Ground-Water Assessments in Areas of Limited Supply

The Big and Little Chino Aquifers and the Upper Verde River

USGS

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U.S. Geological Survey
Crustal Imaging and Characterization Team, Denver

science for a changing world

Geologic Framework of Aquifer Units and Ground-Water Flowpaths, Verde River Headwaters, North-Central Arizona

Open-File Report 2004-1411

http://www.usgs.pubs/of/2004/1411

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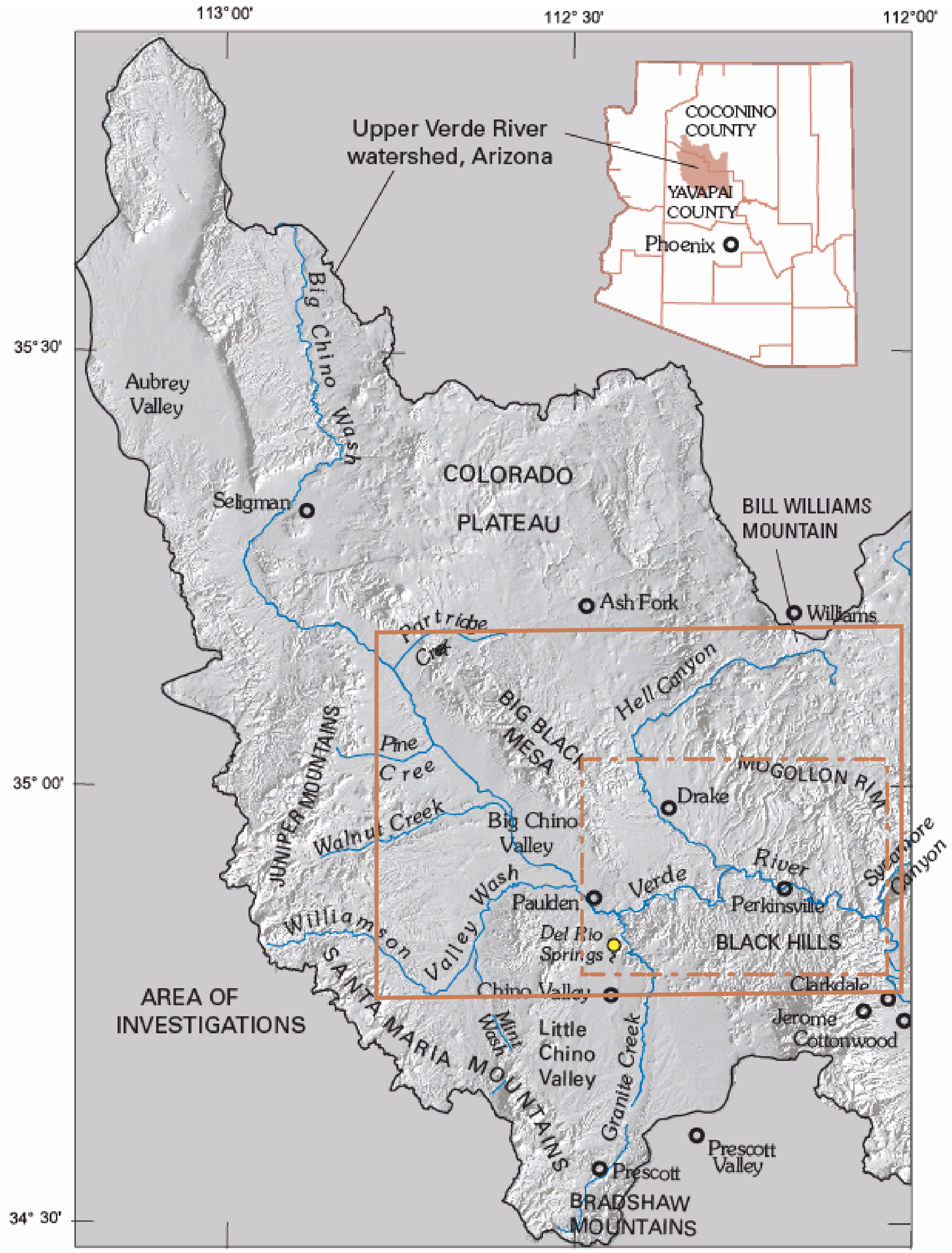
Geologic Framework of Aquifer Units and Ground-Water Flowpaths, Verde River Headwaters, North-Central Arizona

Edited by Laurie Wirt, Ed DeWitt, and V.E. Langenheim

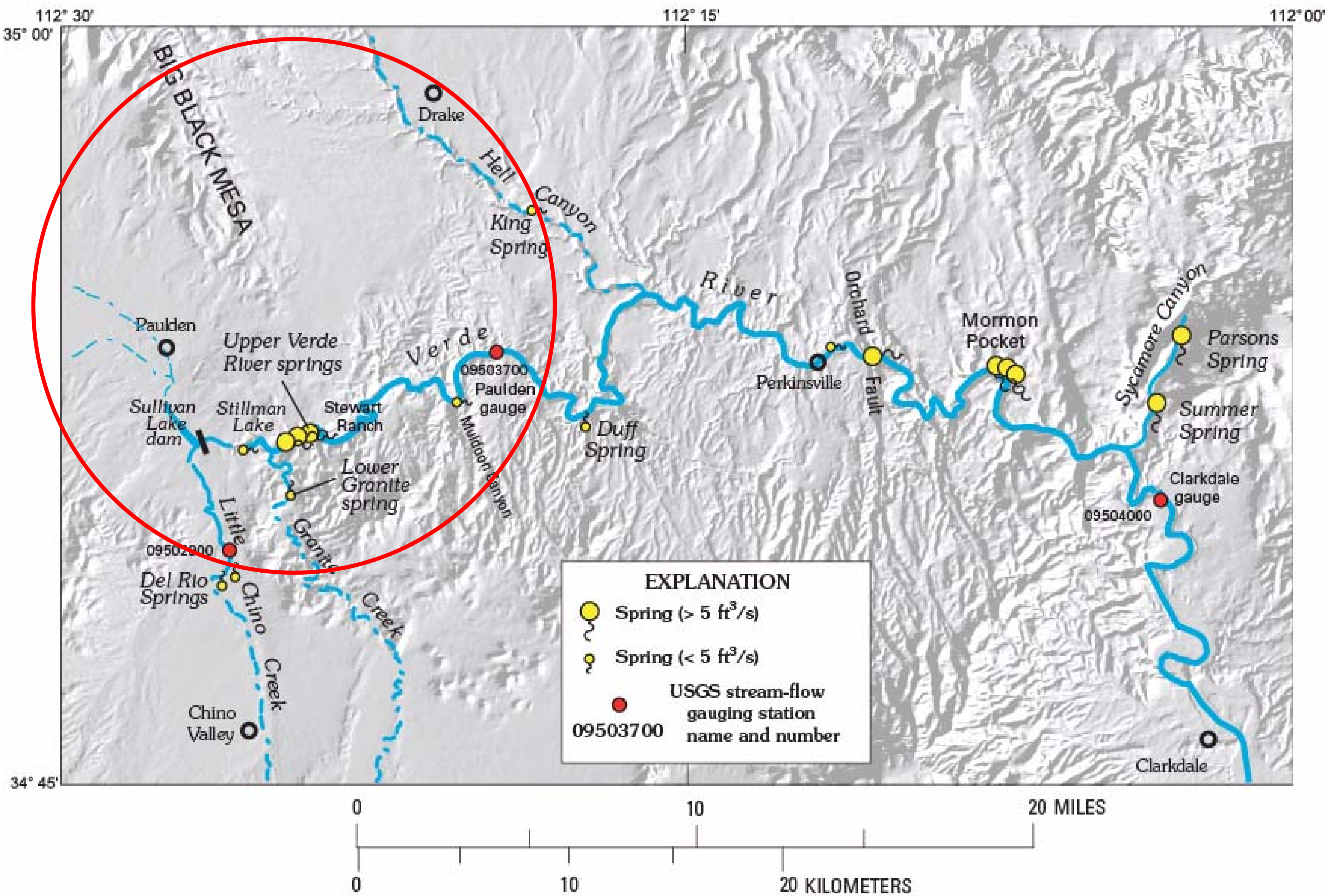
A. Introduction, environmental setting, and predevelopment conditions
B. Geologic Framework
C. Geophysical Framework
D. Hydrogeological Framework
E. Geochemistry of Major Aquifers and Springs
F. Tracer Study and Geochemical Model
G. Synthesis

Multiple Lines of Evidence:

- A. Summarizes the environmental setting, predevelopment conditions, and evaluates information in previous studies
- B. Geologic Framework
- C. Geophysical Framework
- D. Hydrogeological Framework
- E. Geochemical Trends of Aquifers and Springs
- F. Tracer Study and Geochemical Model
- G. Synthesis


113° 00'
112° 30'
112°00'
35° 30'
35° 00'
34° 30'
Upper Verde River
watershed, Arizona
COCONINO
COUNTY
YAVAPAI
COUNTY
Phoenix
Big Chino Wash
Aubrey
Valley
Seligman
COLORADO
PLATEAU
BILL WILLIAMS
MOUNTAIN
Ash Fork
Williams
Partridge
Creek
Hell Canyon
BIG BLACK
MESA
JUNIPER MOUNTAINS
Pine
Creek
MOGOLLON RIM
Drake
Walnut Creek
Big Chino
Valley
Sycamore
Canyon
Williamson
Valley
Wash
Paulden
Verde
River
Perkinsville
Del Rio
Springs
BLACK HILLS
Clarkdale
Chino Valley
Jerome
Cottonwood
AREA OF
INVESTIGATIONS
SANTA MARIA MOUNTAINS
Mint
Wash
Little
Chino
Valley
Granite Creek
Prescott
Valley
Prescott
BRADSHAW
MOUNTAINS

USGS

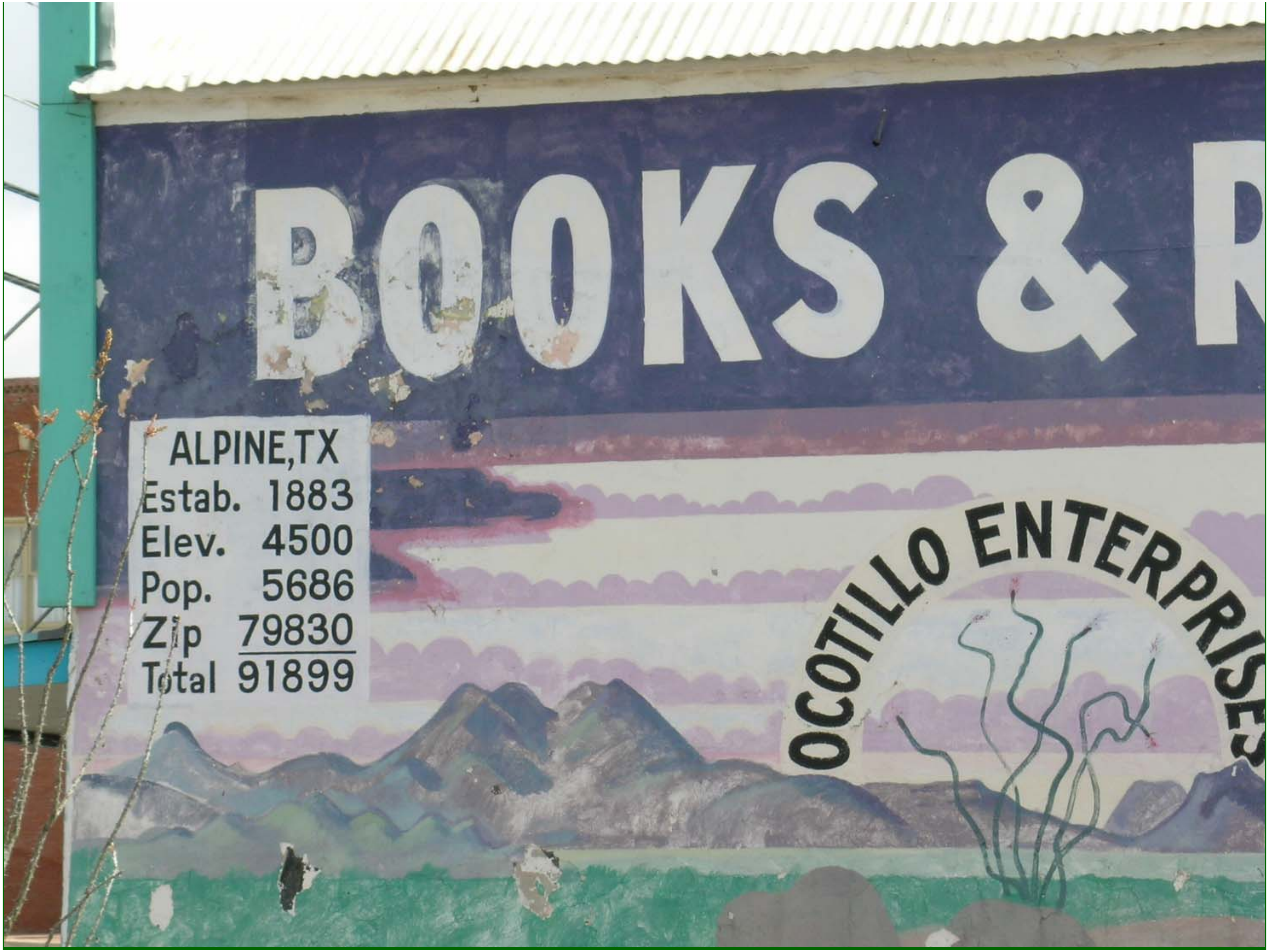


112° 30'
112° 15'
112° 00'
35° 00'
34° 45'
BIG BLACK MESA
Drake
Hell Canyon
King Spring
Verde River
Paulden
Upper Verde River springs
Sullivan Lake dam
Stillman Lake
Stewart Ranch
09503700
Paulden gauge
Lower Granite spring
Muldoon Canyon
Duff Spring
Orchard Fault
Perkinsville
Mormon Pocket
Sycamore Canyon
Parsons Spring
Summer Spring
Clarkdale gauge
09504000
09502000
Little Chino Creek
Granite Creek
Del Rio Springs
Chino Valley
Clarkdale
EXPLANATION
Spring (> 5 ft³/s)
Spring (< 5 ft³/s)
USGS stream-flow gauging station name and number
09503700
0
10
20 MILES
0
10
20 KILOMETERS

