Solute Chemistry and Isotope Tracers of Groundwater Systems in the Middle San Pedro Basin, Arizona

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Acknowledgements

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- Thank you to the citizens of the San Pedro Basin and to my colleagues at the U of A for field help and lab help
- Jennifer McIntosh, Chris Eastoe, Tom Meixner, and Jesse Dickinson are thanked for their support and advice

PLAN

1. Introduction to isotopes
2. Candice's research approach
3. Water quality issues
4. Questions addressed by isotope data

Introduction to isotopes

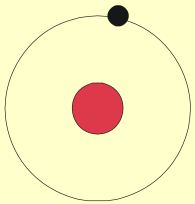
O and H isotopes

Tritium

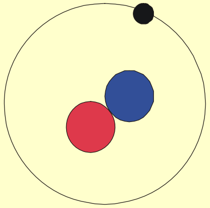
Carbon-14

Sulfur – not discussed here.

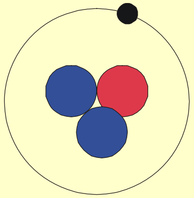
Isotopes of Hydrogen



Hydrogen-1 (protium)



Hydrogen-2 (deuterium)



Hydrogen-3 (tritium)

Radioactive > helium + electron

Half-life about 12.5 years

Isotopes of Oxygen

Oxygen-16	8 protons, 8 neutrons
Oxygen-17	8 protons, 9 neutrons
Oxygen-18	8 protons, 10 neutrons

All stable

Isotopes of Carbon

stable

Carbon-12 6 protons, 6 neutrons

Carbon -13 6 protons, 7 neutrons

radioactive

Carbon -14 6 protons, 8 neutrons

Half-life about 5730 years

Where do tritium and carbon-14 come from?

Cosmic rays strike upper atmosphere

Atmospheric testing of nuclear weapons, 1950s-1970s

Use of tritium

Groundwater once fell as rain containing measurable tritium.

Tritium decays – half life 12.4 years

Tritium below detection indicates pre-1955 rainwater.

Detectable tritium indicates presence of post-1955 rainwater

Use of carbon-14

Groundwater once fell as rain that soaked into soil and dissolved soil gas containing C-14.

C-14 decays – half life 5730 years

High C-14 indicates younger water; low C-14 indicates older water (exact ages difficult to calculate).

Age range 0 to about 20,000 years

δ-values

$\delta^{18}O = \{ (R_{sample} / R_{standard}) - 1 \} \times 1000$ ‰

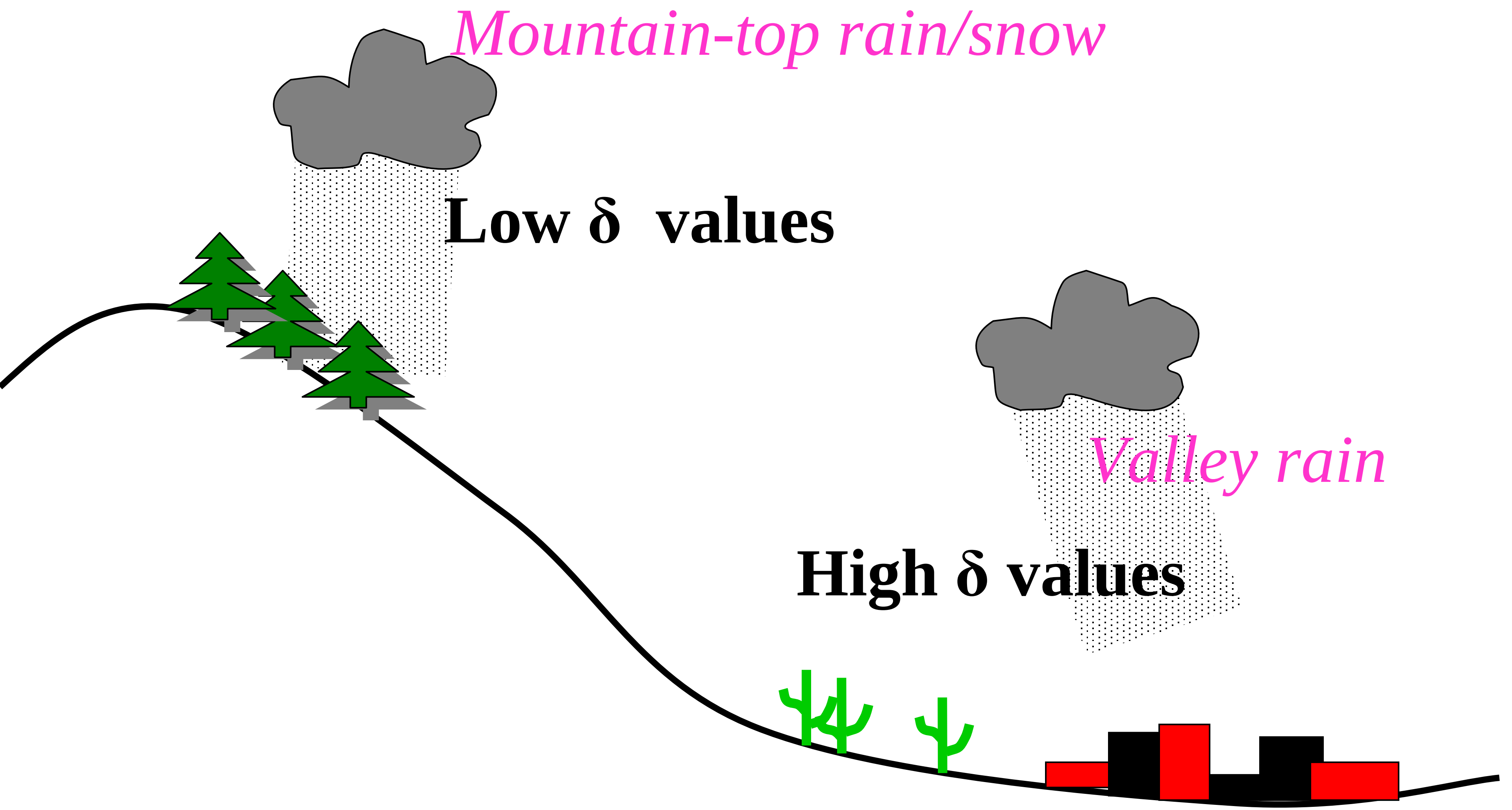
$R = {}^{18}O / {}^{16}O$

Similarly, δD with $R = D / H$

Higher δ- value implies more of the heavy isotope

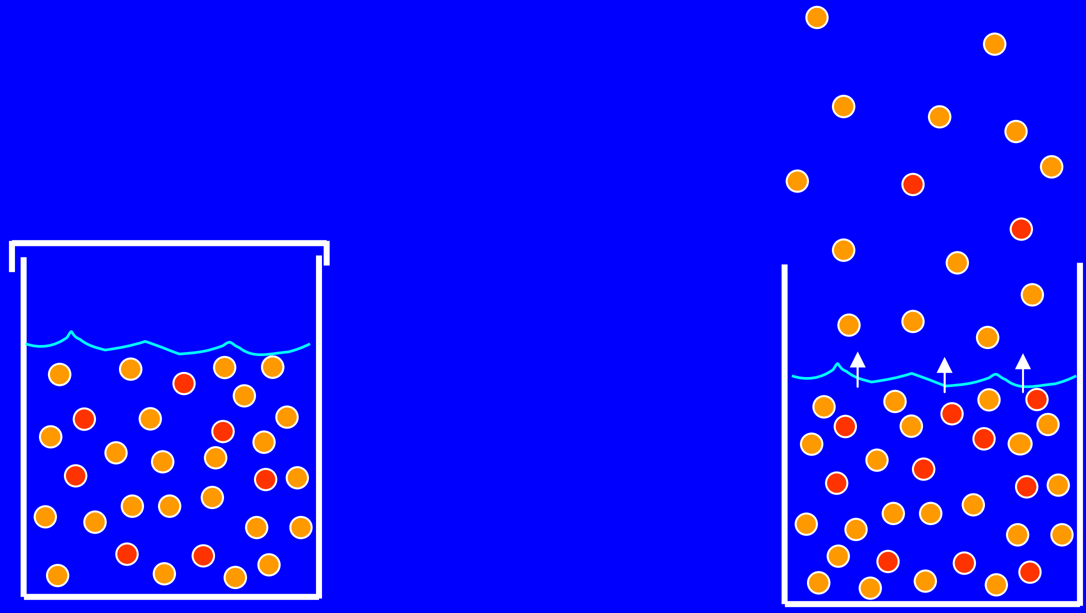
$\delta^{18}O$ =	-40	-12 to -6	0
	Antarctic ice	NM rain	ocean

