Fundamentals of Thermal Heating for Geo-active & -inactive Regions

Presented by

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Credits for some content: DOE, Idaho & California Agencies & Public records

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Agenda

Fundamentals of Thermal Heating for Geo-active & -inactive Regions

1. Geological & Geographical Basics
2. Geo-zones, geo-types, physical & chemical properties
3. Thermal Heating
   a) Fundamentals
   b)Case Example, Boise City Mall
   c)Past and future
4. Utilization of geo-Inactive Region
5. Quiz Review

Table 1.12 Definitions & Synonyms

name	field of science or other note	meaning	long or other name, if any
Tectonics	geology generally	geological structural features as a whole	
Tectonics	geology particularly to planet	the structure of the crust of a planet and especially the formation of folds and faults in it	
Tectonics	Geology, particularly to Earth's crust	the structure of the Earth's crustal surface & how it changes over time	
geo-	basic word definition	earth or of the earth	
thermal	basic word definition	heat	
geothermal	basic geology definition	of, relating to, or using the natural heat produced inside the earth	
Geothermal energy	current common terminology	pockets of hot water or steam near the Earth's surface that can be accessed at reasonable cost	
climate	basic geology definition	conditions at surface of earth	climatic
near surface geo-structure	structure at earth surface	geological structural features within feet where there is no geothermal source	
GTHP	Near-surface Geo-Structure	Optimizing Use of Near-surface Geo-Structure and climate	Geothermal Heat Pump
GTHP optimization	Near-surface Geo-Structure & Climate	Optimum Use = f(location, Climatic Conditions, Near surface Geo-Structure)	Optimization of Geothermal Heat Pump Systems

References & Data in some Slides is noted when from optional reference Geothermal Utilization, Wiley, 1979, E F Wahl

Review of Basics

Chapter 1 of Wiley book(optional reference)

Review geo- data, concepts and theories necessary to understand the geothermal fluids that are available at the earth's surface and therefore how to use them profitably.

Because the time frame of changes is in the billions of years, this data is unchanged but has been updated with information from NASA studies, USSR geologic commission circa 1960 and others not included in 1979 edition.

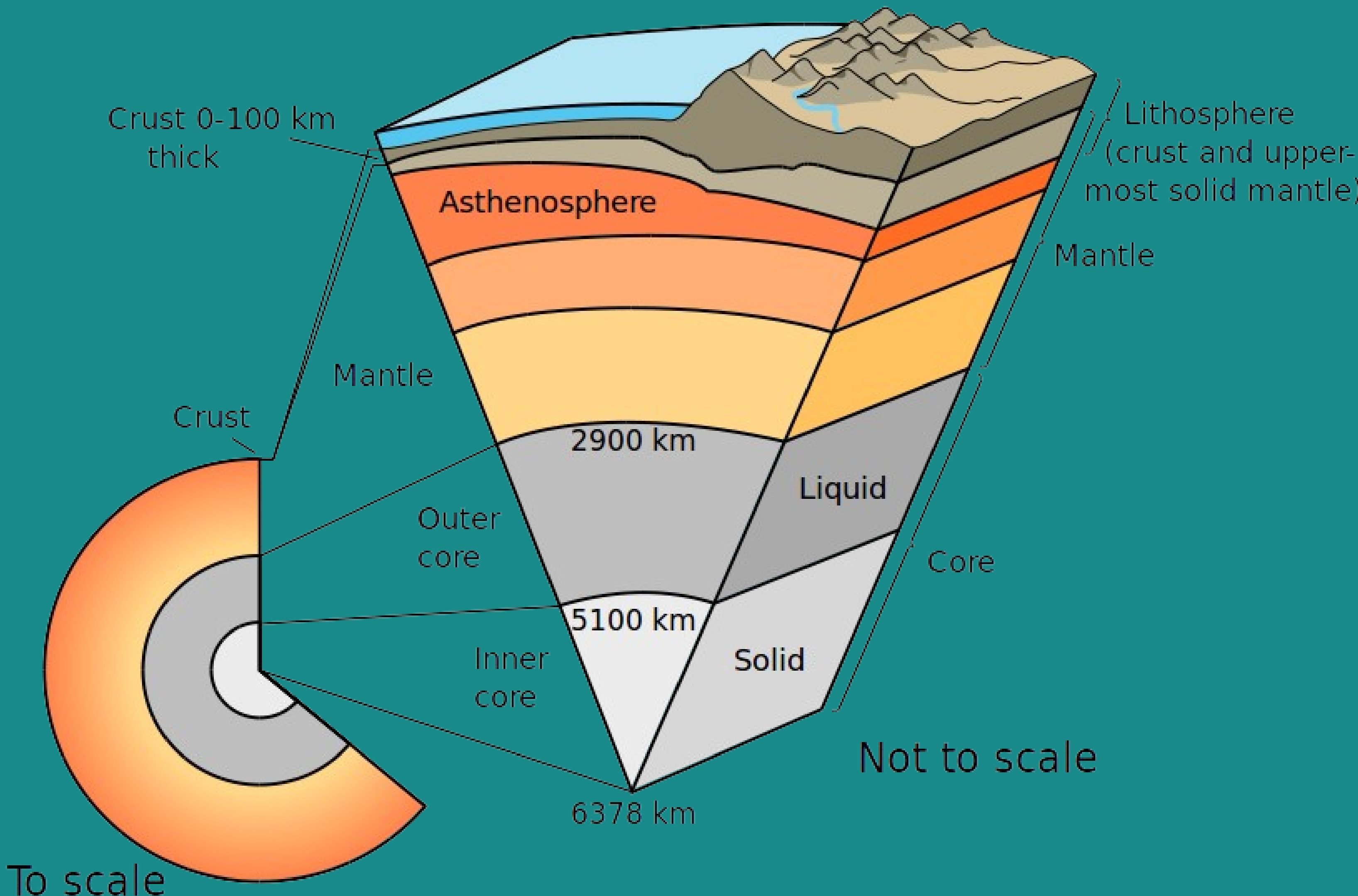
Table 1.3 Temperature Distribution and Transition Zones Between Regions of Earth's Interior

Region	State	Connecting Zone	Depth (km)	Temperature (°C)	Density (g/cm^3)	Composition	Region
			0	0-50			
						Na,K alumino-silicates[a]	
Crust	Rigid Plates		10-20[c]	?	2.7		
					3.0	Fe,Ca,Mg alumino-silicates[b]	
		Moho	6-70	500-1000			Lithosphere
	Solid						
		Solidus	100-200	1200			
Mantle	Viscous Mass				3.6-4.4	Fe,Mg silicates	Asthenosphere
		Solidus	700	1900			
	Rigid Mantle				4.5-5.5	Fe,Mg silicates &/or oxides	Mantle
		Solidus	2800	3700			
	Liquid				10-12		
Core		Solidus	5500	4300		Fe,Ni	Core
	Solid				12-13		
		Center	6340	4500		Fe,Ni	

[a]Sial: Silicic crust - consisting of composition shown, non-existant in oceanic crust.

[b]Sima: Mafic crust - consisting of composition shown.

[c]Conrad discontinuity, 0 under oceans.


Crust 0-100 km
thick
Asthenosphere
Lithosphere
(crust and upper-
most solid mantle)
Mantle
Mantle
Crust
2900 km
Liquid
Outer
core
Core
5100 km
Inner
core
Solid
Not to scale
6378 km
To scale

Surface Zone Geology, Subduction

Fig 1.5 Chapter 1 of Wiley book(optional reference)

