Resource Assessment

Geological:

- Identify fracture swarms or faulted areas
- Porous or fractured rocks
- Water source
- Heat source
- Fault mapping

Resource Assessment

Surface Evaluation

- Shallow temperature surveys – anomalies
- Surface anomalies
- Surface minerals - silica, calcium carbonate, sulfates, borates
- Water Chemistry - anomalous spring/groundwater geochemistry
- Hot springs, fumaroles, and mud pots
- Gas discharge zones
- Hydrothermal eruption breccias
- Fault scarps
- Vegetation anomalies
- Young volcanic rocks
- Existing wells

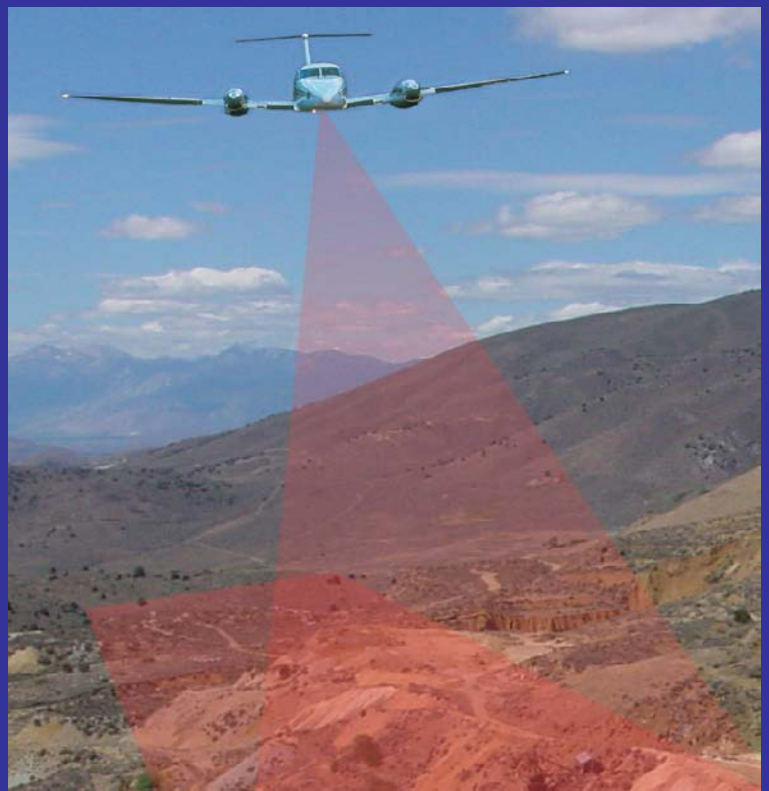
Resource Assessment

Hyperspectral & Multispectral Evaluation (Remote sensing):

- Diagnostic Spectral Features
  - **Mapping mineralogy**
    - **siliceous sinter**
    - **carbonaceous travertine/tufa**
    - **sulfate and borate evaporites**
    - **hydrothermal alteration (clay)**

