7_1 Exploration and Characterization - Geological Setting

Recap:

1. Dissolution/precipitation important within reservoirs and external plant
2. Equilibrium chemistry defines modes of precipitation/dissolution
3. Reaction rates determine rates of precipitation/dissolution

Movies: You now know enough to benefit from these

Reservoir Characteristics - Interpreting Temperature and Pressure Measurements from Wells
Rick Allis, Utah Geological Survey
https://www.youtube.com/watch?v=fClumFc3n5Y&t=2312s

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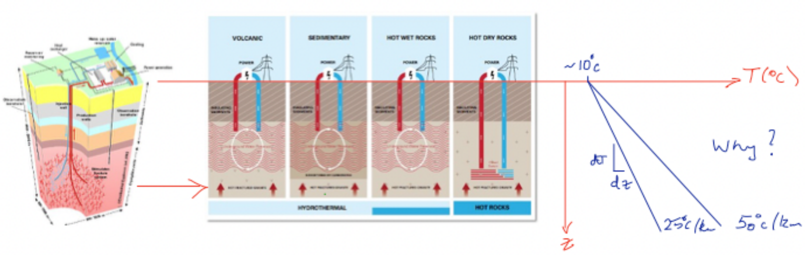
Predicting and Detecting Natural and Induced Flow Paths for Geothermal Fluids in Deep Sedimentary Basins - Stuart Simmons, EGI, University of Utah
https://www.youtube.com/watch?v=ZOJWIWzWLDg&t=2997s

Others as on the syllabus - at the Penrose SedHeat Meeting:
https://www.youtube.com/channel/UCBHQHy4hVyBJQFogrKvKUAg/videos

Resources: WG6

Motivation:

1. Motivation [10%] Provide context for the topic. *Use of relevant public domain videos* are a useful method for this. Why is this particular topic or sub-topic important in the broad view of geothermal energy engineering?



Quality of resource defined by Thermal_power = Mass_rate * c * delta_T
Therefore prospect for:
- (i) High Mass_rate/permeability/overpressure and
- (ii) High T at shallow depth

Less crucial in "engineered" systems - "EGS" and "GSHP"

Scientific Questions:

2. Scientific Questions to be Answered/Outline [10%] What questions arise from the motivation. What are the sub-topical areas that address these scientific questions.

1. What geological habits/characteristics are indicative of geothermal reservoirs?
2. What methods are available to discover them and characterize the resource?
   - A. Geology/Geophysics
   - B. Drilling/Instrumentation
   - C. Well completion/Testing

