West Coast Regional Carbon Sequestration Partnership
westcarb.org

WESTCARB Regional Partnership

Geologic Carbon Sequestration Potential in Arizona

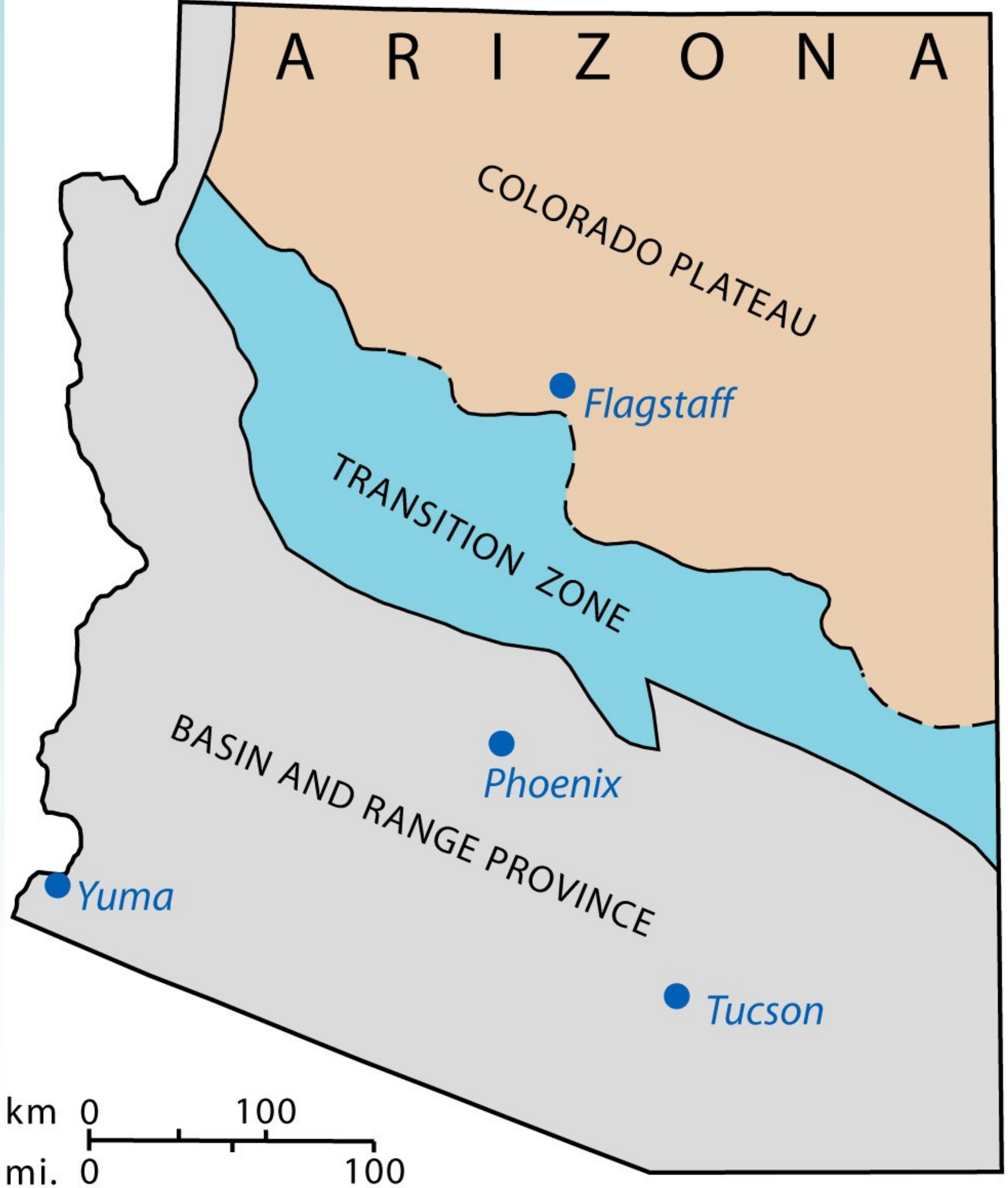
Jon Spencer, jon.spencer@azgs.az.gov
Arizona Geological Survey
Senior Geologist

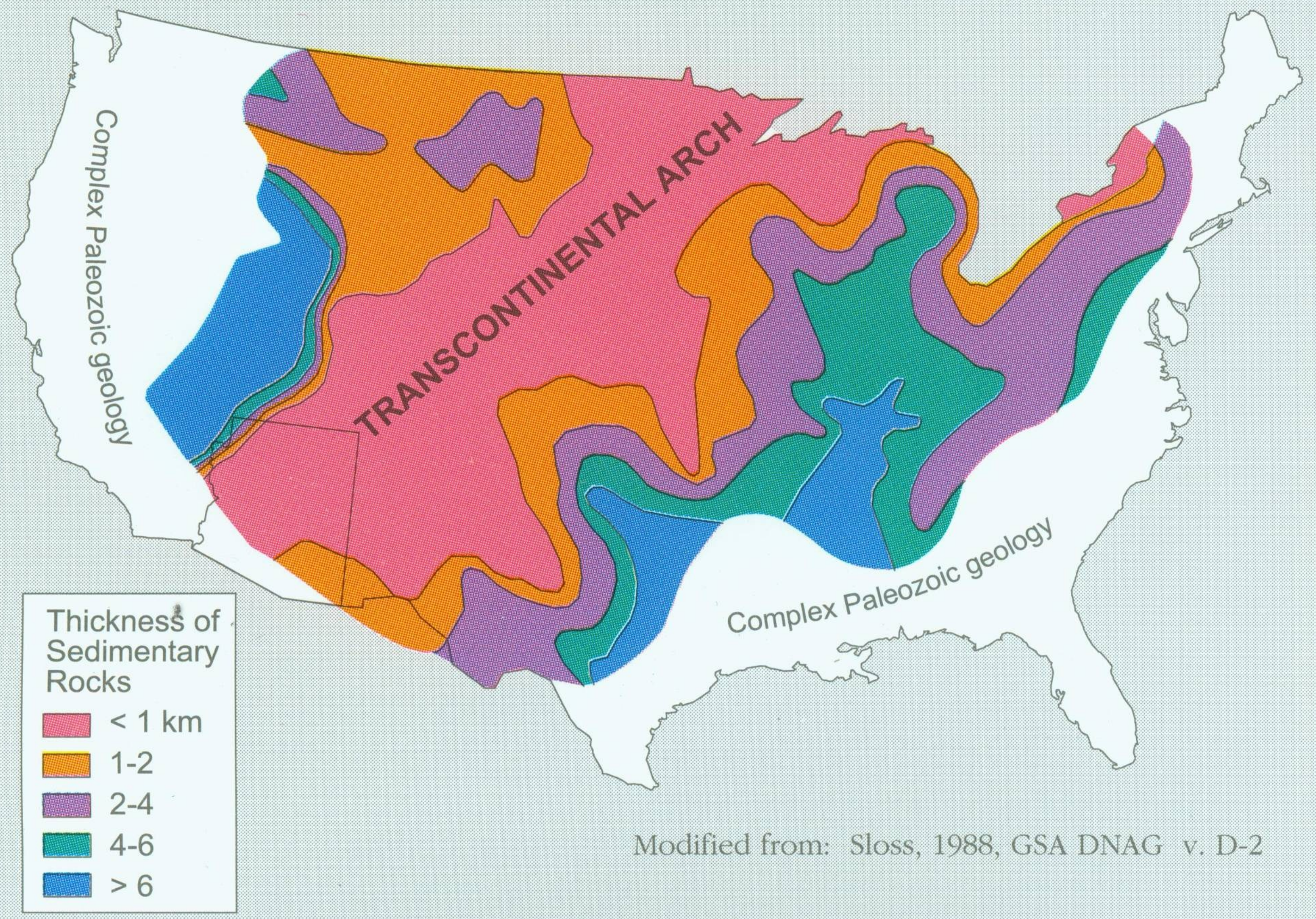
WESTCARB Annual Business Meeting
Bakersfield, CA