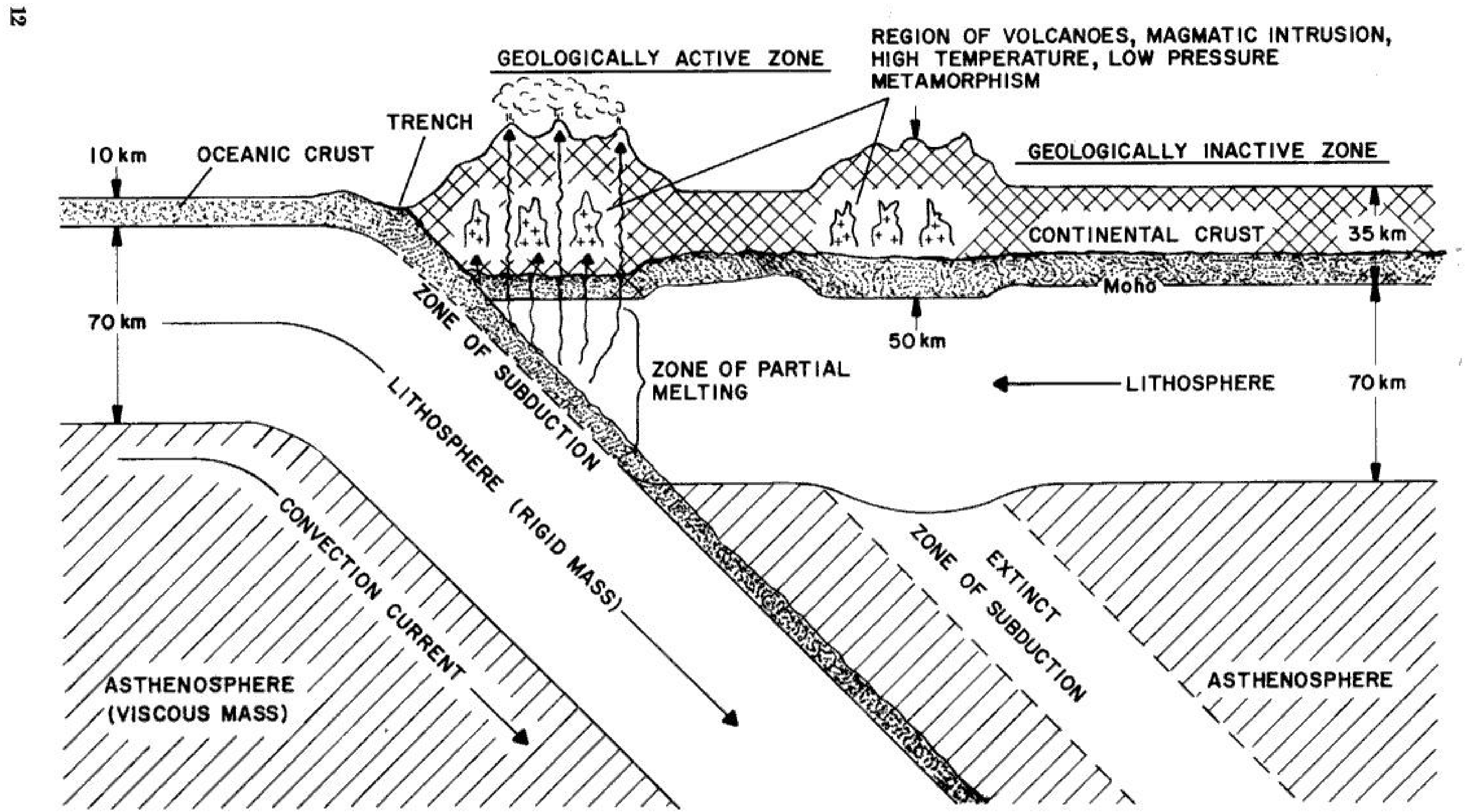
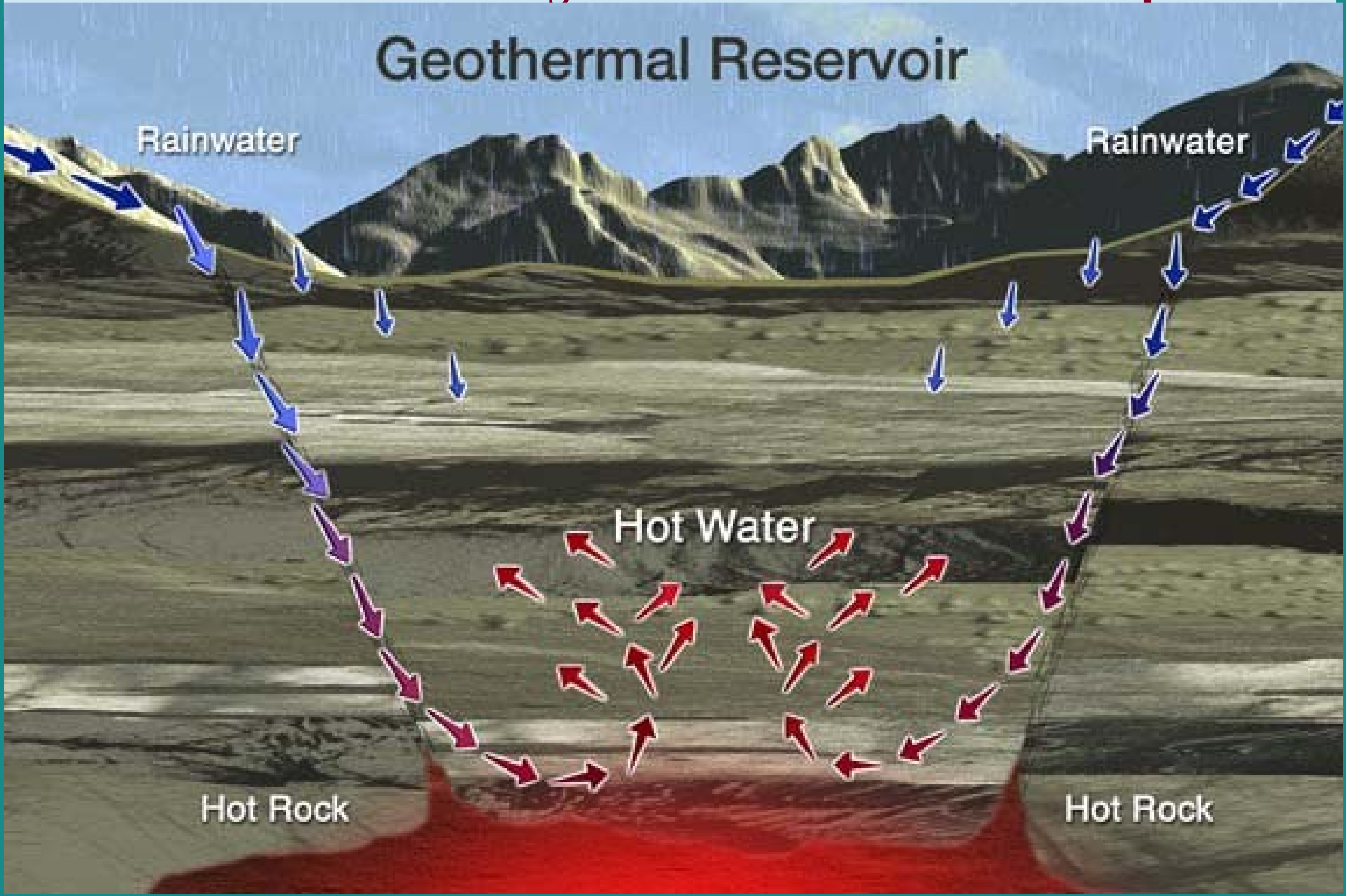


Figure 1.5 Plutons formed by subduction.

One of Many Scenarios for Formation of Geo-energy within Economically Accessible Depth