USGS

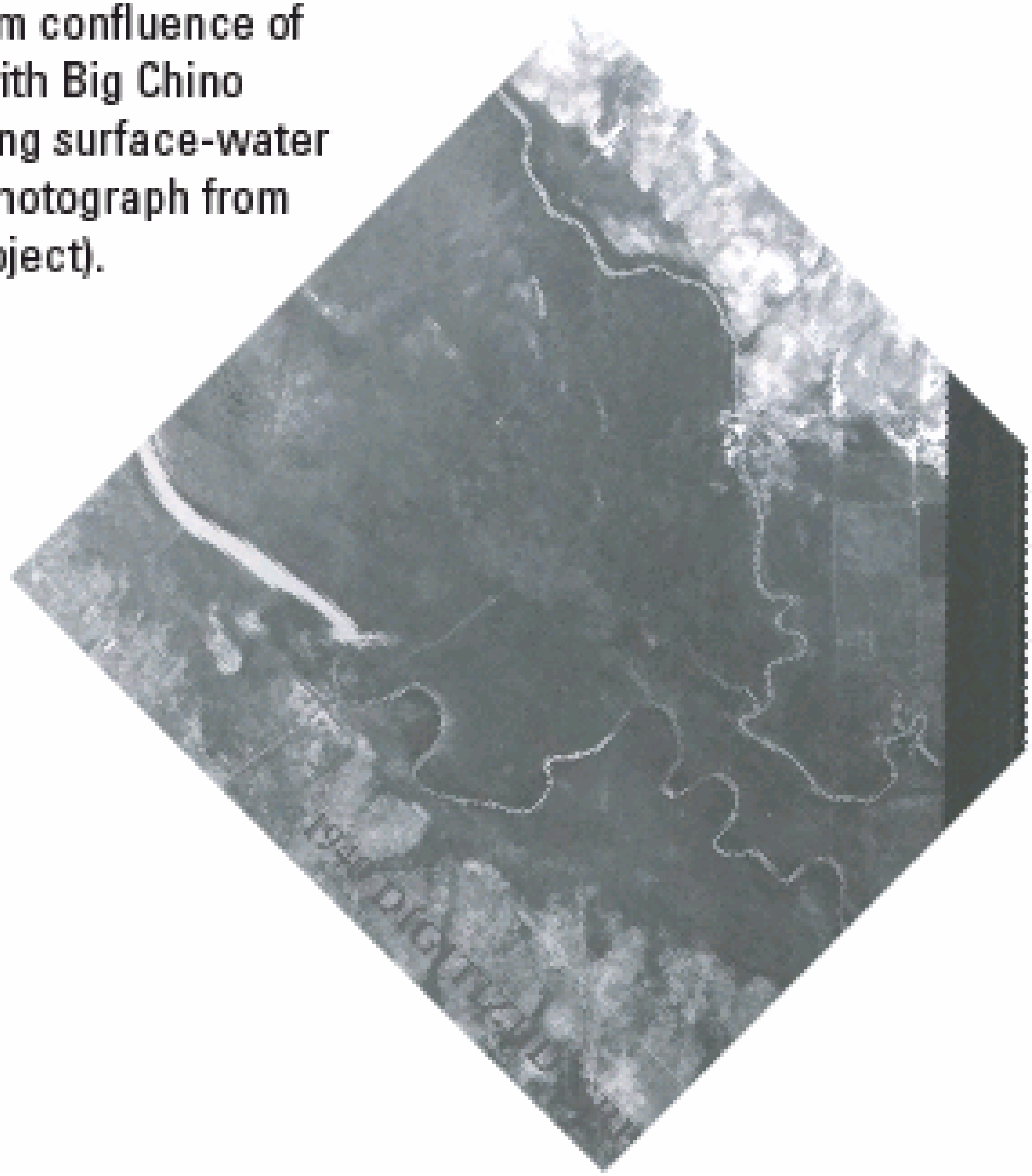
Predevelopment Conditions

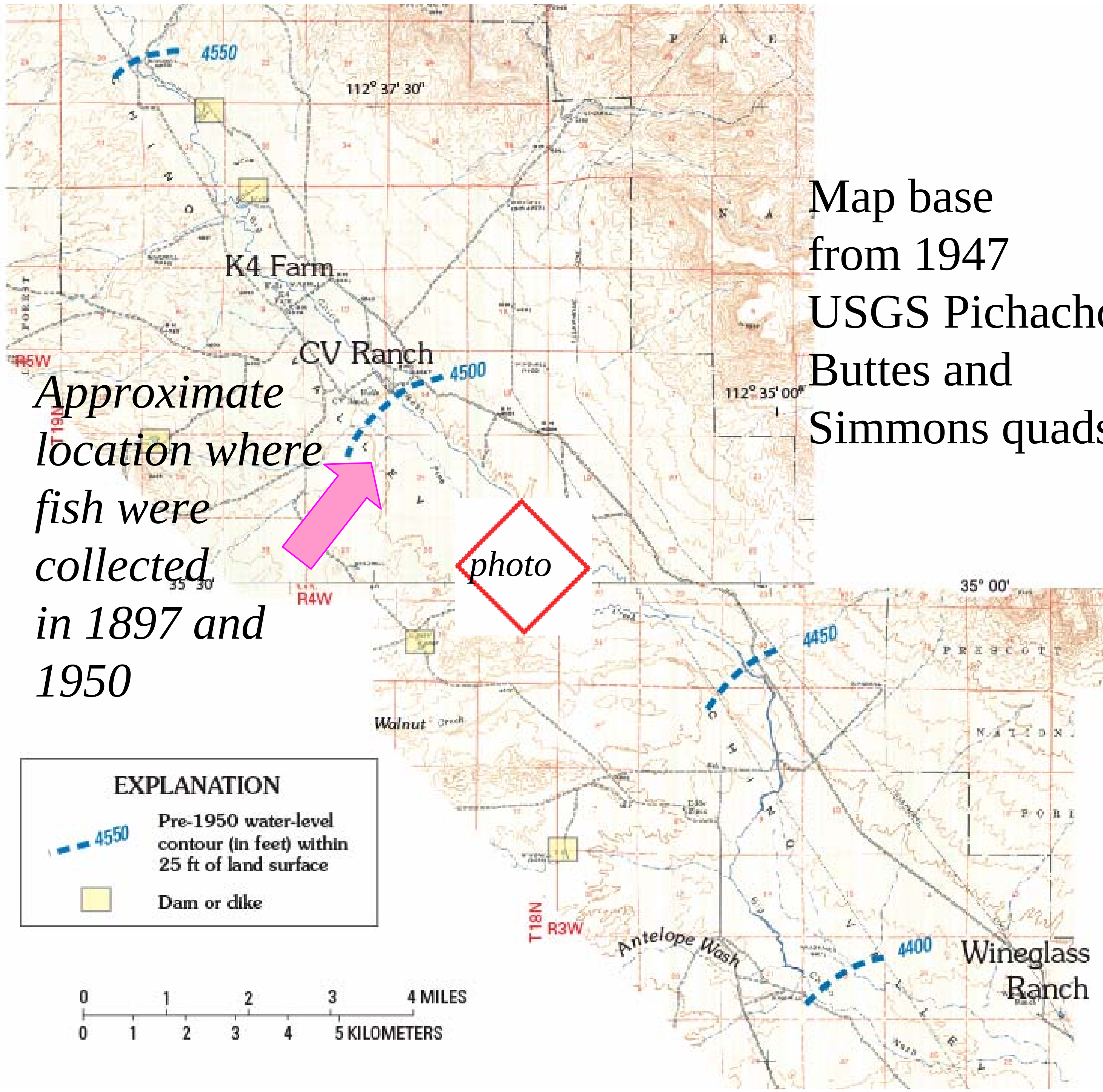
Basin	**Recharge (ac-ft/yr)**	**Data Source**
Big Chino	21,600 21,500	Ewing and others, BOR, 1994 Freethey and Anderson, USGS, 1986
Little Chino	5,000 4,000 4,500	Schwalen, UA, 1967 Matlock and others, UA, 1973 Freethey and Anderson, USGS, 1986
Big Black Mesa	1,250	Ford, Leonard Rice Associates, 2002
Headwaters Total	**27,300**	Using above data sources
Baseflow for Verde River near Paulden	**18,000*** **16,000***	Wirt and Hjalmarson, USGS, 2000 Freethey and Anderson, USGS, 1986


BOOKS & R
ALPINE,TX
Estab. 1883
Elev. 4500
Pop. 5686
Zip 79830
Total 91899
OCOTILLO ENTERPRISES

USGS

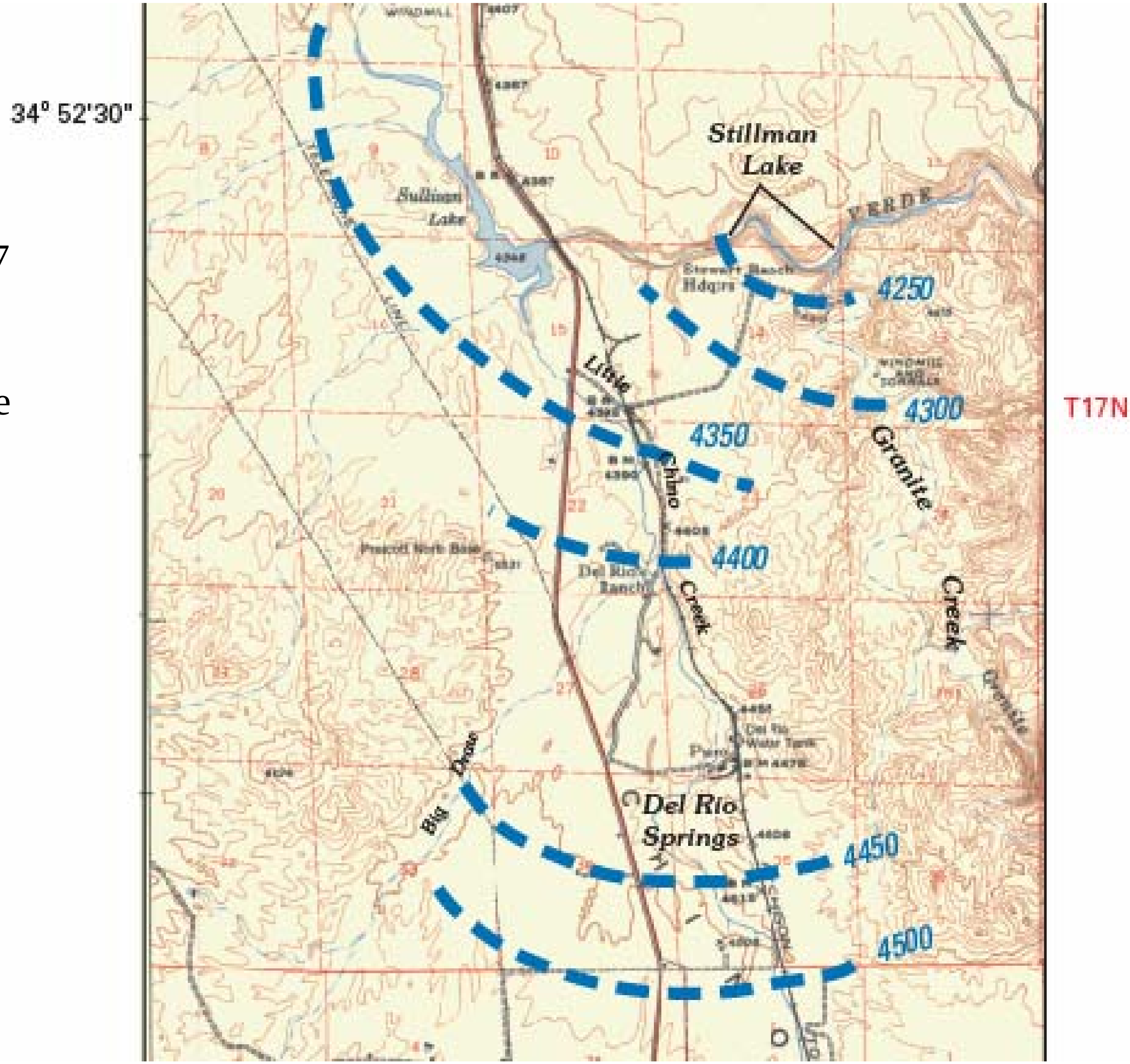
1940 oblique aerial photograph upstream from confluence of Pine Creek with Big Chino Wash, showing surface-water diversions (photograph from Salt River Project).

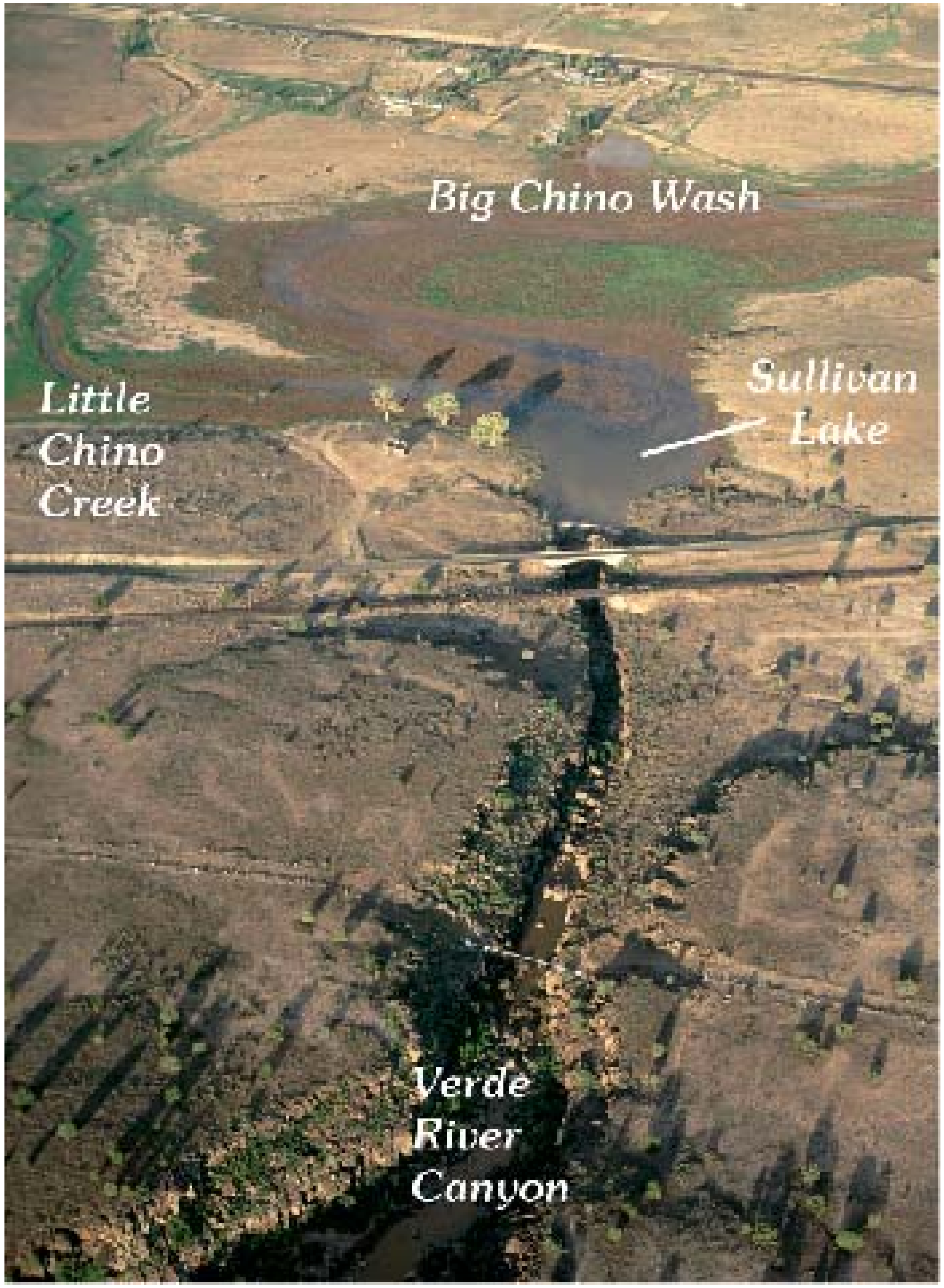




Map base from 1947 USGS Pichacho Buttes and Simmons quads

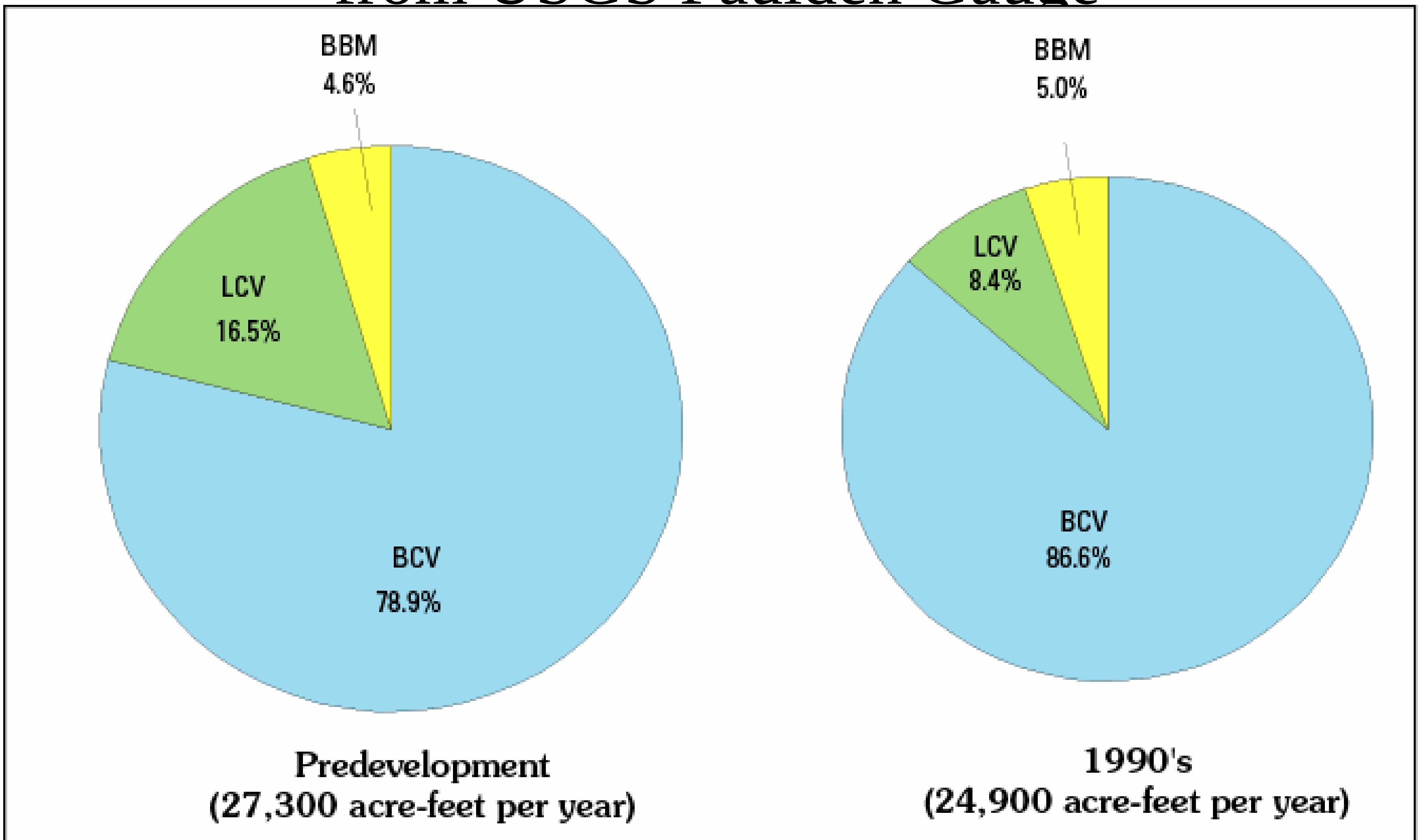
From 1947 USGS Paulden quadrangle




Big Chino Wash
Sullivan Lake
Little Chino Creek
Verde River Canyon

USGS

Initial Conceptual Model for Sources of Recharge to the Upper Verde River upstream from USGS Paulden Gauge



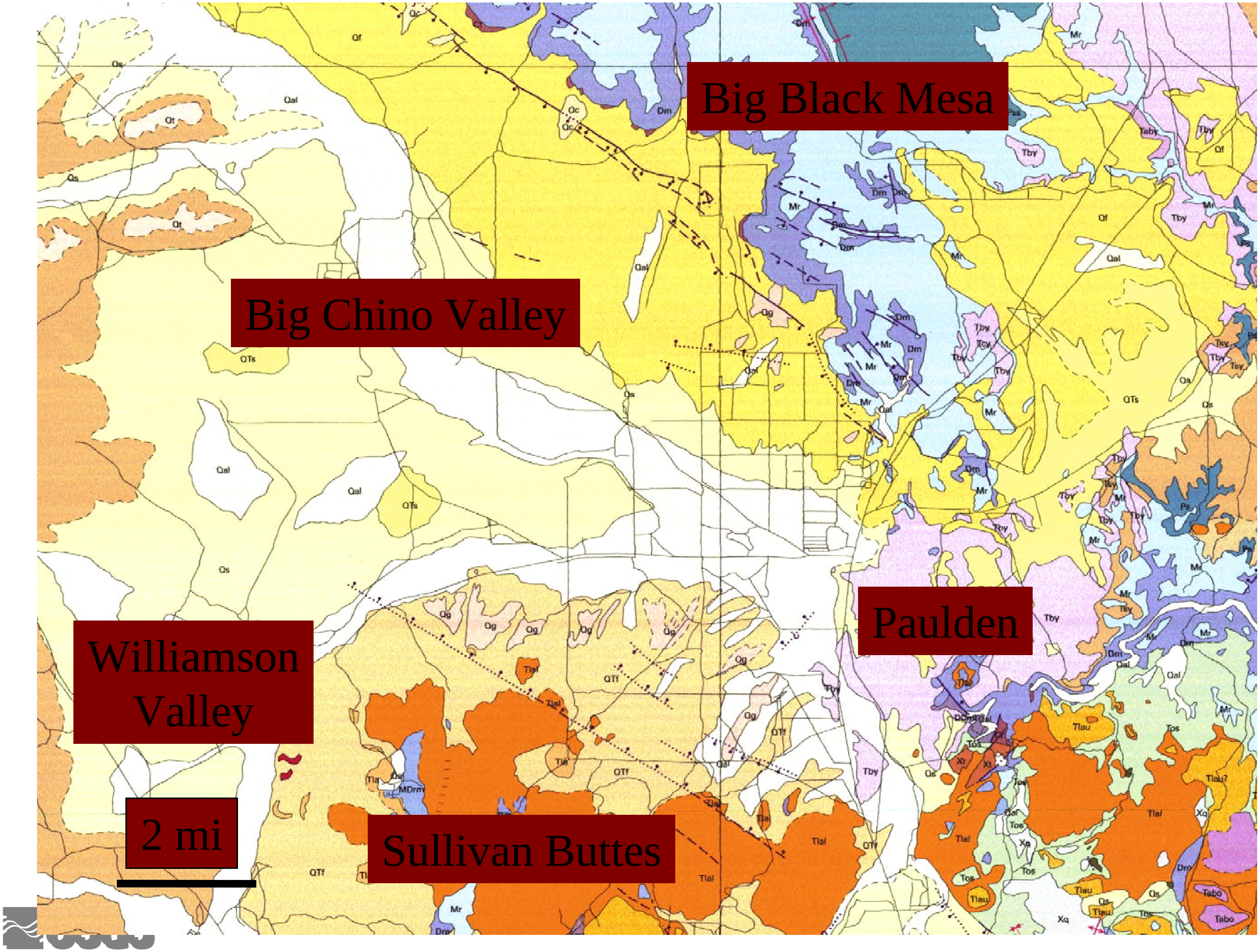
Major Findings, Chapter A:

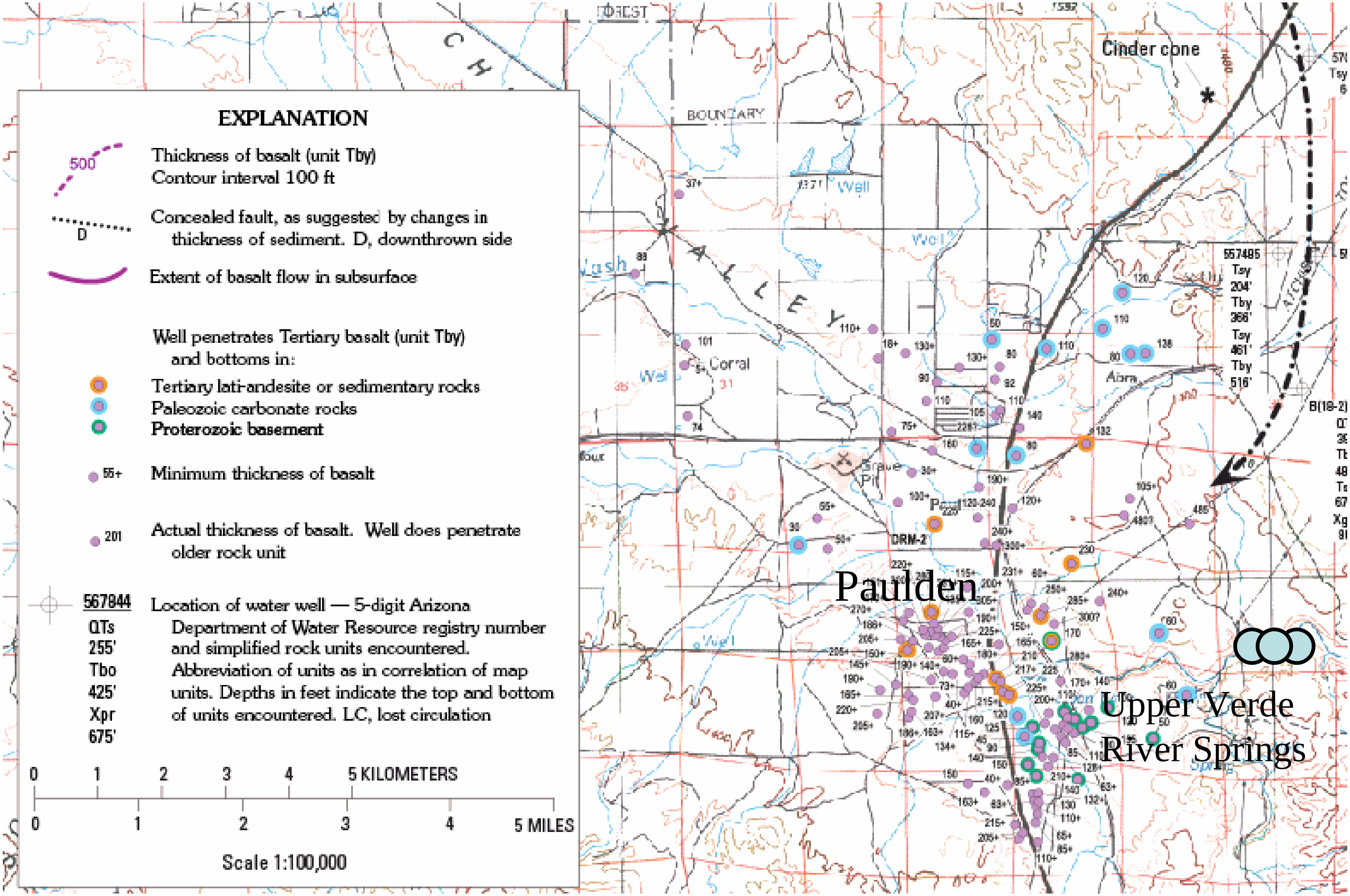
- More than 6 miles of perennial stream segments have been lost since ~1950
- Segments of upper Big Chino Wash had native fish until at least ~1950
- Water levels nr Sullivan Lake have declined by >80 ft since 1947*
- Data gaps identified include Big Black Mesa and the different carbonate aquifers
- Available water-budget data is far better for Little Chino Valley than Big Chino Valley

USGS

Multiple Lines of Evidence:

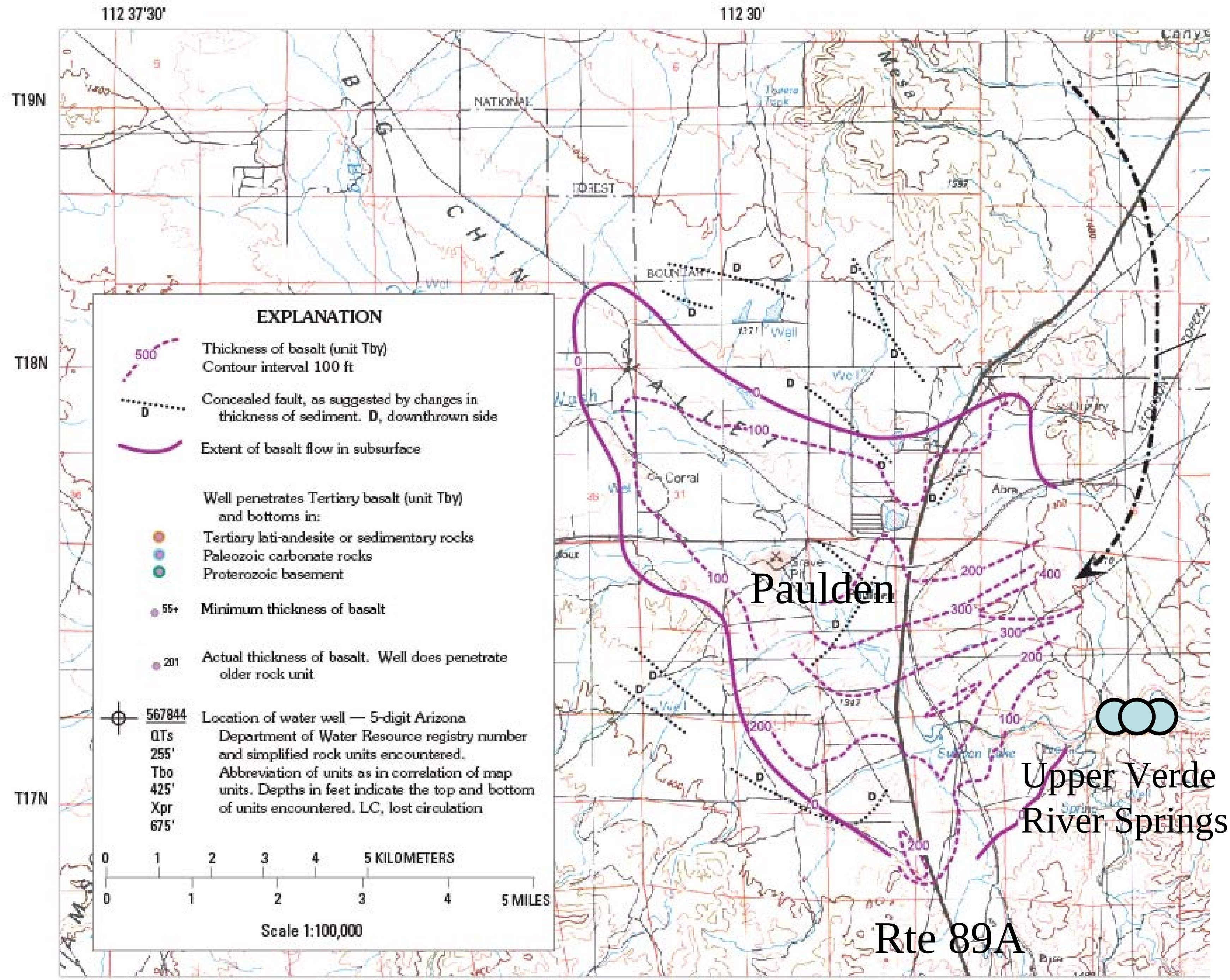
A. Summarize environmental setting, predevelopment conditions, and previous studies
B. Geologic Framework
C. Geophysical Framework
D. Hydrogeological Framework
E. Geochemistry of Major Aquifers and Springs
F. Tracer Study and Geochemical Model
G. Synthesis


Big Black Mesa
Big Chino Valley
Paulden
Williamson Valley
2 mi
Sullivan Buttes


EXPLANATION
500
Thickness of basalt (unit Tby) Contour interval 100 ft
D
Concealed fault, as suggested by changes in thickness of sediment. D, downthrown side
Extent of basalt flow in subsurface
Well penetrates Tertiary basalt (unit Tby) and bottoms in:
Tertiary lati-andesite or sedimentary rocks
Paleozoic carbonate rocks
Proterozoic basement
55+
Minimum thickness of basalt
201
Actual thickness of basalt. Well does penetrate older rock unit
567844
QTs
255'
Tbo
425'
Xpr
675'
Location of water well — 5-digit Arizona Department of Water Resource registry number and simplified rock units encountered. Abbreviation of units as in correlation of map units. Depths in feet indicate the top and bottom of units encountered. LC, lost circulation
0 1 2 3 4 5 KILOMETERS
0 1 2 3 4 5 MILES
Scale 1:100,000
Cinder cone
BOUNDARY
Corral
Well
DRM-2
Paulden
Upper Verde River Springs

Rte 89A

USGS


112 37'30"
112 30'
T19N
T18N
T17N
EXPLANATION
500
Thickness of basalt (unit Tby)
Contour interval 100 ft
Concealed fault, as suggested by changes in thickness of sediment. D, downthrown side
Extent of basalt flow in subsurface
Well penetrates Tertiary basalt (unit Tby) and bottoms in:
Tertiary lati-andesite or sedimentary rocks
Paleozoic carbonate rocks
Proterozoic basement
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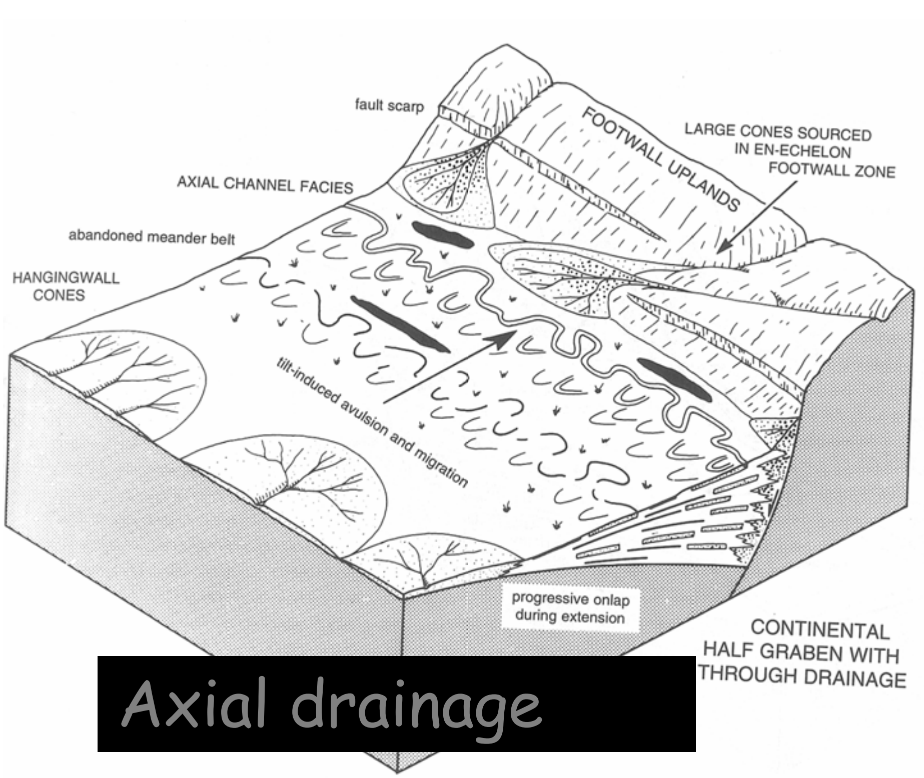
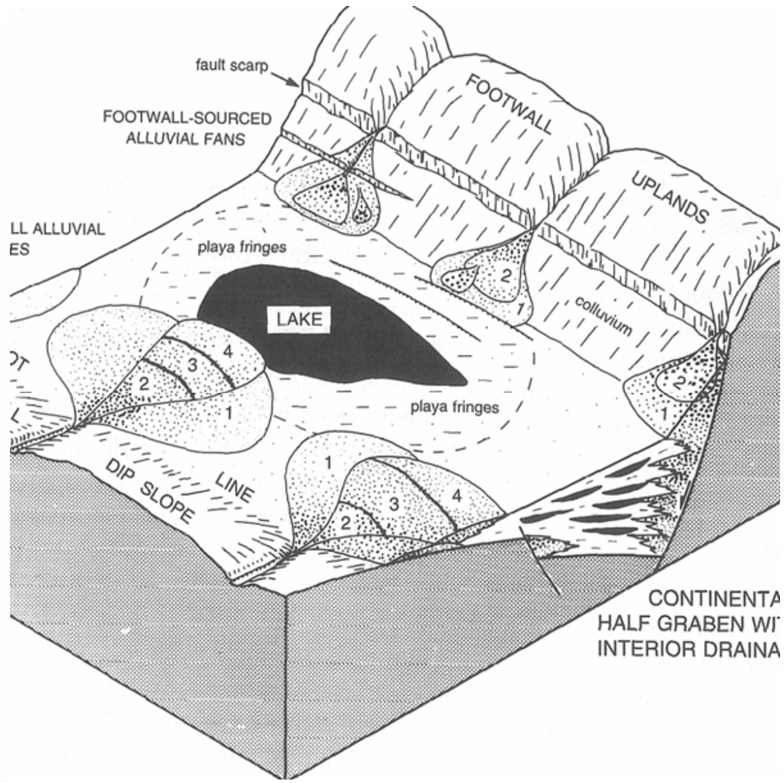
0 1 2 3 4 5 KILOMETERS
0 1 2 3 4 5 MILES
Scale 1:100,000
BIG CHINO VALLEY
NATIONAL
FOREST
BOUNDARY
Paulden
Upper Verde River Springs
Rte 89A
Corral
Well
Sullivan Lake
0
100
200
300
400

Open and Closed Basin Drainage Models



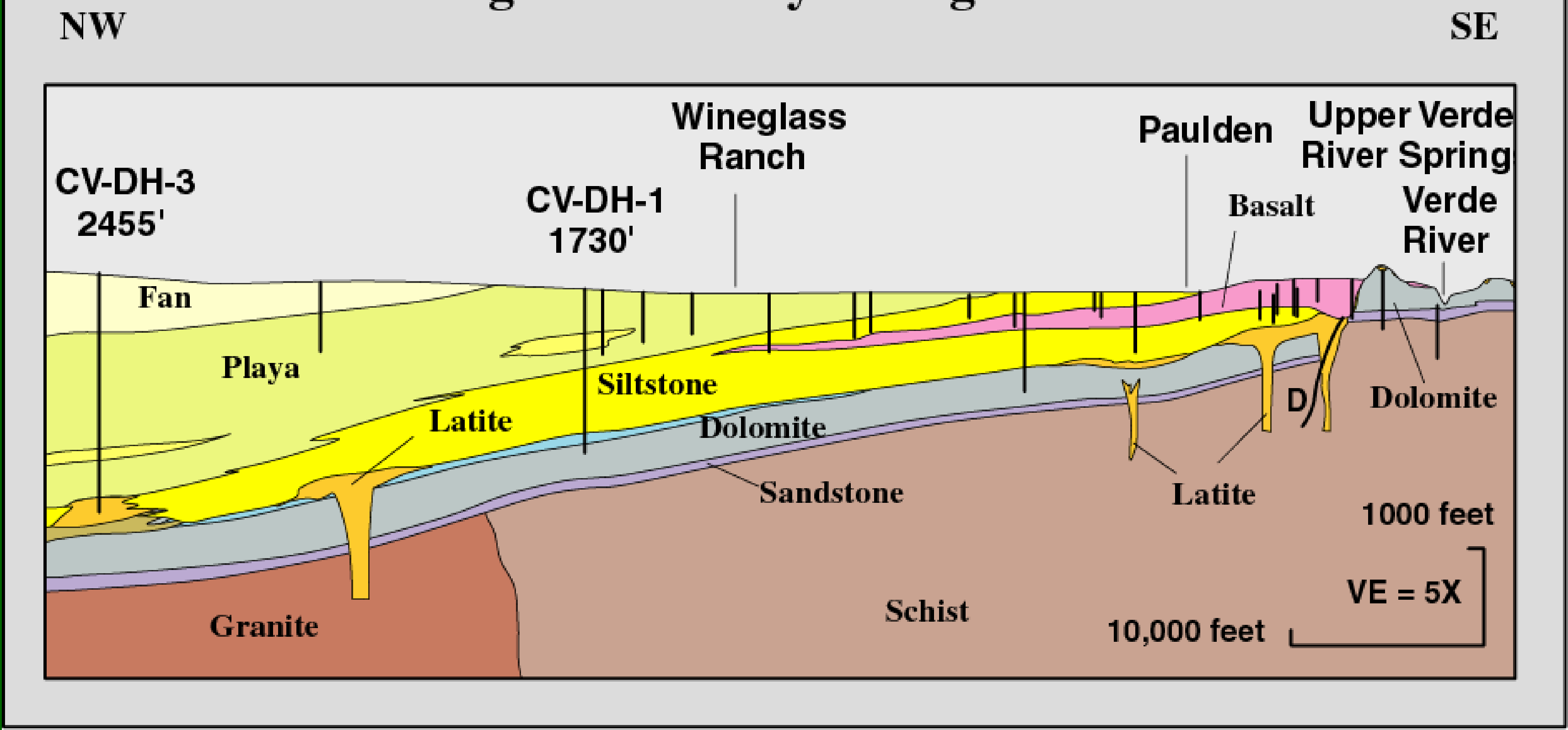
Axial drainage



Closed Basin with Playa
(Leeder and Gawthorpe, 1987)

USGS

Big Chino Valley - Long Section



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Langenheim, others—Geophysical Framework Based on Analysis of Aeromagnetic and Gravity Data—U.S. Geological Survey Scientific Investigations Report 2005–5278

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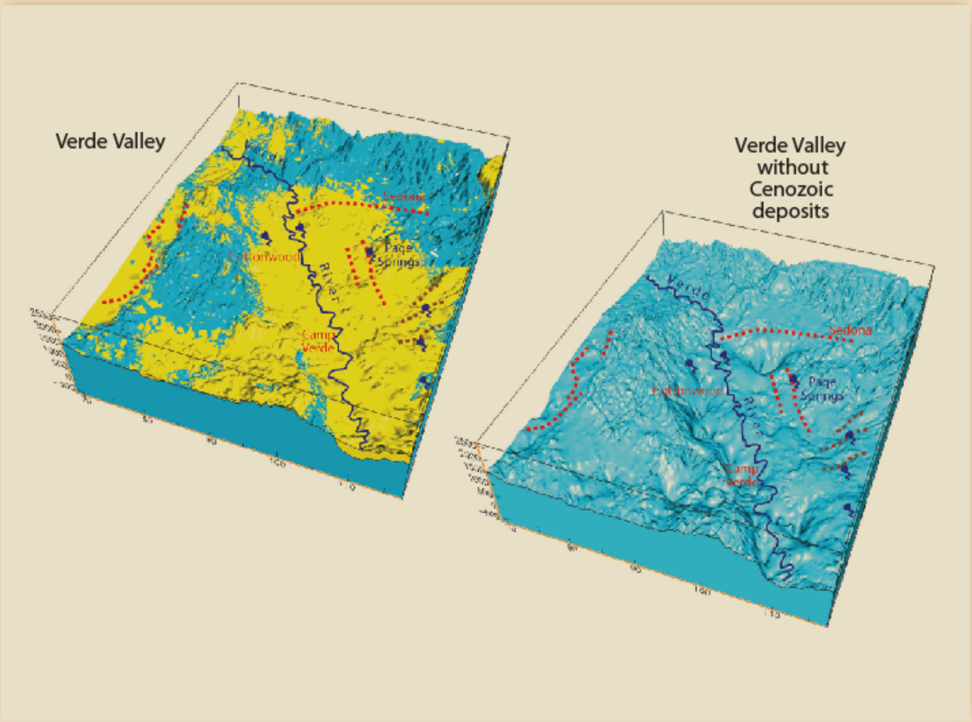
Geophysical Framework Based on Analysis of Aeromagnetic and Gravity Data, Upper and Middle Verde River Watershed, Yavapai County, Arizona



