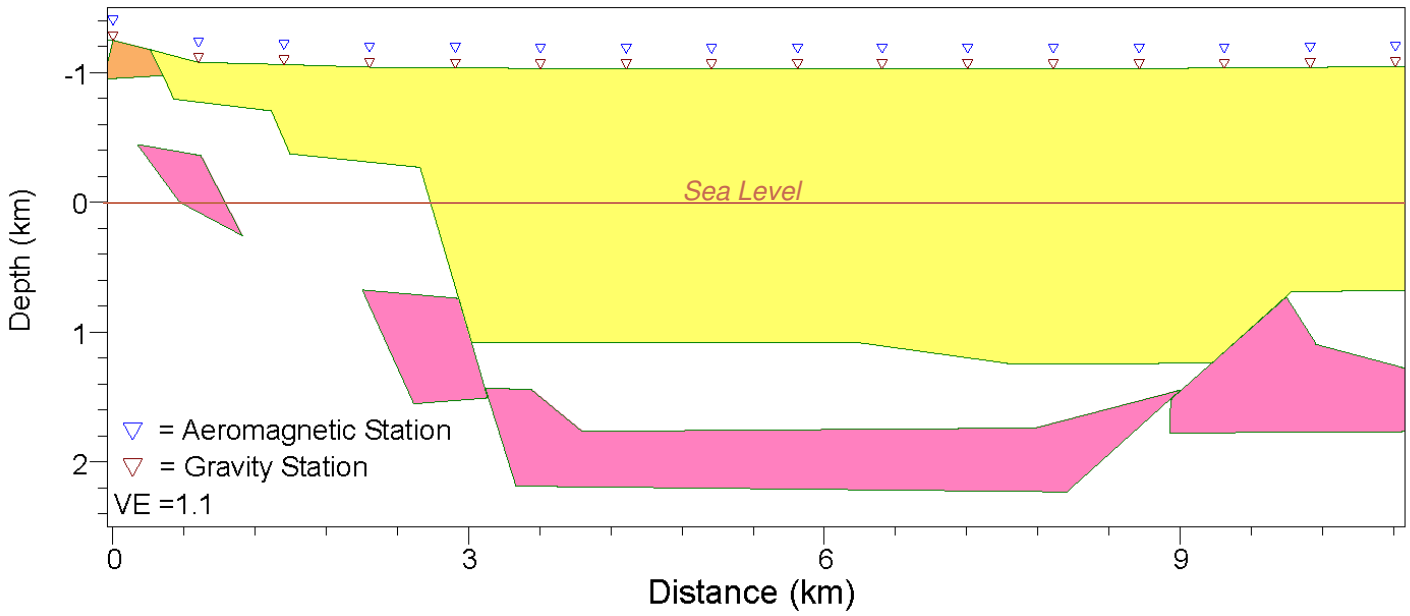
Model cross-section

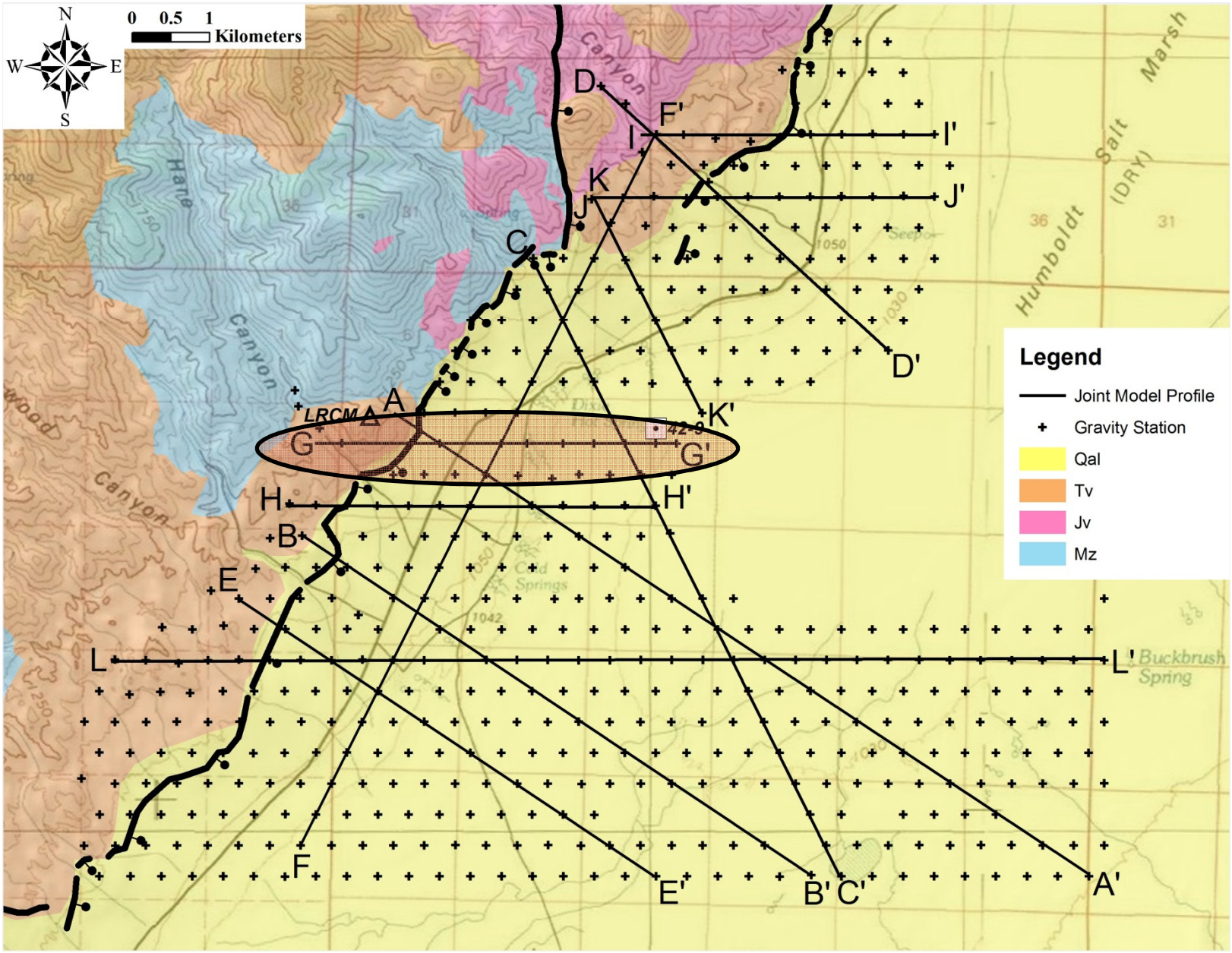


Representative geologic units, and their geophysical properties, for joint model profiles.

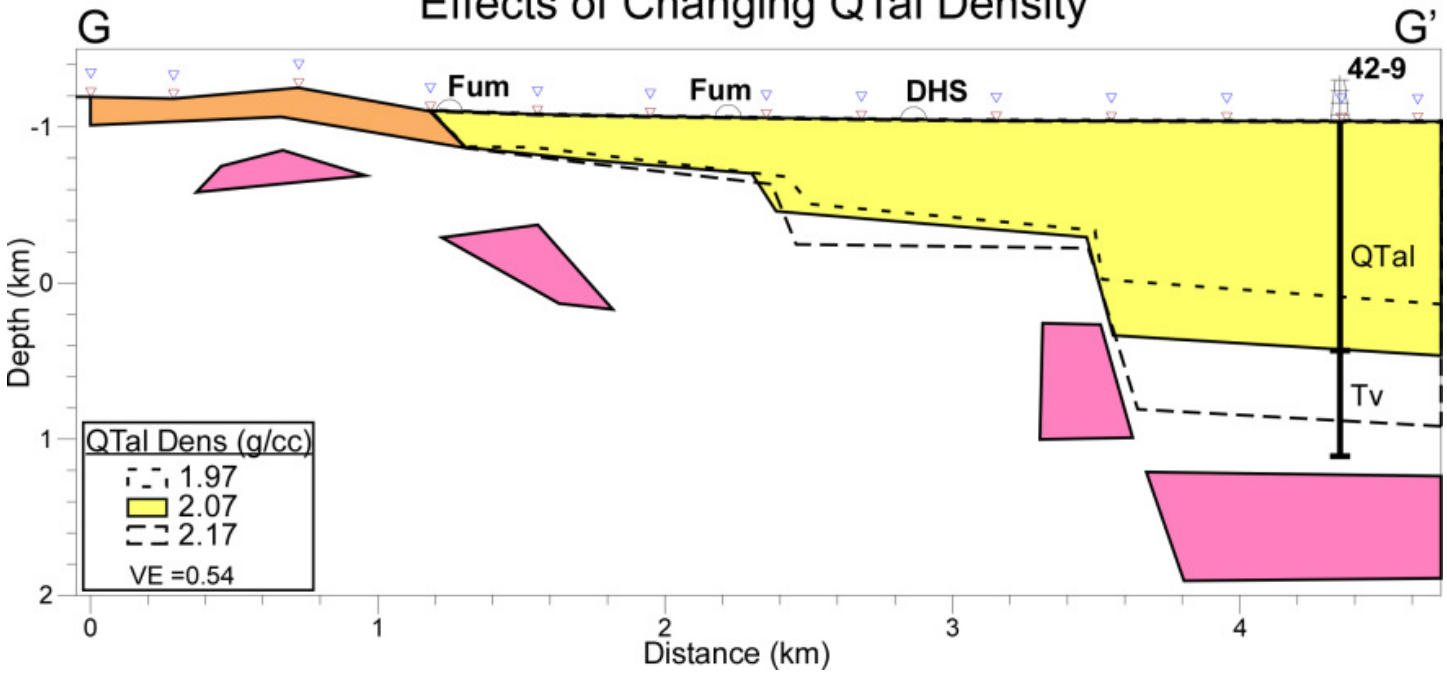
Model Unit	Density	Mag Sus	Symbol	Description
Background	2.35	0.000		Bouguer reduction density
Bedrock	2.67	0.000		Pre-Quaternary rocks
QTal	2.07	0.000		Quaternary/Tertiary alluvial and lacustrine basin fill
Tv	2.30	0.000		Exposed Tertiary volcanics*
Jv	2.67	0.007		Jurassic volcanics (Humboldt igneous complex)

* Exposed Tertiary volcanics, primarily constituting of late Oligocene tuffs, are porous/vesicular and relatively low density (2.3 g/cc) material; burial and overburden pressurization induces induration and pore closure that tends to increase the density of the tuffs to that of nominal bedrock at 2.67 g/cc (e.g., Tv encountered in 42-9).