Why isotope ratios in water vary: Condensation

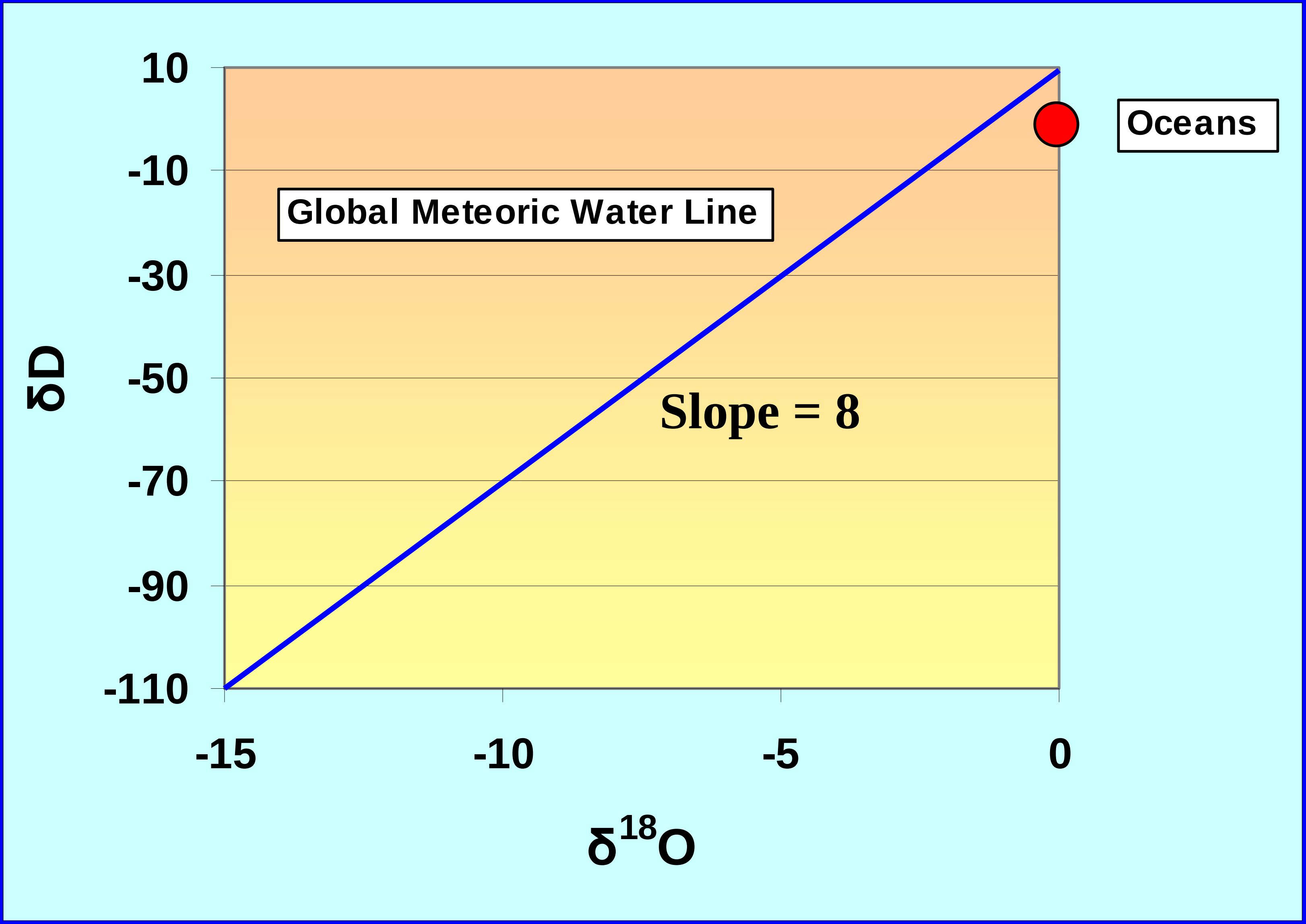


Why isotope ratios in water vary: Evaporation

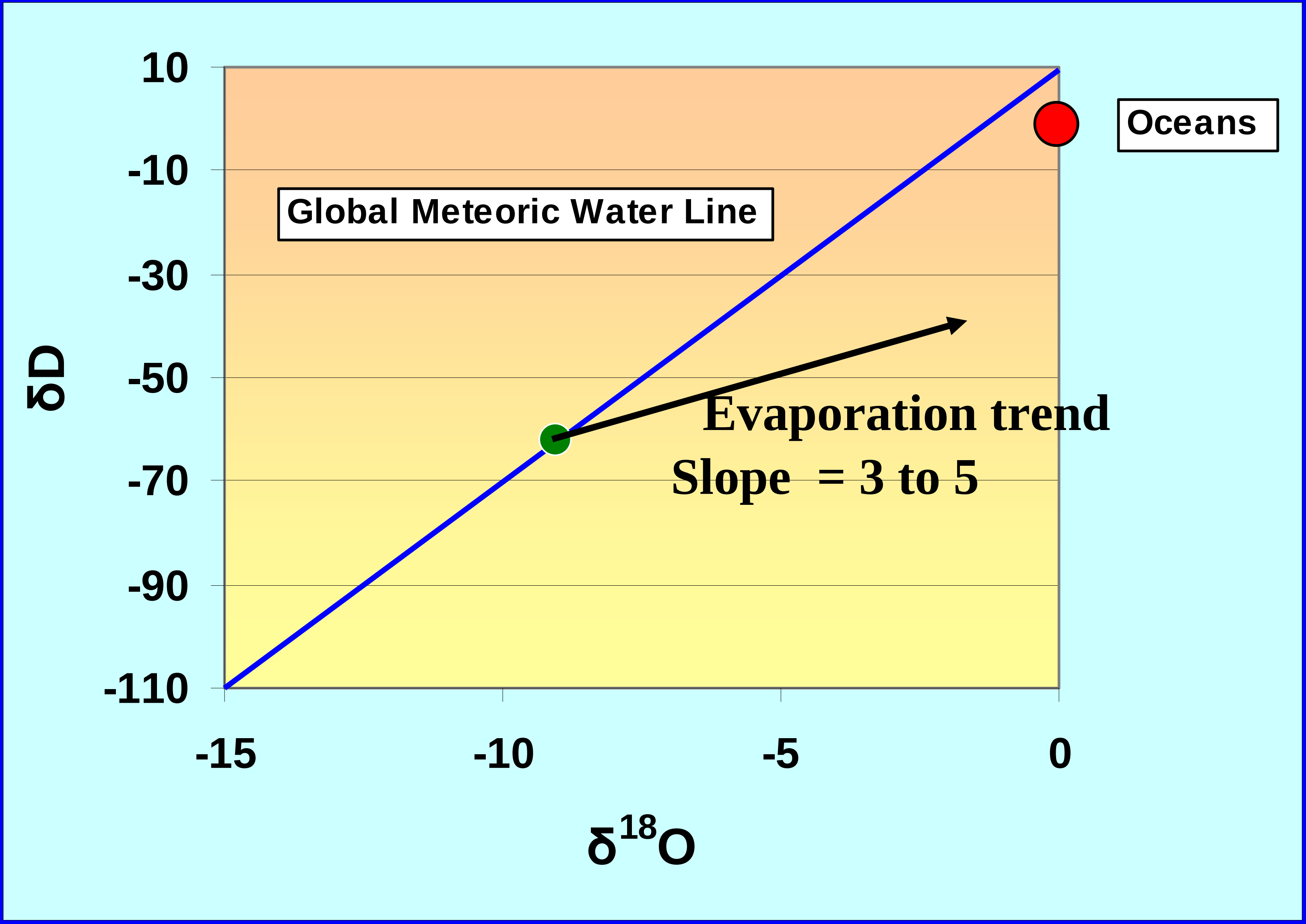
- **Lighter molecule (^{1}H, ^{16}O)**
- **Heavier molecule (^{2}H, ^{18}O)**



