What happens to the underlying aquifer when you put 1000 meters of ice on top?

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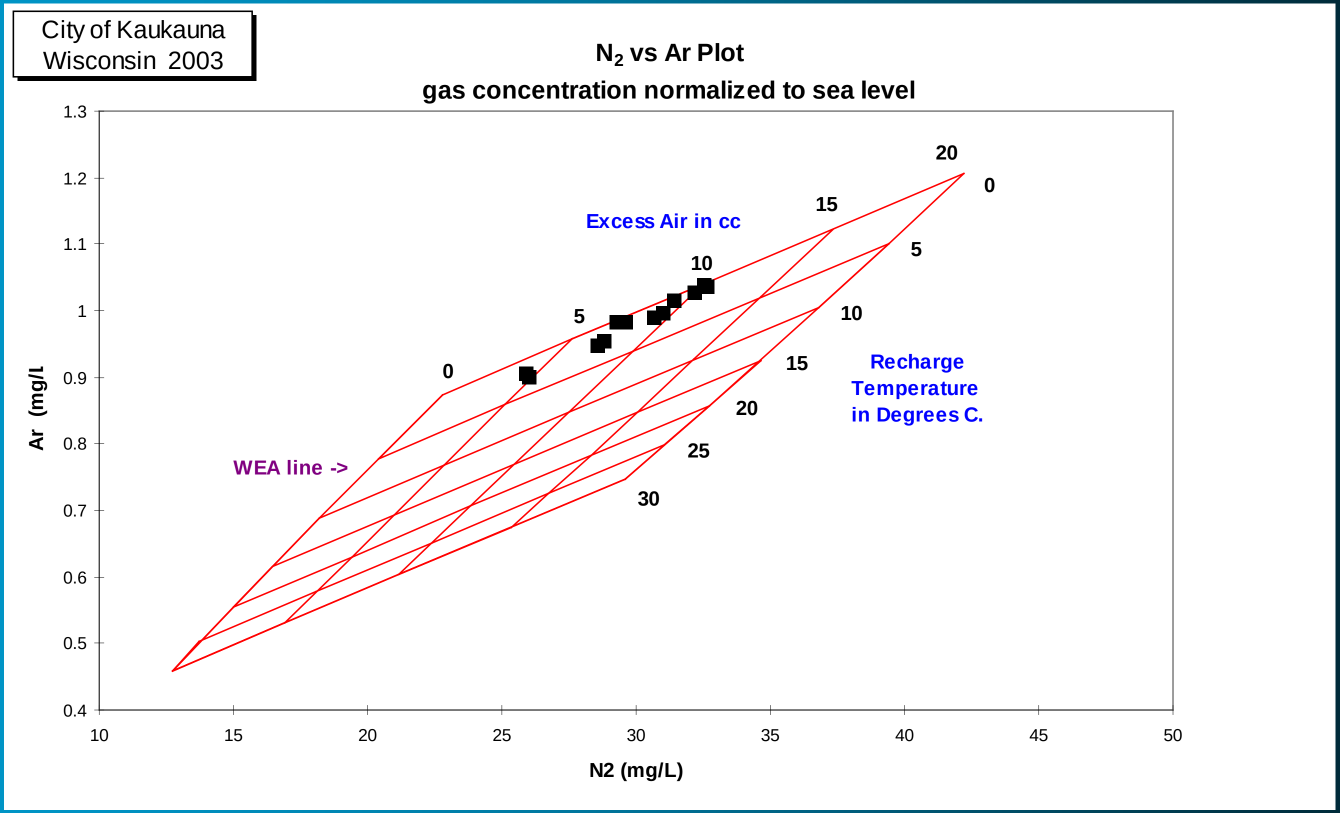
UW System Groundwater Research Program (project WR09R004)

This kind of study is possible only with the help of:

- *The computerized drinking water database maintained by the WDNR*
- *Regional groundwater modeling efforts (WGNHS; USGS)*
- *Near universal cooperation from water utilities*

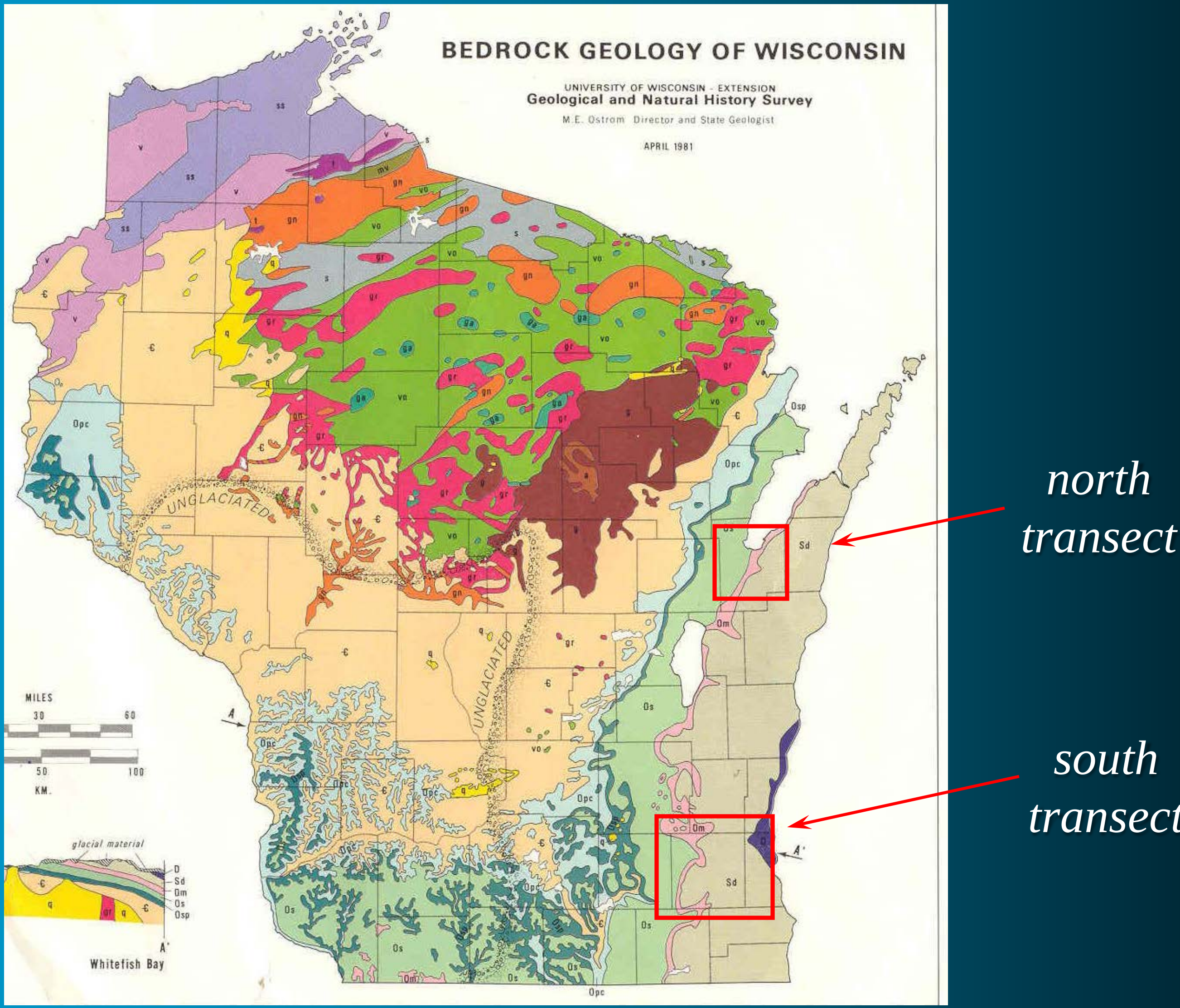
Can you tell me why my water is cloudy?



Presentation outline

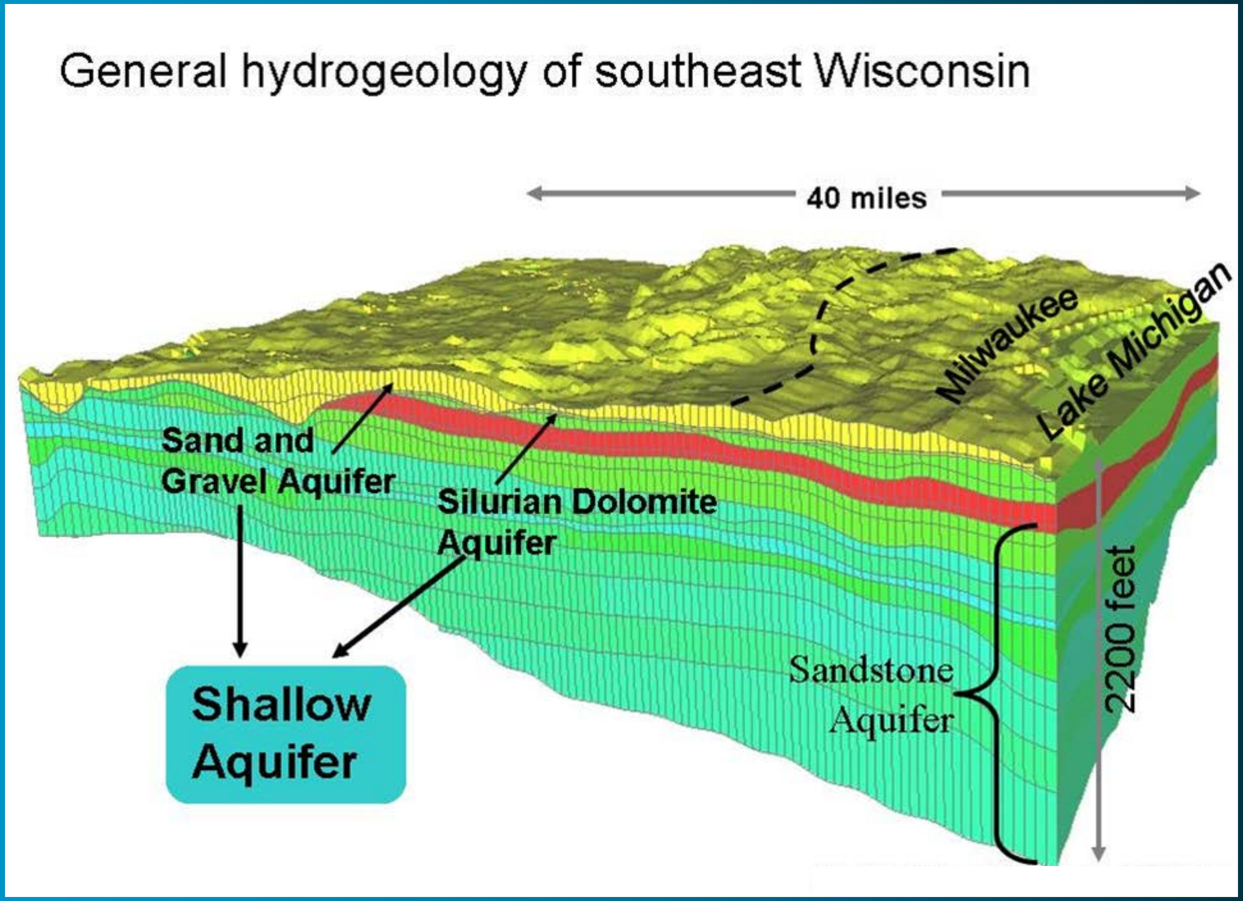
- *The set up: regional hydrogeology, glacial history, isotope and noble gas tracers*
- *Methods – data collected, etc.*
- *Pleistocene history as expressed in the north transect near Green Bay*
- *Comparison to Pleistocene history as expressed in the south transect near Milwaukee*
- *Some insight into the physical mechanisms that generate subglacial recharge water*

