

Regional Hydrogeology of the Bakken Formation in the Williston Basin

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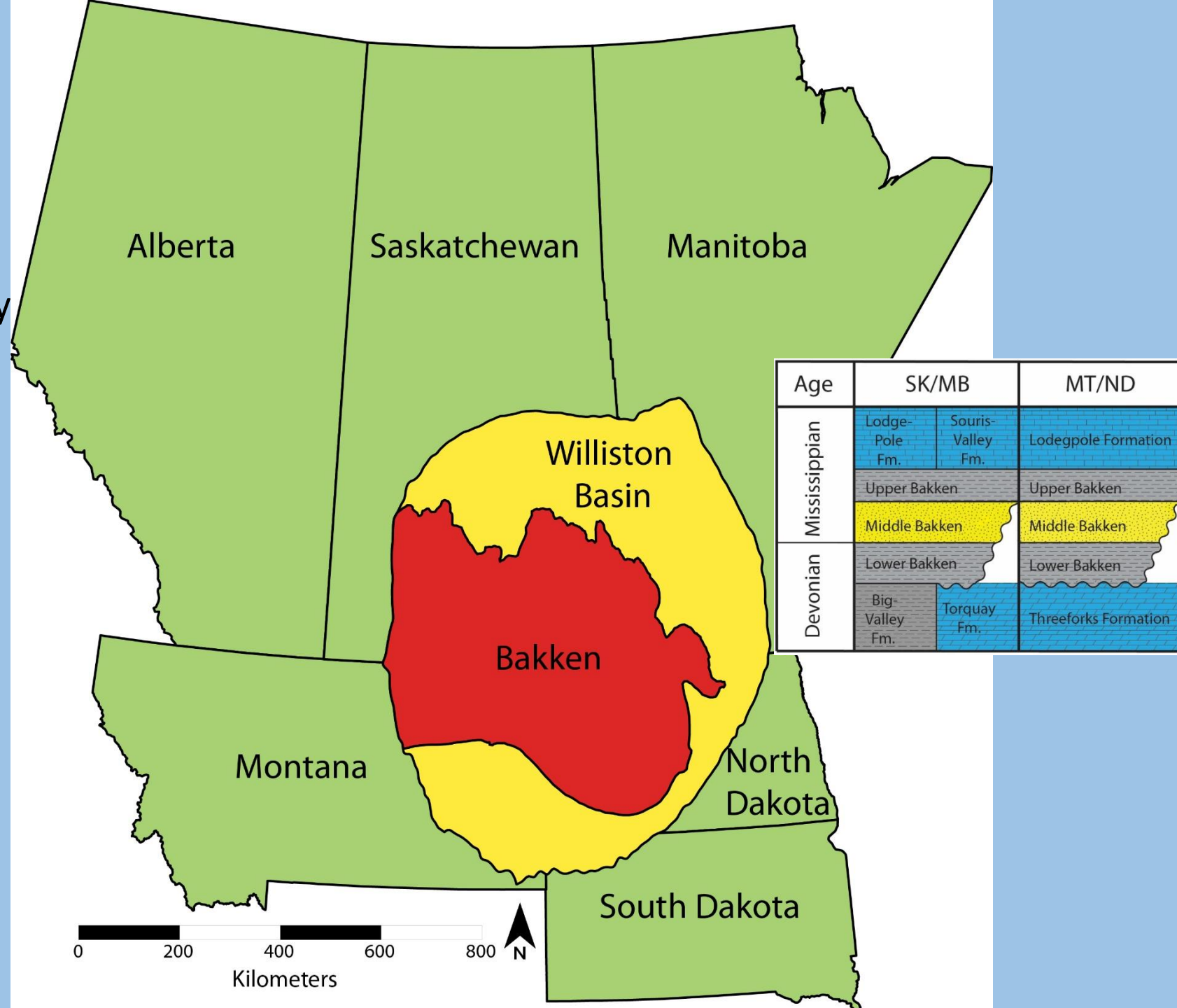
1. Introduction

Williston Basin

- Large intracratonic sedimentary basin
- Basin boundary based on 40 m Silurian Interlake contour
- Basin area 560,000 km²

Bakken Formation

- Spans portions of Saskatchewan, Manitoba, Montana, North Dakota
- Composed of 3 members
- Formation spans 270,000 km²