GEOLOGY

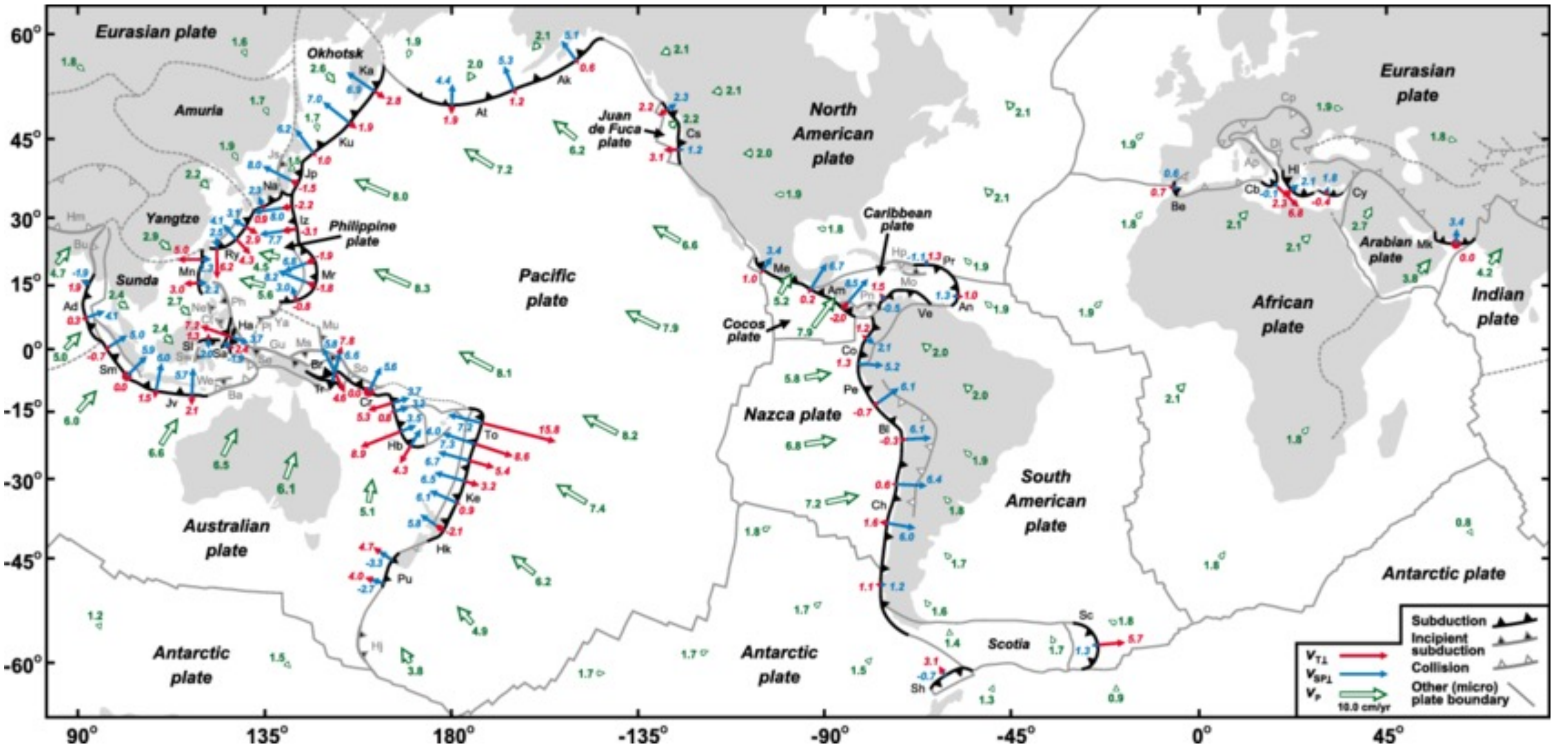
1. What geological habits/characteristics are indicative of geothermal reservoirs?
    A. Analysis of geology at a variety of scales - plate boundary to local
        a. Reports
        b. Surface features - remote sensing and imagery
        c. Drilling records
    B. Initiate local investigation
        a. Geochemical signatures
        b. Geophysical investigation
        c. Drilling and sampling
        d. Well completion then well testing

