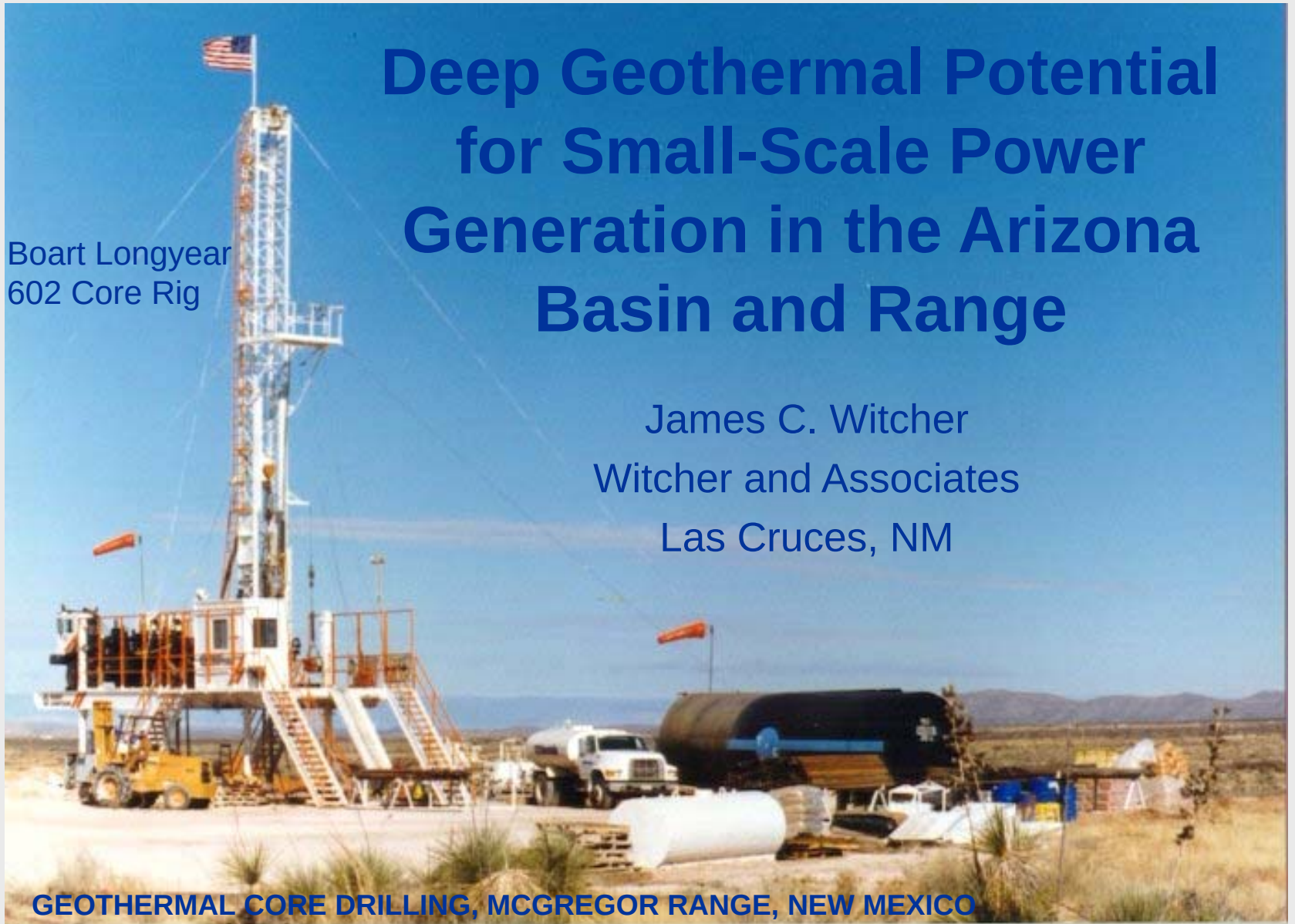


Deep Geothermal Potential for Small-Scale Power Generation in the Arizona Basin and Range

Boart Longyear
602 Core Rig

James C. Witcher
Witcher and Associates
Las Cruces, NM

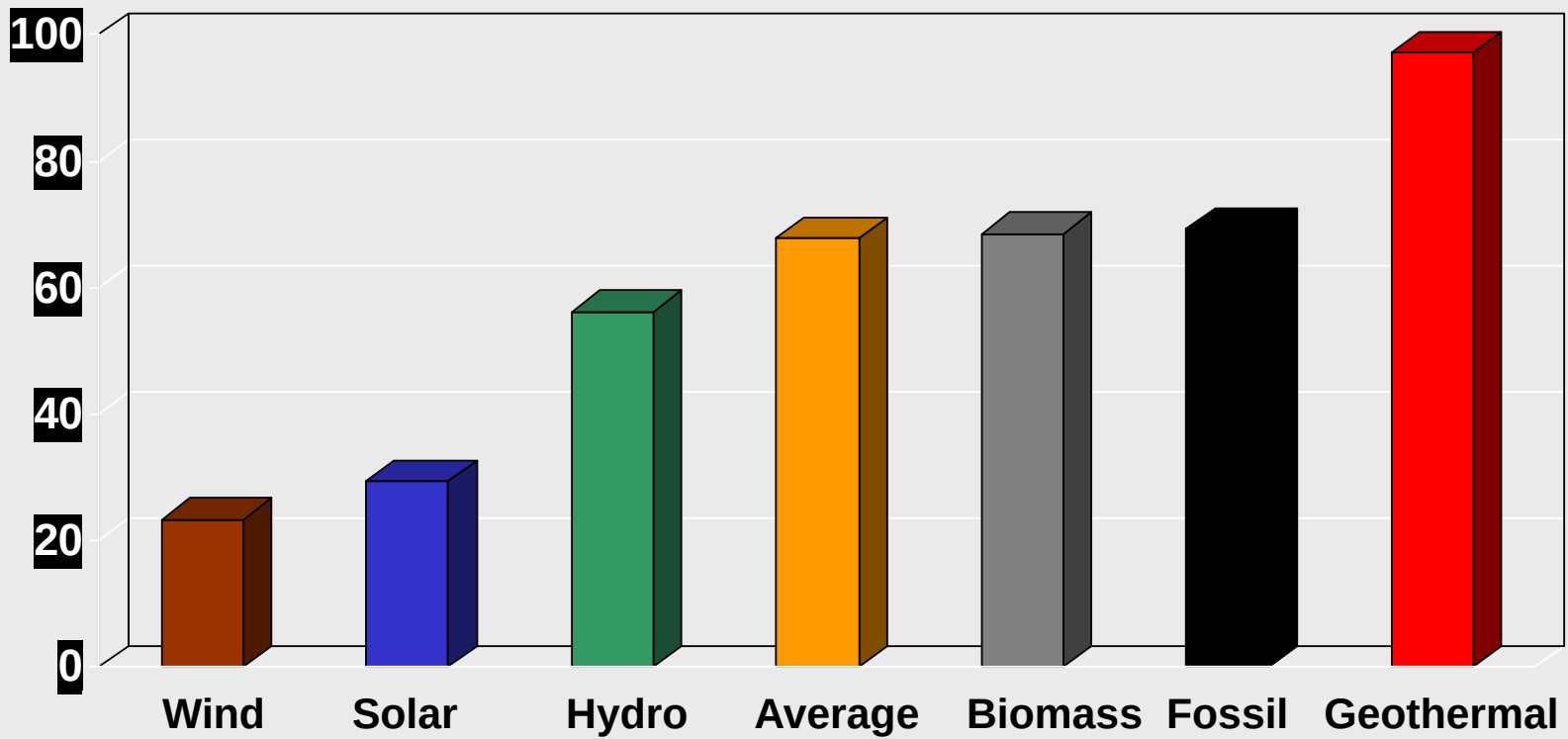
GEOHERMAL CORE DRILLING, MCGREGOR RANGE, NEW MEXICO



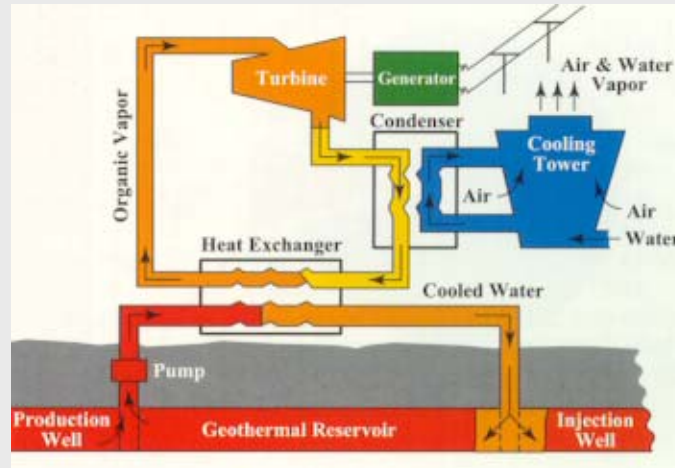
OVERVIEW

- **Geothermal binary power generation**
- **Convective geothermal vs Conductive geothermal**
- **Model - Raft River geothermal system, Idaho**
- **Highly extended Arizona terrain and heat flow**
- **Case study in Rio Grande rift at Albuquerque**
- **Economics**

