Understanding Recharge and Flow Dynamics in our Complex Basalt Aquifer System

Jeff Langman, Earth and Spatial Sciences
University of Idaho

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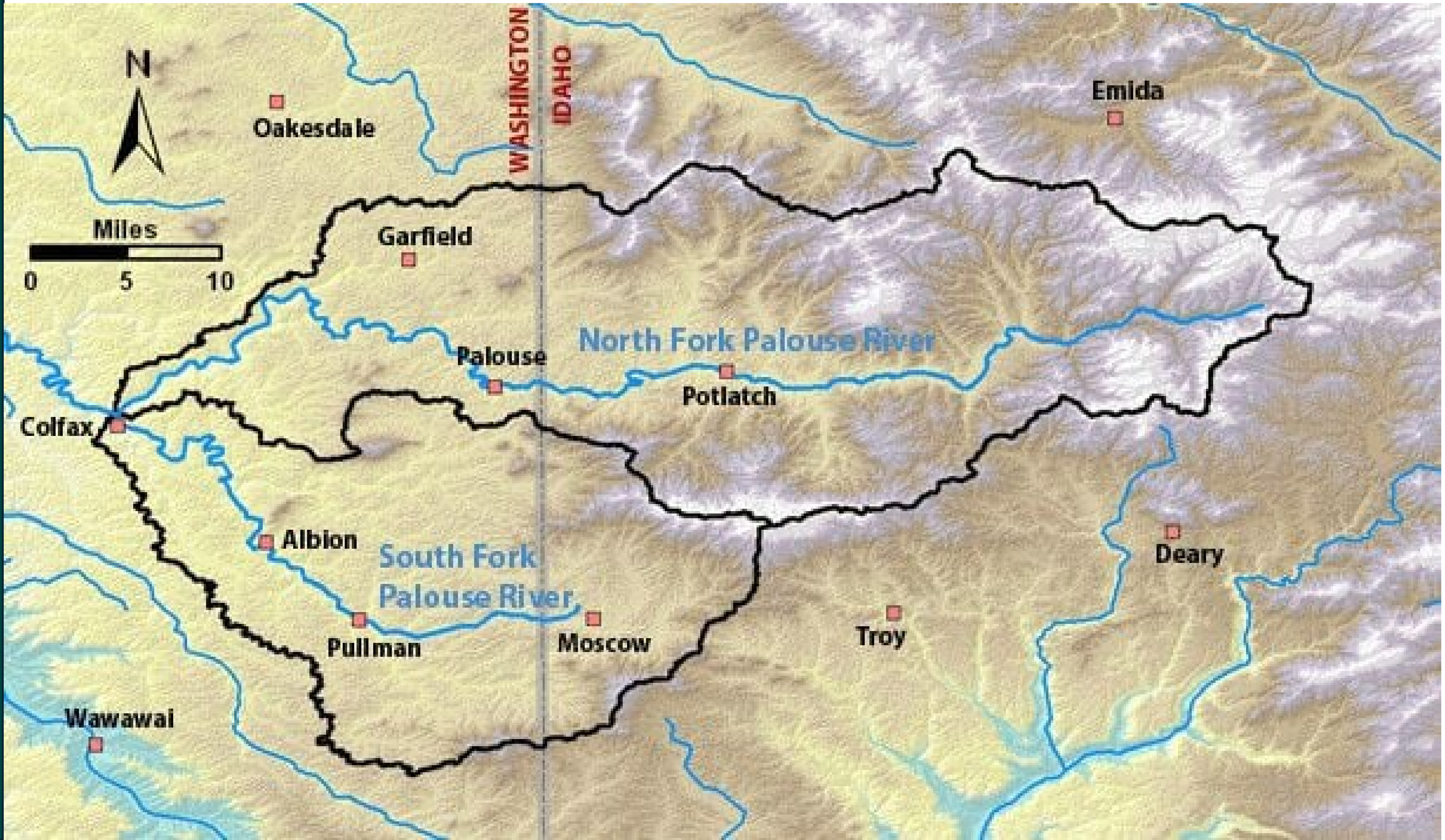
Our basin setting

- Eastern granitic highs bound our South Fork sub-basin



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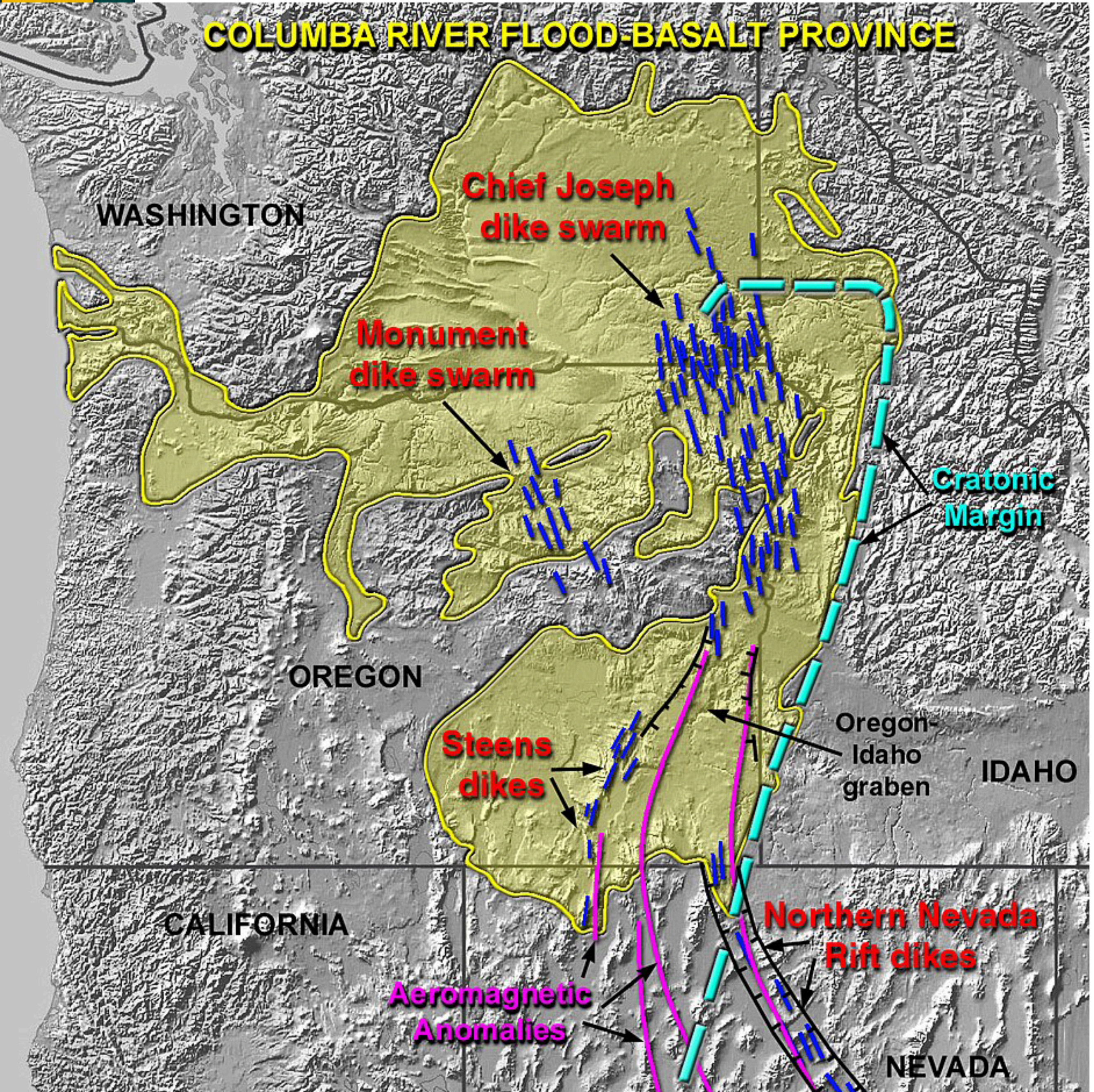
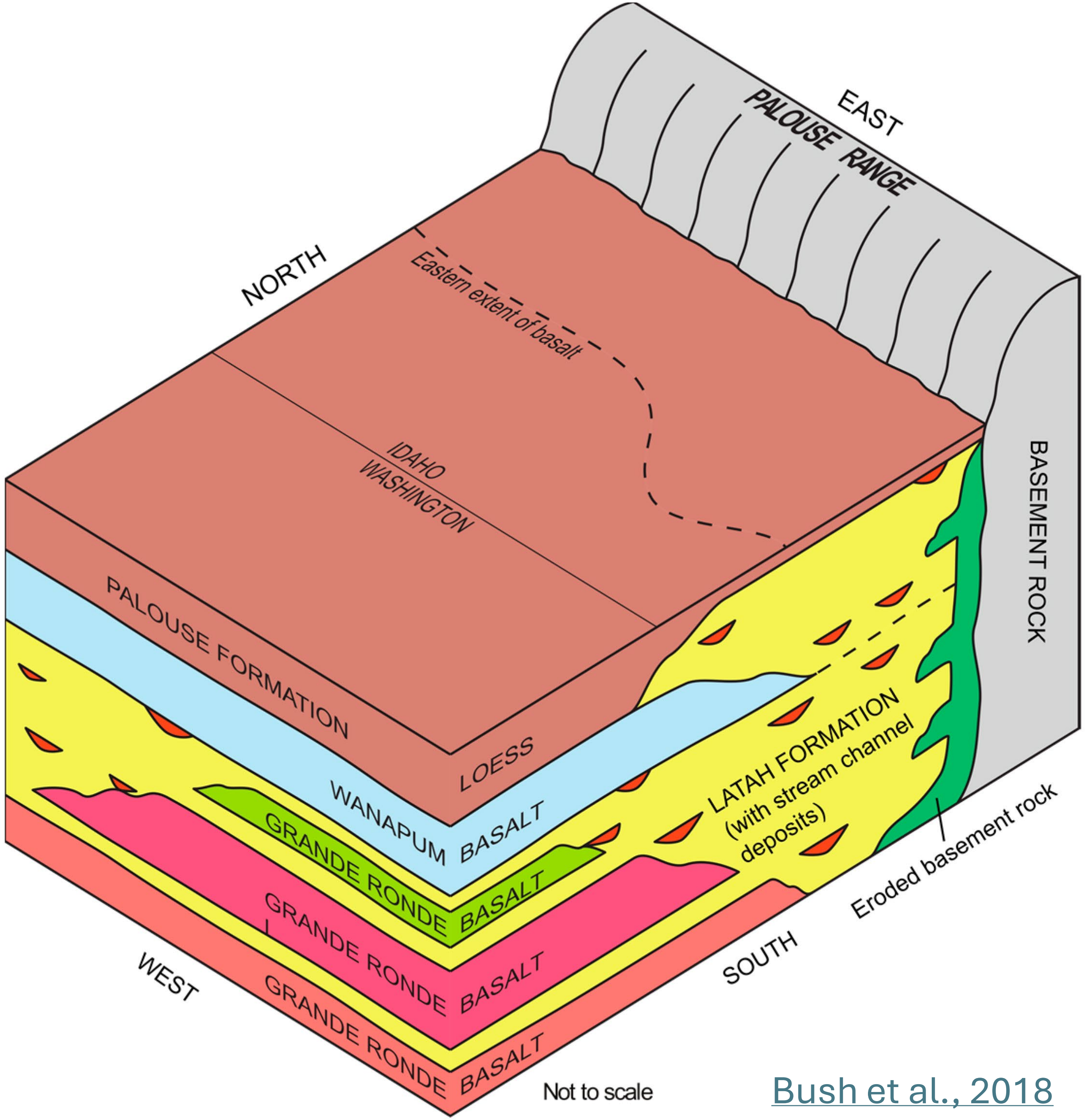
Our geologic setting: basalt, sediment, basalt…

