Geothermal Decision Making And Risk

for

NZGA

by

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The Terminology of Geothermal Sustainability

- Terminology matters
  - Regulators will use these terms
  - Regulations are hard to change
  - Terms should sound like they mean
  - Using “excessive” instead of “non-steady state” exploitation may predetermine the decision outcome

Geothermal Sustainability and Risk

- It's people who make risky decisions
  - Resource management can be taught
  - 1986-2003 hiatus shows that industry experience loss has a significant impact on quality of risky decisions
  - Sustainability of human resources
- Value of data
  - More data better if it cost-effectively improves decisions but
  - Cost, not just in funds but also management attention, project timing, research priorities, etc
  - Incremental comparative benefit, can you get 80% of the value for 20% of the cost using another approach?
    - Geochemistry often trumps geophysics
    - Natural state temperature versus geoscience

Geothermal Decision Styles

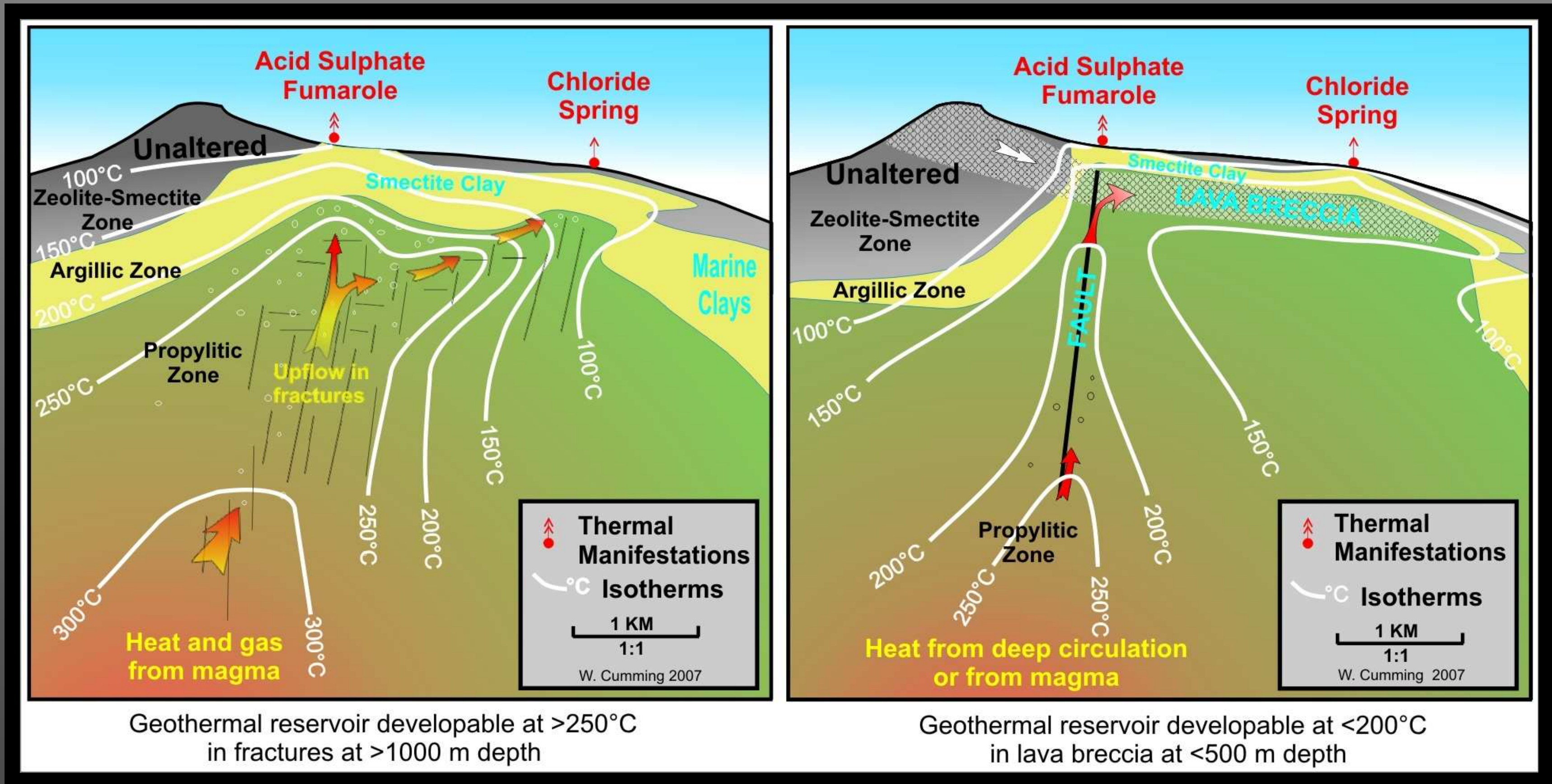
- Deciders and Oracles
  - Experienced manager, sometimes with time and interest to understand experts
  - Experts, sometimes in-house, often not
  - Methods that the manager is sold on
- Decision Teams
  - Experienced team who are experts or are responsible for understanding expert advisors
  - Team is responsible for decision recommendation
  - Decision tools like trees and tables