2. Previous work

- Bakken extensively studied on various scales; regional to local
- Many aspects investigated including
 - Petroleum system, stratigraphy, structure, geochemistry
- Limited hydrogeology especially on regional scale

3. Motivation

Determine the regional hydrogeology and hydrochemistry of the Bakken Formation

- Basin wide study
- Integrate recent horizontal drilling data
- Determine regional flow in the Bakken on a basin scale
- Determine TDS and water type distribution over the entire Williston Basin
- Determine the presence and effects of density dependent flow within the Bakken Fm.
- Determine area of over pressure and the resulting effects on flow/chemistry
- Determine Bakken Formation water origin

4. Methods

4.1 Data

Pressure Data

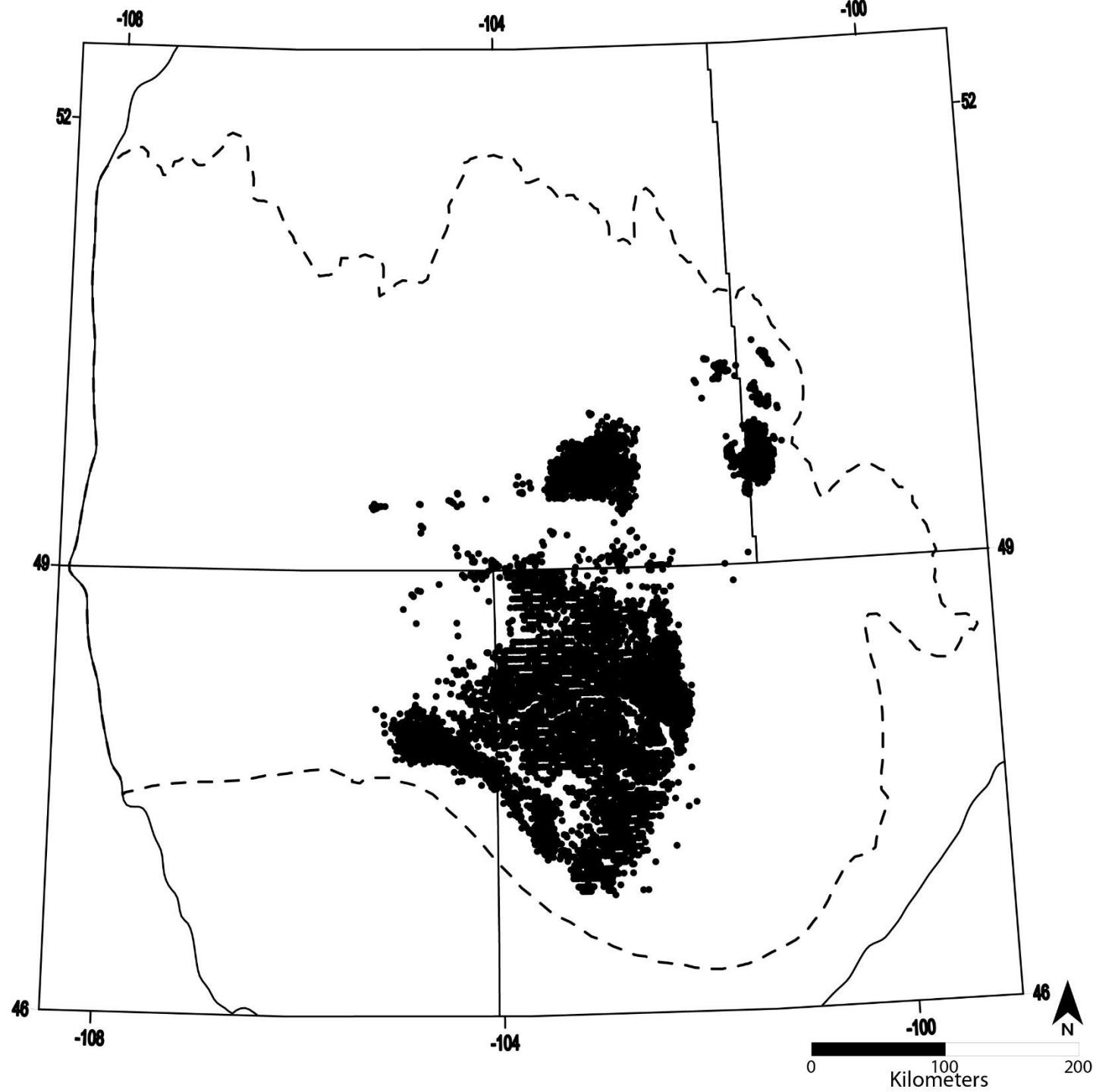
- Drill Stem Tests
- Initial Production tests
- ~1400 DST's

