Strontium Isotope Evolution of Produced Water in the East Poplar Oil Field, Montana*

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Abstract

The East Poplar oil field on the Fort Peck Indian Reservation in eastern Montana has been in production for about 60 years, mostly from the Charles Formation of the Mississippian Madison Group. The Poplar dome is in the western part of the Williston Basin and is breached by faults and modified by local dissolution of Mississippian evaporites as described by Orchard in 1987. Because of past disposal practices, groundwater in the shallow aquifers has been contaminated in places by oil-field brines with salinities up to several times that of seawater. With funding from the Fort Peck Office of Environmental Protection, the U.S. Geological Survey (USGS) is continuing hydrochemical studies by Thamke and others with the addition of strontium (Sr) isotopes as described by Peterman and others in 2010.

Samples of uncontaminated and contaminated groundwater from domestic wells define a trend with a narrow range in $^{87}Sr/^{86}Sr$ values (mean of 0.70817 ± 0.00017) but a fifty-fold increase in Sr concentrations (0.24 to 12.5 mg/L) with increasing contamination. Twenty samples of brine collected directly from producing oil wells define two isotopic groups. One group (10 samples) has a small range in $^{87}Sr/^{86}Sr$ (0.70816 ± 0.00024 with 12.2 to 338 mg/L Sr) and could represent the groundwater contaminant. The other group has a larger range in $^{87}Sr/^{86}Sr$ (0.71061 ± 0.00190 and 34.5 to 51.7 mg/L Sr) and could not have produced the contaminant trend. Two of the brine samples in this second group are from the Late Mississippian Heath Formation overlying the Madison Group and have $^{87}Sr/^{86}Sr$ values of 0.70928 and 0.70942. The remaining samples are from the Madison Group and have $^{87}Sr/^{86}Sr$ values ranging from 0.70962 to 0.71175. These brines probably originated in older clastic units and migrated upward because of the long-term production from the East Poplar field. This is consistent with the suggestion of Jarvie in 2001 that oil from the Bakken Formation has mixed with oil from the overlying Charles Formation.

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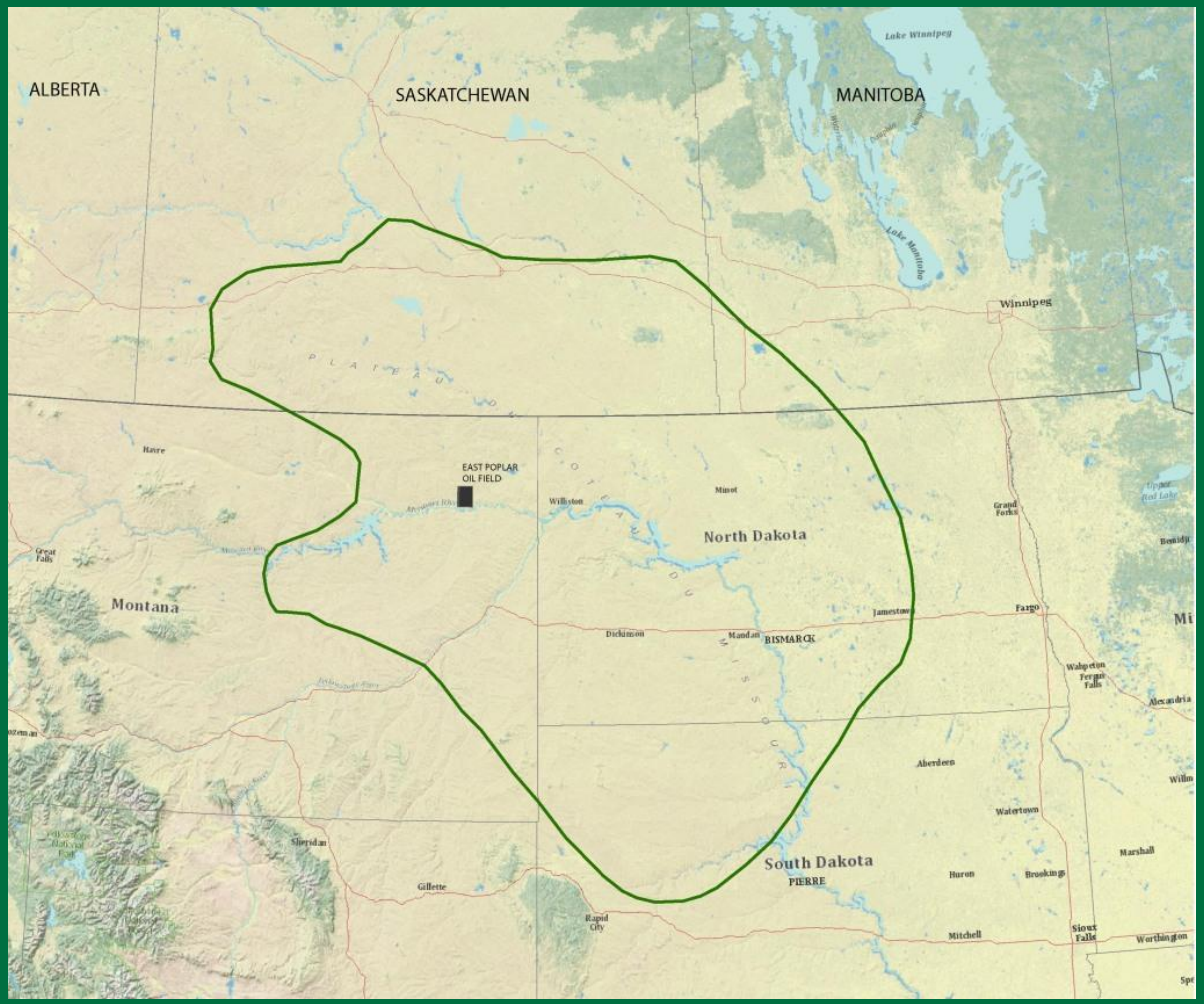
U.S. Department of the Interior
U.S. Geological Survey

Williston Basin

- 60 percent of historic oil production from Madison Group
- Other units have produced <10 percent individually
- Increased activity on the Bakken Shale
- East Poplar oil field discovered in 1952
  - No Bakken development yet