October 15–17, 2012

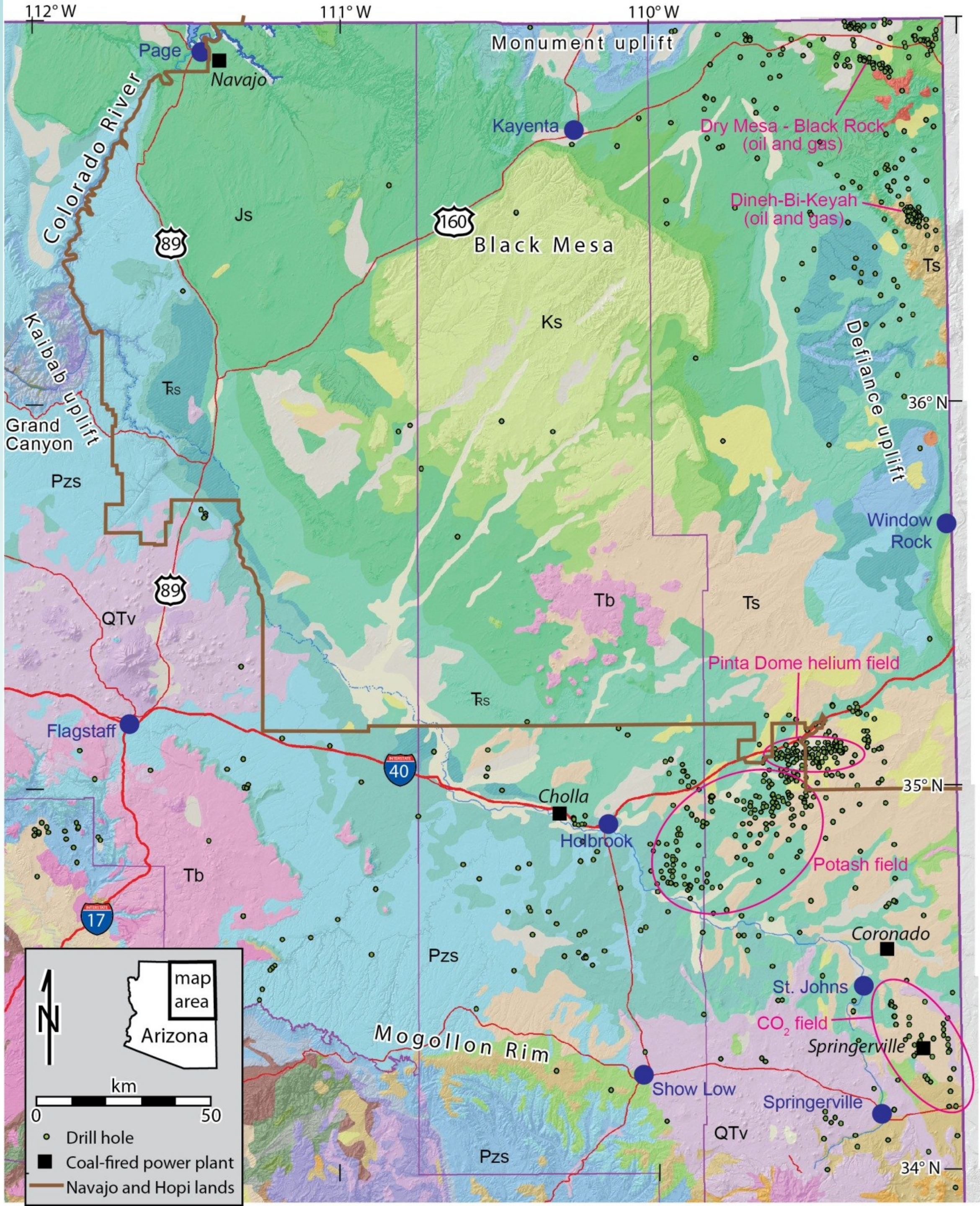
Arizona Geological Survey
WESTCARB Phase III Objectives

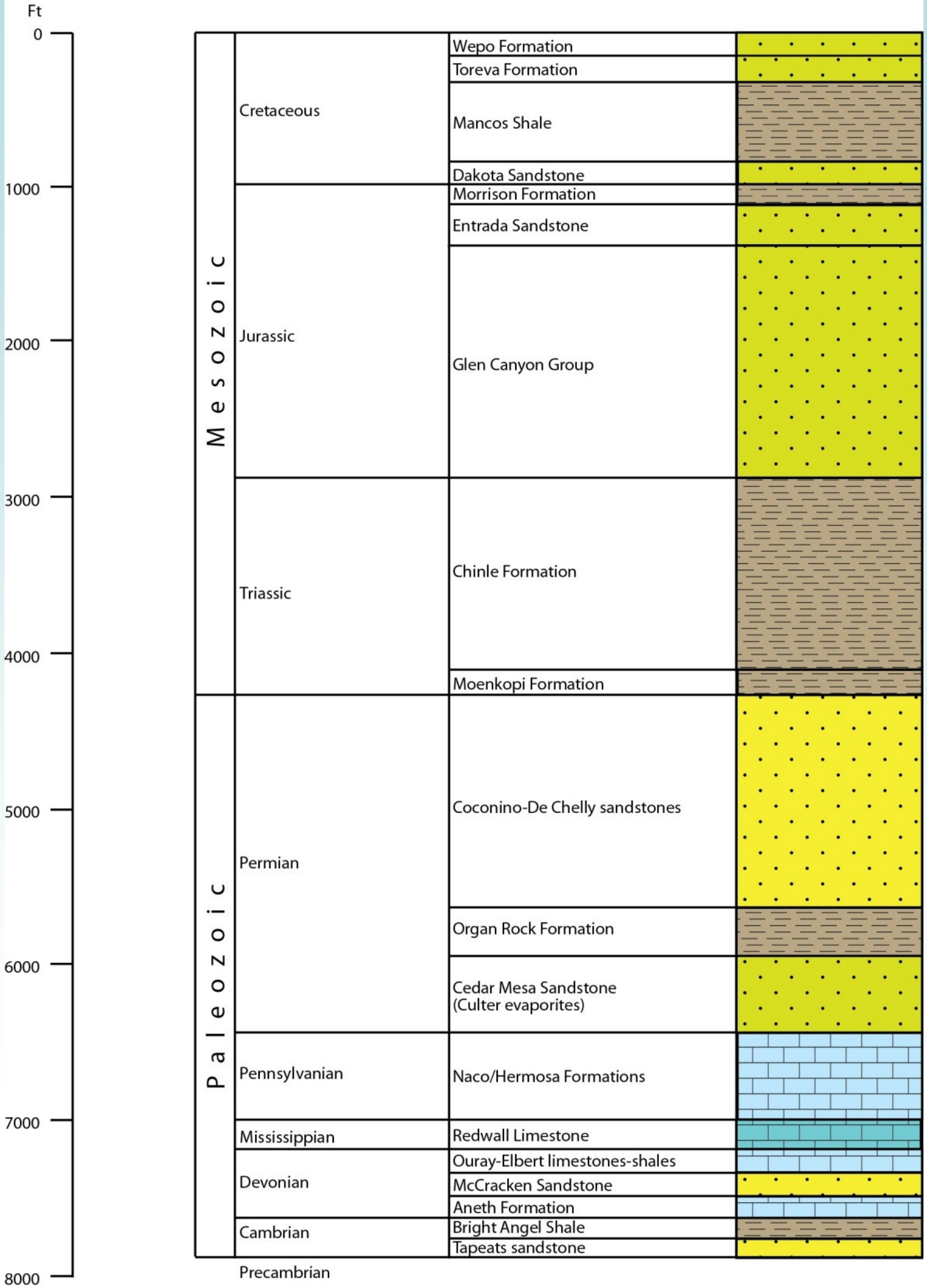
- Identify and assess subsurface geologic formations in the Colorado Plateau and Basin and Range provinces of Arizona for CO_2 sequestration potential
- Identify areas where deep-groundwater salinity exceeds 10,000 milligrams per liter (mg/l TDS) in areas with potential for CO_2 sequestration