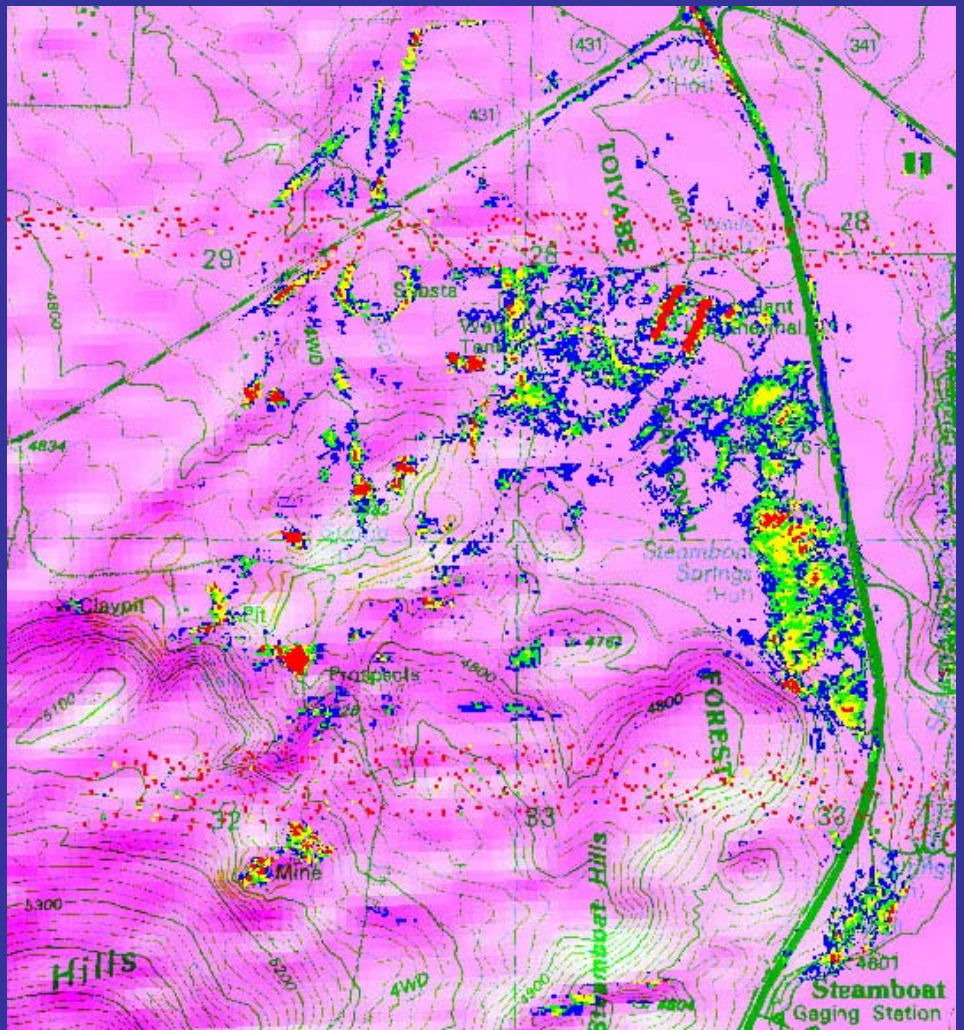
Resource Assessment

- Remote sensing
  - **Thermal anomalies**
  - **Thermal & Short Wave Infrared**
  - **Satellite images**