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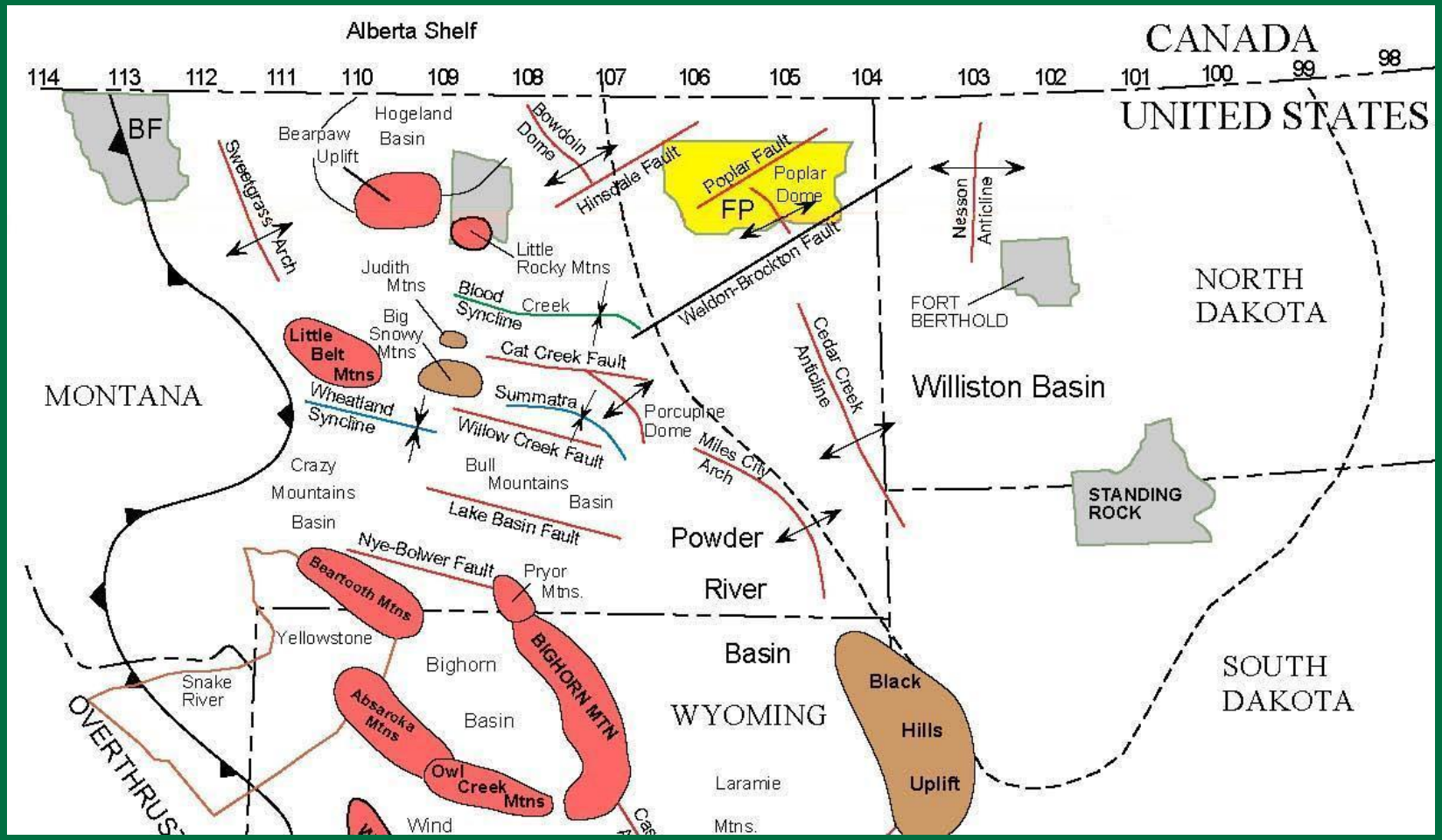
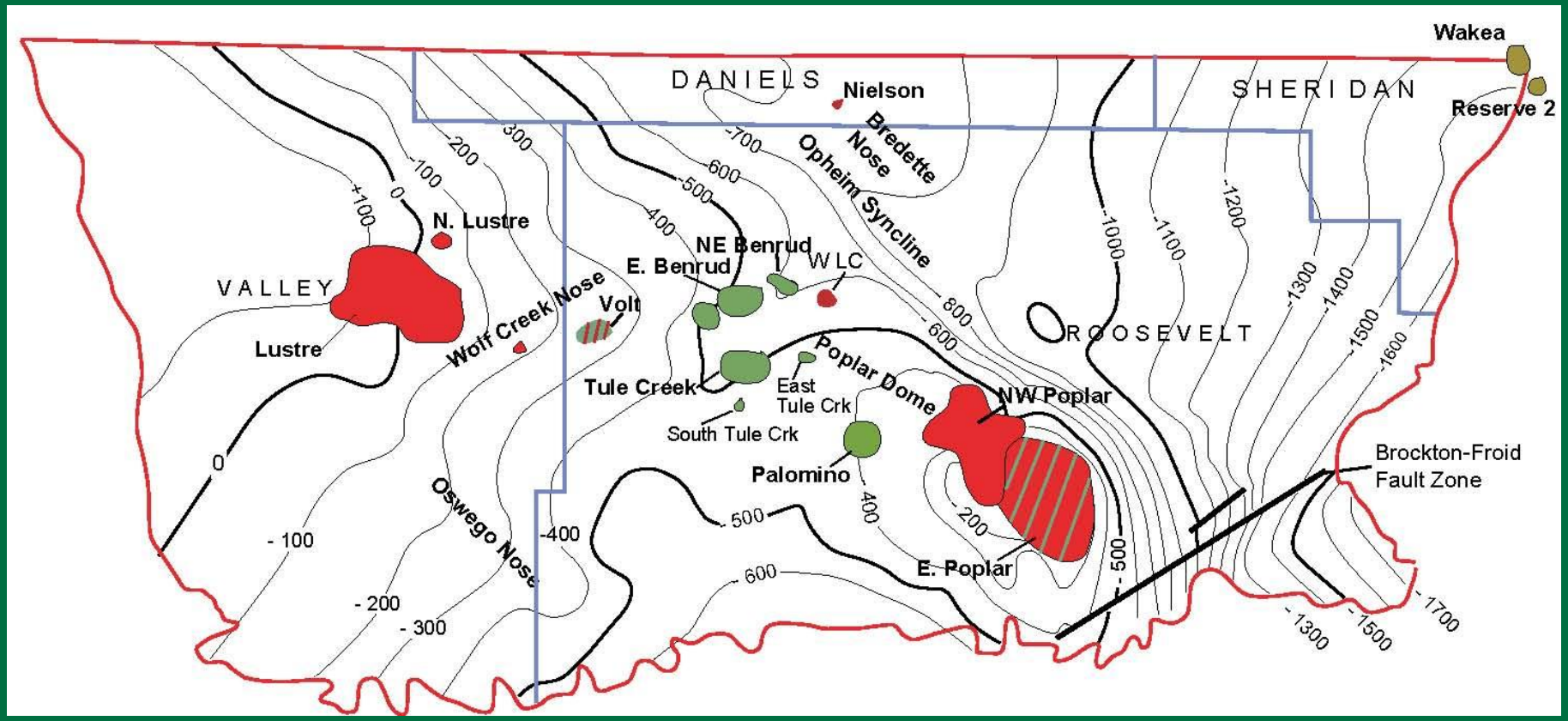
Fort Peck Reservation in Northeast Montana contains the Poplar Dome and Associated Oil Fields