Chemistry data

- DST sample recoveries
- Produced water samples
- ~950 water samples

Data sources

- AccuMap
- geoSCOUT
- Literature
- ND DMR



4.2 Data Culling

Pressure Culling

- Interval testing (ie. Test straddles multiple formations)
- Insufficient shut in time (ie. No stabilized Fm. Pressure).
- Wells affected by production/injection (Cumulative Interference Index)
- DST quality code
- Qualitative DST chart analysis
- Removed >90% of data

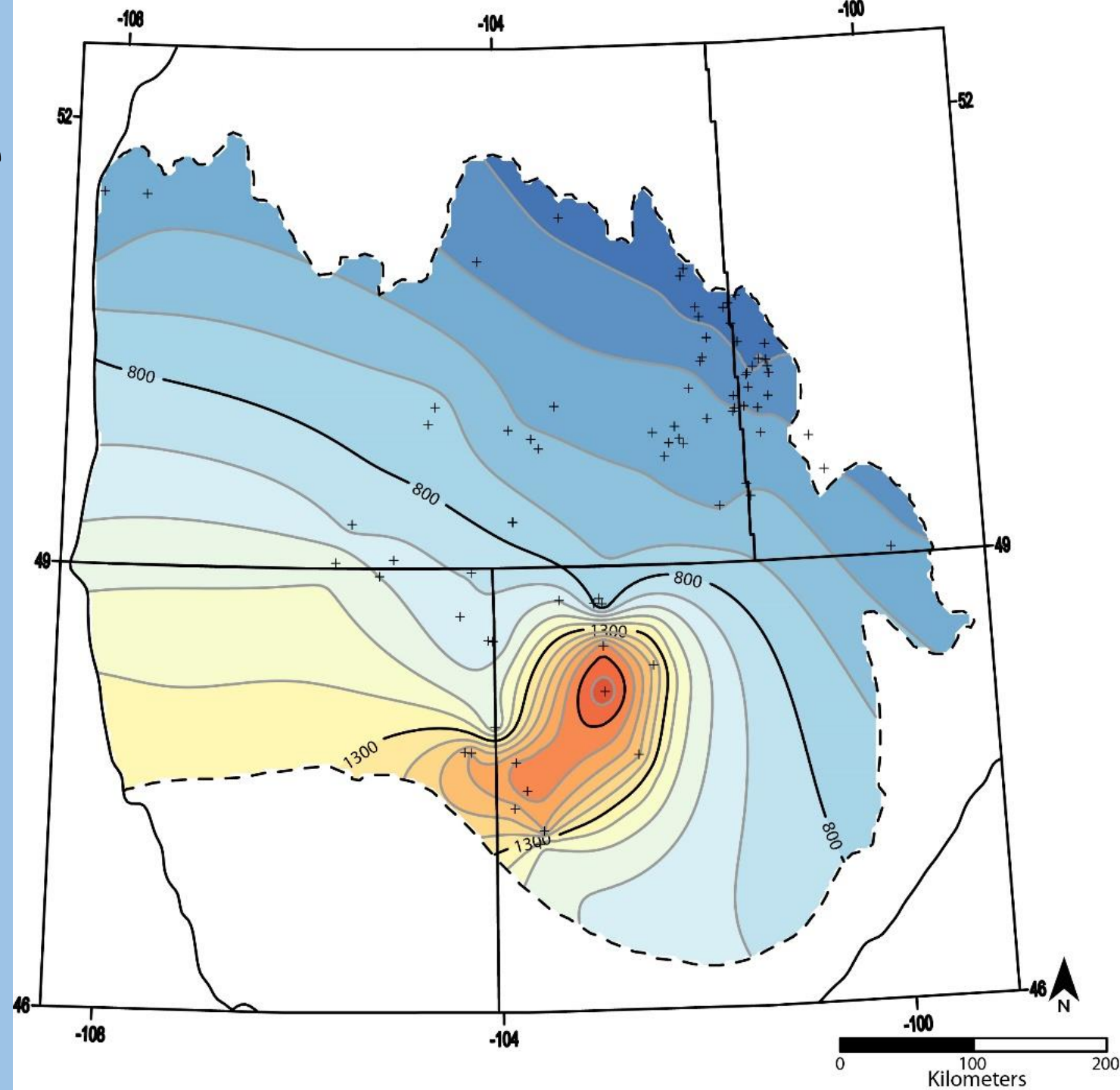
Chemistry Culling

- Out of zone samples
- Charge balance errors
- Ion Ratio errors
- Iterative process
- Flag based
- Removed 85% of data