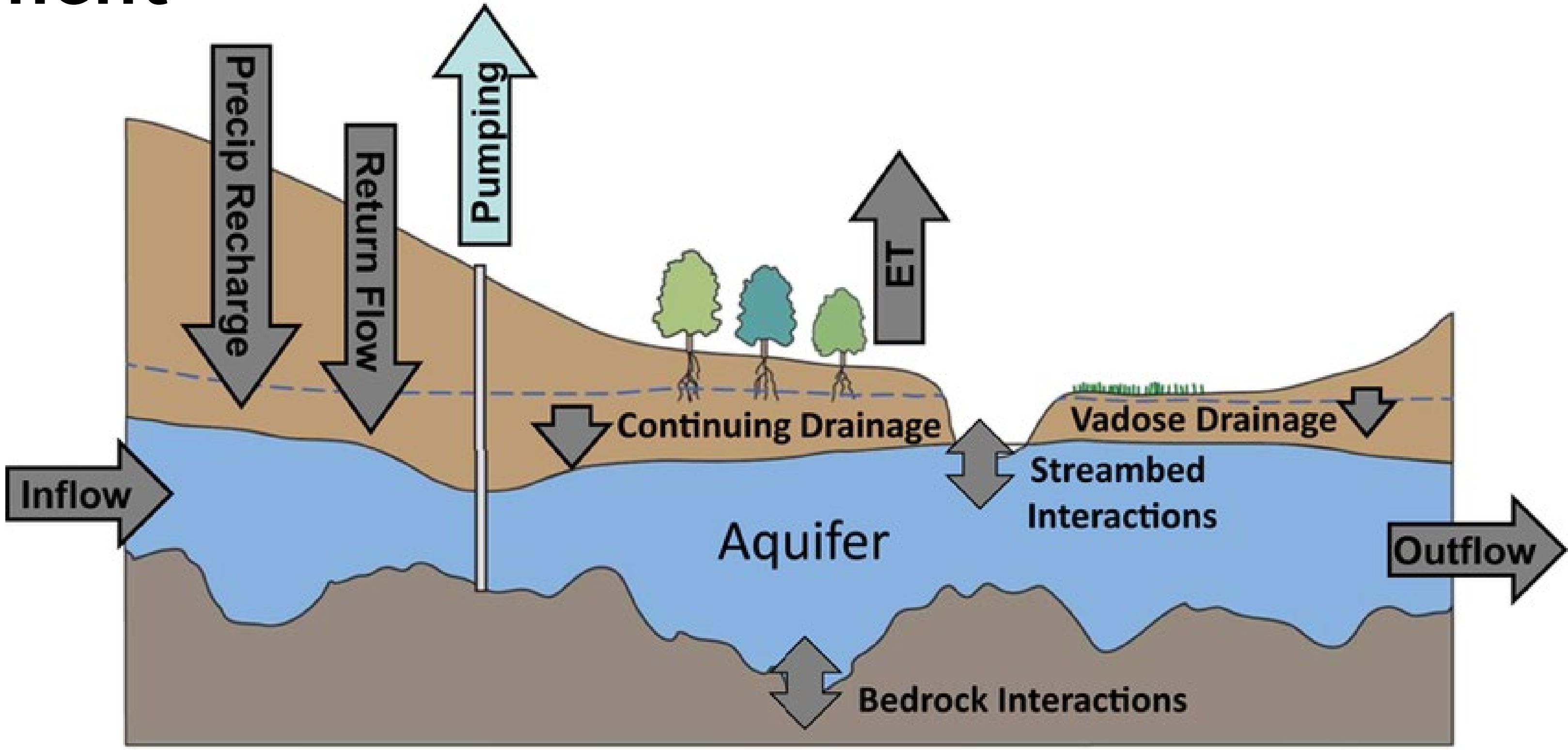




Bush et al., 2018

Recharge and aquifer dynamics

- Recharge is the replenishment of groundwater that leaves the aquifer because of flow or pumping
  - Provides the basis for understanding the water balance
  - Critical for GW management



The beginning…….

- With the noticeable decline in groundwater levels, the first attempts to understand recharge and discuss new supplies (artificial recharge)

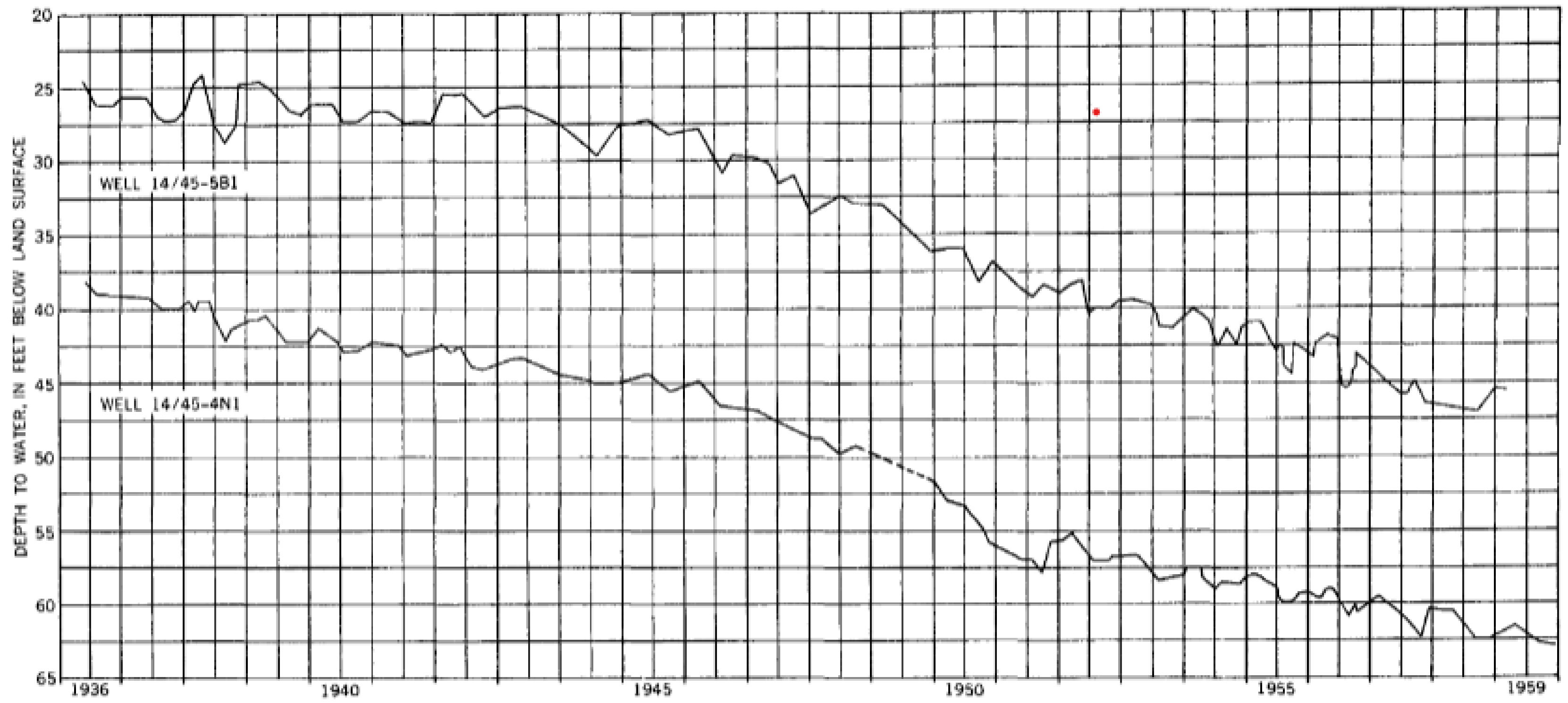
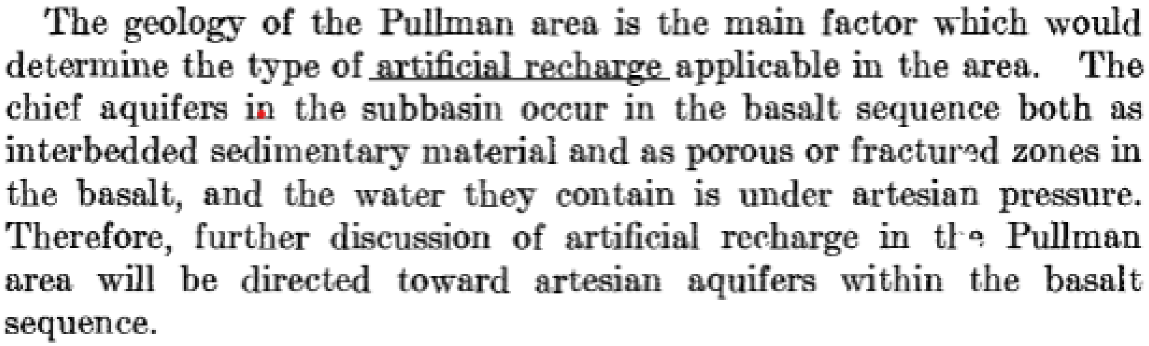


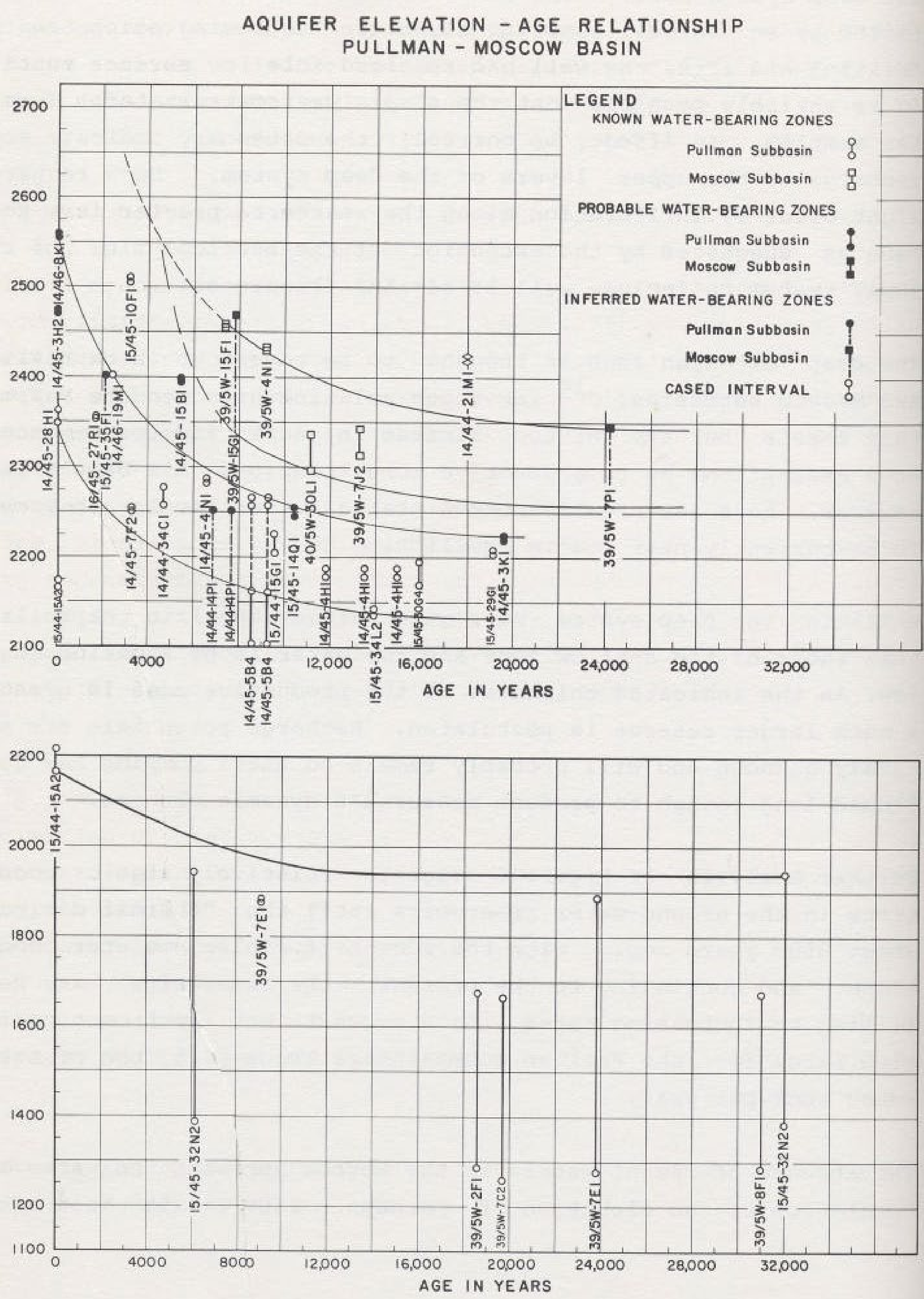
FIGURE 5.—Hydrographs of wells 14/45-4N1 and -5B1, showing fluctuation of water level in the principal artesian aquifers in the Pullman subbasin.