Continental and Oceanic Temperature versus Depth

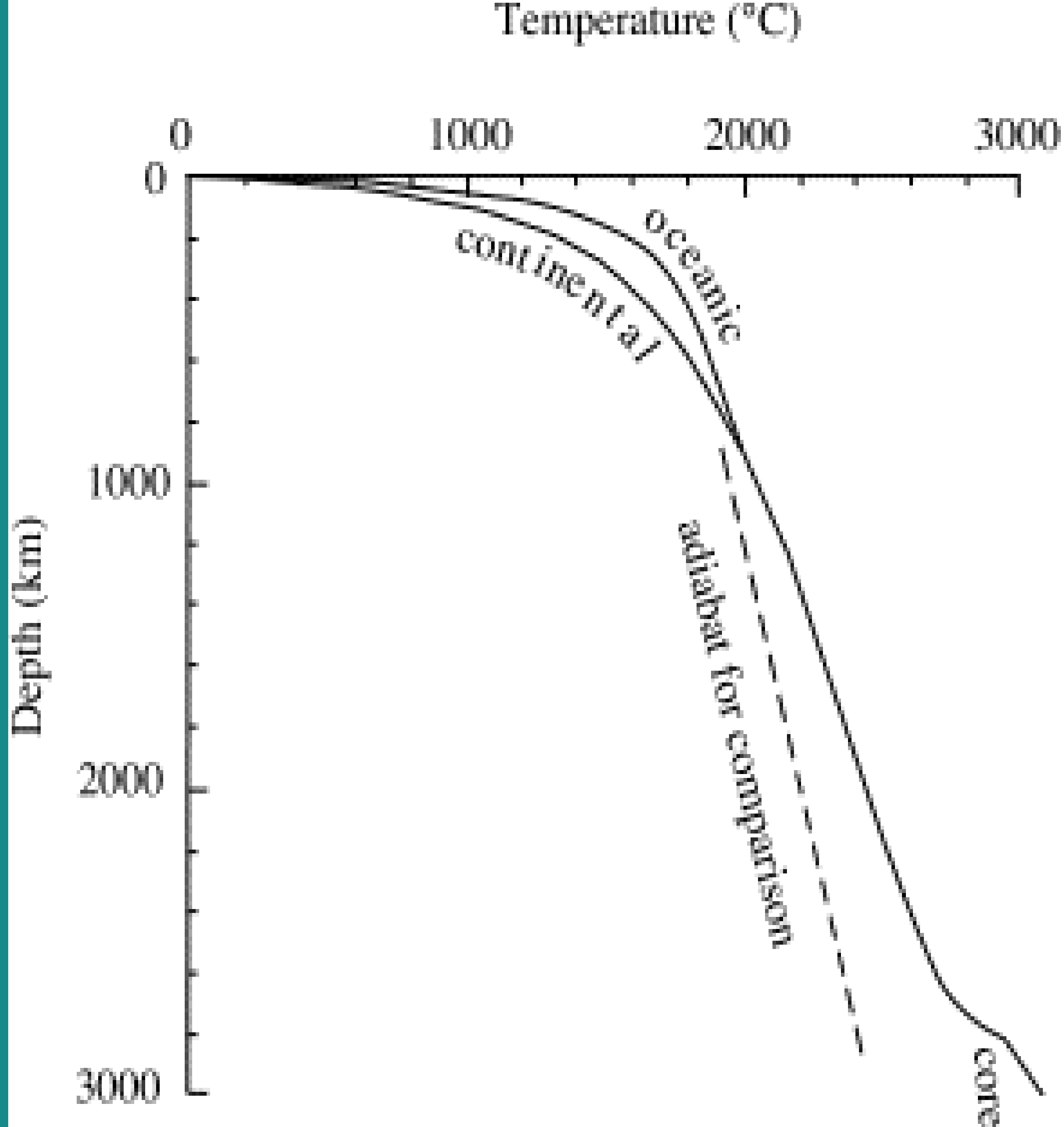


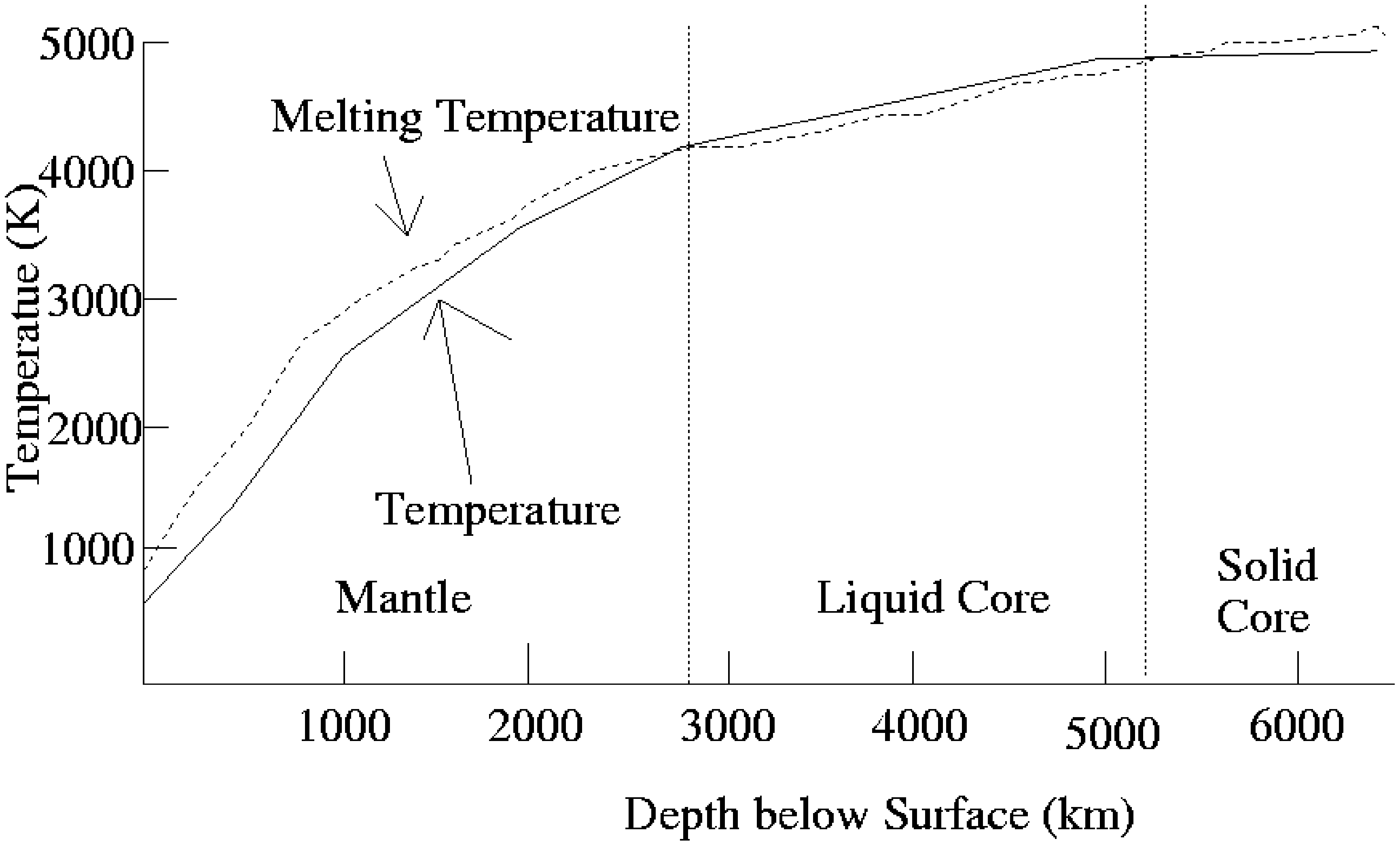
Table 1.3. Tabular Schematic Of Geo-Regions, Temperatures, Properties

depth km				temperature Kelvin	Centigrade
0 (Surface)		Lithosphere Crust & upper most solid mantle	crust	293	20
6 ocan 70 contnt	moho		Mantle		
410	Lithosphere > Aesthenosphere	Asthenosphere viscous mass			
660	Upper > Lower Mantle	Lower Mantle Rigid		1,900	1,627
2800 to 2900	Lower Mantle> > Outer Core	Upper Core Liquid	Core	3000	2,727
5100	Outer Core > Inner Core	Lower Core Solid		5,000	4,727
6370	Center of Earth (mean)			7,000	6,727

Table 1.3. Other Useful Information

other information and notes below					
Rate of thickening of the continental lithosphere, m/billion years	~20		Surface Area		
			region	Billion km^2	%
Rate of horizontal extension of the continental lithosphere, m/billion years	~2		Continents	149	29.2
			Ocean	361	70.8

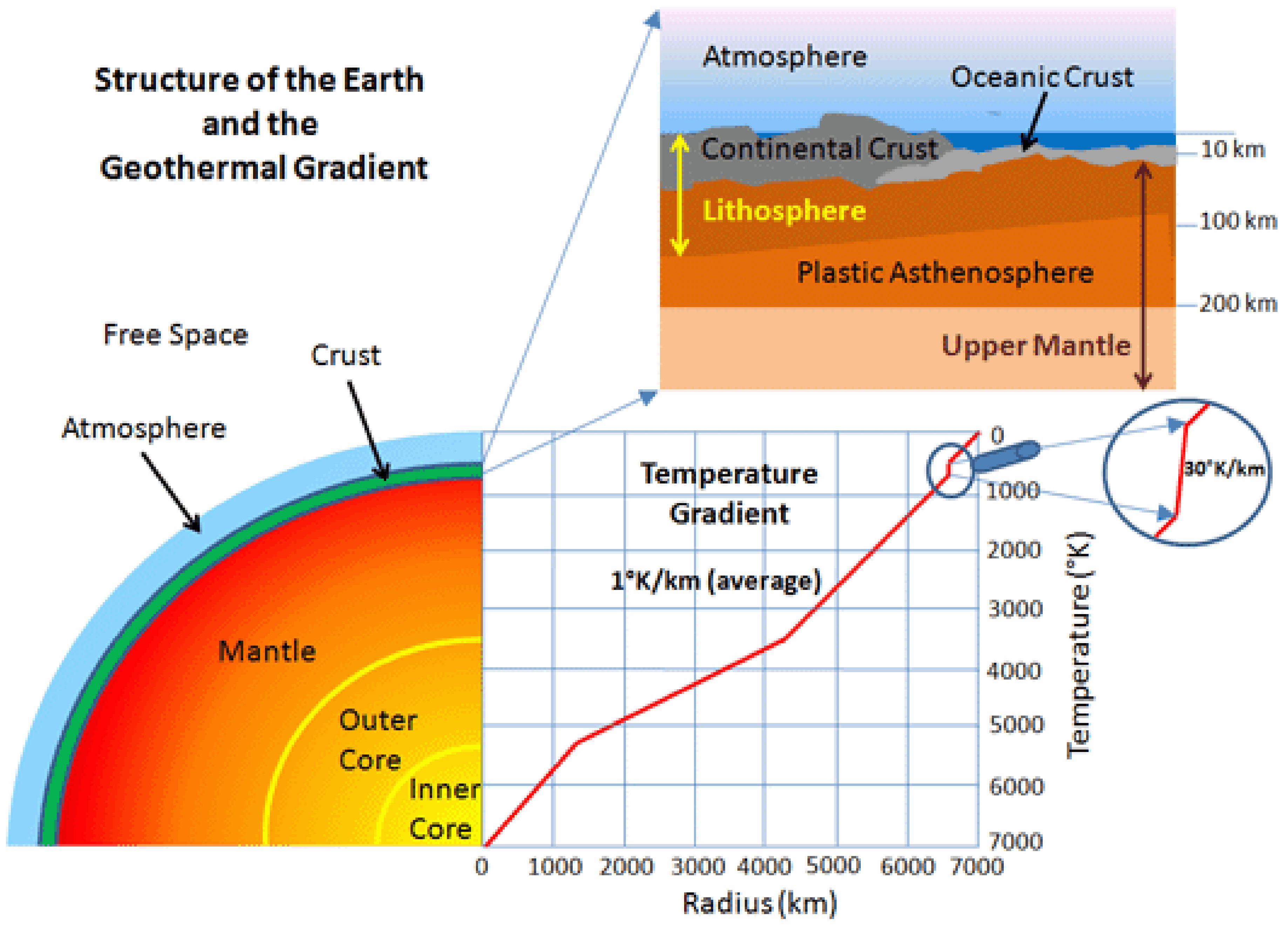
Cartoon of the Earth's Interior Temperature



The Earth is solid where T is less than T_melt.

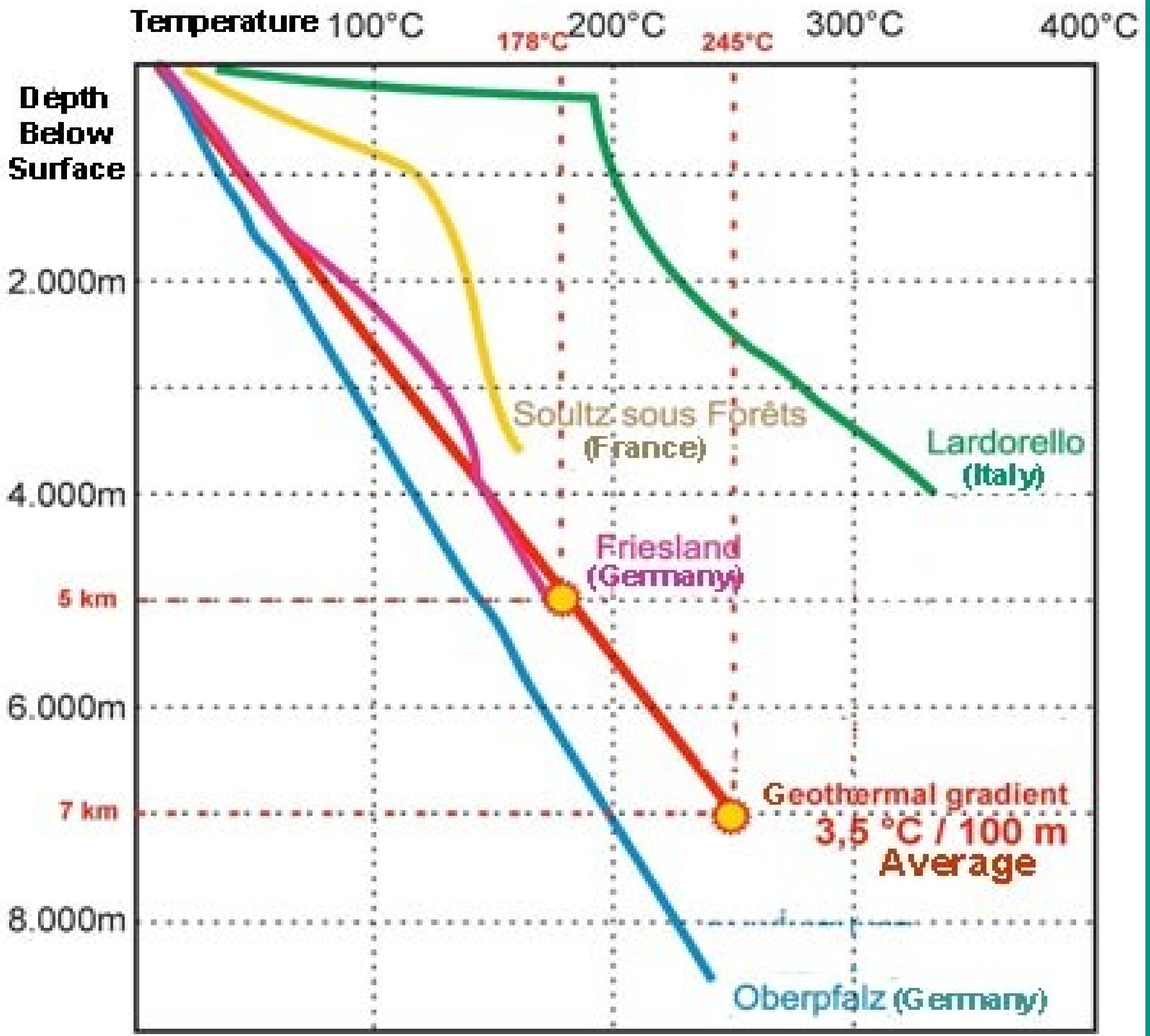
(Se-431)