Bedrock geology of Wisconsin



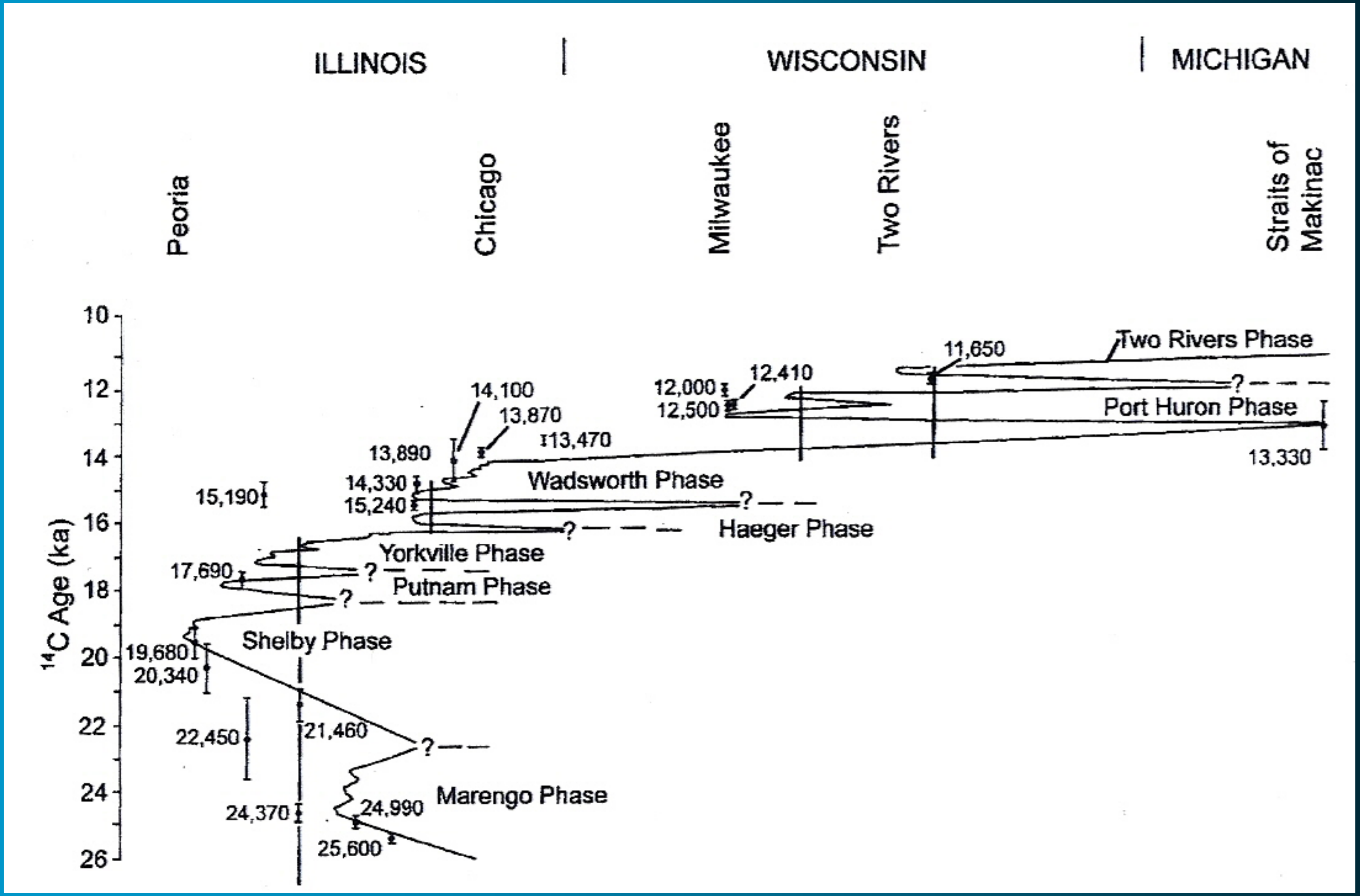
Modified from WGNHS

Diagrammatic stratigraphy



from Ken Bradbury, WGNHS

timing of Last Glacial Maximum



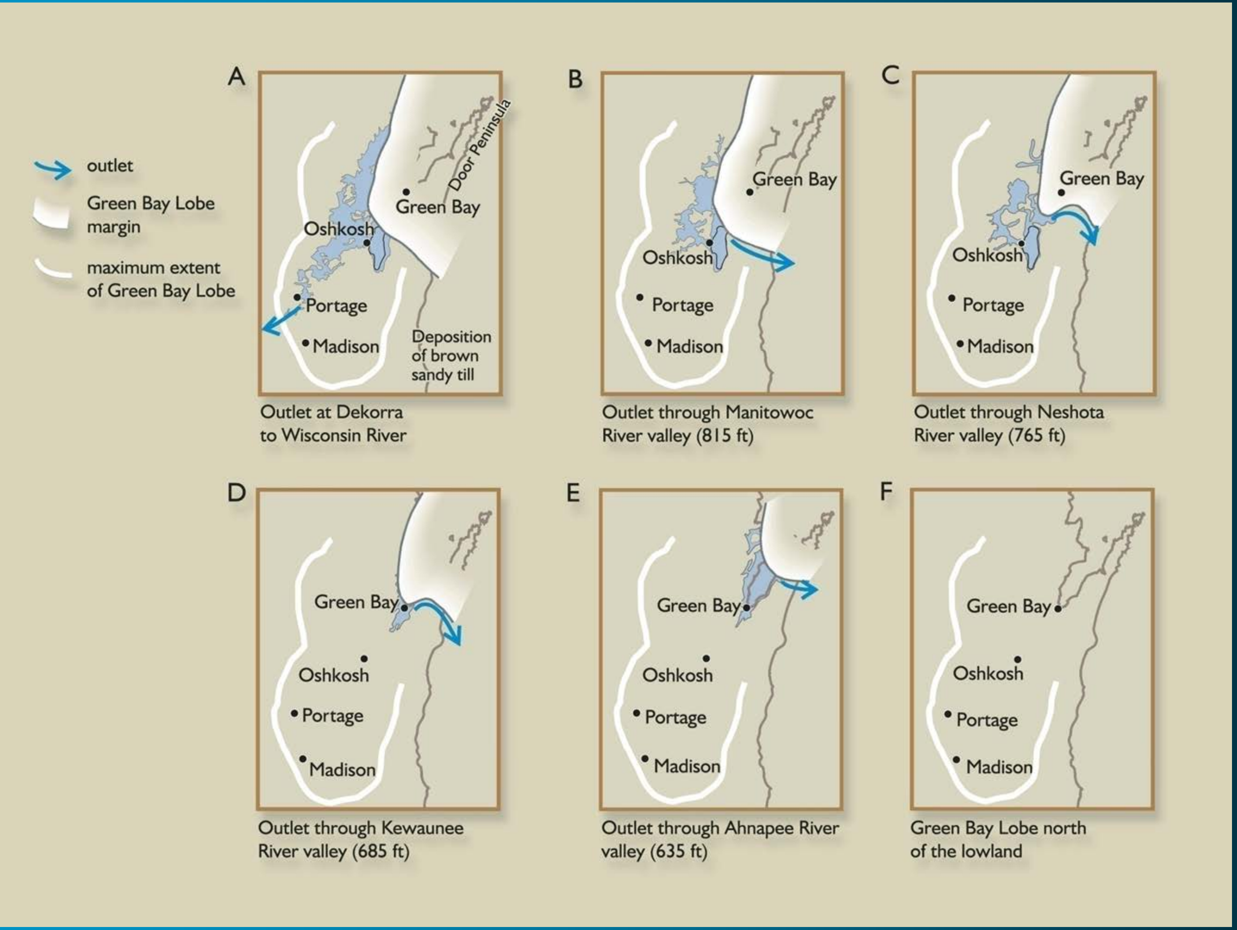
from Mickelson and Colgan, 2004

Below the "equilibrium line" glaciers are rotten

and melting fast.

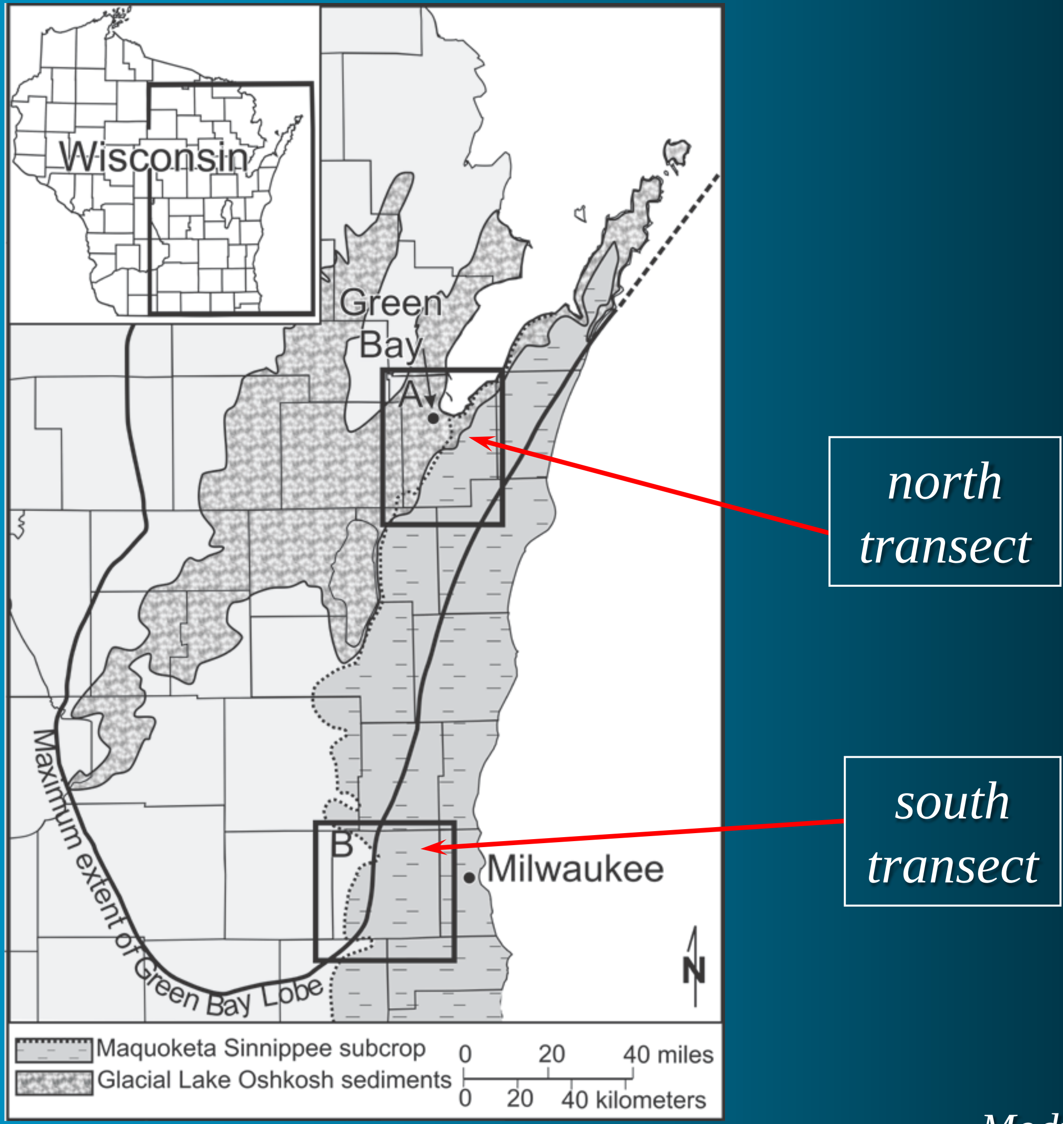
from NASA website (they have a neat movie too)

Formation of Glacial Lake Oshkosh



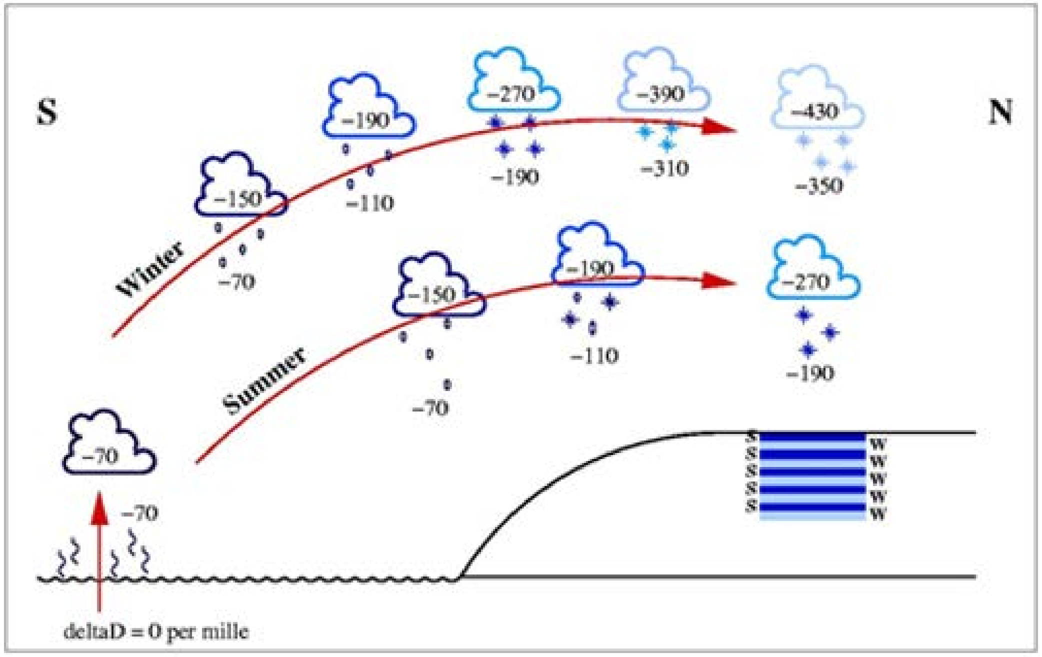
after Hooyer (2007), Late glacial history of east-central Wisconsin