The geology of the Pullman area is the main factor which would determine the type of artificial recharge applicable in the area. The chief aquifers in the subbasin occur in the basalt sequence both as interbedded sedimentary material and as porous or fractured zones in the basalt, and the water they contain is under artesian pressure. Therefore, further discussion of artificial recharge in the Pullman area will be directed toward artesian aquifers within the basalt sequence.

Foxworthy and Washburn, 1963

Initial tracing/age dating of the aquifer and recharge

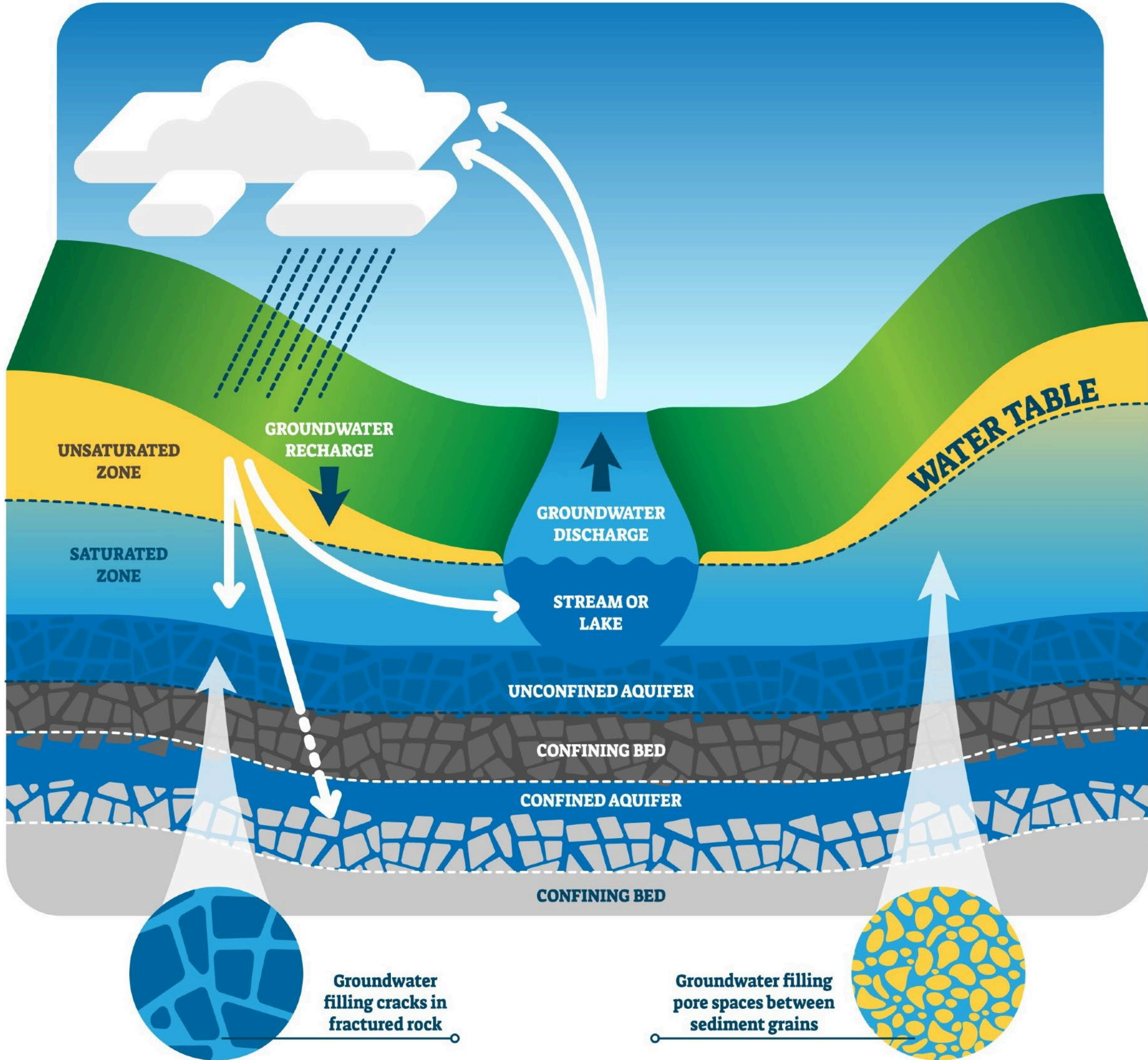
- Crosby and Chatters (1965) presented ^{14}C data indicating that groundwater in our basin ranged from modern water to > 32,000 yr
- The “old water” idea has dominated our recharge discussion ever since
    - Most of the water was dated > 5,000 yr



Crosby and Chatters, 1965

After Crosby and Chatters

- Multiple attempts to model the aquifer (e.g., Barker)
- Multiple attempts to understand recharge
- Critical concept: how does recharge enter the aquifer?
  - This question persists

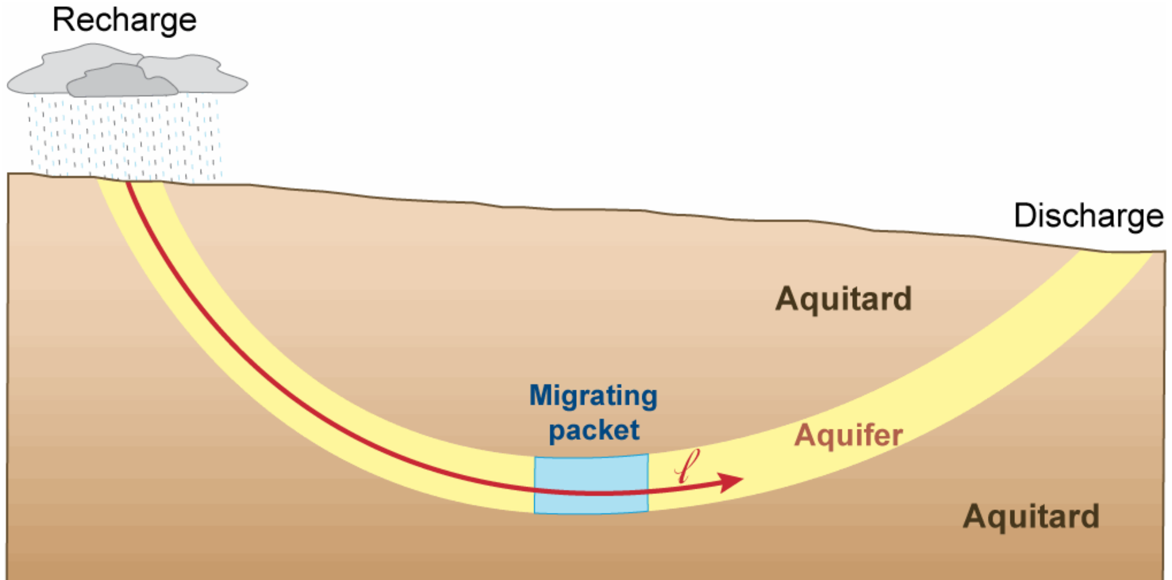


Some interesting ideas….

- Larson et al., 2000 : Grande Ronde is filled with Lake Missoula water (depleted water isotopes)
  - Continues the Crosby and Chatters old water discussion
- Douglas et al., 2007 : Much of our groundwater is old water (additional ^{14}C data)
  - More of the same old water discussion

Shift in recharge perception

- Lum (1990) model perceived basin-wide vertical recharge
  - Different flux than Barker (1979)
  - Shift towards other mechanisms because new geo knowledge
    - Johnson (1996) model



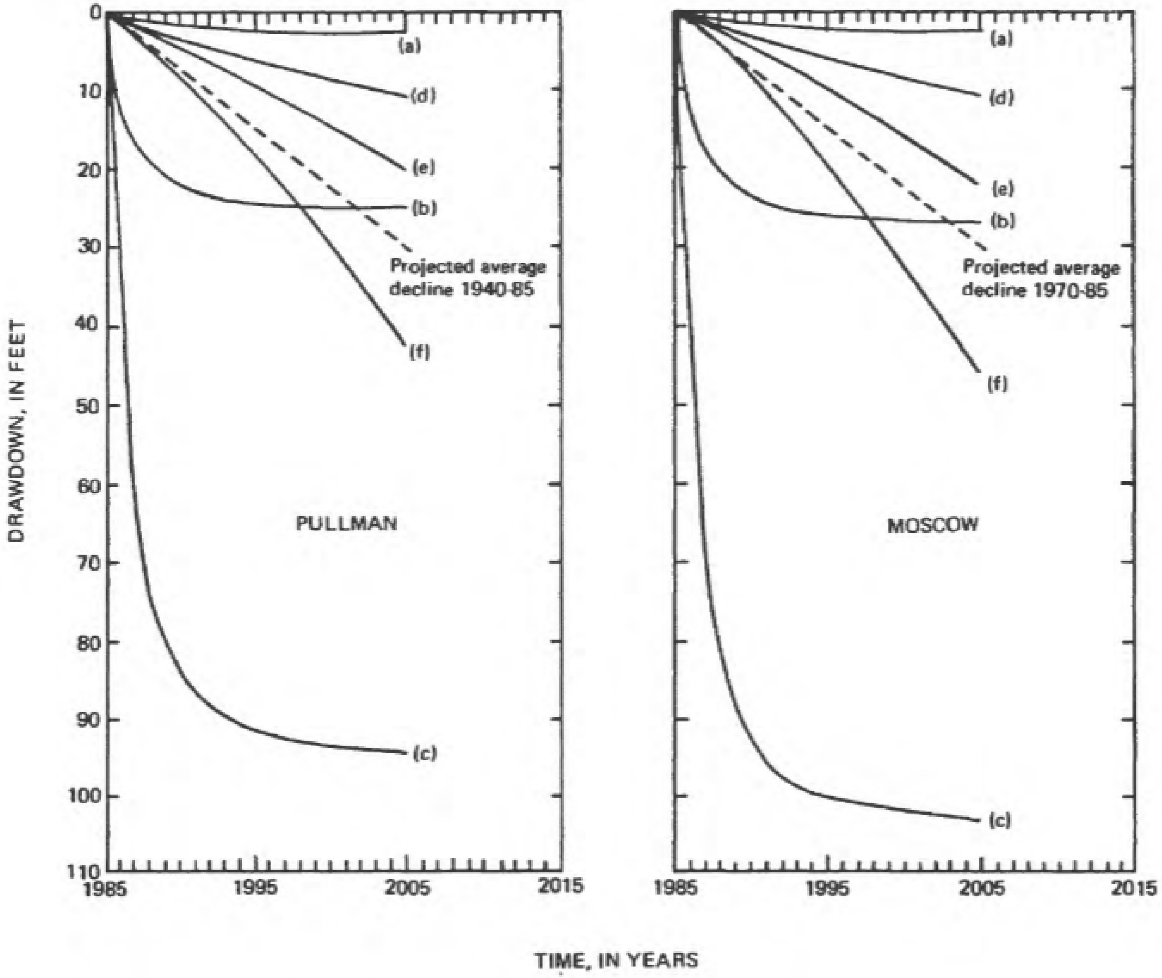
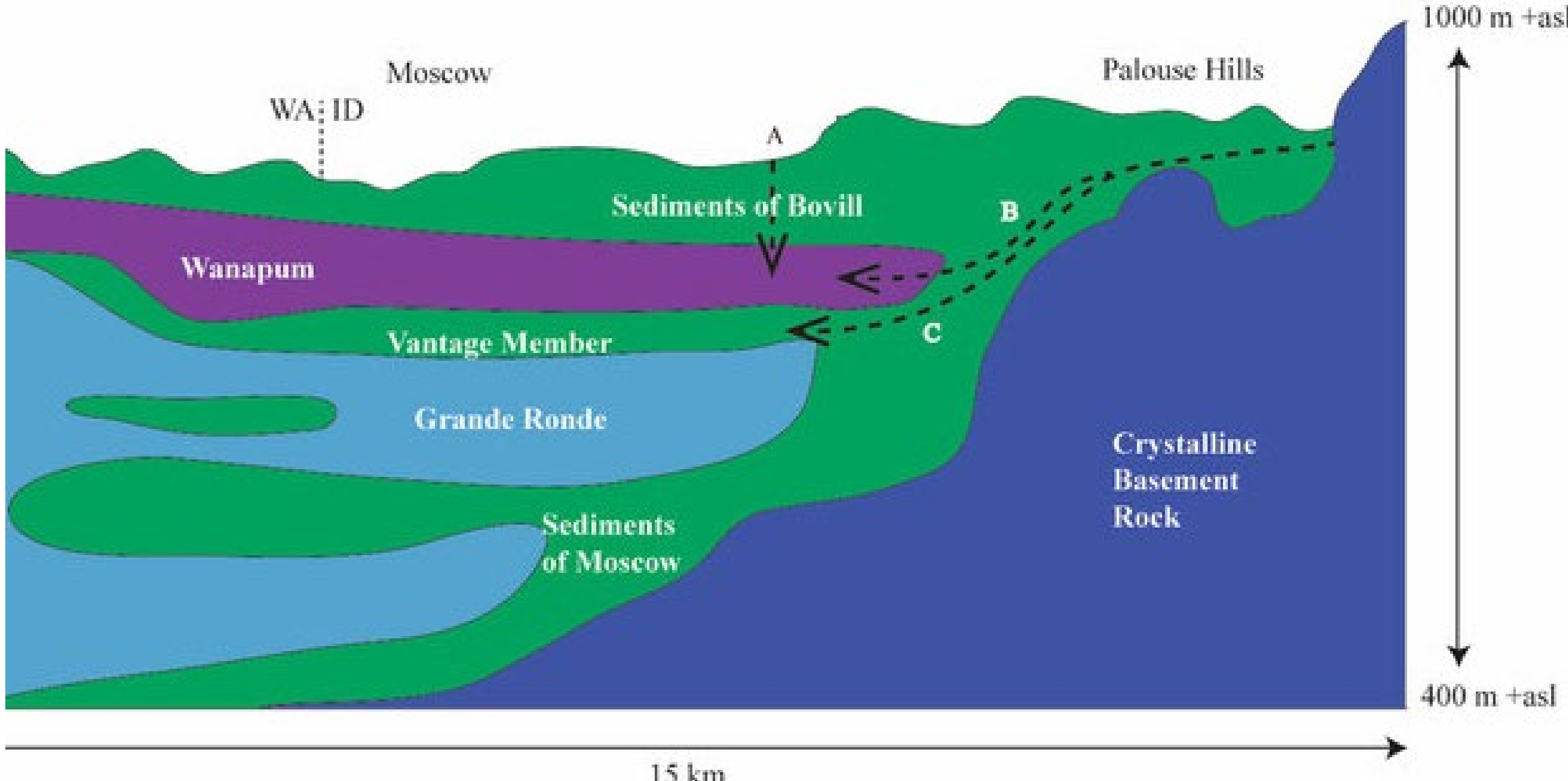