Scientific Investigations Report 2005–5278

U.S. Department of the Interior
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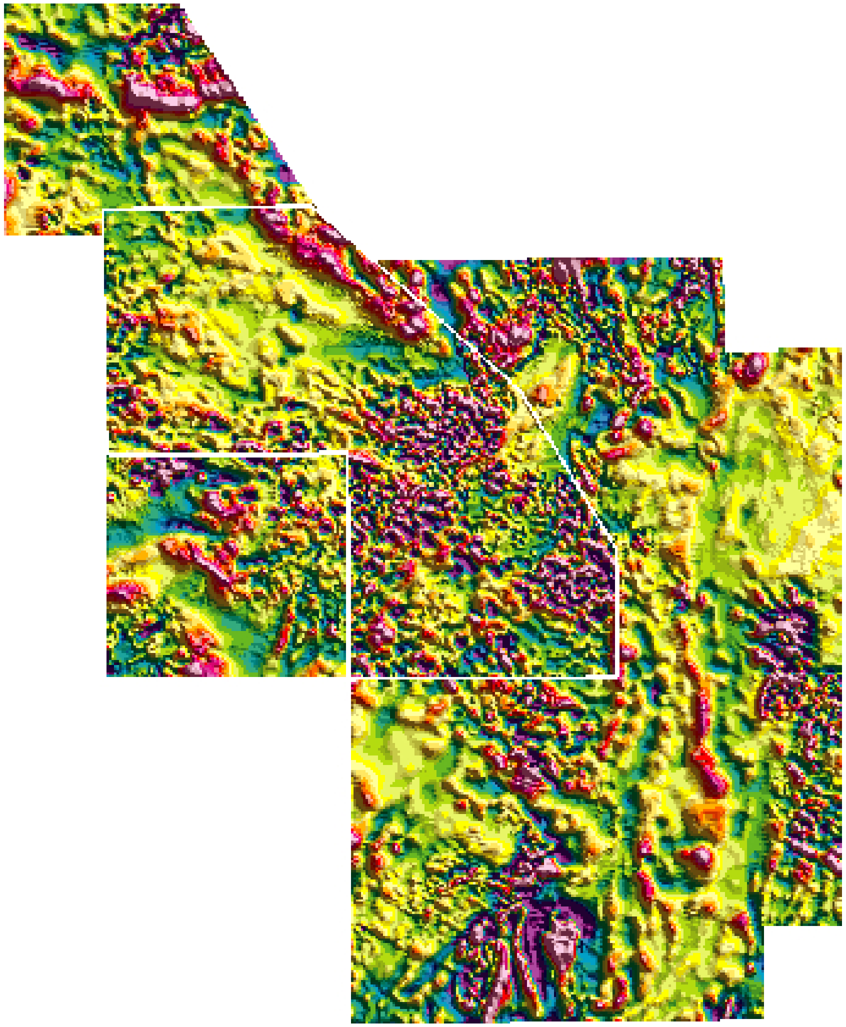
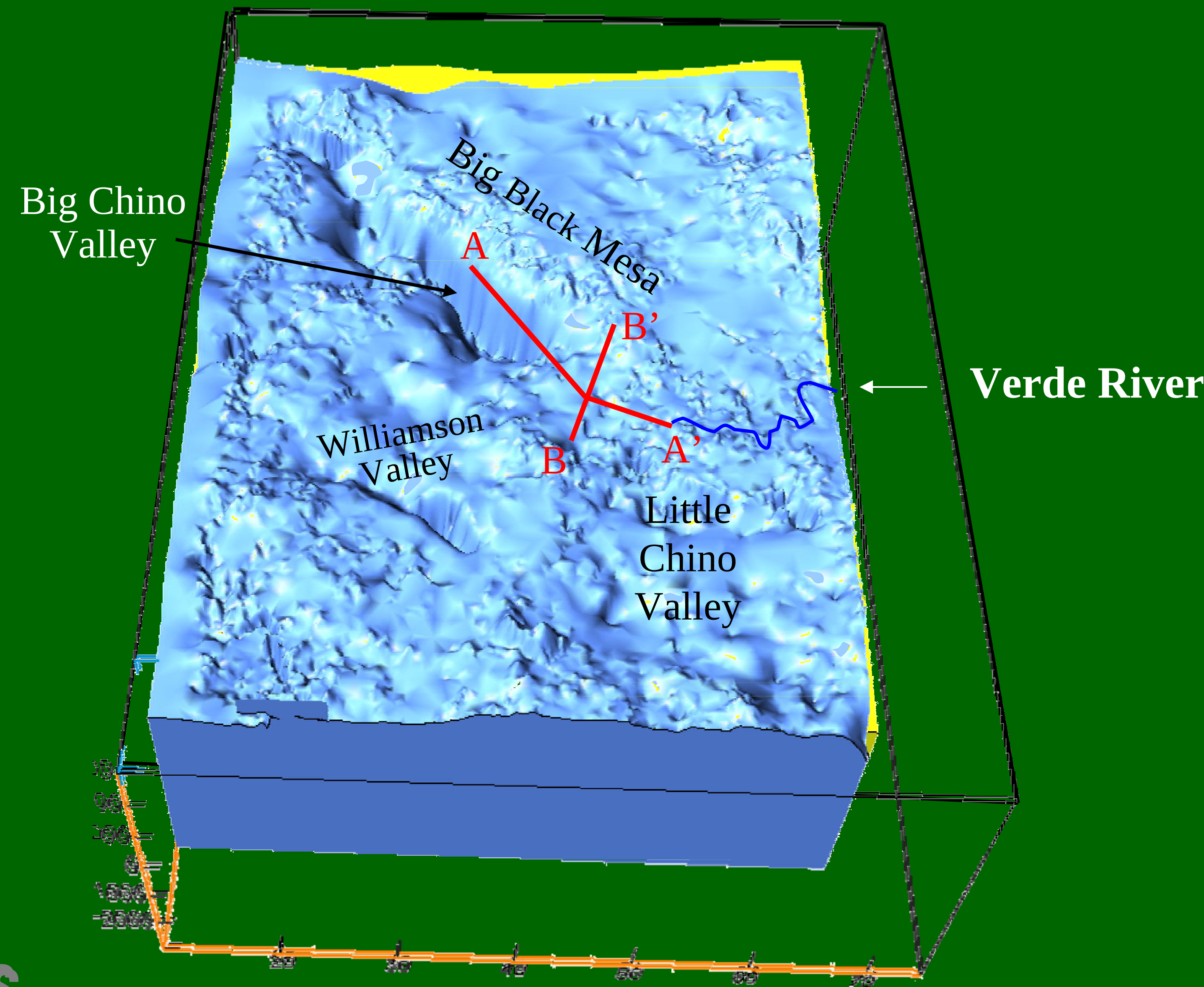
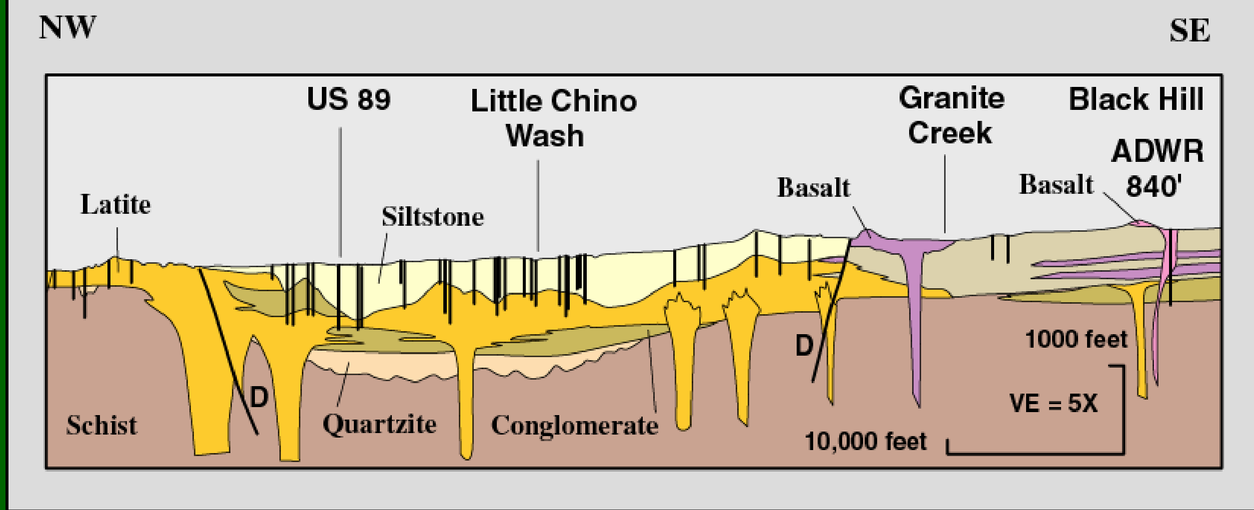
Aeromagnetic Map



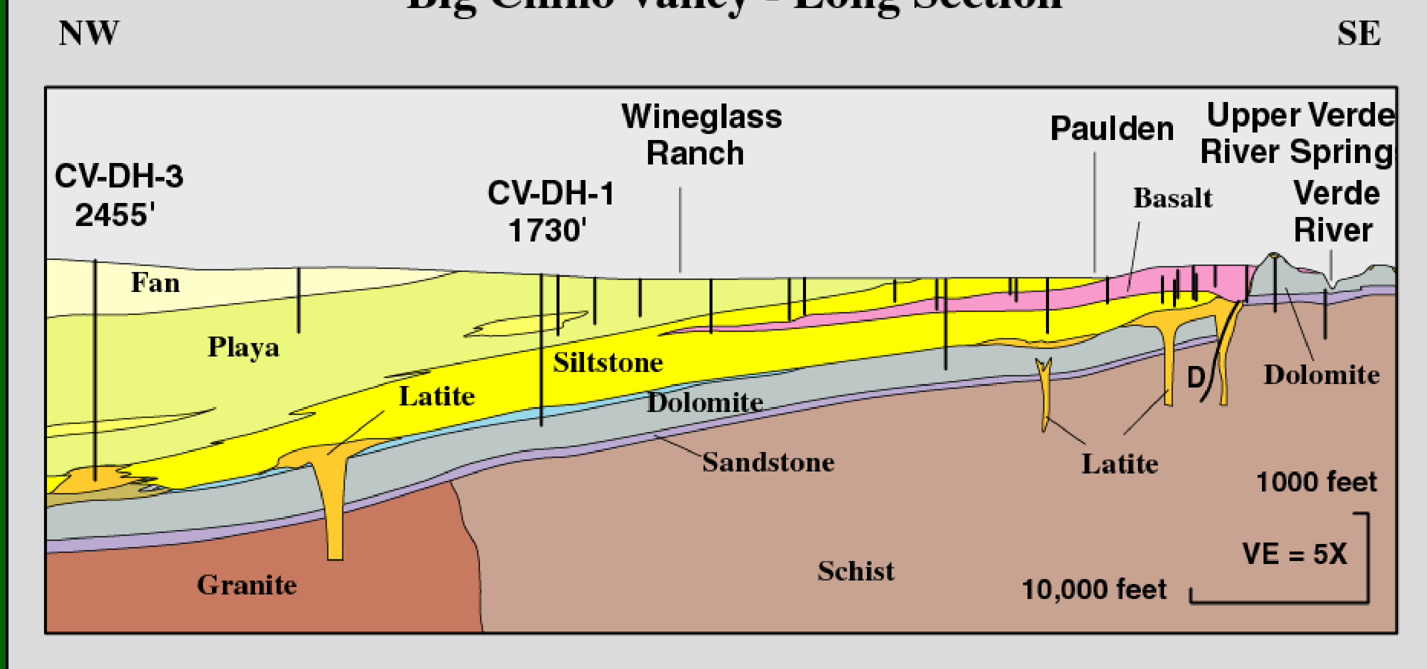
BASIN THICKNESS FROM GRAVITY DATA

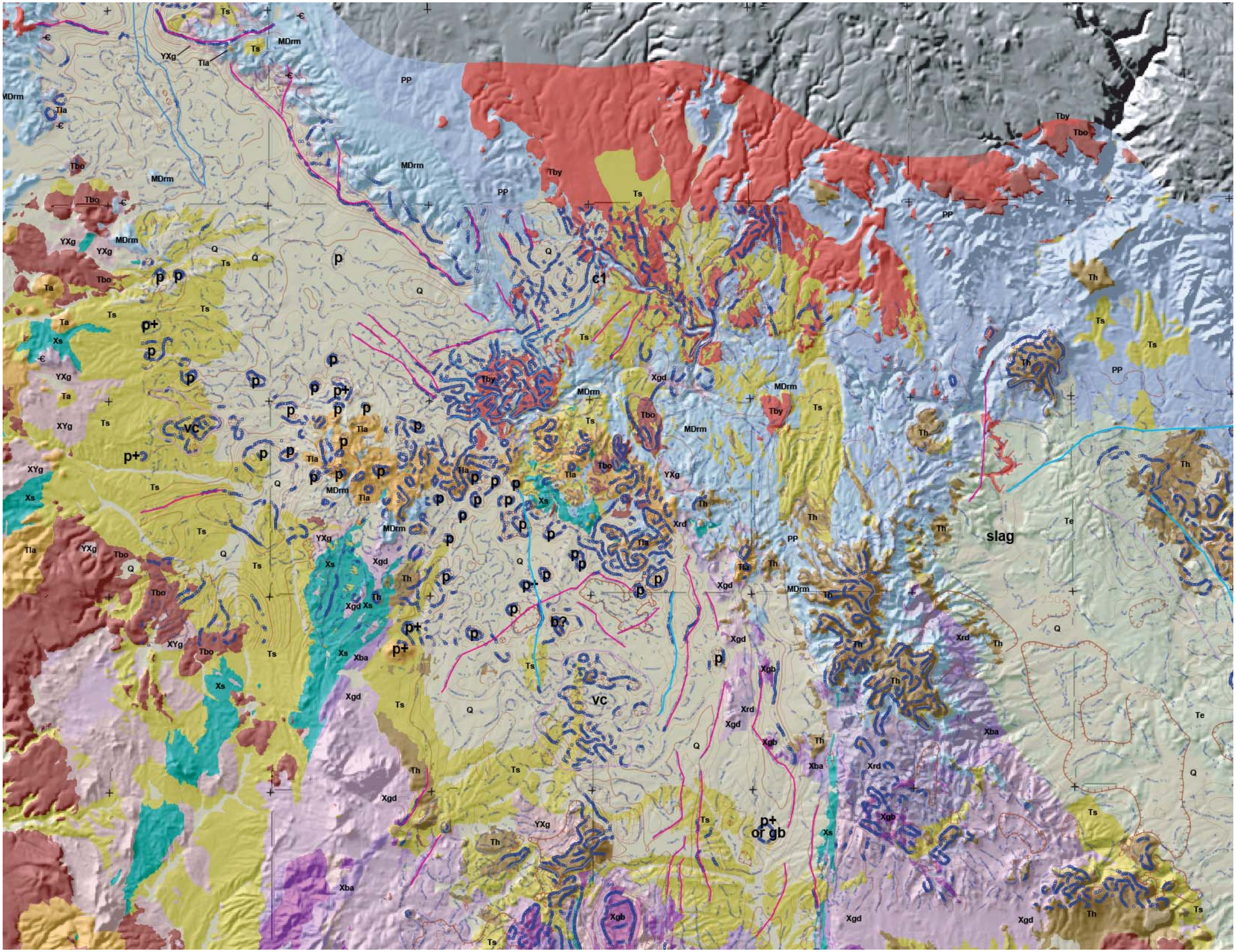


Little Chino Valley - Long Section



Big Chino Valley - Long Section





Ts
MDrm
YXg
Tla
PP
Tbo
Tby
Q
p
c1
Ta
Xs
p+
Xgd
vc
MDrm
Th
Te
slag
Xrd
b?
Xba
Xgb
p+
or gb

Major Findings of the Geology & Geophysics Investigations:

- Improved understanding of basin depth, geometry, and structural features
- Improved understanding of the nature of the playa deposits (“clay plug”) in BCV
- Improved understanding of the occurrence and location of buried volcanic rocks within and adjacent to the basin-fill aquifers, particularly near the GW outlets

Multiple Lines of Evidence:

A. Summarize environmental setting, predevelopment conditions, and previous studies
B. Geologic Framework
C. Geophysical Framework
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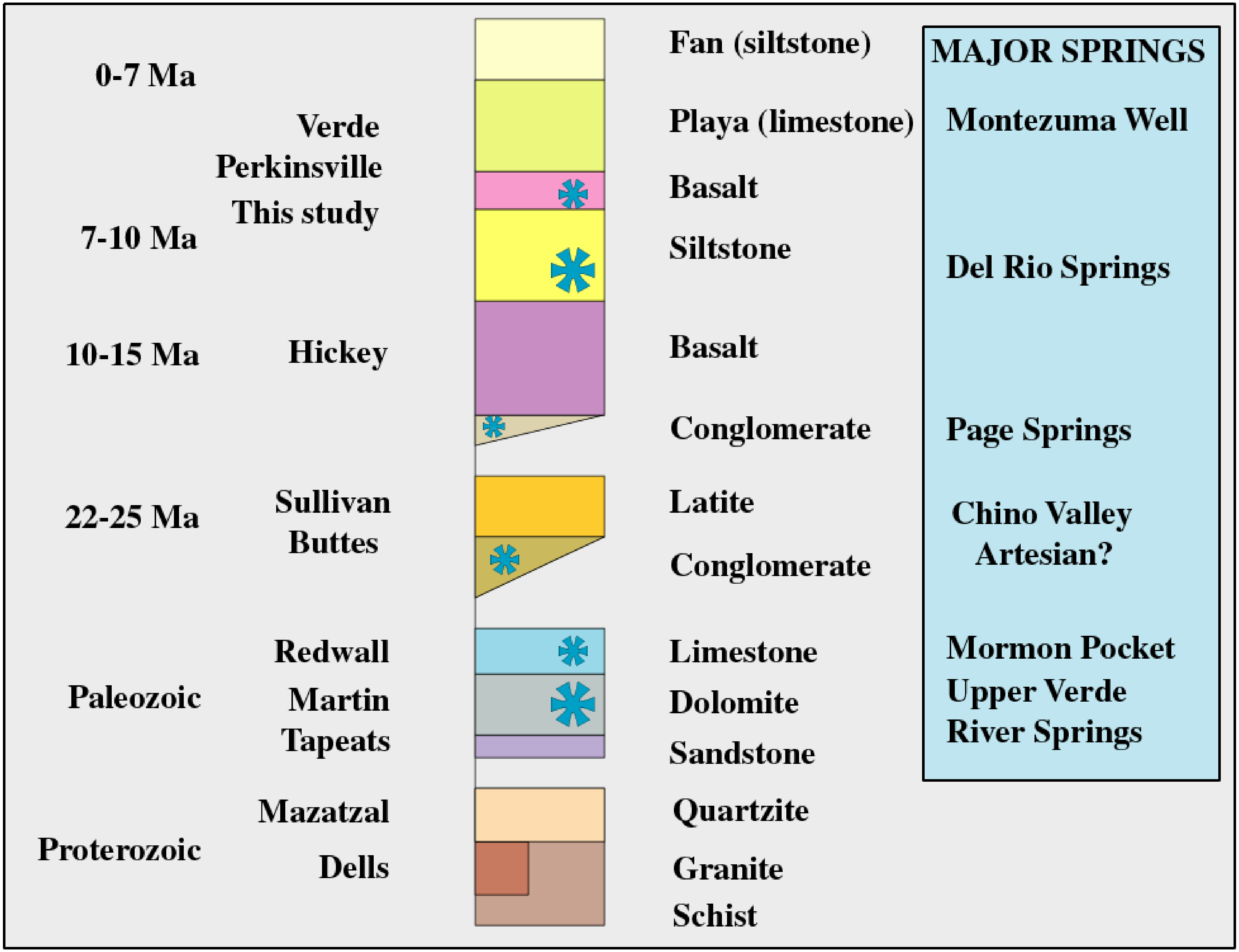
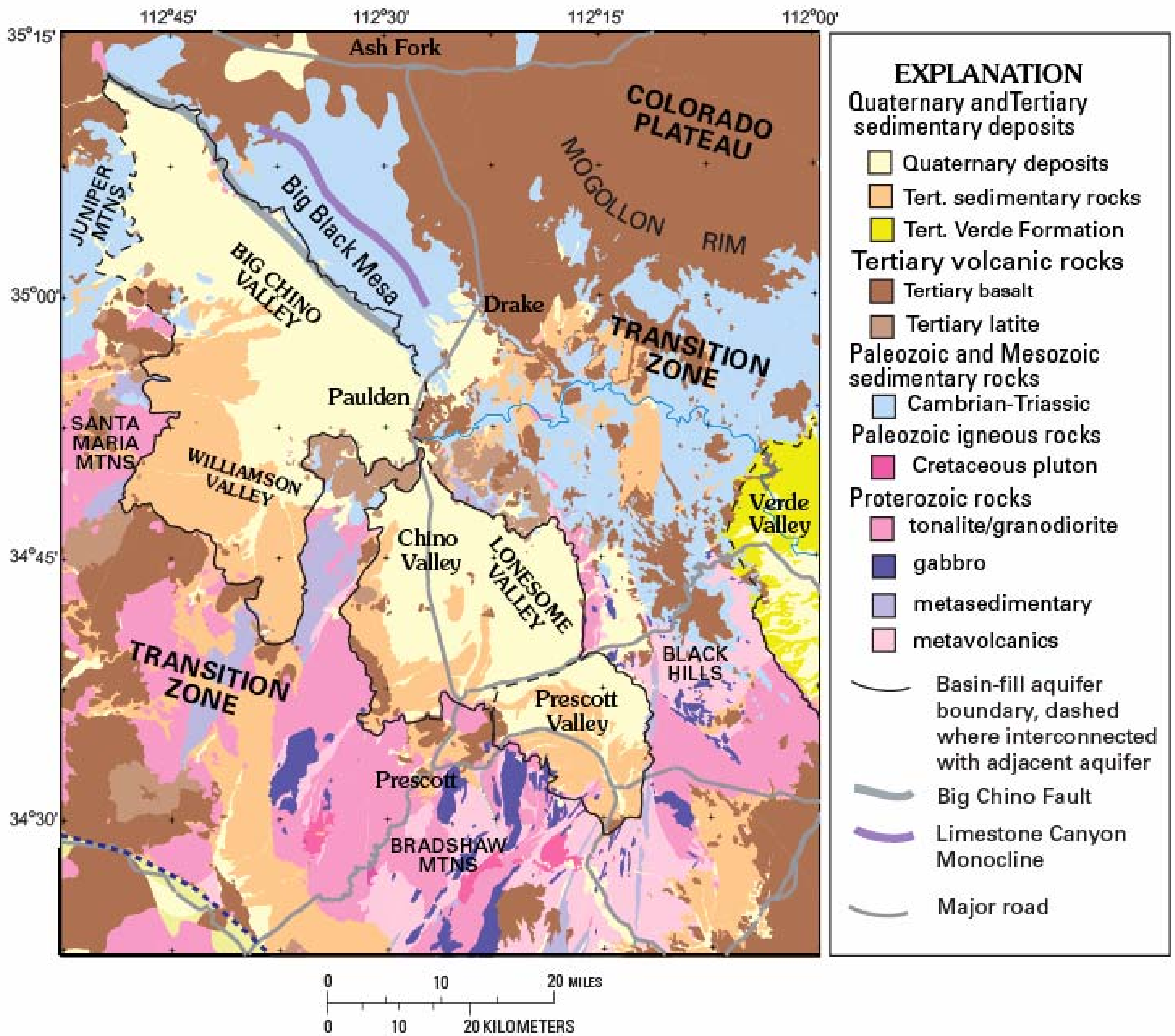


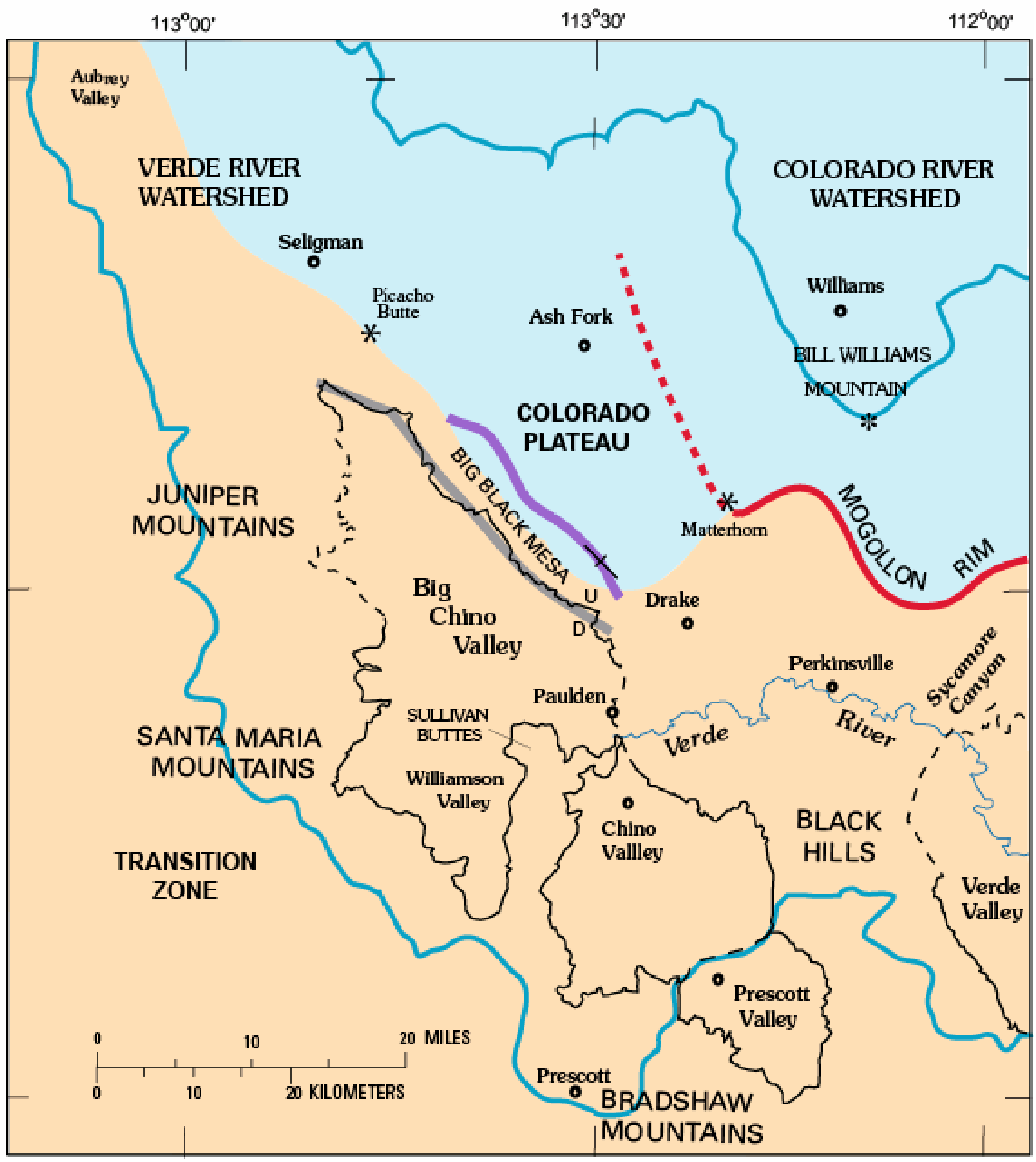
0-7 Ma
Verde
Perkinsville
This study
7-10 Ma
10-15 Ma
Hickey
22-25 Ma
Sullivan
Buttes
Paleozoic
Redwall
Martin
Tapeats
Proterozoic
Mazatzal
Dells
Fan (siltstone)
Playa (limestone)
Basalt
Siltstone
Basalt
Conglomerate
Latite
Conglomerate
Limestone
Dolomite
Sandstone
Quartzite
Granite
Schist
MAJOR SPRINGS
Montezuma Well
Del Rio Springs
Page Springs
Chino Valley
Artesian?
Mormon Pocket
Upper Verde
River Springs

USGS



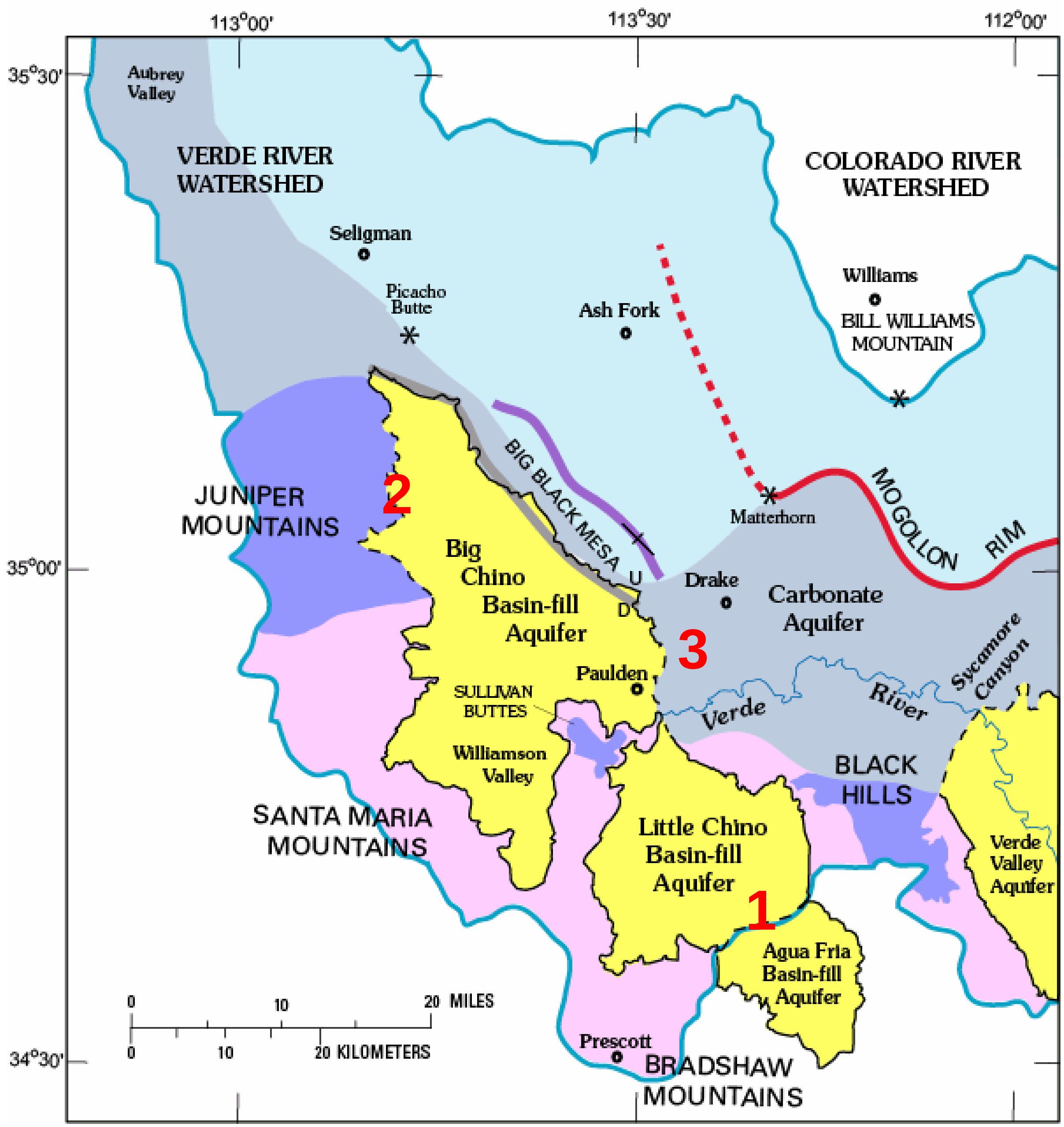
112°45'
112°30'
112°15'
112°00'
35°15'
35°00'
34°45'
34°30'
Ash Fork
COLORADO PLATEAU
MOGOLLON RIM
JUNIPER MTNS
Big Black Mesa
BIG CHINO VALLEY
Drake
TRANSITION ZONE
Paulden
SANTA MARIA MTNS
WILLIAMSON VALLEY
Chino Valley
LONESOME VALLEY
Verde Valley
TRANSITION ZONE
BLACK HILLS
Prescott Valley
Prescott
BRADSHAW MTNS
EXPLANATION
Quaternary and Tertiary sedimentary deposits
Quaternary deposits
Tert. sedimentary rocks
Tert. Verde Formation
Tertiary volcanic rocks
Tertiary basalt
Tertiary latite
Paleozoic and Mesozoic sedimentary rocks
Cambrian-Triassic
Paleozoic igneous rocks
Cretaceous pluton
Proterozoic rocks
tonalite/granodiorite
gabbro
metasedimentary
metavolcanics
Basin-fill aquifer boundary, dashed where interconnected with adjacent aquifer
Big Chino Fault
Limestone Canyon Monocline
Major road
0 10 20 MILES
0 10 20 KILOMETERS