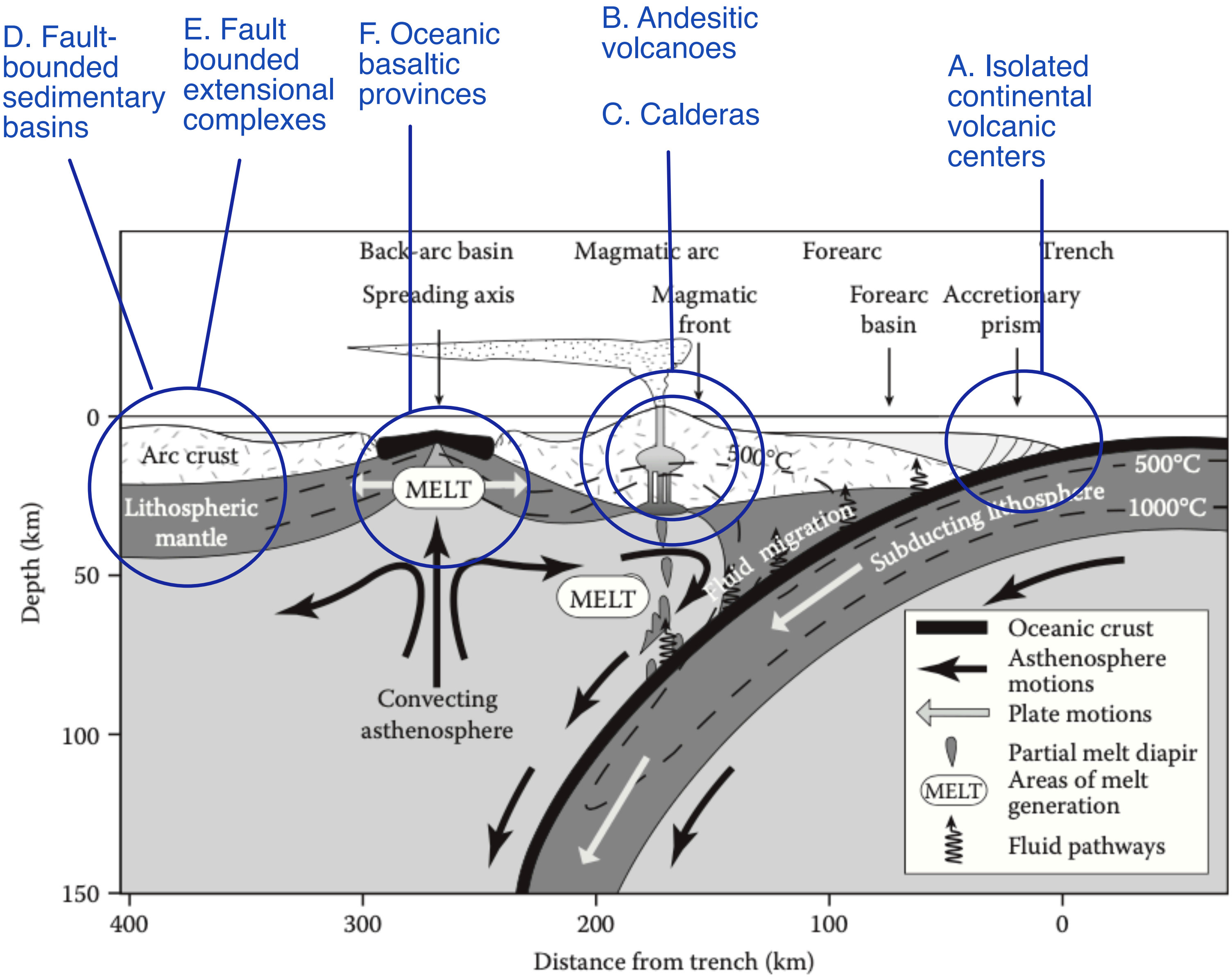
Classification of Geothermal Systems - Regional Perspective (WG6)

TABLE 6.1
Geological Settings That Host Geothermal Systems

Type of System	Topography	Depth to Resource (m)	Surface Manifestations	Permeability
Isolated continental volcanic centers (A)	Mountainous	Moderate to deep (2000 to >4000)	Hot springs, pools	Low to moderate
Andesitic volcano (B)	Mountainous	Moderate to deep (2000 to >4000)	Restricted, depending upon depth and groundwater level	Low to moderate, but fracture permeability can be high
Caldera (C)	Rugged ring fractures, gentle floor	Shallow to moderate (1500–2500)	Springs, pools, geysers, mud pots common	High permeability in tuffaceous units, some fault permeability
Extensional sedimentary basin and spreading centers (D, E)	Rugged on horsts, gentle in grabens	Usually deep (>2500 m)	Normally along bounding faults	Mainly along bounding faults or transverse faults
Oceanic basaltic provinces, hot spots (F)	Rugged	Shallow (<2000 m)	Lava flows, hot springs common	High horizontal permeability along flow units/breccias, etc.; low vertical, mainly fractures

Source: Paul Brophy, pers. comm.