Figure 26.--Simulated water levels at a constant pumpage rate equal to: (a) the 1981-1985 average rate; (b) 125 percent of the 1981-85 average rate; and (c) 200 percent of the 1981-85 average rate; and at an annual pumpage rate increase from each preceeding year of: (d) ½ percent; (e) 1 percent; and (f) 2 percent; starting with the 1981-1985 average rate.

Lum et al., 1990

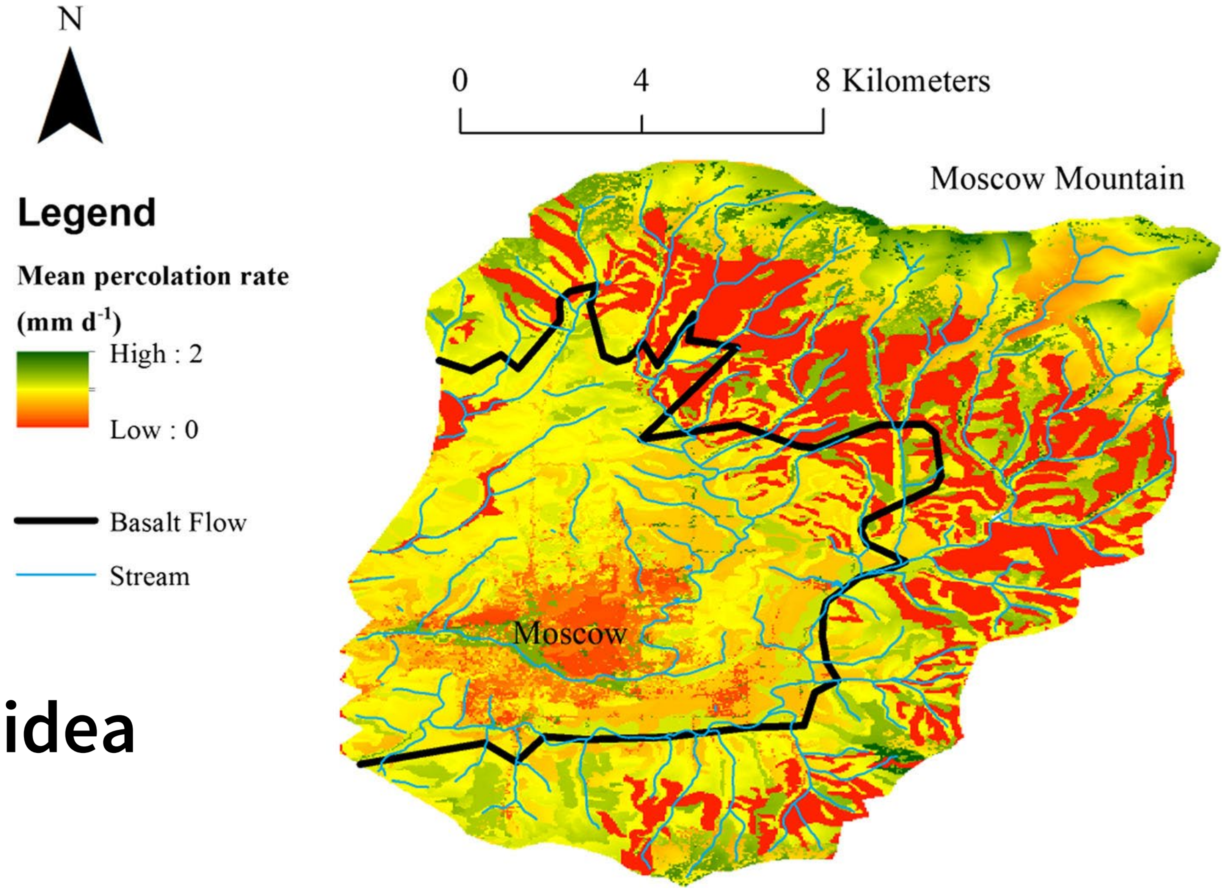
Mountain-front recharge

- The mountain-front became an important idea for recharge
- Our aquifer system: upper system = Wanapum, lower system = Grande Ronde
  - Lateral flow after initial infiltration
  - Balance of ↓and ←?



Recharge: a surface water view

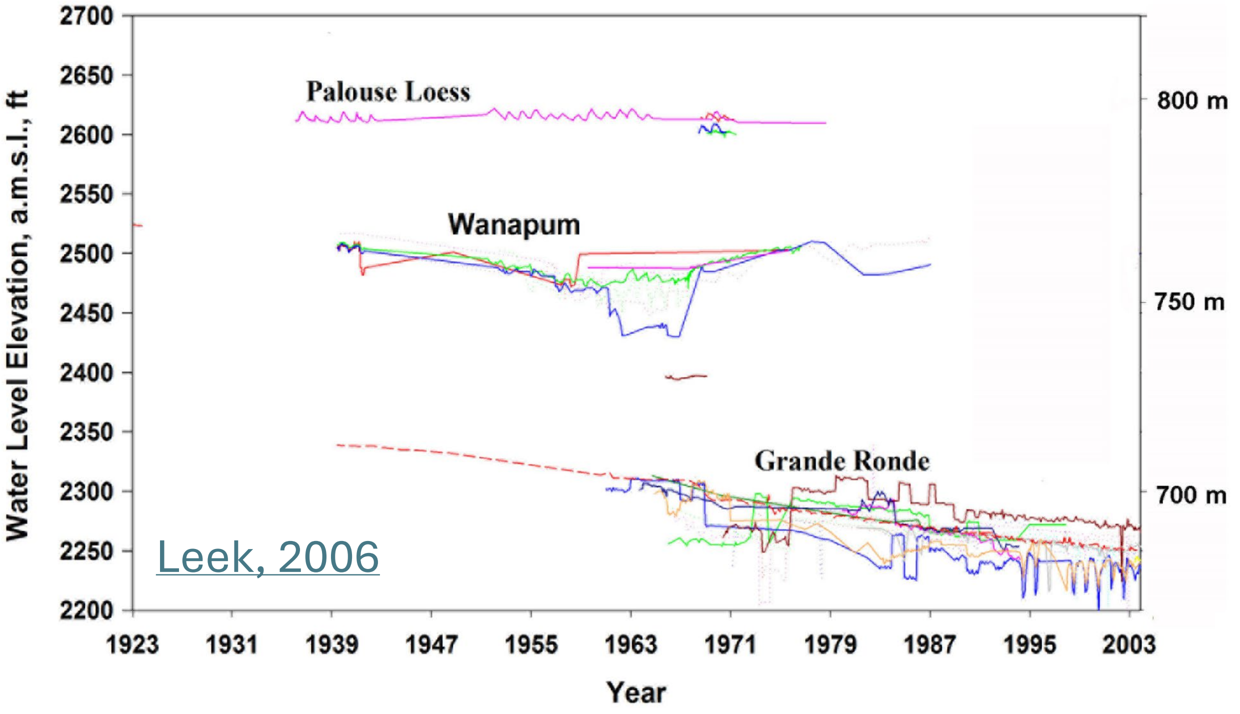
- Candel et al. (2016) and others chased recharge from a surface view
  - Where is precipitation occurring?
  - What soils will allow for infiltration?
  - What barriers exist for percolation?
- Half the story
  - What happens in the saturated zone?
  - Candel/Sanchez/Dijksma = lateral flow idea
  - Bush = supporting geologic data