USGS

Contours on Top of Greenhorn Delineate Poplar Dome. Production: Red—Charles, Green—Nisku, Brown—Red River



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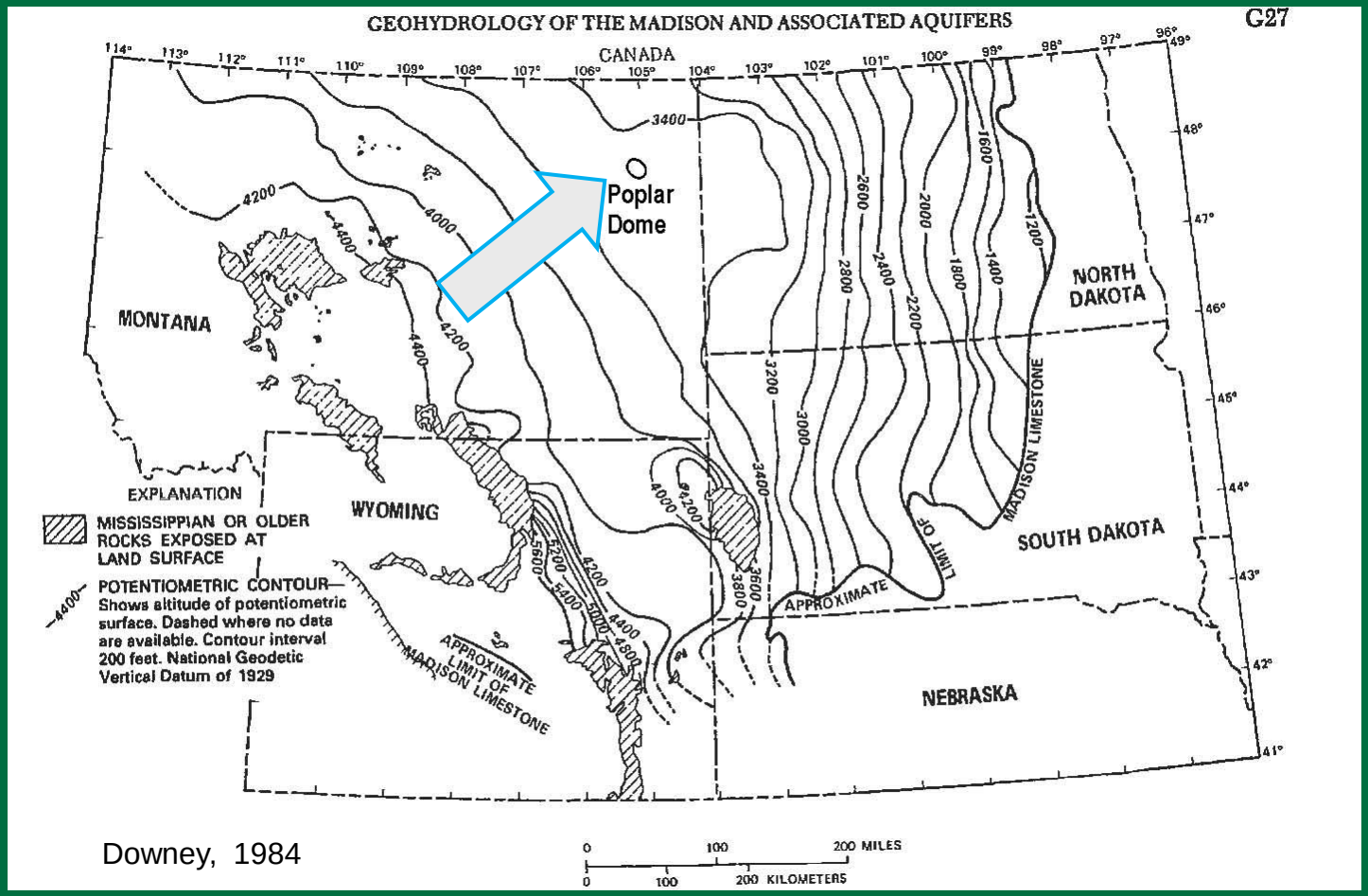
Head and Water Pressure in the Madison Aquifer Sustains an Active Water Drive in the East Poplar Oil Field



Downey, 1984

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Groundwater Contamination and Long-term Evolution of Produced Water in the East Poplar Oil Field

- Phase I—2009 and 2010
  - Used strontium isotopes with water-quality data to assess groundwater contamination by oil-field brine
  - USGS Open-File Report 2010-1326
- Phase II—2011
  - 20 brine samples collected from producing wells and analyzed