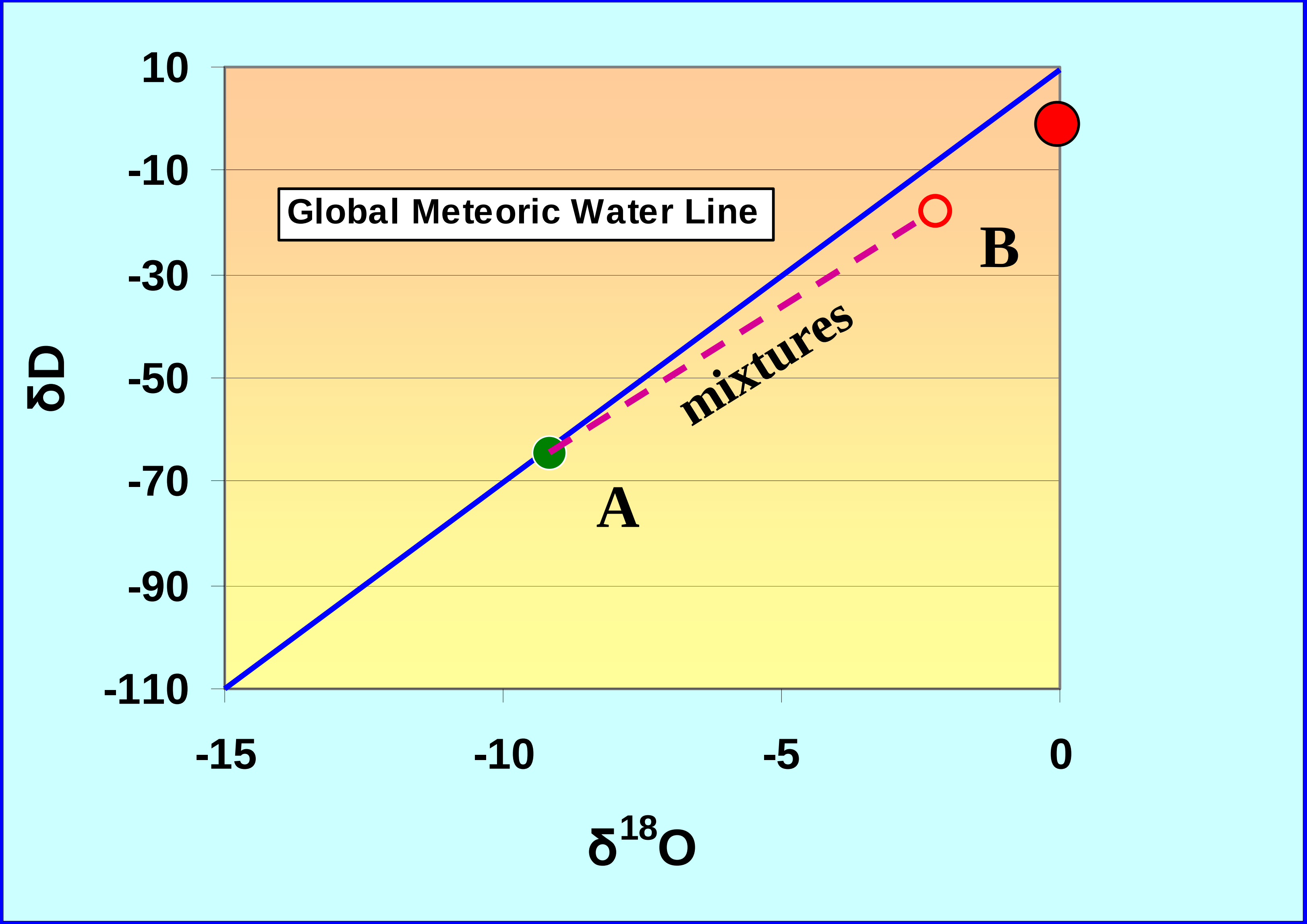
The basic diagram



Evaporation



Mixing


10
-10
-30
-50
-70
-90
-110
δD
Global Meteoric Water Line
B
mixtures
A
-15
-10
-5
0
δ18O

How Candice approached the research problem:

1. Detailed sampling in all four aquifers, and of river water
2. Analyses of major ions: sodium, potassium, calcium, magnesium, strontium, bicarbonate, chloride, sulfate, nitrate, bromide, fluoride
3. Analyses of isotopes: stable isotopes of hydrogen, oxygen, carbon and sulfur; radioactive isotopes carbon-14 and tritium
4. NETPATH modeling to correct carbon-14 data.

Water Quality Issues

Potential problems: fluoride (F) and nitrate (NO3)

No data for arsenic

EPA Maximum contaminant levels (MCLs):

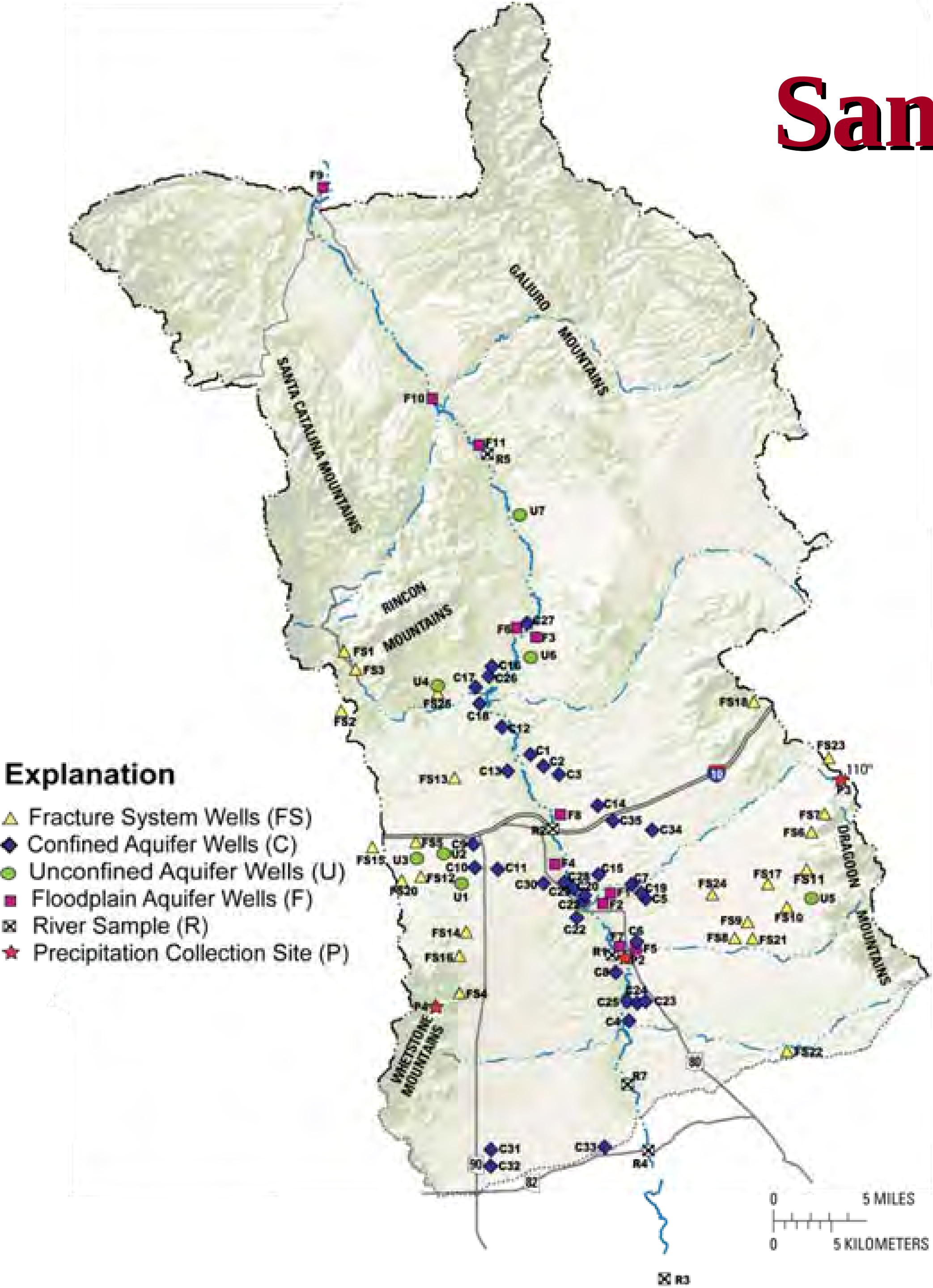
F	**4 mg/L**
NO3	**44 mg/L**

	Fracture Sys.	Unconfined	Confined	Flood plain
No. samples	25	7	35	11
F > 4 mg/L	1	0	5	2
NO3 > 44 mg/L	0	0	0	0
NO3 > 10 mg/L	4	1	2	3

The news is generally good!