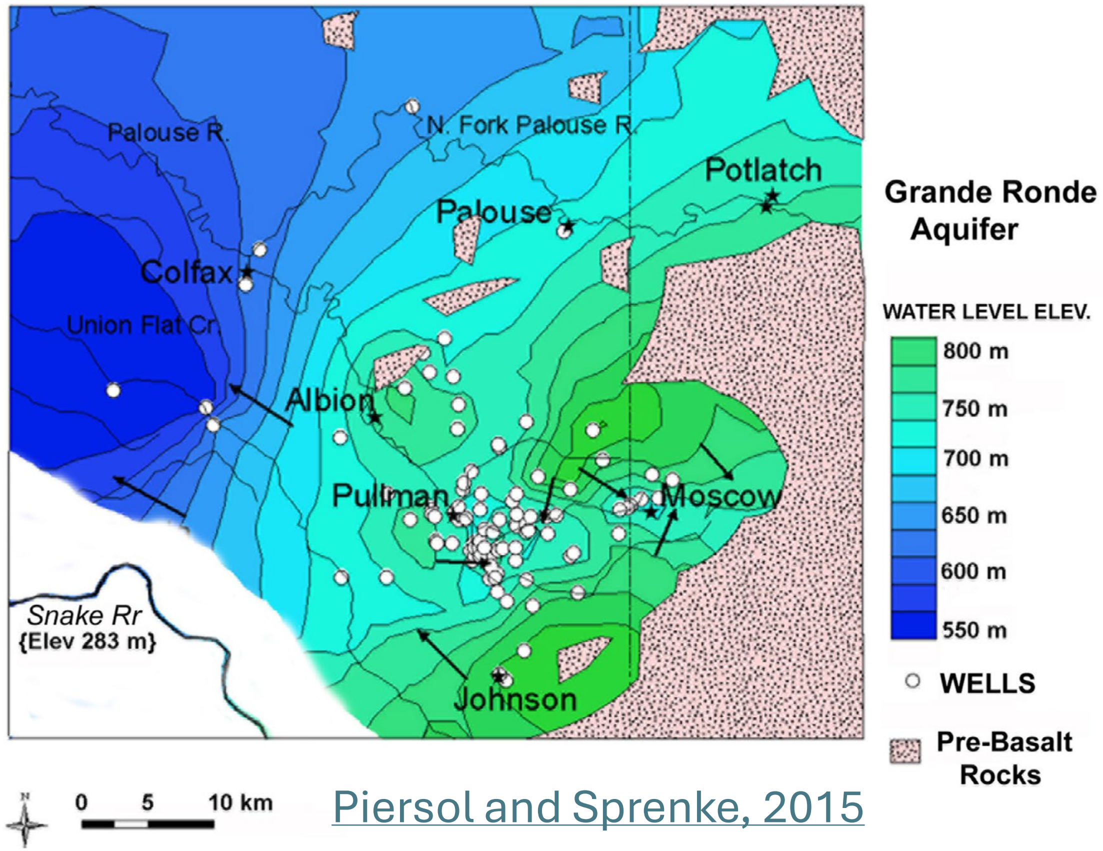
Cande et al., 2016

Old vs young water: the conundrum

- With the acceptance of the mountain-front recharge:
  - Still stuck with the old water issue
  - Old water issue = <u>compartment idea</u>
- But, how could we pump from the deeper portions of the aquifer where the old water was supposedly located and not deplete the aquifer?



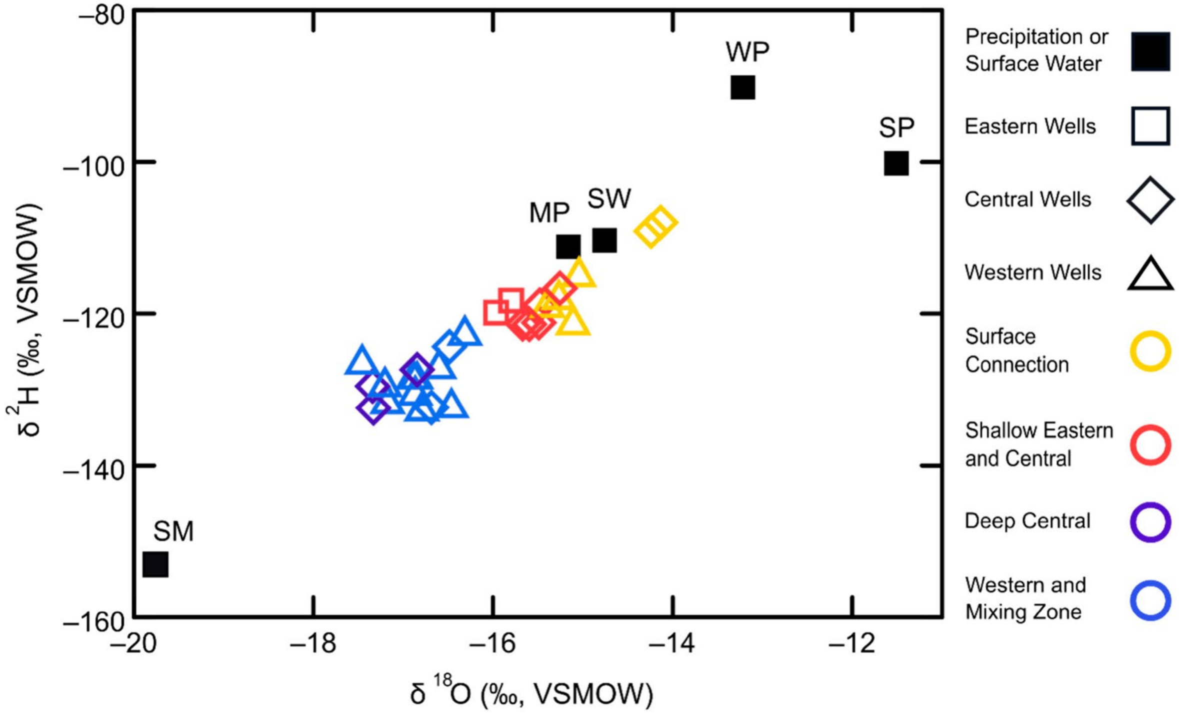
Leek, 2006

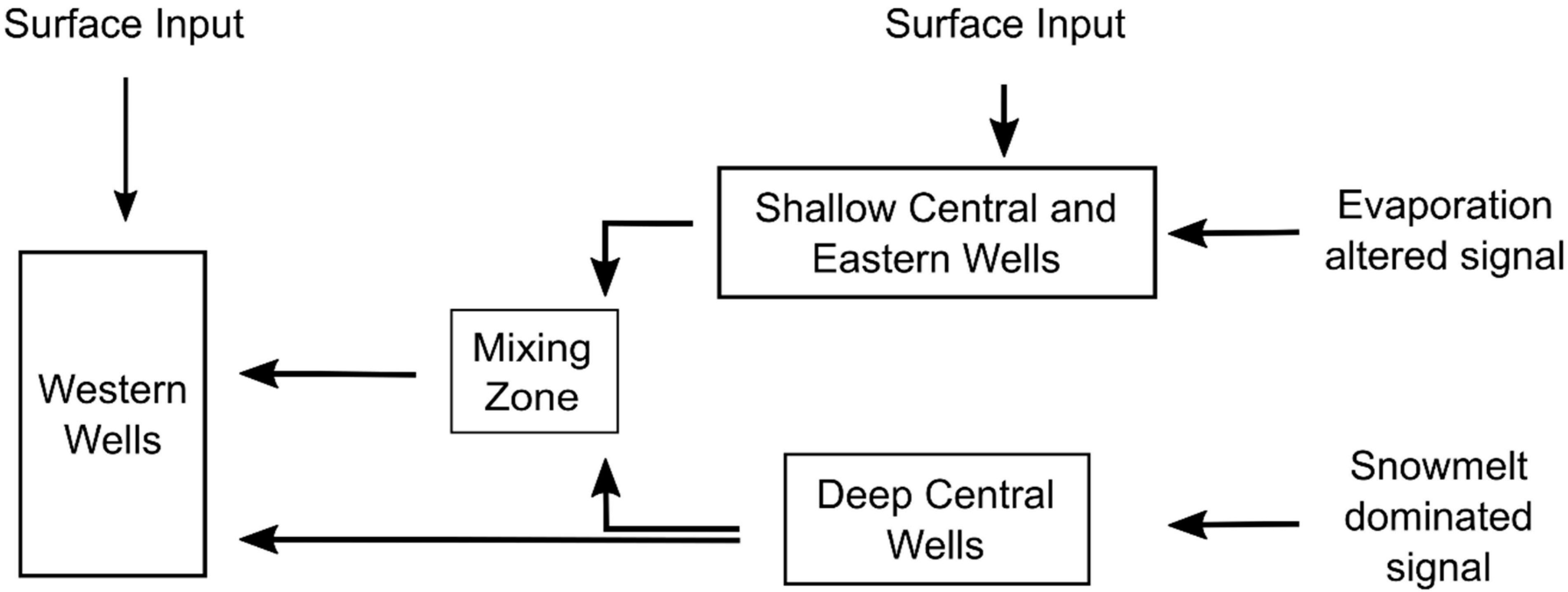


Piersol and Sprenke, 2015

Not compartmentalized

- Duckett et al. (2019) picked up the Candel/Sanchez/Dijksma torch
    - Water is a mixture of different sources from the mountain front and some from the basin surface