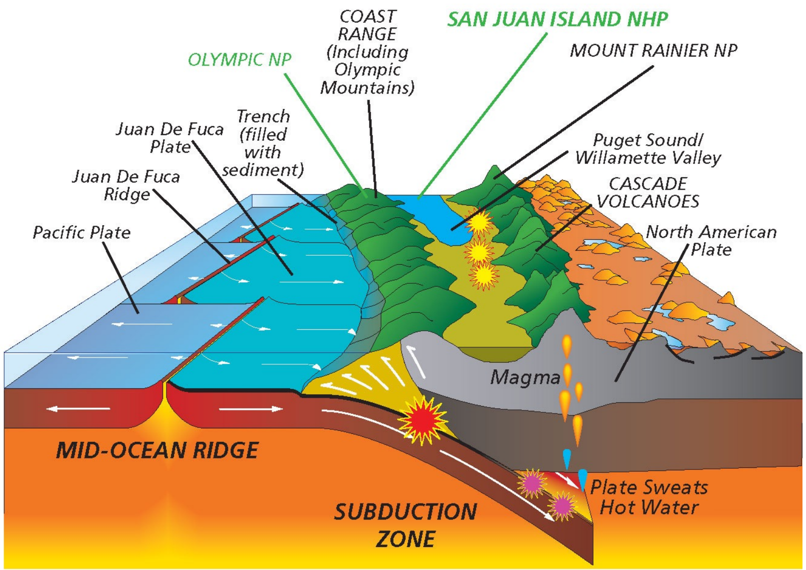

Eurasian plate
Okhotsk
Amuria
Yangtze
Philippine plate
Sunda
Pacific plate
Juan de Fuca plate
North American plate
Caribbean plate
Cocos plate
Nazca plate
South American plate
Scotia
Eurasian plate
African plate
Arabian plate
Indian plate
Australian plate
Antarctic plate
Antarctic plate
Antarctic plate
Antarctic plate
Subduction
Incipient subduction
Collision
Other (micro) plate boundary
10.0 cm/yr
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
90°
135°
180°
-135°
-90°
-45°
0°
45°


D. Fault-bounded sedimentary basins
E. Fault bounded extensional complexes
F. Oceanic basaltic provinces
B. Andesitic volcanoes
C. Calderas
A. Isolated continental volcanic centers
Back-arc basin
Magmatic arc
Forearc
Trench
Spreading axis
Magmatic front
Forearc basin
Accretionary prism
Arc crust
Lithospheric mantle
MELT
500°C
500°C
1000°C
MELT
Fluid migration
Subducting lithosphere
Convecting asthenosphere
Oceanic crust
Asthenosphere motions
Plate motions
Partial melt diapir
Areas of melt generation
Fluid pathways
Depth (km)
0
50
100
150
400
300
200
100
0
Distance from trench (km)

A. Isolated continental volcanic centers (e.g. The Geysers)

B. Andesitic volcanoes (e.g. Cascade volcanoes incl. Newberry, Montserrat, BWI)

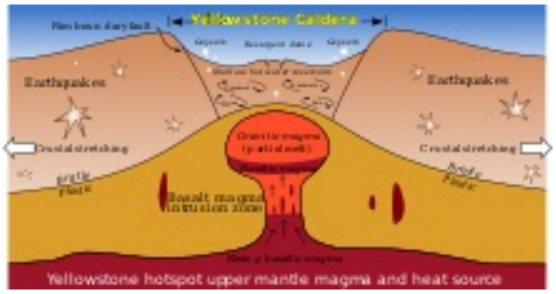
C. Calderas (e.g. Valles Caldera, NM (Fenton Hill), Yellowstone, Crater lake, OR, Long Valley, CA)

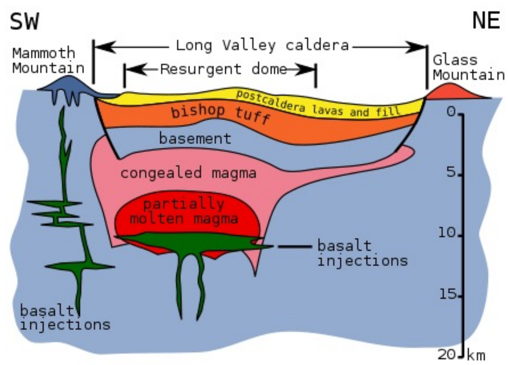


Cascadia earthquake sources

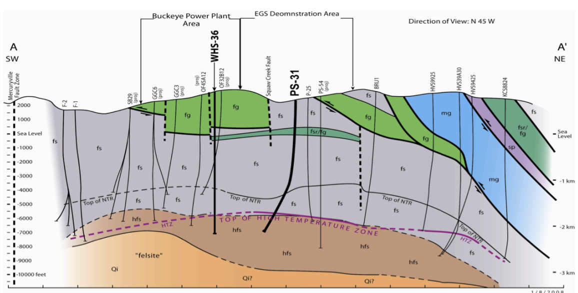
Source	Affected area	Max. size	Recurrence
Subduction Zone	West. WA, OR, CA	M 9	500-600 years (1700)
Deep Juan De Fuca Plate	West. WA, OR	M 7+	30-50 years (1949, 1965, 2001)
Crustal faults	WA, OR, CA	M 7+	hundreds of years? (CE 900, 1872)