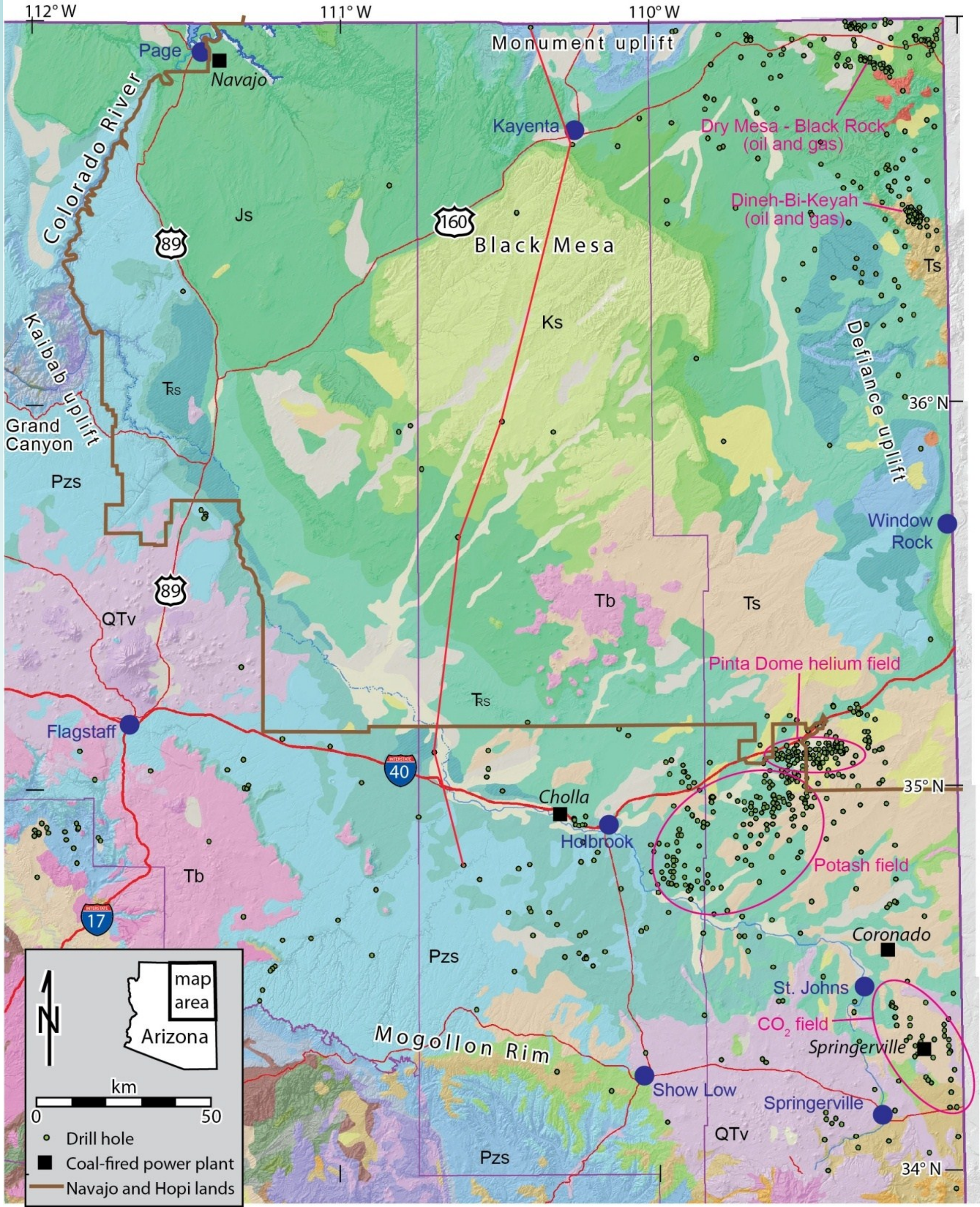

ARIZONA
COLORADO PLATEAU
Flagstaff
TRANSITION ZONE
BASIN AND RANGE PROVINCE
Phoenix
Yuma
Tucson
km 0 100
mi. 0 100



TRANSCONTINENTAL ARCH
Complex Paleozoic geology
Complex Paleozoic geology
Thickness of Sedimentary Rocks
< 1 km
1-2
2-4
4-6
> 6
Modified from: Sloss, 1988, GSA DNAG v. D-2


112° W
111° W
110° W
Monument uplift
Page
Navajo
Kayenta
Colorado River
Dry Mesa - Black Rock (oil and gas)
Dineh-Bi-Keyah (oil and gas)
Js
89
160
Black Mesa
Ts
Ks
Kaibab uplift
Defiance uplift
36° N
Grand Canyon
Pzs
Window Rock
QTv
Tb
Ts
Pinta Dome helium field
Flagstaff
40
Cholla
35° N
Holbrook
Potash field
Tb
17
Coronado
Pzs
St. Johns
map area
Arizona
N
CO2 field
Springerville
Mogollon Rim
km
0
50
Show Low
Springerville
QTv
Drill hole
Coal-fired power plant
Pzs
34° N
Navajo and Hopi lands


Ft
0
1000
2000
3000
4000
5000
6000
7000
8000
Mesozoic
Paleozoic
Cretaceous
Jurassic
Triassic
Permian
Pennsylvanian
Mississippian
Devonian
Cambrian
Precambrian
Wepo Formation
Toreva Formation
Mancos Shale
Dakota Sandstone
Morrison Formation
Entrada Sandstone
Glen Canyon Group
Chinle Formation
Moenkopi Formation
Coconino-De Chelly sandstones
Organ Rock Formation
Cedar Mesa Sandstone (Culter evaporites)
Naco/Hermosa Formations
Redwall Limestone
Ouray-Elbert limestones-shales
McCracken Sandstone
Aneth Formation
Bright Angel Shale
Tapeats sandstone



