

40th Anniversary

Chemical Characteristics of Geothermal Fluids in Jiaodong Peninsula, Shandong, China

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Geothermal developments in Shandong



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Problems of geothermal resource development

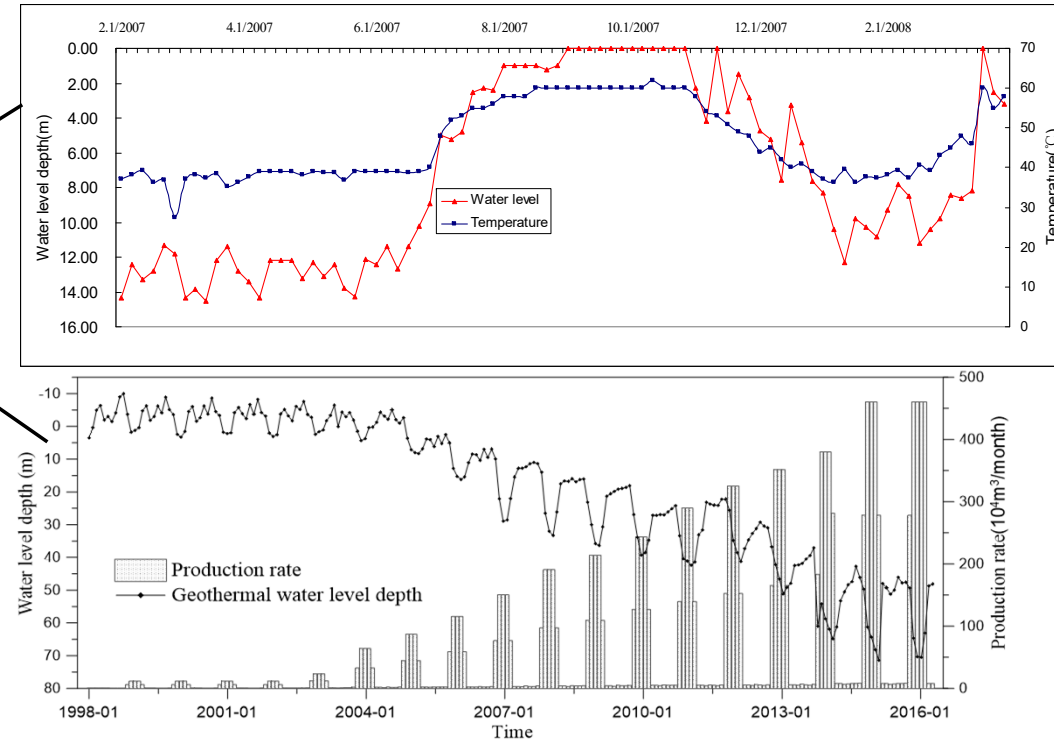
Water level decline and temperature changes



- Low to medium temperature: $< 150^{\circ}\text{C}$
- Over extraction has occurred and induced some corresponding environmental issues, including continuous water level decline, colder water intrusion, temperature drop, etc.

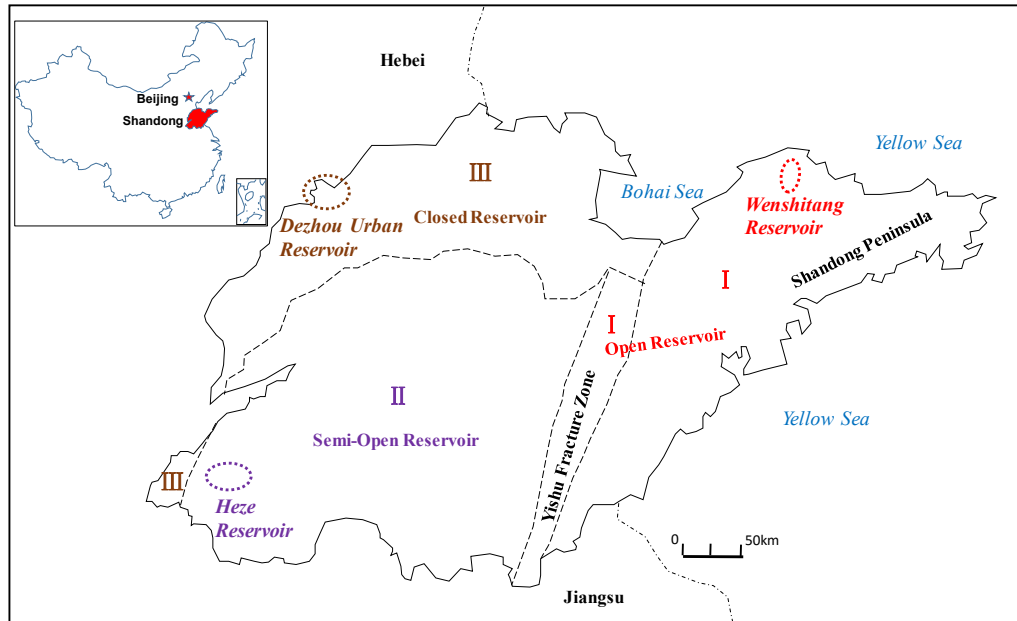
Main reasons for issues :

- Reservoir recharge, runoff and discharge conditions are not clear enough
- Lack of reinjection or rapid reinjection rate decline
- Previous calculations of geothermal fields' production potential were not based on the restrictions set by water level and temperature drawdown



Objectives of study

Classification of reservoirs based on renewability



My study focus on solving these problems and preventing new issues occurring:

- Build up a classification based on reservoirs' renewability
- Study factors influencing renewability and sustainable utilization
- Use case studies to show how to assess sustainable yield