C. Yellowstone & Long Valley

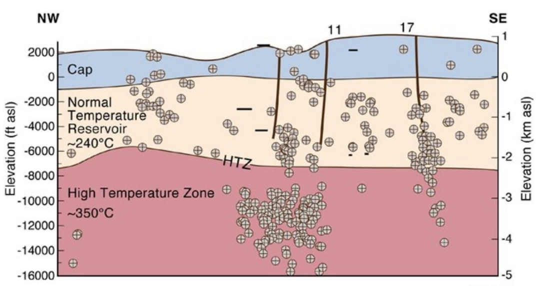




A. The Geysers

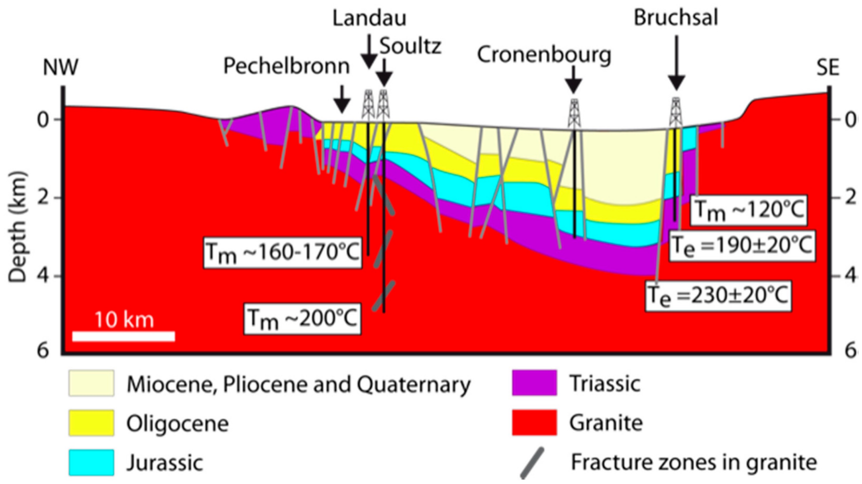


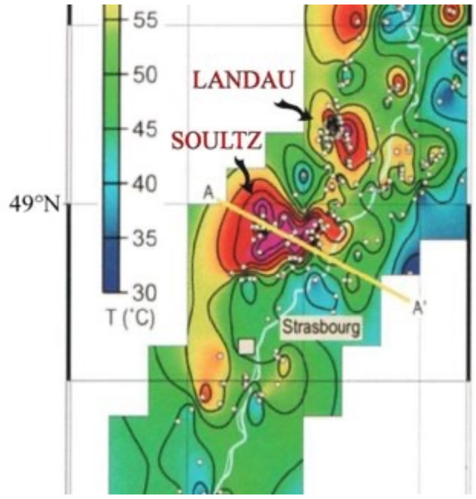
Major faulting General geologic features

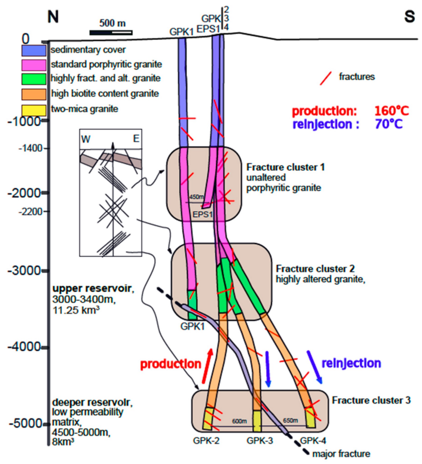


B. Soufrière Hills Volcano, BWI

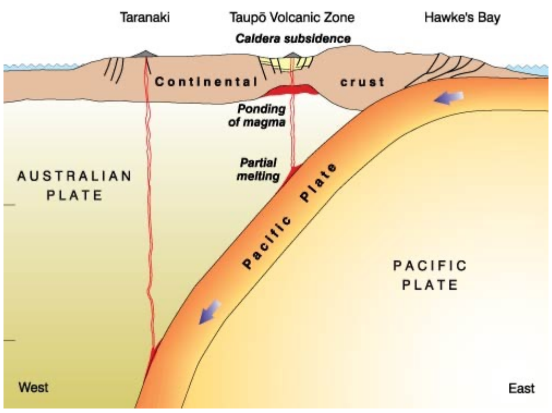
D. Fault-bounded sedimentary basins (e.g. Rhine graben France/German and Soultz EGS, Salton Sea, CA)