112° W
111° W
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Monument uplift
Page
Navajo
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Dry Mesa - Black Rock (oil and gas)
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Colorado River
Js
89
160
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Defiance uplift
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Grand Canyon
TRS
36° N
Pzs
Window Rock
QTv
Tb
Ts
Pinta Dome helium field
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Flagstaff
40
Cholla
Holbrook
35° N
Potash field
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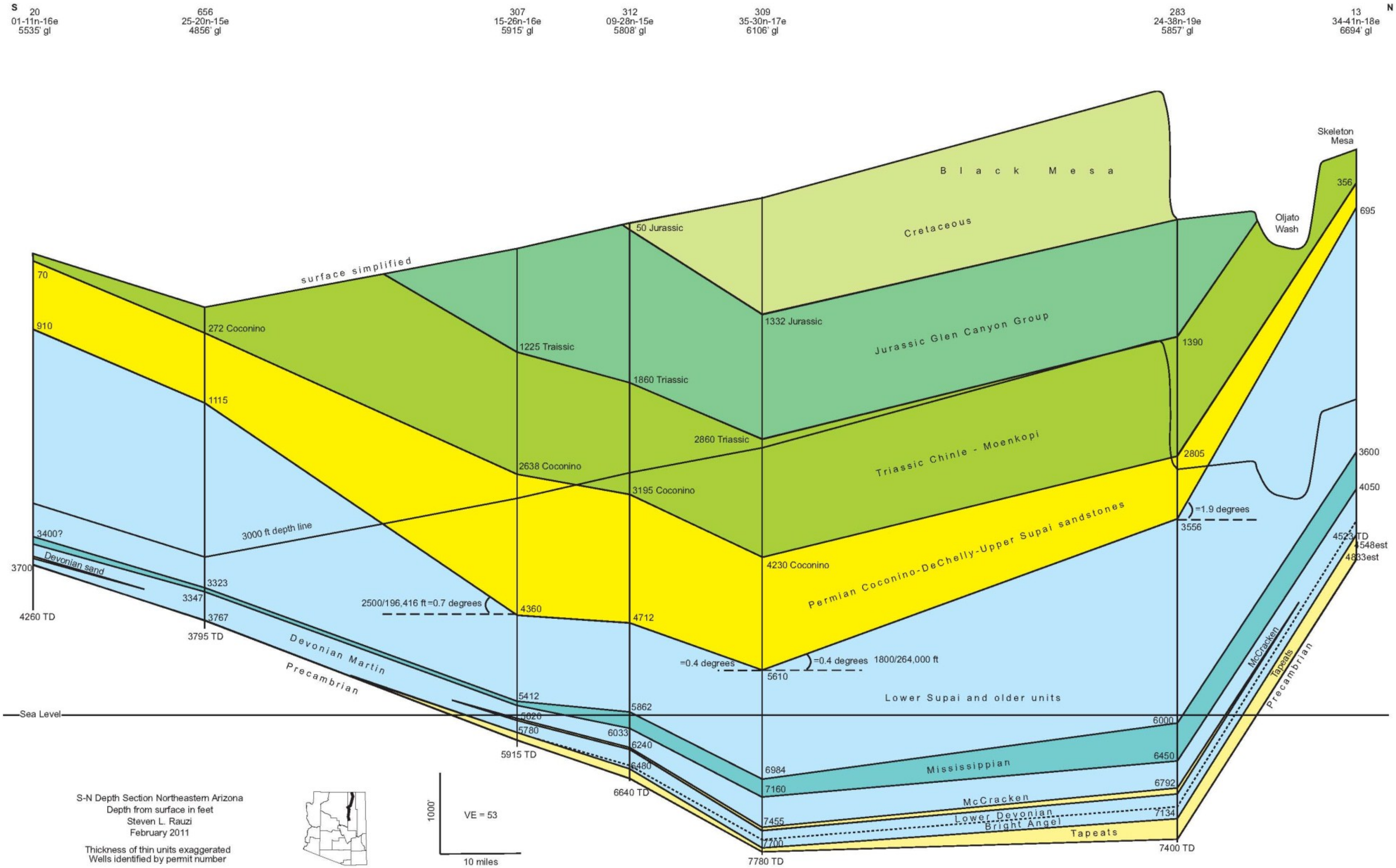
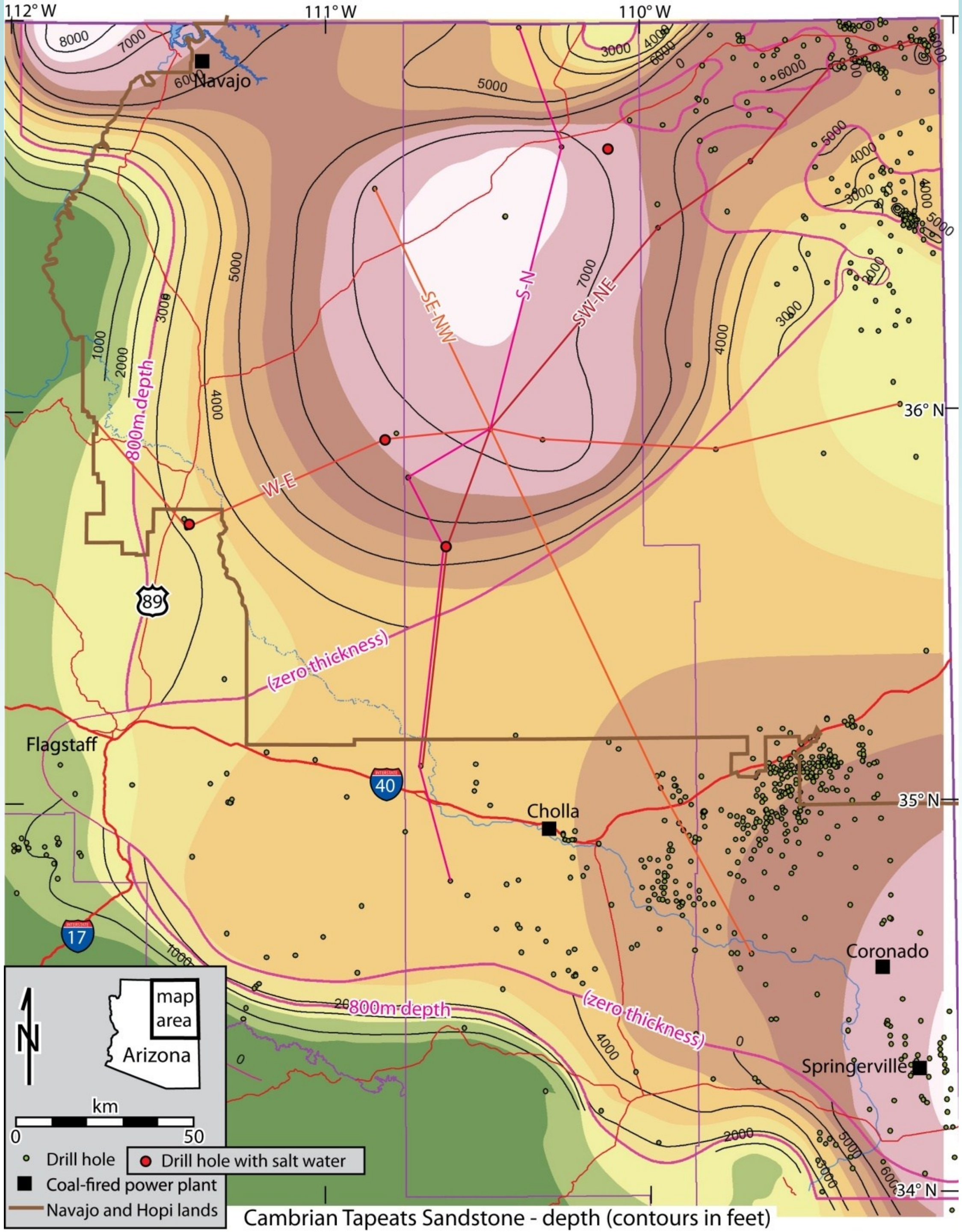
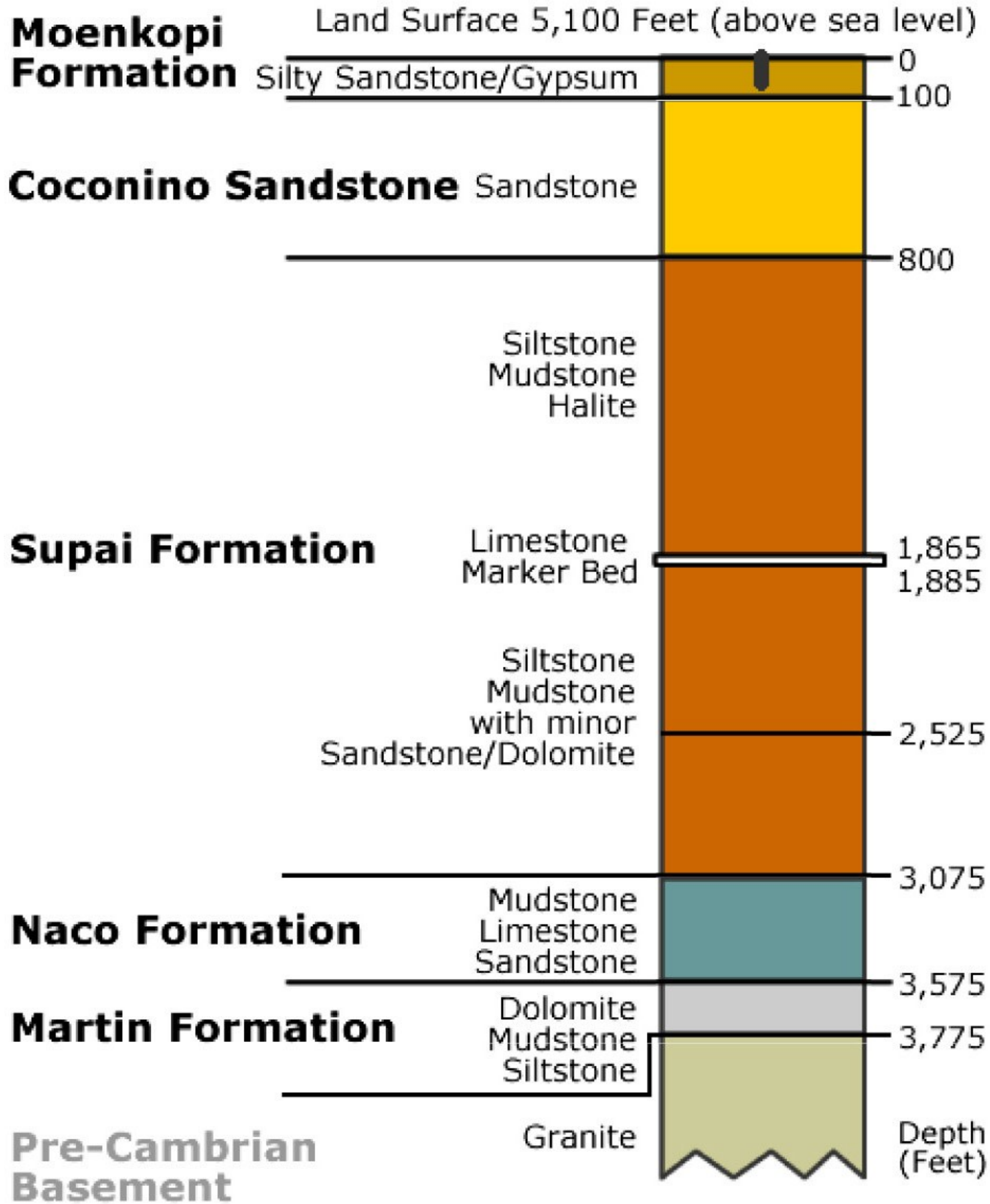
17
Coronado
Pzs
St. Johns
CO_2 field
Springerville
Mogollon Rim
Show Low
Springerville
QTv
Pzs
34° N
map area
Arizona
N
km
0
50
Drill hole
Coal-fired power plant
Navajo and Hopi lands