USGS

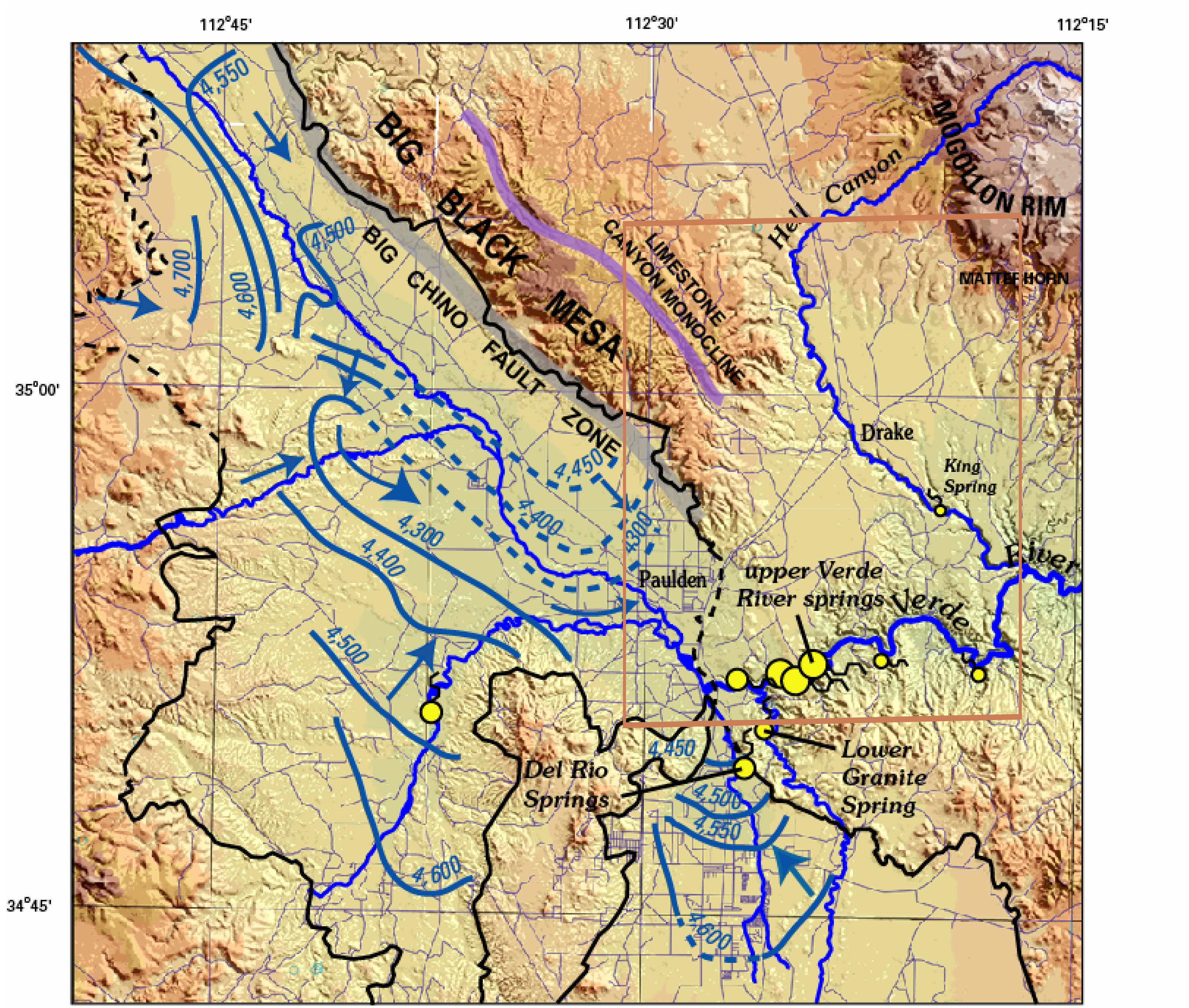


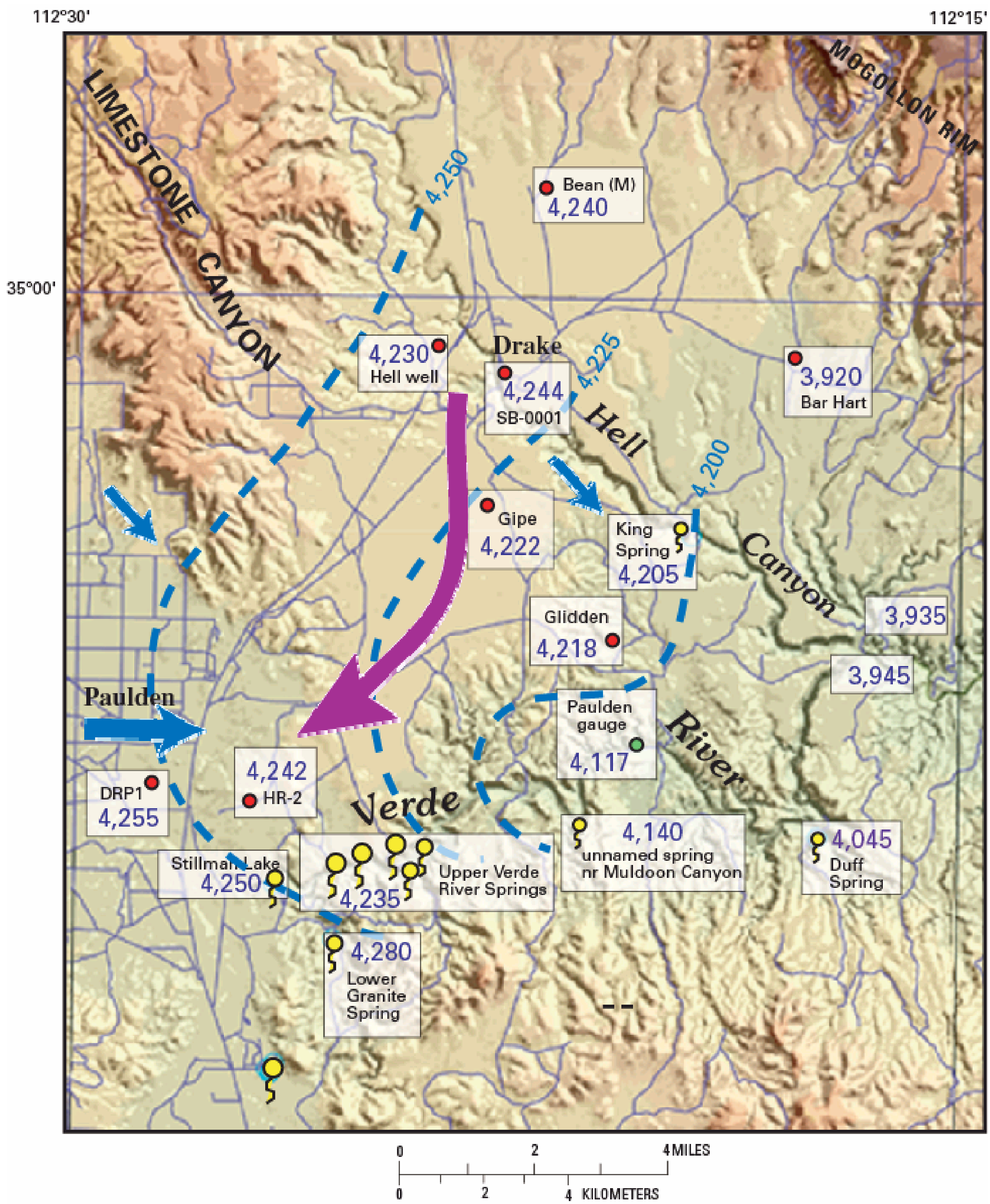
113°00'
113°30'
112°00'
35°30'
35°00'
34°30'
Aubrey Valley
VERDE RIVER WATERSHED
COLORADO RIVER WATERSHED
Seligman
Picacho Butte
Ash Fork
Williams
BILL WILLIAMS MOUNTAIN
COLORADO PLATEAU
BIG BLACK MESA
Matterhorn
MOGOLLON RIM
JUNIPER MOUNTAINS
Big Chino Valley
U
D
Drake
Perkinsville
Sycamore Canyon
Paulden
SULLIVAN BUTTES
Verde River
SANTA MARIA MOUNTAINS
Williamson Valley
Chino Vallley
BLACK HILLS
TRANSITION ZONE
Verde Valley
Prescott Valley
Prescott
BRADSHAW MOUNTAINS
0 10 20 MILES
0 10 20 KILOMETERS

USGS



113°00'
113°30'
112°00'
35°30'
35°00'
34°30'
Aubrey Valley
VERDE RIVER WATERSHED
COLORADO RIVER WATERSHED
Seligman
Picacho Butte
Ash Fork
Williams
BILL WILLIAMS MOUNTAIN
JUNIPER MOUNTAINS
BIG BLACK MESA
U
D
Matterhorn
MOGOLLON RIM
Drake
Carbonate Aquifer
Big Chino Basin-fill Aquifer
Paulden
SULLIVAN BUTTES
Williamson Valley
Verde River
Sycamore Canyon
BLACK HILLS
SANTA MARIA MOUNTAINS
Little Chino Basin-fill Aquifer
Verde Valley Aquifer
Agua Fria Basin-fill Aquifer
Prescott
BRADSHAW MOUNTAINS
0 10 20 MILES
0 10 20 KILOMETERS
1
2
3


112°45'
112°30'
112°15'
35°00'
34°45'
BIG BLACK MESA
BIG CHINO FAULT ZONE
LIMESTONE CANYON MONOCLINE
Hell Canyon
MOGOLLON RIM
MATTERHORN
Drake
King Spring
Paulden
upper Verde River springs
Verde River
Del Rio Springs
Lower Granite Spring
4,550
4,500
4,700
4,600
4,450
4,400
4,300
4,600



112°30'
112°15'
35°00'
LIMESTONE CANYON
MOGOLLON RIM
4,250
Bean (M)
4,240
4,230
Hell well
Drake
4,244
SB-0001
4,225
3,920
Bar Hart
Hell
4,200
Gipe
4,222
King Spring
4,205
Canyon
Glidden
4,218
3,935
3,945
Paulden
Paulden gauge
4,117
River
4,242
HR-2
DRP1
4,255
Verde
Stillman Lake
4,250
4,235
Upper Verde River Springs
4,140
unnamed spring nr Muldoon Canyon
4,045
Duff Spring
4,280
Lower Granite Spring
0
2
4 MILES
0
2
4 KILOMETERS

USGS

Major Findings of the Hydrogeologic Framework:

- A ground-water divide separates the Colorado Plateau and Transition Zone carbonate aquifer units
- The CP part of the carbonate aquifer contributes little if any recharge to the BC aquifer or to UVR
- Recharge from Big Black Mesa contributes directly to BCBF aquifer or enters along BC basin-outlet flowpath

USGS

Multiple Lines of Evidence:

A. Summarize environmental setting, predevelopment conditions, and previous studies
B. Geologic Framework
C. Geophysical Framework
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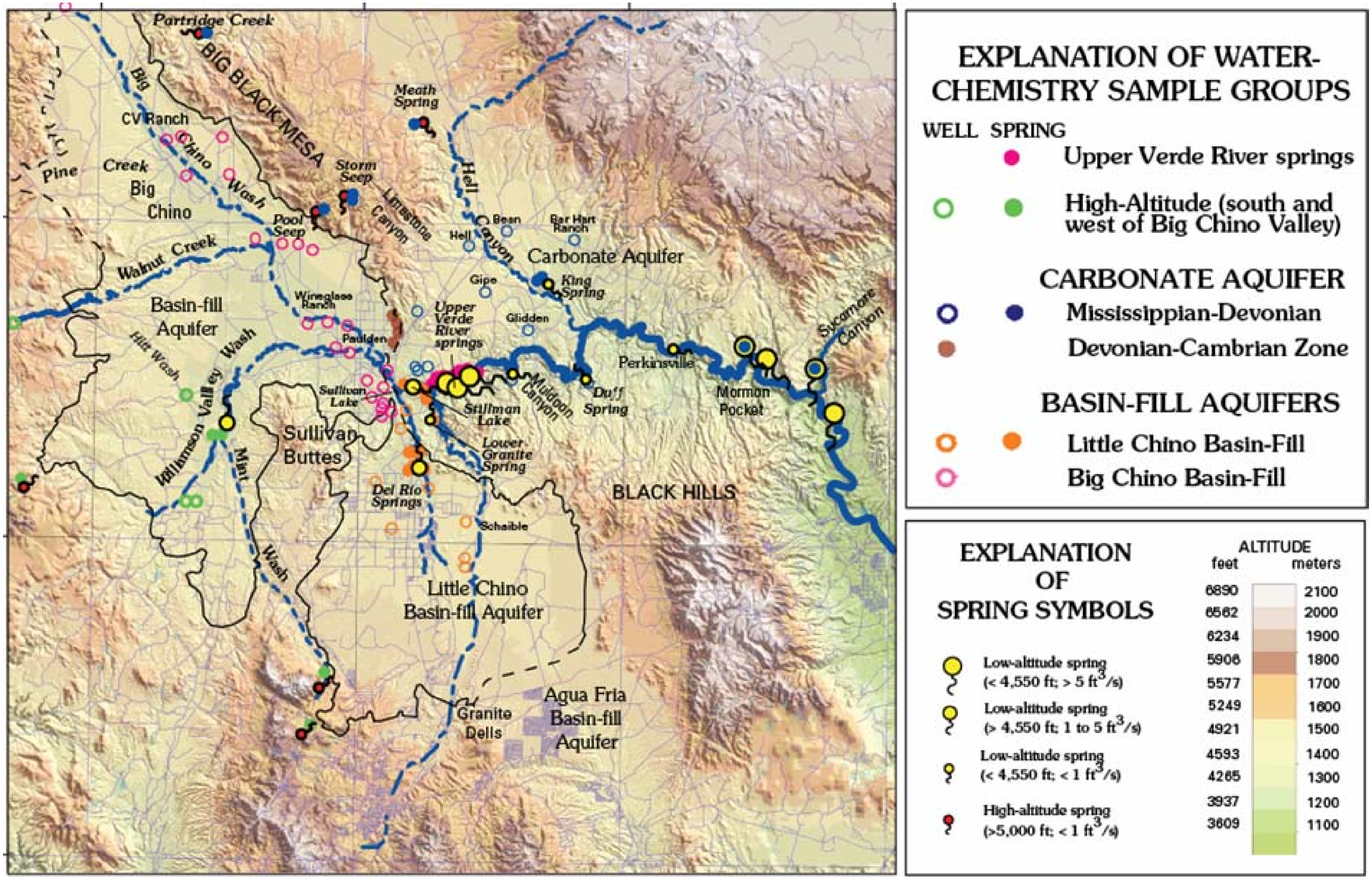
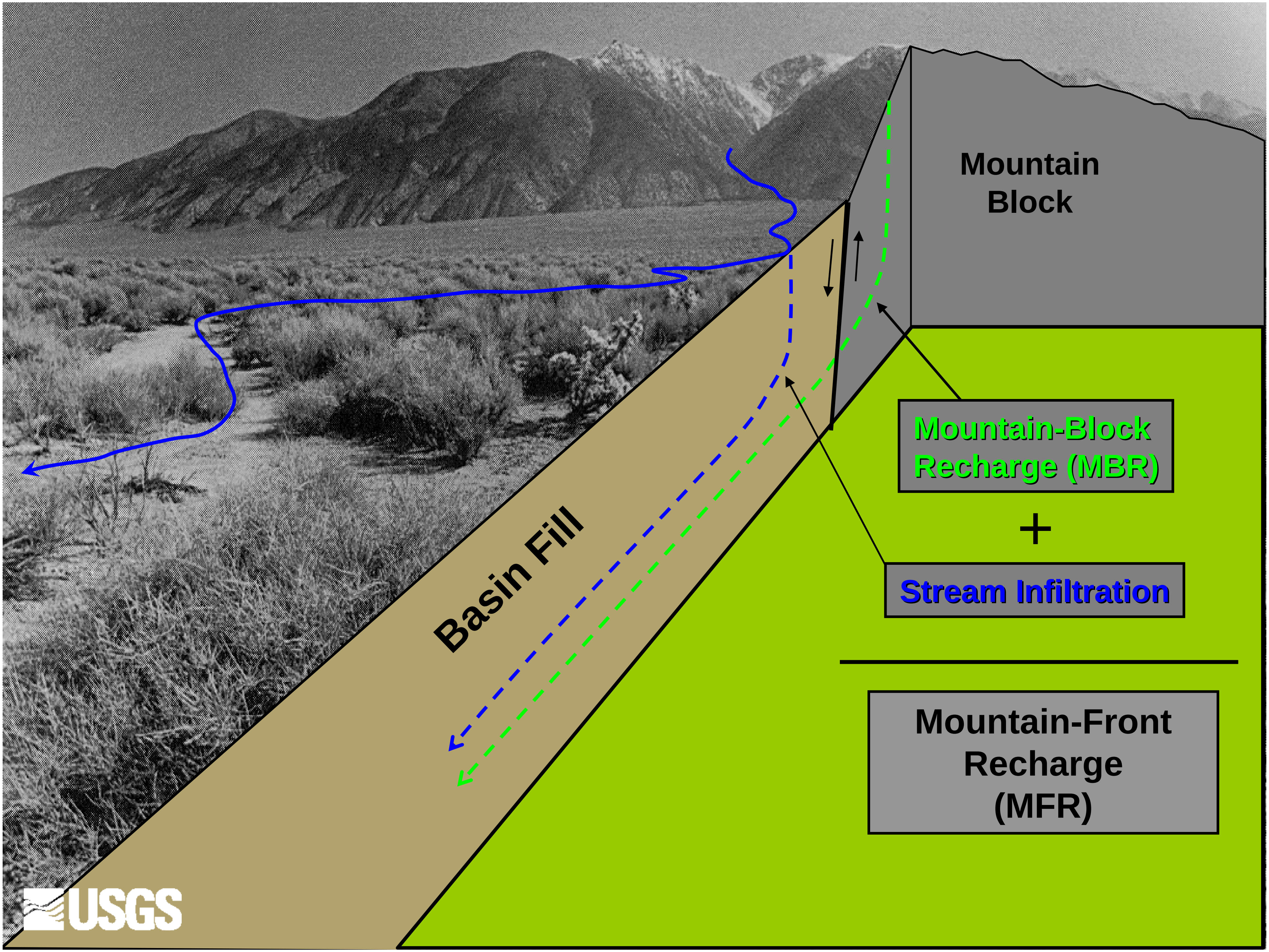
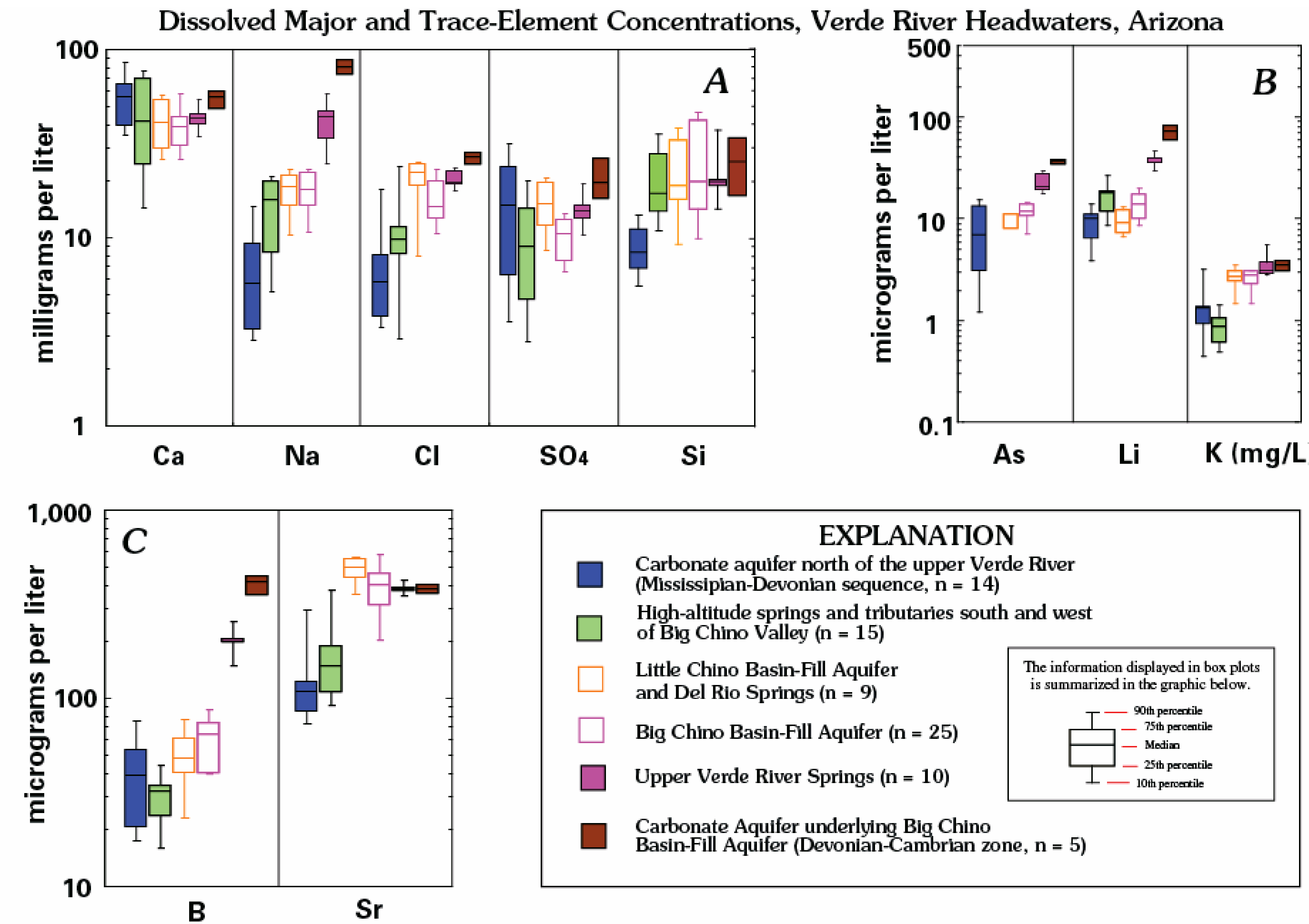
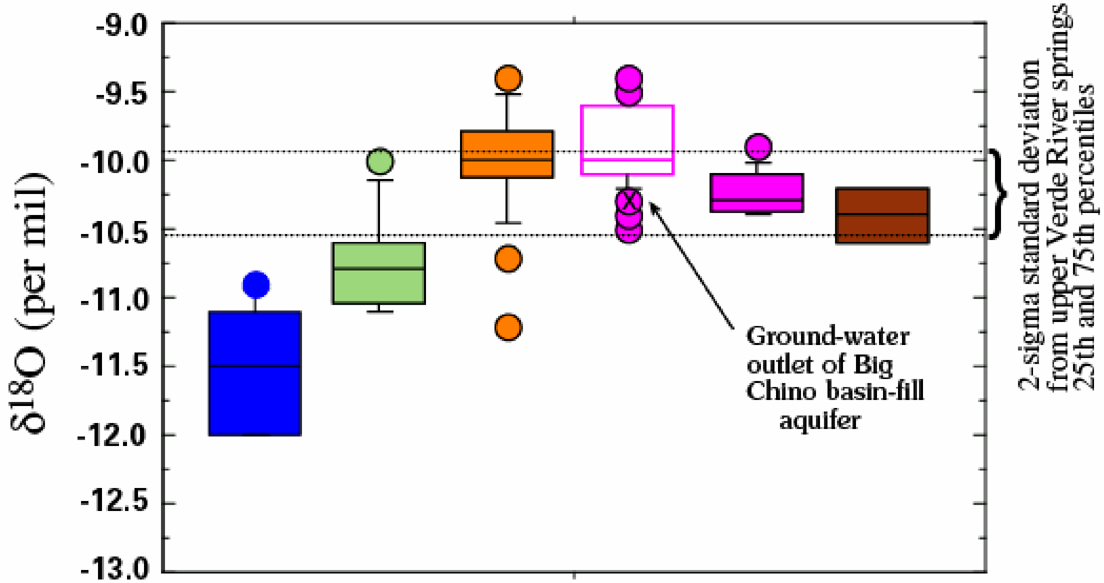