Base map with glacial deposits



Modified from WGNHS

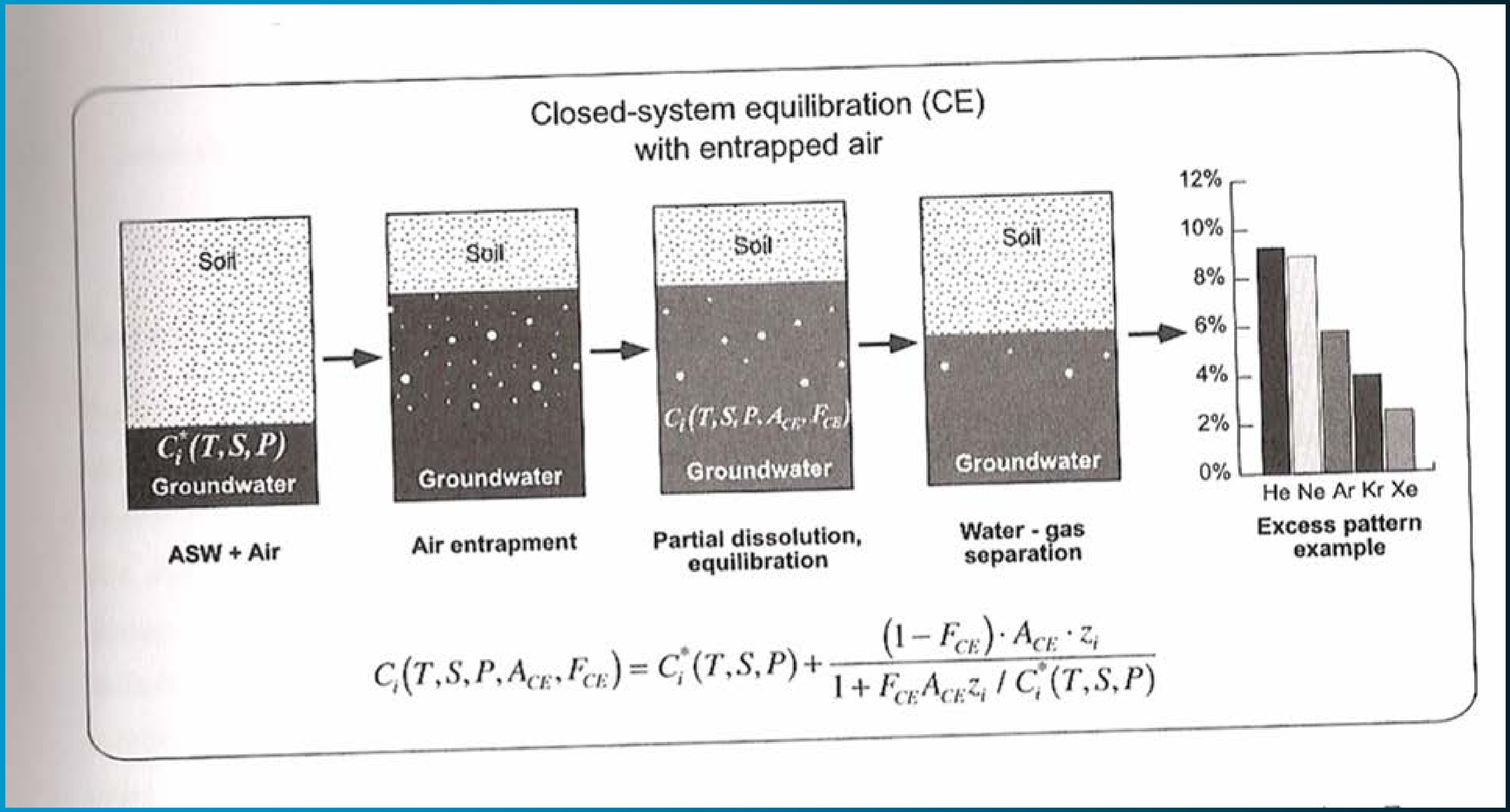
How $\delta^{18}O$ (and δD) reflect temperature variations



$$\delta^{18}O = 0.54T - 13.3$$

Taken from: http://www.iceandclimate.nbi.ku.dk/research/past_atmos/past_temperature_moisture/fractionation_and_temperature/

How noble gases work – CE model



from Holocher, 2002

Methodology for tracer study

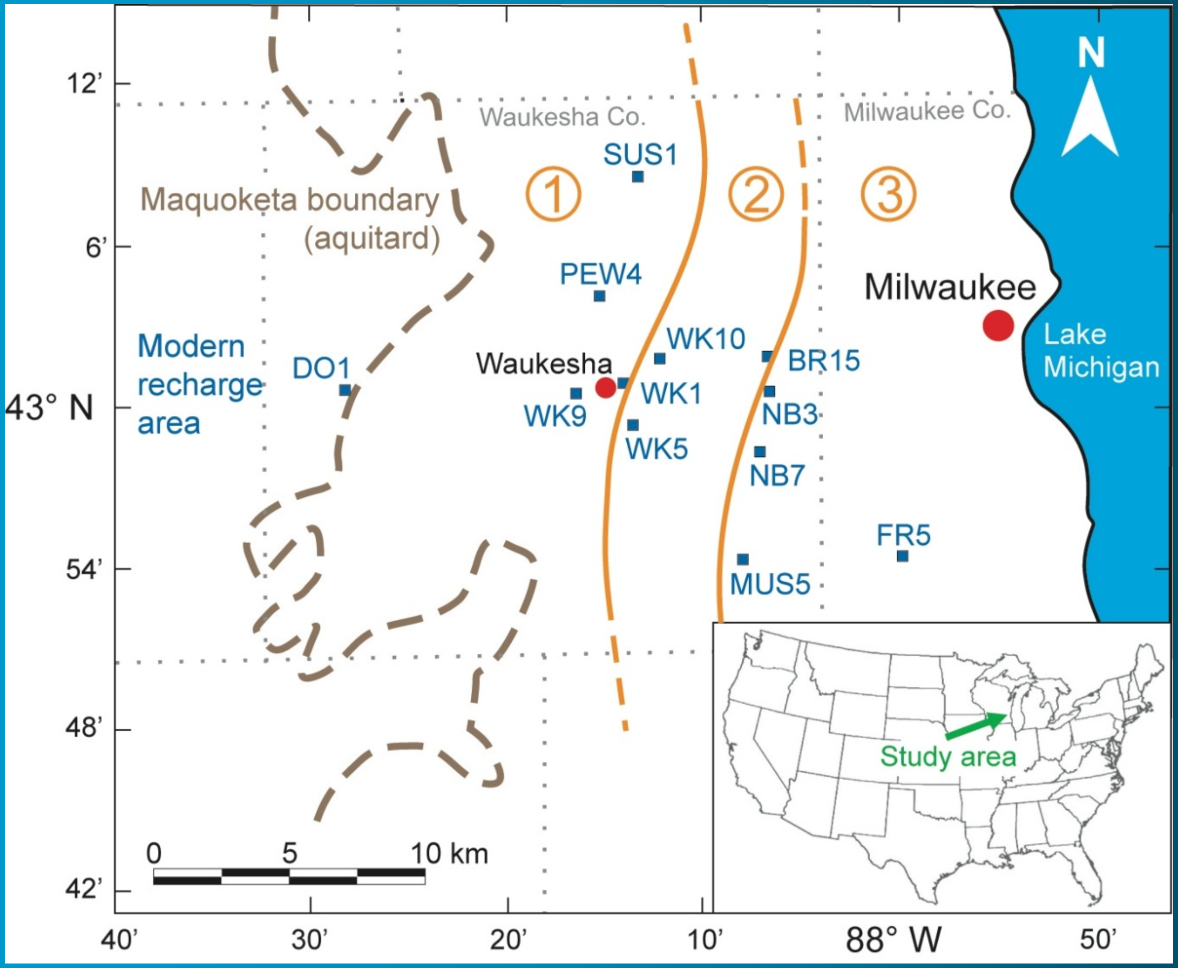
WHERE:

- *Municipal wells screened only in deep aquifer*
- *Previous chemical history*
  - *Consistency with numeric flow models (USGS)*
- *Physical access needed*

- *WHAT:*
- *Analyzed for*
  - *Major ions*
  - *Stable isotopes ($\delta^{32}S$, $\delta^{13}C$, $\delta^{18}O$, δD)*
  - *^{14}C dates*
  - *Noble gases (excess air/temperatures/fractionation/pressure factor)*

Glacial history as seen in the aquifer

south transect



from Klump, et al., 2008

Pre-glacial (3)

^{14}C >26Kyr

NGT warm

$\delta^{18}O$ enriched (pre-glacial climate)

Glacial (2)

14Kyr < ^{14}C <26Kyr

NGT and $\delta^{18}O$ cold

Post glacial (1)

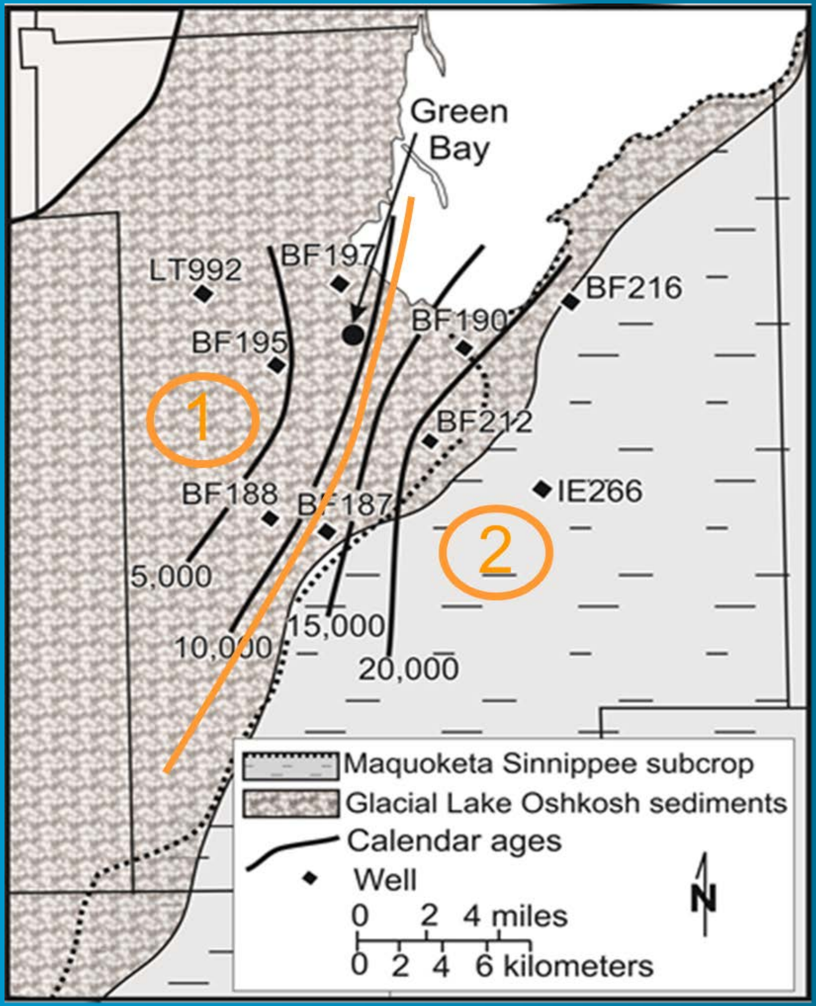
^{14}C <14Kyr

^{14}C dates match modeled values

NGT and $\delta^{18}O$ warm

Glacial history as seen in the aquifer

north transect



Glacial (2)

10Kyr < ^{14}C dates <26Kyr

cold $\delta^{18}O$ temperatures (< 0° C)

high pressure factors (q)