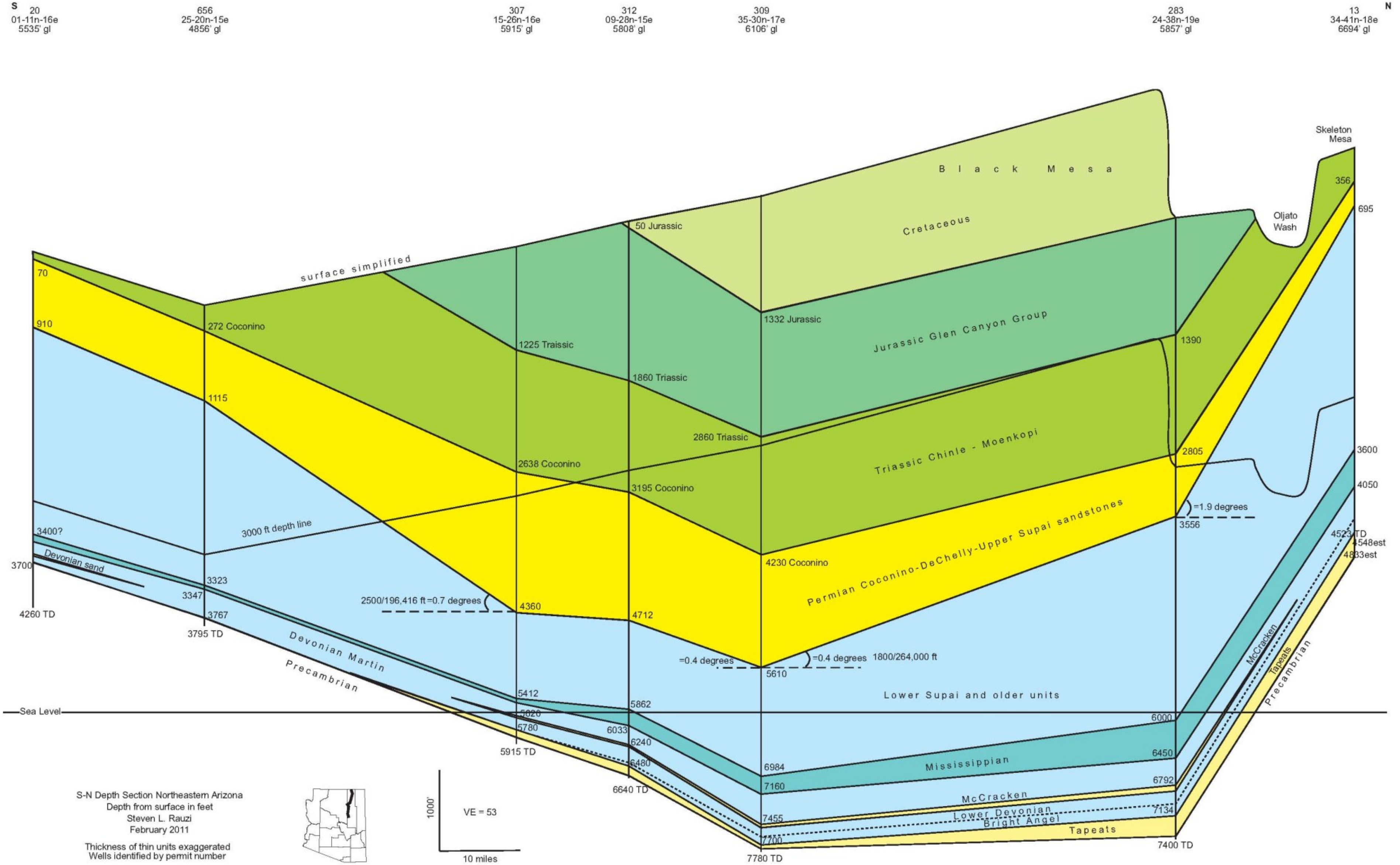

S
N
20
01-11n-16e
5535' gl
656
25-20n-15e
4856' gl
307
15-26n-16e
5915' gl
312
09-28n-15e
5808' gl
309
35-30n-17e
6106' gl
283
24-38n-19e
5857' gl
13
34-41n-18e
6694' gl
Skeleton Mesa
Oljato Wash
Black Mesa
Cretaceous
surface simplified
50 Jurassic
1332 Jurassic
Jurassic Glen Canyon Group
1225 Traissic
1860 Triassic
2860 Triassic
Triassic Chinle - Moenkopi
272 Coconino
2638 Coconino
3195 Coconino
4230 Coconino
Permian Coconino-DeChelly-Upper Supai sandstones
3000 ft depth line
2500/196,416 ft=0.7 degrees
=0.4 degrees
=0.4 degrees 1800/264,000 ft
=1.9 degrees
Lower Supai and older units
Devonian sand
Devonian Martin
Precambrian
Mississippian
McCracken
Lower Devonian
Bright Angel
Tapeats
Sea Level
70
910
1115
3400?
3700
4260 TD
3323
3347
3767
3795 TD
4360
5412
5620
5780
5915 TD
4712
5862
6033
6240
6480
6640 TD
5610
6984
7160
7455
7700
7780 TD
356
695
1390
2805
3556
3600
4050
4523 TD
4548est
4833est
6000
6450
6792
7134
7400 TD
VE = 53
1000'
10 miles
S-N Depth Section Northeastern Arizona
Depth from surface in feet
Steven L. Rauzi
February 2011
Thickness of thin units exaggerated
Wells identified by permit number



Cambrian Tapeats Sandstone - depth (contours in feet)



Source: Errol L. Montgomery & Associates


S
N
20
01-11n-16e
5535' gl
656
25-20n-15e
4856' gl
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=0.4 degrees
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3795 TD
5915 TD
6640 TD
7780 TD
7400 TD
S-N Depth Section Northeastern Arizona
Depth from surface in feet
Steven L. Rauzi
February 2011
Thickness of thin units exaggerated
Wells identified by permit number
1000'
VE = 53
10 miles