DJ Jeffery
UNLV 2003



Structure of the Earth and the Geothermal Gradient
Atmosphere
Oceanic Crust
Continental Crust
Lithosphere
Plastic Asthenosphere
Upper Mantle
10 km
100 km
200 km
Free Space
Crust
Atmosphere
Mantle
Outer Core
Inner Core
Temperature Gradient
1°K/km (average)
30°K/km
0
1000
2000
3000
4000
5000
6000
7000
Temperature (°K)
0 1000 2000 3000 4000 5000 6000 7000
Radius (km)

Crust Temperature Profile at Different Locations



CHEMICAL COMPOSITION OF ROCKS

Reprinted from "Sedimentary Rocks" (1948) with the permission of F. J. Pettijohn, author, and Harper Brothers, publishers.

Element	Average igneous rock	Average shale	Average sandstone	Average limestone	Average sediment
SiO_2	59.14	58.10	78.33	5.19	57.95
TiO_2	1.05	0.65	0.25	0.06	0.57
Al_2O_3	15.34	15.40	4.77	0.81	13.39
Fe_2O_3	3.08	4.02	1.07	0.54	3.47
FeO	3.80	2.45	0.30		2.08
MgO	3.49	2.44	1.16	7.89	2.65
CaO	5.08	3.11	5.50	42.57	5.89
Na_2O	3.84	1.30	0.45	0.05	1.13
K_2O	3.13	3.24	1.31	0.33	2.86
H_2O	1.15	5.00	1.63	0.77	3.23
P_2O_5	0.30	0.17	0.08	0.04	0.13
CO_2	0.10	2.63	5.03	41.54	5.38
SO_3		0.64	0.07	0.05	0.54
BaO	0.06	0.05	0.05		
C		0.80			0.66
	99.56	100.00	100.00	99.84	99.93

Flowing Well Properties

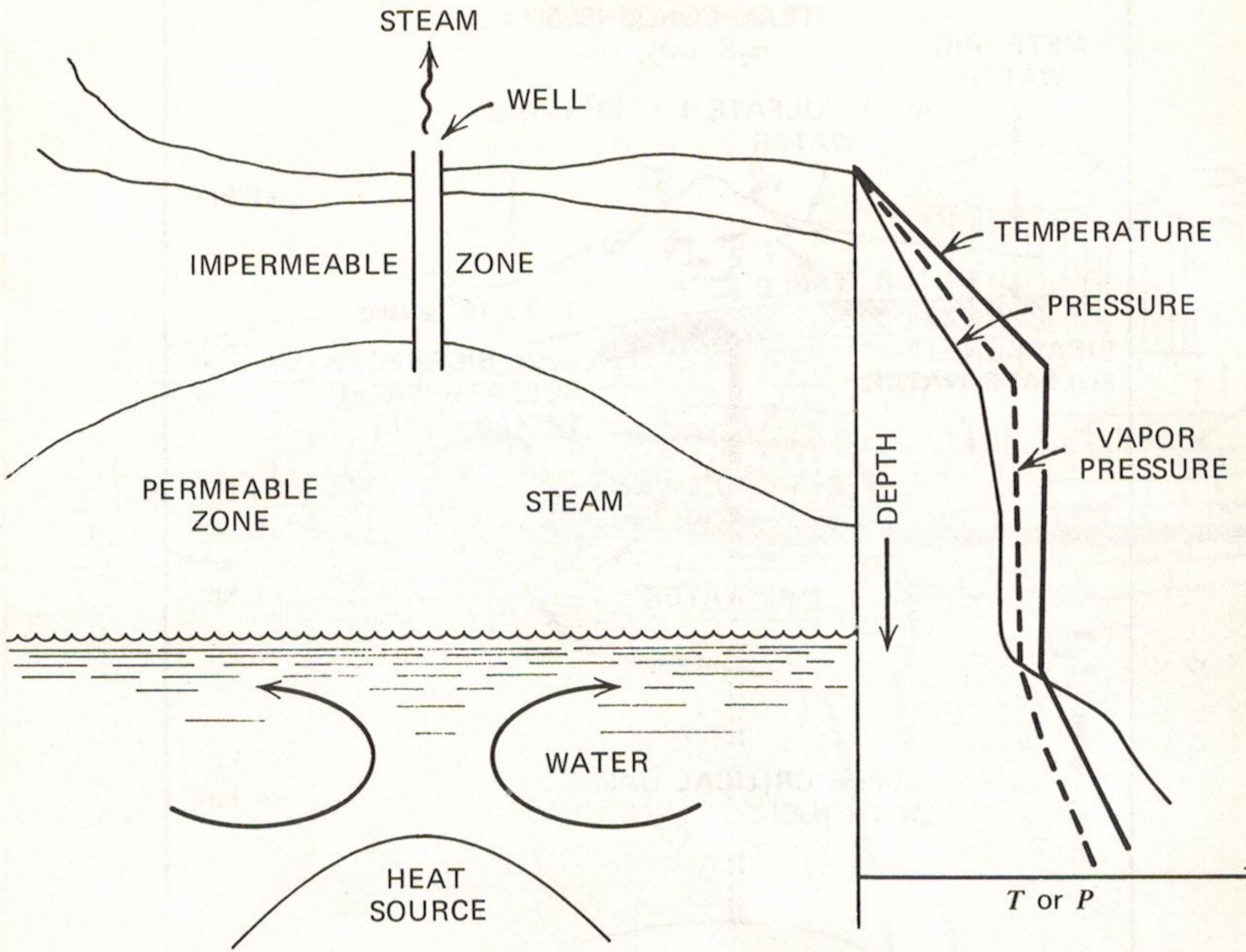


Figure 1.14 Model of a steam field showing the temperature distribution in the cent

Physical & Chemical Properties

Chapter 2-4 of Wiley book(optional reference)

The extensive and valuable information in these chapters are not available elsewhere.

Chapter 2. The physical & chemical properties of geothermal fluids

Noteworthy is that Calcium (Ch.3) & Silica (Ch.4) are generally the most serious scale deposition components.

Detailed discussion is beyond the scope of this course but is summarized and provided for your possible interest

SUMMARY OF THEORY & PREDICTION

On Deposition and Physical Properties

Deposition can be predicted/estimated

Equations for Physical properties are simple & useful

Geothermal Brine Physical Properties

Density:

$$\rho = \rho_W + 0.0073 w_t [1 + 1.6 \times 10^{-6} (T - 273)^2] \qquad (2.7)$$

Heat capacity:

$$c = c_w \left(1 - \frac{w_t}{100}\right) - 0.002 w_t \qquad (2.15a)$$

See also Equations 2.14, 2.15b, and 2.15c.

Vapor pressure:

$$p = p_W \left(1 - \frac{0.004 w_t}{\rho}\right) \qquad (2.21)$$

Surface tension:

$$\sigma = 0.0757 (T_c - T)^{0.776} (1 + 0.0039 w_t + 4.35 \times 10^{-5} w_t^2) \qquad (2.29b)$$

Viscosity:

$$\mu = \mu_W (1 + 0.021 w_t + 0.00027 w_t^2) \qquad (2.25)$$

Enthalpy:

Calcium Carbonate Deposition

Predictable

Dependant on pH

Thus affected by flashing

Also temperature dependent

Please see Chapter 3 of

Wiley book optional reference

Silica Deposition

Experience is best predictor

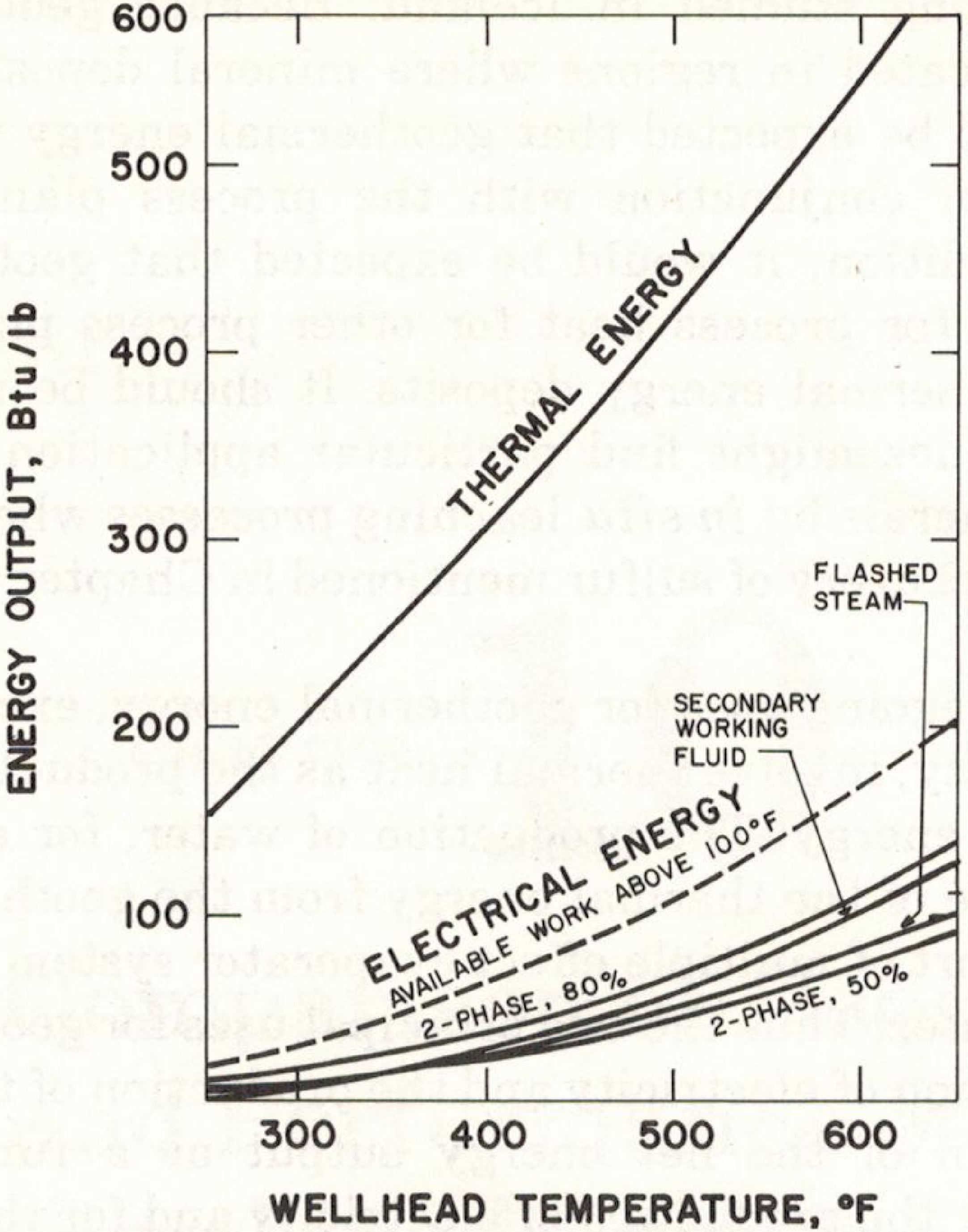
Tests on specific site best.

Polymerization rate varies from minutes to months.

Extensive data is available in the literature for prediction

Ratio of Thermal to Electrical Output Varies from: <5 at 600F to <15 at 200F

Fig 6.5 of Wiley book (optional reference)



SUMMARY OF PRECEEDING

On Electrical & Thermal Productivity

- Sensitive to ambient temperature
- Thermal Productivity 4 to 15+ times higher than Electrical Productivity

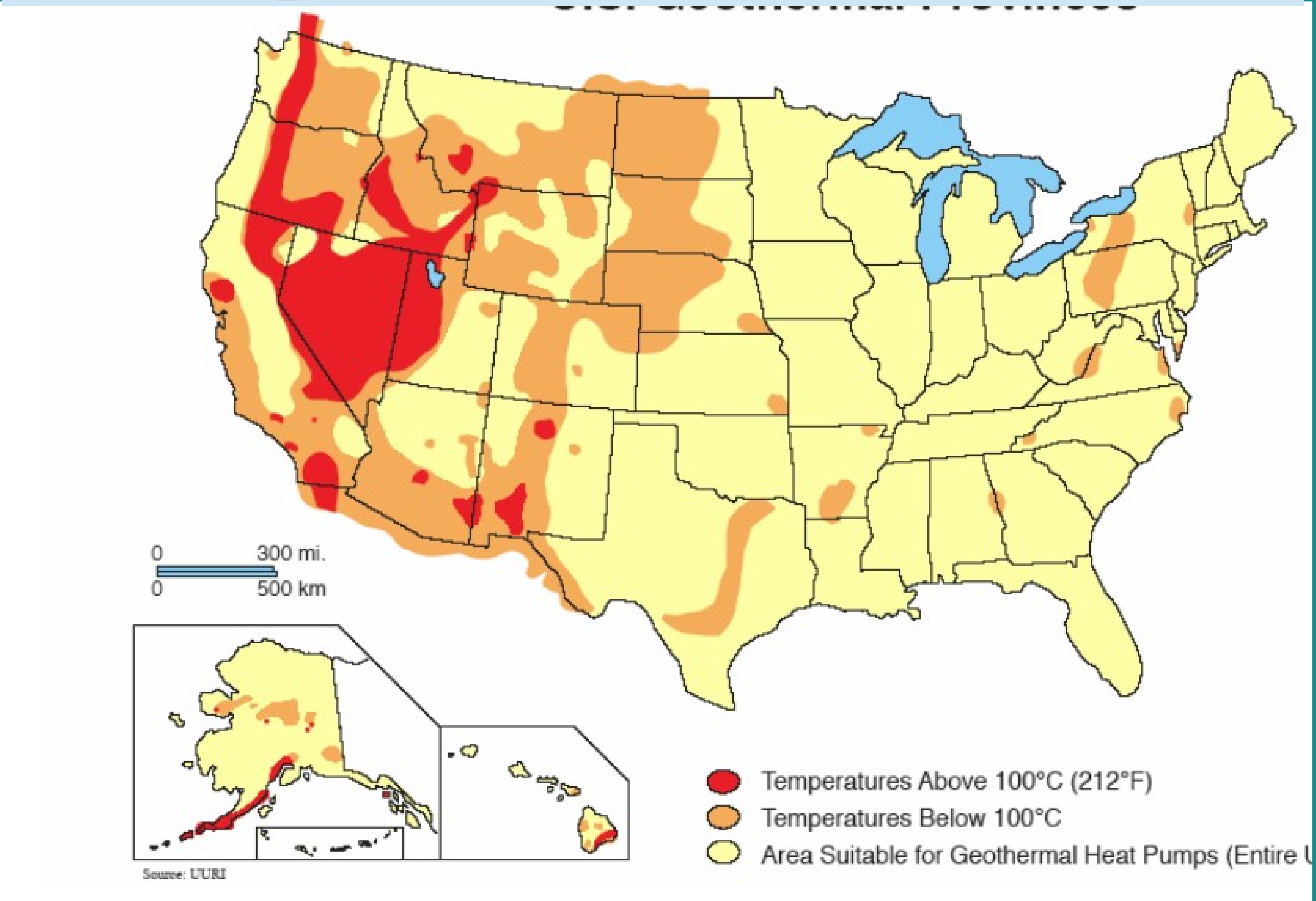
Pertinent Important Concepts

Based on Chapters 6-9 of Wiley book(optional reference)

Three concepts are

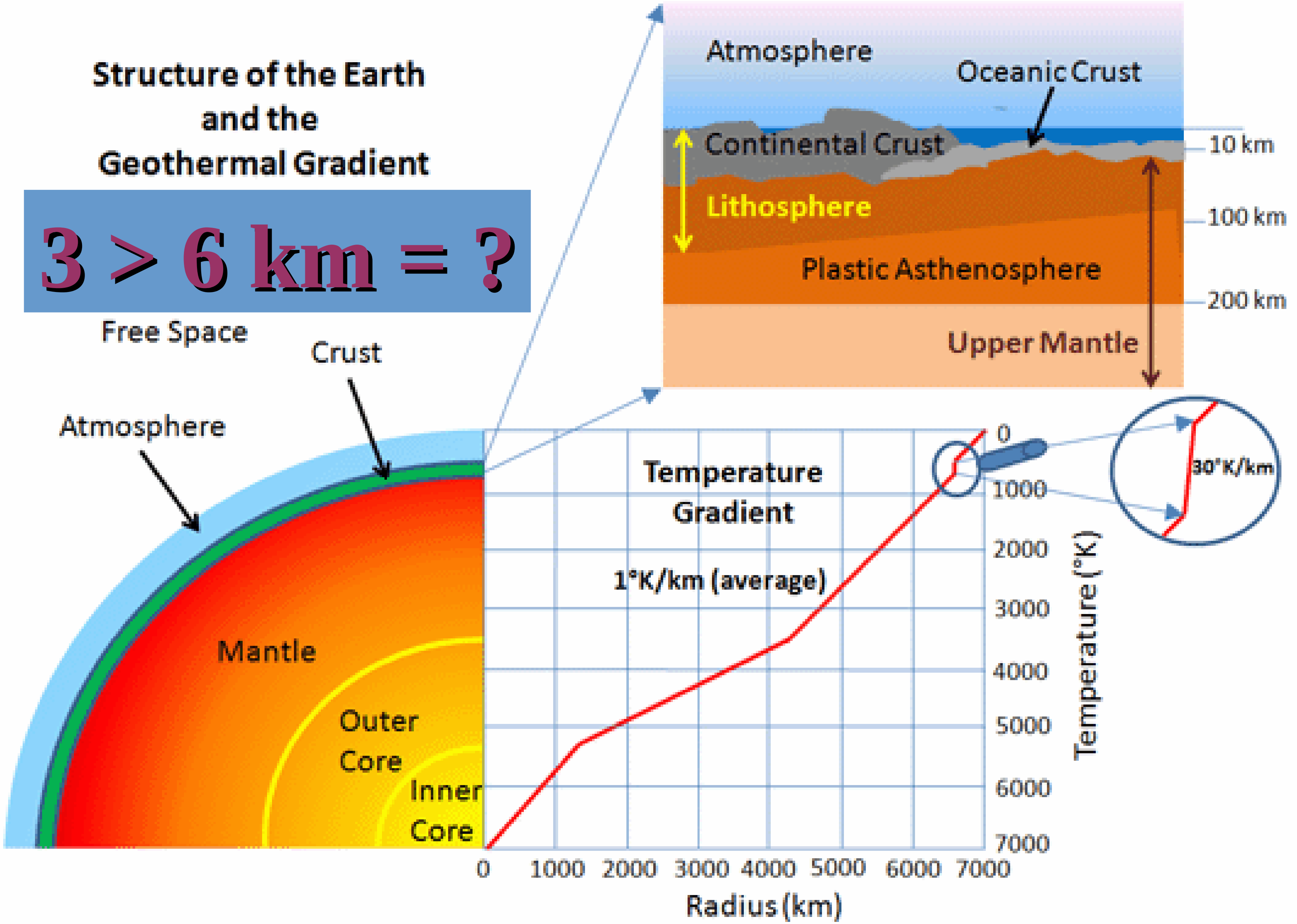
- ◊ net power produced improves as ambient temperature drops
- ◊ **most valuable product is direct thermal use for process or other heating purposes**
- ◊ **as resource temperature drops, thermal use > preferred economic use**