5. Results

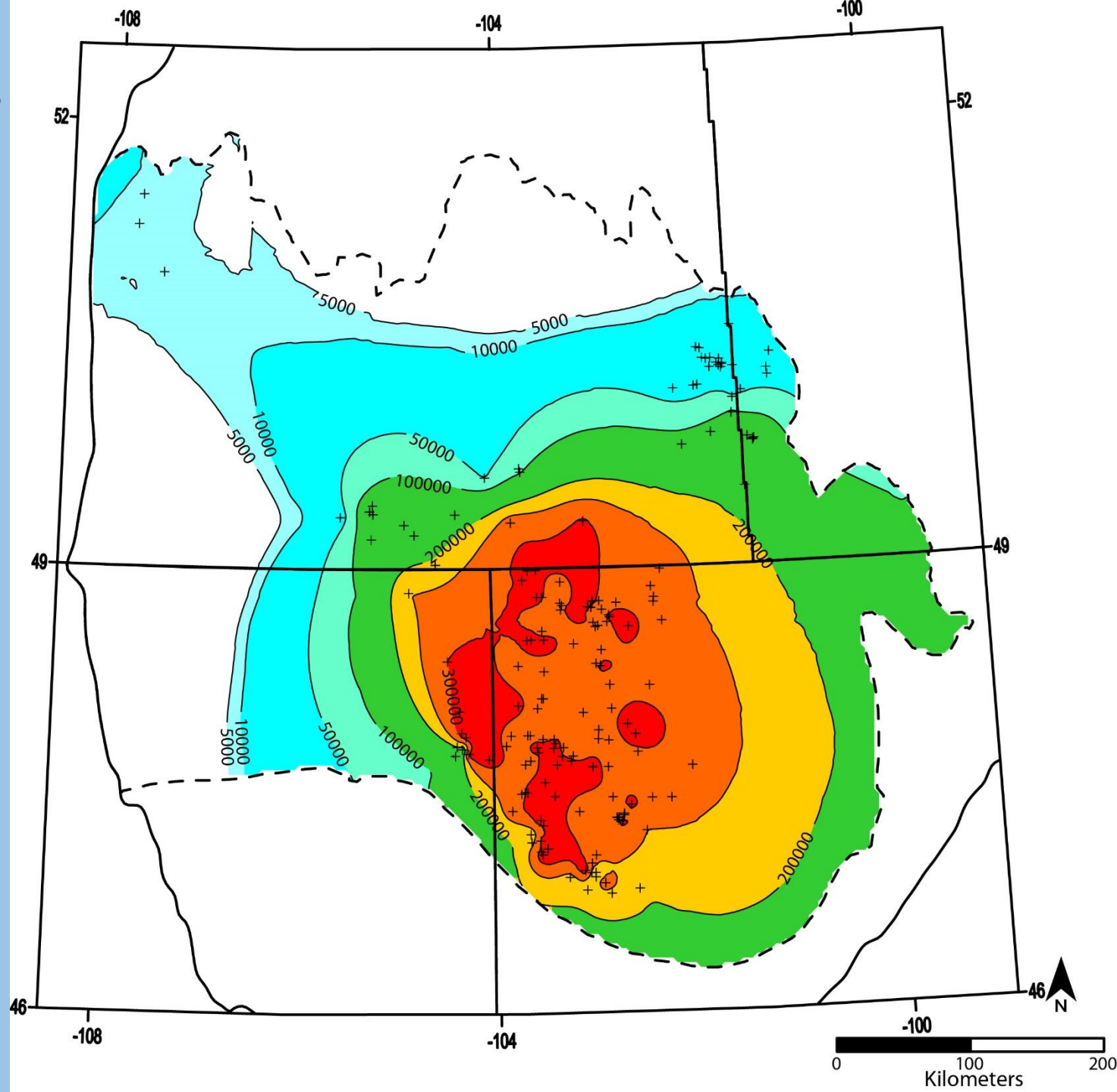
5.1 Potentiometric Surface

- Heads from 2000 m to < 400 m
- Closed potentiometric high in North Dakota
- Regional high in SW
- Regional low in NE
- Regional flow from SW to NE
- Little to no flow in center of basin
- High gradient surrounding closed high in ND
- Low gradient over most of the basin