Materials and Methodology

- (1) Regional geological and hydrogeological survey
- (2) Hydro-chemical and isotope sampling and analysis of geothermal water
- (3) Pumping test, reinjection and tracer test
- (4) Measuring geothermal water level, temperature and quality, together with production rates
- (5) To understand recharge, runoff and discharge conditions through hydrogeological survey, hydro-chemical and isotope analysis, as well as regimes observation and pumping test
- (6) To find out the potential risk of cooling and clogging of long term reinjection through reinjection and tracer tests and long term monitoring of temperature, water level and chemistry
- (7) To determine the factors influent sustainability quantitatively, and then to evaluate the reservoir's open degree as open, semi-open and closed
- (8) Modeling for sustainable yield and optimize production for Open, Semi-open and Closed reservoirs



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The Shandong area



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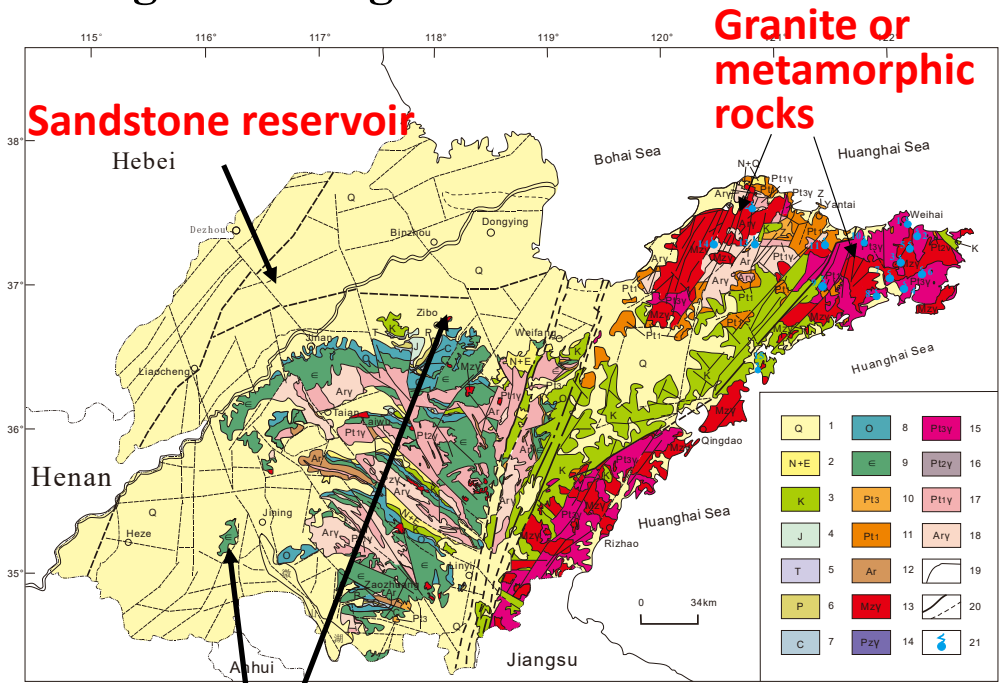
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Research area background

Geological setting



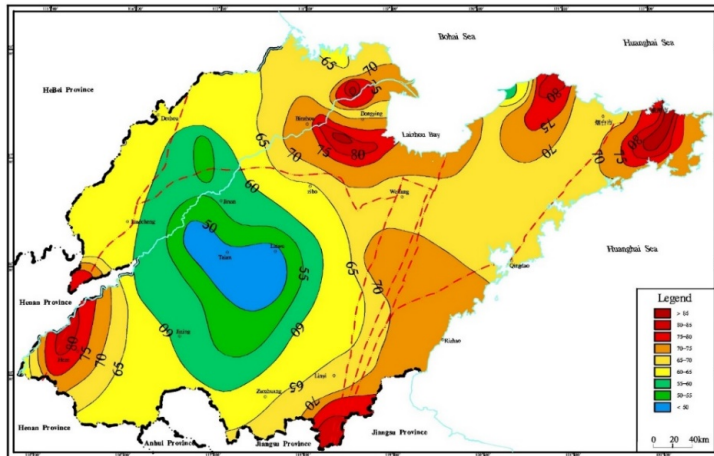
Simplified Geological map of Shandong Province



- **Main aquifers:** Sandstone(Neogene)
- **Distribution:** Northwestern Shandong sedimentary plain, conduction-dominated
- **Main aquifers:** limestone (Cambrian and Ordovician)
- **Distribution:** Southwestern Shandong Plain and middle Shandong uplift, conduction-dominated
- **Main aquifers:** Granite and metamorphic rocks
- **Distribution:** Shandong Peninsula, Controlled by: Neotectonic and large- deep faults, convective heat flow