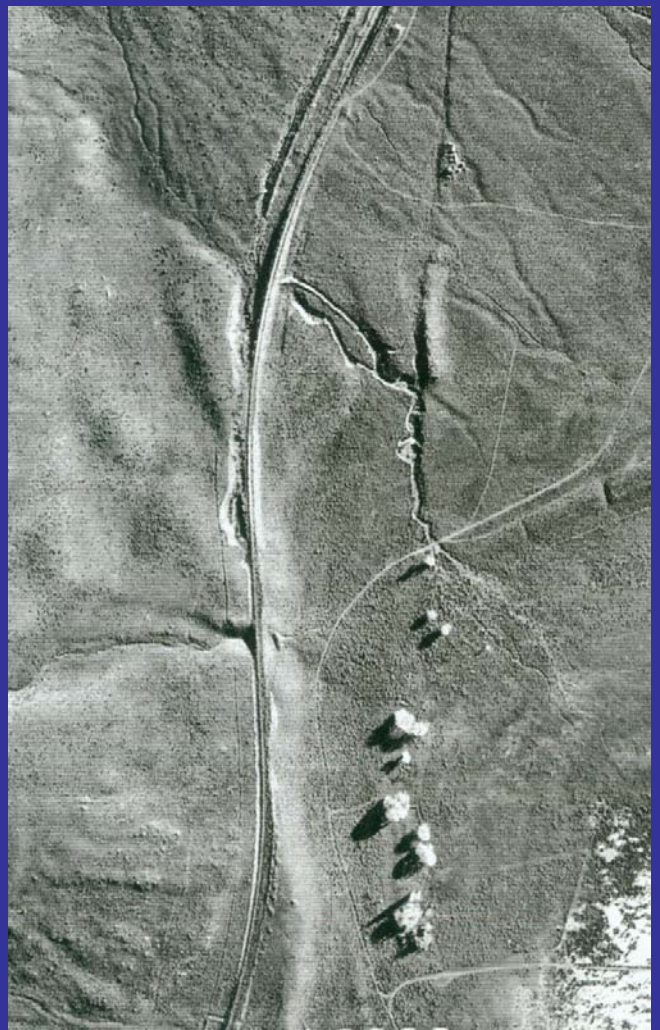


Resource Assessment

Heat flux anomalies



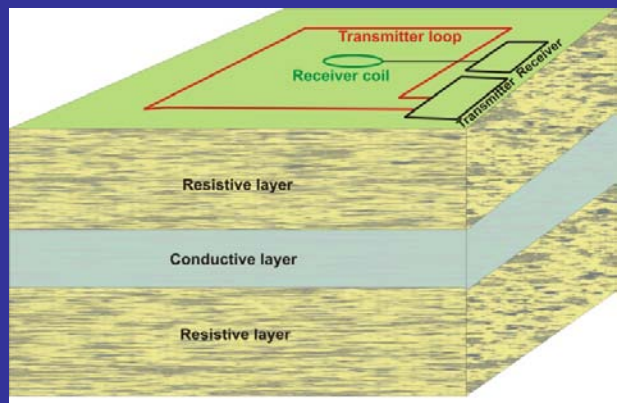
Airborne hyperspectral scanner HYMAP

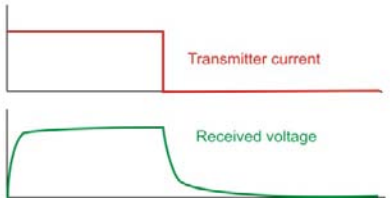


Geophysics

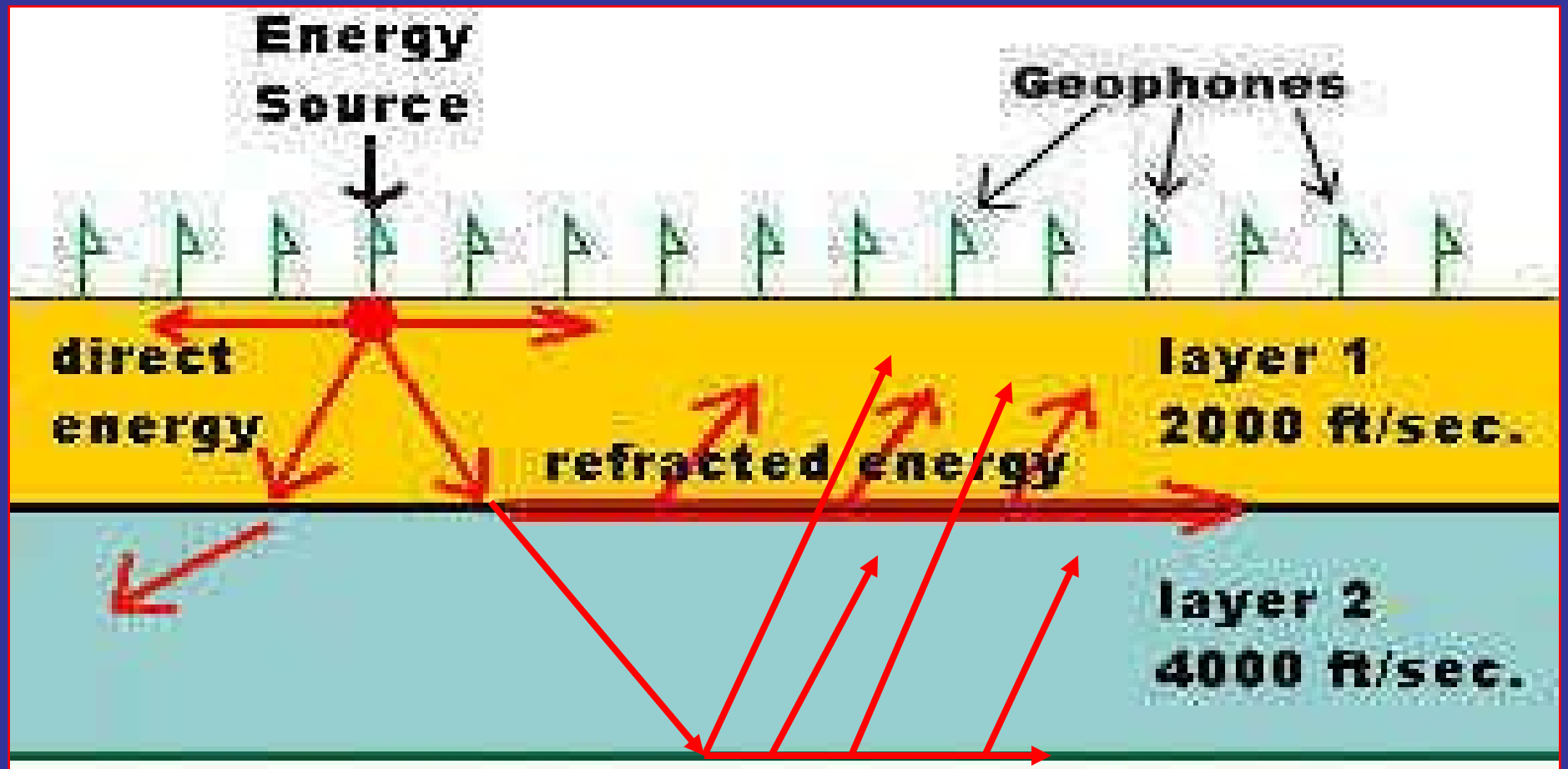
Time Domain Electromagnetic (TDEM)

- Maps resistivity layering in the subsurface
- Depth of investigation +5000 ft
- Soundings made using the central loop mode with transmitter loops 1,500 feet on a side
- Readings used to map the variation in the bulk electrical resistivity at depth
- Geothermal cells altered rocks
- Less $ than seismic