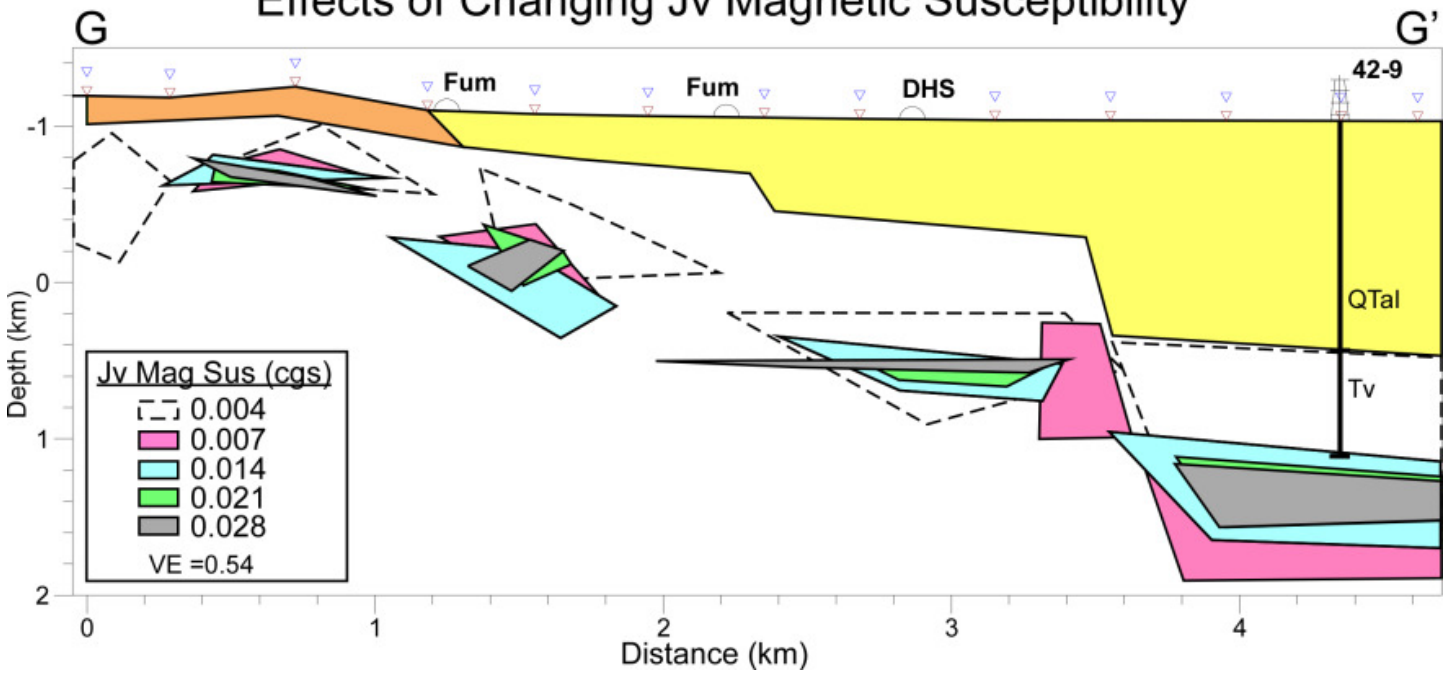


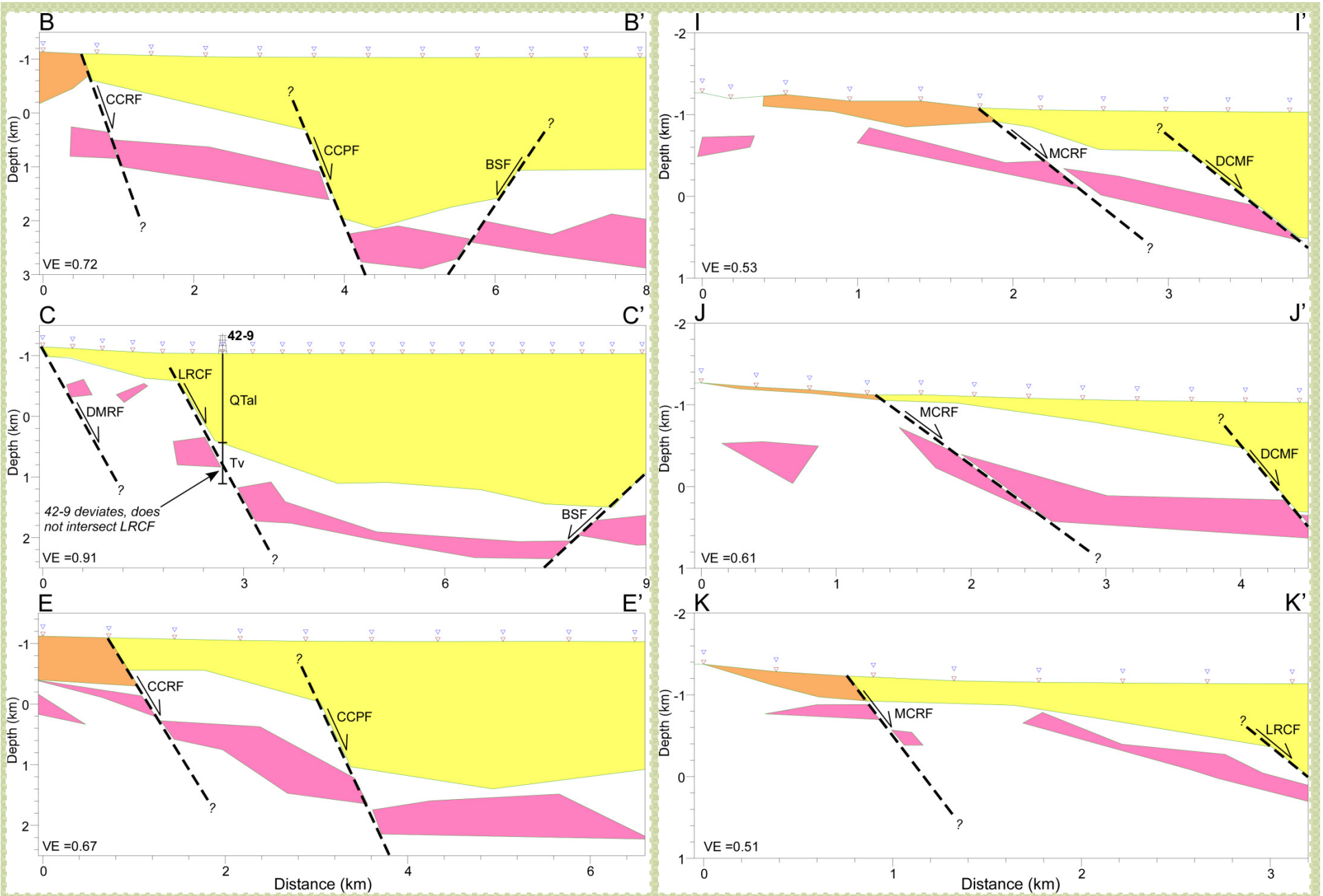

N
W
E
S
0 0.5 1
Kilometers
Legend
Joint Model Profile
Gravity Station
Qal
Tv
Jv
Mz
LRCM
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
H
H'
I
I'
J
J'
K
K'
L
L'
Hare Canyon
Canyon
Humboldt Salt Marsh
(DRY)
Buckbrush Spring