USGS

Strontium Isotopes as Groundwater Tracers

- Strontium (Sr) is an alkaline-earth element that closely follows calcium (Ca)
- It is composed of four stable isotopes: ^{84}Sr, ^{86}Sr, ^{87}Sr, and ^{88}Sr
- Usefulness of Sr as a natural tracer derives from the increase in ^{87}Sr by the beta decay of ^{87}Rb ($t_{1/2}$ = 48.8 billion years)
  - Rocks of different ages and Rb/Sr ratios have different $^{87}Sr/^{86}Sr$ ratios
  - Variation of $^{87}Sr/^{86}Sr$ in Phanerozoic sea water is well known (marine carbonates have a predictable Sr isotope ratio)

USGS

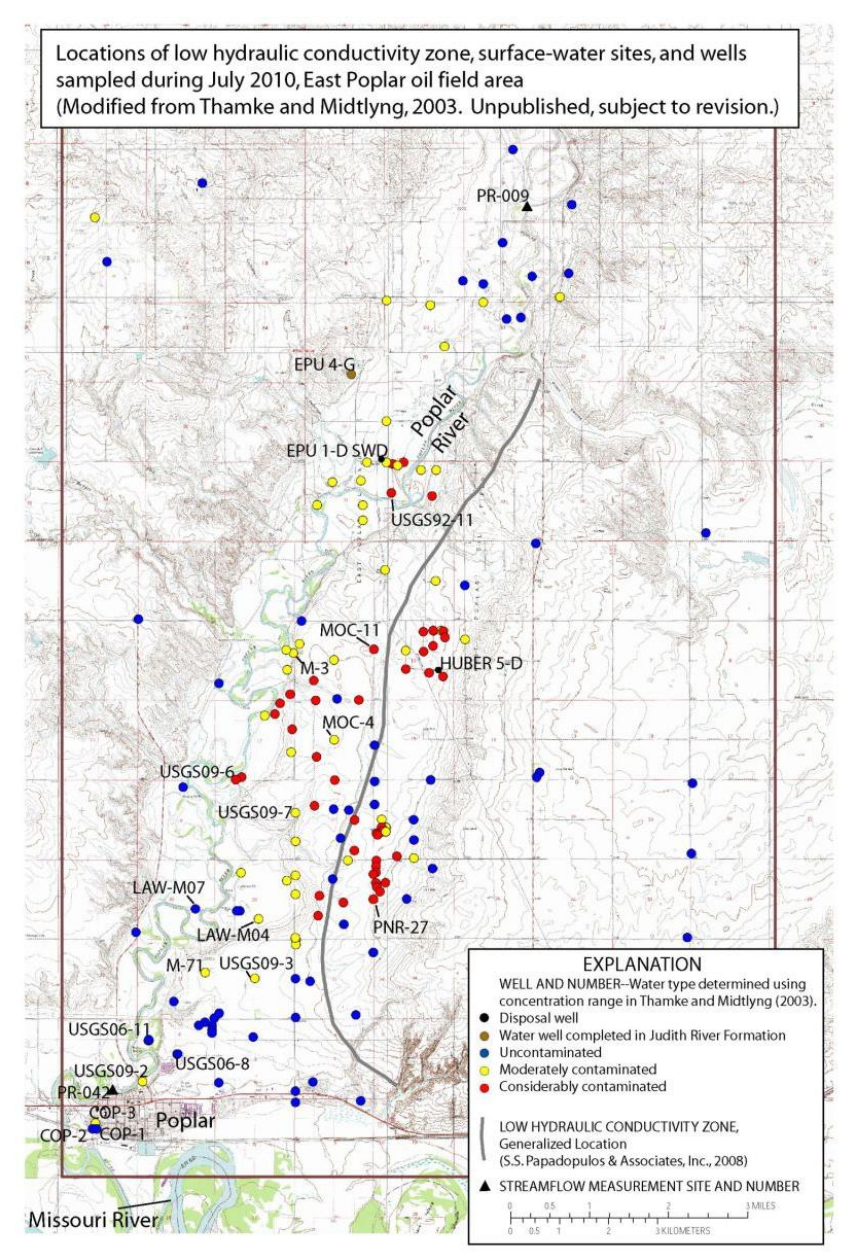
Mixing of Brines and Fresh Water

- Sr concentrations of fresh water and brine differ by two to three orders of magnitude
- Mixing of waters with different $^{87}Sr/^{86}Sr$ ratios and reciprocal Sr concentrations will produce linear trends (Faure, 1998)
  - $^{87}Sr/^{86}Sr = (a/[Sr]) + b$
  - where a = slope and b = intercept

USGS

Locations of Sample Sites

- Water wells, Poplar River, and brine disposal sites were sampled in 2009 and 2010 (wells with labels)
- Samples were analyzed for Sr isotopes, dissolved ions, and trace metals
- Contamination classification based on Cl concentration
  - Considerably (red), Moderately (yellow), Uncontaminated (blue)