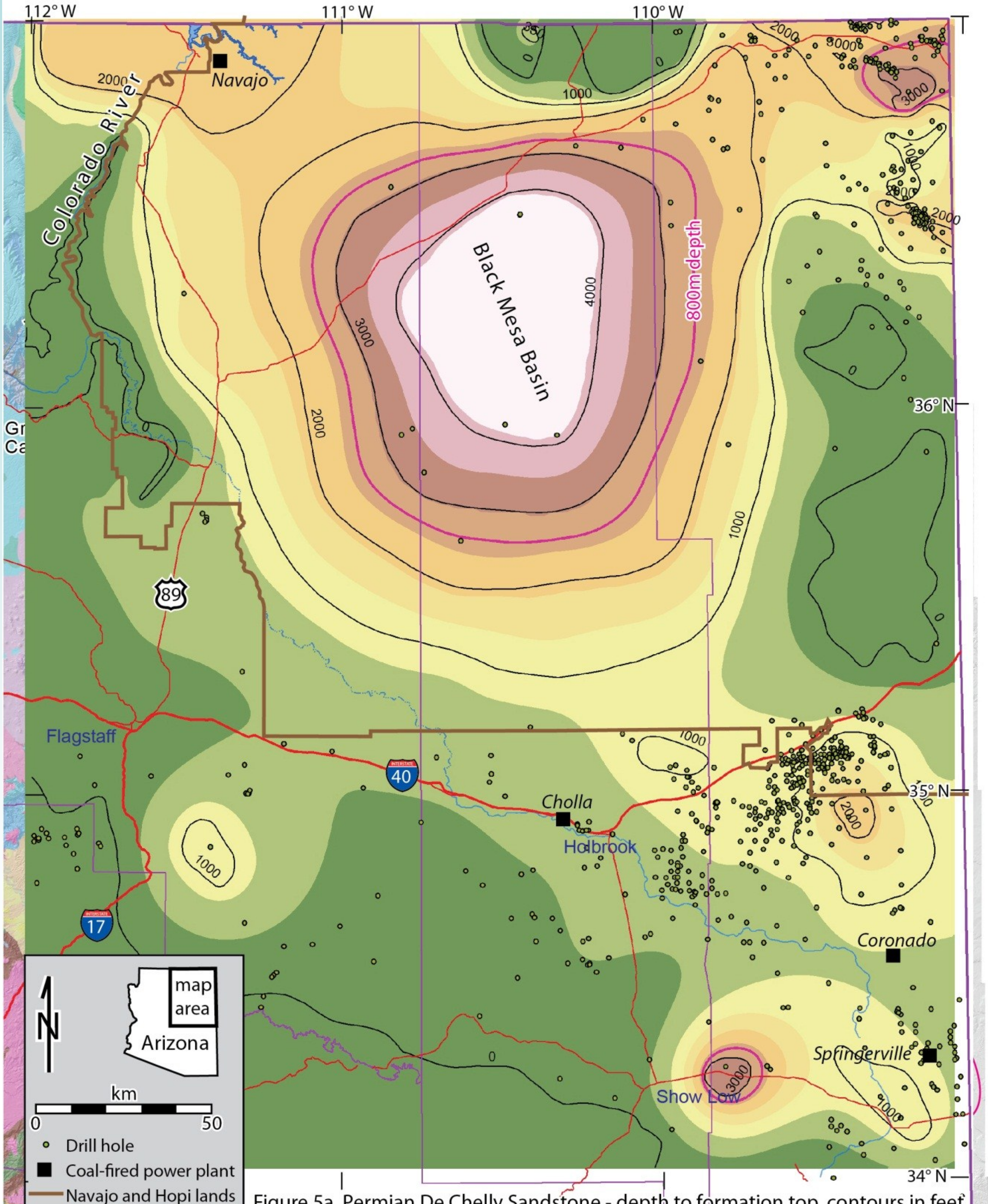


Figure 5a. Permian De Chelly Sandstone - depth to formation top, contours in feet.

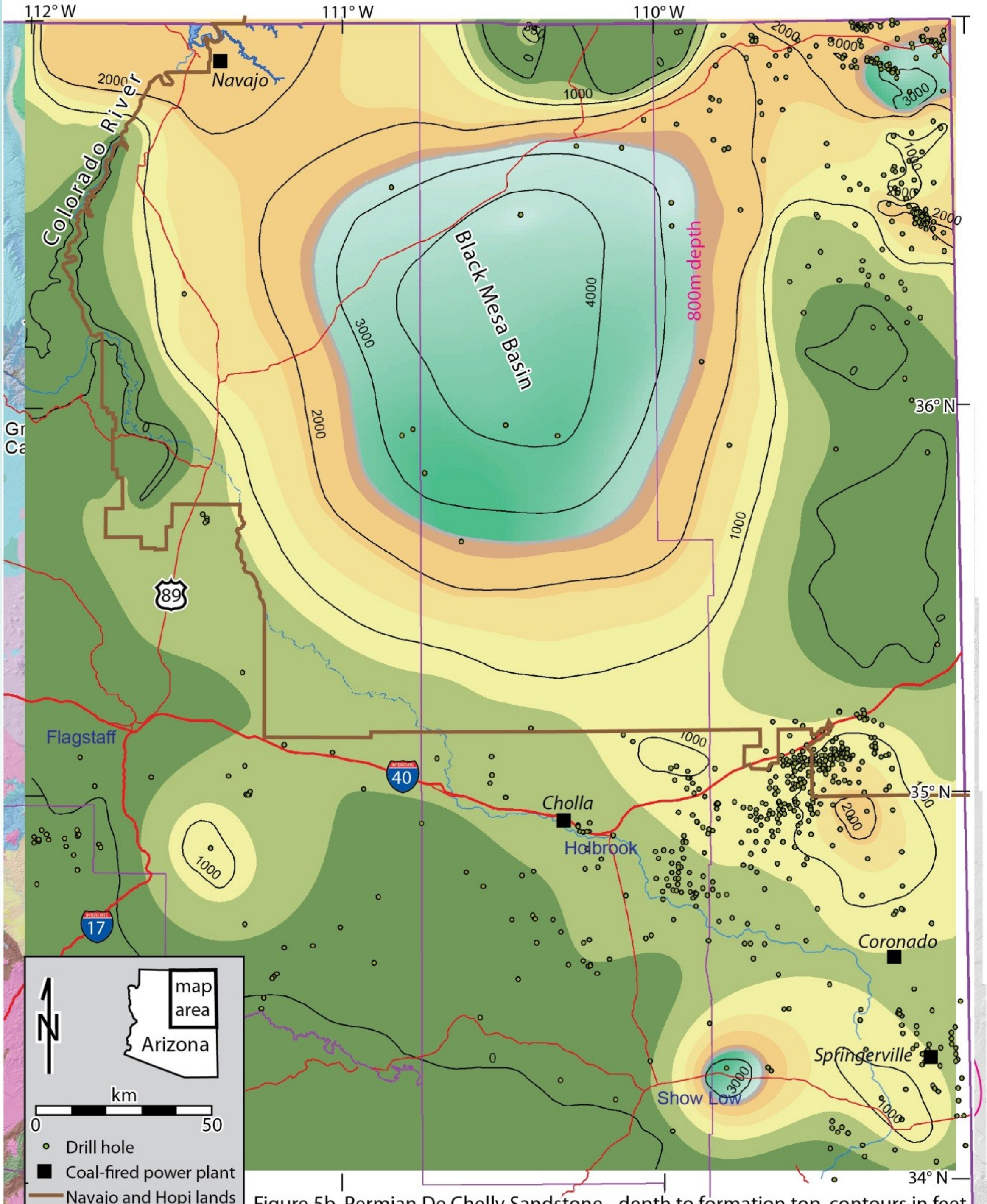


Figure 5b. Permian De Chelly Sandstone - depth to formation top, contours in feet.