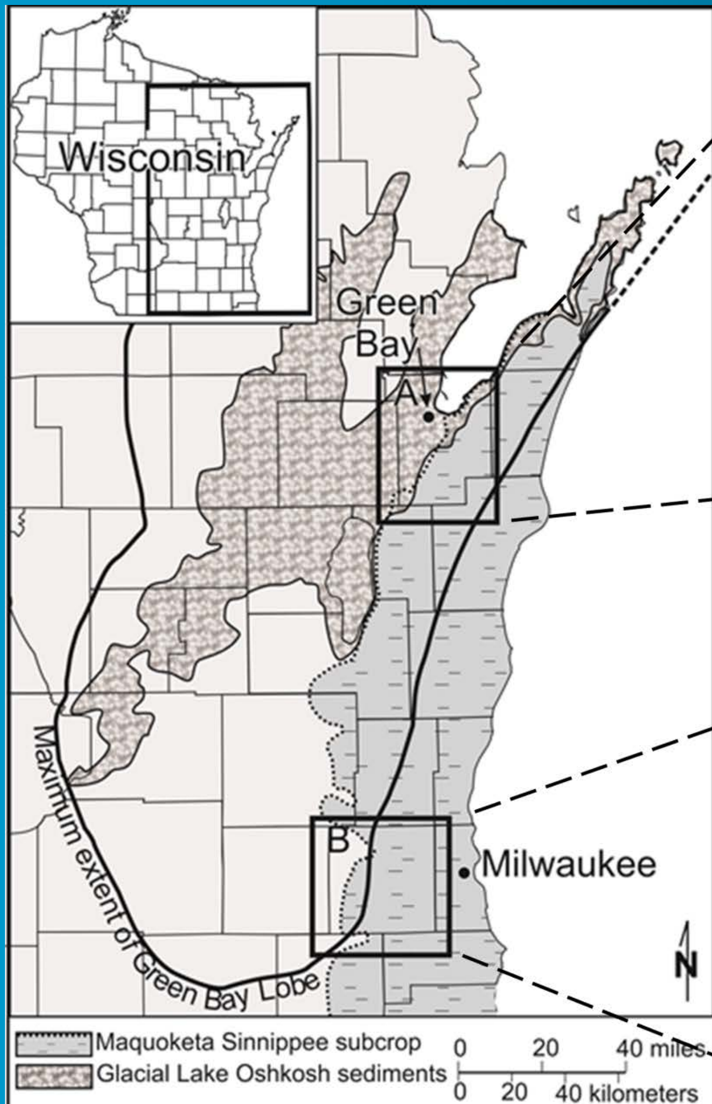
Post glacial (1)

^{14}C dates <10Kyr

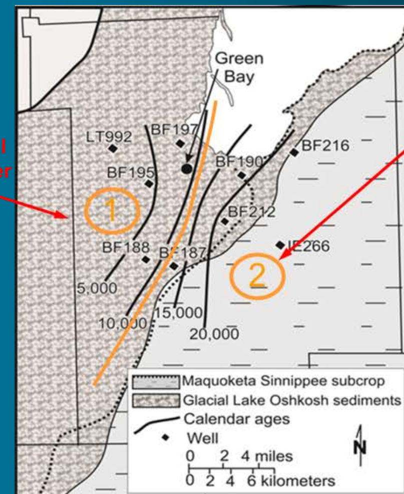
warm $\delta^{18}O$ temperatures (> 0° C)

lower pressure factors (q)

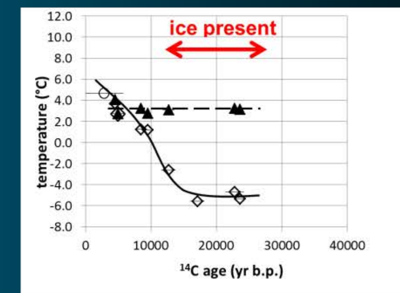
What happens along the ice axis?



post-glacial groundwater



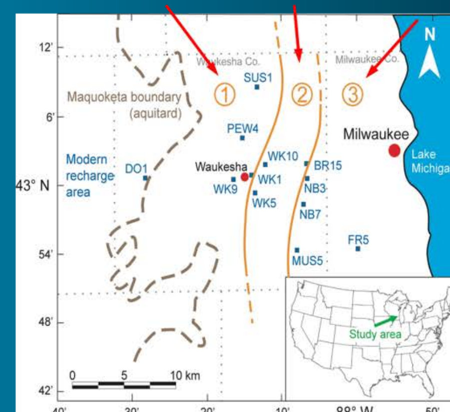
glacial groundwater

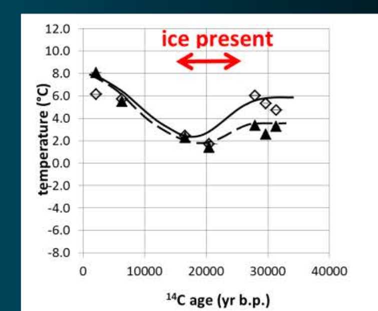


post-glacial groundwater

glacial groundwater

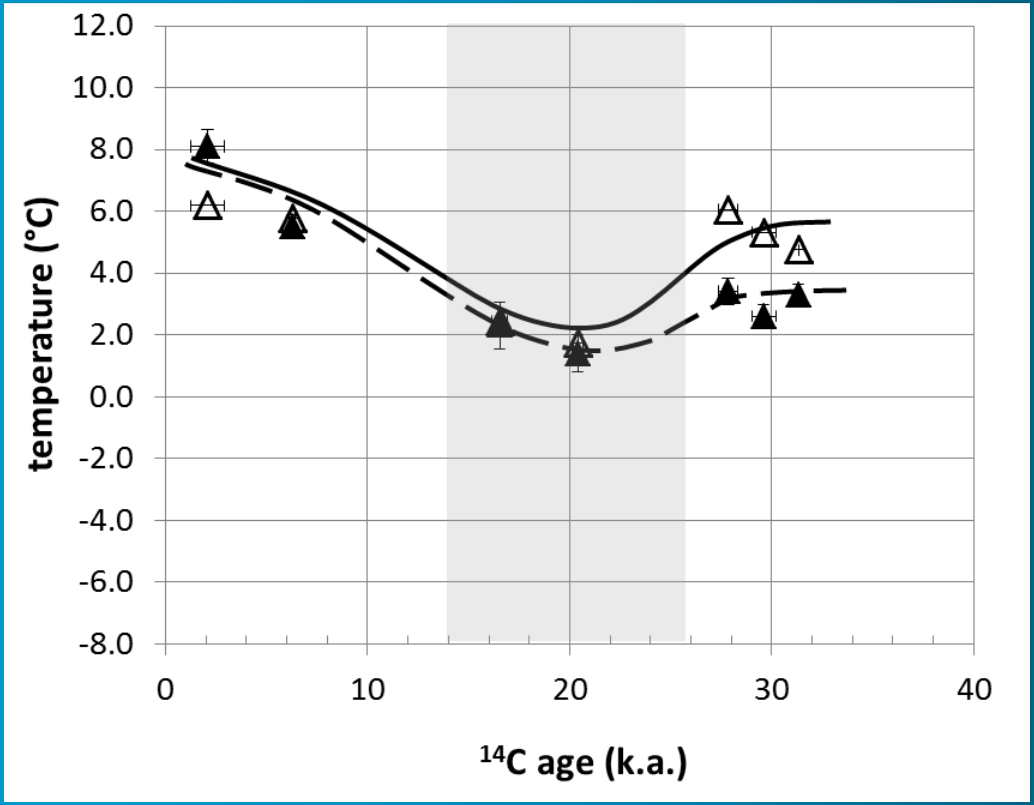
pre-glacial groundwater





$\delta^{18}O$ and noble gas thermometry

south transect



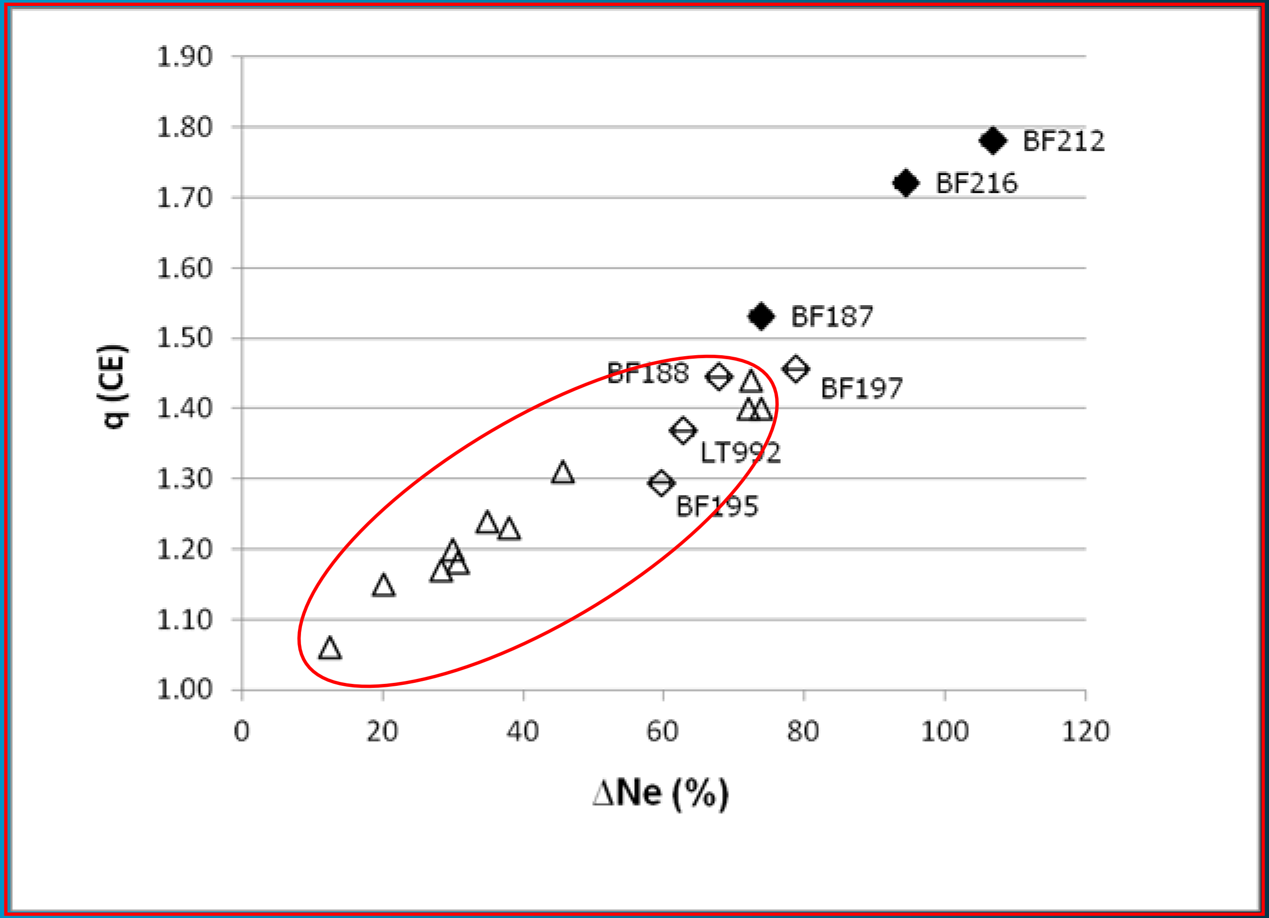
congruent and reasonable temperature records