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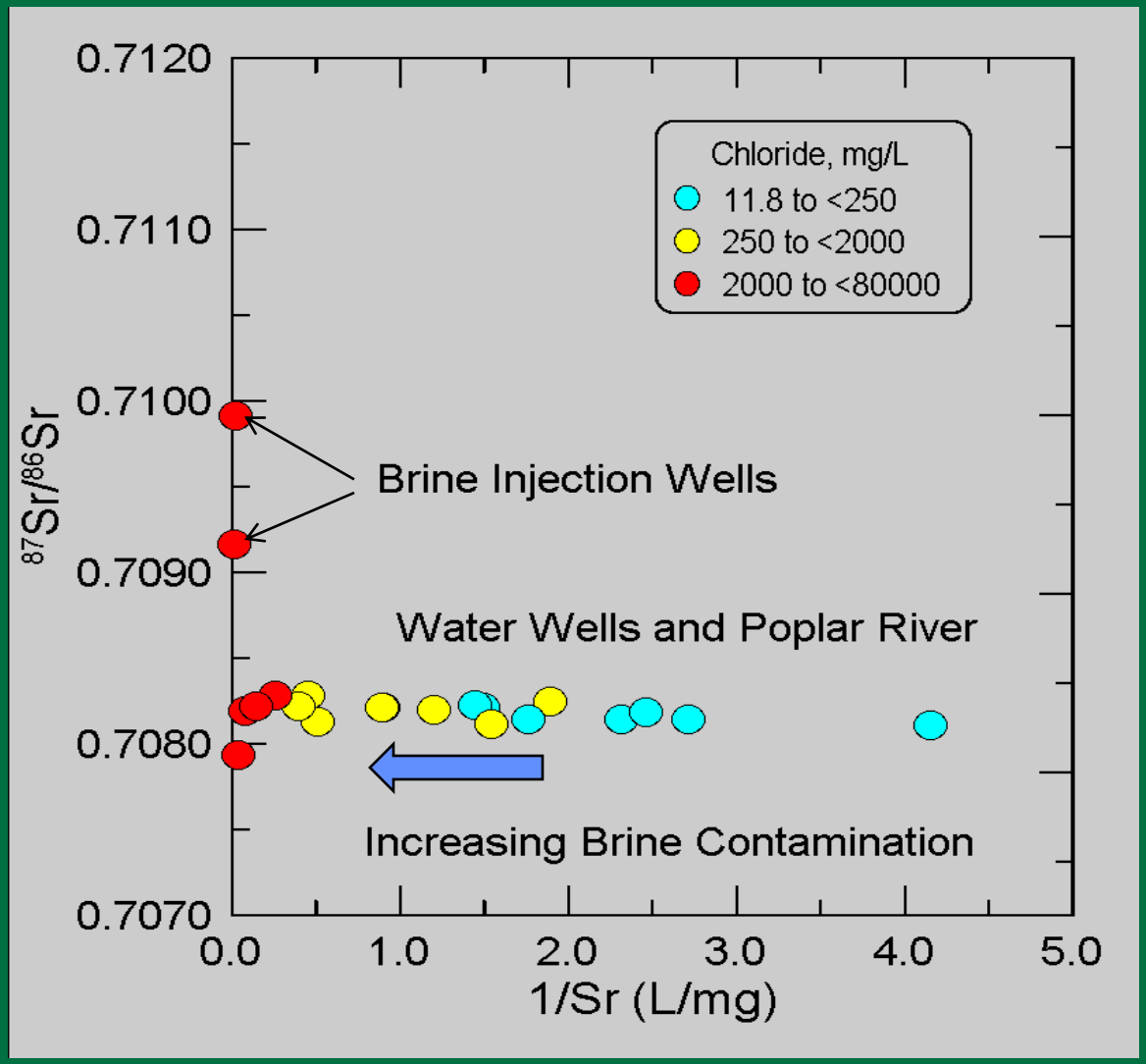
Phase I. Sr Isotope Characterization of Brine Contamination

- Sr and Cl are highly correlated in brines
- Mixing produces linear arrays
- Found no mixing between injected brine and ground-water
- What is the contaminant?



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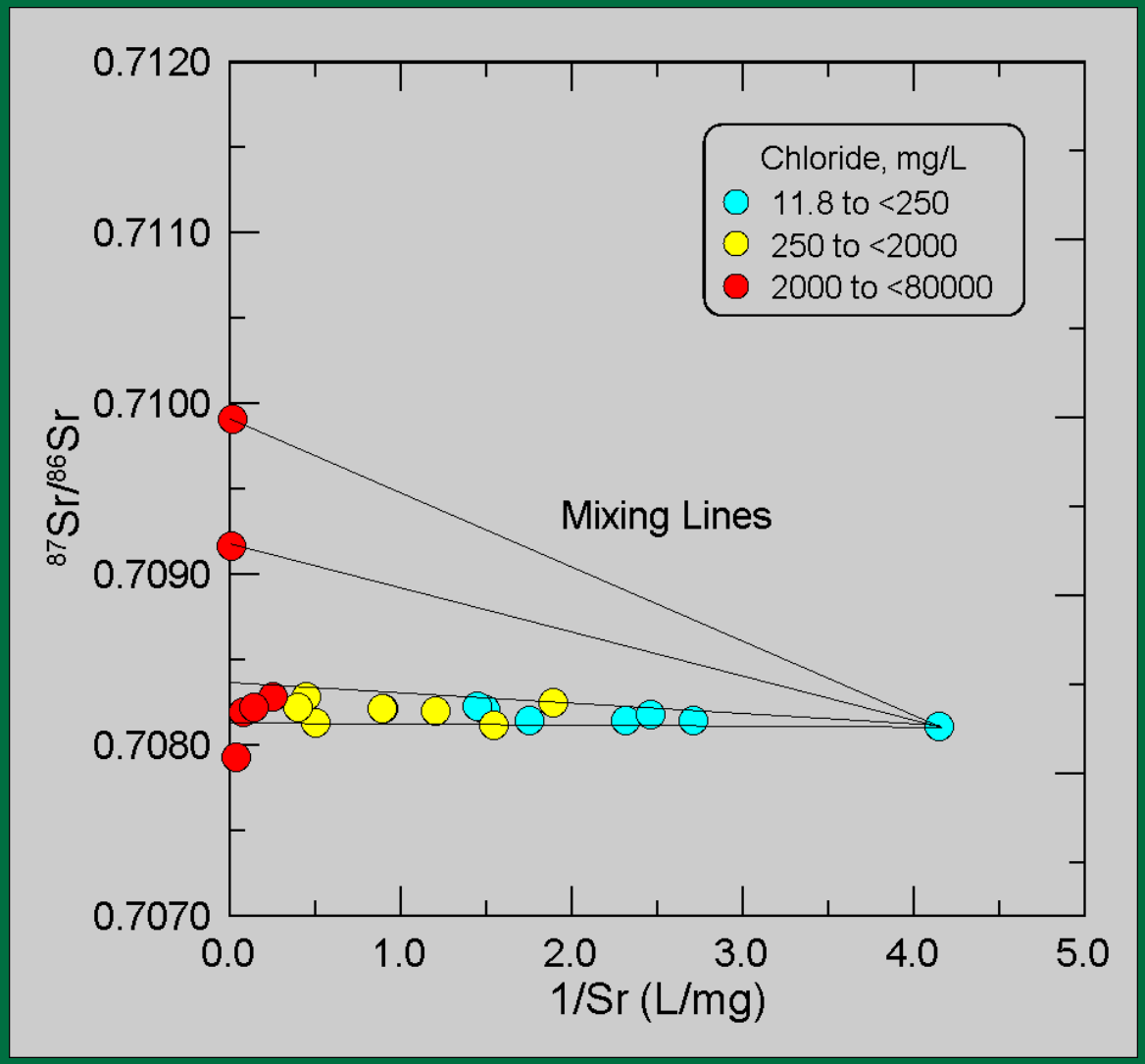
Phase I. Sr Isotope Characterization of Brine Contamination