Geophysics



As sound travels faster in harder material, the refracted energy from layer 2,at some distance, will become the "first breaks" at the geophones

Geophysics

Energy Sources

Dependent on depth of investigation

- **Dynamite**
  - –Hole depth
  - –Surface material
  - –Size of charge
- **Trucks**
  - –Typical size – 60,000 #, size of a semi-truck/trailer
  - – Black Hawk small unit – 17,000 lbs – (7000 ft investigative depth max)

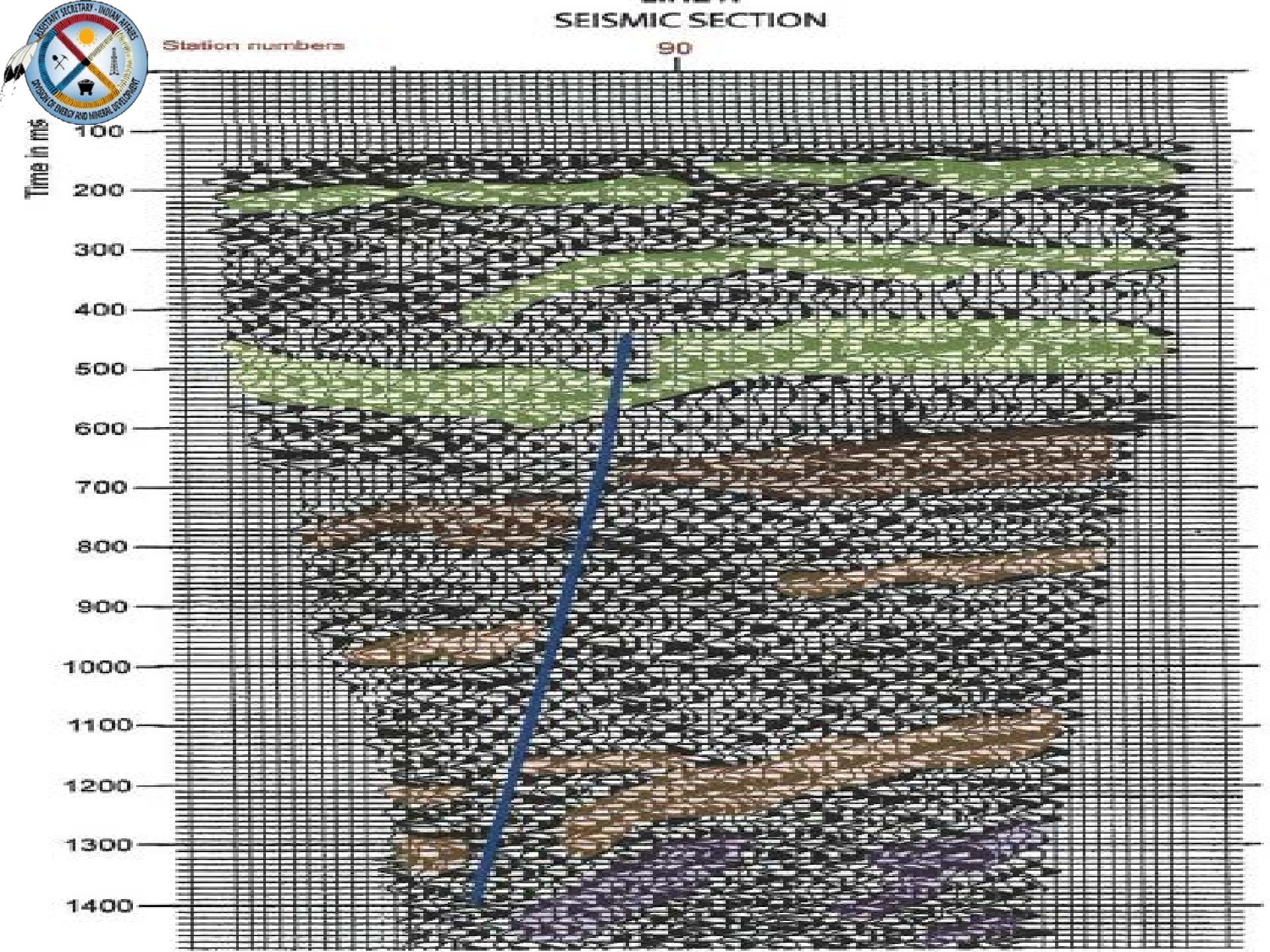
Smaller Truck

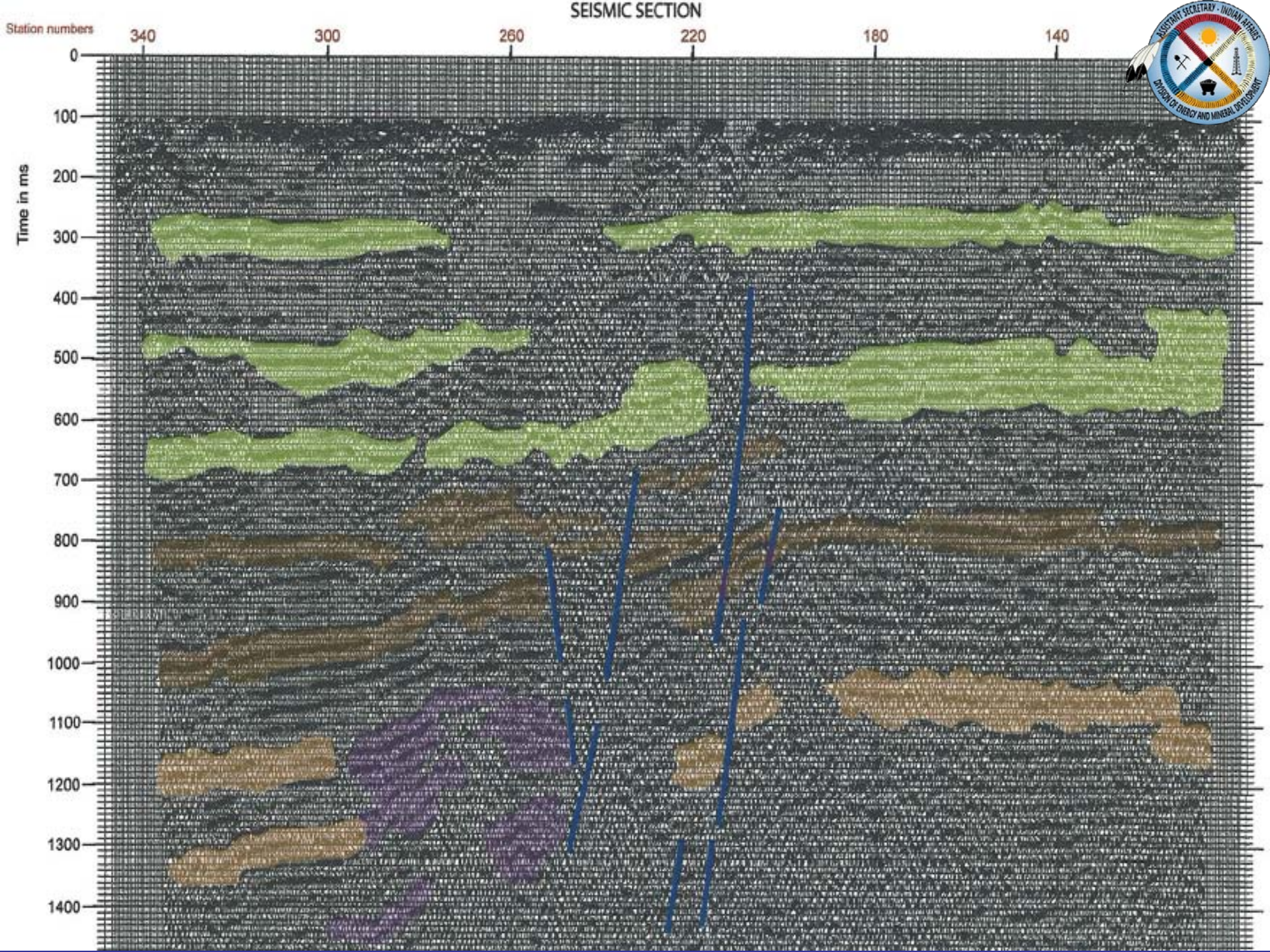
Smaller Truck

Surface disturbance