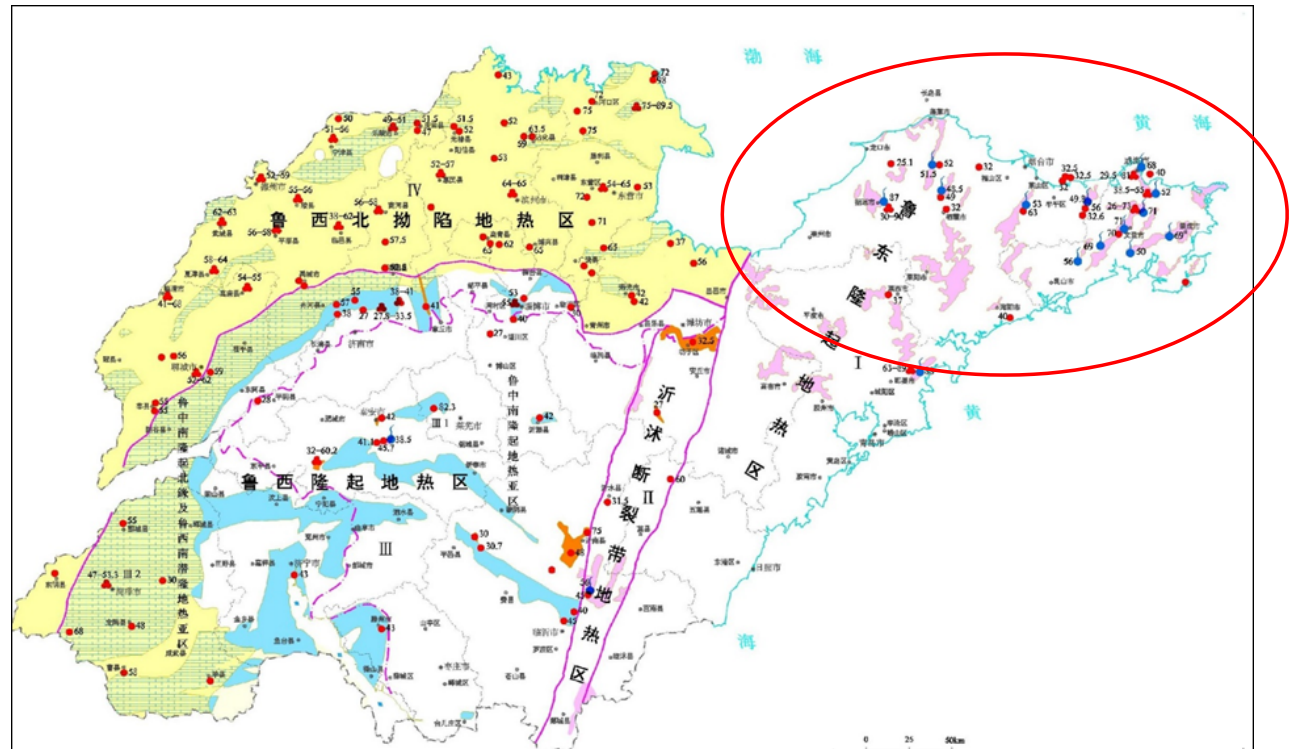
Research area background

Distribution of geothermal fields



Heat Flow map of Shandong Province (mW/m^2)

Partial data from JIANG G Z, et al. 2016.



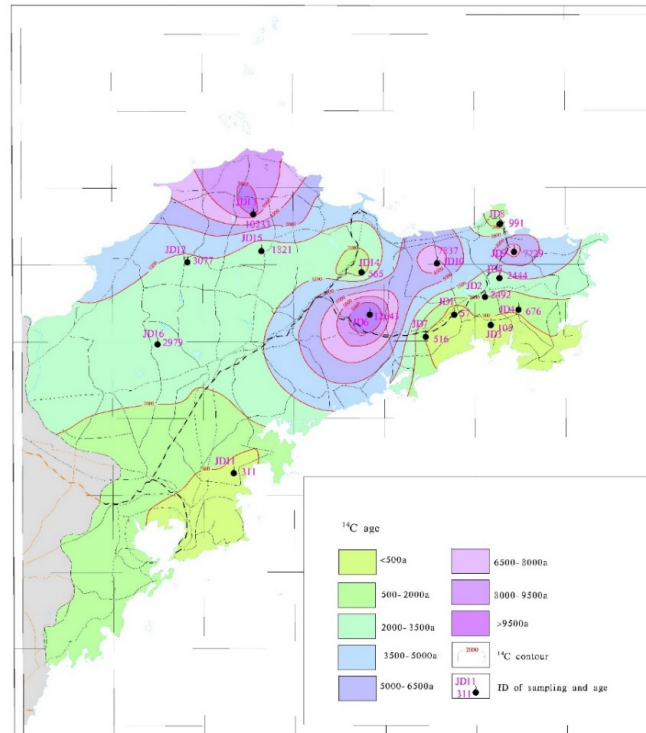
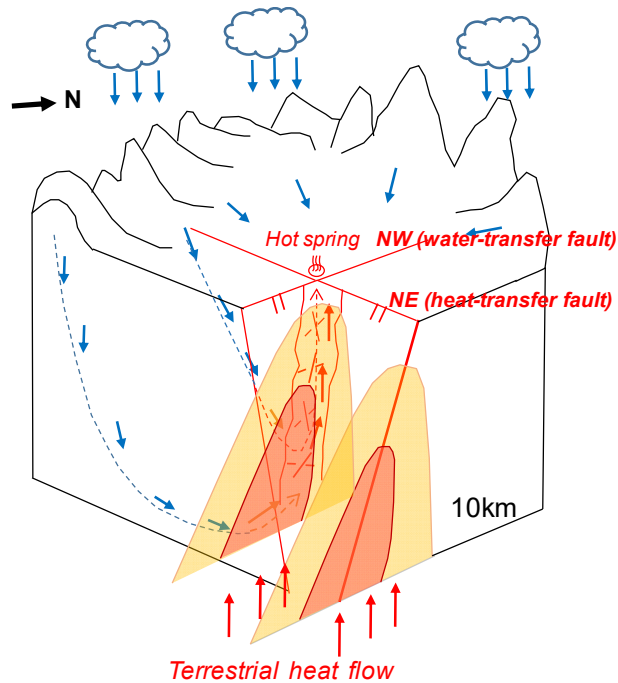
Geothermal fields distribution in Shandong Province

- 16 hot springs mainly distributed in Shantung Peninsula, with temperatures ranging from 50 to 100 °C. More than 150 geothermal wells have been successfully drilled in Shandong Province, with temperatures between 40 and 100 °C



General reservoir characteristics

Open reservoir



- **Controlled by:**
- Neotectonic large and deep faults
- Convective heat flow
- **Main aquifers:**
- Granite and metamorphic rocks
- **Manifestations:**
- Geothermal springs (50-100°C)
- **Distribution:**
- Shandong Peninsula
- **Ground water age:**
- Most less than 1000a, some can be around 10000a

Results



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Why ?