- Loci of mixing constrained by data
- Found no mixing between injected brine and uncontaminated ground-water
- What is the brine that produced the contaminant trend?



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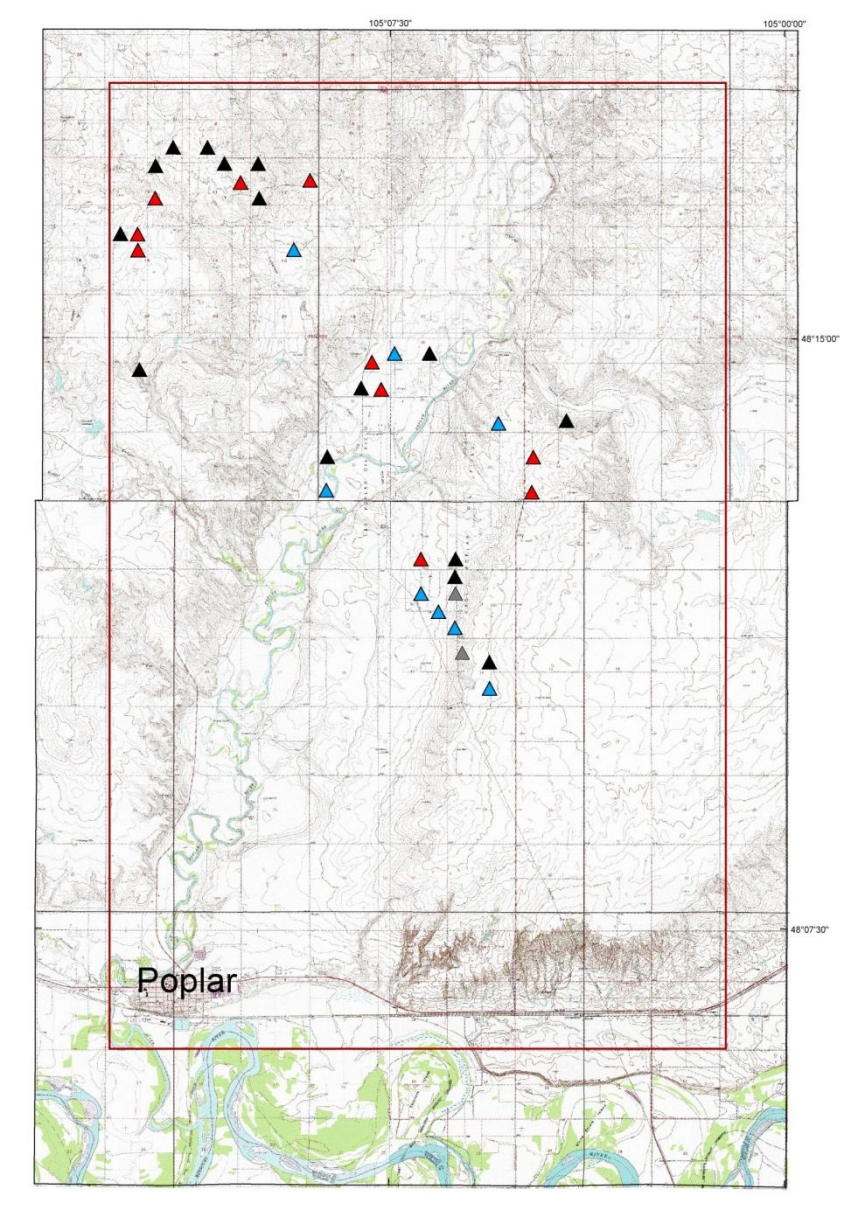
Locations of Sample Sites

- 20 brine samples collected from producing wells in 2011
- Emphasized spatial coverage
- Strontium isotopes define two groups: Red, <0.709 and blue and gray >0.709
- Black triangles are other active wells not yet sampled