EXPLANATION OF WATER-CHEMISTRY SAMPLE GROUPS
WELL SPRING
Upper Verde River springs
High-Altitude (south and west of Big Chino Valley)
CARBONATE AQUIFER
Mississippian-Devonian
Devonian-Cambrian Zone
BASIN-FILL AQUIFERS
Little Chino Basin-Fill
Big Chino Basin-Fill
EXPLANATION OF SPRING SYMBOLS
Low-altitude spring (< 4,550 ft; > 5 ft³/s)
Low-altitude spring (> 4,550 ft; 1 to 5 ft³/s)
Low-altitude spring (< 4,550 ft; < 1 ft³/s)
High-altitude spring (>5,000 ft; < 1 ft³/s)
ALTITUDE
feet meters
6890 2100
6562 2000
6234 1900
5906 1800
5577 1700
5249 1600
4921 1500
4593 1400
4265 1300
3937 1200
3609 1100
Partridge Creek
BIG BLACK MESA
Big Chino Wash
CV Ranch
Pine Creek
Big Chino
Meath Spring
Storm Seep
Limestone Canyon
Hell Canyon
Pool Seep
Walnut Creek
Bean
Bar Hart Ranch
Hell
Carbonate Aquifer
Gipe
King Spring
Basin-fill Aquifer
Wineglass Ranch
Upper Verde River springs
Glidden
Sycamore Canyon
Paulden
Hitt Wash
Williamson Valley Wash
Perkinsville
Sullivan Lake
Stillman Lake
Muldoon Canyon
Duff Spring
Mormon Pocket
Sullivan Buttes
Lower Granite Spring
Mint Wash
Del Rio Springs
BLACK HILLS
Schaible
Little Chino Basin-fill Aquifer
Agua Fria Basin-fill Aquifer
Granite Dells

USGS


Mountain
Block
Basin Fill
Mountain-Block
Recharge (MBR)
+
Stream Infiltration
Mountain-Front
Recharge
(MFR)
USGS


Dissolved Major and Trace-Element Concentrations, Verde River Headwaters, Arizona
A
milligrams per liter
100
10
1
Ca
Na
Cl
SO4
Si
B
micrograms per liter
500
100
10
1
0.1
As
Li
K (mg/L)
C
micrograms per liter
1,000
100
10
B
Sr
EXPLANATION
Carbonate aquifer north of the upper Verde River (Mississipian-Devonian sequence, n = 14)
High-altitude springs and tributaries south and west of Big Chino Valley (n = 15)
Little Chino Basin-Fill Aquifer and Del Rio Springs (n = 9)
Big Chino Basin-Fill Aquifer (n = 25)
Upper Verde River Springs (n = 10)
Carbonate Aquifer underlying Big Chino Basin-Fill Aquifer (Devonian-Cambrian zone, n = 5)
The information displayed in box plots is summarized in the graphic below.
90th percentile
75th percentile
Median
25th percentile
10th percentile

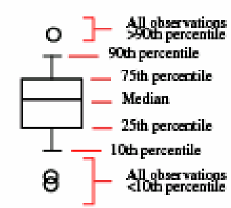
OXYGEN-18/OXYGEN-16 RATIO FOR MAJOR AQUIFERS AND SPRINGS, VERDE HEADWATERS, ARIZONA



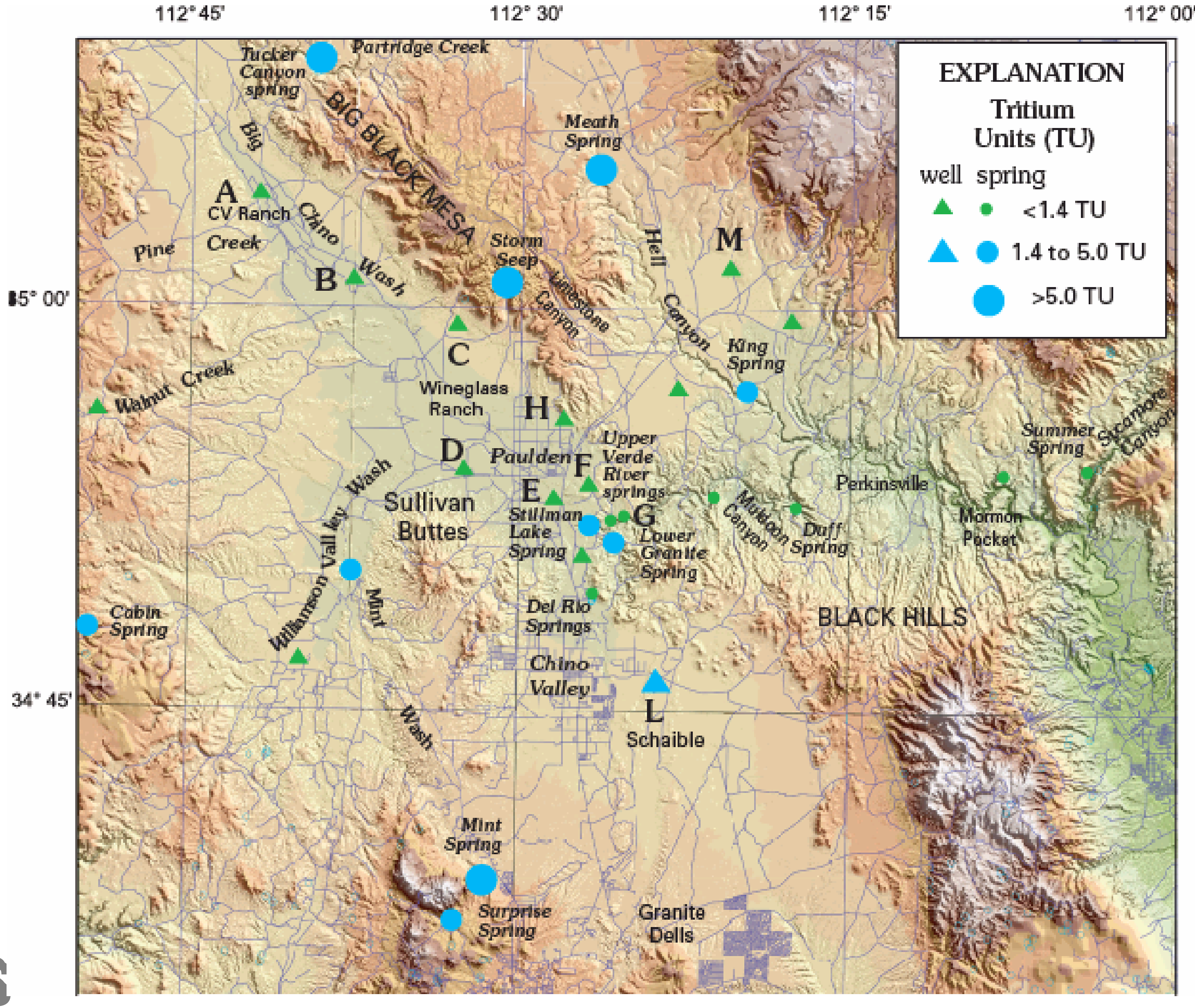
EXPLANATION

- Carbonate aquifer north of the upper Verde River (Mississipian-Devonian sequence, n = 7). King Spring samples interpreted as influenced by evaporation and therefore not included in statistical grouping
- High-altitude springs and tributaries south and west of Big Chino Valley (n = 14)
- Little Chino Basin-Fill Aquifer and Del Rio Springs (n = 22)
- Big Chino Basin-Fill Aquifer (n = 35)
- Paulden well E at B(17-02)04ddc at outlet of Big Chino basin-fill aquifer
- Upper Verde River Springs (n = 11 samples from 6 sites)
- Devonian-Cambrian zone (n = 7 samples from 4 wells)

The information displayed in box plots is summarized in the graphic below.



Tritium (TU)



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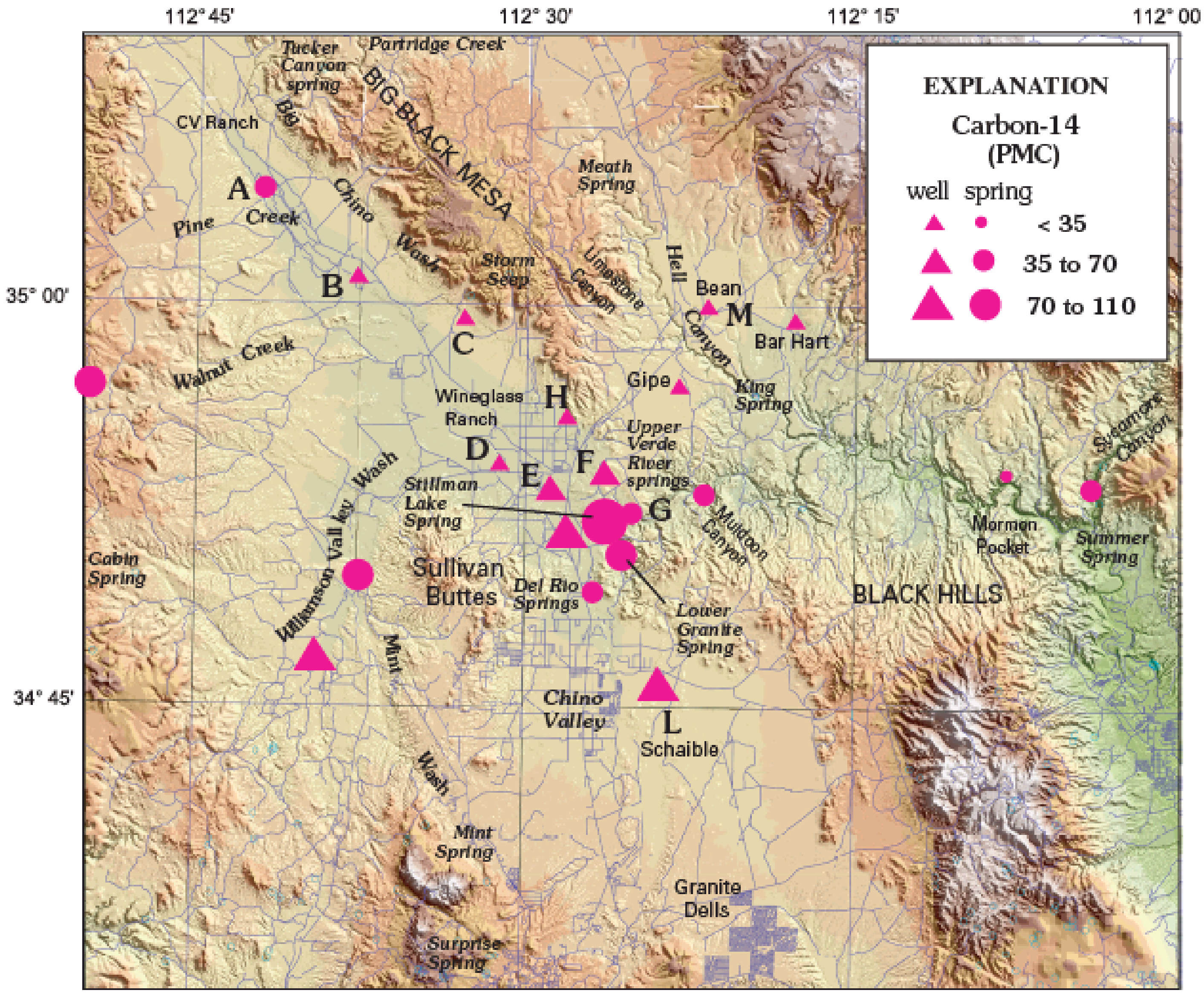
Carbon-14 (PMC)



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Major Findings, Spatial Geochemical Trends:

- Distinctive trends were linked to recharge areas *or* water-rock interactions
  - Higher concentrations of trace elements were found in the carbonate aquifer beneath the BC basin-fill aquifer
  - Higher strontium concentrations were spatially associated with volcanic rocks
- Tritium and C-14 indicate modern recharge has occurred beneath ephemeral streams

Multiple Lines of Evidence:

A. Summarize environmental setting, predevelopment conditions, and previous studies
B. Geologic Framework
C. Geophysical Framework
D. Hydrogeological Framework
E. Geochemical Trends of Aquifers and Springs
F. Tracer Study and Geochemical Model
G. Synthesis

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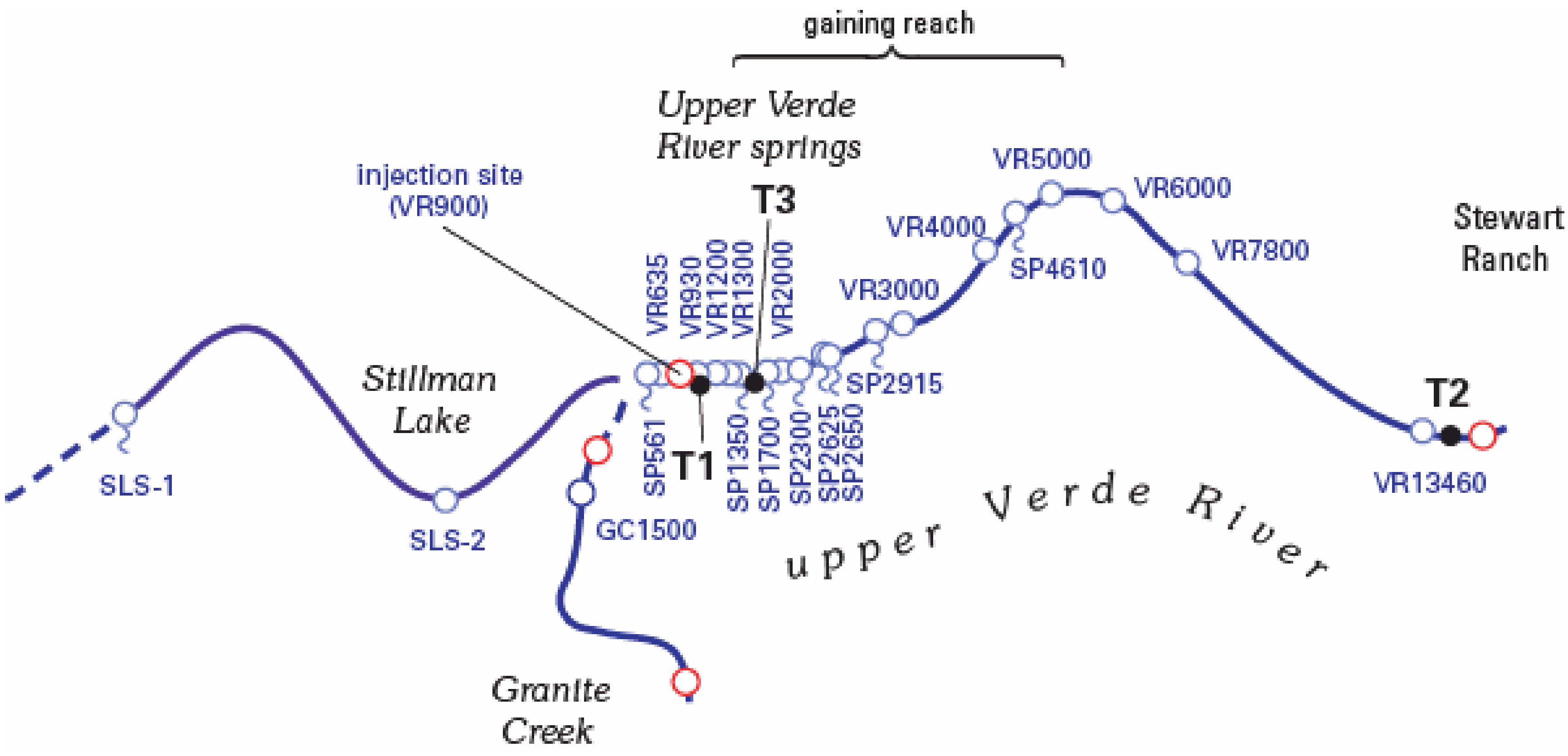
Tracer Dilution Study
Synoptic Sample Locations