- **Chemical characteristics of geothermal fluids**
- Understanding of the mechanism of reservoir formation, including origin of water, mixing processes, runoff and discharge conditions is not clear enough
- Reservoir temperatures assumed before are not very credible
- Water-rock interaction processes are mostly ignored in previous studies



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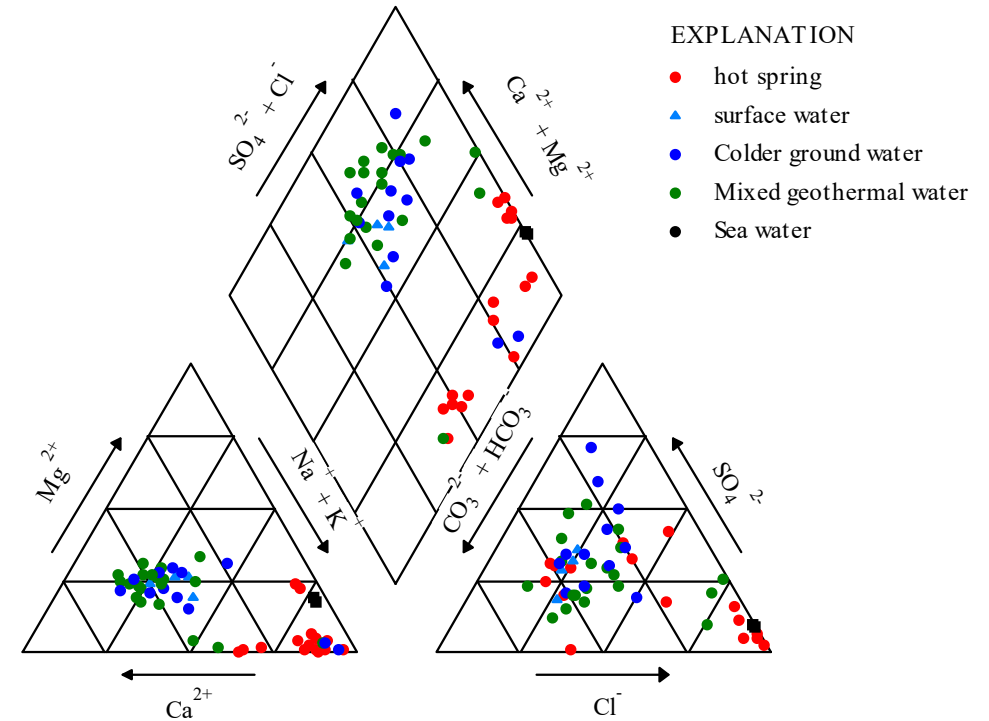
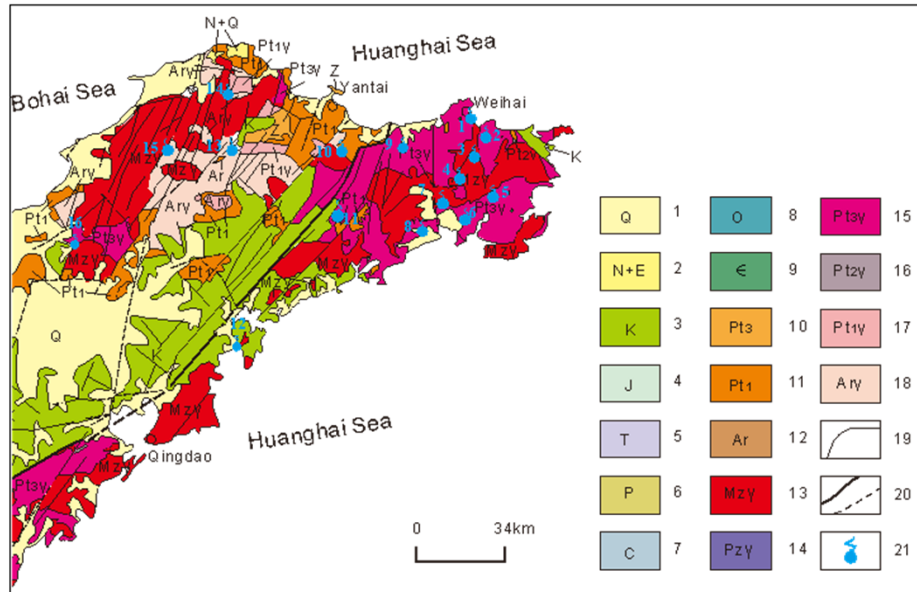
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Chemical characteristics of geothermal fluids