Map Geo resources to 3 km

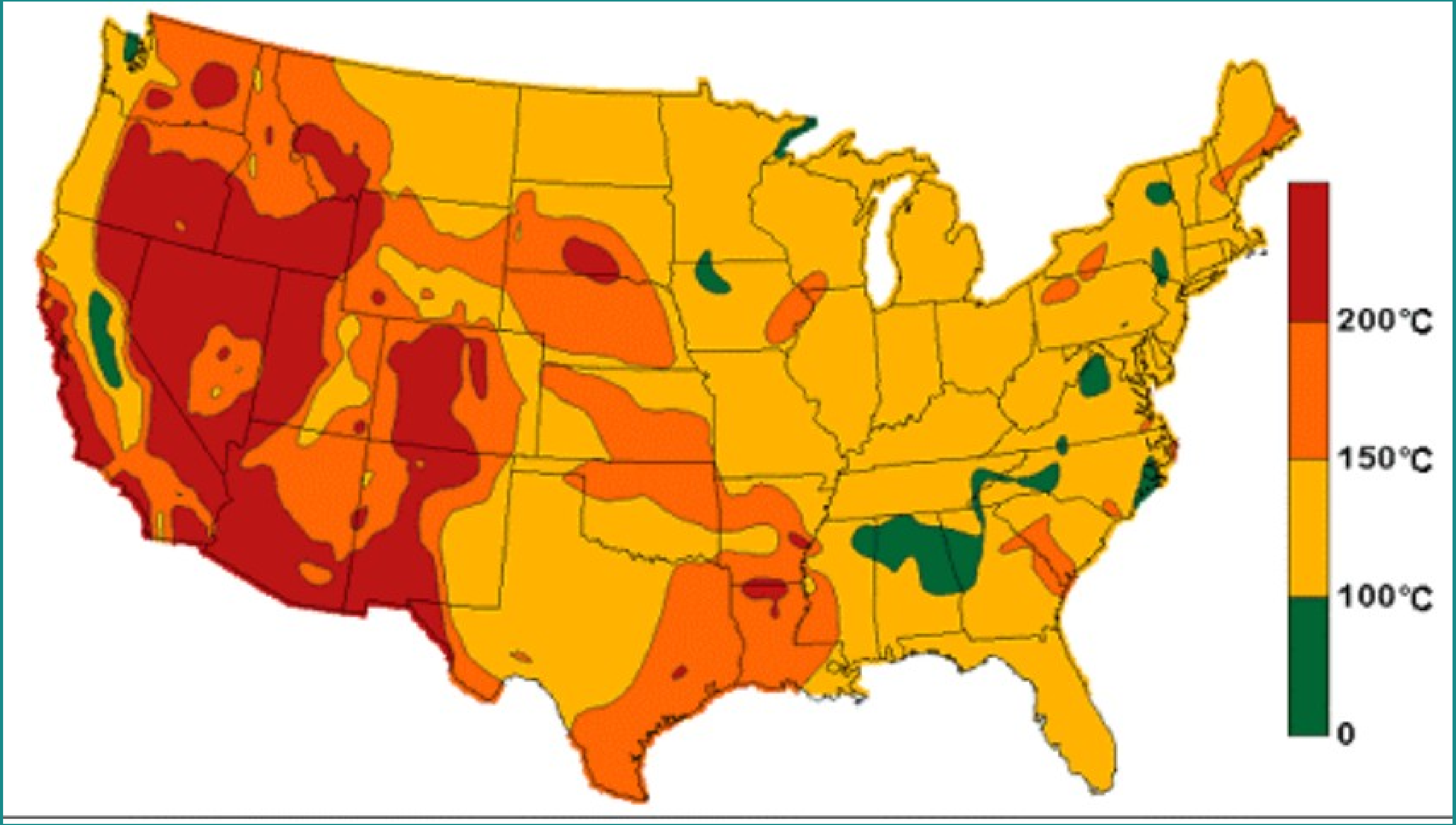


Structure of the Earth and the Geothermal Gradient

3 > 6 km = ?



Map Geo resources to 6 km



Maps show % area of US most economically usable

at 3 km depth* for Geo-Power 10, Geo-Thermal Heating 15, inactive region 65

at 6 km depth* for Geo-Power 10, District Geo-Thermal & water heating 45, District Geo-Thermal heating 5-42, inactive region 3 -40

***Note: less costly to drill & produce low pressure geo-well for thermal use than for power which requires high pressure to drive**

GTHP might apply to a large portion of inactive region with careful consideration of the economics.

District Heating Boise Idaho

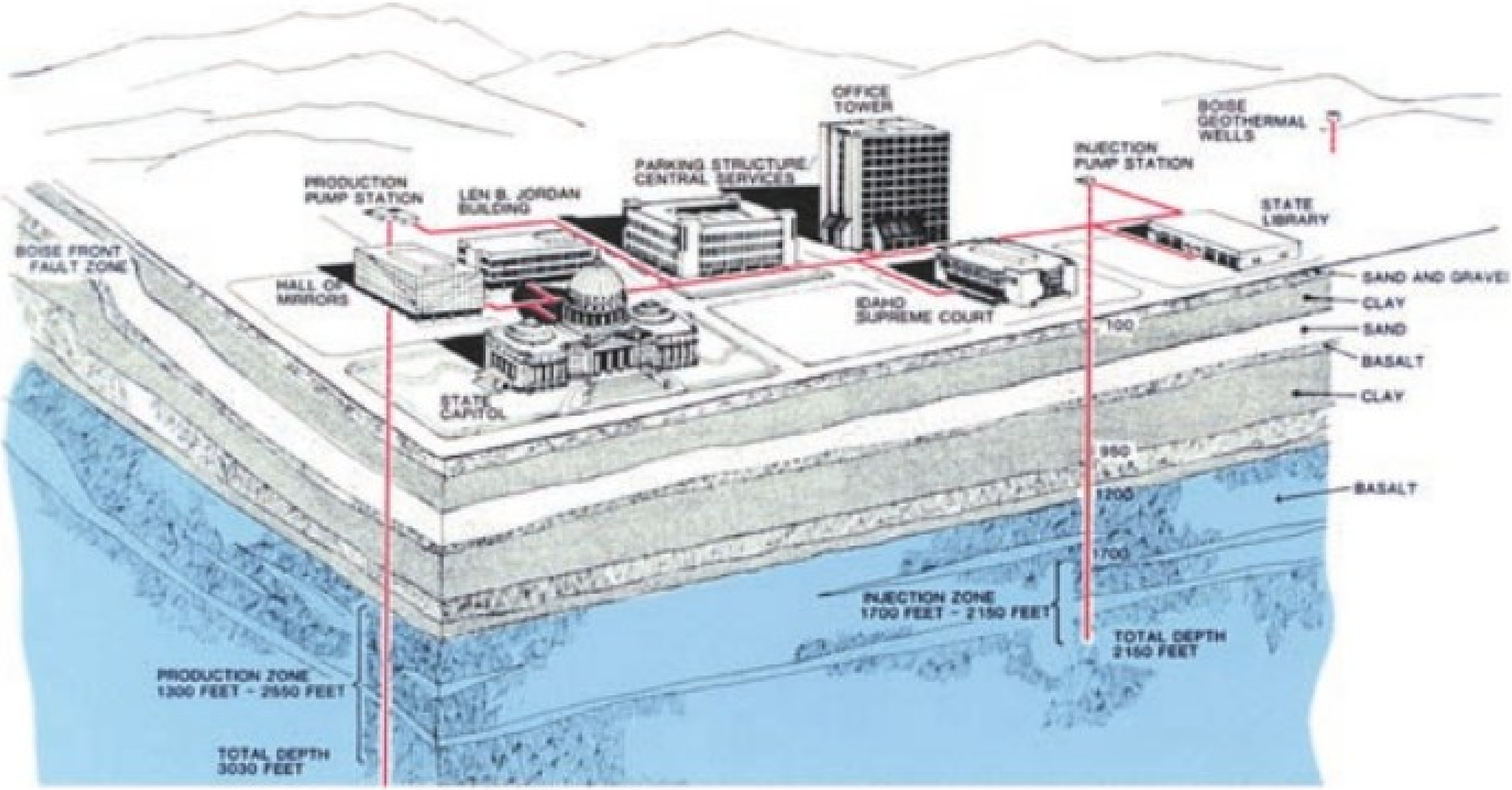
A Case Example of
Direct Thermal Heating