▲ = *NG temperature*

△ = *$\delta^{18}O$ temperature*

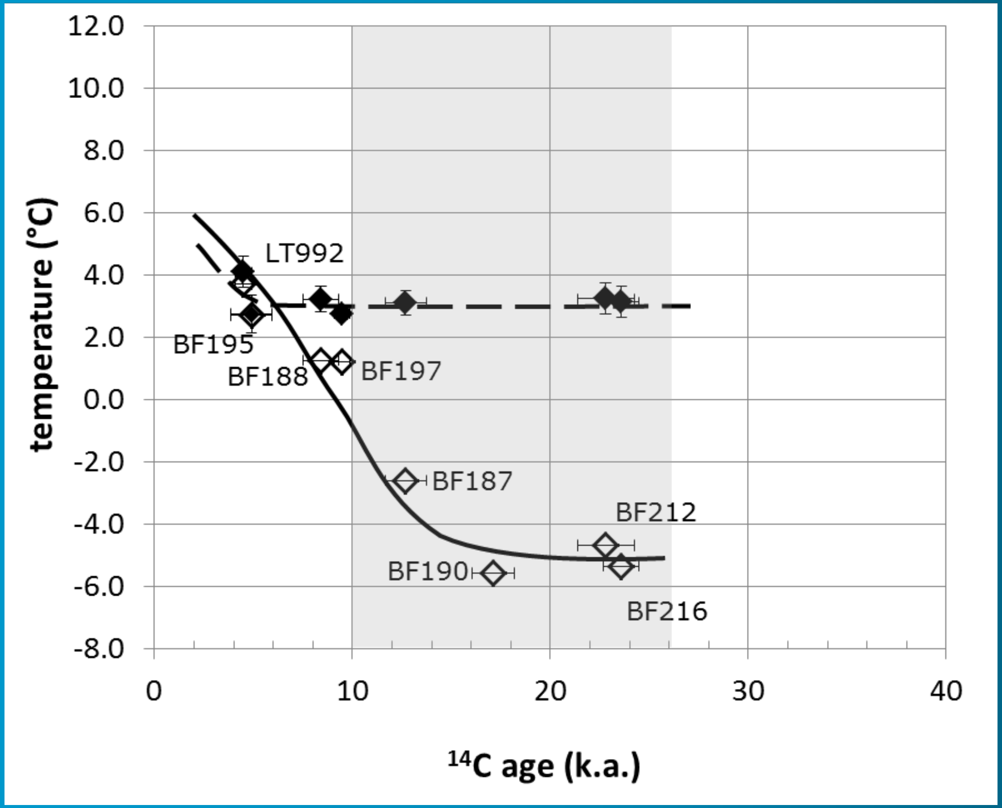
from Klump, et al., 2008

Excess air and pressure factors
north and south transects



$\delta^{18}O$ and noble gas thermometry

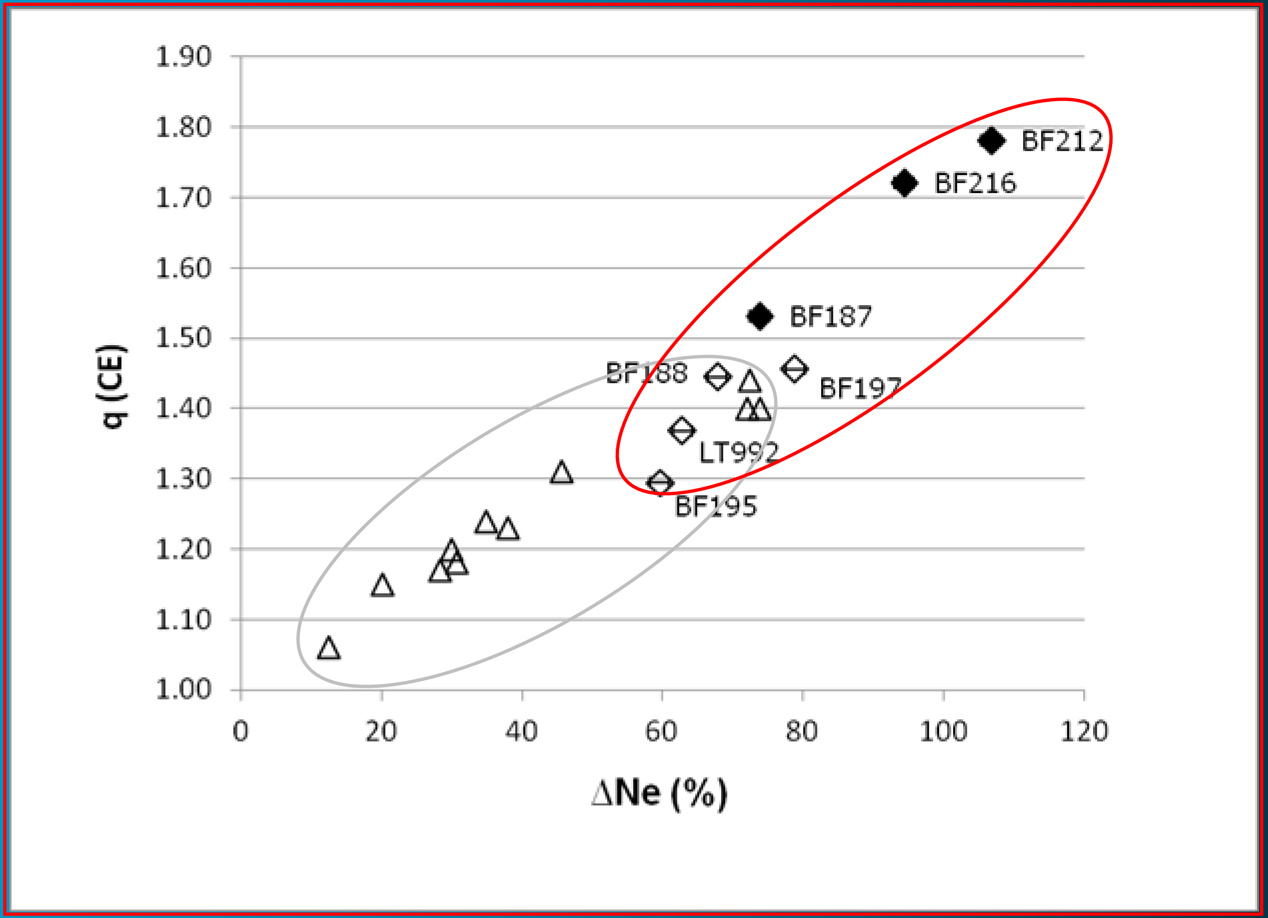
north transect



incongruent and unreasonable temperature records (at least initially)

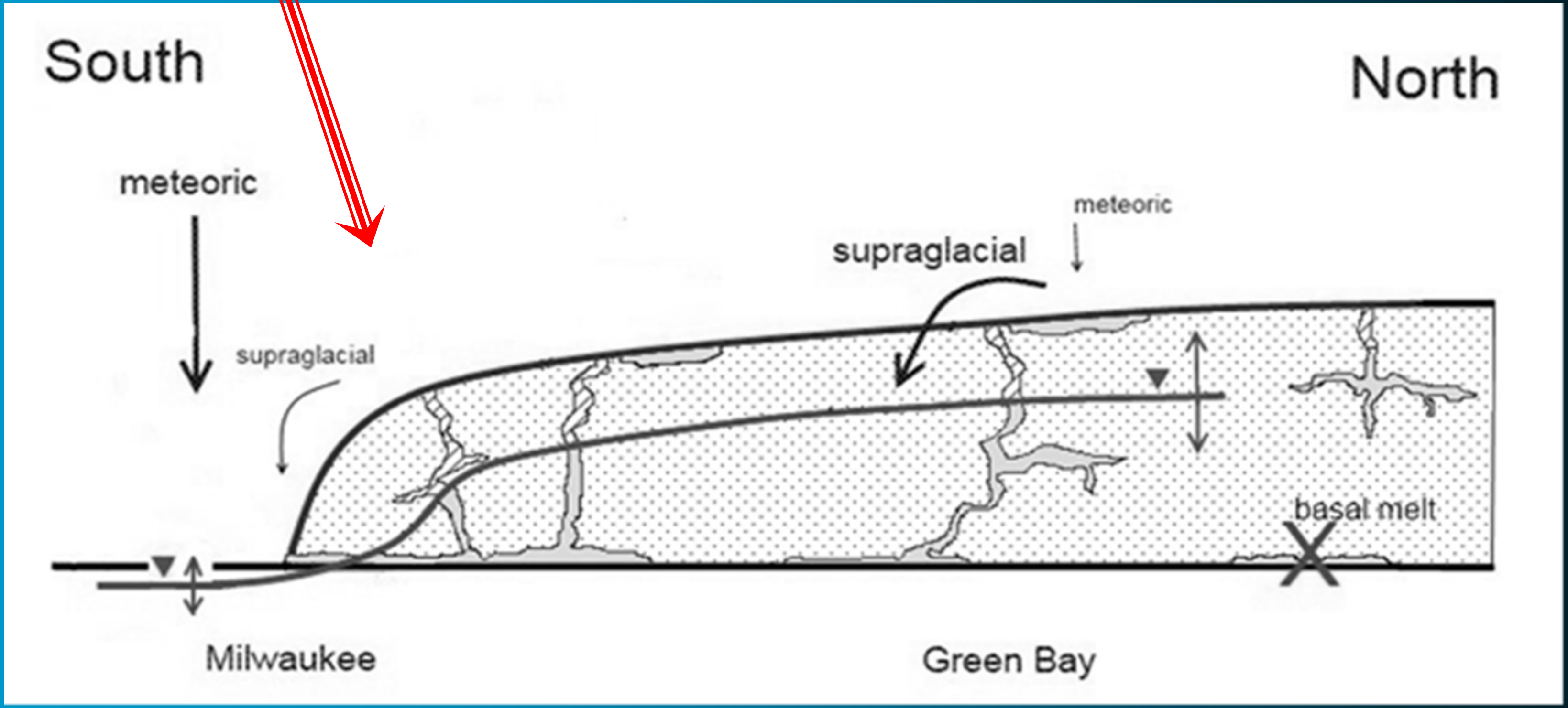
◆ = *NG temperature*
◇ = *$\delta^{18}O$ temperature*

Excess air and pressure factors
north and south transects



Genesis of recharge water

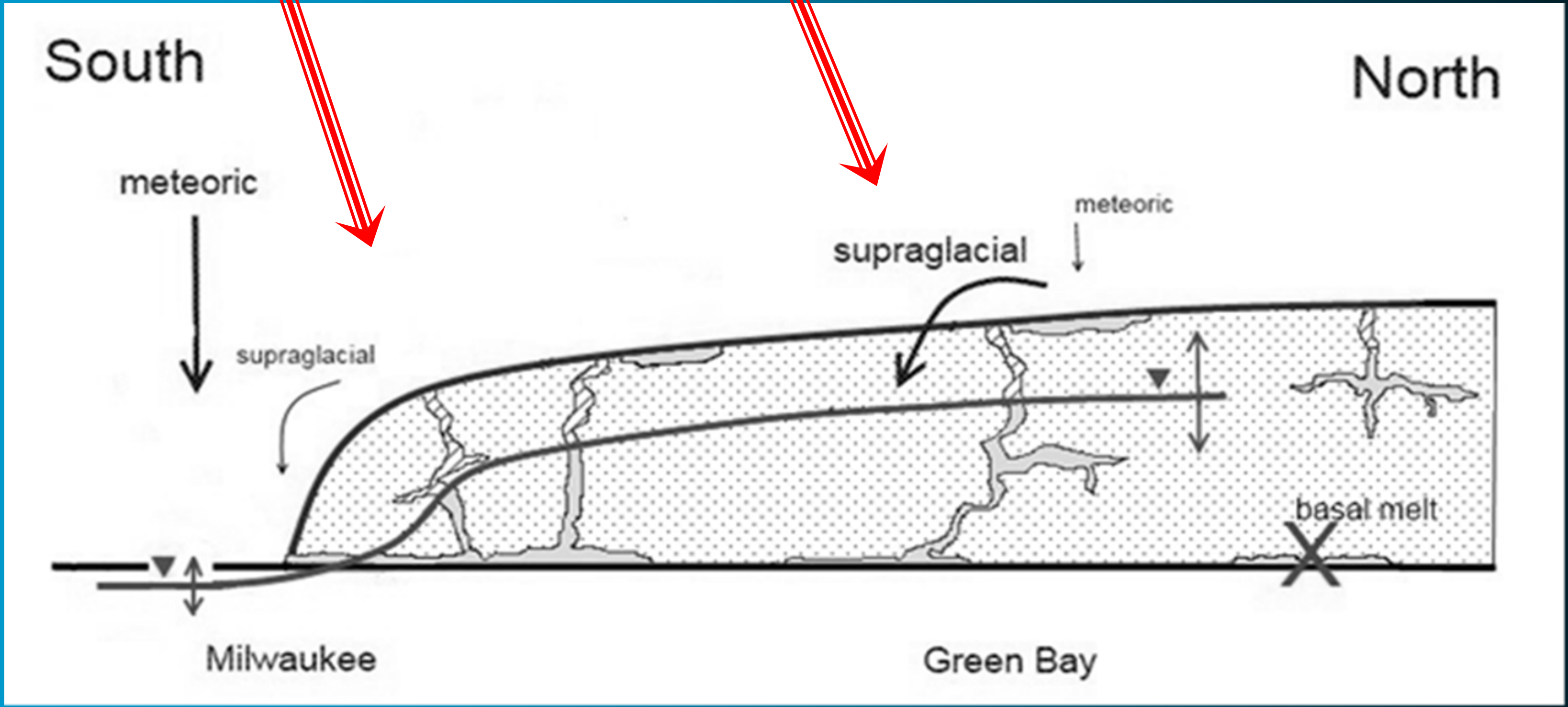
NGT reflects local climate
$\delta^{18}O$ temp reflects local climate
ΔNe less than 70%
Recharge heads 0.5 - 4 meters
Normal CE fractionation