Geophone

SEISMIC SECTION



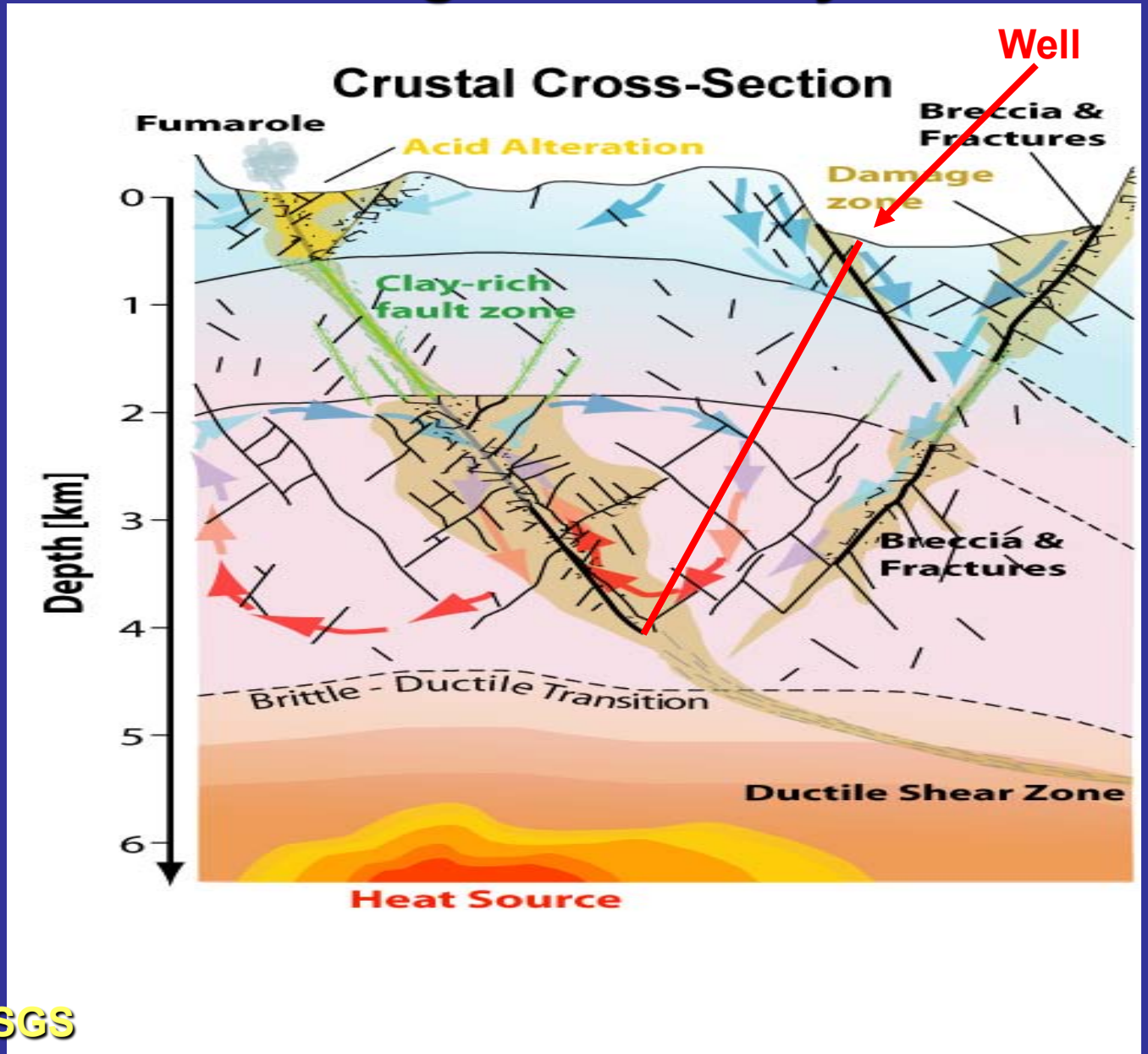

SEISMIC SECTION
Station numbers
340
300
260
220
180
140
Time in ms
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
ASSISTANT SECRETARY - INDIAN AFFAIRS
DIVISION OF ENERGY AND MINERAL DEVELOPMENT

Resource Evaluation

Geophysical Cost

- Dependent on terrain
- Multi-project cost sharing
- Unalaska
  - Dynamite for energy source
  - Est. ± .75 to 1 mile/ day
  - Est. $ 10,000/ day
  - Mobilization cost high

Faults, fault rocks, stress & fluid flow - How real fault-hosted geothermal systems evolve



N.Davatzes – USGS

Resource Evaluation

Resource Base vs. Recoverable Resource

- Metrics Influencing Recoverable Resource
  - Fractured volume
  - Fracture spacing
  - Resource temperature
  - Resource Depth
- Determining Developable Resource
  - Inaccessible areas
  - Distance to customer
  - Undevelopable areas

Resource Base vs. Reserves

- Earth's Heat is Vast
  - Accessible resource
  - Recoverable resource
  - Resource available depends on economics
- Reserves
  - Emerging technology
  - Some testing but no operating projects
  - Economics can be estimated