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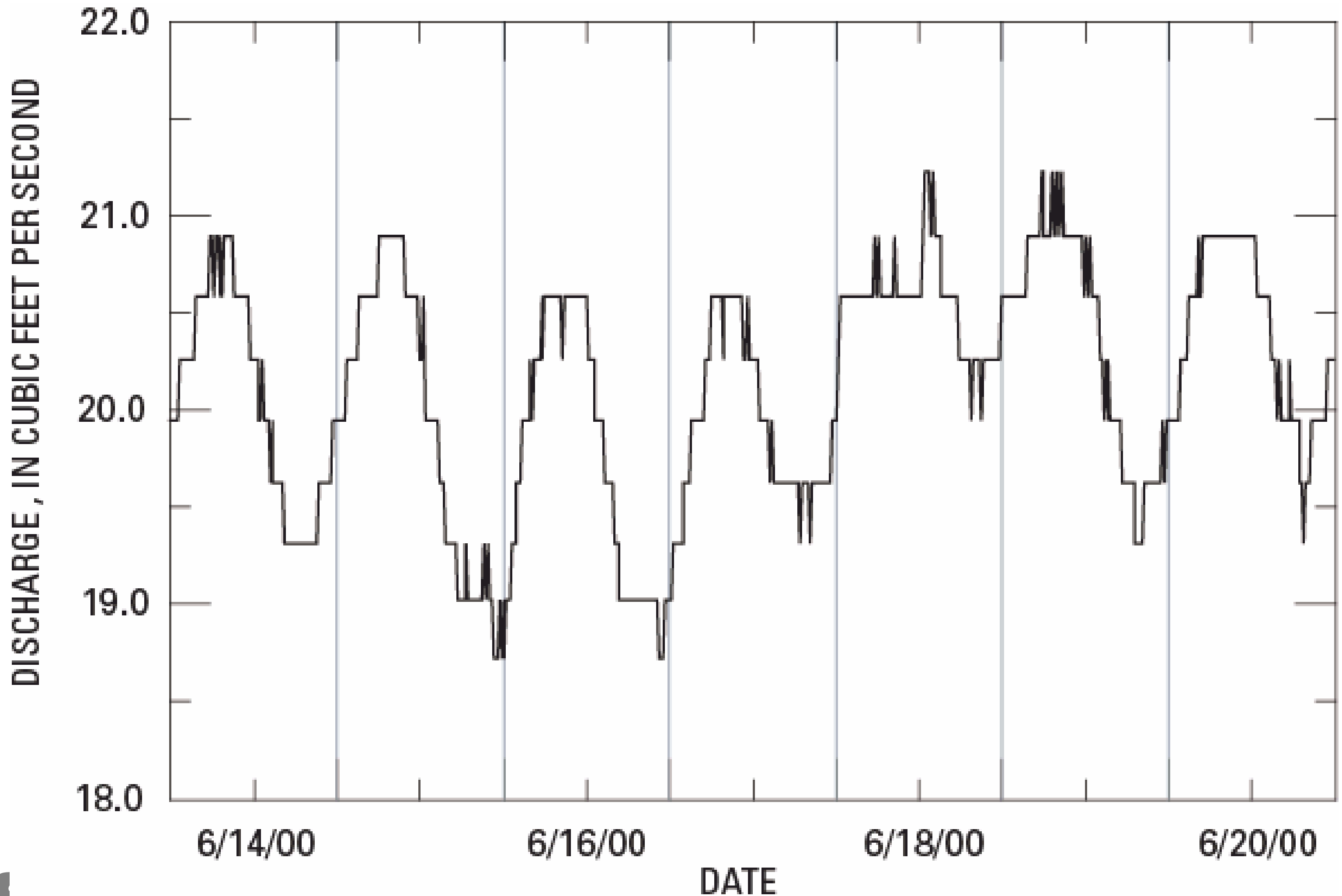
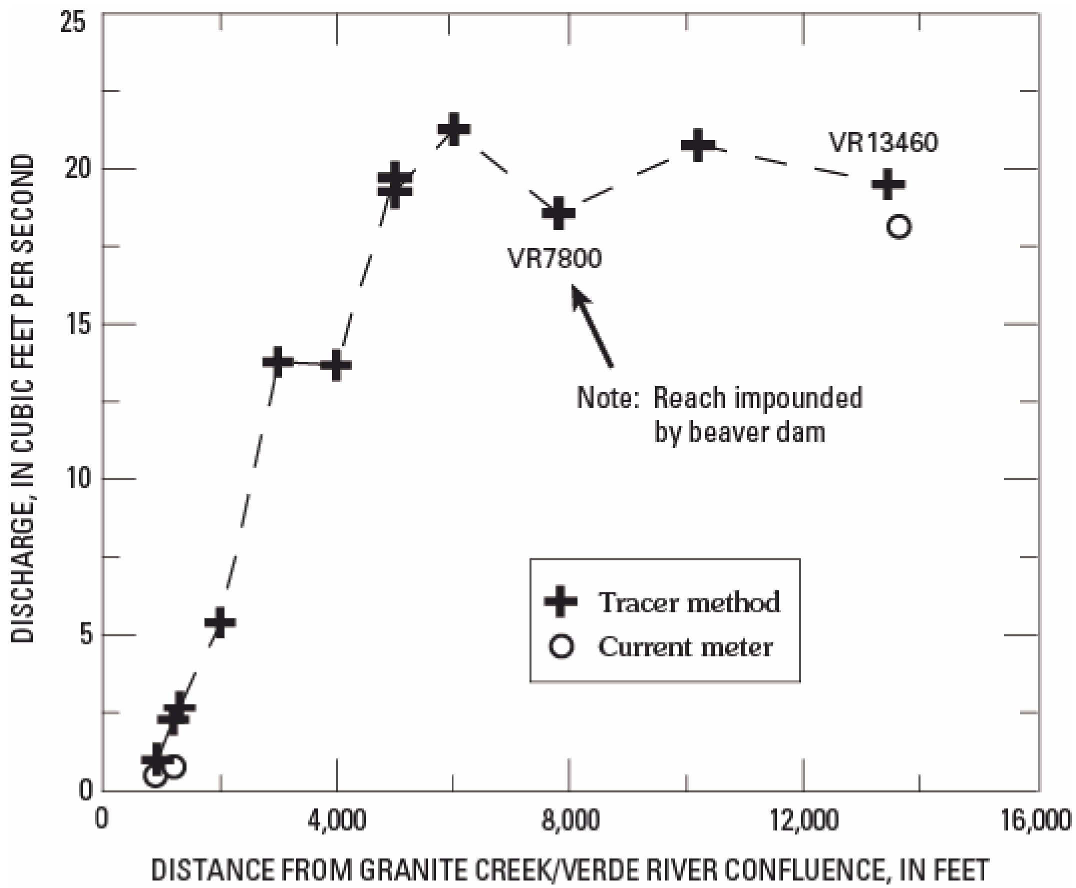
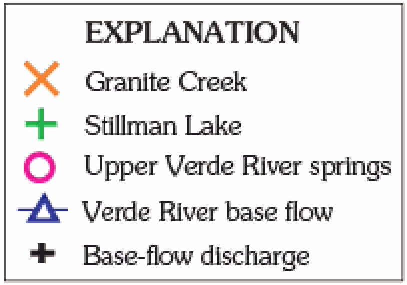
Daily Variation in Baseflow Discharge (June 2000)



Tracer-dilution Calculated Discharge Upper Verde River



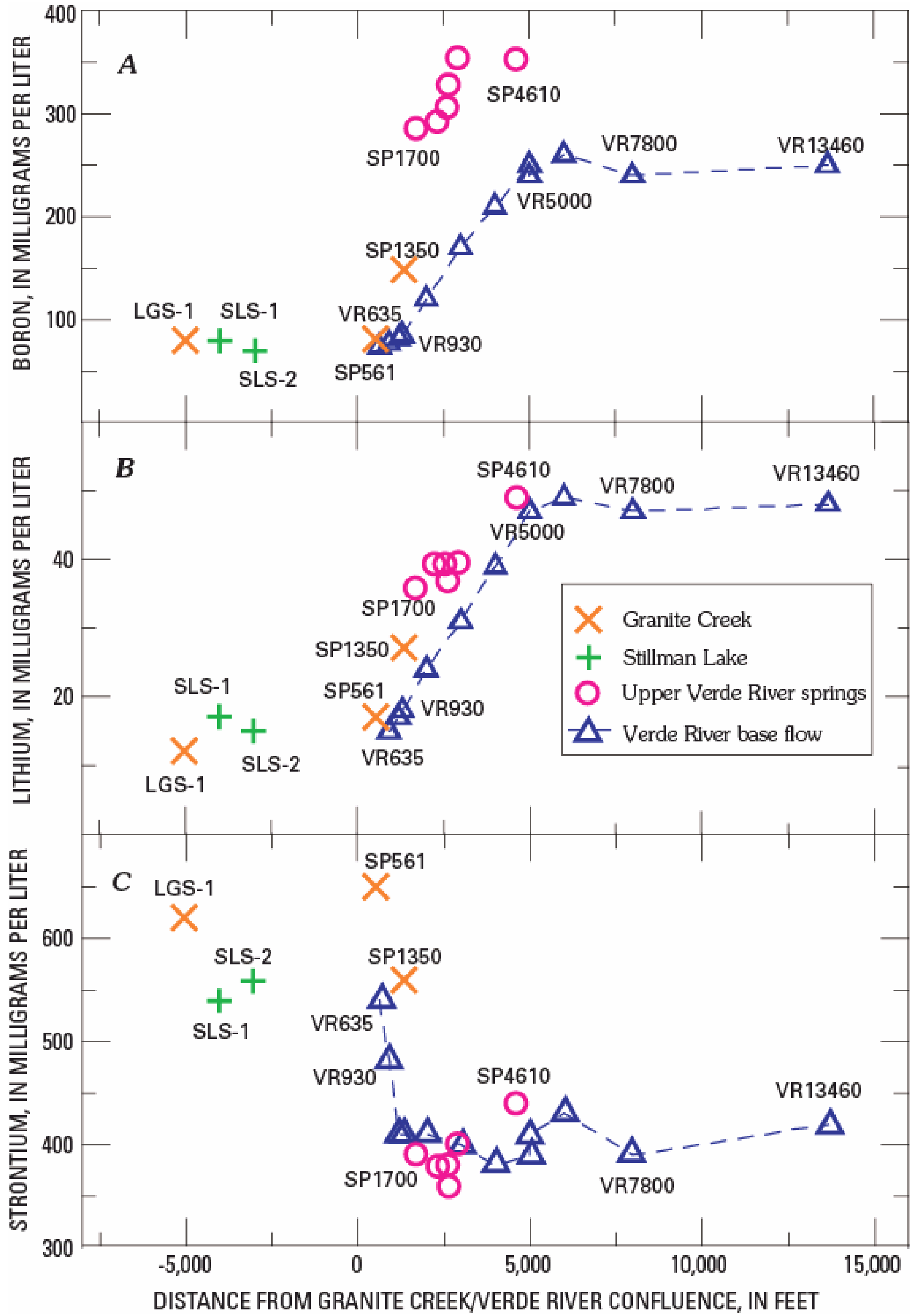
Downstream Trends In Trace Elements

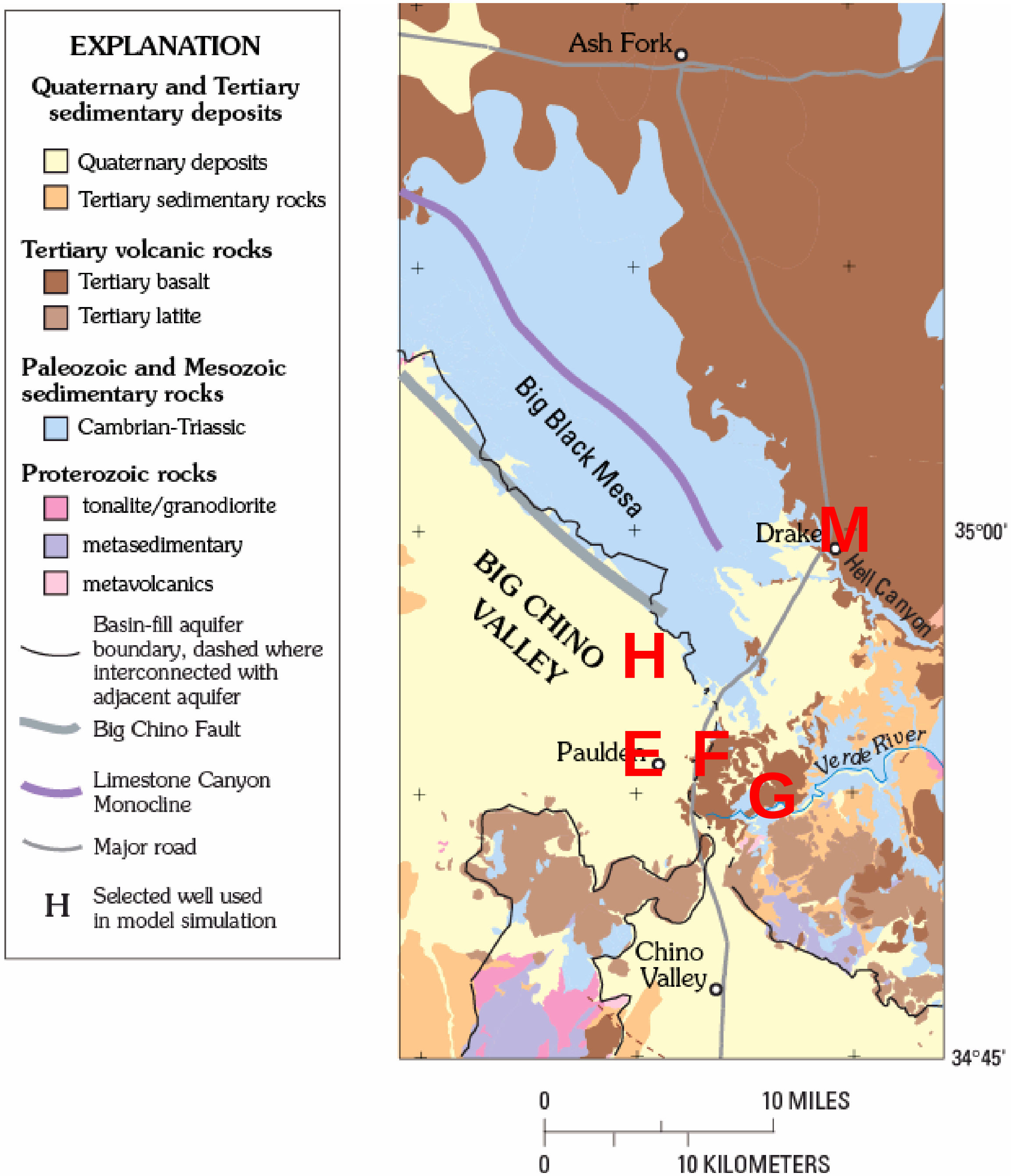


B

Li

Sr




EXPLANATION
Quaternary and Tertiary sedimentary deposits
Quaternary deposits
Tertiary sedimentary rocks
Tertiary volcanic rocks
Tertiary basalt
Tertiary latite
Paleozoic and Mesozoic sedimentary rocks
Cambrian-Triassic
Proterozoic rocks
tonalite/granodiorite
metasedimentary
metavolcanics
Basin-fill aquifer boundary, dashed where interconnected with adjacent aquifer
Big Chino Fault
Limestone Canyon Monocline
Major road
H Selected well used in model simulation
Ash Fork
Big Black Mesa
Drake
M
Hell Canyon
35°00'
BIG CHINO VALLEY
H
Paulden
E
F
G
Verde River
Chino Valley
34°45'
0
10 MILES
0
10 KILOMETERS

Chemical Parameters Used in Model

- pH
- Bicarbonate
- Calcium
- Magnesium
- Sodium
- Chloride
- Sulfate
- Silica
- Fluoride
- Strontium
- Potassium
- Deuterium
- Oxygen-18
- Carbon-13
- Carbon-14

PHREEQCI (Parkhurst and others) Mole Phase Transfers for UVRS

Model	SiO_2	CO_2	NaCl	Talc	$CaCO_3$	Gypsum	$SrSO_4$
1		E-04				E-05	
2			E-05	E-05			E-07
3	E-04	E-04	E-05				E-07
4						E-05	E-07
5				E-05		E-05	
6	E-04		E-05				E-07
7	E-04					E-05	
8			E-05			E-05	
9				E-05		E-05	E-07
10				E-05	E-05	E-05	
11			E-05	E-05		E-05	
12		E-04				E-05	E-07
13			E-05			E-05	E-07

PHREEQCI (Parkhurst and others) Model Mixing Fractions for UVRS

Model	Big Chino Waters			Sum of BC	Drake	FINAL
	H	E	F	H+E+F	M	
1	.14	.00	.79	0.94	.06	1.00
2	.10	.25	.66	1.00	.00	1.00
3	.10	.25	.66	1.00	.00	1.00
4	.12	.12	.76	1.00	.00	1.00
5	.13	.16	.67	0.96	.04	1.00
6	.10	.25	.66	1.00	.00	1.00
7	.13	.23	.61	0.97	.03	1.00
8	.10	.00	.83	0.93	.07	1.00
9	.13	.00	.87	1.00	.00	1.00
10	.13	.00	.81	0.94	.06	1.00
11	.12	.00	.82	0.94	.06	1.00
12	.14	.00	.86	1.00	.00	1.00
13	.10	.00	.90	1.00	.00	1.00

Major Findings, Tracer Study & Inverse Model:

- Sources of spring inflows can "fingerprinted" using distinct geochemical trends
- Tracer dilution approach works well to quantify diffuse spring inflows
- By subtraction, a small amount of additional inflow occurs between Stewart Ranch and Paulden gage
- Adjusted calculations for base flow at Paulden:
  - LC basin-fill aquifer, 14%
  - Combined BC aquifers, 80 to 86%
  - Carbonate aquifer (north of river), 0 to 6%

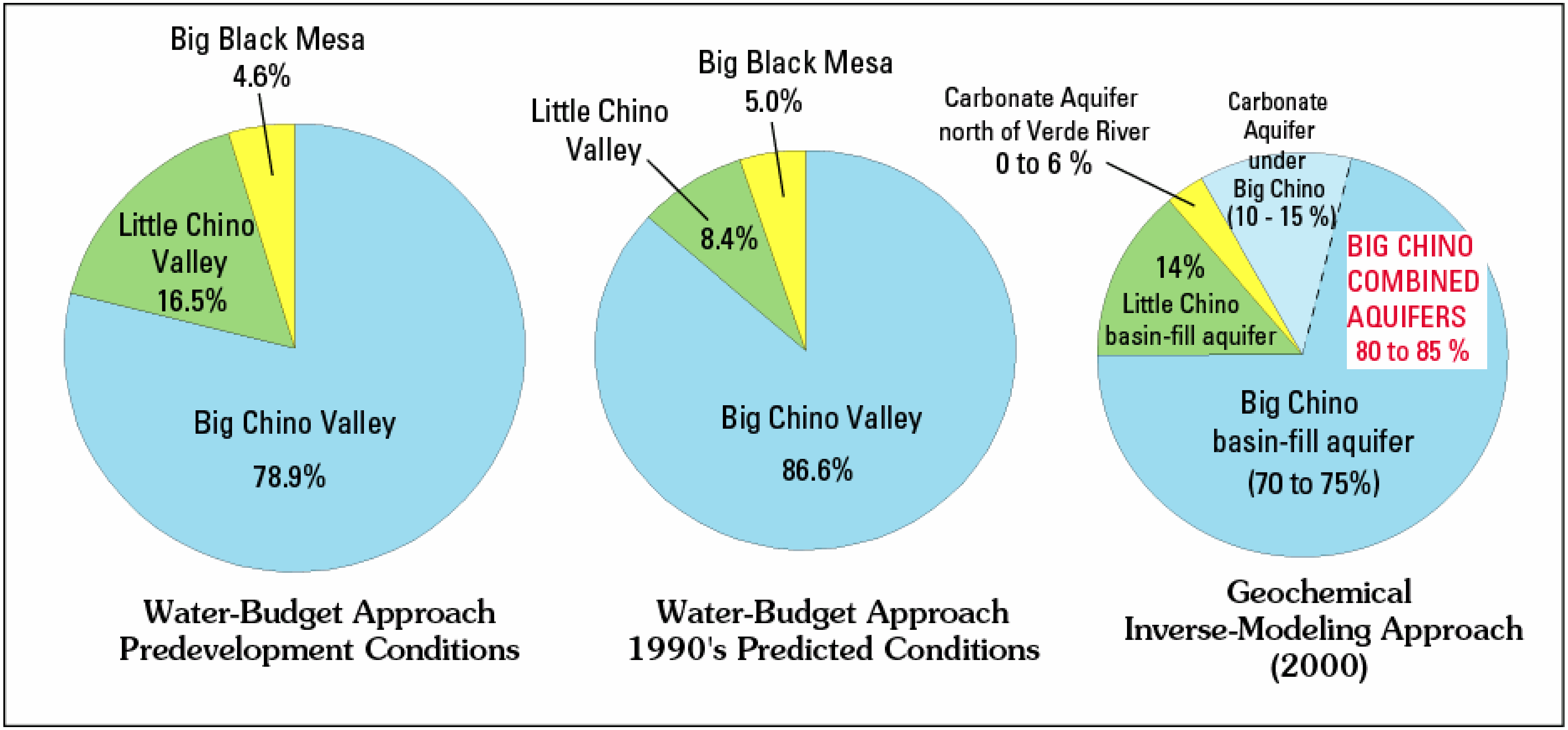
Multiple Lines of Evidence:

A. Summarize environmental setting, predevelopment conditions, and previous studies
B. Geologic Framework
C. Geophysical Framework
D. Hydrogeological Framework
E. Geochemical Trends of Aquifers and Springs
F. Tracer Study and Geochemical Model
G. Synthesis

Summary of Approach

- Determine geologic framework of major aquifers, including geometry, structure, and stratigraphy
- Evaluate regional ground-water gradients and build conceptual model of outlet flowpath(s)
- Characterize water quality of subgroups (large springs and parts of major aquifers)
- Apply tracer approach to quantify GW inflows from each aquifer to VR base flow
- Use geochemical modeling to integrate multiple lines of chemical and isotopic evidence along selected flowpath and calculate mixing fractions

Synthesis and Summary:



Important Note: All 3 pie charts represent base flow at USGS Streamflow-Gaging Station near Paulden

USGS


?Questions?