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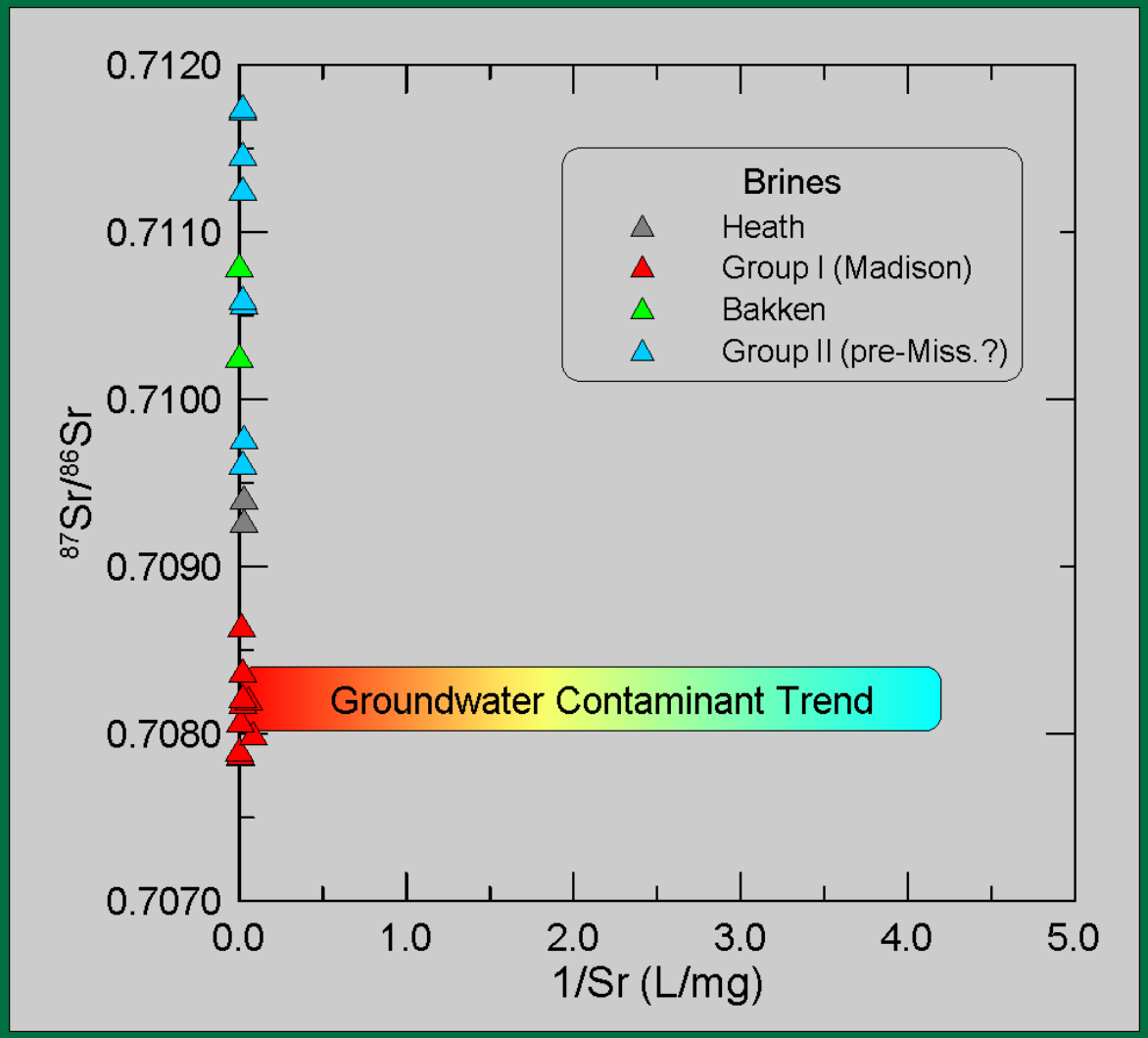
Phase II. Determined Sr Isotopes in Twenty Brine Samples from Producing Wells

- Half the brines have Sr isotopes consistent with contamination trend (Group I)
- Others have Sr isotope ratios too large for contamination trend (Group II)
- Bakken brines are in Group II



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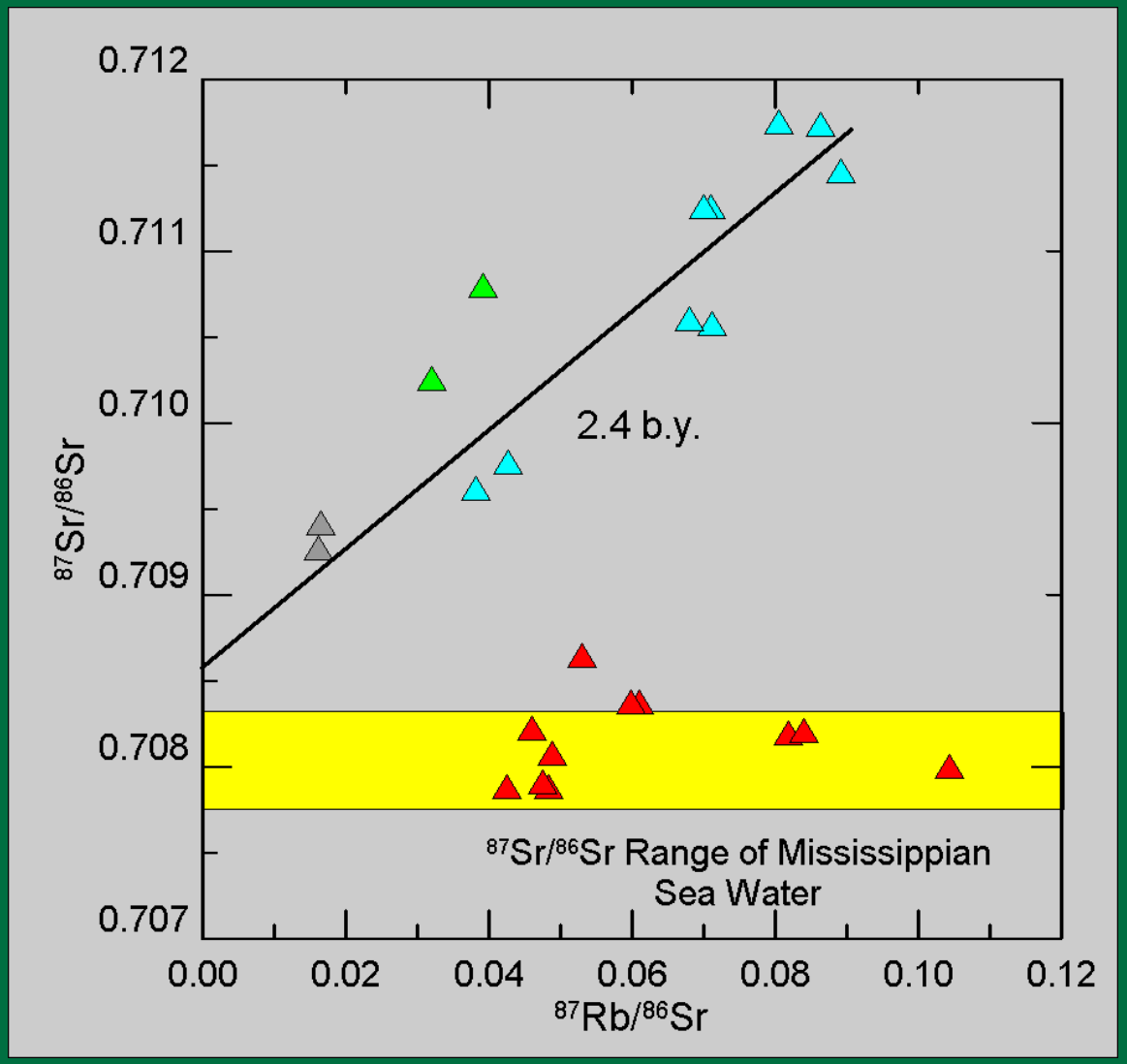
Parent-Daughter Correlations

- Significance?
- Correlation suggests clastic source rocks for brines
- May reflect age of source terrane—Superior Craton to the east of the basin??