Factors Influencing Recoverable Reserves

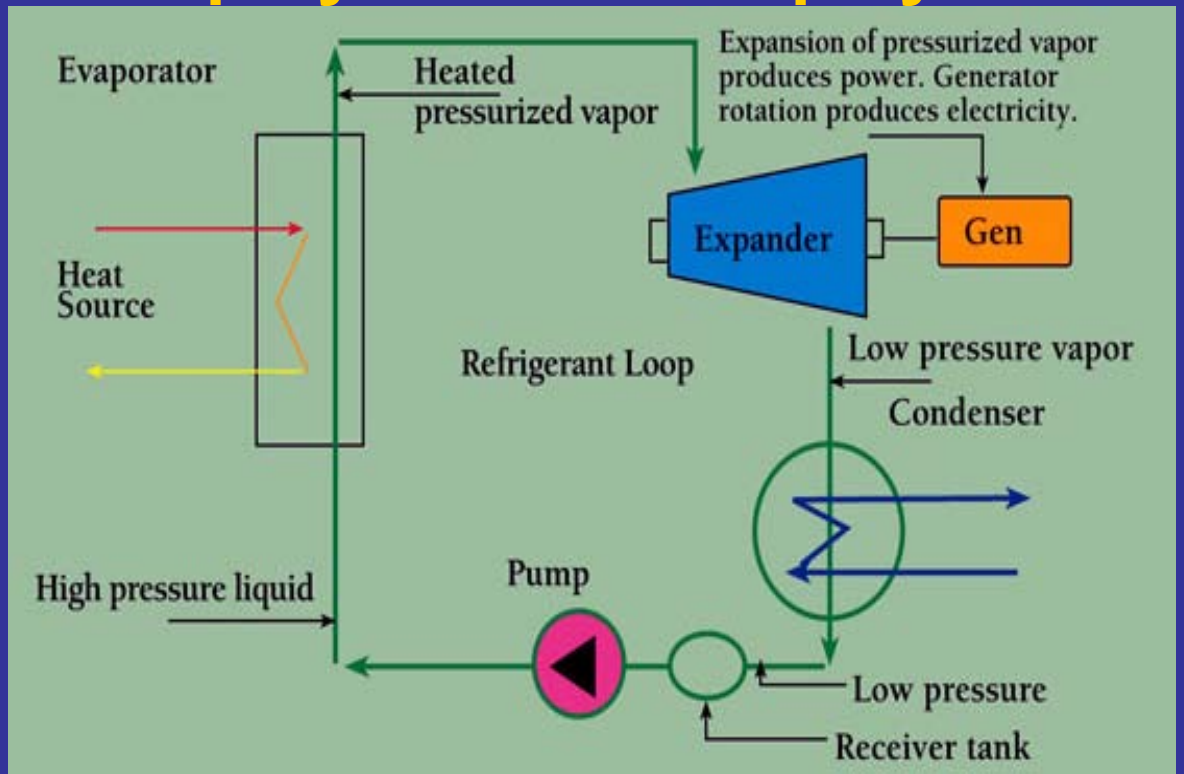
- Temperature
- Fractured Rock Volume
- Fracture Spacing
- Fracture Surface Area
- Water flow rate/ replenish rate

Resource Evaluation

- Volume Method
- Surface Heat Flux
- Planar Fracture Methods
- Magmatic Heat Budget

Rankin Cycle

- Makes electricity by recycling existing low level waste heat or pressure
- Consumes no fuel
- Creates no emissions
- Employs closed loop system



Surplus heat captured by the evaporator is used to "boil" the working fluid into a vapor.

Under pressure, the vapor is forced through the screw expander, turning it to spin an electric generator.

The vapor is cooled and condensed back into a liquid in the condenser.

The working fluid liquid refrigerant is pumped to higher pressure and returned to the evaporator to repeat the process.

Resource Application

- Geothermal sources
- Hydrothermal sources
- Stationary IC engines
- Coal fired power plants
- Oil & Gas Industry
- Industrial process waste heat

Resource Application

Hot Liquids to Power*

Output kW (60Hz)	Heat Input (Btu/hr)	Minimum Waste Heat Temp (°F)	Flow Rate (gpm)
30	1,000,000	200°F	100
50	1,900,000	200°F	200
100	5,000,000	200°F	500
500	22,500,000	200°F	2,000

*Sources: Stationary IC Engines - Geothermal - Landfill - Biomass - Hot Water from Industrial Processes

Hot Gases to Power*
Exhaust Temp °F - Exhaust Flow = CFM

Output kW (60HZ)	400°F	500°F	600°F	700°F	800°F	900°F	1000°F
20	7,038	4,392	3,159	2,580	2,274	2,112	1,961
40	13,715	8,622	6,228	5,063	4,495	4,110	3,860
100	33,133	20,427	14,814	12,122	10,788	9,817	9,069
500	158,123	99,193	71,490	57,933	51,588	47,032	43,505
1000	302,675	190,732	138,042	112,021	99,732	90,981	85,110
1500	444,304	277,999	200,101	162,252	144,839	132,134	122,180

*Sources: Micro-turbines - Stack Gases - Food Processing - Thermal Oxidizers - Factories