Surface Input

Surface Input

Shallow Central and Eastern Wells

Evaporation altered signal

Western Wells

Mixing Zone

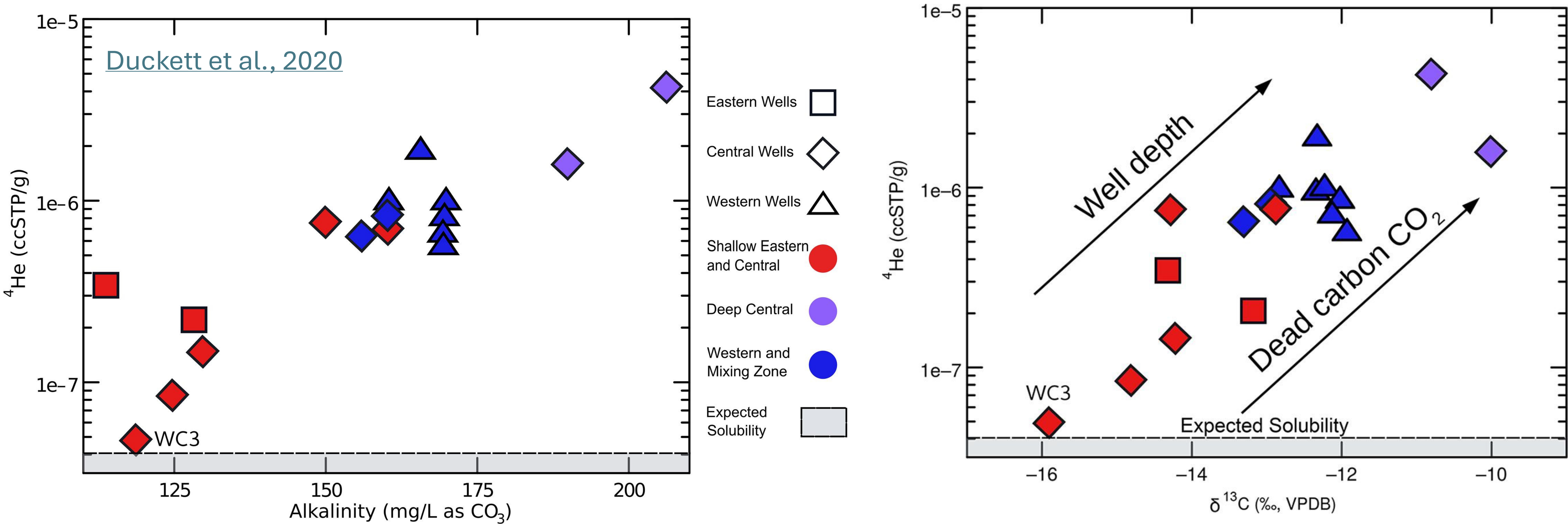
Deep Central Wells

Snowmelt dominated signal

Duckett et al., 2019

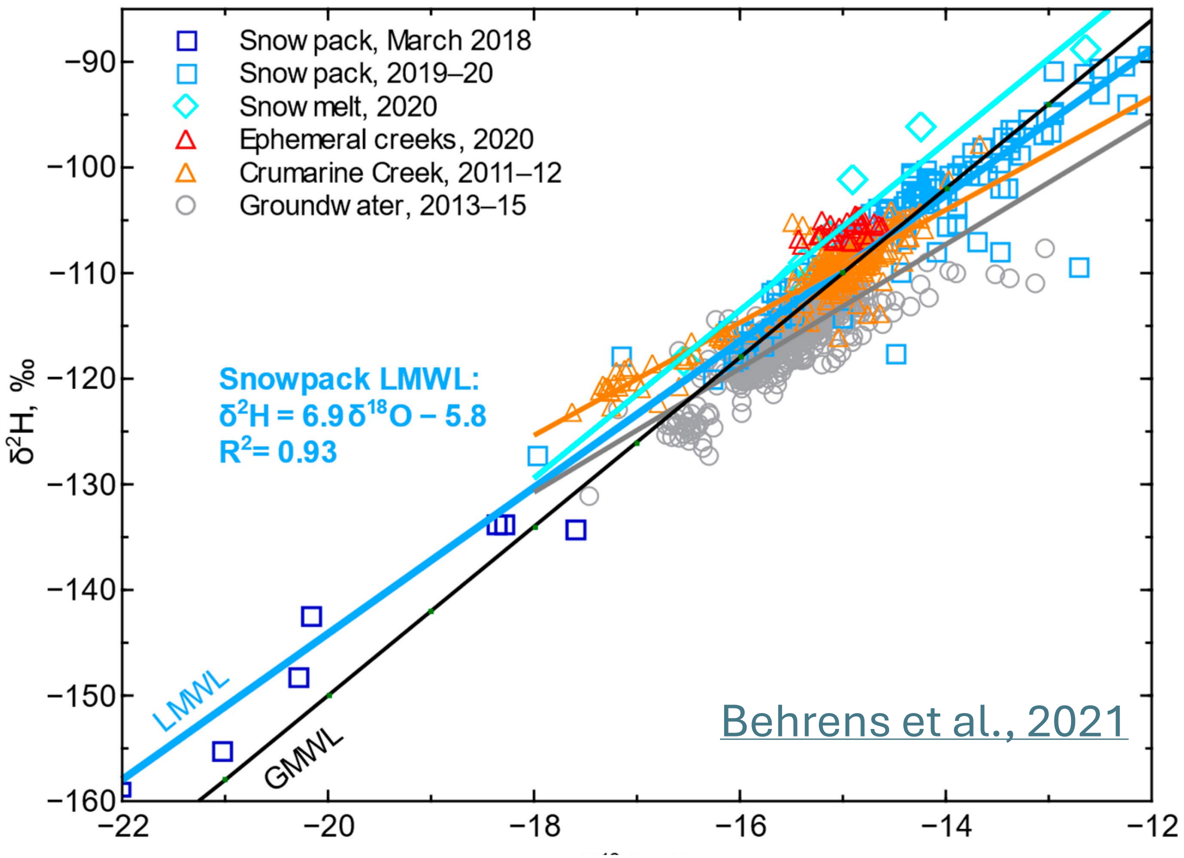
Duckett then addressed the old water issue

- There had to be a reason for the perceived old water across the basin
  - Our dead carbon assumption was wrong
  - Mantle gases are intruding into the aquifer (this is really cool!)

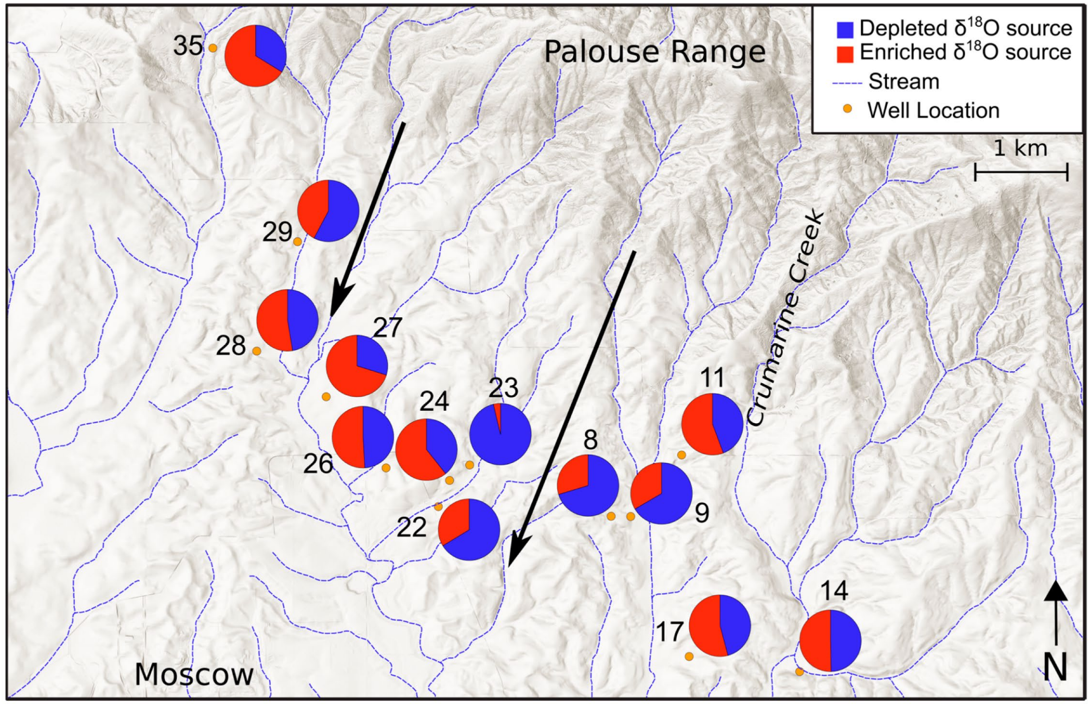


Duckett needed help

- Duckett's work was a breakthrough, but he did not fully resolve the old water issue
    - Water isotopes still could be interpreted as from an old climate
- Behrens said, maybe I can help
    - Behrens et al. (2021) found similar isotope signals in snow and young water
    - Modern water can have the same old isotope signal

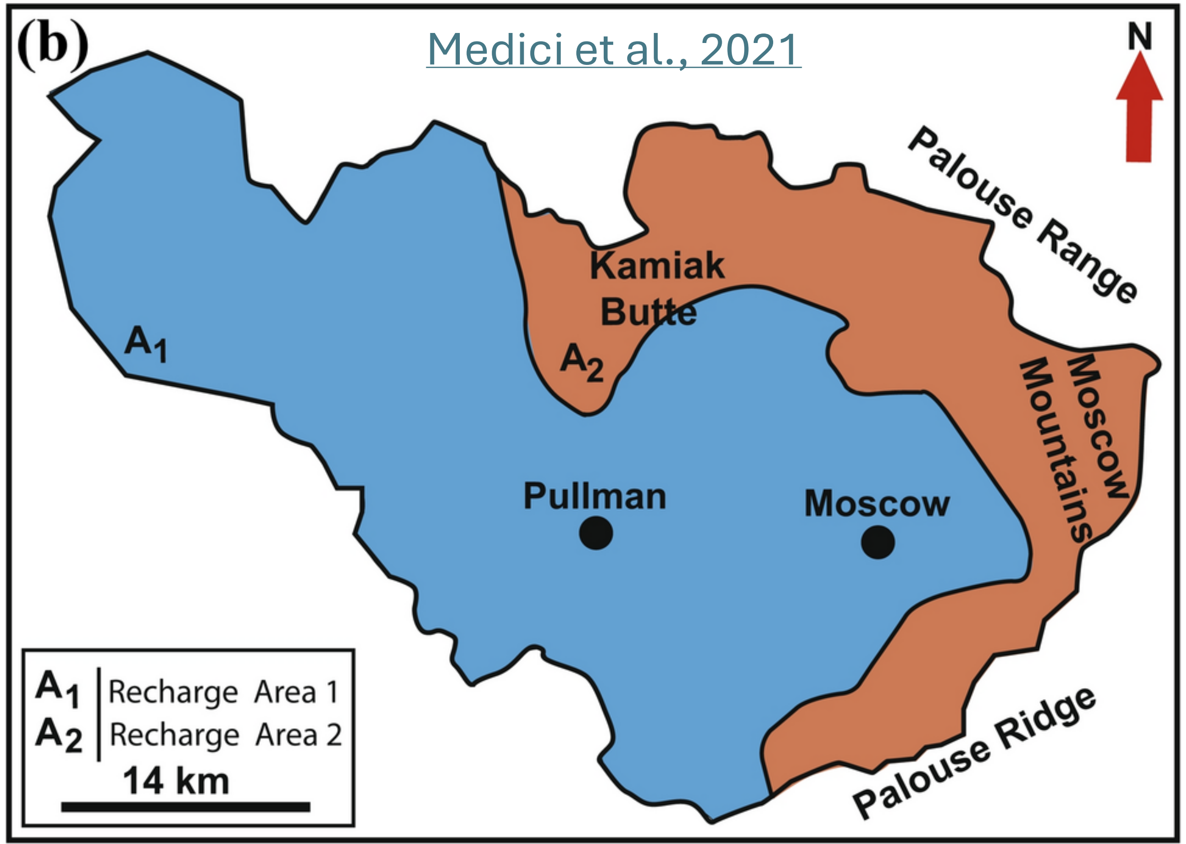


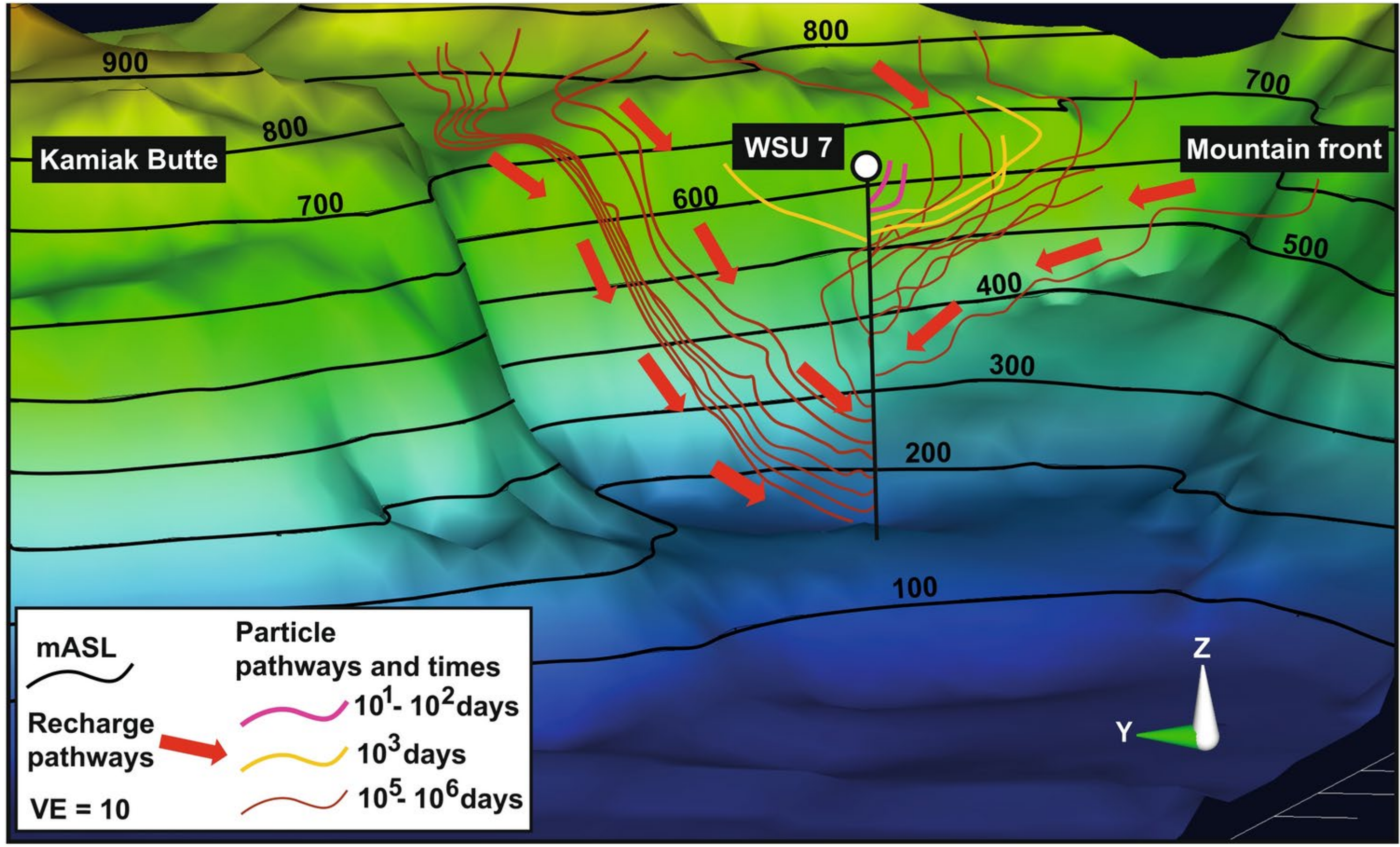
Behrens et al., 2021



Medici wanted in and said “let’s model!”