CAPACITY FACTORS



BINARY-CYCLE POWER



USDOE



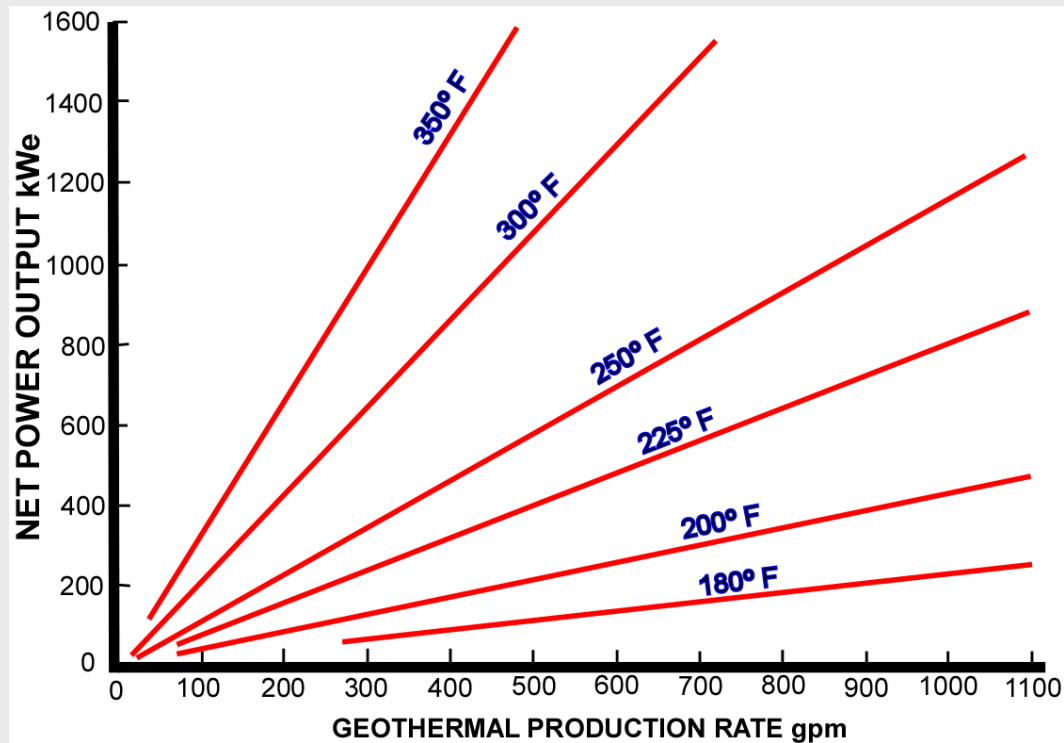
Soda Lake, Nevada, 26.1 MWe Binary Power Plant

Witcher



Witcher

TEMPERATURE AND PRODUCTION RATE REQUIREMENTS



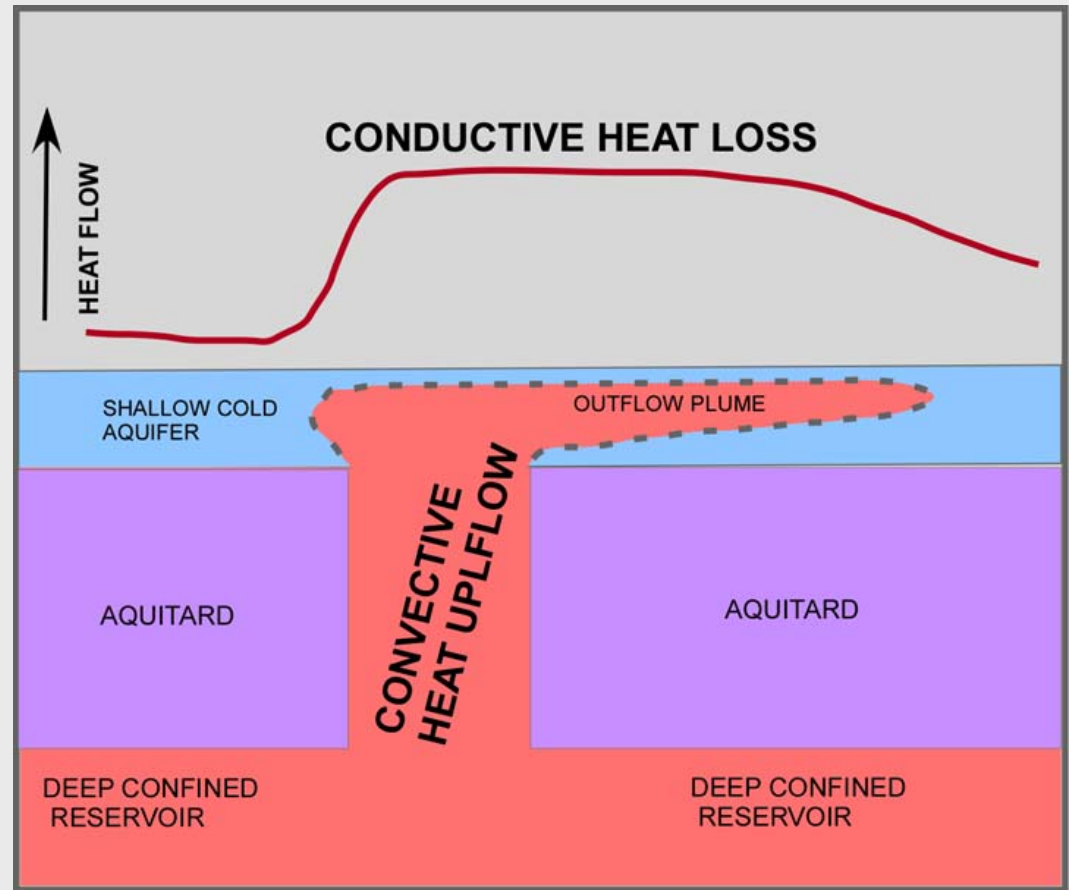
BarberNichols

COST OF BINARY POWER

- 190 to 360 °F
- 250 kWe to 10 MWe
- Hydrothermal Resource
 - Convective
 - Deep Conductive
- Water Cooled Condenser (water rights)
- Inefficiency in Arizona Summer
- **Levelized Cost (30-yr)**
\$0.06 to \$0.09 per kWh
- **Capital Cost**
\$3,500 to \$4,500 per kW
- **O&M**
\$0.02 to \$0.03 per kWh
- CEC P500-04-051 (4/2004)
- CEC 100-03-001F (6/2003)
- WGA Task Force (1/2006)
- USDOE Power Technologies Data Book
- GEA (various reports 2005-2006)
- Entingh and others (1994)
- NREL (various reports 1998-2001)

CONVECTIVE GEOTHERMAL SYSTEM

- $q_z = k(dT/dz)$
 - q_z conductive heat flow (mW/m^2)
 - k thermal conductivity ($W/m^{\circ}K$)
 - dT/dz temperature gradient ($^{\circ}C/km$)
 - $k = 1.8 W/m^{\circ}K$ basin fill
 - $k = 2.2 W/m^{\circ}K$ volcanics
- $Q = \downarrow q_z dA - \downarrow q_b dA$
 - Q total system heat loss
 - q_b regional heat flow (70 to $100 mW/m^2$)
 - dA area of integration (km^2)



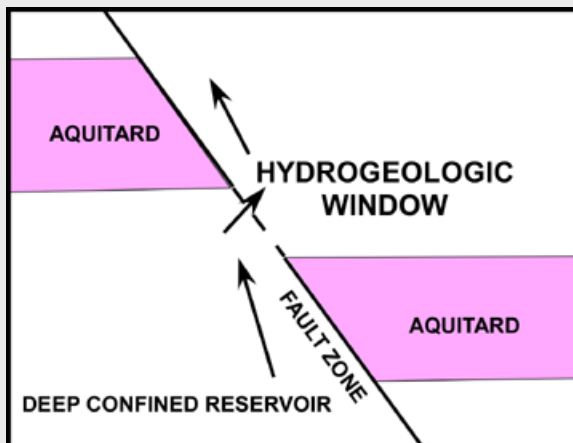
Assumptions:

- All heat is lost by conduction over top of outflow plume.
- Estimated thermal conductivity does not introduce excessive error.
- Borehole density is adequate to characterize system.