Isotopes help us to answer the following questions about groundwater in the Middle San Pedro basin:

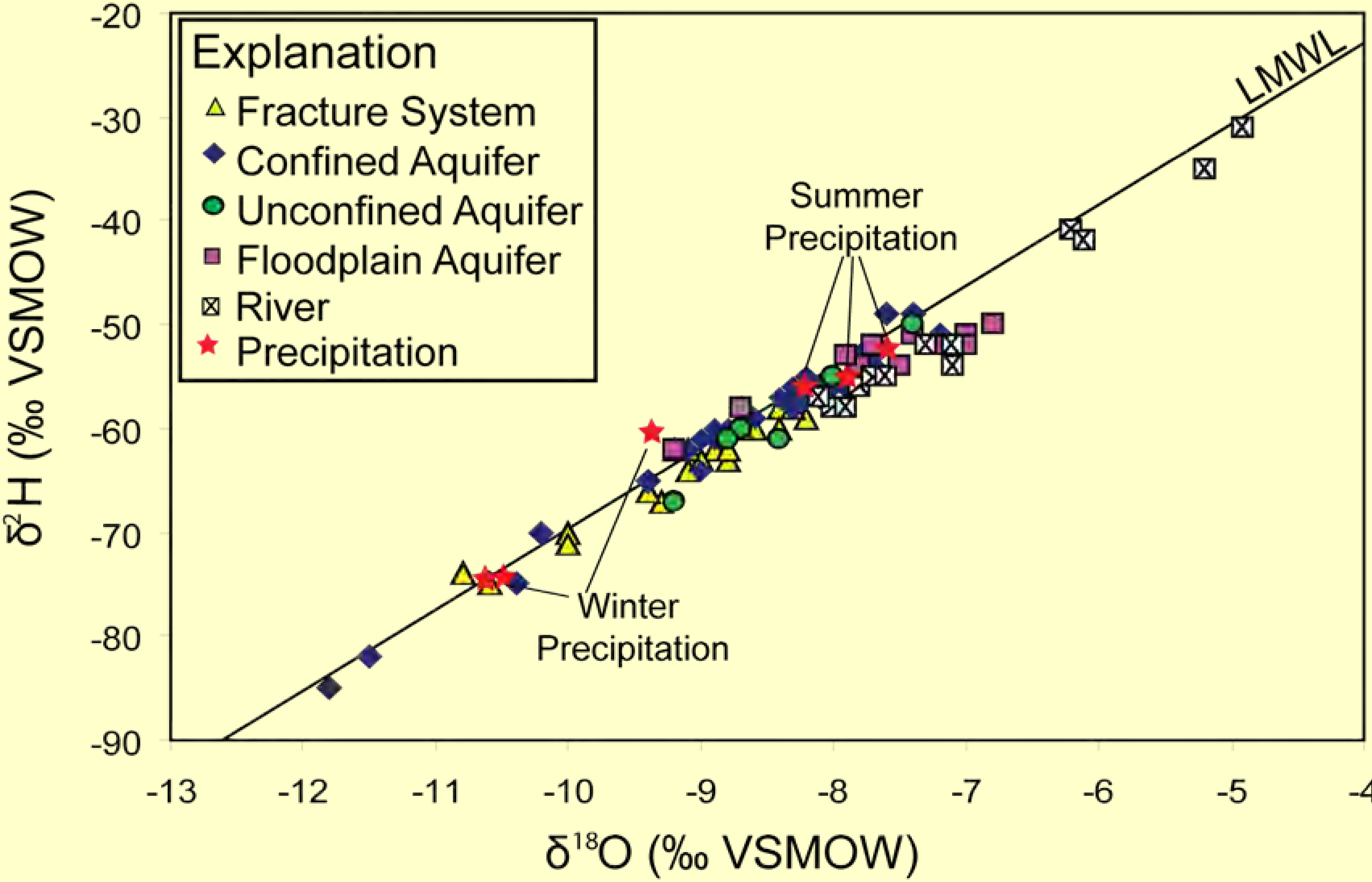
1. Where does recharge occur?
2. Is recharge limited to summer or winter?
3. Is the confined aquifer connected hydrologically to the flood plain aquifer?
4. How long does water take to flow from the basin margins to the confined aquifer beneath the river?



Sampling Strategy

- •Sampled groundwater from various points in basin, targeting transects, washes, and wells along the river
- •Collected base flow of the rive throughout the year
- •Determined isotopic composition of precipitation from various elevations and different seasons
- •Sampled wells of varying depths to target relationship between deep confined and shallow alluvial aquifer

Stable Isotopes to Determine Areas of Recharge



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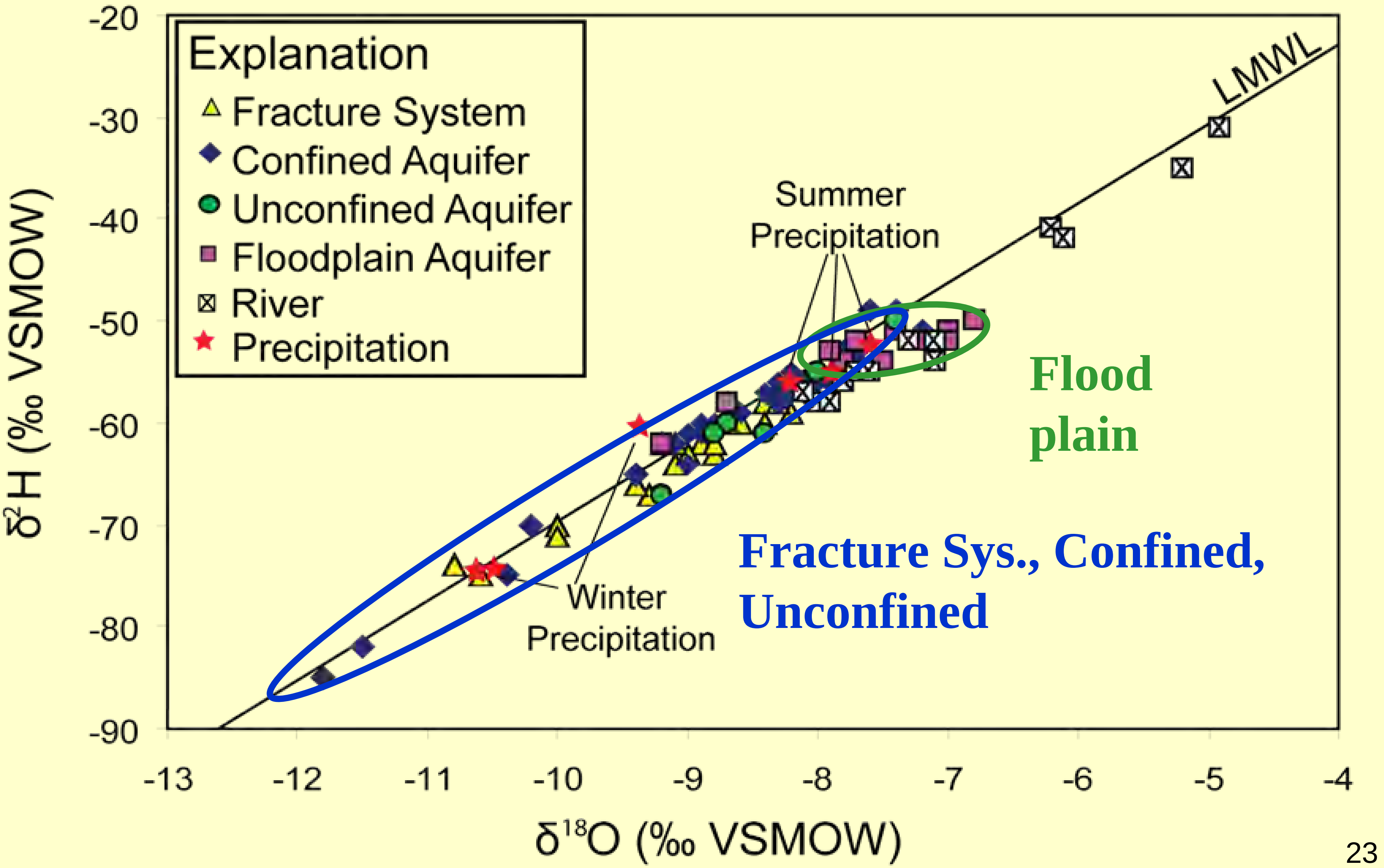
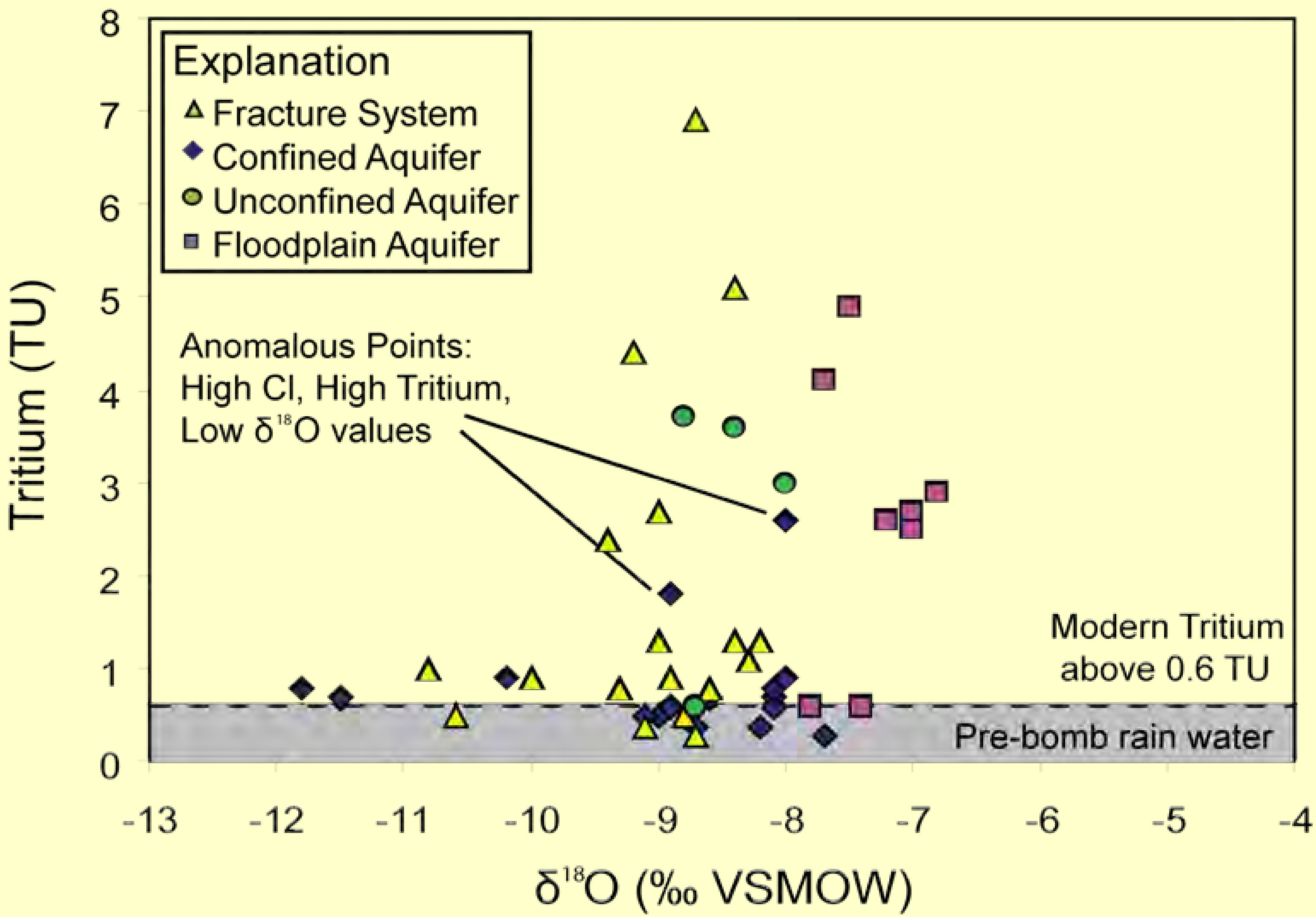