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Observations

- Oil-field brines in the East Poplar field are composed of at least two isotopic types
- In the early production, produced water was primarily from the Charles Fm of the Madison Group
- As production continued, formation water from other (older?) units began to recharge the Madison reservoir
- This brine has not appeared in detectable amounts in the water wells that have been sampled so far

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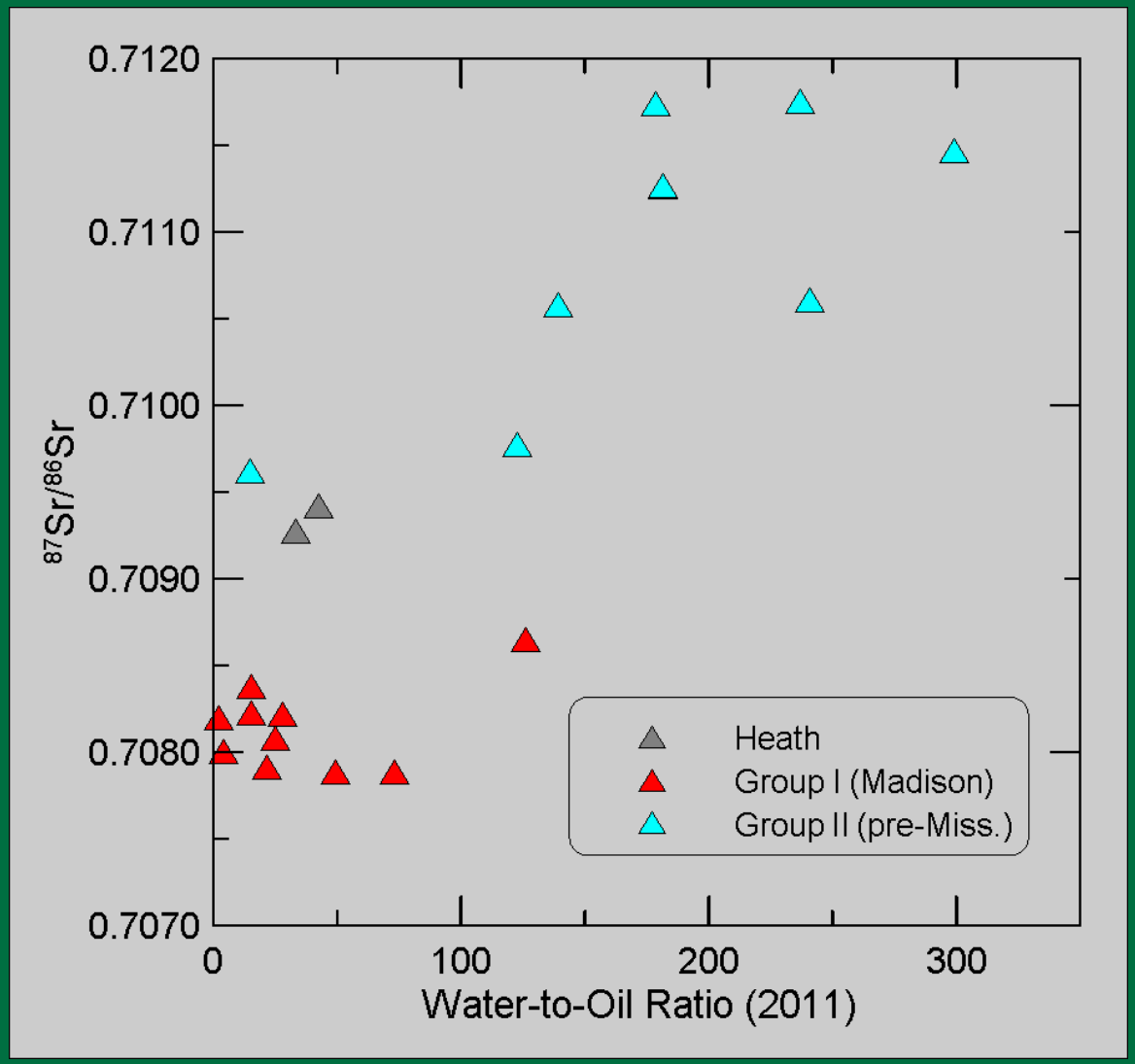
2011 Water-Oil Ratios (WOR) for Sampled Wells

- WORs generally increase with production
- Six of the Group II brines have larger WORs than Group I brines
- Relationship indicates that cross flow from older (?) units increases with production



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Stable Isotopes also Useful Fingerprints

- Pre-Mississippian formation water isotope stratigraphy developed by Rostron and Holmden (2000)
- $\delta^{18}O$ "Stratigraphy" of brines:

Bakken	+5.3
Birdbear	+5.6
Duperow	+6.1
Winnipegosis	-1.8
Ordivician/Silurian	-2.5
Yeoman	-1.1
Cambro-Ordovician	-2.9

USGS

Conclusions

- Two or more isotopically distinct brines are being produced in the East Poplar Oil Field
- During the 60 years of oil production from the East Poplar oil field, brines from older (?) units began to recharge the Madison reservoir by cross flow probably along faults
- These “older” brines did not contribute to the contamination of groundwater sampled to date
- 15 percent of sampled wells in Williston Basin produce “out of zone” water according to Arkadakskiy et al

USGS