- Medici et al. (2021) produced a new flow model with particle tracking
  - Used data from Duckett/Behrens for mountain-front recharge
  - Sort of worked, but basin heterogeneity/anisotropy is tough to overcome

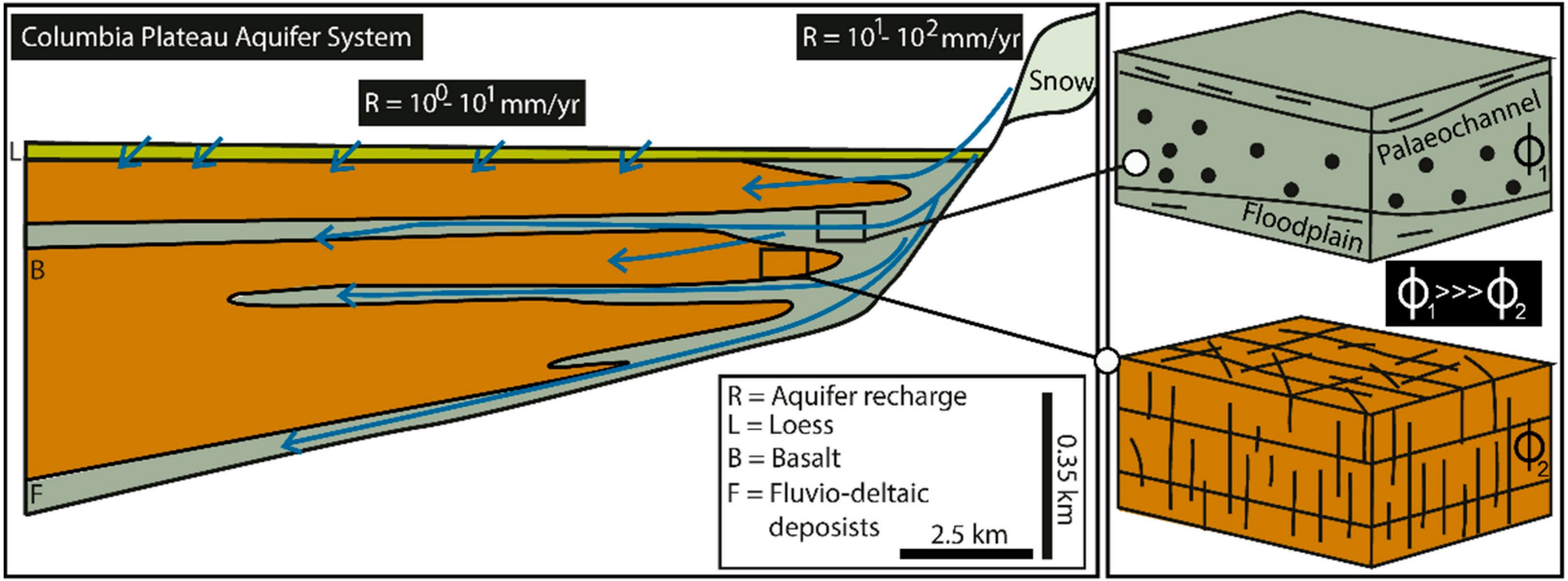

Medici et al., 2021



Medici took another shot

- Medici and Langman (2022) said recharge pathway is correct, but timing is still not quite right

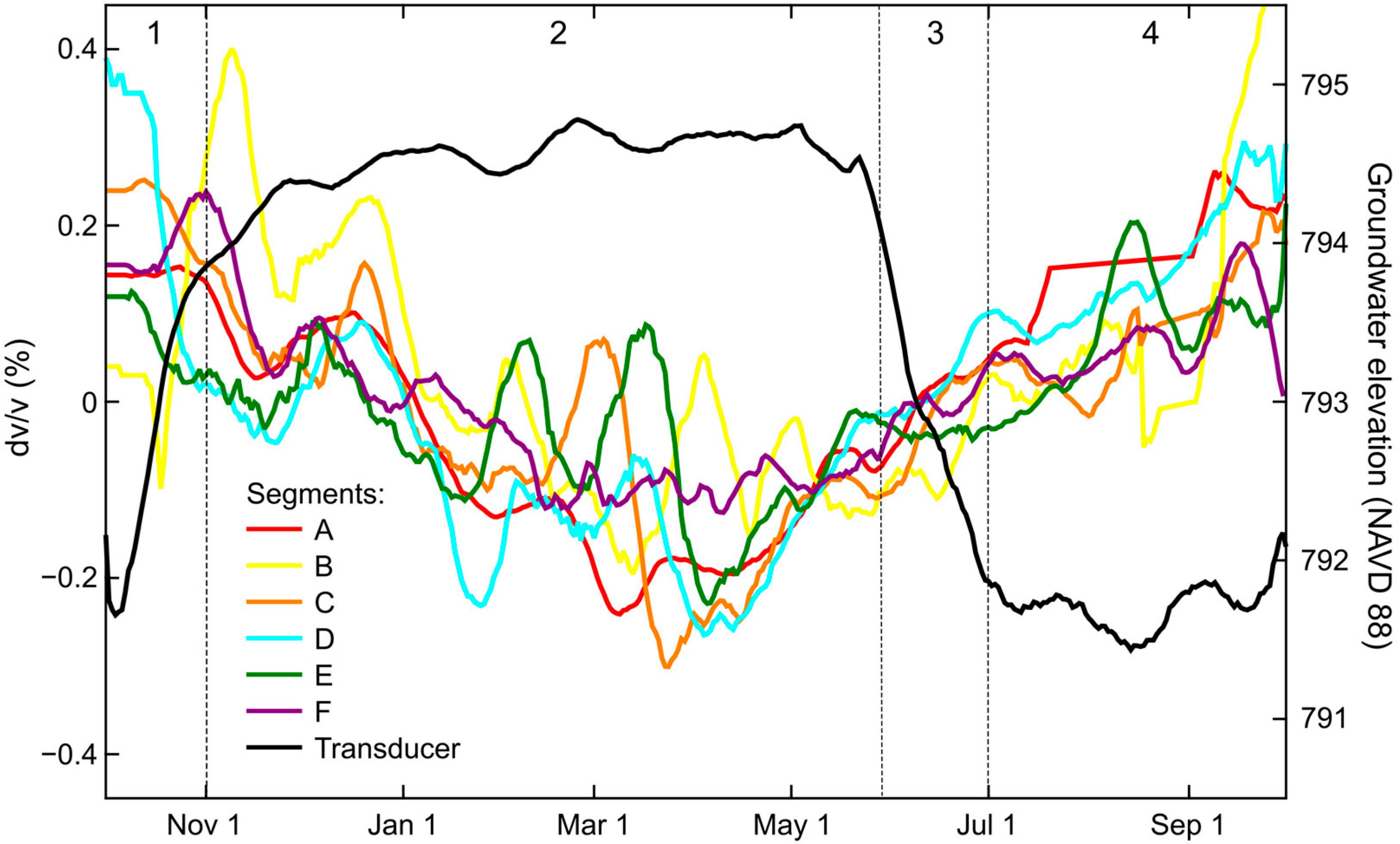
Medici and Langman, 2022



R = Aquifer recharge
L = Loess
B = Basalt
F = Fluvio-deltaic deposists

Behrens and Buzzard joined together

- Buzzard et al. (2023) said “why not chase the mountain-front recharge to understand the timing issue?”



Buzzard et al., 2025

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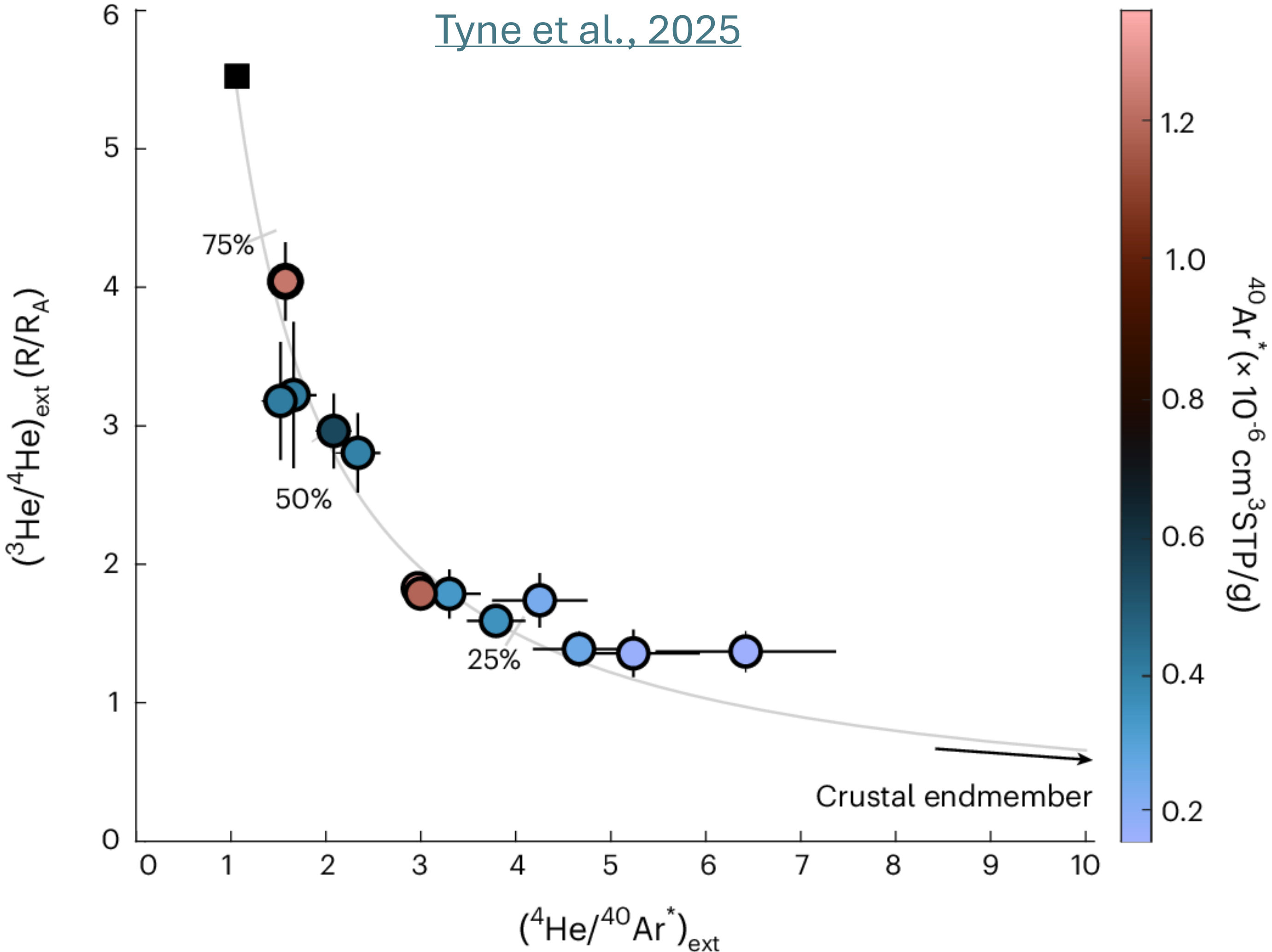
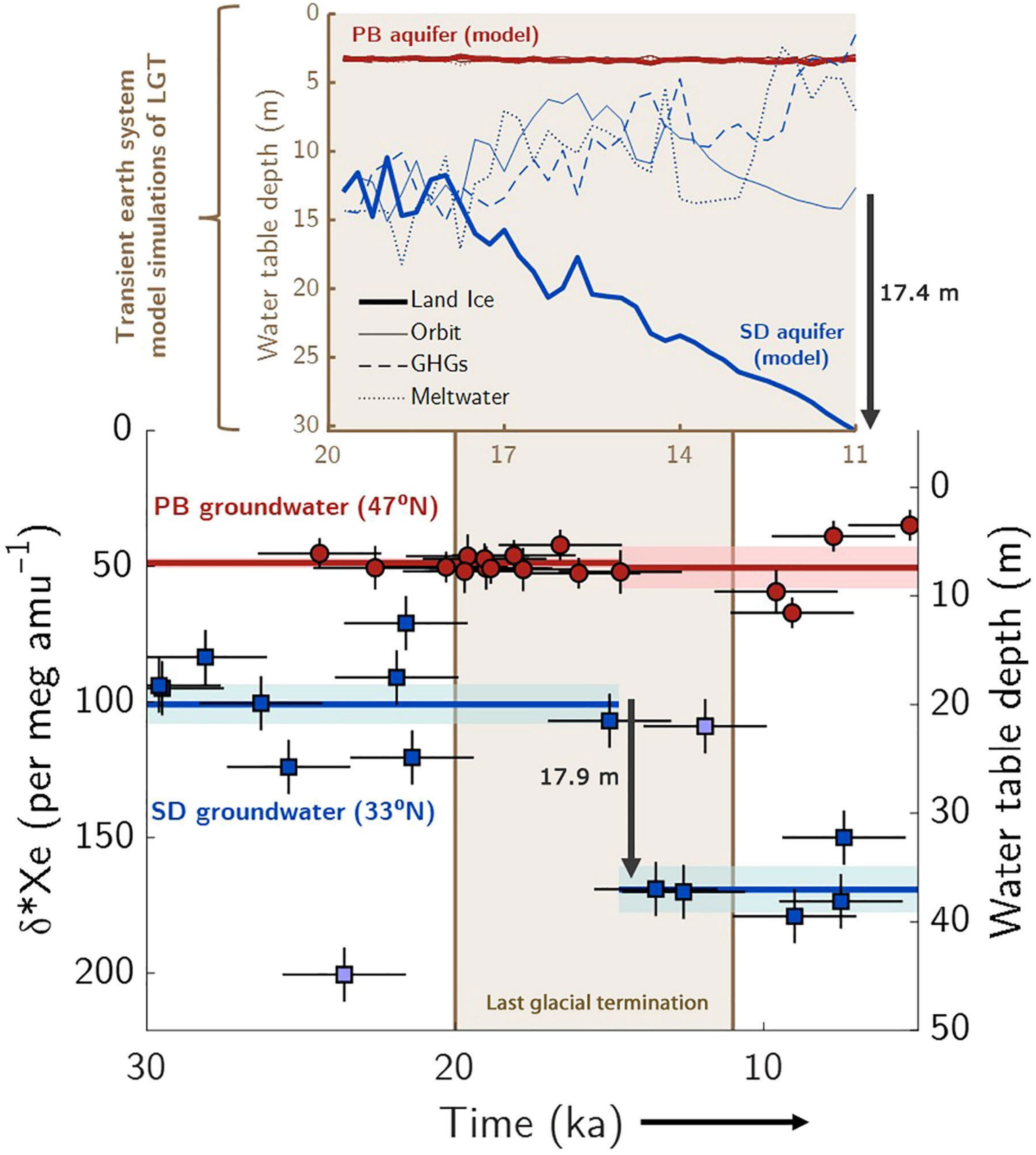
WHOI decided to join the fun