Open reservoirs- Jiaodong Peninsula

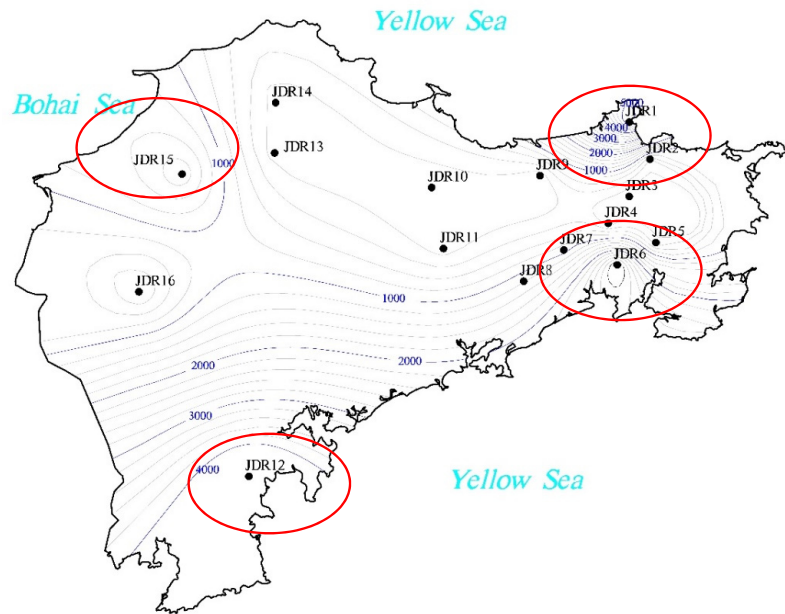


- Strata: intrusive rocks, metamorphic rocks, cretaceous sediments, volcanic accumulation and loose deposits of the Quaternary period
- So far, 16 hot springs were found , all flow out in points formed at the cross positions of the structures
- The strikes of faults that controlled the formation of hot springs occur in four types: NE, NW, NNE and NNW