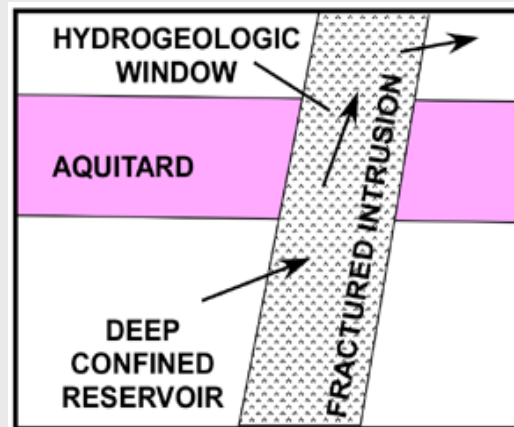
HYDROGEOLOGIC WINDOWS

- Structure highs.
- Provide rapid vertical flow past regional aquitards.
- Relatively low elevation.
- On or near regional drainage.
- Feed geothermal outflow plumes.

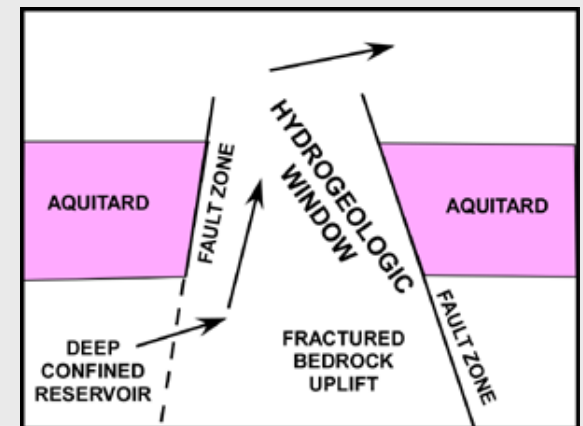
Rincon



Radium Springs

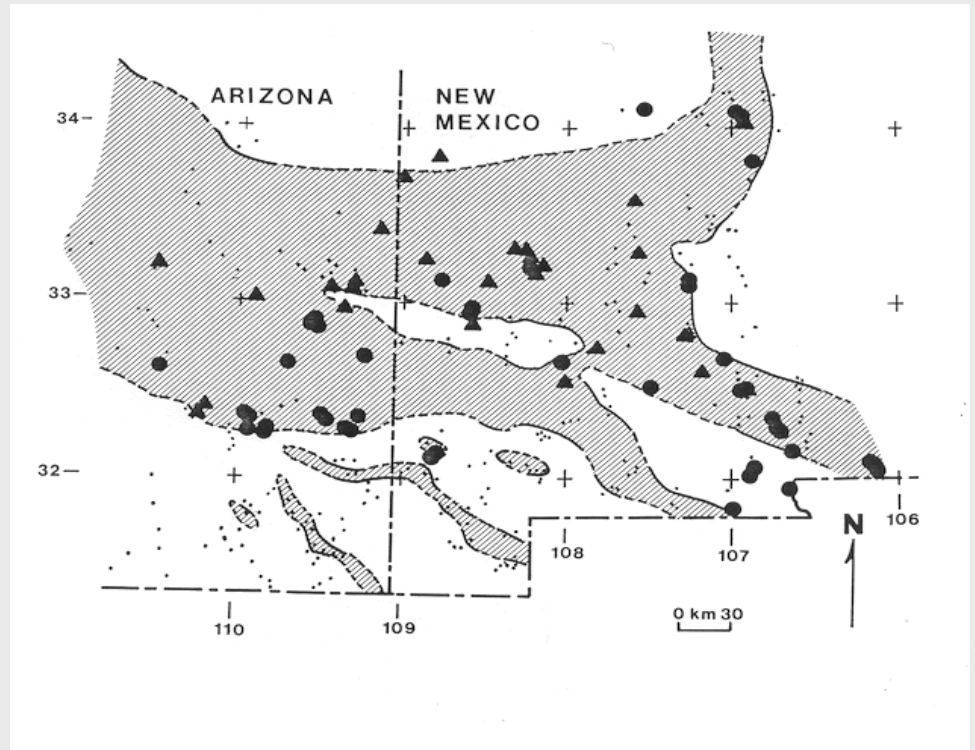
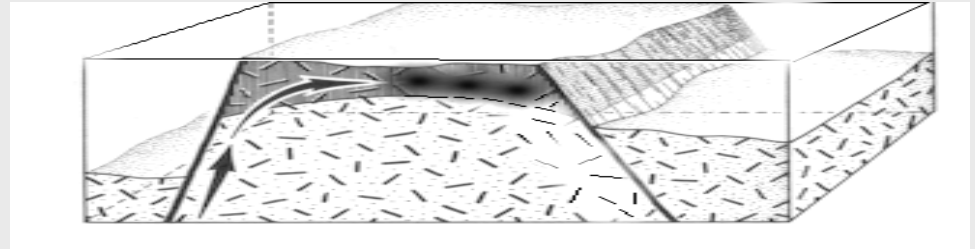