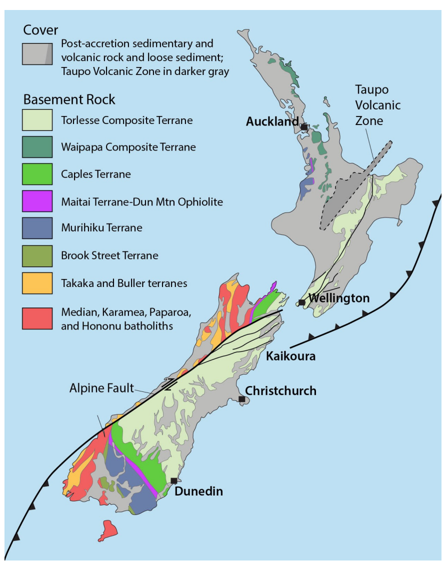




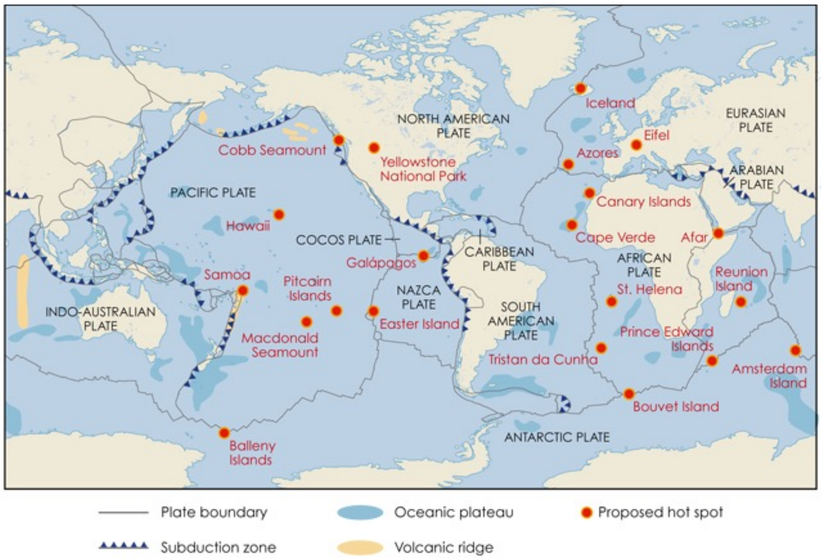


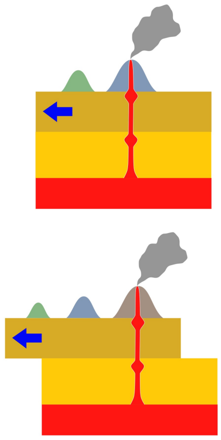
E. Fault bounded extensional complexes (e.g. Taupo Volcanic Zone, NZ, East Africa Rift)