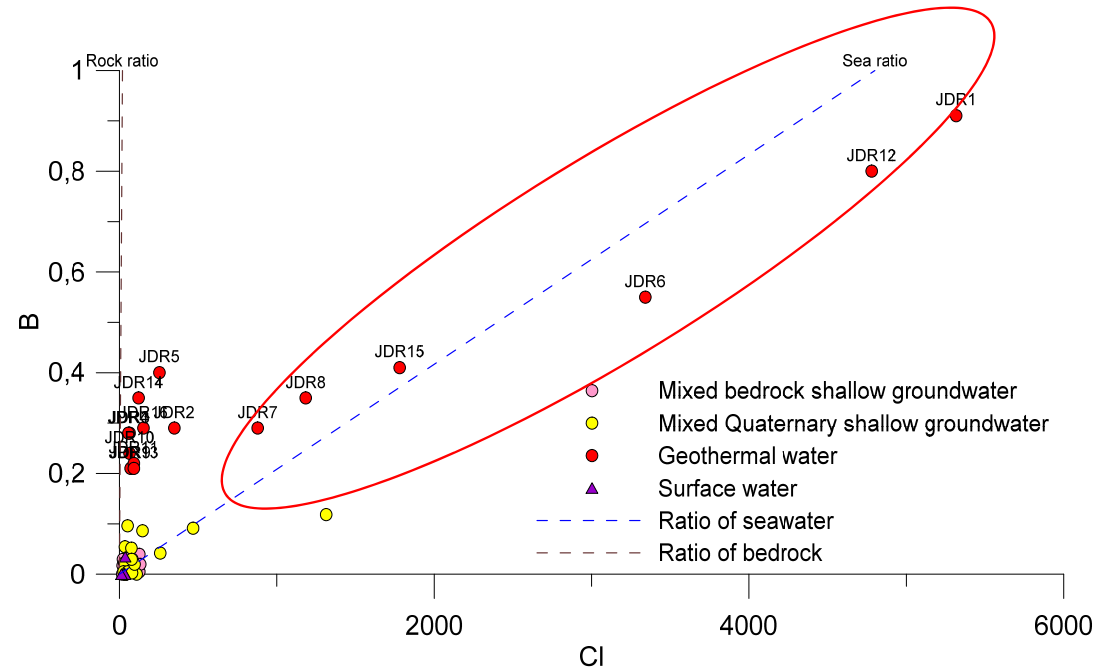


Chemical characteristics of geothermal fluids

Origin of geothermal water



Concentration counter map of Cl in geothermal water, Jiaodong Peninsula

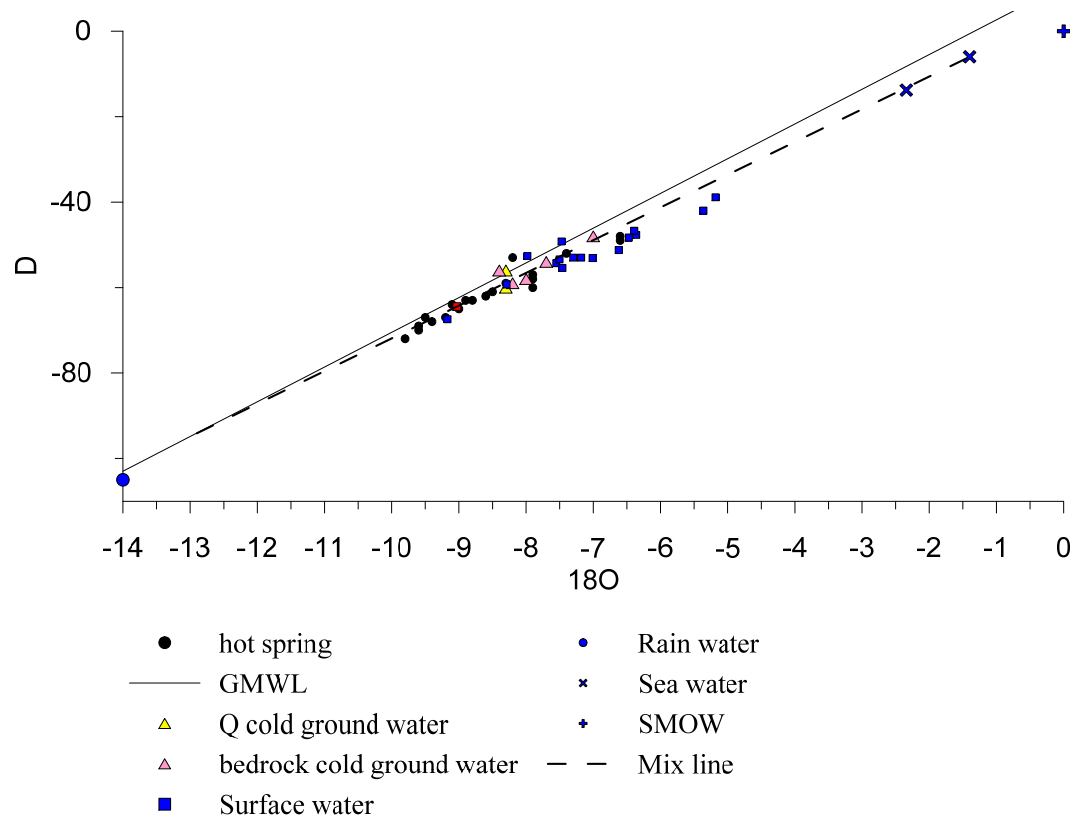


Variation of B with Cl (in ppm) in surface water, geothermal water and mixed shallow colder water



Chemical characteristics of geothermal fluids

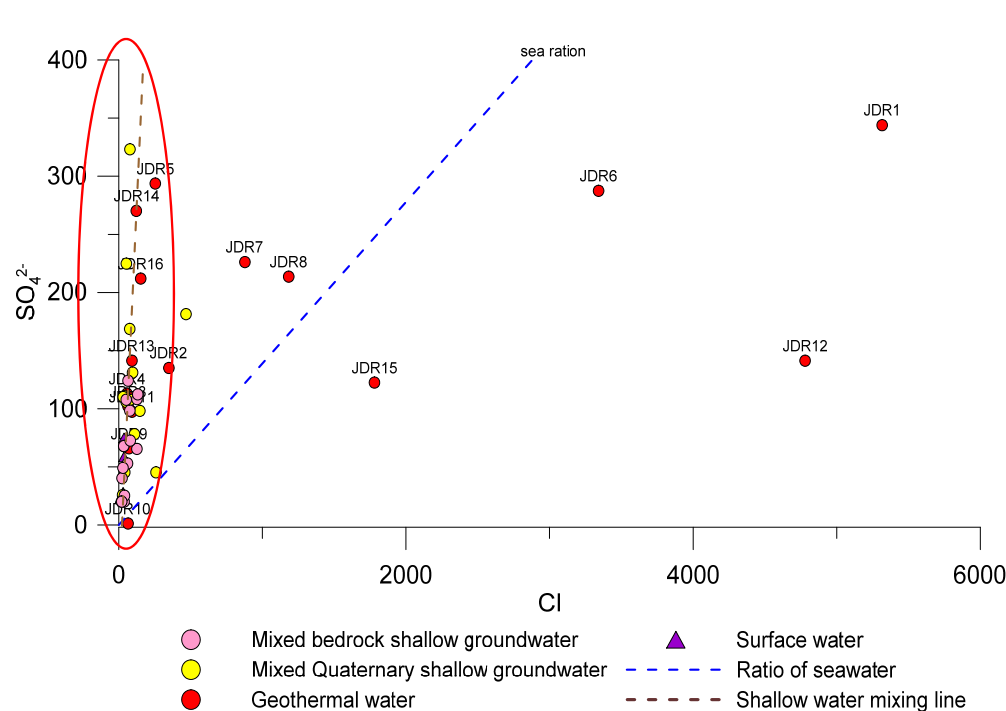
Origin of geothermal water



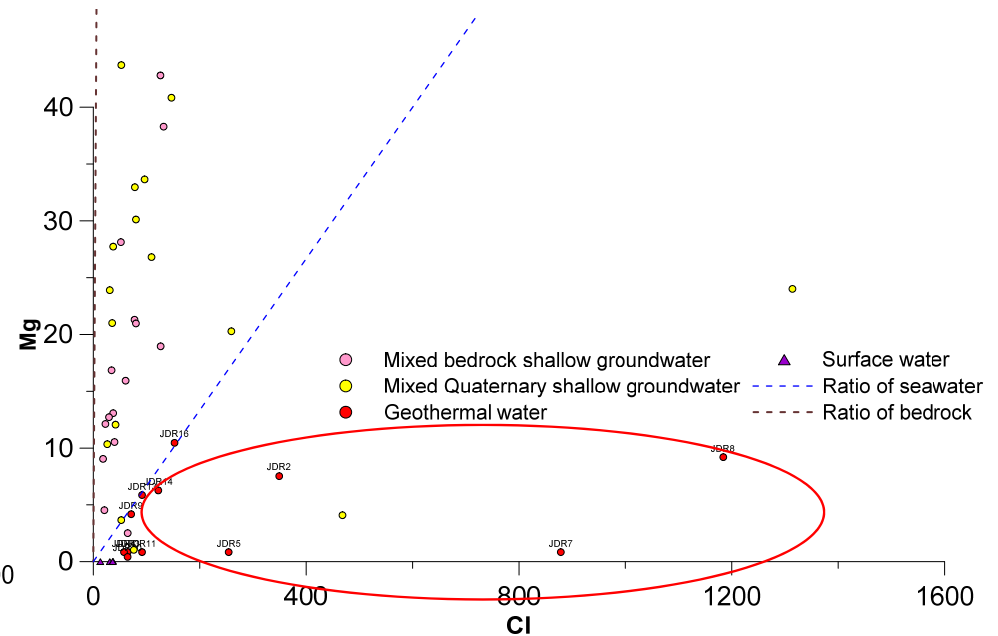
- Open reservoirs mainly recharged by modern atmospheric precipitation mixed with seawater or shallow groundwater
- Controlled by deep faults with NNE strike and the distributions of Mesozoic intrusive rocks