Effects of Changing QTal Density

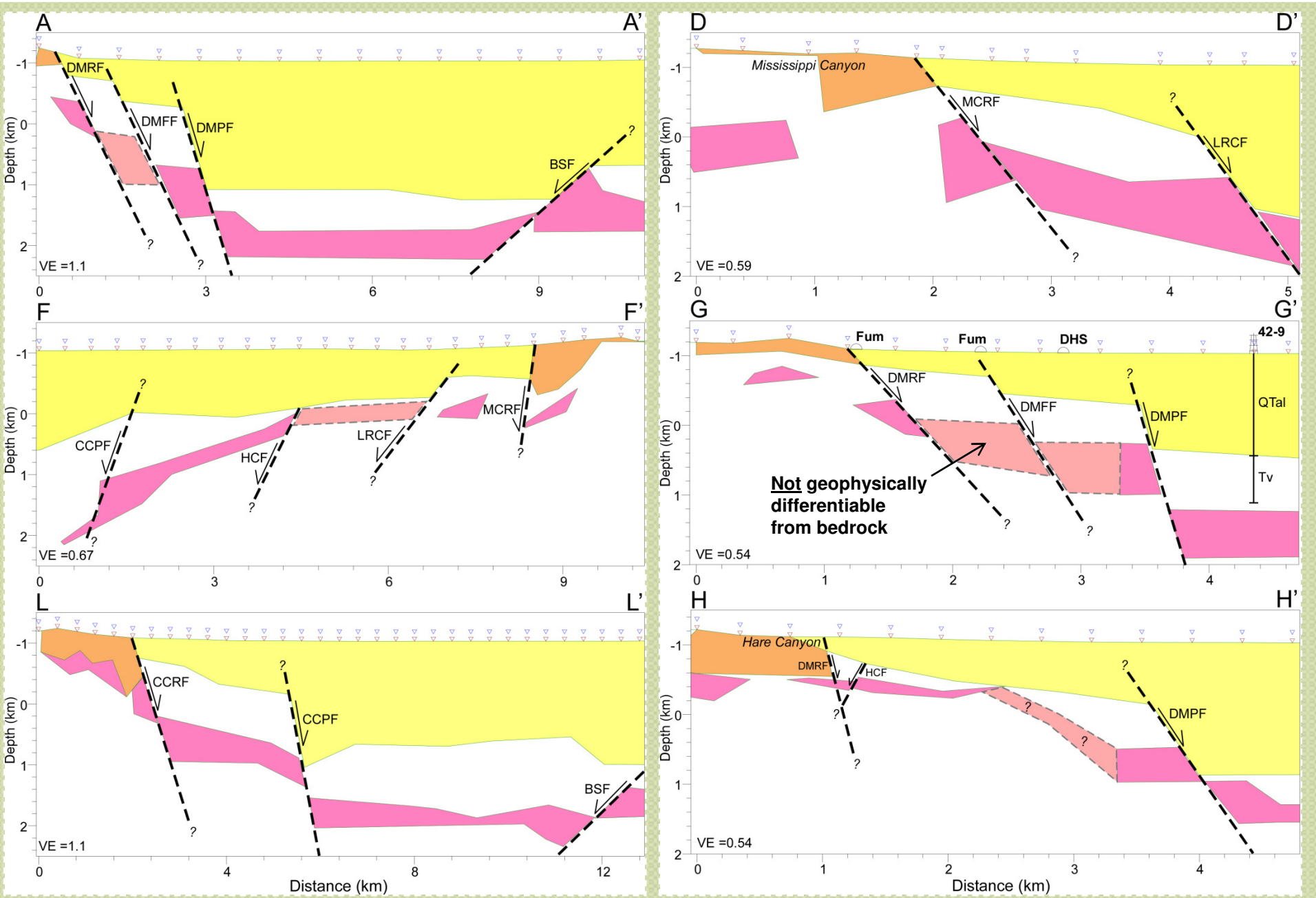


Effects of Changing Jv Magnetic Susceptibility

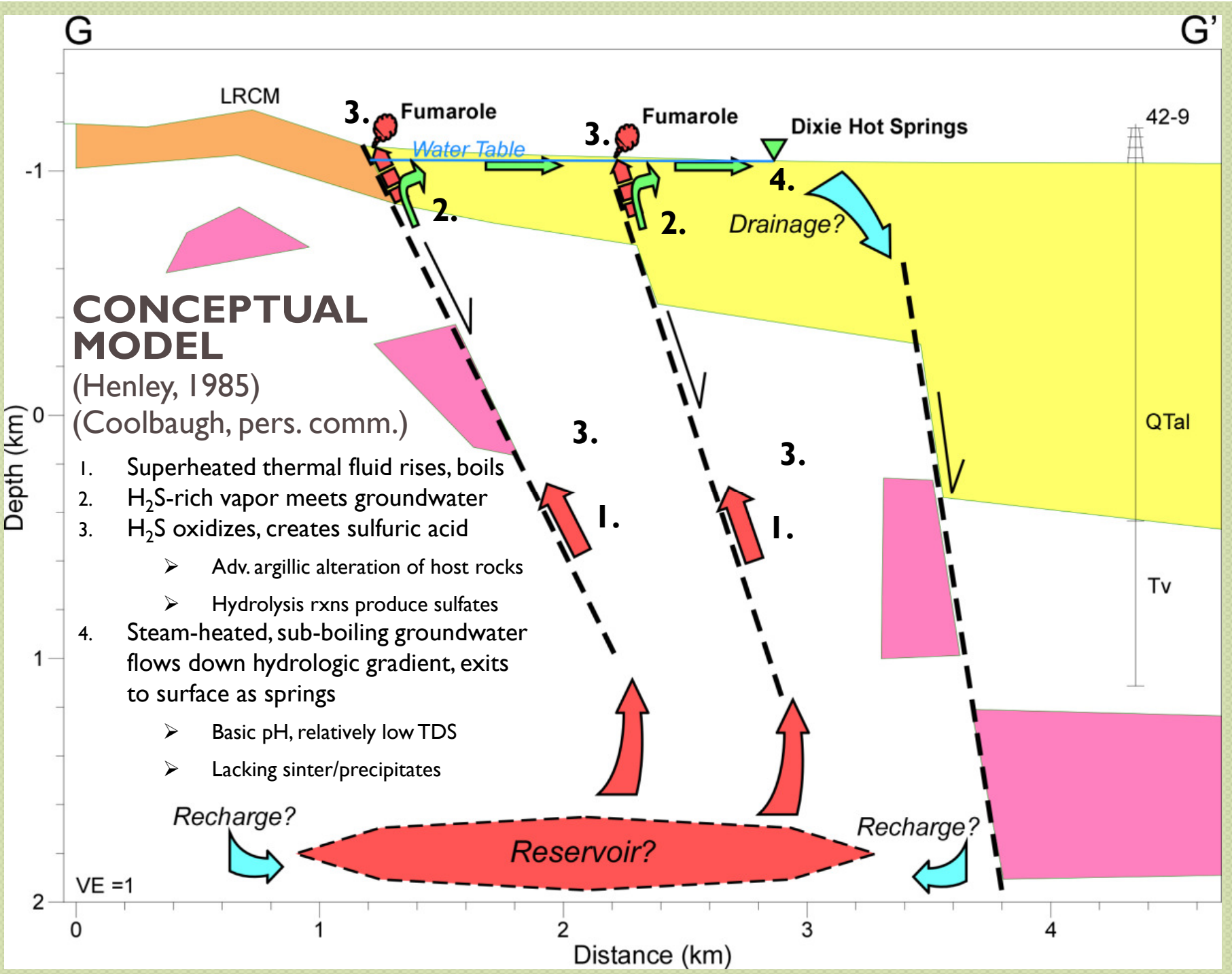




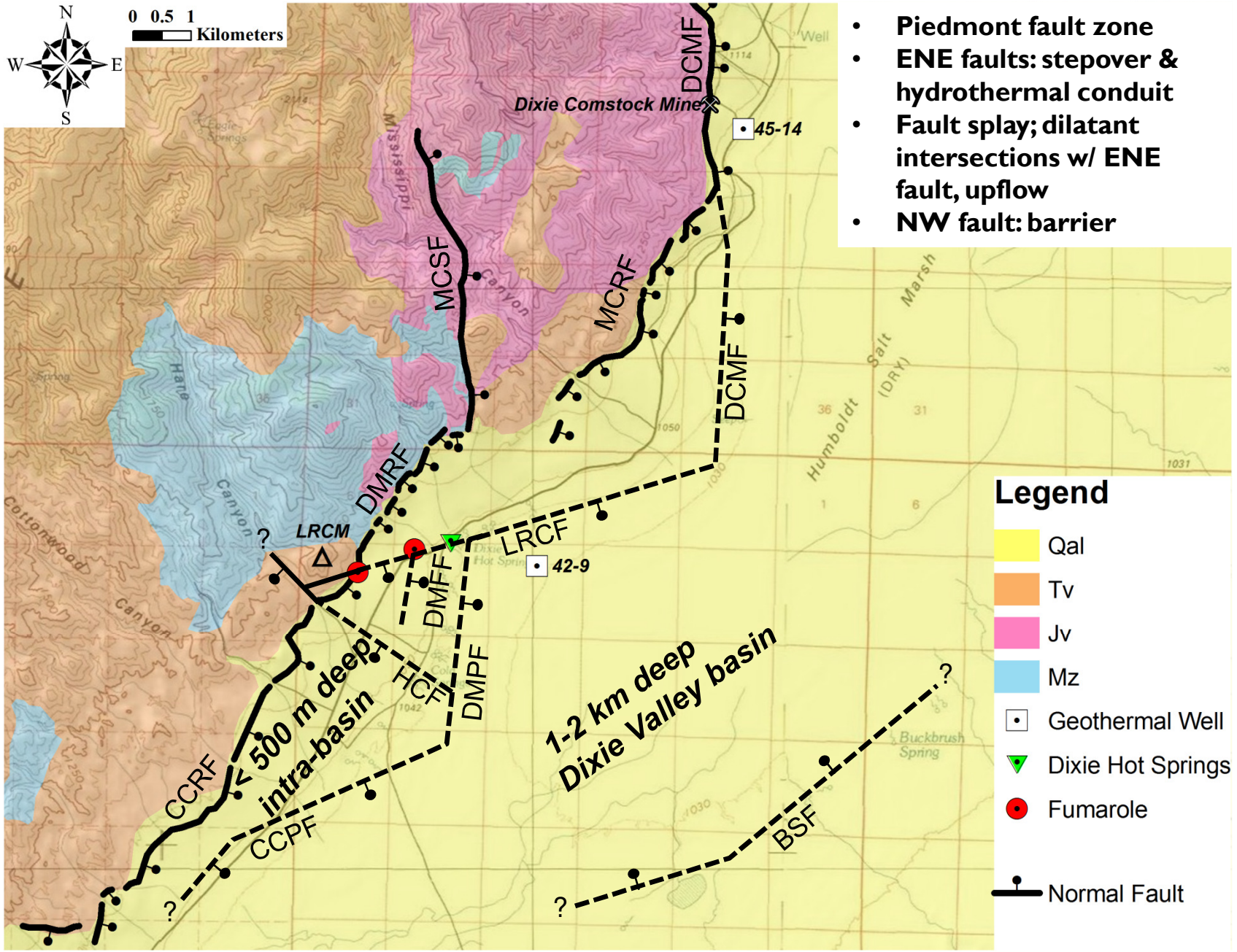
Model Cross-Sections



Hydrothermal Alteration?


G
G'
LRCM
3.
Fumarole
Water Table
3.
Fumarole
Dixie Hot Springs
42-9
4.
2.
2.
Drainage?
CONCEPTUAL MODEL
(Henley, 1985)
(Coolbaugh, pers. comm.)
1. Superheated thermal fluid rises, boils
2. H_2S-rich vapor meets groundwater
3. H_2S oxidizes, creates sulfuric acid
➢ Adv. argillic alteration of host rocks
➢ Hydrolysis rxns produce sulfates
4. Steam-heated, sub-boiling groundwater flows down hydrologic gradient, exits to surface as springs
➢ Basic pH, relatively low TDS
➢ Lacking sinter/precipitates
3.
3.
1.
1.
QTal
Tv
Recharge?
Reservoir?
Recharge?
VE =1
Depth (km)
-1
0
1
2
0
1
2
3
4
Distance (km)