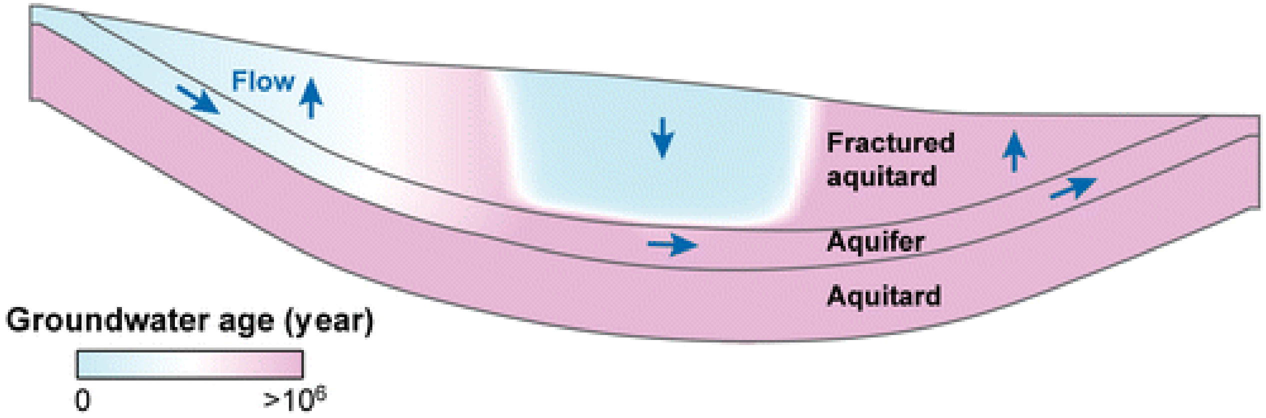
- Our mantle gas idea intrigued them, along with the old water problem

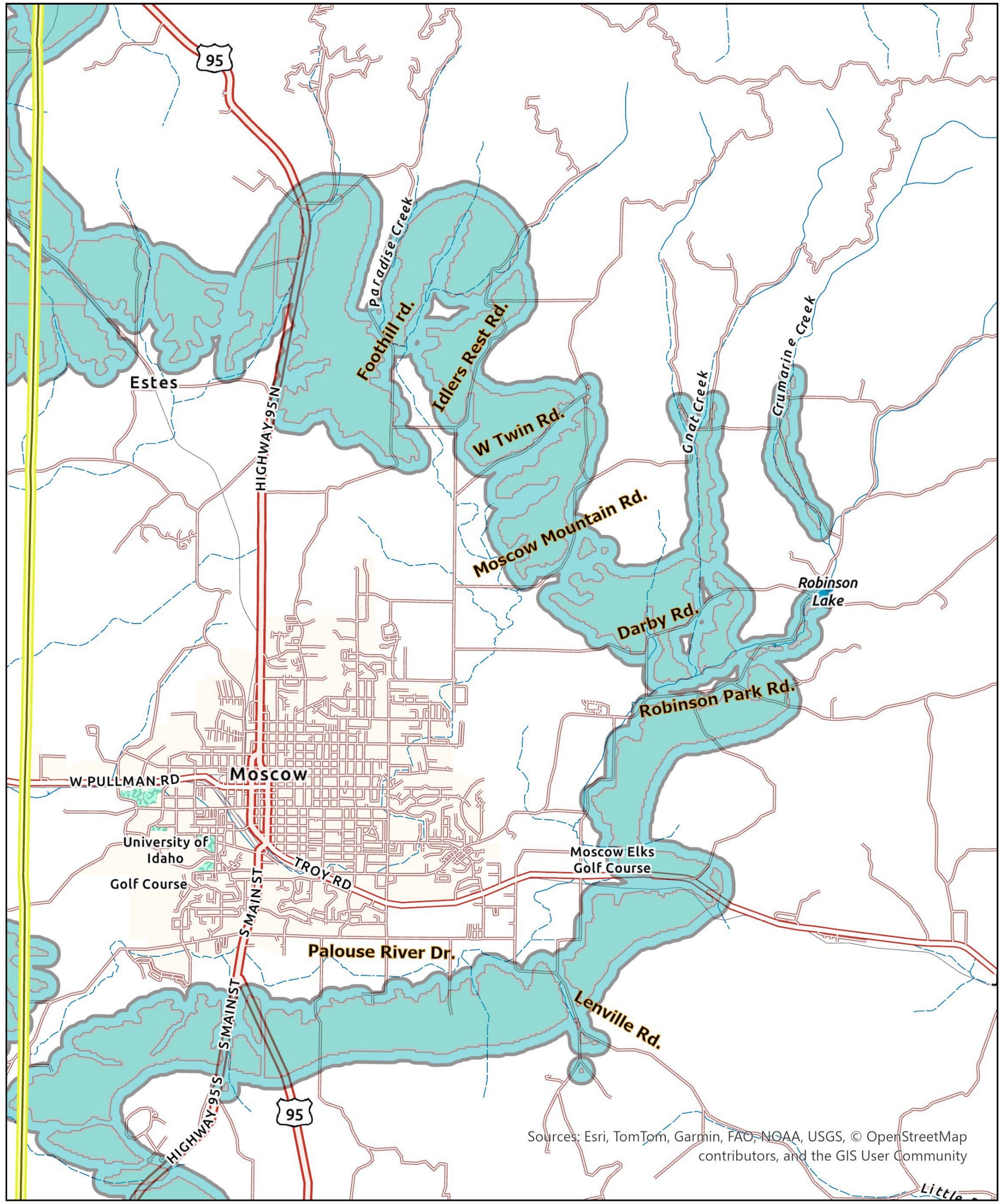

Tyne et al., 2025

Seltzer et al., 2025


Hall did not want to be left out

- Hall is trying to delineate fast or slow (gradation) pathways around the entire mountain front
  - CFCs/SF_6
  - PFAS
  - Water isotopes

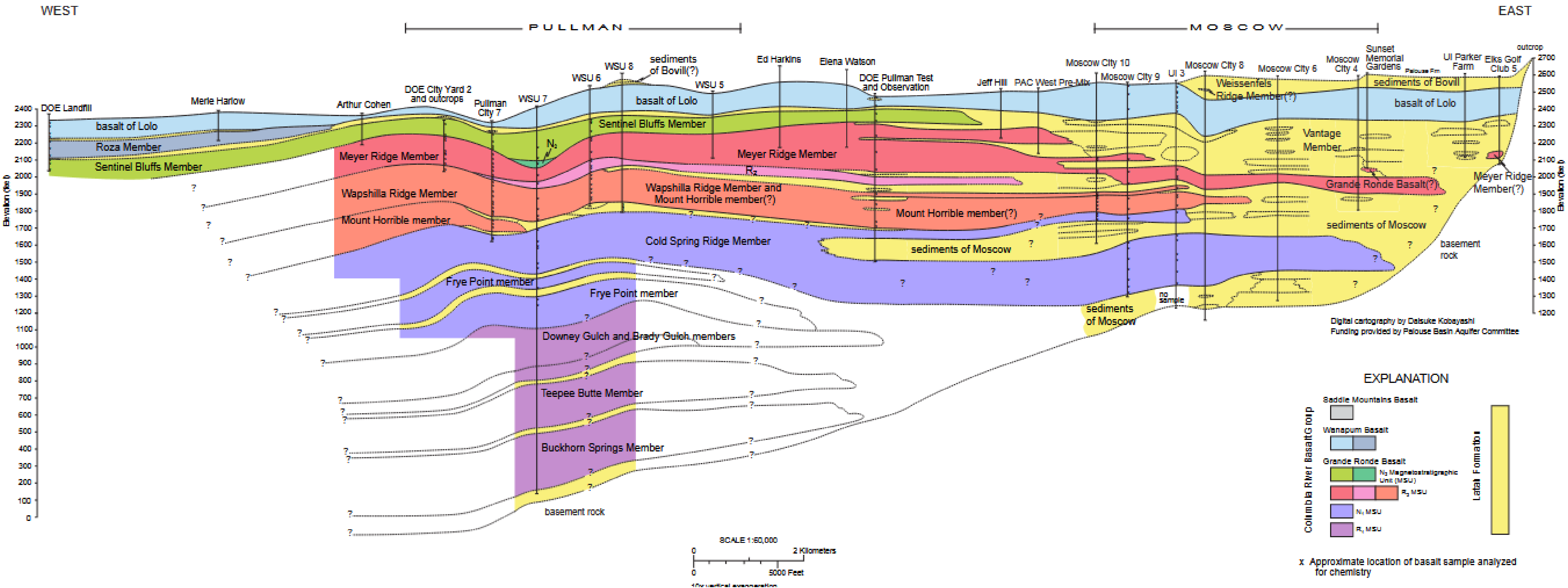




Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

System resolution: are we there yet?

- Bush’s work is equally important: synthesizing the matrix (geology) with the chemical signals of the groundwater
- We have come a long ways, but it is a heterogeneous system



Digital cartography by Daisuke Kobayashi
Funding provided by Palouse Basin Aquifer Committee

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