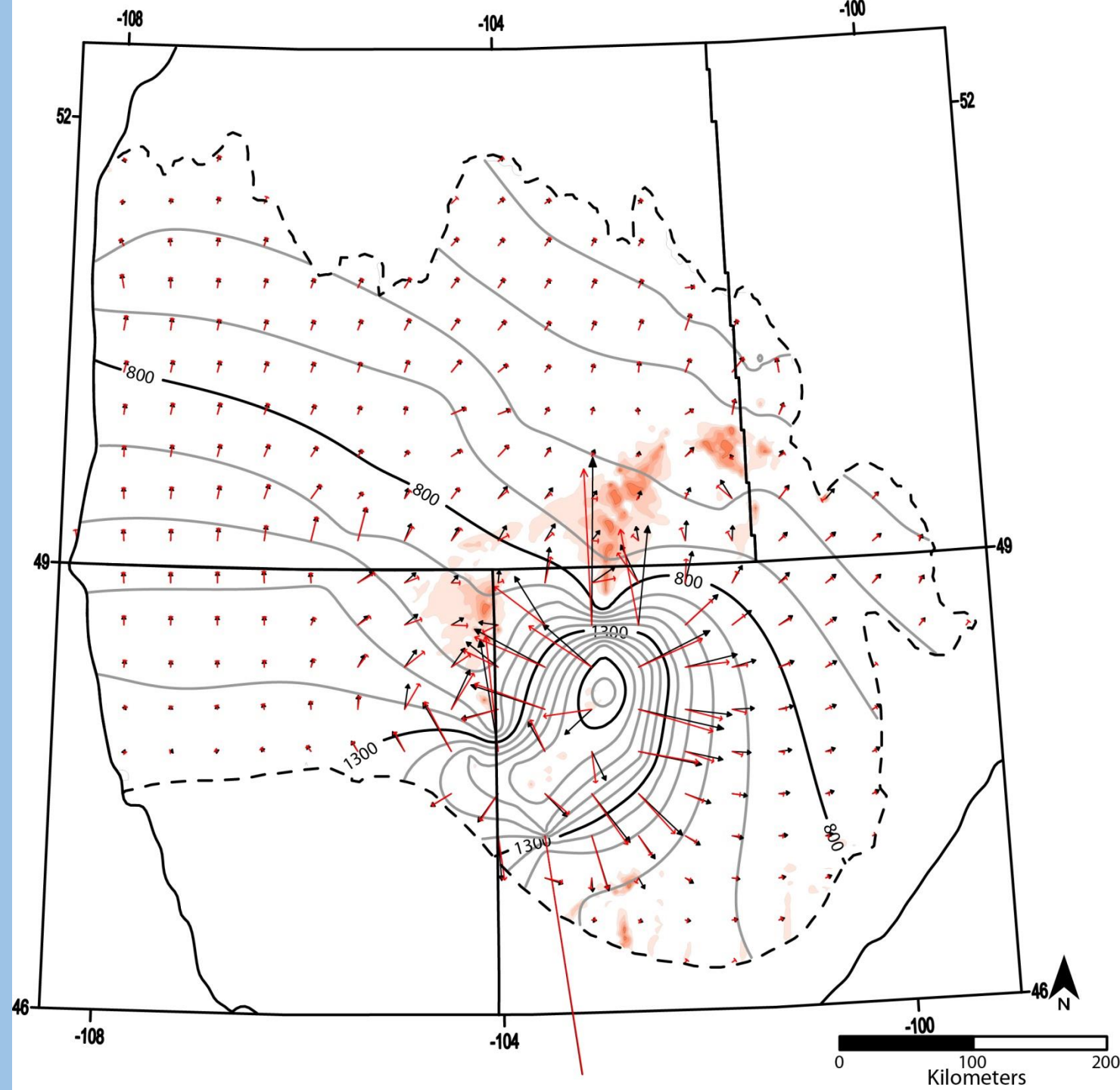
5.2 Total Dissolved Solids

- Total dissolved solids <5,000 mg/l to >300,000 mg/l
- Highest TDS in deeper portion of basin
- Lower TDS on basin margins
- Progressively lower TDS radially outwards from deepest Bakken
- Dominated by Na-Cl type waters
- Local Na-SO₄ waters in North