Geothermal Decision Makers

- Smaller geothermal developers
  - Manage risk for few fields and prospects
  - Small geothermal staff
  - Sometimes limited case history exposure unless they skillfully exploit consultancies
  - Some are thinly-capitalized
- Larger geothermal developers
  - There aren’t any like in O&G and mining
  - Some implement team decision making
  - Some use decision and risk tools

Geothermal Systems

>200℃ <200℃



Geothermal Resource Risk Issues in Exploration Phase

- Access timing and cost
- Temperature
  - >230℃ for flashed power
  - ~120 to 180℃ for binary
- Permeability (MW well deliverability)
- Chemistry
  - corrosion and scaling risk
- Surface Heat Loss (minimum size)
- Initial Well Targeting Confidence
- Area (most important component of size)
- Resource depth

Exploration Data to Assess Geothermal Resources

Is it there?

- Temperature: Water and gas geochemistry on all features
- Chemistry: Same as temperature but using process plots
- Permeability: Deep resistivity sections. Structural model. Map of thermal features and altered ground.

If yes, how big is it? P_{10}, P_{50}, P_{90}

- Area: Similar to combined chemistry and temperature
- Thickness, porosity: Resistivity sections, geology
- Recovery factor: Analogous fields, plausible MW/km^2

Are there fatal risks?

- Access and hazards: Review access and hazards
- Environmental etc: Assess risk for permit denial etc

Exploration Geoscience Questions

Integrate geochemistry, geophysics and geology in a consistent geothermal conceptual model.

- **Does a reservoir exist?**

  $POS_{exploration} = P_{temperature} * P_{permeability} * P_{chemistry}$

- **If it exists, how big is it?**

  Characterize uncertainty P_1, P_{10}, P_{20}, P_{50}, P_{80}, P_{90}, P_{99}

  Estimate: $P_{Exploration\ Failure}$, $P_{Appraisal\ Failure}$

  $P_{Feasible\ Development\ Cases}$: High, Most Likely, Low

- **What is the lowest cost drilling strategy to discover, then prove, and then develop the resource?**

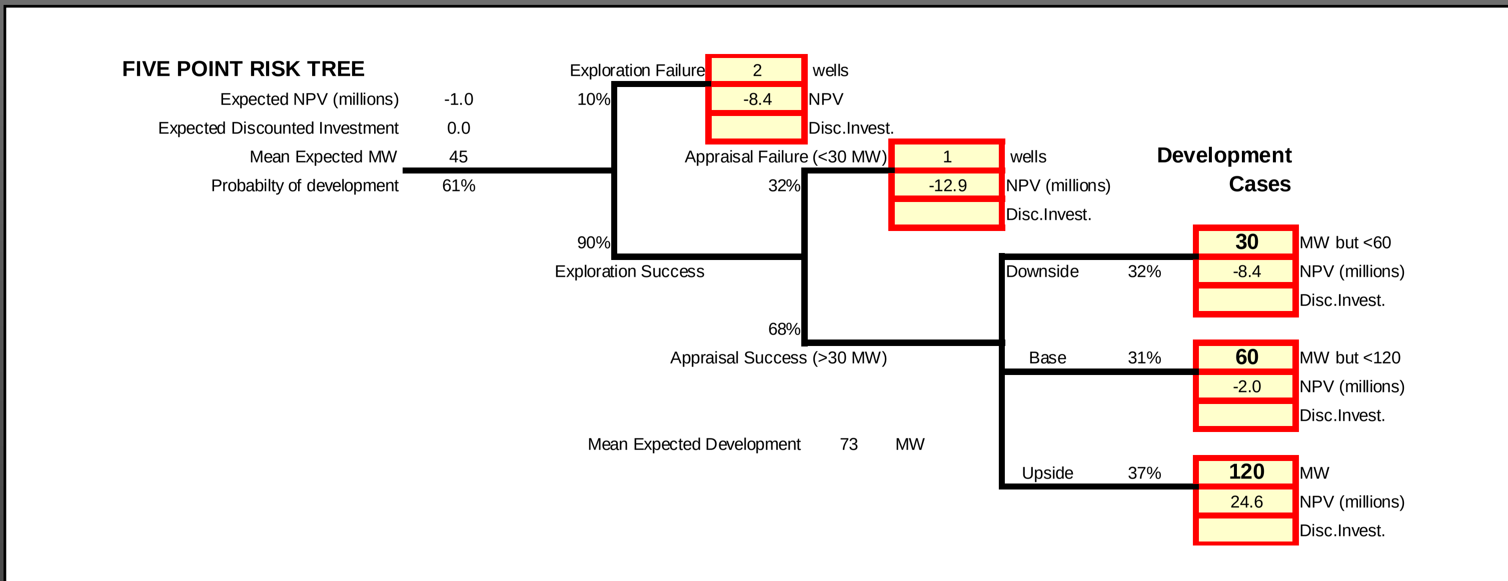
  Drilling tree consistent with resource cases

  Failure cases as well as success cases

Geothermal Resource Capacity Assessment

Assess Probabilities for ~5 Cases with the Largest Economic "Break Points"

- Exploration success and failure
  - Answers the question, "Is it there?"
- Appraisal success and failure
  - Answers the question, "Assuming that it's there, is it big enough to develop?"
- ~3 development cases
  - Answers the question, "Assuming that it's big enough to develop, what's the likely range of development size?"