Genesis of recharge water

NGT reflects local climate
$\delta^{18}O$ temp reflects local climate
ΔNe less than 70%
Recharge heads 0.5 - 4 meters
Normal CE fractionation

NGT reflects moulin air temp
$\delta^{18}O$ temp reflects glacial ice
ΔNe between 70% and 110%
Recharge heads 2.5 – 8 meters
Normal CE fractionation

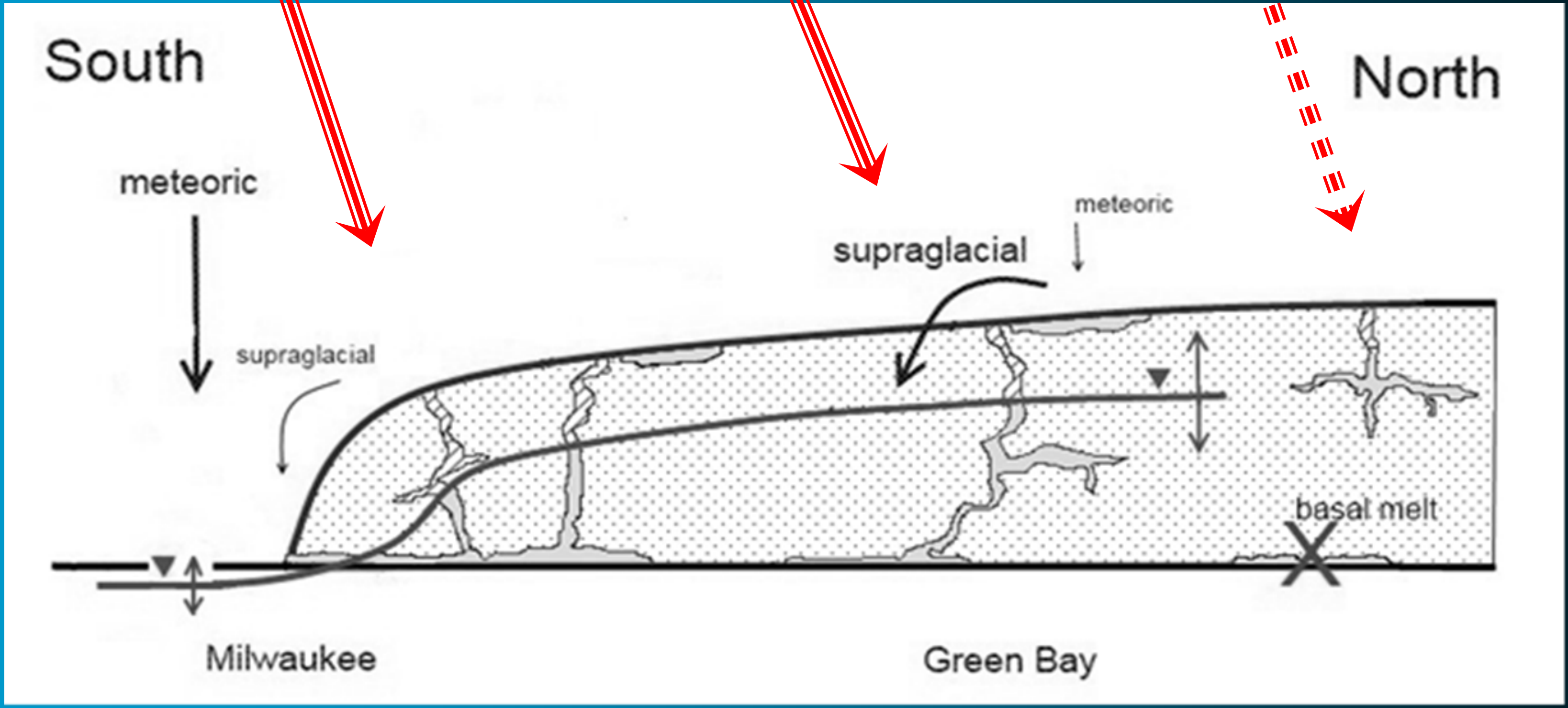


Genesis of recharge water – a suggestion

NGT reflects local climate
$\delta^{18}O$ temp reflects local climate
ΔNe less than 70%
Recharge heads 0.5 - 4 meters
Normal CE fractionation

NGT reflects moulin air temp
$\delta^{18}O$ temp reflects glacial ice
ΔNe between 70% and 110%
Recharge heads 2.5 – 8 meters
Normal CE fractionation

$\delta^{18}O$ temp reflects glacial ice
ΔNe of several hundred %
Very little fractionation
NGT indefinable by CE model
Recharge heads indefinable

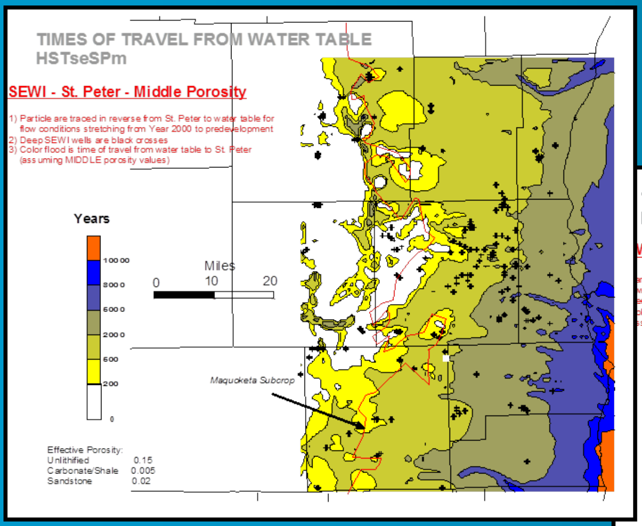


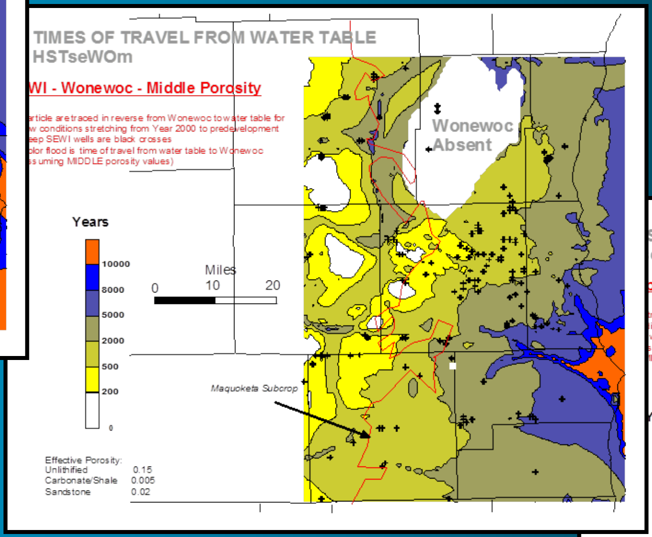
Conclusions about that 1000 m of ice

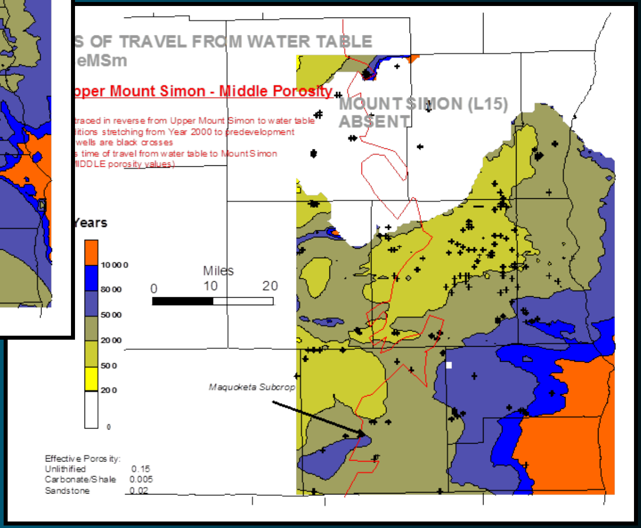
- *Identifiably distinct packets of water exist within a stratigraphically continuous aquifer*
- *Aquifer was not sealed off Last Glacial Maximum (LGM)*
- *Source of LGM recharge varies as a function of distance from terminus*
- *Large amounts of LGM water exist in the aquifer (universally true in northern hemisphere basins?)*
- *Possible technique for determining the provenance of basal water in modern ice sheets*


Thanks for inviting me

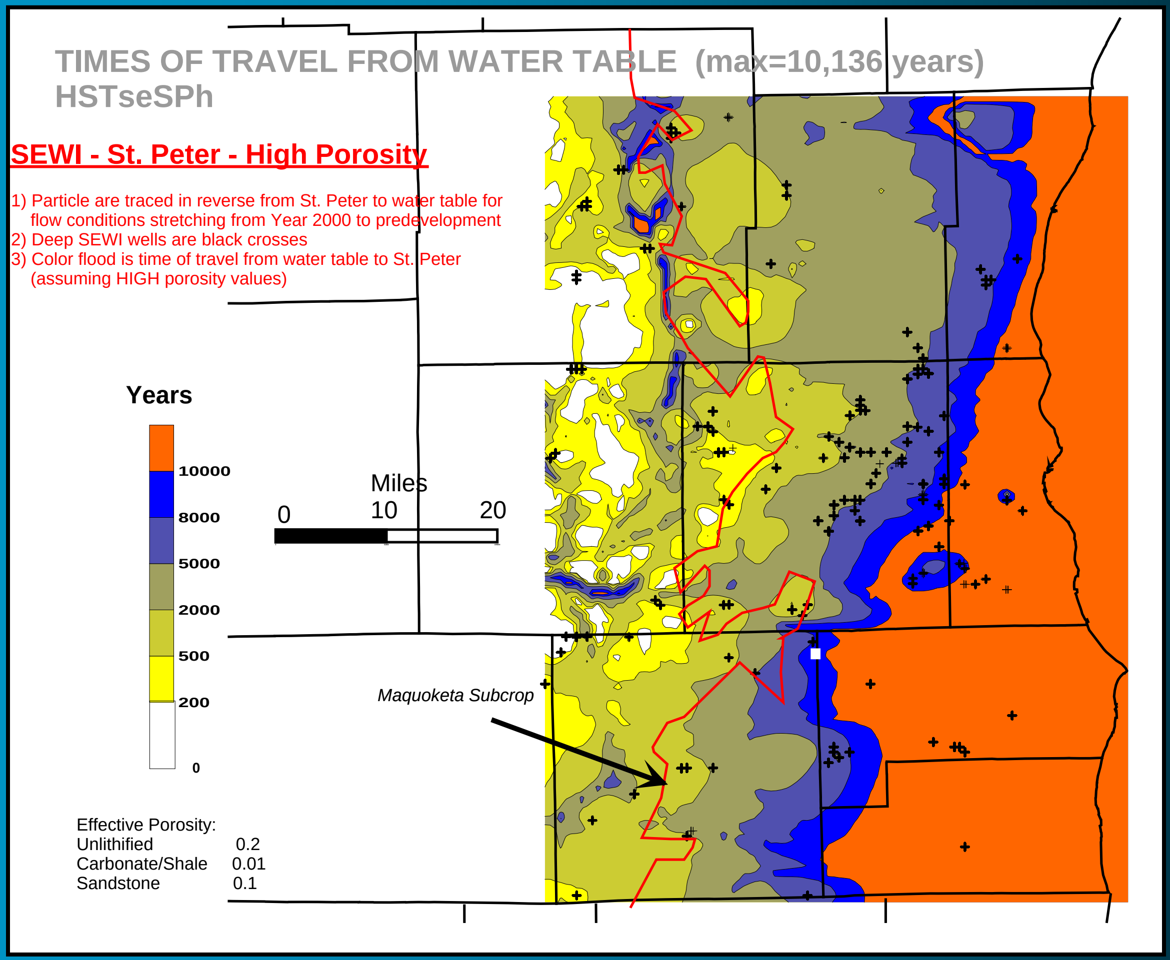
What does the SE Wisconsin regional model say about travel time?