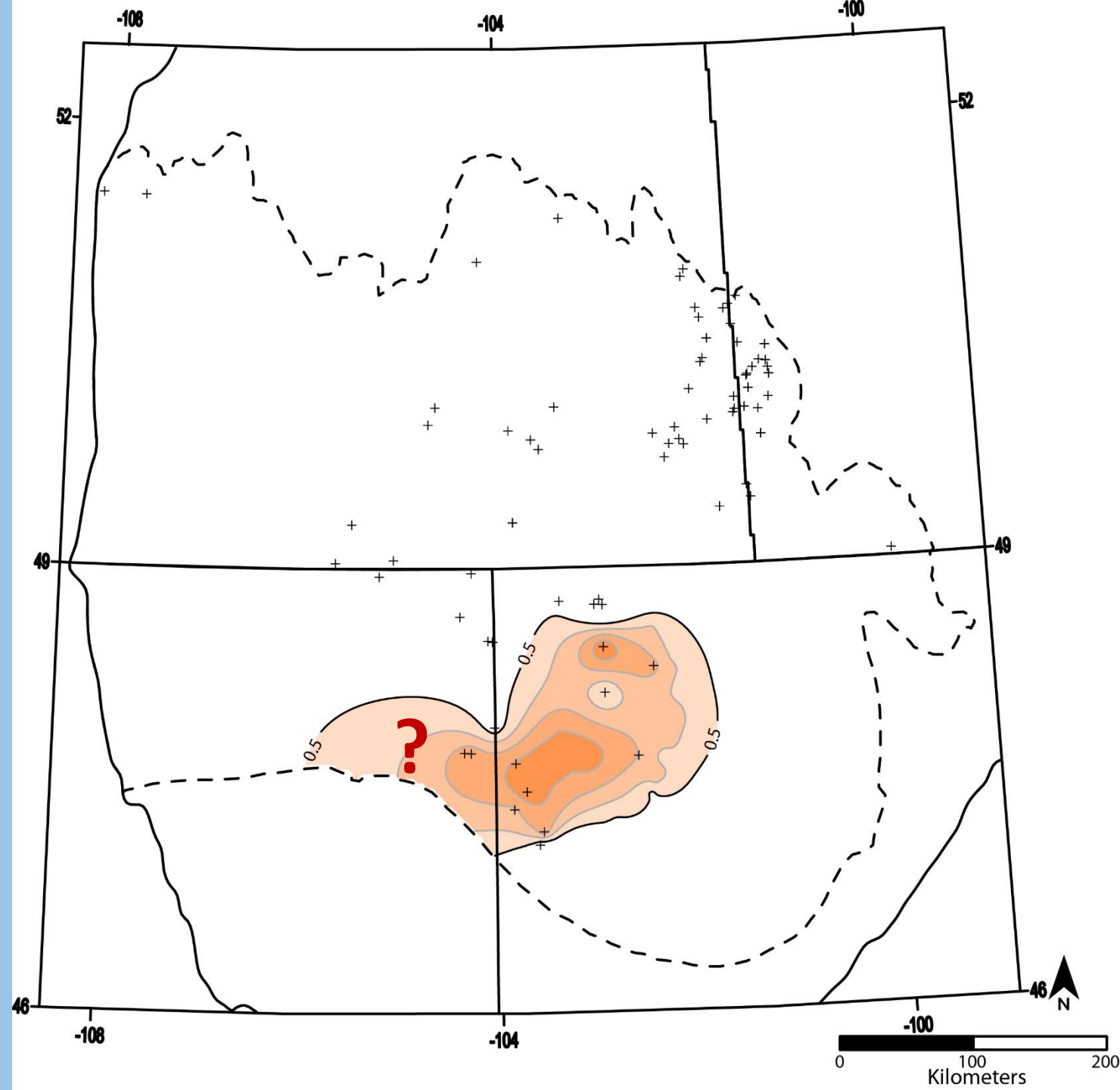
5.3 Driving force

- Flow direction largely similar to uncorrected potentiometric surface map
- Orange highlights areas of greatest density effects/deviation from expected flow direction
- No flow in deep center of basin
- Regional flow from SW to NE