Las Cruces East Mesa



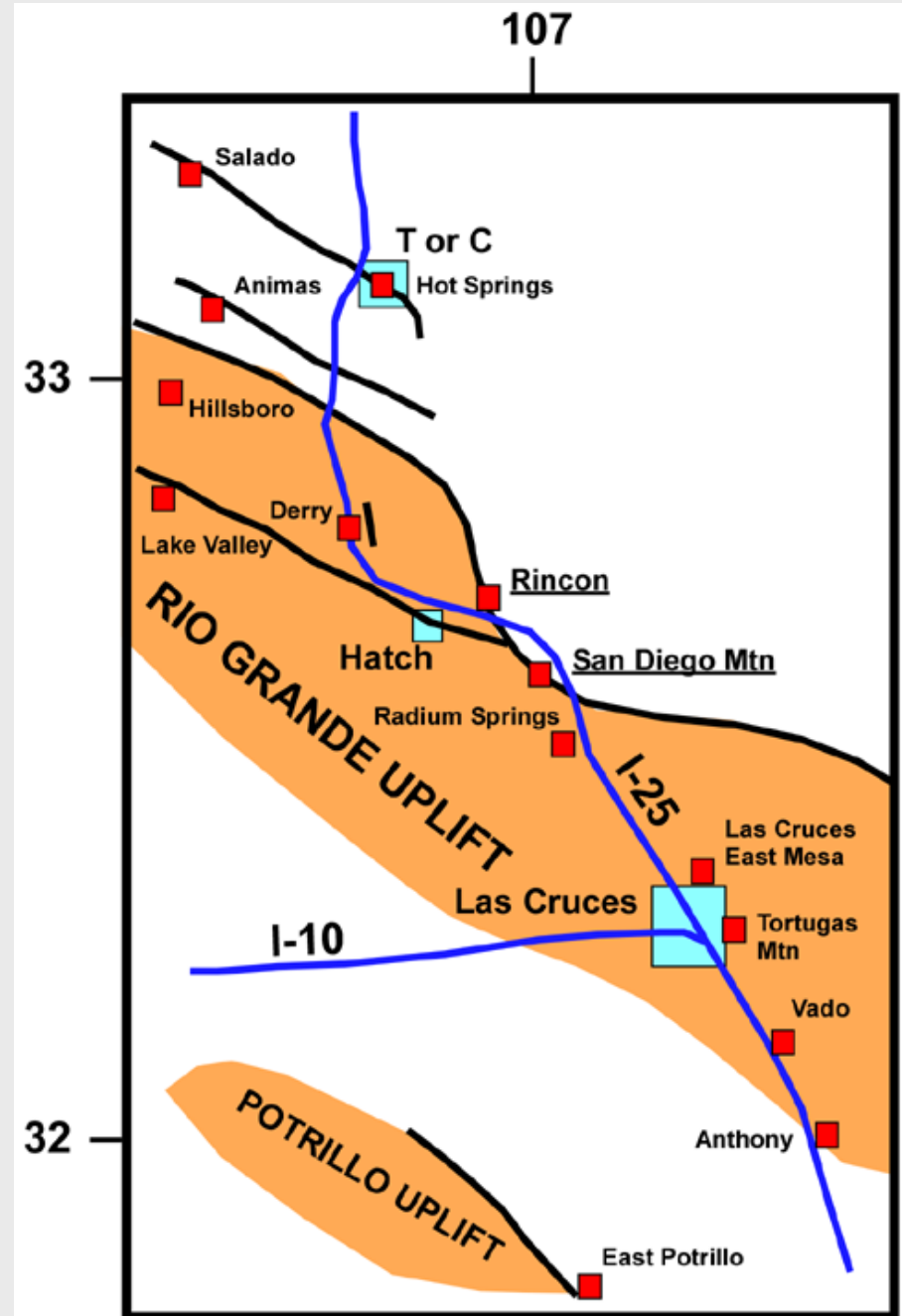
CONVECTIVE GEOTHERMAL RESOURCES

- CONVECTIVE UPFLOW OF HOT WATER ALONG STRUCTURES
- RESERVOIRS AT SHALLOW DEPTH



STRUCTURE CONTROL

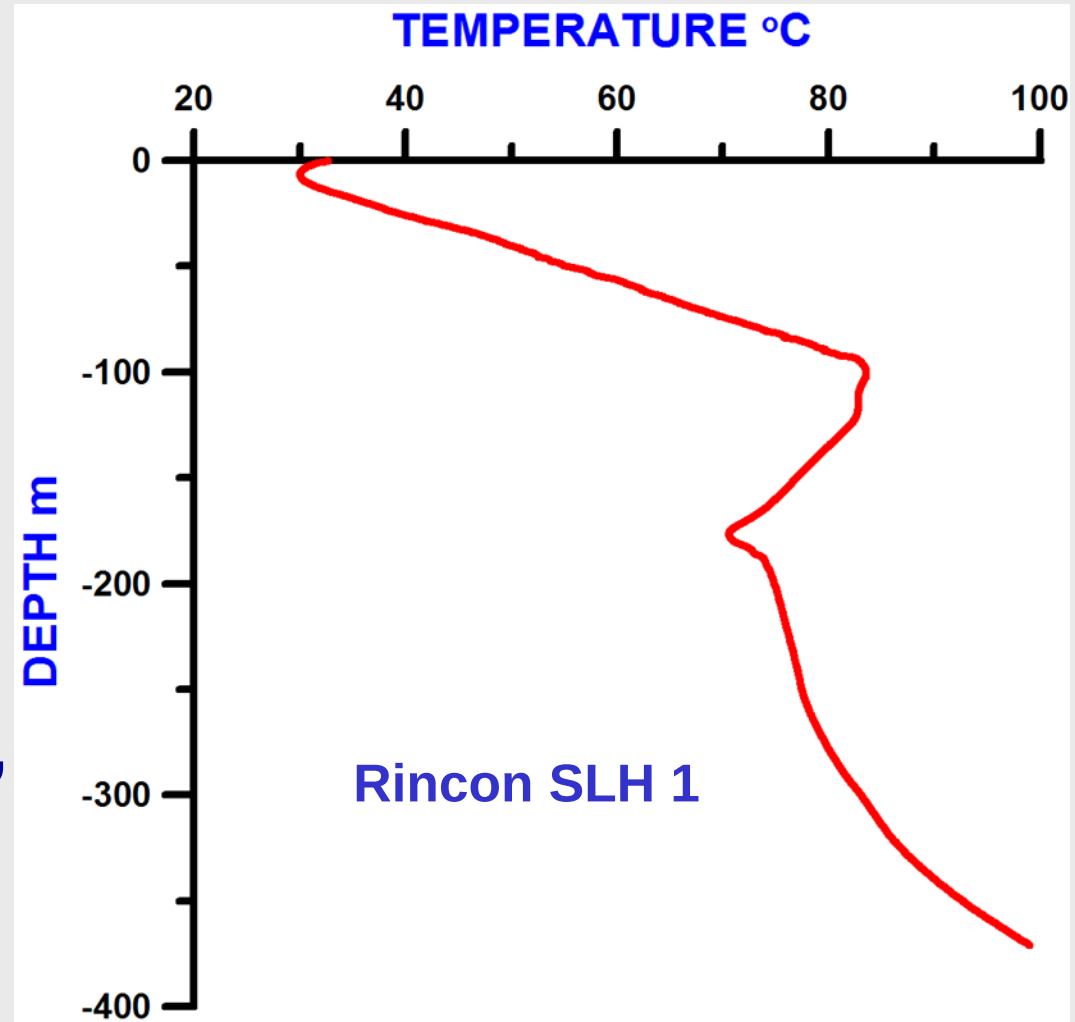
- Laramide uplifts.
- Rift horst blocks.
- Ring fracture zones of mid-Tertiary cauldrons.
- Pleistocene faults.
- Fault transfer zones.



Modified from Seager and Mack (2003)

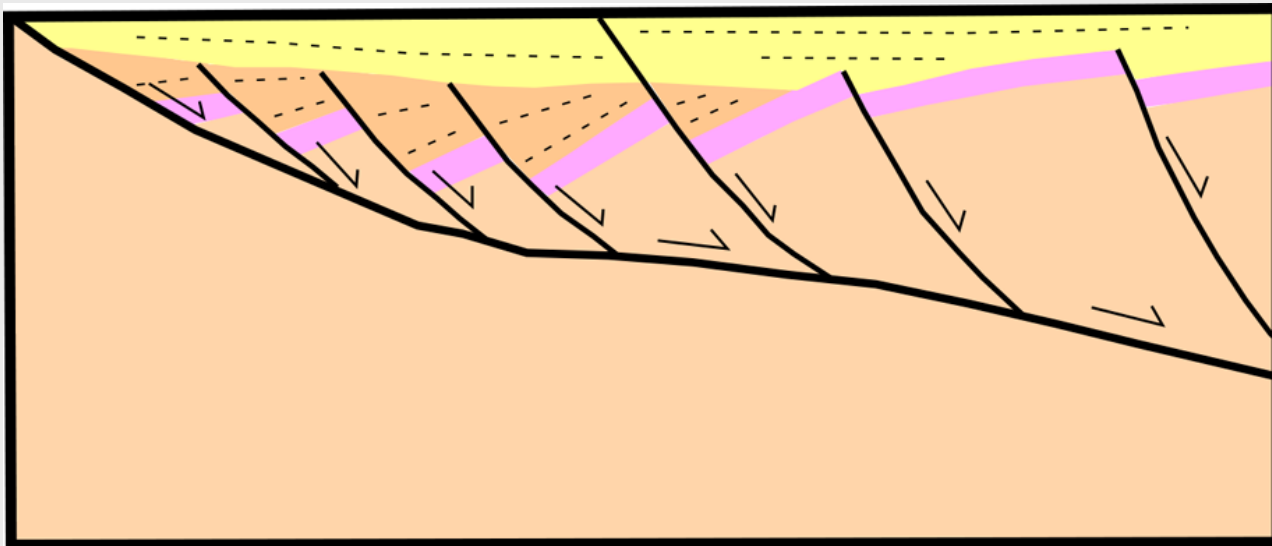
EXAMPLE OF CONVECTIVE GEOTHERMAL REGIME

- Annual temperature wave near surface
- Conductive gradient above water table or geothermal system
- Temperature “rollover” in outflow plume