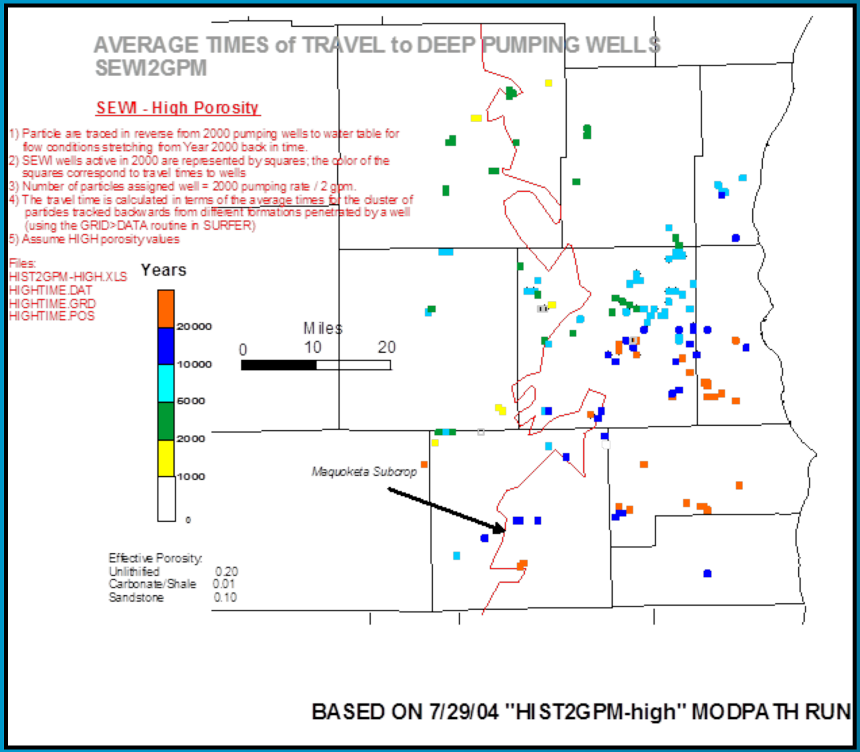




After whining for more porosity



After even more whining on my part

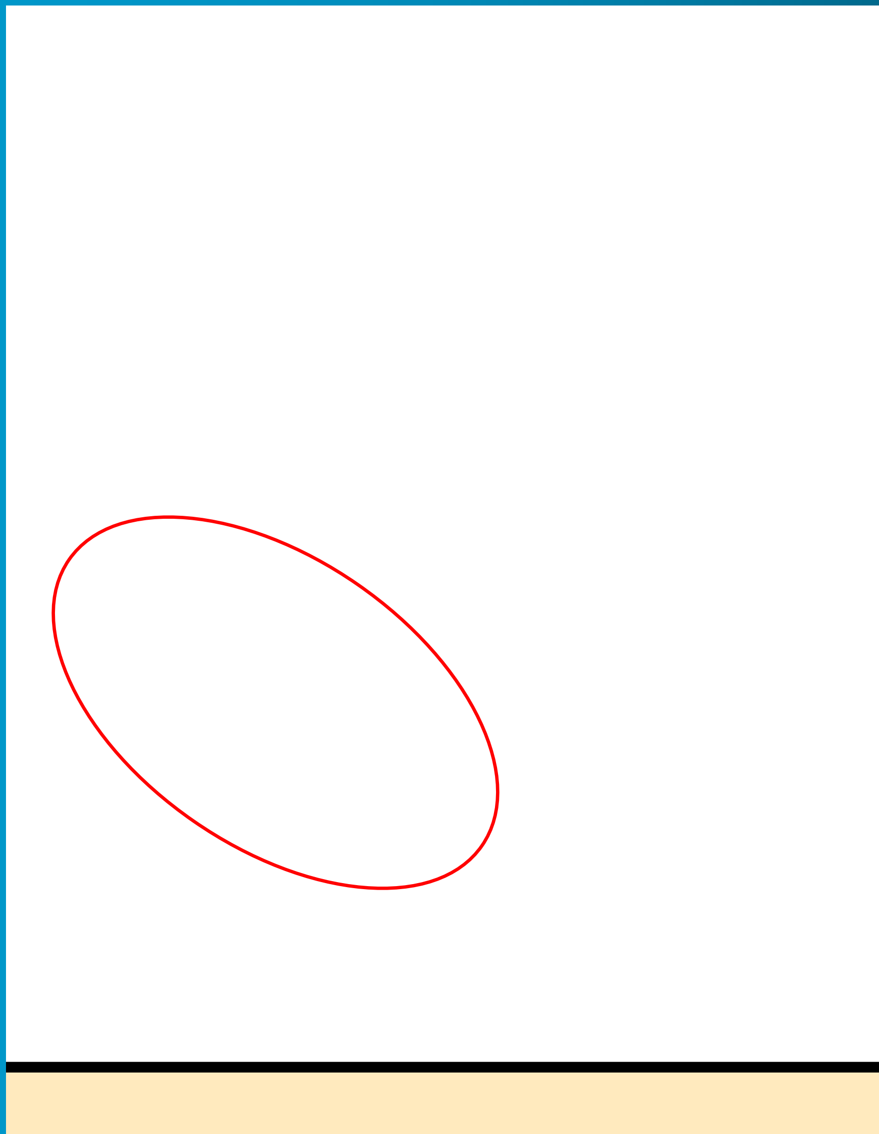


"I still think 10% porosity for the deep sandstone is too high -"

"<u>- even perhaps for you</u>, given the ages well in excess of 20,000 yrs in Milw/ Racine/Kenosha counties."

"A porosity of 5% <u>might be more bearable."</u>

Study Area Basemap



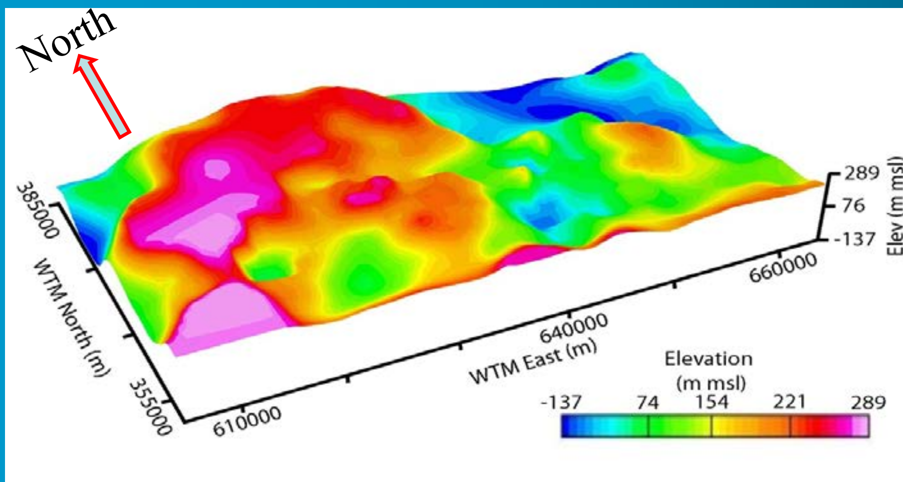
Center transect

Fond du Lac, Washington, and Ozaukee Counties

Problem!

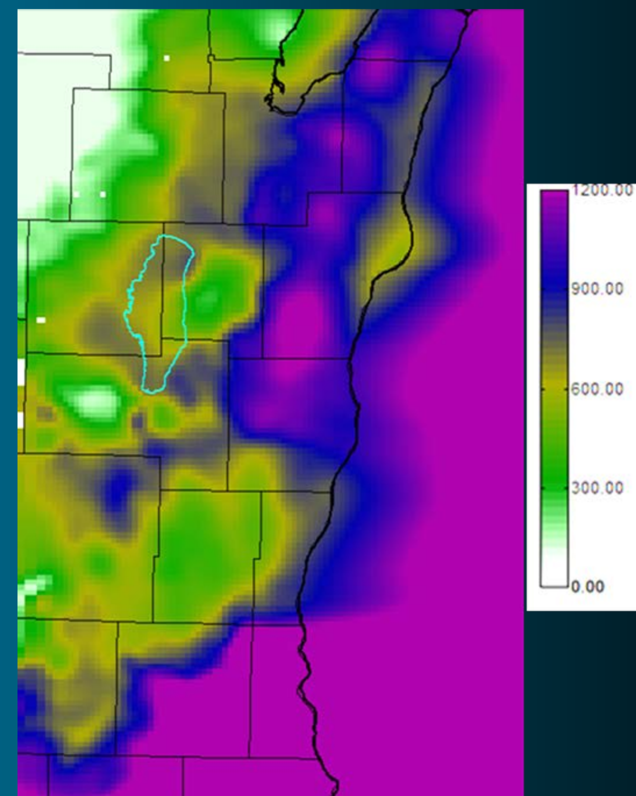
Why this area is a problem…

elevation of basement



from John Skalbeck

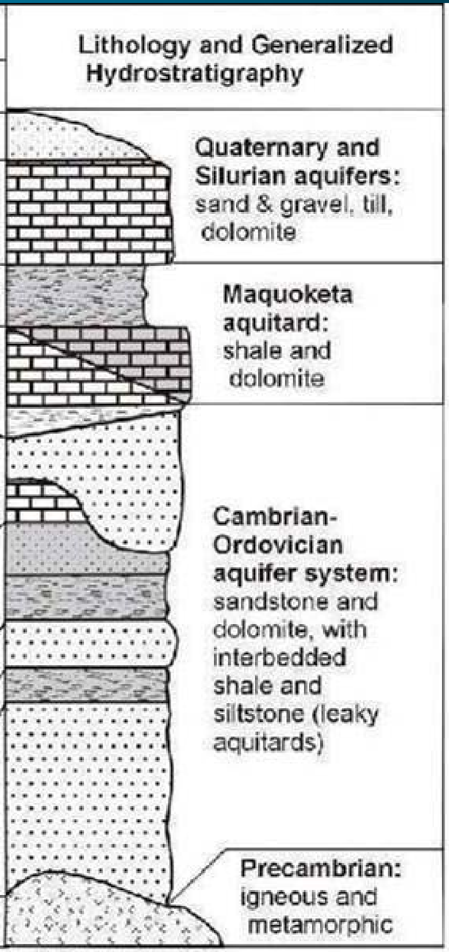
aquifer thickness



from Nate Magnusson

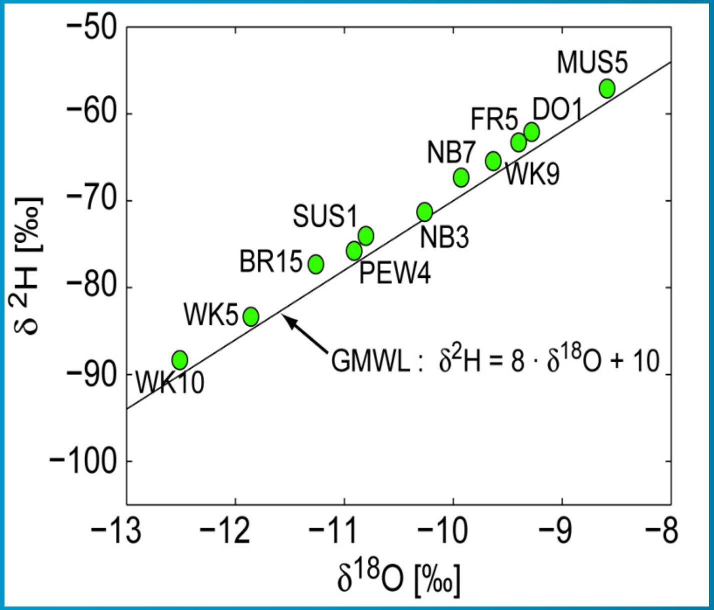
Simplified hydro-stratigraphic column

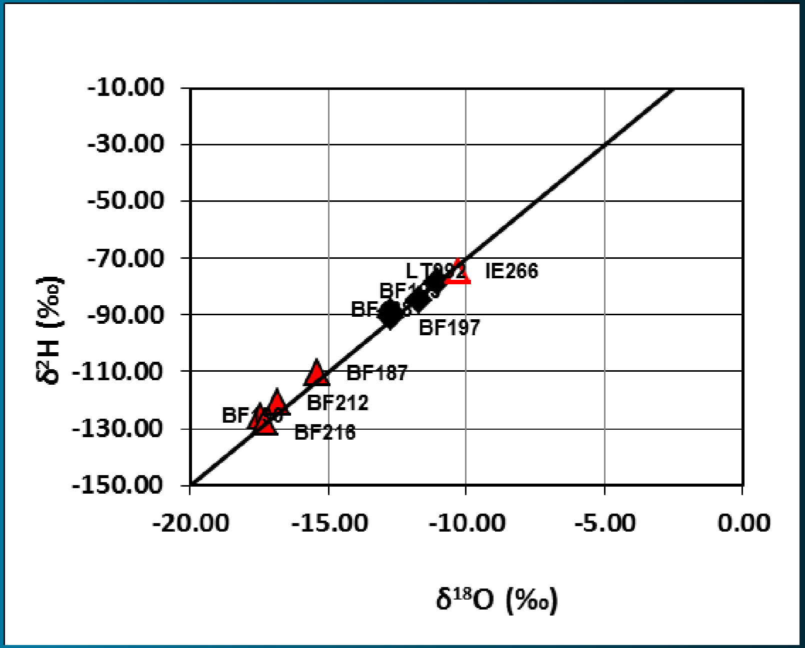
Stratigraphic Nomenclature		Hydraulic conductivity
Group	Formation	Kh (m/d)
Quaternary	(undiff.)	0.06-30
Devonian	(undiff.)	9
Silurian	(undiff.)	0.3-1.2
	Maquoketa	9E-5 - 0.09
Sinnipee	Galena	0.012-0.09
	Platteville	
Ancell	Glenwood	0.36-1.8
	St. Peter	
Prairie du Chien	(undiff.)	
Trempealeau	Jordan	0.07-0.7
	St. Lawrence	
Tunnel City	(undiff.)	
Elk Mound	Wonewoc	0.7-2.6
	Eau Claire	0.18-1.1
	Mt. Simon	0.36-1.8
Precambrian	impermeable	