Chemical characteristics of geothermal fluids

Mixing of shallow water and secondary minerals formed



Variation of SO_4^{2-} with Cl (in ppm) in surface water, geothermal water and mixed shallow colder water

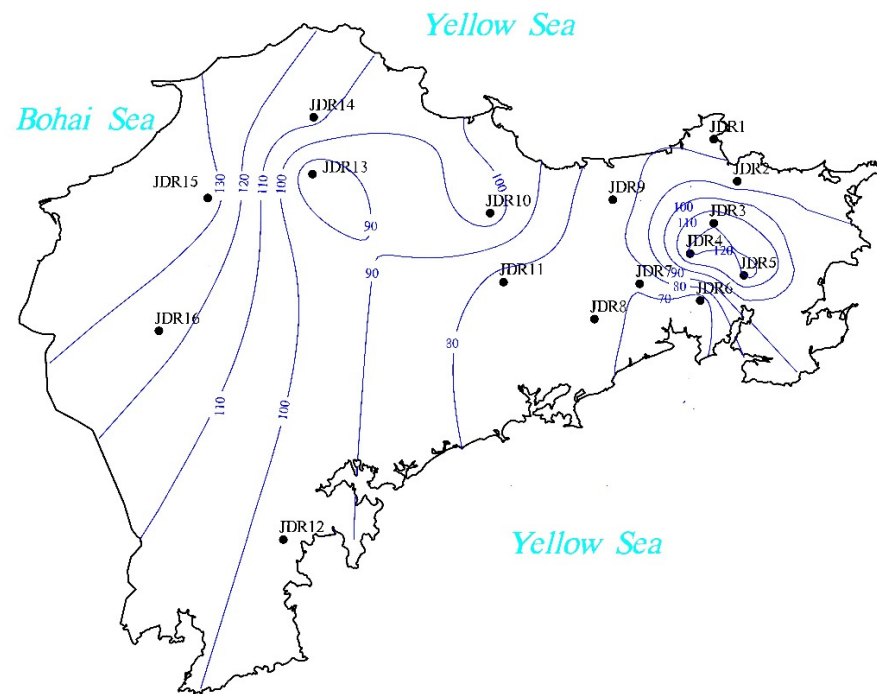
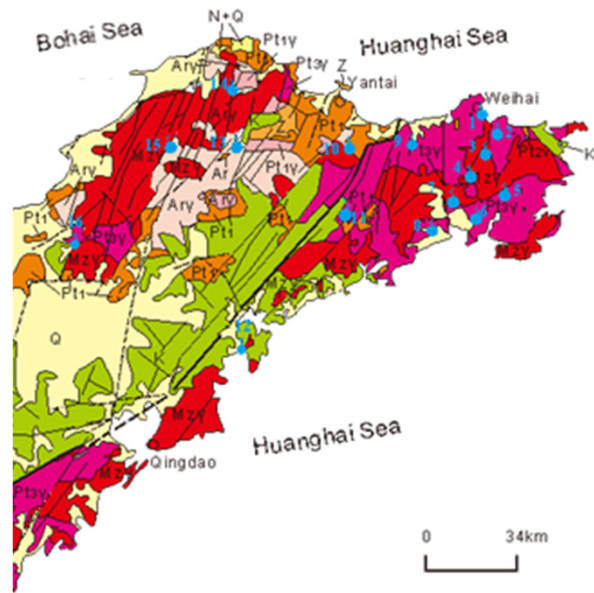


Variation of Mg with Cl (in ppm) in surface water, geothermal water and mixed shallow colder water