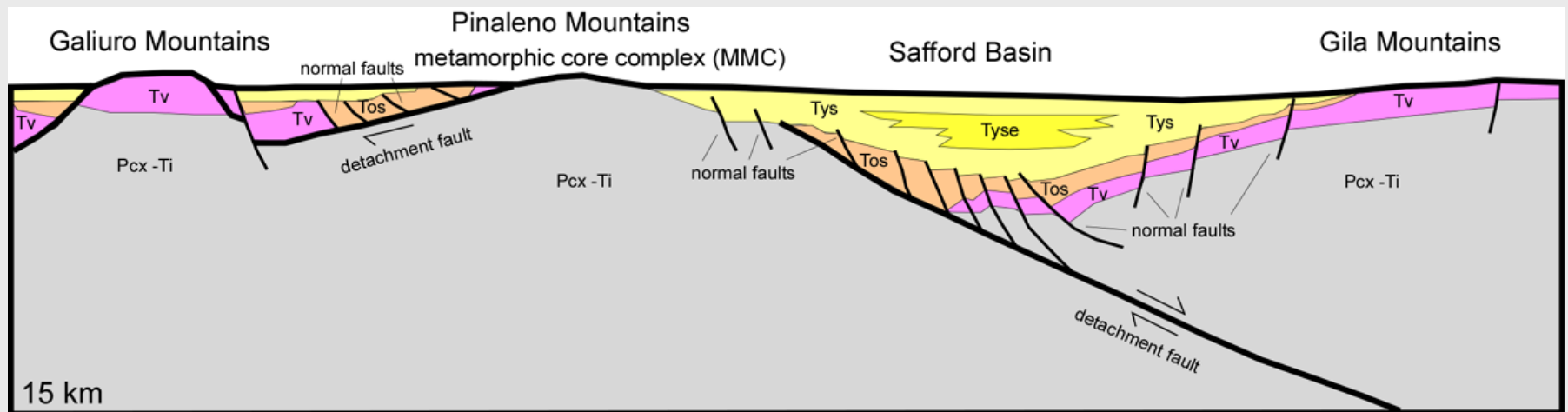


SCHEMATIC CROSS SECTION SHOWING GEOLOGIC MODEL OF RAFT RIVER GEOTHERMAL SYSTEM IDAHO

Fracture Permeability
in Rotated Fault Blocks Above
Detachment Fault



GENERALIZED CROSS SECTION OF THE SAFFORD BASIN AND PINALENO METAMORPHIC CORE COMPLEX

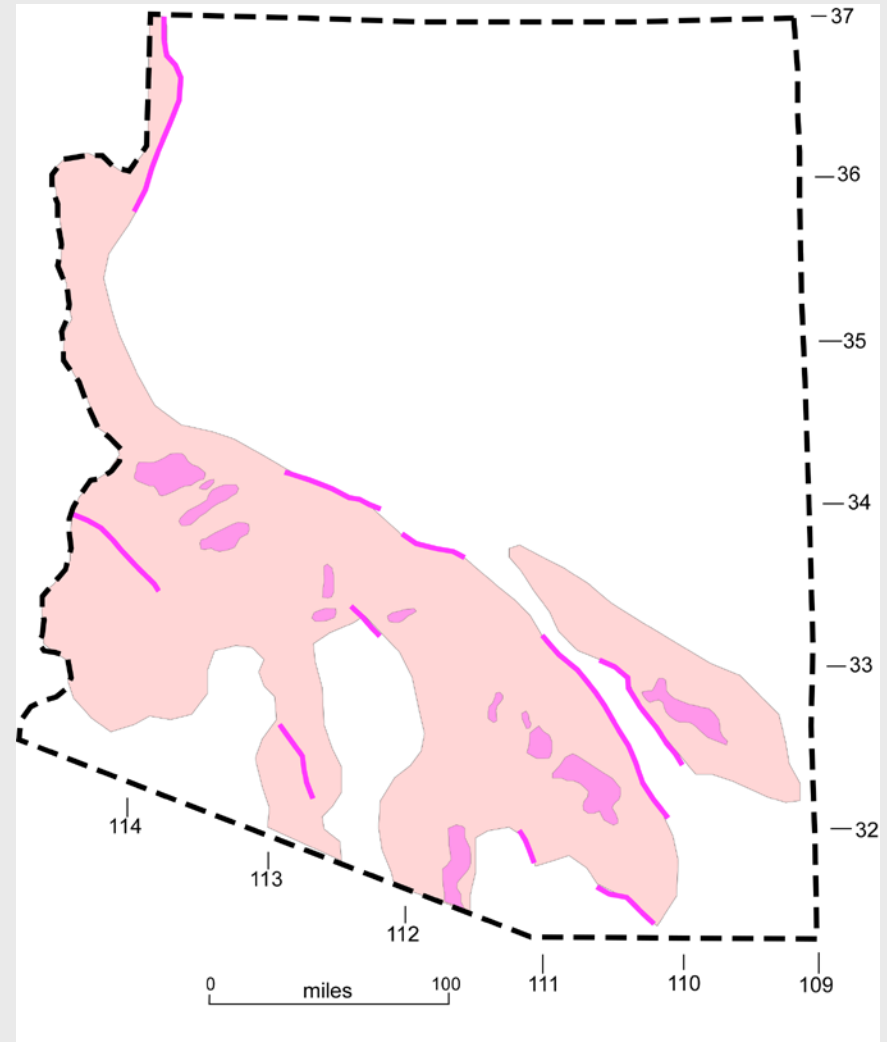


Modified from seismic interpretation of Kruger and Johnson (1994)

- Tys** - Miocene-Quaternary basin fill alluvial basin fill deposits.
- Tyse** - Miocene-Pliocene Tertiary evaporite deposits (inferred).
- Tos** - Oligocene-Miocene Tertiary alluvial basin fill deposits.
- Tv** - mid-Tertiary volcanics.
- Pcx-Ti** - Precambrian plutonic and metamorphic rocks and Laramide and mid-Tertiary plutonic intrusive rocks

HIGHLY EXTENDED STRUCTURAL DOMAINS IN ARIZONA

- light purple – highly extended regions with rotated mid-Tertiary volcanics and sediments
- dark purple – exposed metamorphic core complexes
- dark purple lines – possible break away faults for detachment extension



Modified from Spencer and Reynolds (1989)

GENERALIZED HEAT FLOW MAP OF ARIZONA

1) Geothermal Kinetics Power Ranches

2 wells, 9,081 and 9,131 ft,
244° F and 248° F

2) Exxon Humble 1 State 32

12,556 ft, 296° F

3) Funk Benevolent 1 Fee

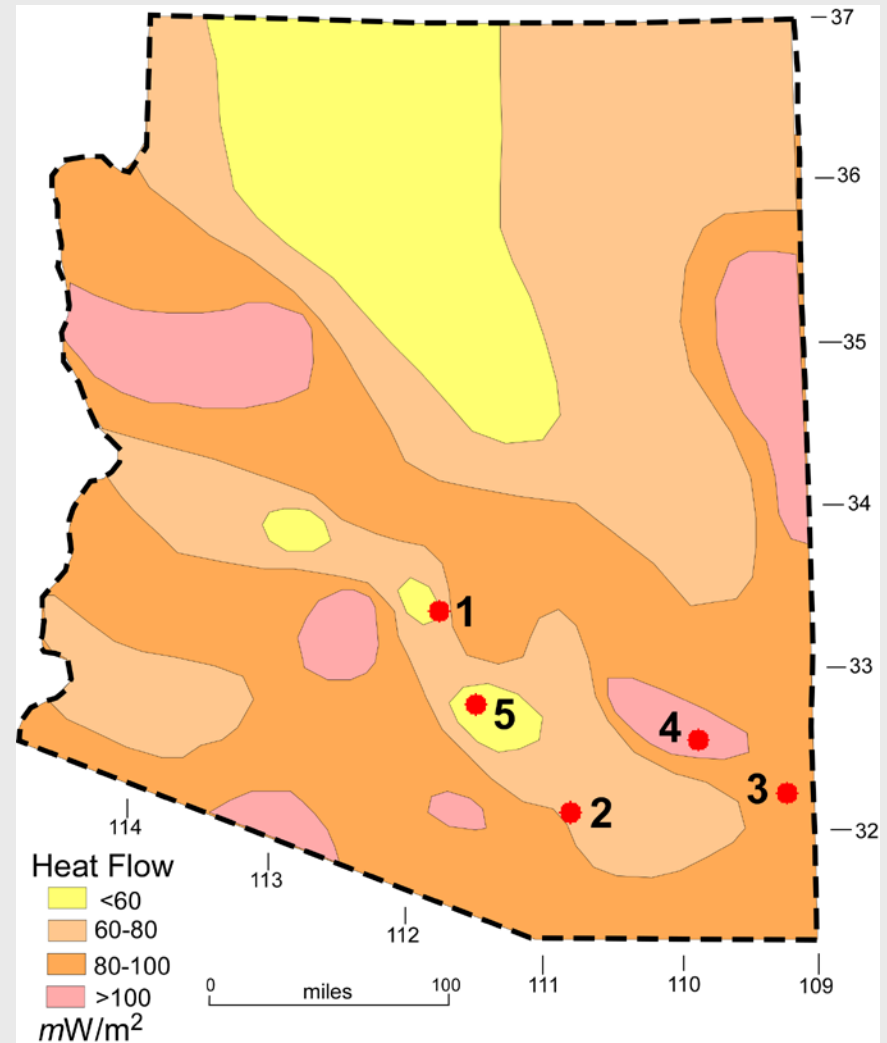
6,667 ft, 273° F

4) Waddel Duncan McCombs 1

6,686 ft, 196° F

5) Geothermal Kinetics – AMAX 1 Pima Farms

8,025 ft, 180° F



Modified from Sass and others (1994)