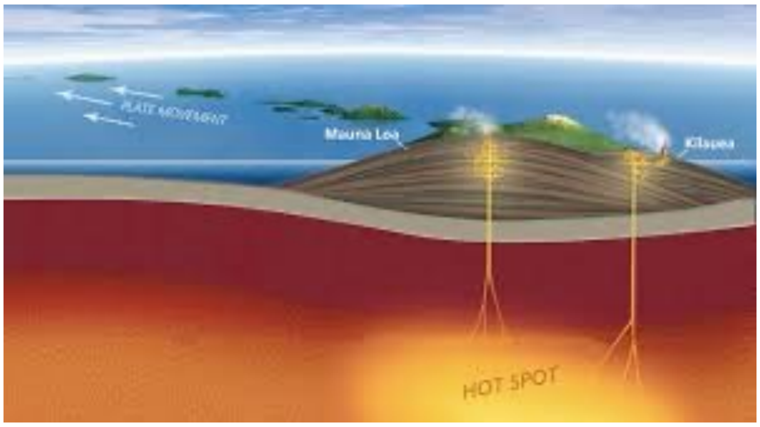




F. Oceanic basaltic provinces (e.g. Hawaii, Canary Islands, Azores, Iceland)





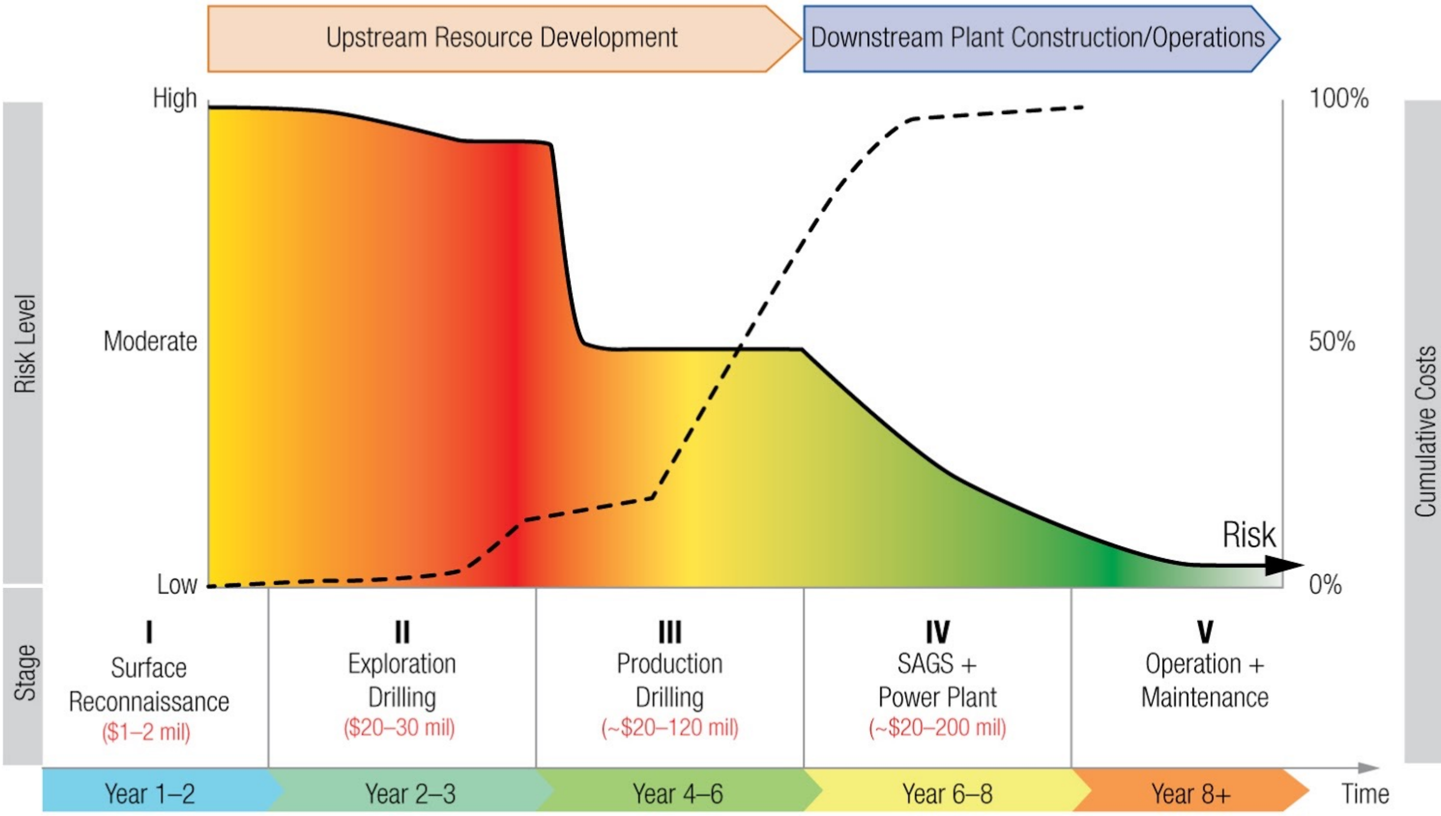


These geological settings control the location of largely hydrothermal resources

What determines the optimal placement of wells? What methods are available to de-risk exploration

What about EGS in widespread locations and sedimentary aquifers ......

Figure 1 | A Conceptual Representation of Risks and Costs during the Different Stages of a Geothermal Development



Source: Adapted from Geothermal Handbook (ESMAP 2012).