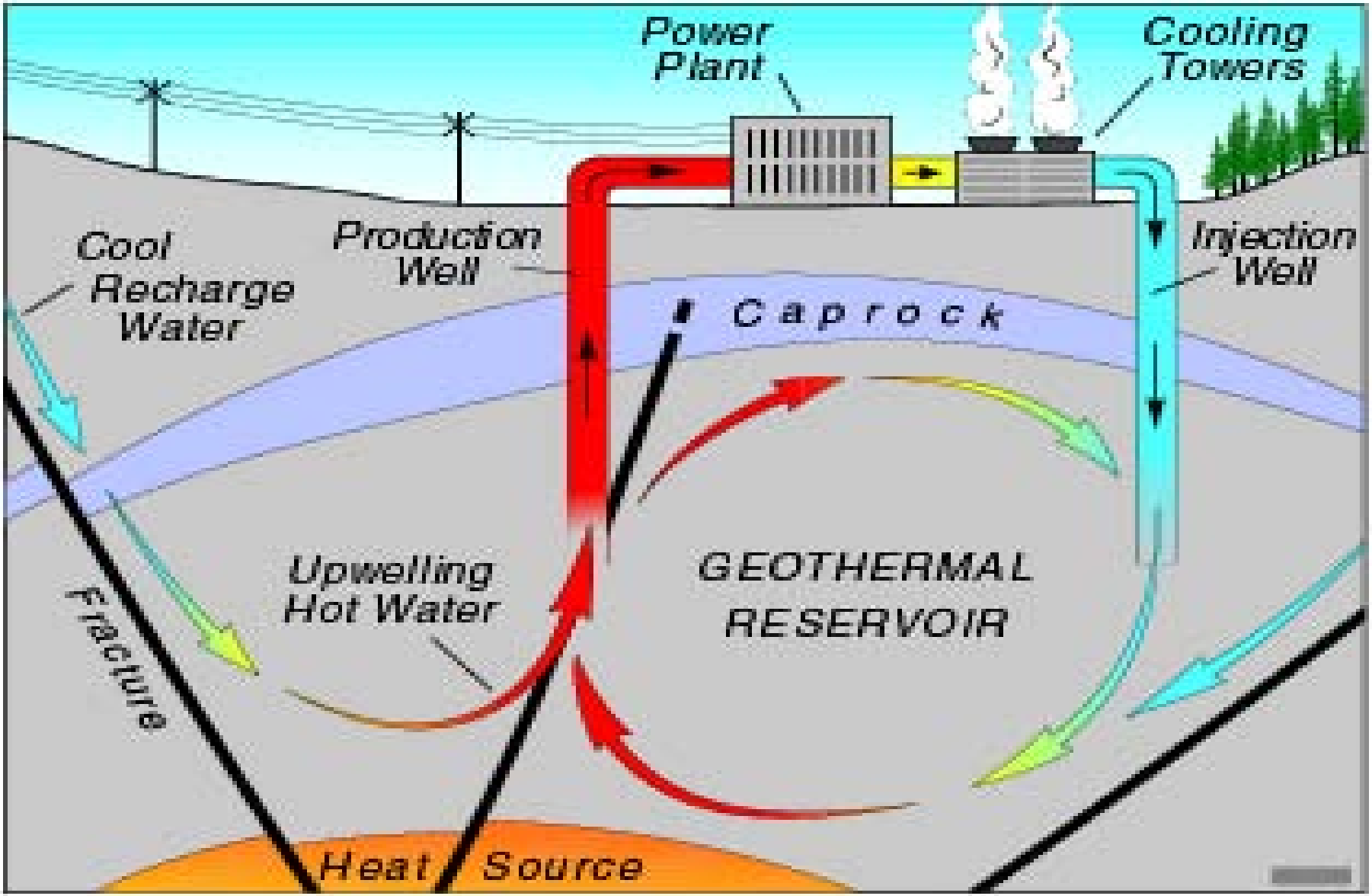
Pressure to Power*

Output kW (60HZ)	Inlet Pressure	Outlet Pressure	Flow (kg/s)	Flow (scfm)
30	290psi/20Bar	86psi/6Bar	0.3	940
650	600psi/41.5	100psi/6.9Bar	4.5	14,000
1450	600psi/41.5	100psi/6.9Bar	27.3	85,500

*Sources: Pipeline Pressure Letdown Stations - Geo Pressure from Oil Wells

Resource Evaluation

Application Economics

System Size kW	Capex	Annual Operating Hours	Value of Electricity Annual $.50/kWh	Annual OPEX	Payout years
30	$81,500	8500	$127,500	$1,275	0.65
50	$128,500	8500	$212,500	$2,125	0.61
100	$250,000	8500	$425,000	$4,250	0.59
200	$465,700	8500	$850,000	$12,750	0.56
500	$1,215,000	8500	$2,125,000	$21,000	0.58

Idealized Geothermal Reservoir