SUMMARY MAP

1) Geothermal Kinetics Power

Ranches

2 wells, 9,081 and 9,131 ft,
244° F and 248° F

2) Exxon Humble 1 State 32

12,556 ft, 296° F

3) Funk Benevolent 1 Fee

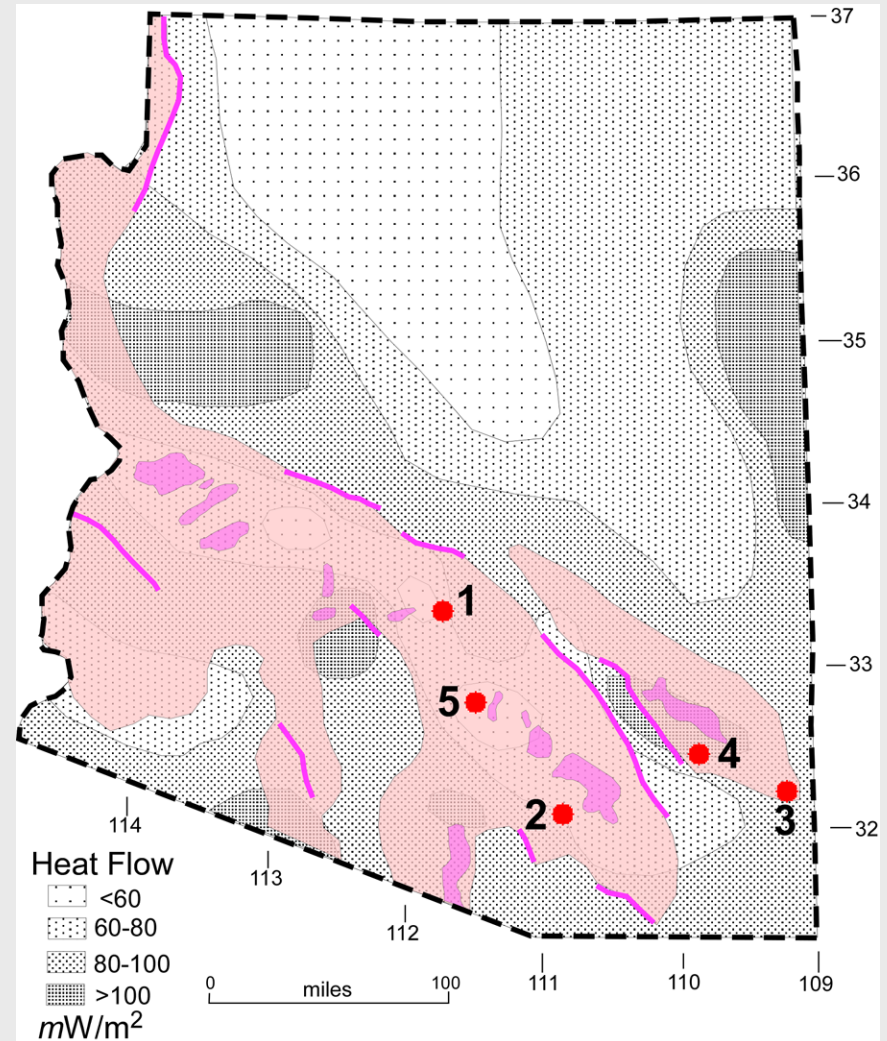
6,667 ft, 273° F

4) Waddel Duncan McCombs 1

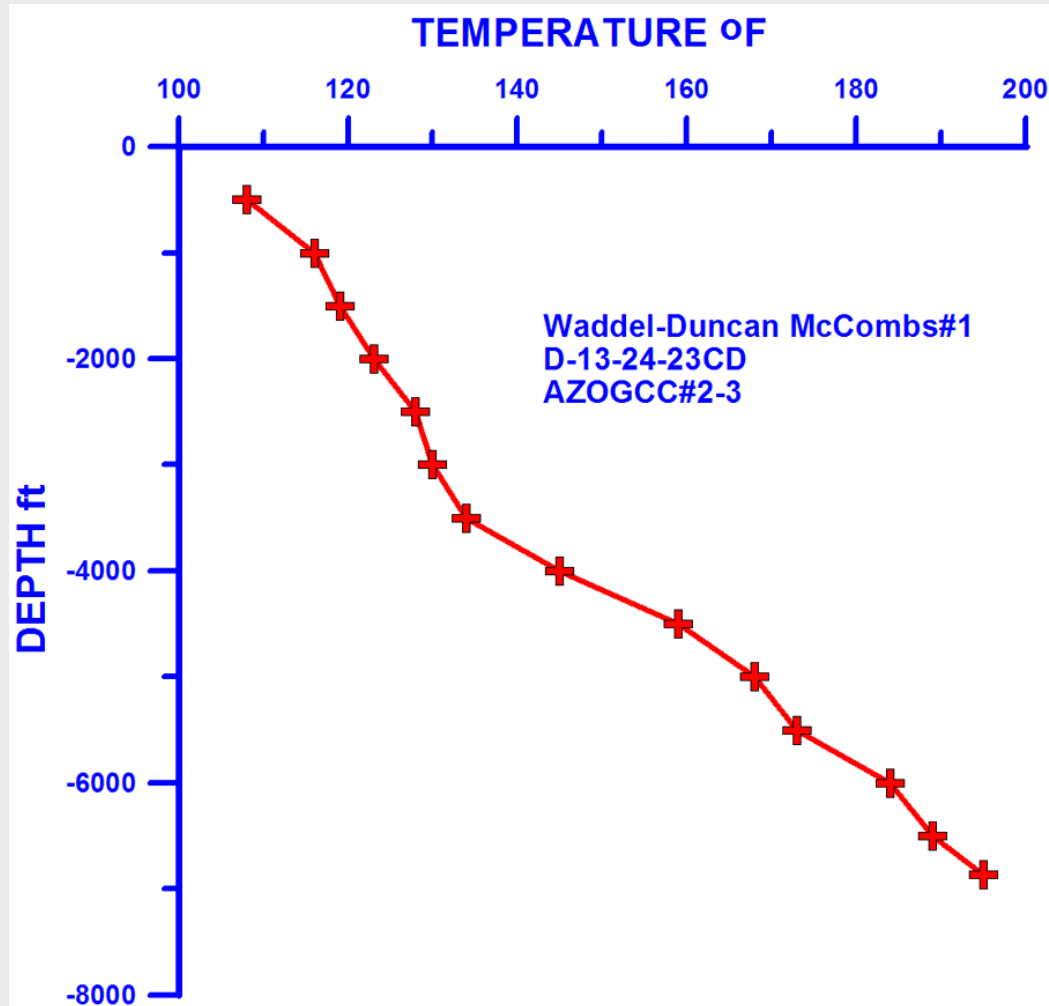
6,686 ft, 196° F

5) Geothermal Kinetics – AMAX 1 Pima Farms

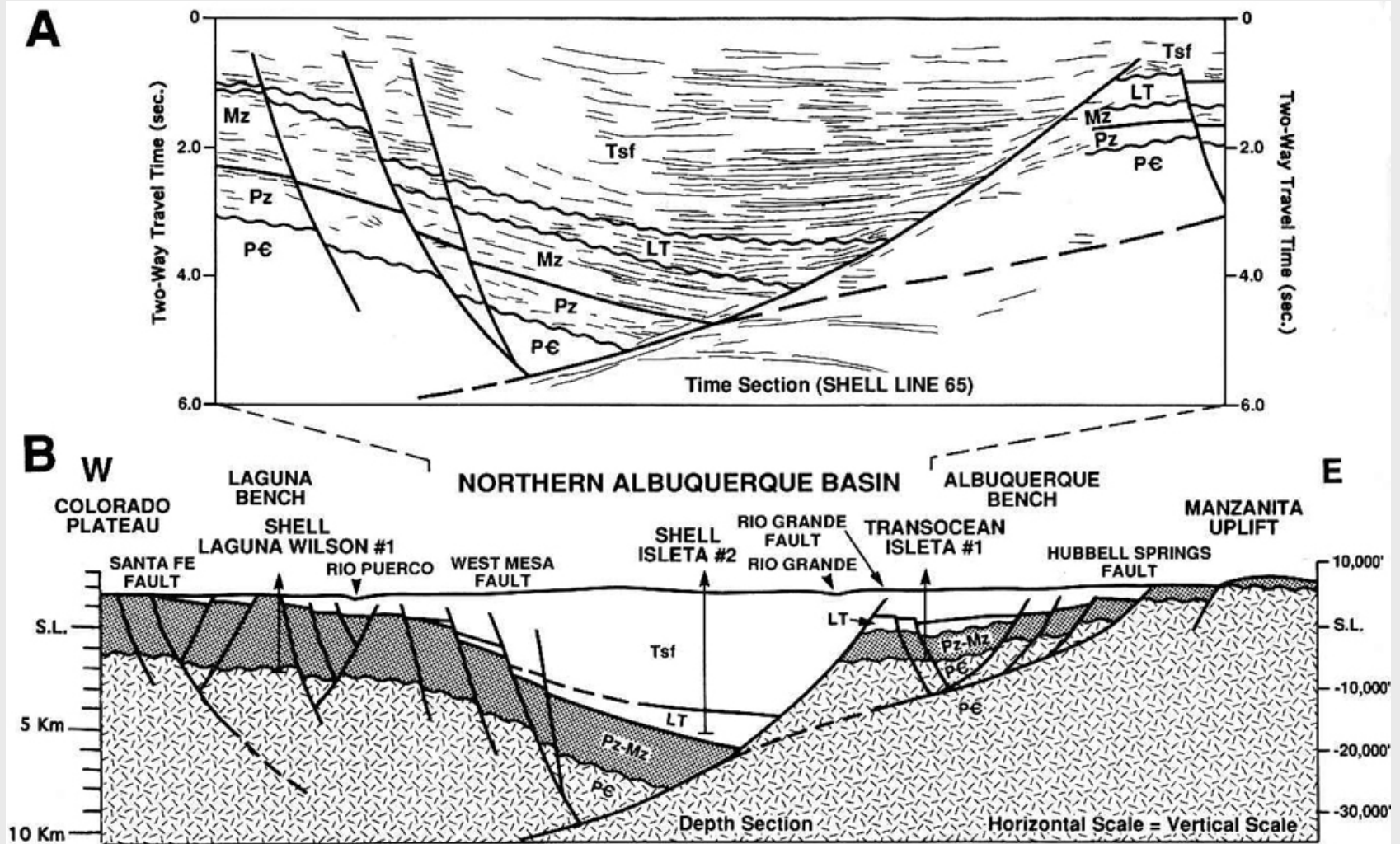
8,025 ft, 180° F



EXAMPLE OF CONDUCTIVE GEOTHERMAL REGIME

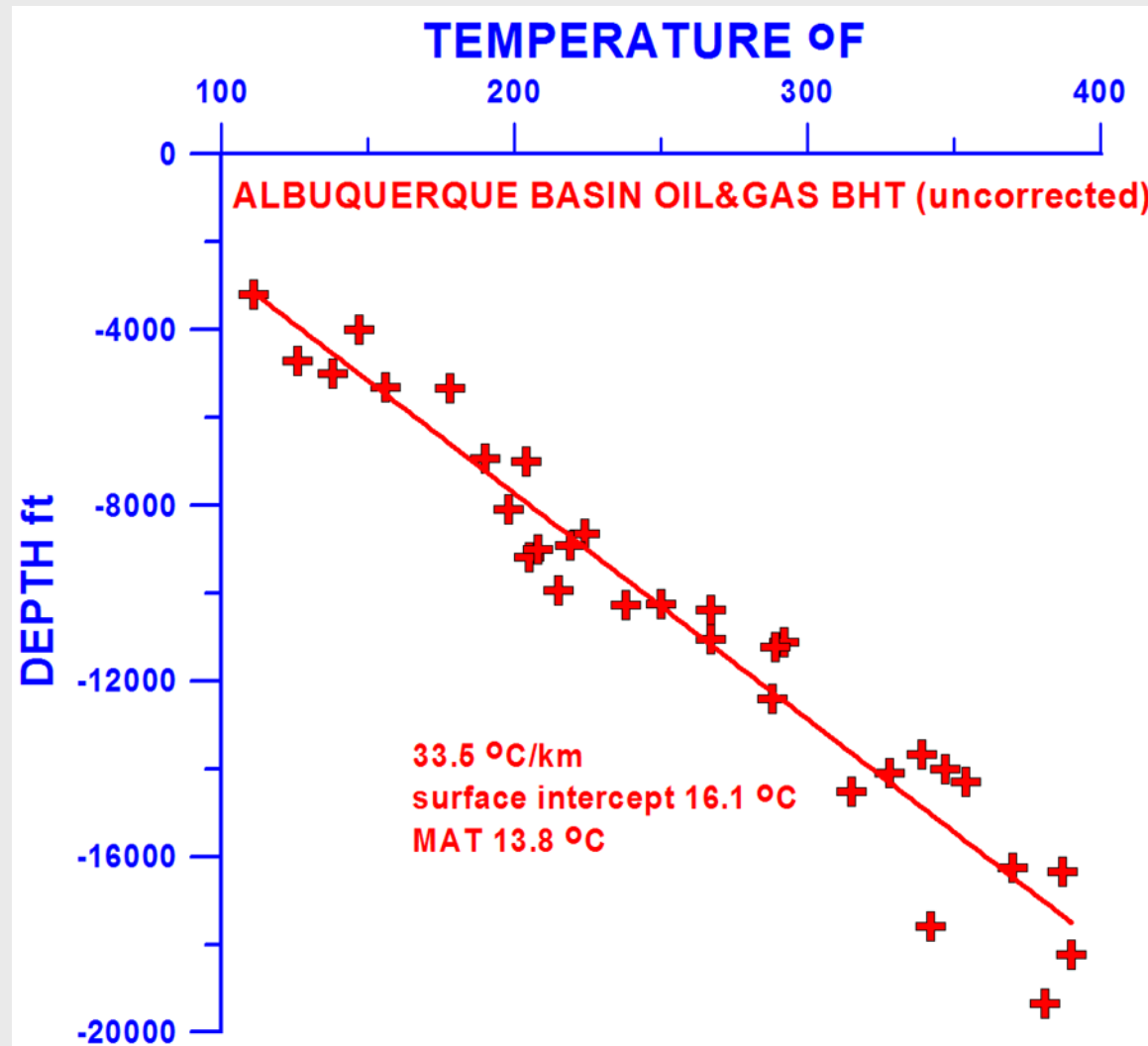


GENERALIZED GEOLOGIC CROSS SECTION BENEATH MESA DEL SOL



GEOPHYSICAL LOG

BOTTOM HOLE TEMPERATURES



STRATIGRAPHY MESA DEL SOL

ALBUQUERQUE BASIN (East-West) I-40 on north/south boundary Isleta Pueblo on south)			
MESA DEL SOL AREA			
AGE	UNIT	THICKNESS ft	NOTES
Tertiary	Sante Fe Group	5,050	reservoir potential not evaluated/TransOcean Isleta #1/Lozinski (1994)
Tertiary	Galisteo Fm	2,900	reservoir potential not evaluated/TransOcean Isleta #1/Black (1982)
Cretaceous	Menefee Fm	1,100	thickness preserved below Tertiary unconformity (Black, 1982)/aquitard
Cretaceous	Crevasse Canyon	200	possible reservoir in Dalton SS/same properties as Point Lookout?
Cretaceous	Mancos Fm	900	important aquitard, thickness xsection (Black 1982)
Cretaceous	Dakota SS	200	reservoir
Jurassic	Morrison Fm	350	total thickness preserved below Cretaceous unconformity (Black, 1982)
	Brushy Basin Mbr	100	aquitard
	Salt Wash Mbr	250	reservoir
Jurassic	Summerville Fm	150	aquitard
Jurassic	Todilto Fm	100	aquitard
Jurassic	Entrada SS	100	reservoir
Triassic	Chinle Grp	1,600	total thickness
	Petrified Forest Fm	1,300	includes other Chinle Group formations/important aquitard
	Aqua Zarca Fm	300	reservoir
Permian	San Andres Fm	300	total thickness preserved below Triassic unconformity (Black, 1982)
	San Andres Mbr	150	reservoir
	Glorieta Mbr	150	reservoir
	Yeso	500	total thickness
	San Ysidro Mbr	400	aquitard
	Meseta Blanca Mbr	100	reservoir
Permian	Abo	650	aquitard
Pennsylvanian	Madera Grp	850	total thickness/total thickness in Sandia and Manzano about 1350 ft
	Bursum Fm	100	aquitard
	Wild Cow Fm	450	reservoir(s)(?) and aquitards (unit about 800 ft in Sandia and Manzano)
	Los Moyos Fm	300	reservoir (unit about 450 ft in Sandia and Manzano Mtns)