Tritium and Oxygen Isotopes as Residence Time Tracers



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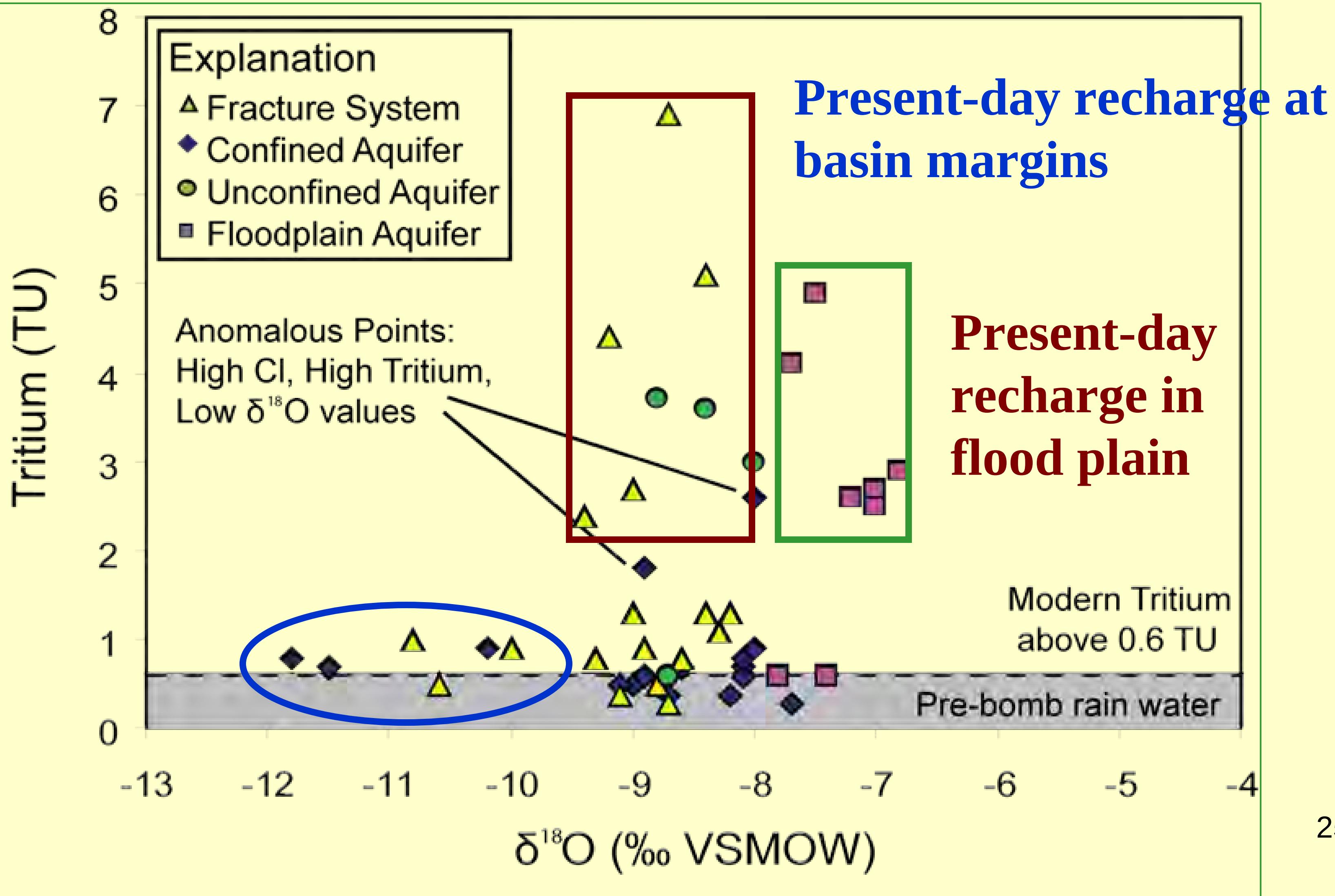
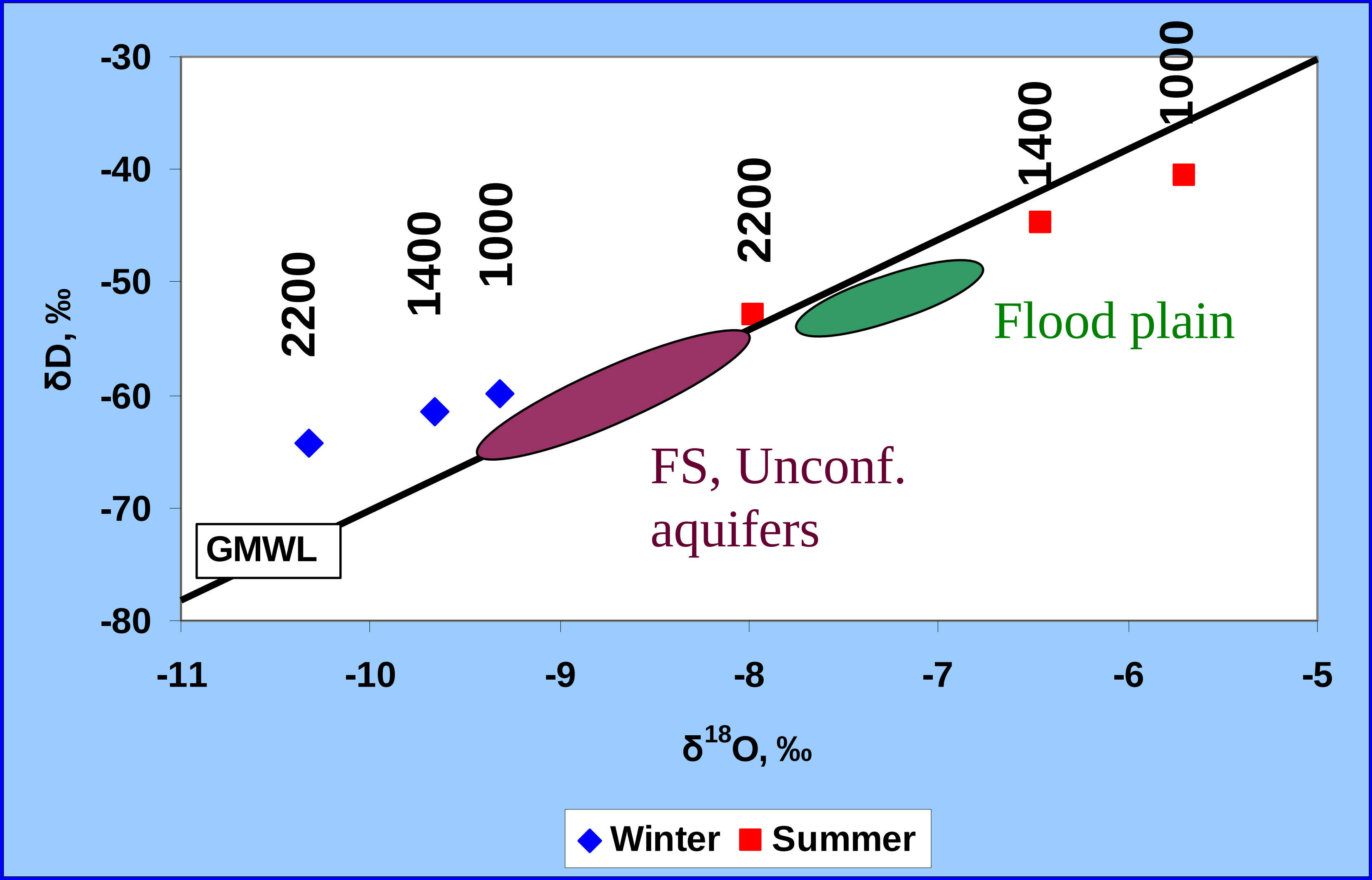