5.4 Overpressure

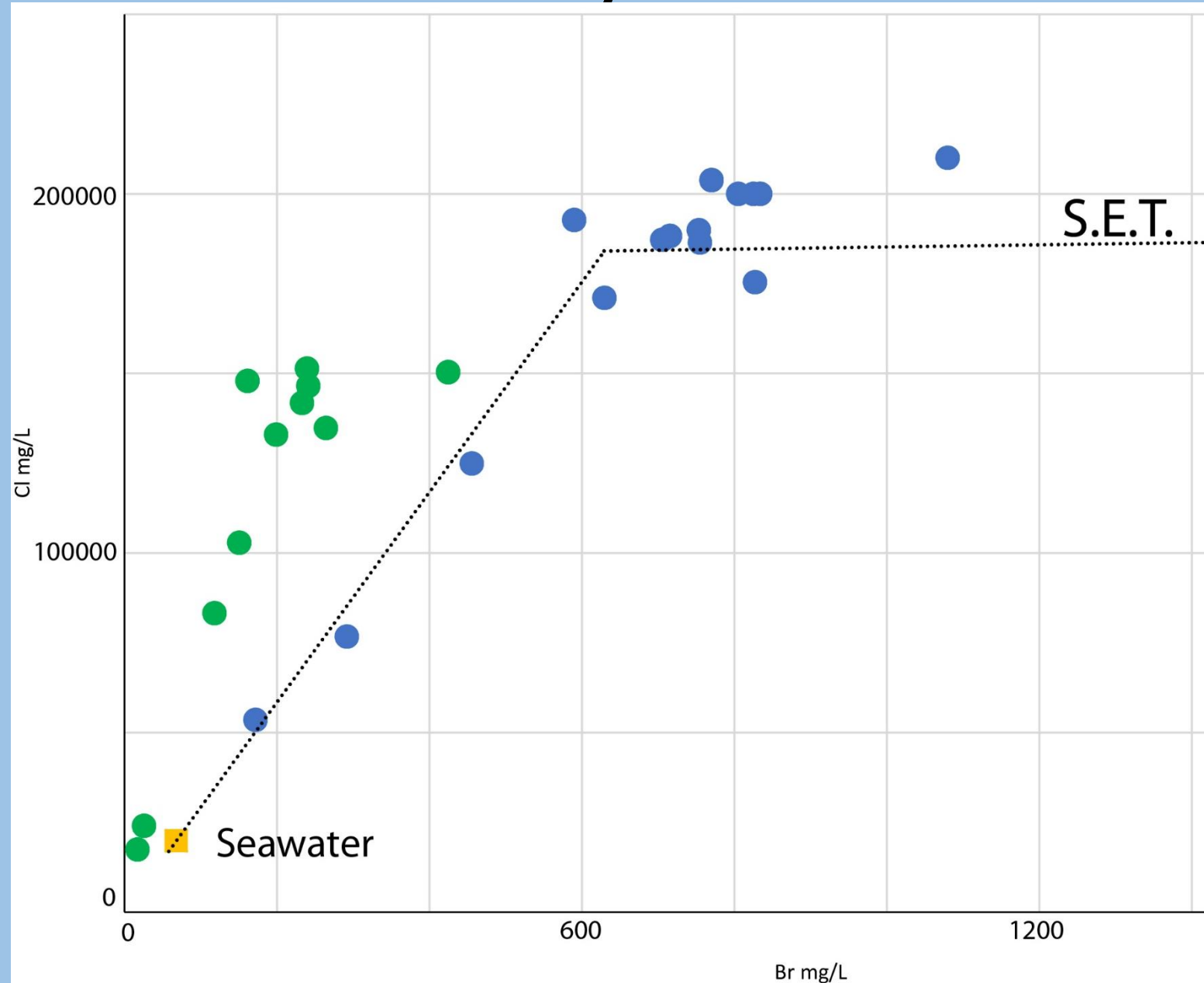
- Bakken Formation Overpressured in deepest portion of basin in North Dakota
- Returning to hydrostatic conditions away from center of basin