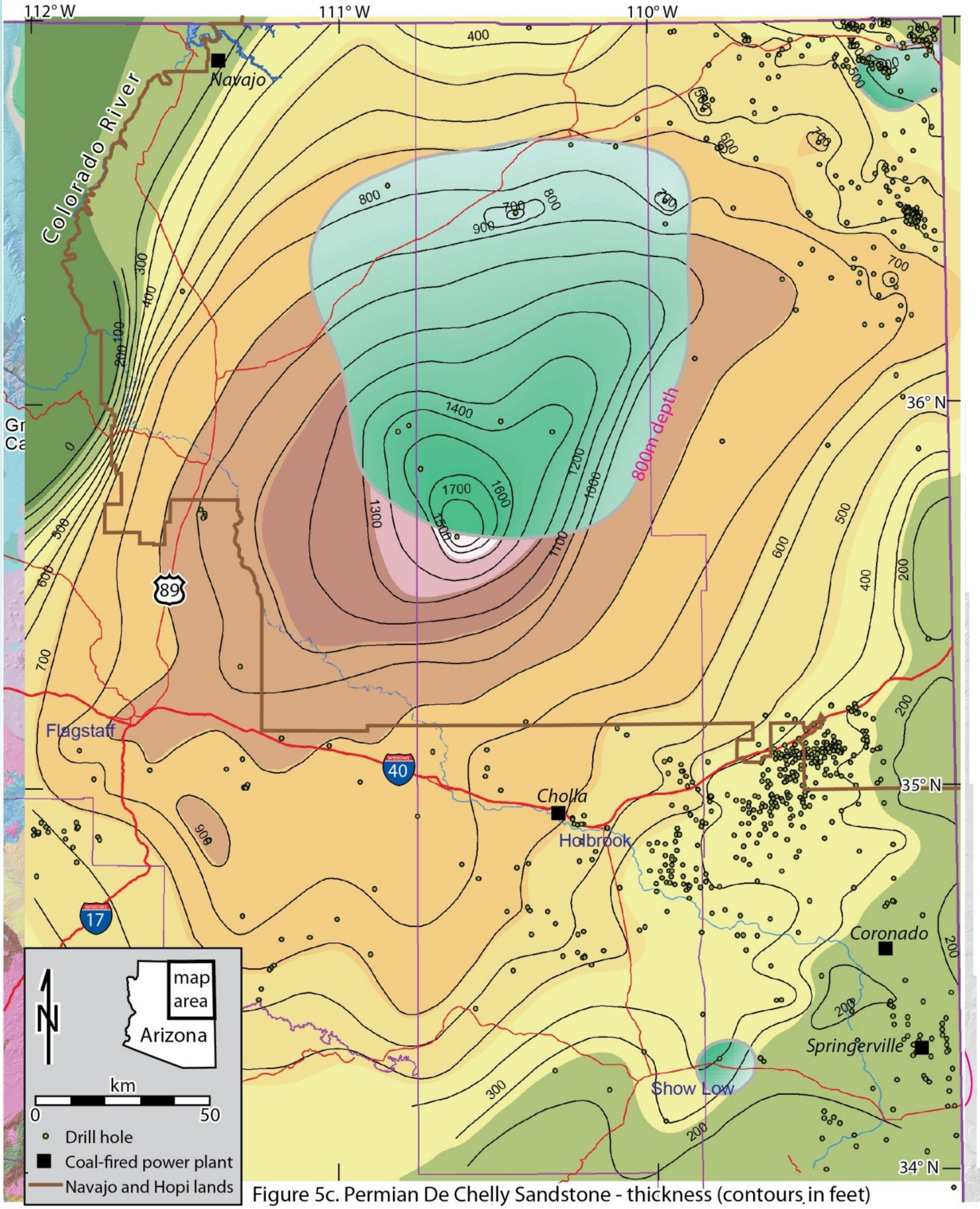


Figure 5c. Permian De Chelly Sandstone - thickness (contours in feet)

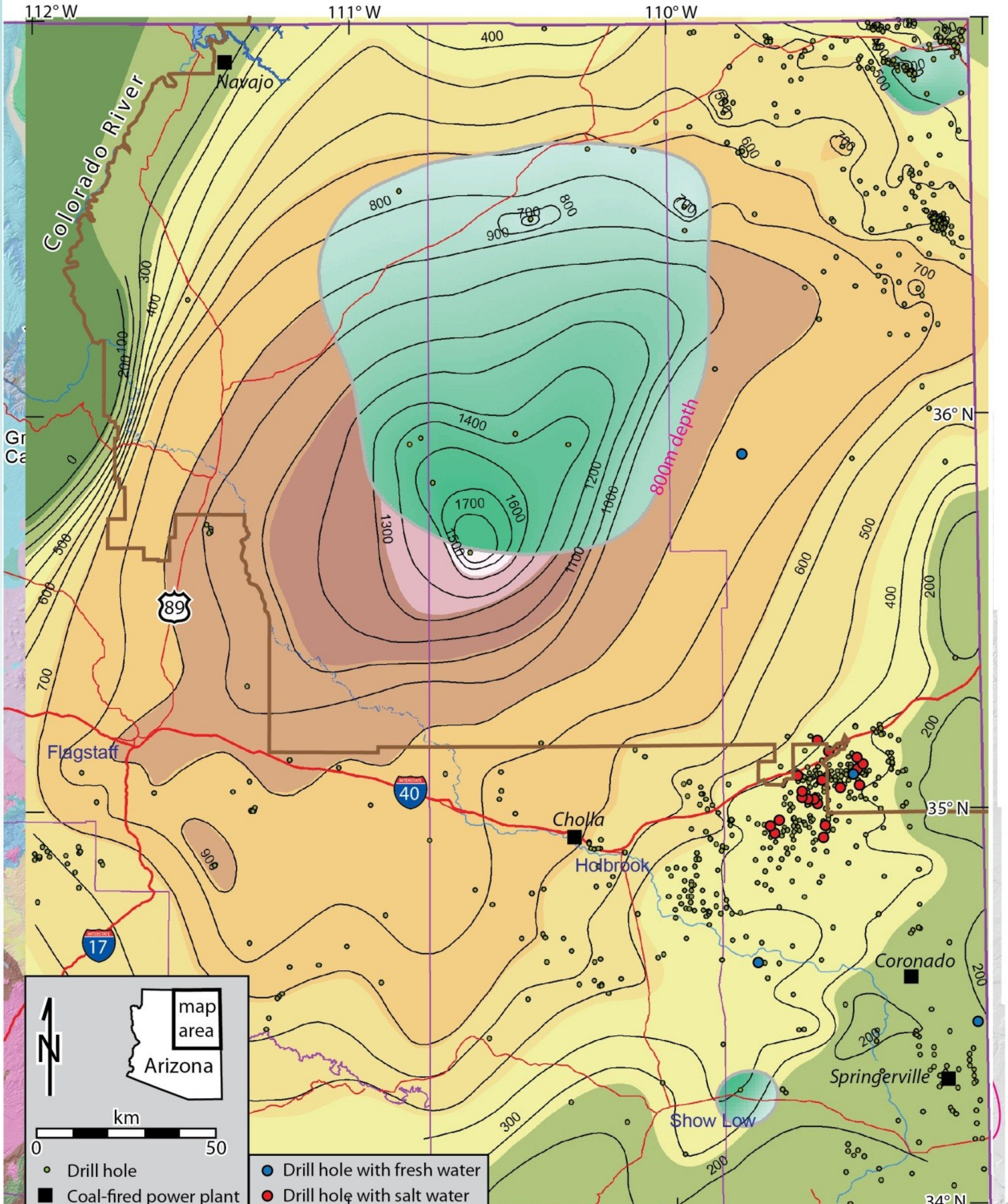


Figure 5c. Permian De Chelly Sandstone - thickness (contours in feet)

Drill-hole bottom temperatures in northeastern Arizona (Apache, Navajo, and Coconino Counties)