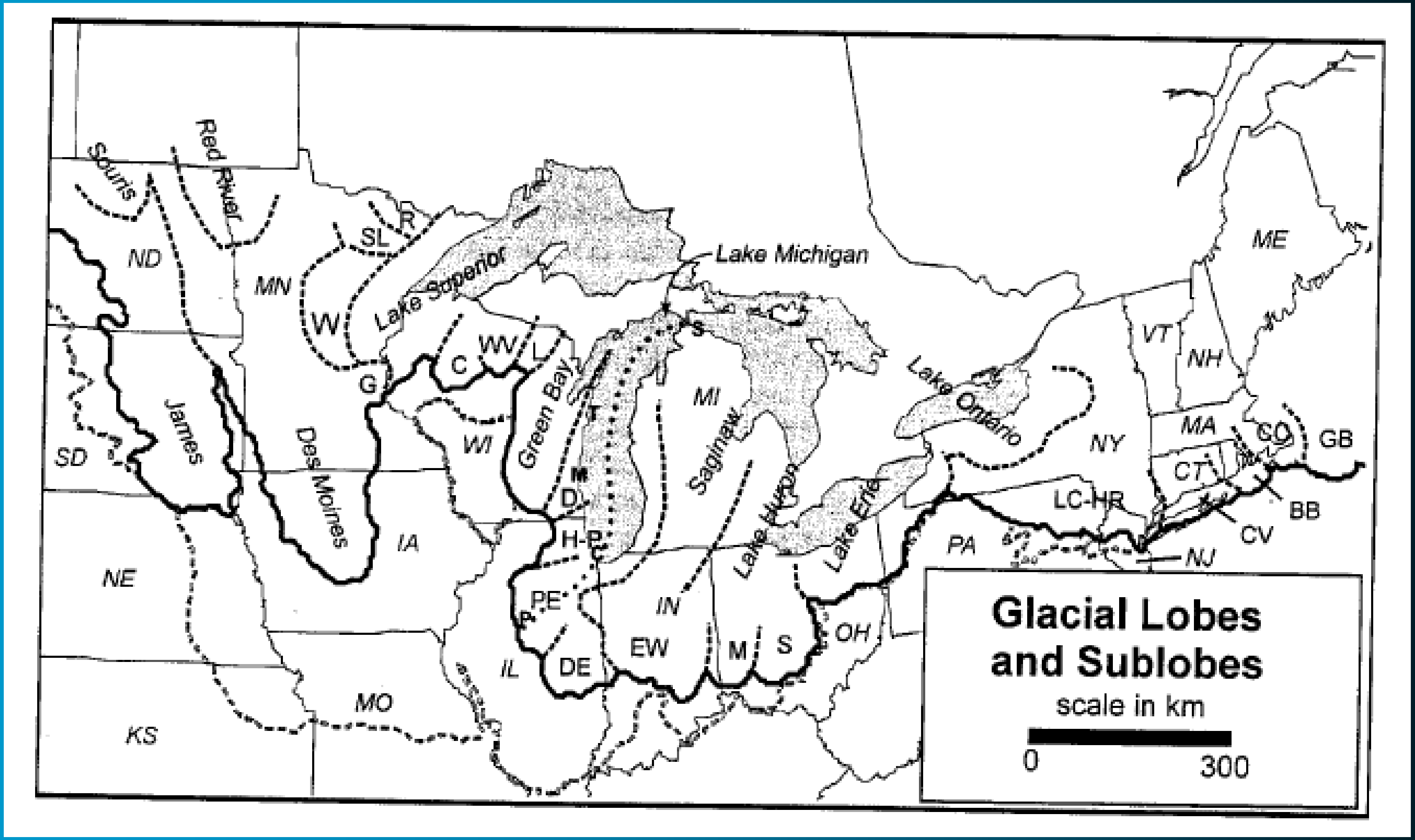
modified from Feinstein, et al., 2004

Stable isotope constraints



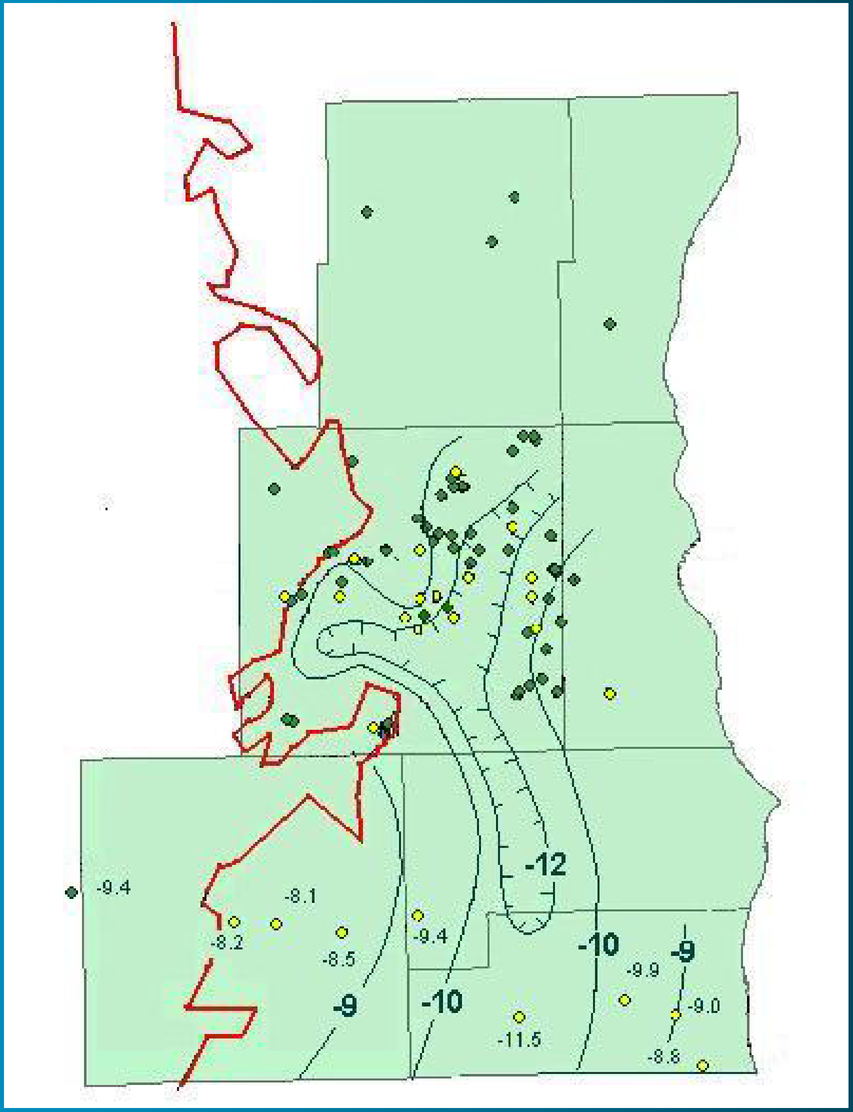


Late Wisconsin Glaciation

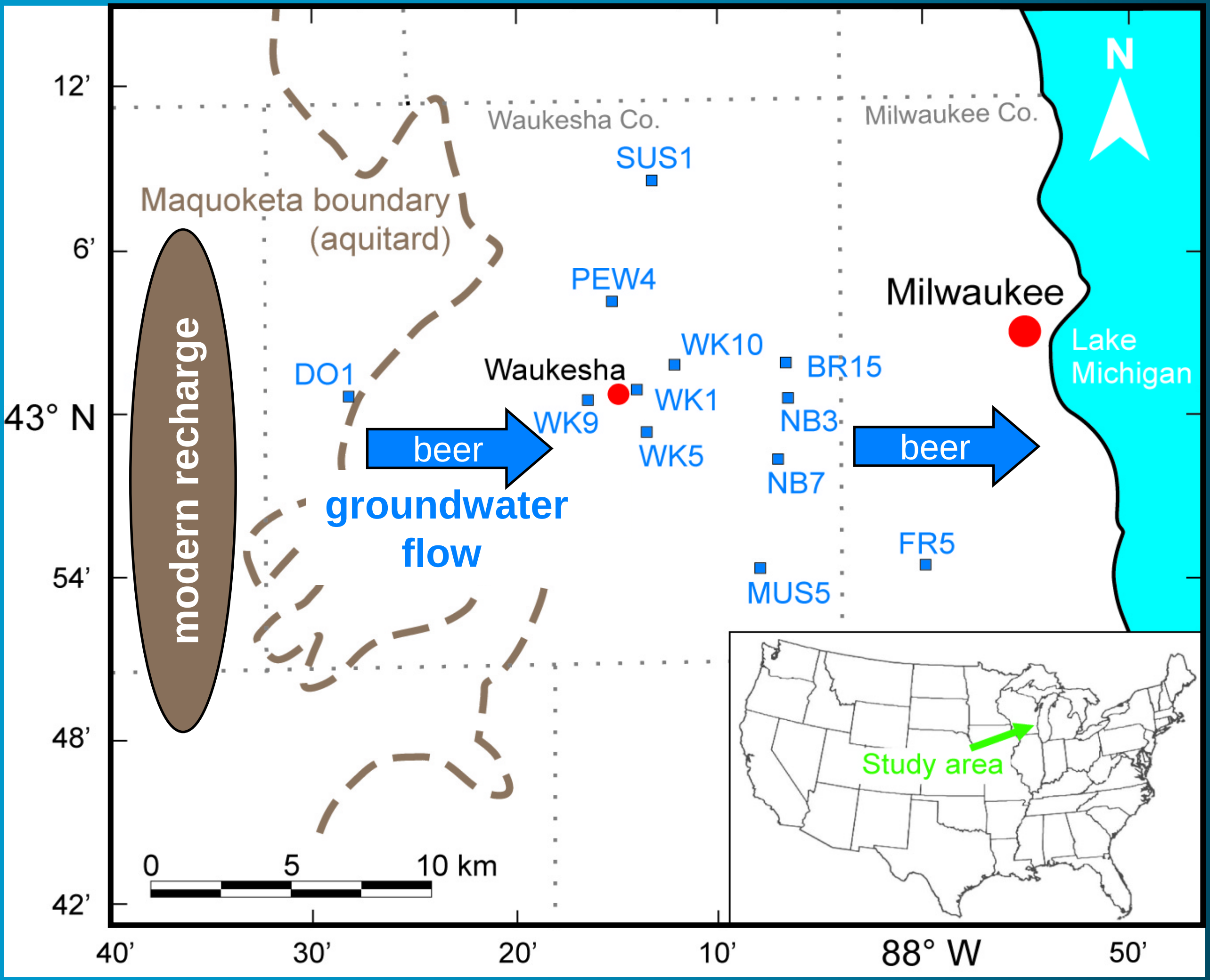


from Mickelson and Colgan, 2004

Isotope transect to the south



Information gathered in Waukesha county



- *Basic geochemistry*
- *Numeric modeling*
- *Stable isotope data*
- *Noble gas data*
- *^{14}C dates*