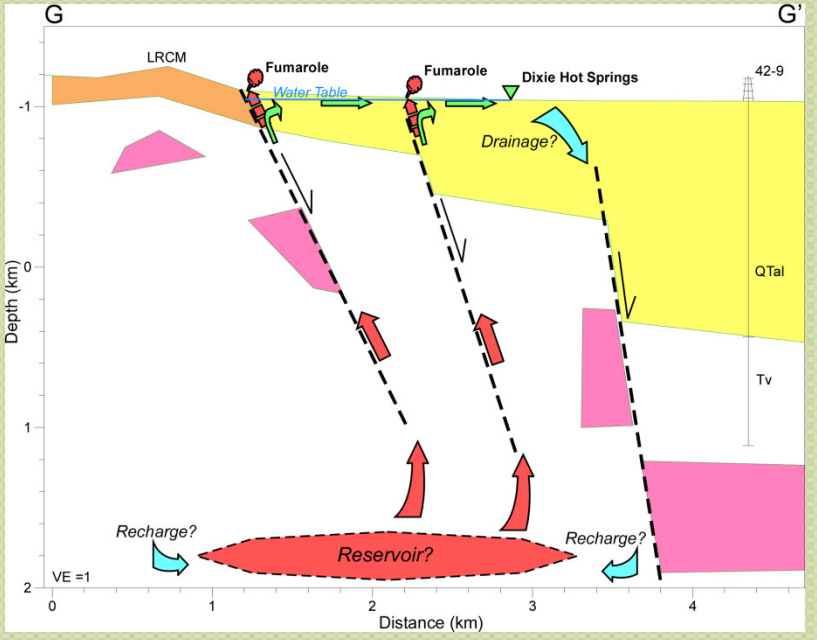
Structural Interpretation

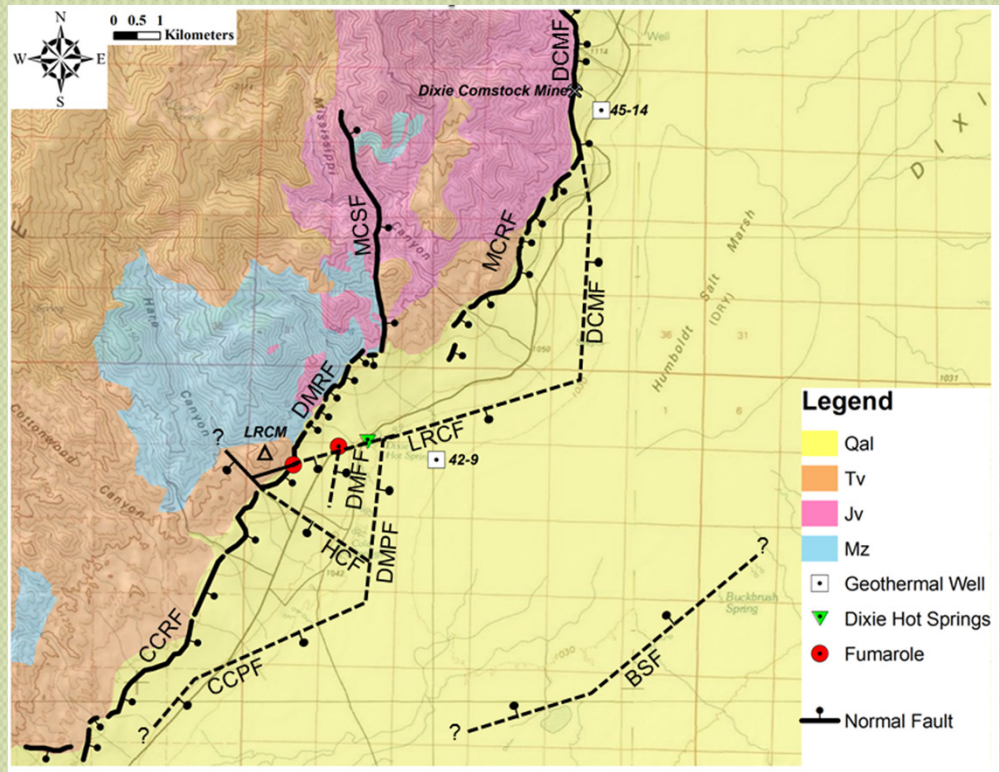


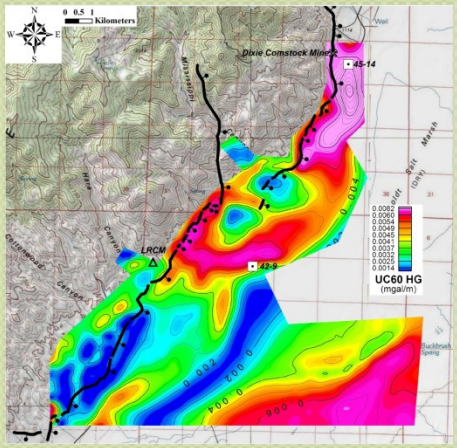
- **Piedmont fault zone**
- **ENE faults: stepover & hydrothermal conduit**
- **Fault splay; dilatant intersections w/ ENE fault, upflow**
- **NW fault: barrier**

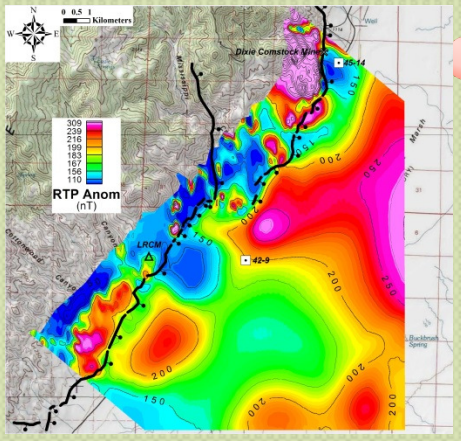
INFERRED CENOZOIC STRUCTURAL CONTROLS & CHRONOLOGY

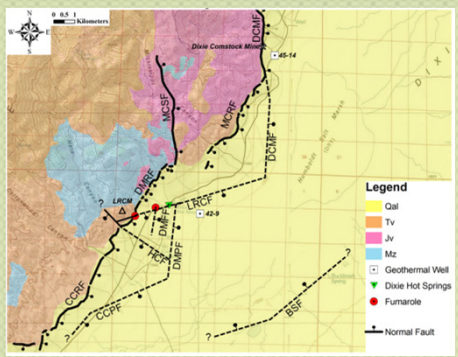
- Hydrothermal flow: intersecting faults
- Also fault splay and step-over kinematics
- ***Look for these patterns at relatively low magnetic anomalies in geothermal***
- Rangefront faults relatively young; piedmont faults former rangefront?
- WNW extension (Hammond and Thatcher, 2004; Thompson and Burke, 1973) initiated 8-10 Ma (Colgan et al., 2004; Fosdick and Colgan, 2008; Surpless et al., 2002); NNE-striking normal faults (Faulds et al., 2004)
- ENE-striking sinistral-normal faults developed contemporaneously in HSZ due to x-fer of dextral motion from WL (Faulds et al., 2004; Rowan & Wetlaufer, 1981)
- N-striking faults inherited from mid-late Miocene E-W extn (e.g., Fosdick and Colgan, 2008; Proffett Jr., 1977; Stockli, 1999; Surpless et al., 2002; Vikre, 1994; Waibel, 1987)
- NW-striking faults associated w/ late Oligocene to early Miocene dextral-normal faulting (e.g., Hudson & Geissman, 1991; John et al., 1989; Boden, 1986). Offset of New Pass tuffs indicates HCF developed ~25-23 Ma (Hudson & Geissman, 1991; John, pers comm)