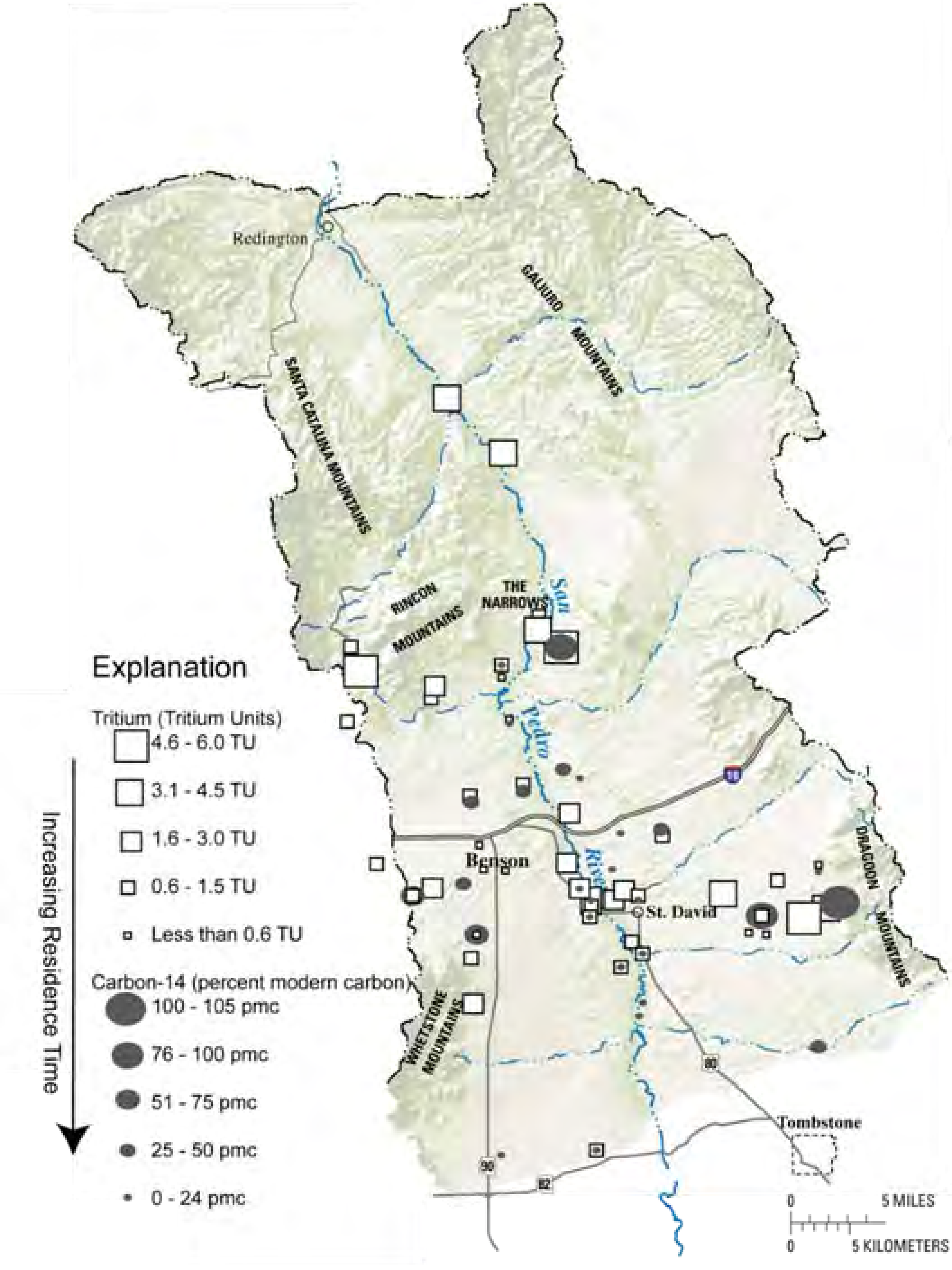
Seasonality of recharge



Tritium distribution

2		7		Flood Plain
4	9	3	3	Fracture System
1		3		Unconfined
10	5	1		Confined
<0.7	0.7 to 2	2 to 5	>5	

Tritium, TU

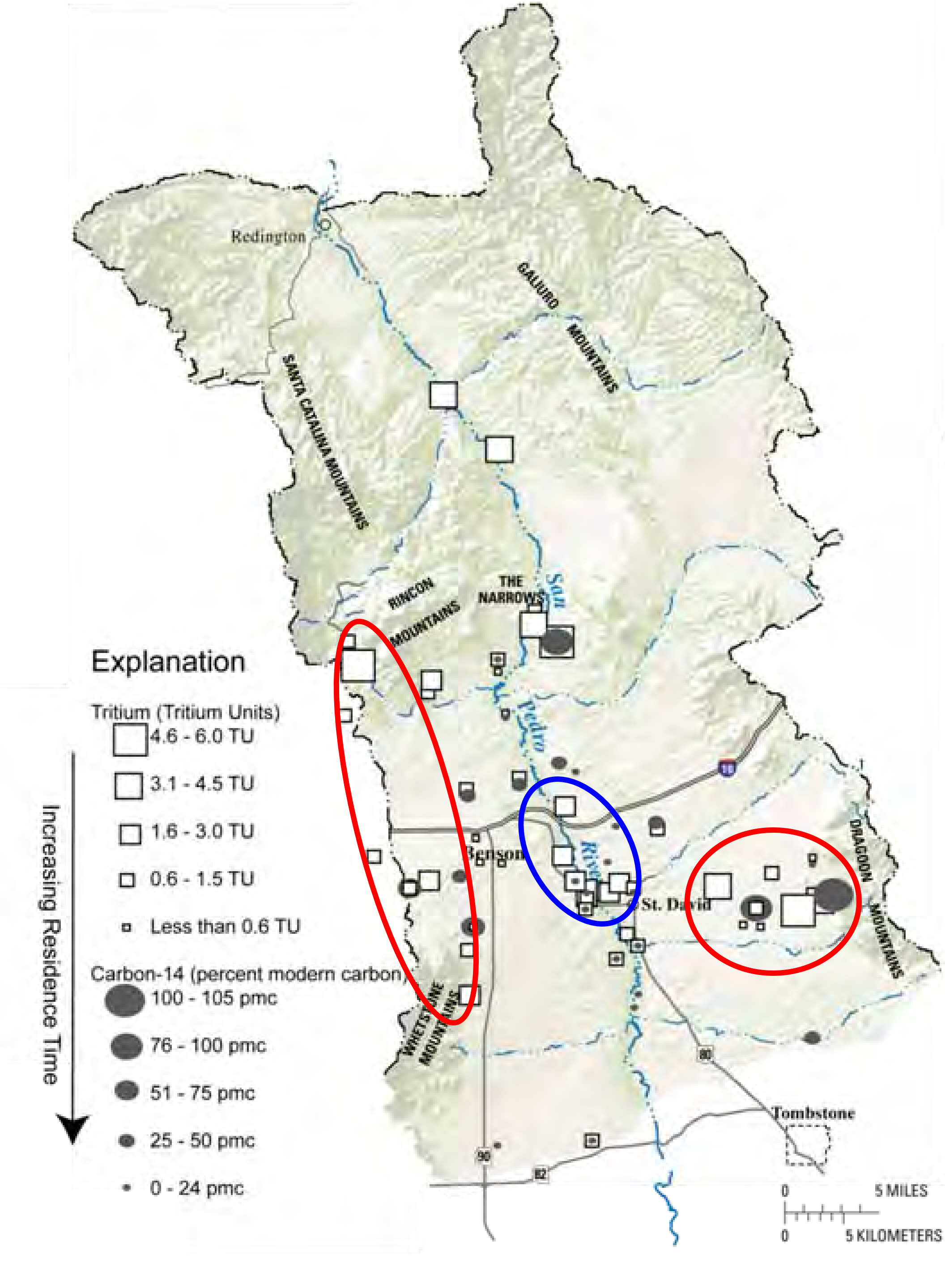


Age Tracer Results

•Detectable tritium values found in shallow wells near river and in mountain system wells