Pennsylvanian	Sandia Fm	30	aquitard (unit is 50 to 300 ft thick in Sanda and Manzano Mtns)
Mississippian	Arroyo Penasco Fm	<50	possible reservoir (probably not be present)
TOTAL		14,980	top Precambrian

SUBSURFACE TEMPERATURE ESTIMATES BENEATH MESA DEL SOL

RESERVOIR TEMPS		MESA DEL SOL								
Mean Annual Temp	13.8	°C								
Background Heat Flow	85	mW/m ²								
Formation	Thickness ft	Thickness m	Depth ft	est Tcond W/m ² K	Tgrad °C/km	δT °C	δT + MAT °C	δT + MAT °F	BHT model uncorr °C	BHT model uncorr °F
Upper Santa Fe	2,500	762.0	2,500	2.00	42.5	32.4	46.2	115.1	39.3	102.8
Lower Santa Fe	2,550	777.2	5,050	2.20	38.6	30.0	76.2	169.2	65.4	149.7
Galisteo	2,900	883.9	7,950	2.30	37.0	32.7	108.9	228.0	95.0	203.0
Menefee	1,100	335.3	9,050	1.80	47.2	15.8	124.7	256.5	106.2	223.2
Crevasse Canyon	200	61.0	9,250	2.50	34.0	2.1	126.8	260.2	108.2	226.8
Mancos	900	274.3	10,150	1.80	47.2	13.0	139.7	283.5	117.4	243.4
Dakota	200	61.0	10,350	3.20	26.6	1.6	141.4	286.4	119.5	247.1
Morrison/Brushy Basin	100	30.5	10,450	2.00	42.5	1.3	142.7	288.8	120.5	248.9
Morrison/Salt Wash	250	76.2	10,700	2.50	34.0	2.6	145.2	293.4	123.1	253.5
Summerville	150	45.7	10,850	2.30	37.0	1.7	146.9	296.5	124.6	256.3
Todilto	100	30.5	10,950	4.00	21.3	0.6	147.6	297.7	125.6	258.1
Entrada	100	30.5	11,050	3.50	24.3	0.7	148.3	299.0	126.6	259.9
Chinle/Petrified Forest	1,300	396.2	12,350	1.80	47.2	18.7	167.0	332.7	139.9	283.8
Chinle/Aqua Zarca	300	91.4	12,650	2.50	34.0	3.1	170.1	338.3	143.0	289.3
San Andres LS	150	45.7	12,800	3.10	27.4	1.3	171.4	340.5	144.5	292.1
Glorieta SS	150	45.7	12,950	4.00	21.3	1.0	172.4	342.3	146.0	294.9
Yeso/San Ysidro	400	121.9	13,350	2.30	37.0	4.5	176.9	350.4	150.1	302.2
Yeso/Meseta Blanca	100	30.5	13,450	3.50	24.3	0.7	177.6	351.7	151.1	304.0
Abo	650	198.1	14,100	2.30	37.0	7.3	184.9	364.9	157.8	316.0
Madera Group/Bursum	100	30.5	14,200	2.30	37.0	1.1	186.1	366.9	158.8	317.8
Madera Group/Wild Cow	450	137.2	14,650	2.80	30.4	4.2	190.2	374.4	163.4	326.1
Madera Group/Los Moyos	300	91.4	14,950	3.10	27.4	2.5	192.7	378.9	166.5	331.6
Sandia	30	9.1	14,980	2.30	37.0	0.3	193.1	379.5	166.8	332.2
Arroyo Penasco	0	0.0	14,980	3.00	28.3	0.0	193.1	379.5	166.8	332.2
TD	14,980					total	172.3			