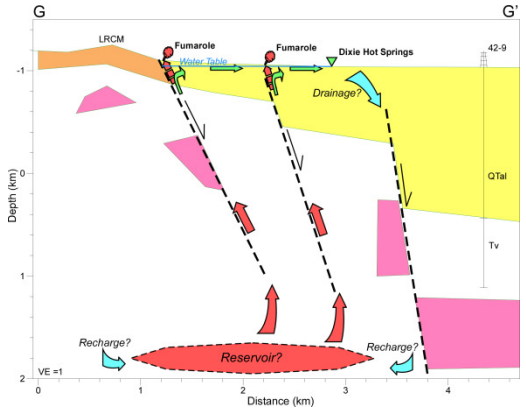




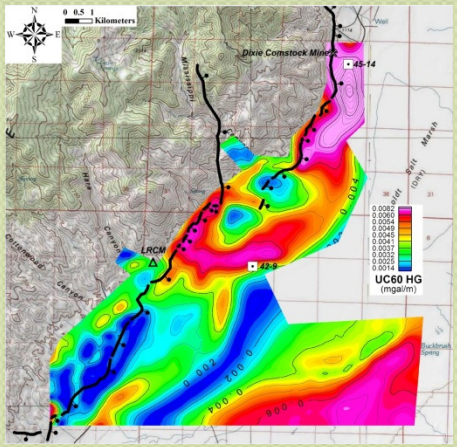


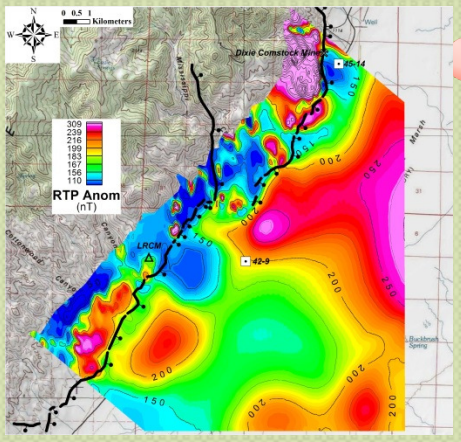


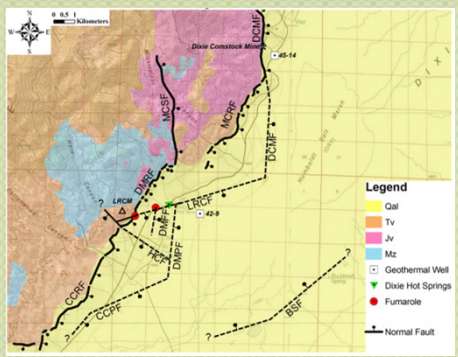
CONCLUSIONS



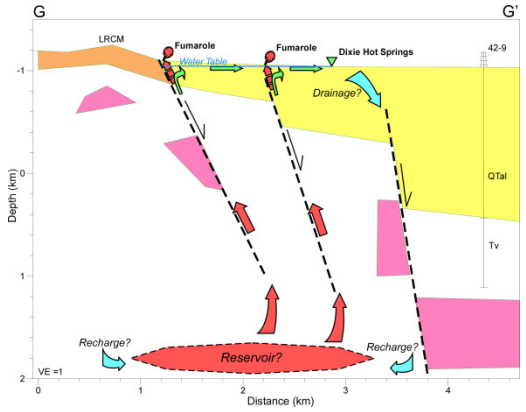
- Joint analysis of gravity and magnetic data enhances delineation of structural grain and exploration targets
- 2D joint gravity/magnetic model profiles:
  1. Delineate subsurface basin/fault structure
  2. Modeled with precision
  3. Oriented for semi-3D structural interpretation
- Dixie Meadows geothermal prospect:
  1. Piedmont fault zone separates basin from intra-basin
  2. Fault intersections are primary hydrothermal conduits
  3. Hydrothermal alteration of Jv? Upflow?
  4. Interpreted 3-phase Cenozoic structural history



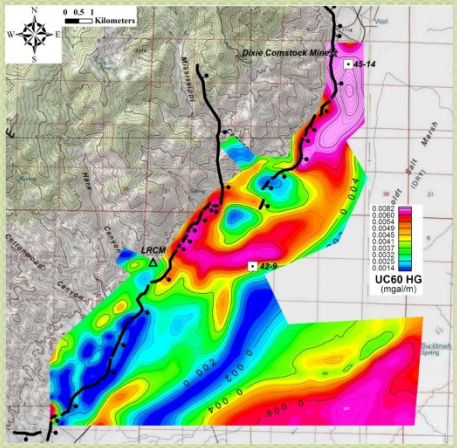


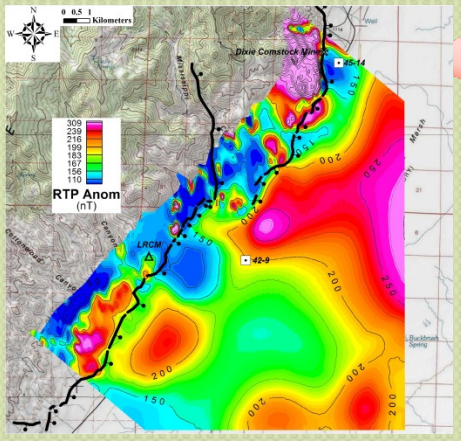


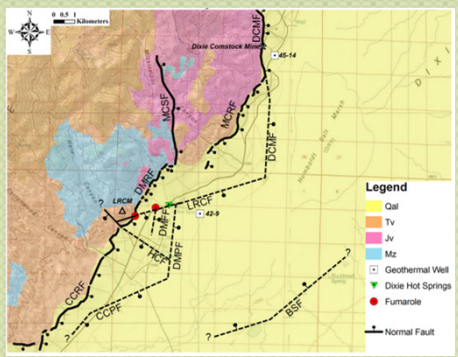
SUGGESTIONS



- Detailed geologic mapping (underway)
- Increase gravity & magnetic coverage into Stillwater Mountains, & in the basin
- Joint 3D modeling of gravity & magnetic data
- Integrate w/ 3D magnetotelluric data inversion to estimate reservoir location, volume, and fluid circulation
- Design seismic survey to image faults - accurately quantify location and dip of faults.
- ***Do the cheaper stuff before the expensive drilling!***

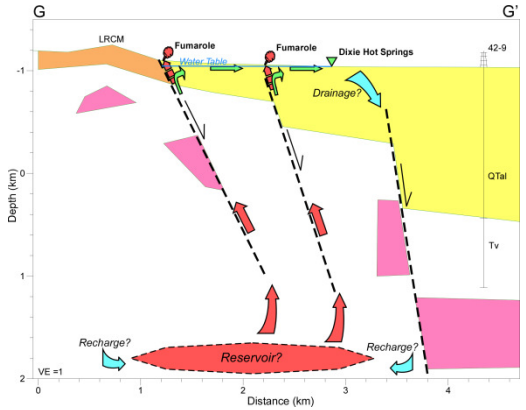






THANK YOU! QUESTIONS?

E-mail: p_schwering88@hotmail.com



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