•C-14 values high in mountain systems and decrease toward basin center

•Deep wells exhibit low C-14 values while shallow wells exhibit high C-14 values



Age Tracer Results

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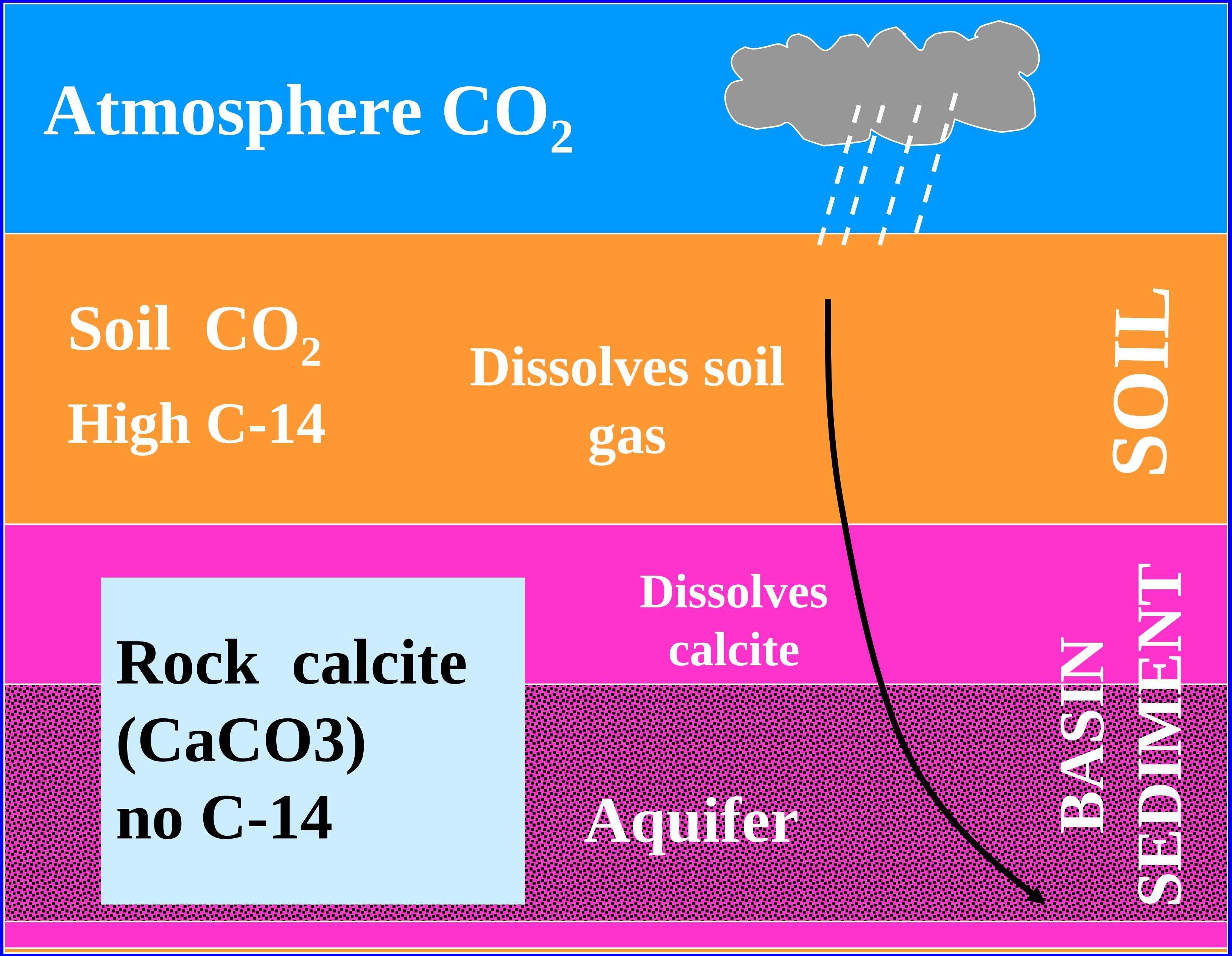
Carbon-14 distribution

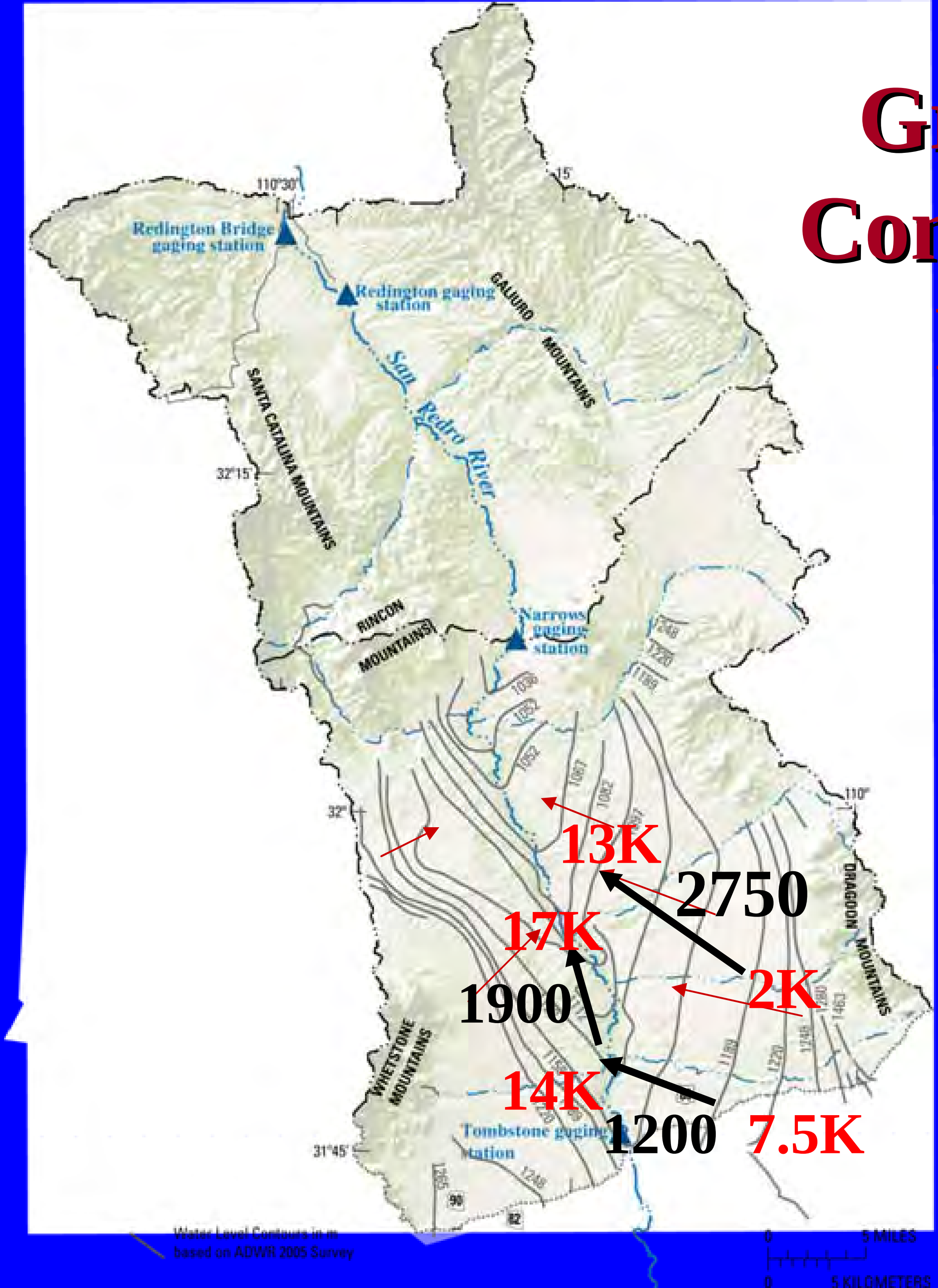
									1		Flood Plain
		2	1		2		1		1		Fracture System
			1							1	Unconfined
4	8	5	1								Confined
0	10	20	30	40	50	60	70	80	90	100	