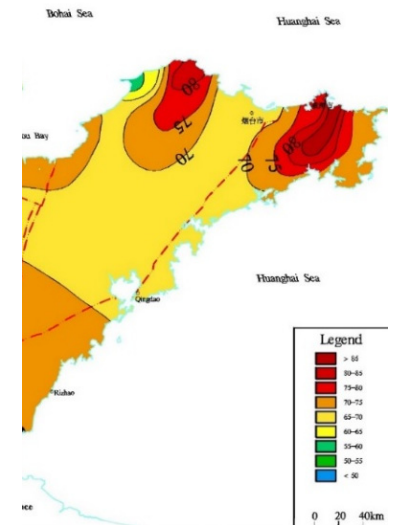


Chemical characteristics of geothermal fluids

Temperature distribution



Counter map of SiO₂ in geothermal water,
North-eastern of Shandong Province



Next steps



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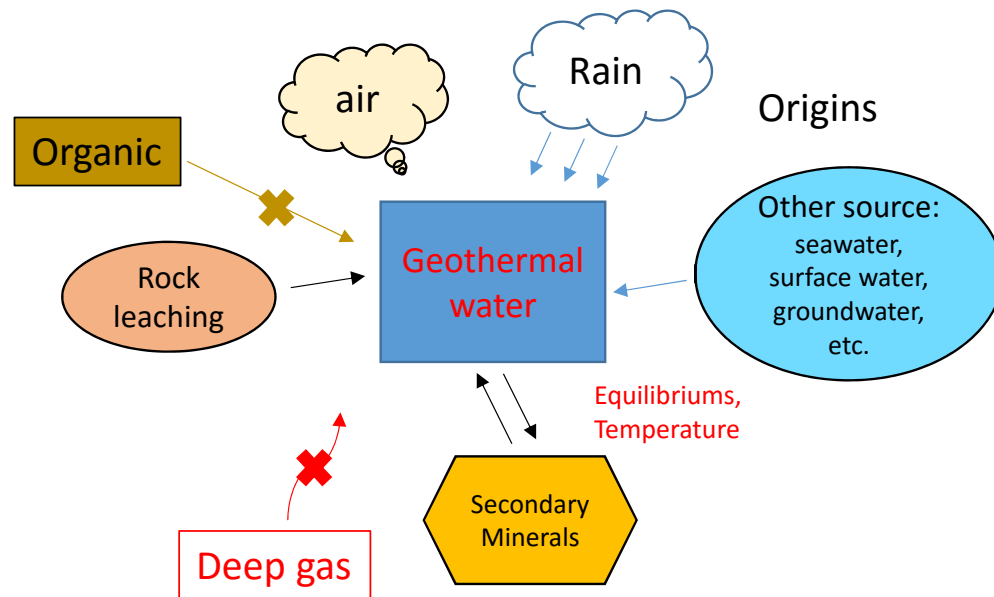
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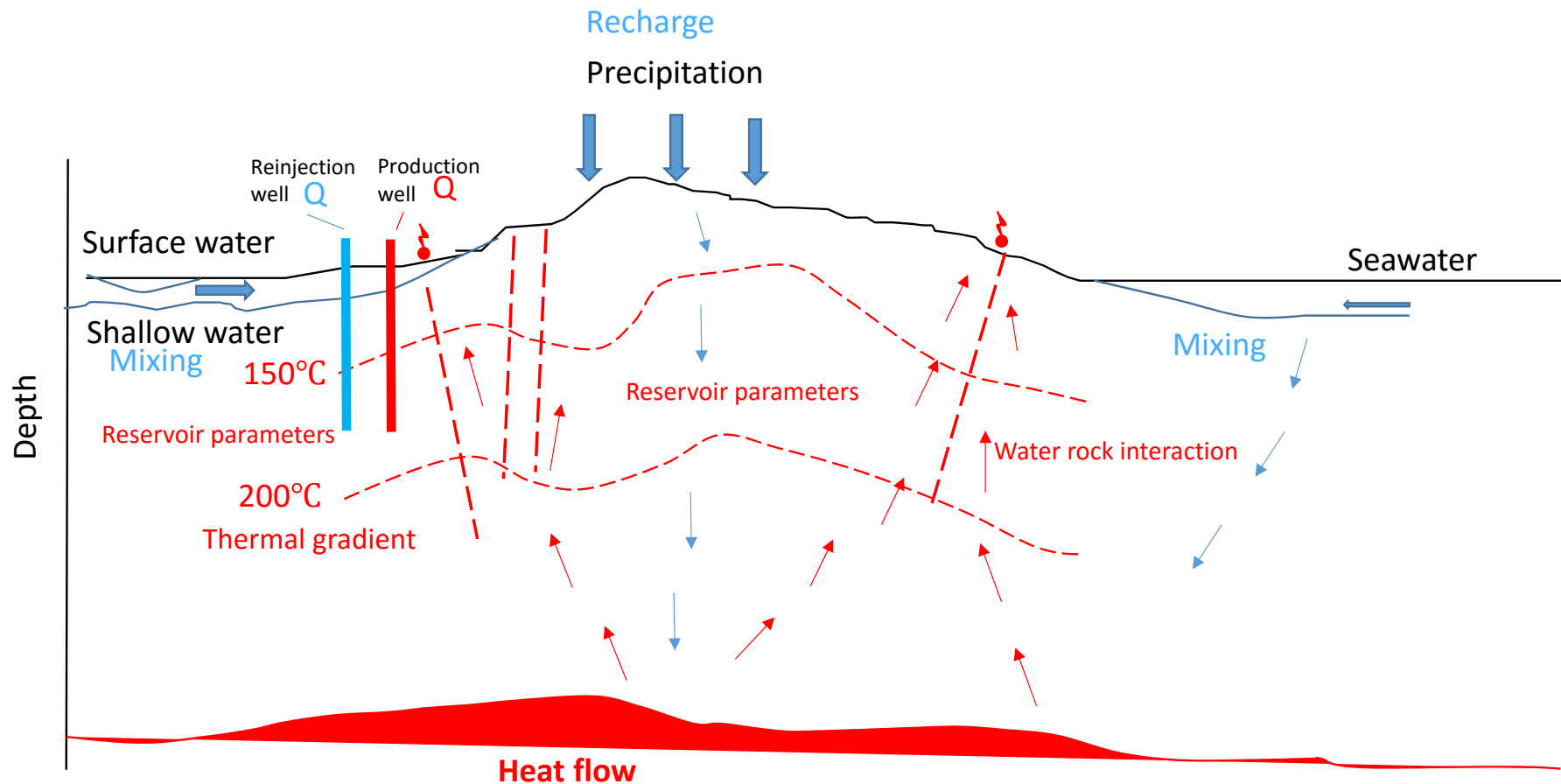
Next steps



- (1) Study equilibria of secondary minerals, estimate reservoir temperature and water-rocks interaction;
- (2) Quantify the variable water sources and mixing.



Add chemistry information to the conceptual model



Sketch map of conceptual model



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Thank you!
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