Production Zone 1300 – 2550 Ft

Depth of Wells 3000 Ft

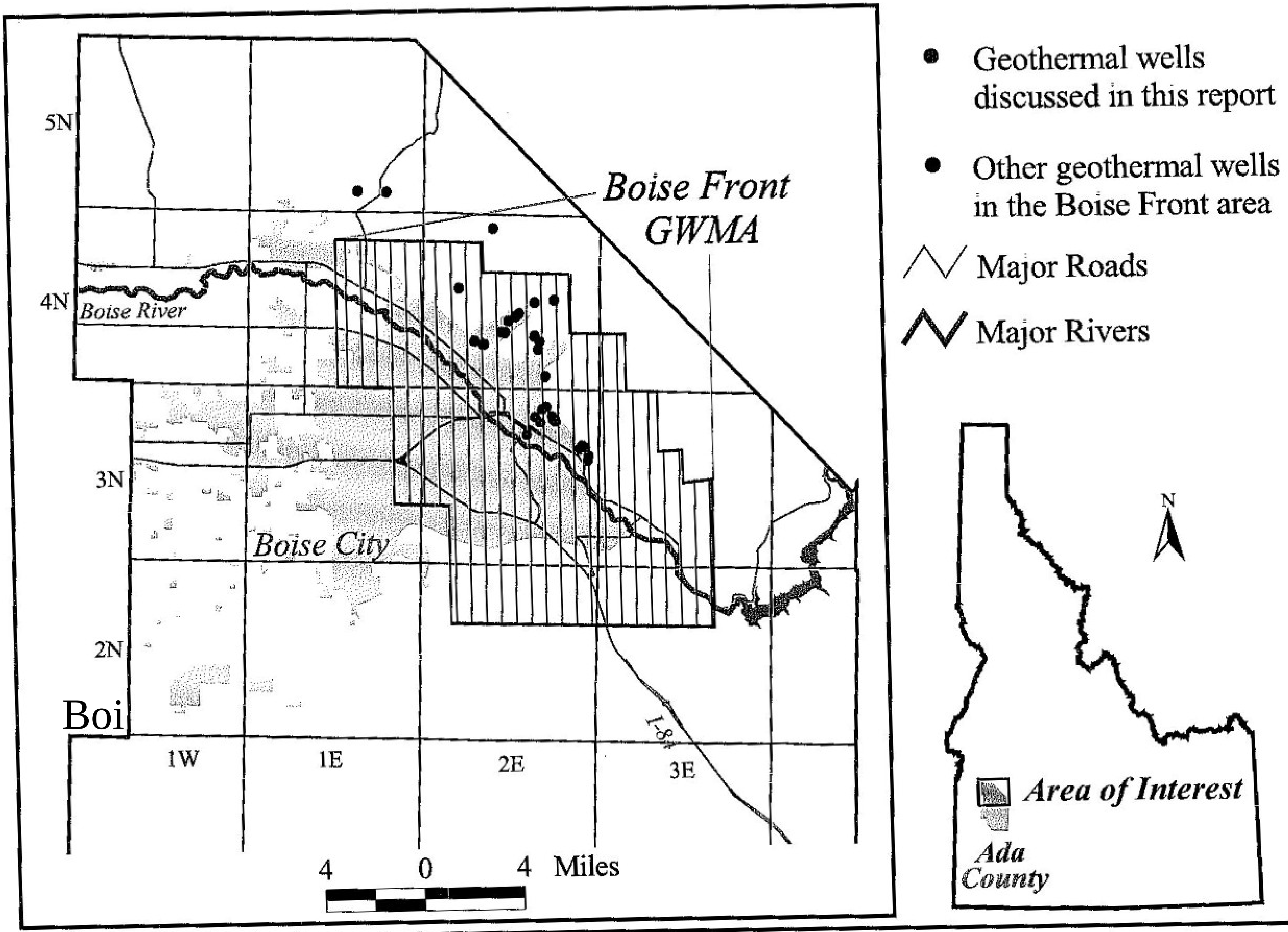
Injection Zone 1700 – 2700 Ft

District Heating Boise Idaho



The Capitol Mall geothermal district-heating system, Boise, Idaho.

HDD⇧by Rain which percolates down & into hot regions. Drill holes bring the hot fluid to surface for Electricity or Heating



wells in the Boise Front area and the Boise Front Low Temperature Geothermal

Boise Heating Degree Days

(Figure 4)

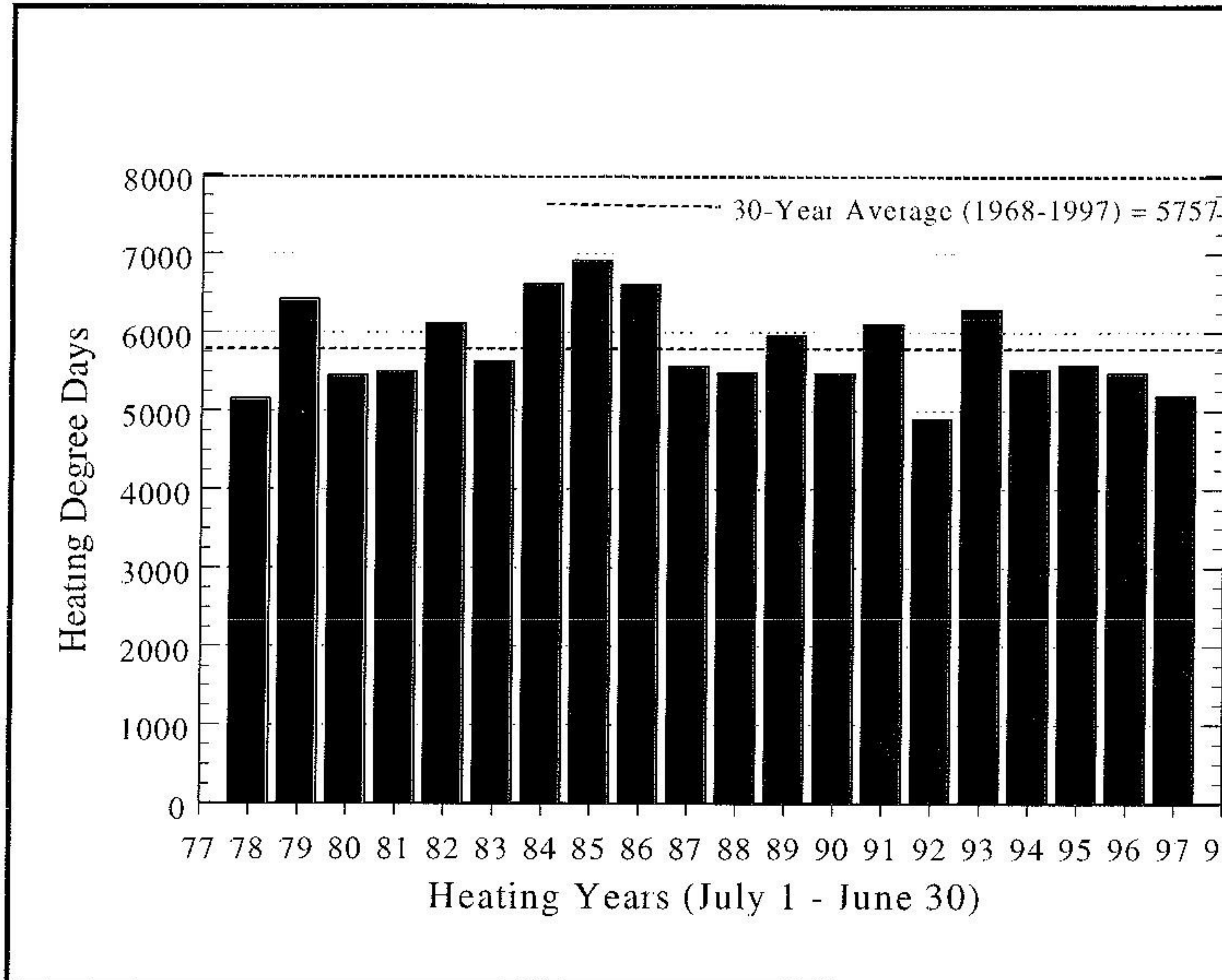


Figure 4. Heating degree day data for Boise for heating years 1978 through 1997

Capital Mall Production

300 Million gal/yr

Table 1. Annual production for the Capitol Mall geothermal system, 1983-1994 (in millions of gallons).

Year	Berkeley Group Inc. (1990)	Daily Logs	Trend Logs
1983	79.1	65.8	
1984	204.8	169.5	
1985	196.4	187.5	
1986	188.6	179.7	
1987	N/A	148.6	
1988	212.6[a]	122.7	
1989	106.3[a]	155.6	
1990		83.4	
1991		159.4	43.6
1992		136.3	75.3
1993		240.2	180.3
1994		167.9	96.3

[a] Estimated from Totalized value of 3.10 x 10 gallons for the period from January, 1988 through June, 1989 (Berkeley Group Inc. (1990)).

Monthly Production

Figure 6 shows the total monthly production for 1983 to 1994 as calculated from the Daily and Trend Logs. Monthly production ranged from 0 to 30.5 million gallons. Appendix A lists the monthly production data.

Daily Discharges

Figures 7 through 18 show the daily discharge readings from the Daily Logs for 1983-1994. The average daily discharge readings from the Trend Logs for 1991-1994 are included in Figures 15-18. The X axis for each figure is incremented by Julian days in the respective calendar year (Day 1 = January 1; Day 365 = December 31)

Definition of (HDD)
Heating Degree Days

HDD is an estimate of the energy to heat a building to a comfort level (~65°F).

CALCULATION OF HEATING DEGREE DAYS

Annual HDD = Sum [daily HDD] for all seasonal heating days.

[daily HDD] = [building comfort temperature (~65°F)]

– [mean outdoor temperature]

DIRECT THERMAL HEATING PROJECTS IN US

Thermal heat projects have large future economic potential and thus are potentially profitable projects.

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GTHP projects are economically inferior to these direct thermal heat projects

Fundamentals of Heating & Cooling for Geo-inactive Regions

All the theory, procedures, available data & calculations for heating are the same for cooling.