Carbon-14, pMC, uncorrected



Atmosphere CO_2
Soil CO_2
High C-14
Dissolves soil gas
SOIL
Dissolves calcite
Rock calcite (CaCO3) no C-14
Aquifer
BASIN SEDIMENT

Groundwater Level Contours and Inferred Flow Directions

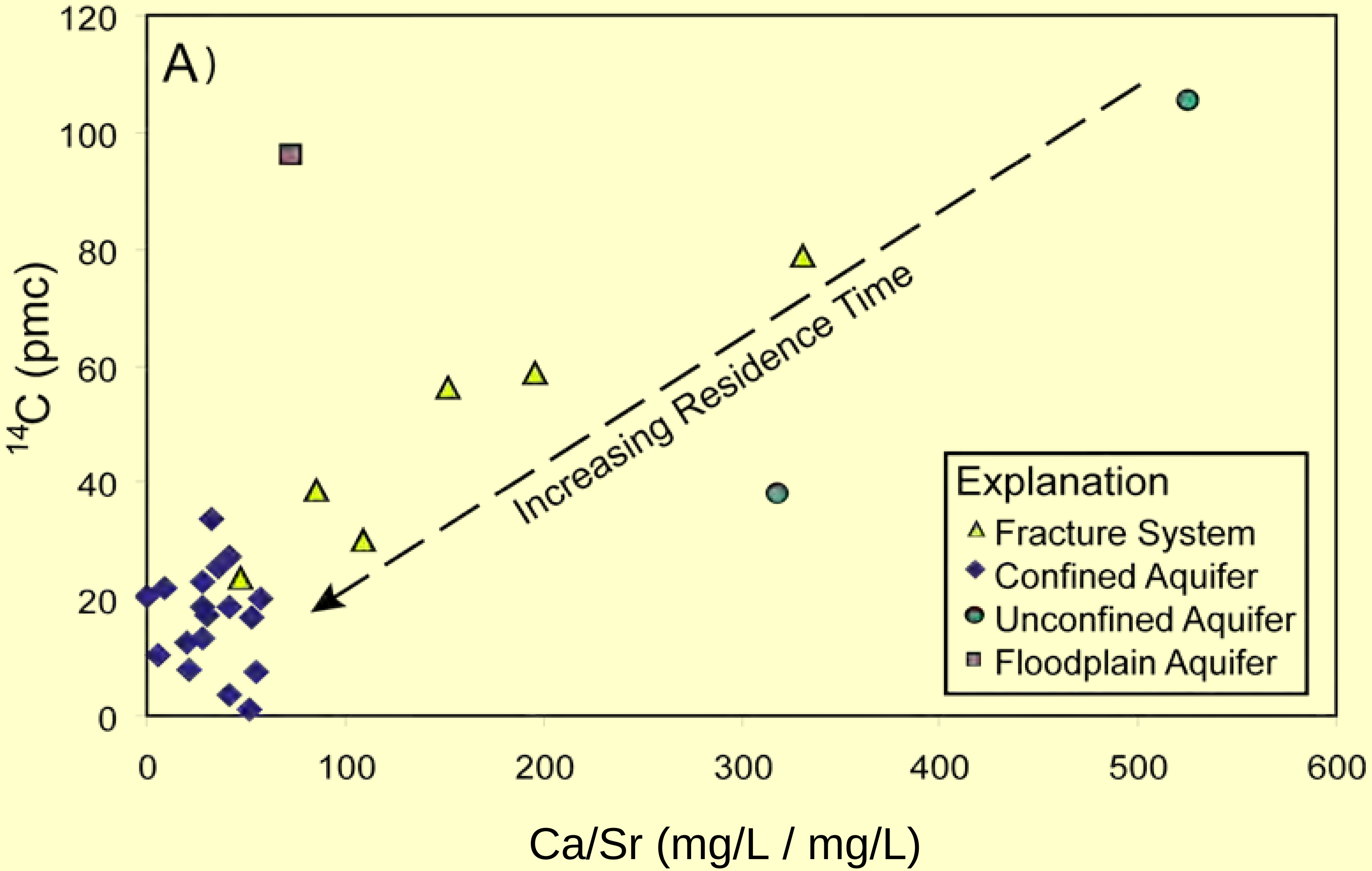


NETPATH – USGS MODELING PROGRAM

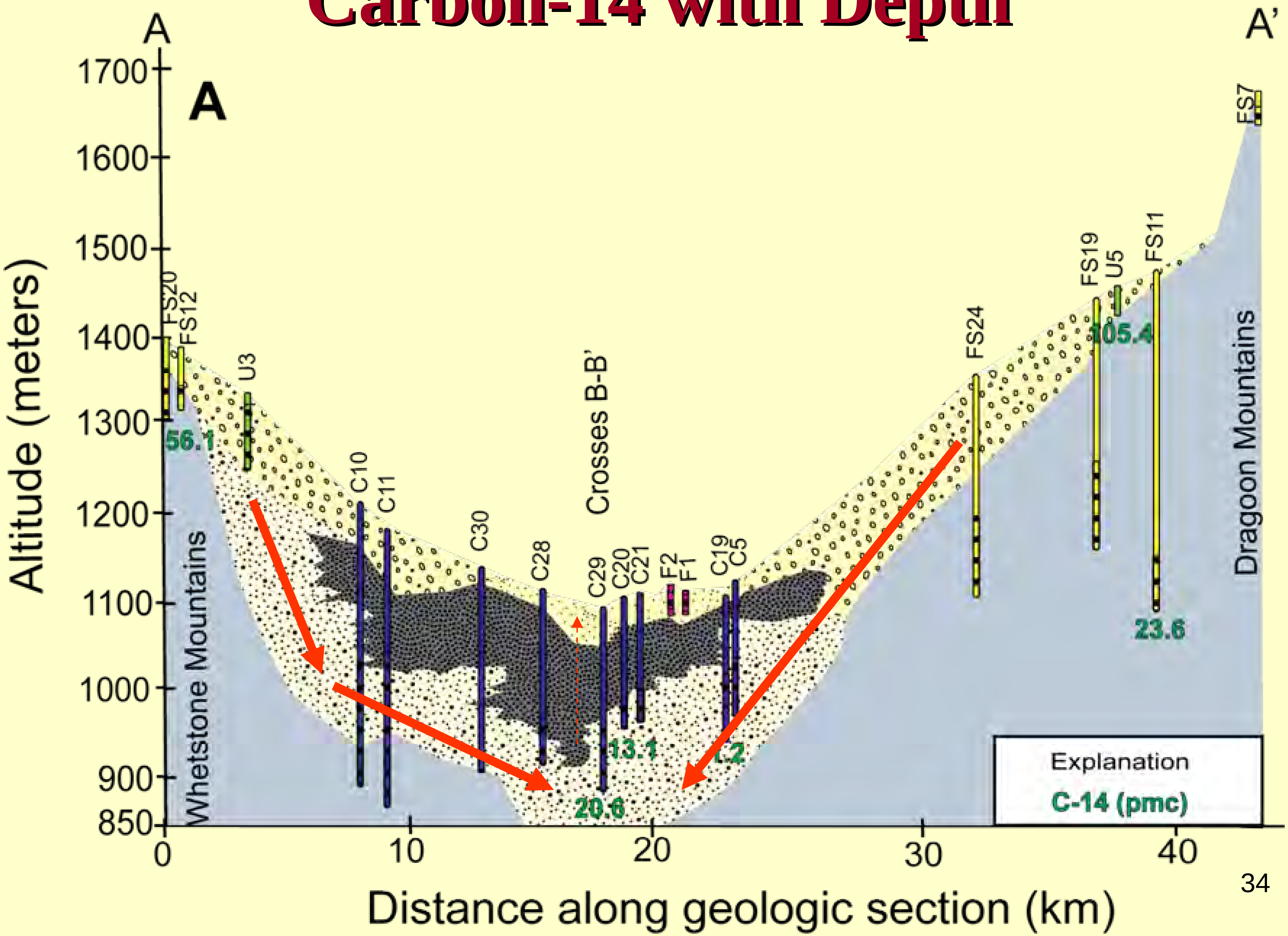
Uncorrected ages

Modeled (corrected) ages

Ca/Sr Ratios Compared with Traditional Age Tracers



Carbon-14 with Depth



Conclusions

1. Recharge to flood-plain aquifer from river, summer recharge dominant.
2. Recharge to fracture-system aquifer (and thence to confined aquifer) from basin margins, with winter recharge dominant.
3. Confined aquifer has little connection with flood-plain aquifer – expressed in O,H isotopes and tritium.
4. Water in the confined aquifer has been resident for thousands of years . In FS aquifer – some water resident only a few decades.