Well Targeting Decision Table

Prepare a decision table comparing target concepts and risks.

1. What first target would have greatest chance of producing >10 MW?
2. What is greatest risk of that first target: tight, cold, or acid?
3. If that greatest risk is true and the first well fails, where next?

Six candidate locations testing conceptually different targets

Indicators	A	B	C	D	E	F
Geochemistry						
MT Geometry						
MT Resistivity						
What Else?						
Conceptual Risk						
Summary						

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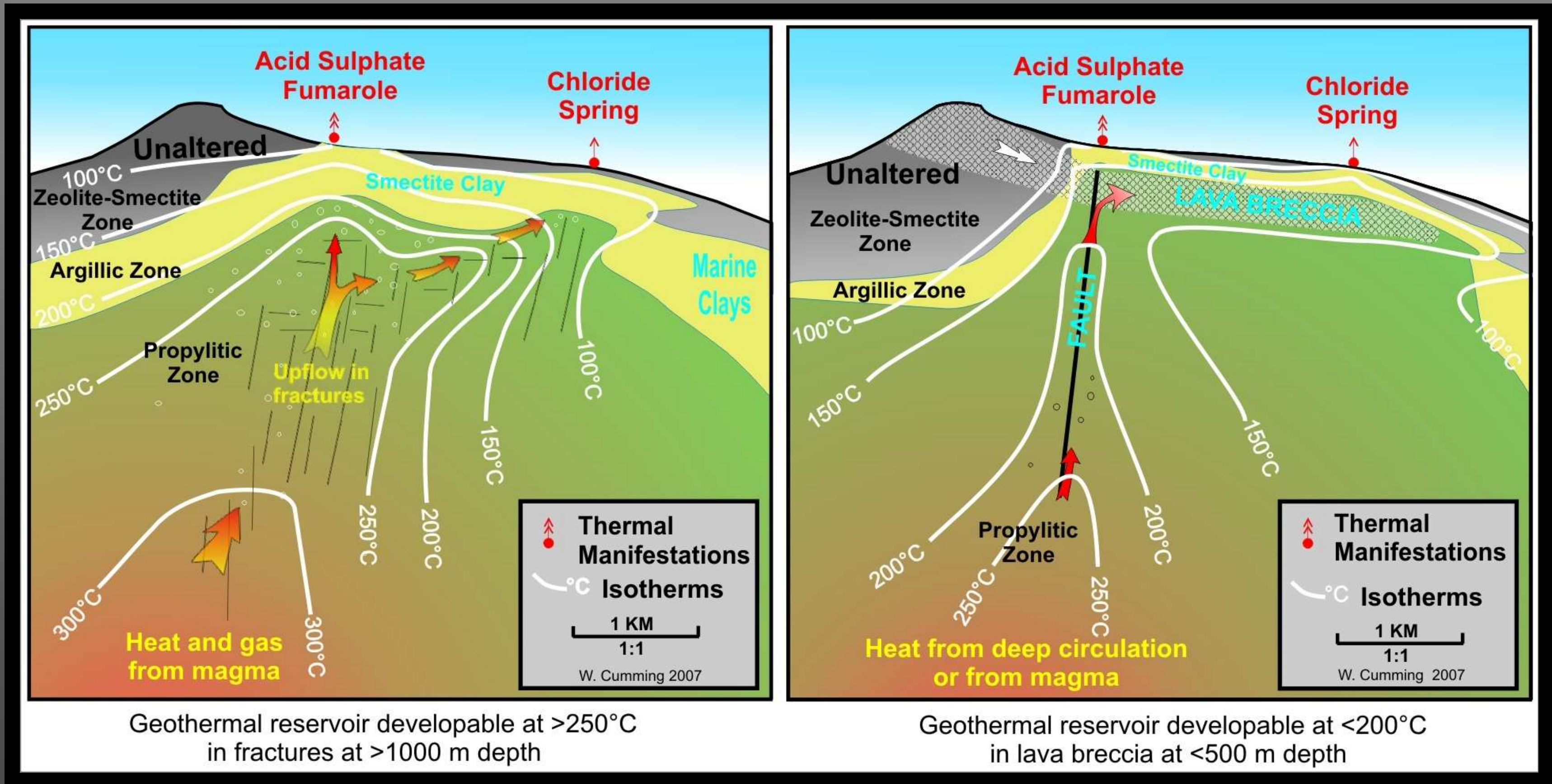

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