ESTIMATED MESA DEL SOL RESERVOIR CHARACTERISTICS

matix permeability	CORE/DST	est	est	min est	T-TDScorr	T-TDScorr
RESERVOIR	LITH	THICK	TEMP	TDS	HCOND K	TRANS T
		ft	°F	mg/L	ft/d	ft2/d
CREVASSE CAN/DALTON SS	SAND	200	260	7,000	0.034	6.90
DAKOTA	SAND	200	285	7,000	0.013	2.52
MORRISON (SALT WASH)	SAND	250	290	7,000		
ENTRADA	SAND	100	300	7,000	4.387	438.67
AQUAZAR/SAN ANDRES/GLOR	LIME/SAND	600	340	15,000	0.047	27.92
DECHELLY/MESETA BLANCA	SAND	100	350	15,000	0.013	1.29
MADERA	LIME/SAND	300	375	15,000	0.278	83.35
solution/fracture permeability	PUMP TEST	est	est	min est	T-TDScorr	T-TDScorr
RESERVOIR	LITH	THICK	TEMP	TDS	HCOND K	TRANS T
		ft	°F	mg/L	ft/d	ft2/d
CREVASSE CAN/DALTON SS	SAND	100	260	7,000		
DAKOTA	SAND	200	285	7,000	0.338	67.50
MORRISON (SALT WASH)	SAND	250	290	7,000	2.071	517.71
ENTRADA	SAND	100	300	7,000	4.810	480.98
AQUAZAR/SAN ANDRES/GLOR	LIME/SAND	600	340	15,000	8.574	5,144.19
DECHELLY/MESETA BLANCA	SAND	100	350	15,000		
MADERA	LIME	300	375	15,000	4.149	1,244.64

PRODUCTION AND INJECTION WELLS

- TD 13,000 ft
- \$5.7 million each
- Designed for 1,000 gpm production or injection

DEEP PRODUCTION/INJECTION HOLE (high capacity)						
	TASKS AND MATERIALS	SIZE	AM NT	UNIT	UNIT COST	TOTALS
A. MOBILIZATION/DEMOBILIZATION						
1	MOBILIZATION	n/a	1	job	\$300,000.00	\$300,000.00
2	DEMOBILIZATION	n/a	1	job	\$200,000.00	\$200,000.00
B. RIG TIME AND DRILLING						
1	RIG TIME (standby)	n/a	200	hour	\$800.00	\$160,000.00
2	DRILL CONDUCTOR HOLE (26 inch rotary)	26	100	feet	\$250.00	\$25,000.00
3	DRILL SURFACE CASING HOLE (17 1/2 inch rotary)	17 1/2	2900	feet	\$160.00	\$464,000.00
4	DRILL INTERMEDIATE CASING HOLE (12 1/4 inch rotary)	12 1/4	8000	feet	\$130.00	\$1,040,000.00
5	DRILL PRODUCTION HOLE (8 1/2 inch rotary)	8 1/2	2000	feet	\$120.00	\$240,000.00
C. CASING AND TUBING						
1	CONDUCTOR CASING (20 inch)	20	100	feet	\$80.00	\$8,000.00
2	SURFACE CASING (13 3/8 inch)	13 3/8	3000	feet	\$60.00	\$180,000.00
3	SURFACE CASING CENTRALIZERS	13 3/8	25	items	\$125.00	\$3,125.00
4	SURFACE CASING FLOAT COLLAR	13 3/8	1	item	\$2,000.00	\$2,000.00
5	SURFACE CASING FLOAT SHOE	13 3/8	1	item	\$700.00	\$700.00
6	INTERMEDIATE CASING (9 5/8 inch)	9 5/8	8000	feet	\$50.00	\$400,000.00
7	PRODUCTION CASING HANGER	9 5/8	1	item	\$2,125.00	\$2,125.00
8	INTERMEDIATE CASING CENTRALIZERS	9 5/8	200	items	\$125.00	\$25,000.00
9	INTERMEDIATE CASING FLOAT COLLAR	9 5/8	1	item	\$1,250.00	\$1,250.00
10	INTERMEDIATE CASING FLOAT SHOE	9 5/8	1	item	\$625.00	\$625.00
11	PRODUCTION CASING CENTRALIZERS	7	25	items	\$125.00	\$3,125.00
12	PRODUCTION CASING HANGER	7	1	item	\$2,125.00	\$2,125.00
13	PRODUCTION BLANK CASING (7 inch)	7	1000	feet	\$45.00	\$45,000.00
14	PRODUCTION LINER (7 inch round punch)	7	1000	feet	\$70.00	\$70,000.00
D. WELL SITE EQUIPMENT						
1	DIVERTER/ROTATING HEAD RENTAL	13 3/8	100	days	\$2,000.00	\$200,000.00
2	ANNULAR/DOUBLE GATE BOPE w /A CCUMULATOR	13 3/8	100	days	\$5,000.00	\$500,000.00
3	DRILLING WELL HEAD/GATE VALVE	13 3/8	1	items	\$6,250.00	\$6,250.00
4	FRAC TANK RENTAL	n/a	1	items	\$10,000.00	\$10,000.00
E. CEMENT CASING						
1	CEMENT CONDUCTOR CASING	n/a	1	job	\$10,000.00	\$10,000.00
2	CEMENT SURFACE CASING	n/a	1	job	\$70,000.00	\$100,000.00
3	CEMENT INTERMEDIATE CASING	n/a	1	job	\$70,000.00	\$100,000.00
F. SUPPLIES AND DRILLING MUD						
1	REIMBURSEMENT OF AUTHORIZED PURCHASES	n/a	n/a	n/a	n/a	\$1,500,000.00
2	GEOPHYSICAL LOGGING	n/a	n/a	n/a	n/a	\$70,000.00
3	GEOLOGIC AND ENGINEERING SERVICES	n/a	n/a	n/a	n/a	\$70,000.00
					TOTAL	\$5,738,325.00
MODEL COMPARISONS			13,000 DEPTH (ft)		Drilling	
		YR			Price Index	
INEL polynomial (NM oil and gas)		2003	\$1,801,491	Slim-hole equivalent	145	
		2006	\$2,422,695	Price Index Corrected	340	
SNL exponential (US geothermal)		2000	\$3,473,466	Large high capacity	120	
		2006	\$6,368,020	Price Index Corrected	340	

RESERVOIR SUMMARY

- **Reservoir**
 - ✓ **Temperature, 338-342° F**
 - ✓ **Thickness, 600 ft**
 - ✓ **Depth, 12,350 to 12,950 ft**
 - ✓ **Transmissivity, 5,140 ft²/d**
- **Compartmentalization?**

SUMMARY OF ECONOMIC ANALYSIS

Category	Explore	Confirm	Site Dev.	Subtotal
\$/kW	\$ 129	\$ 597	\$ 3,781	\$ 4,507
Total	\$1,292,044	\$5,968,879	\$37,805,934	\$45,066,857

Assumptions	Value	Notes
Capacity (MW)	10	Assumed
Capacity Factor	95%	Assumed
Installed Capital Cost (\$/kW)	4,507	
Land Expense (\$000s)	0	Inc reases with inflation
Property Tax (% book value)	1.1%	Assumed
Total First Year Operating Cost (\$/kWh)	0.0175	Increases with inflation
Royalties 4.0%		of Revenues
Effective Income Tax Rate	40.7%	Federal =35%, State=8.84% (deductible)
Production Tax Credit (\$/kWh)	0	Increases with inflation
Investment Tax Credit (%)	10%	Actual
Inflation Rate (%/yr)	2.3%	Assumed
5 Year Equipment	70.3%	Assumed
15 Year Property	0.0%	Assumed
Discount Rate (nominal)	10.0%	Assumed
Real Discount Rate	7.5%	Calculated
Energy Price Escalation Rate	1.0%	Assumed

RESULTS:	Value
Average Debt Service Coverage	1.72
Minimum Debt Service Coverage	1.39
After-Tax IRR on Equity	18%
Real Levelized Price (\$/kWh)	\$ 0.078
Nominal Levelized Price (\$/kWh)	\$ 0.092
First Year Electricity Price	\$ 0.086