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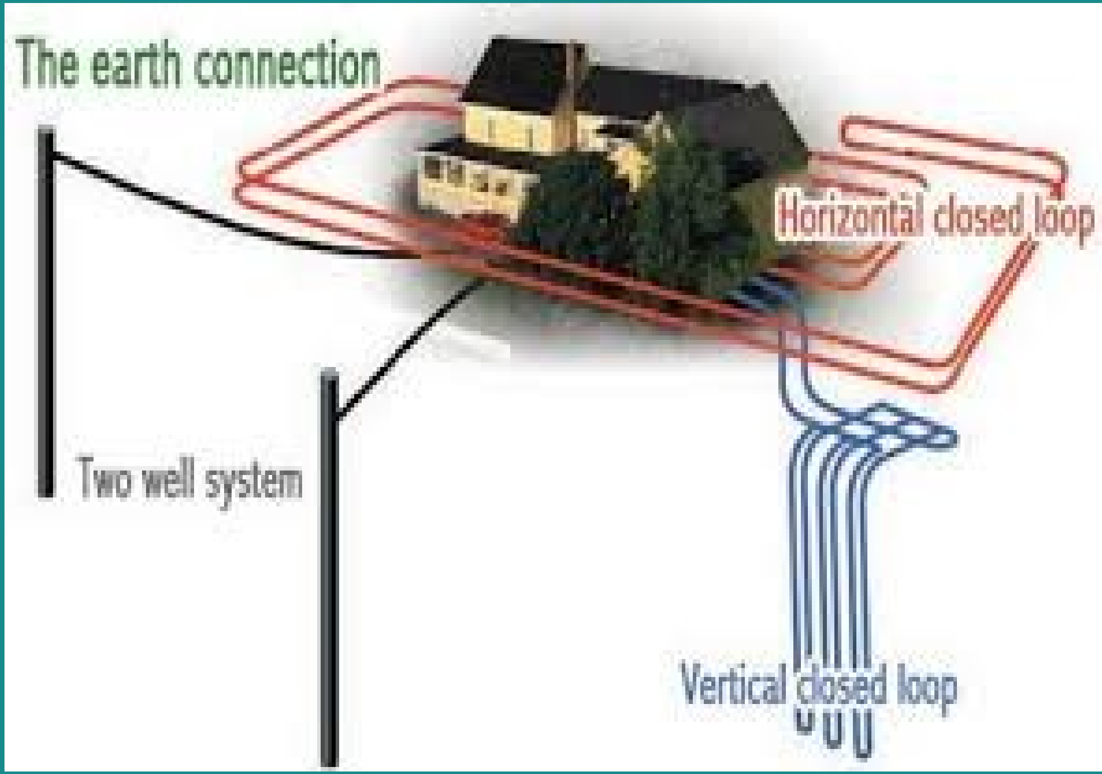
The US map for cooling, and the calculation of CCD replaces HHD using same procedures

GTHP Systems open & closed-loop systems

ponds, lakes, rivers & similar are used advantageously

Economics =f [Location, climate, distance from geothermal source, geology of crustal surface down to 200 feet.

Open Loop System **Closed Loop System**

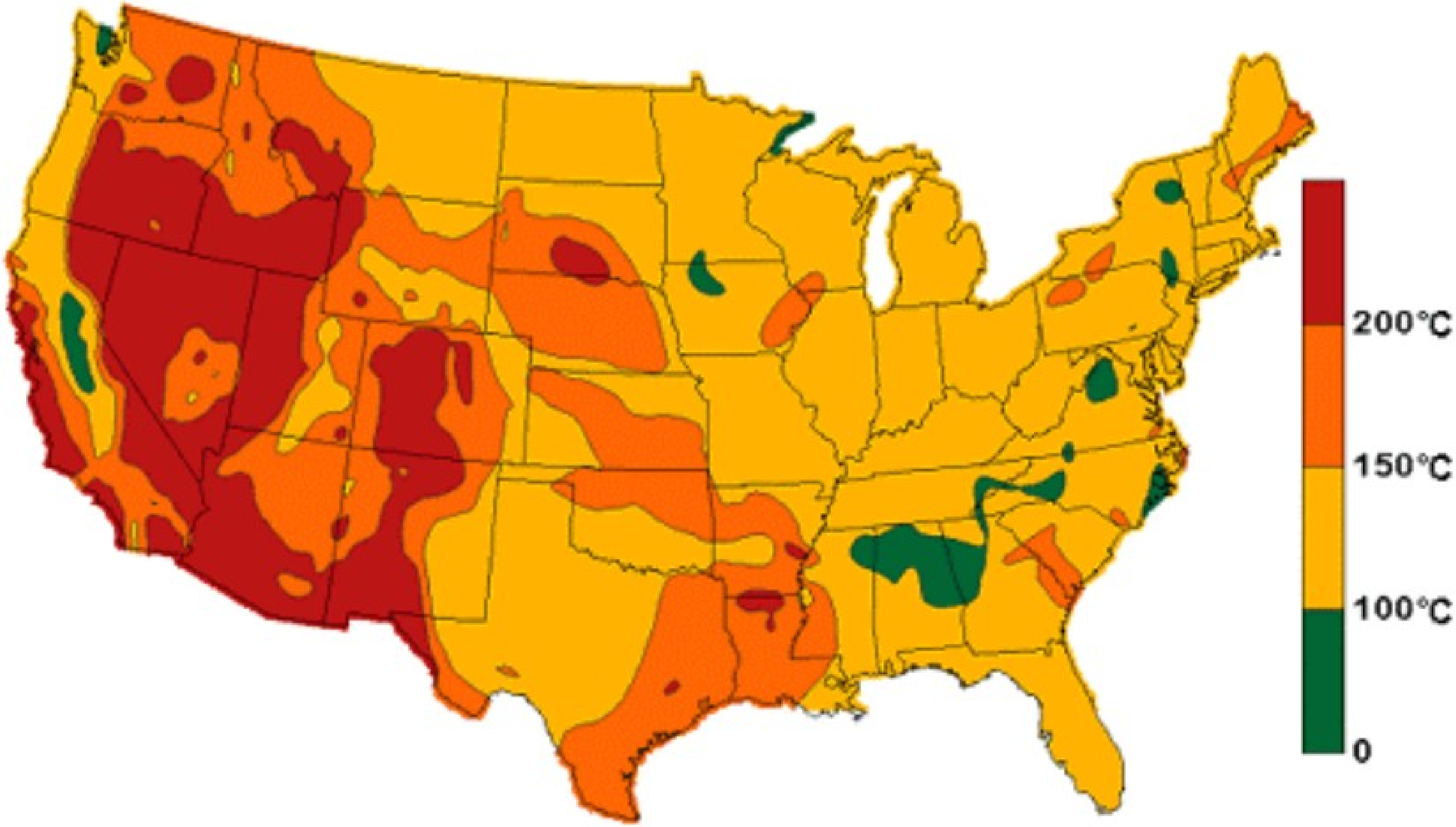


Maps show % area of US most economically usable for GTHP

at 6 km depth 5 to 40% of inactive region of the continental US

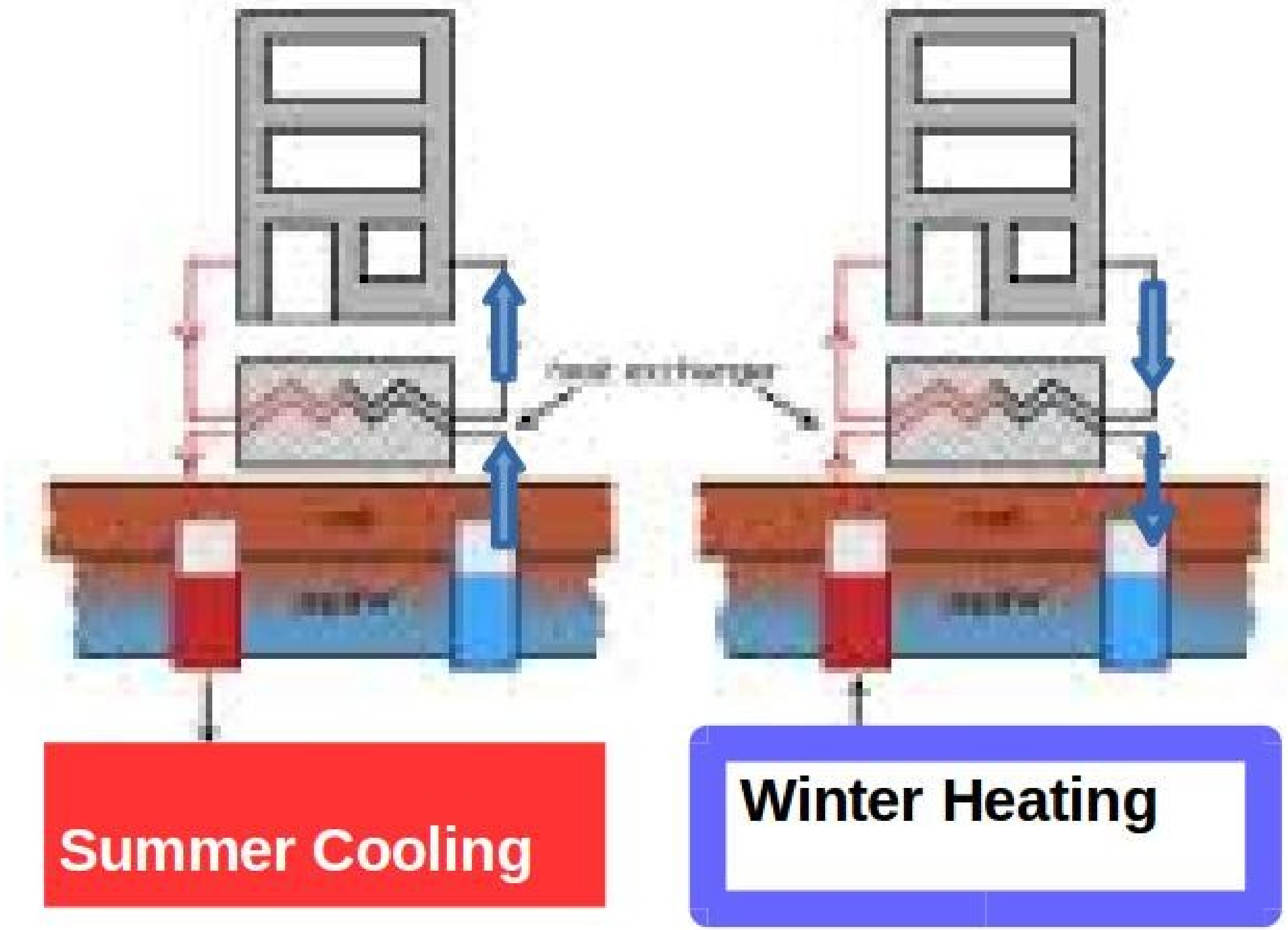
GTHP applies to a large portion of inactive region with careful consideration of the economics.

Resources to 6 km Current Practice



General concept GTHP

FLOW DIRECTION
Summer Reversed in Winter



Thank you for attending.

Questions will be answered.

Author will be pleased to answer questions
receive comments & suggestions on presentation

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