5.5 Formation Water: Evolution History

Cl/Br plot

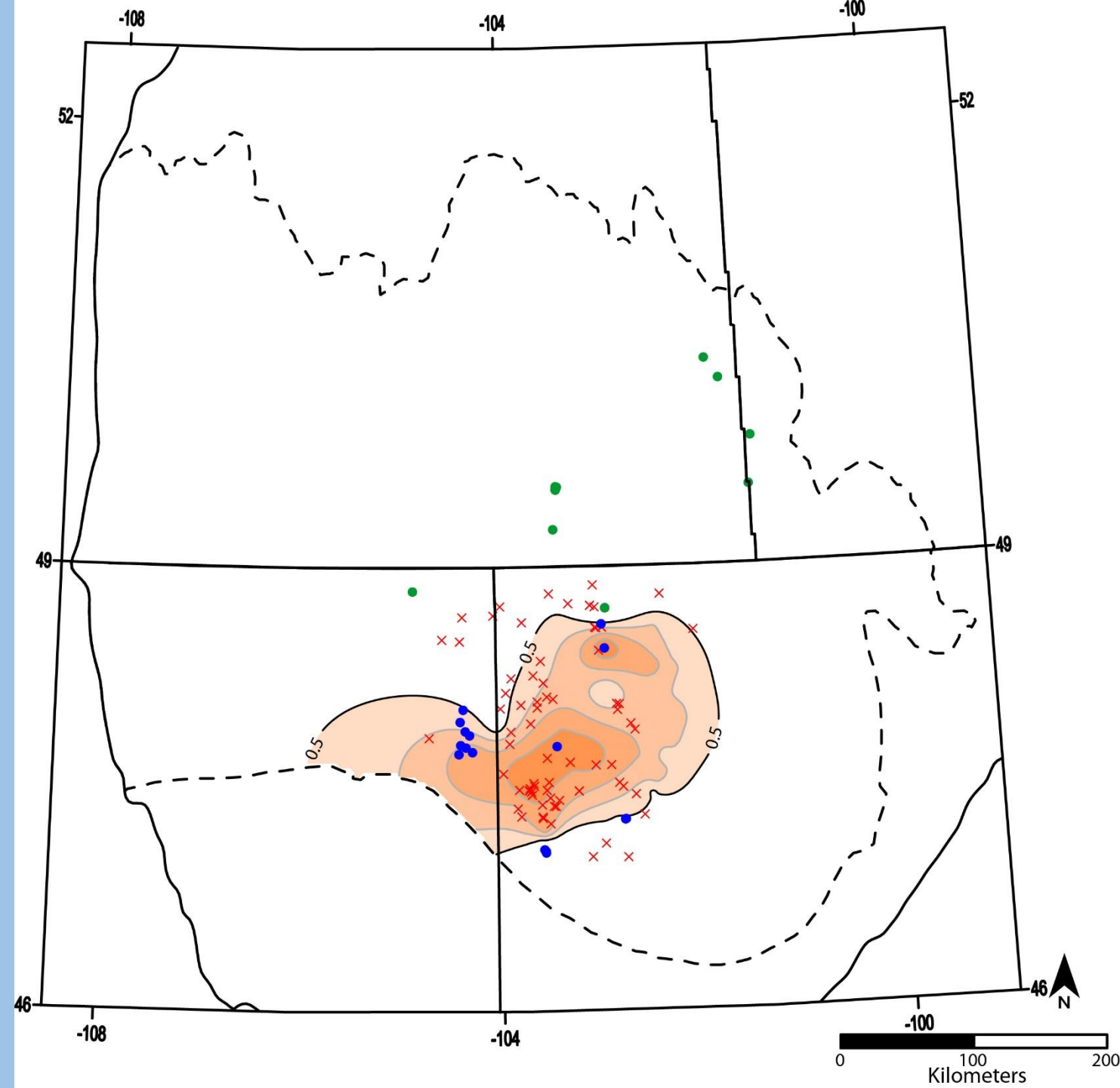
- Two distinct groups
 - Green, above S.E.T.
 - Blue, along S.E.T.
- Two water evolution trends
 - Green, halite dissolution
 - Blue, seawater evolution trend



5.6 Cl/Br Distribution

Spatial distribution of water evolution trends

- **Green**: halite dissolution signature
- **Blue**: seawater evolution trend
- **Red X**: tight hole/flow wells



6. Conclusion

- Regional groundwater flow from SW to NE
- 3 types of flow in Bakken: normal flow, flow resulting from overpressure, density dependent flow
- TDS from $< 5,000$ mg/l to $> 300,000$ mg/l
- Na-Cl type waters dominate system
- Density dependent flow occurs in the southern Saskatchewan
- Little to no flow in center of basin
- Bakken Formation water shows both halite dissolution and seawater evolution signatures

Thank you

Questions?

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The North Dakota department of Mineral Resources for Pressure and Chemistry data