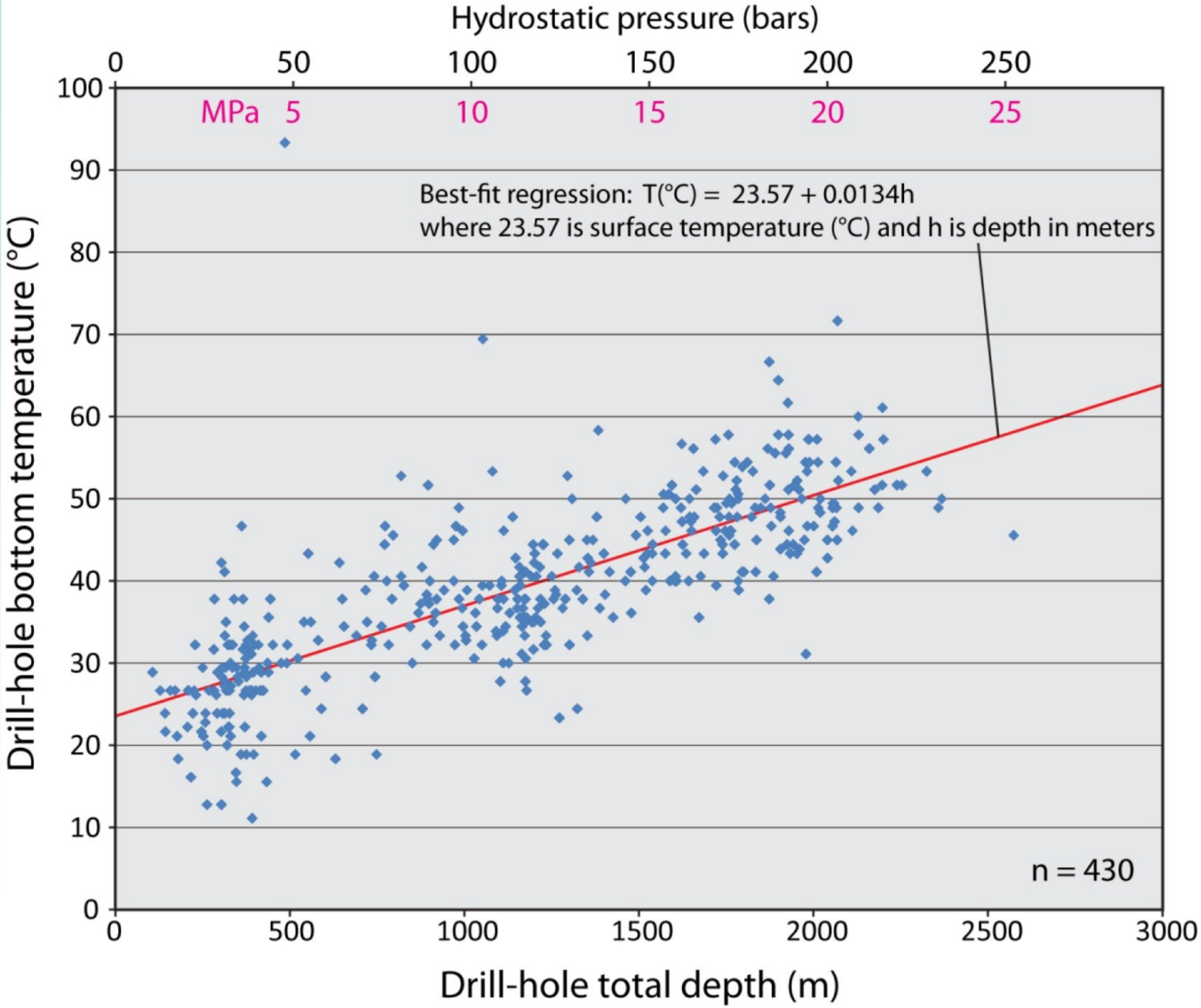


Figure 6. Drill-hole bottom temperatures from 430 bore holes in northeastern Arizona.

Temperature vs density for CO_2 at different pressures

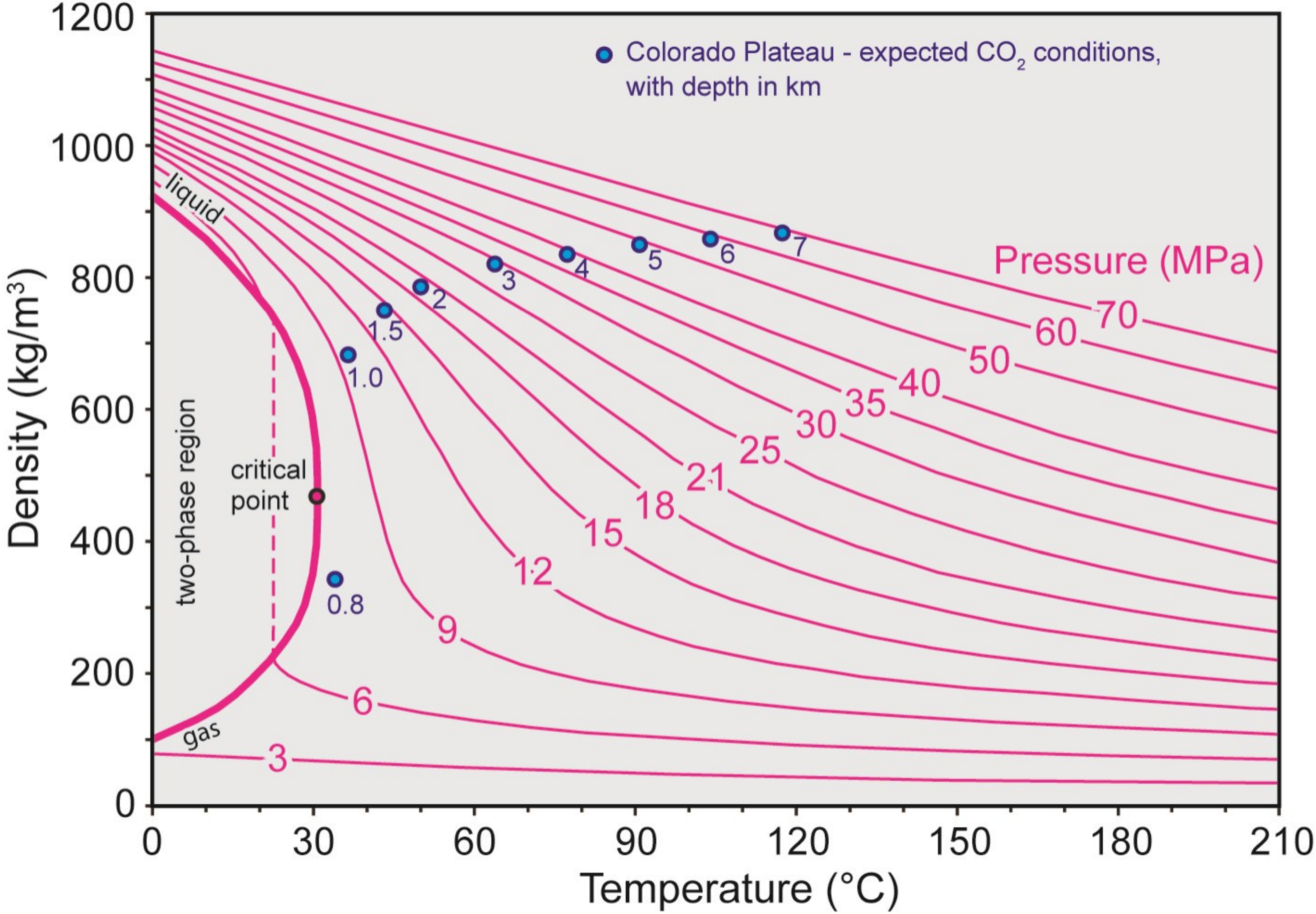


Table 2. Porosity and pore volume for Paleozoic sandstone units below 800m depth on the Colorado Plateau

Basin and unit	Area (km^2)	Volume (km^3)	Porosity low (%)*	Porosity mean (%)	Porosity high (%)*	Pore volume low (km^3)	Pore volume mean (km^3)	Pore volume high (km^3)
De Chelly main	10133	3393	9.3	14.3	19.3	315.57	485.23	654.90
De Chelly NE	345	37	9.3	14.3	19.3	3.44	5.28	7.13
De Chelly SE	172	18	9.3	14.3	19.3	1.69	2.60	3.51
McCracken	33578	531	2	4	8	10.63	21.25	42.50
Tapeats main	28661	1501	1.2	2.4	6	18.02	36.03	90.08
Tapeats south	3645	50	1.2	2.4	6	0.60	1.20	3.00
Tapeats NE	603	3	1.2	2.4	6	0.04	0.07	0.18

*De Chelly Sandstone (n=184): Porosity range is +/- one standard deviation

*McCracken Sandstone (n=112): Porosity range is plus one standard deviation, minus one half of one standard deviation

*Tapeats Sandstone (n=55): Porosity range is plus one standard deviation, minus one third of one standard deviation

Table 3. CO_2 storage capacity for Paleozoic sandstone units below 800m depth on the Colorado Plateau

Sandstone unit and basin	Pore volume low (km^3)	Pore volume mean (km^3)	Pore volume high (km^3)	Storage efficiency, low*	Storage efficiency, median*	Storage efficiency, high*	Effective pore volume, low (km^3)	Effective pore volume, median (km^3)	Effective pore volume, high (km^3)	CO_2 density (kg/m^3)	Potential mass of stored CO_2 (tonnes), low**	Potential mass of stored CO_2 (tonnes), median**	Potential mass of stored CO_2 (tonnes), high**
De Chelly main	315.57	485.23	654.90	0.0051	0.02	0.054	1.6	9.7	35.4	750	1.21.E+09	7.28.E+09	2.65.E+10
De Chelly NE	3.44	5.28	7.13	0.0051	0.02	0.054	0.018	0.11	0.39	750	1.31.E+07	7.93.E+07	2.89.E+08
De Chelly SE	1.69	2.60	3.51	0.0051	0.02	0.054	0.009	0.05	0.19	750	6.47.E+06	3.90.E+07	1.42.E+08
McCracken	10.63	21.25	42.51	0.0051	0.02	0.054	0.054	0.43	2.30	750	4.06.E+07	3.19.E+08	1.72.E+09
Tapeats main	18.02	36.03	90.08	0.0051	0.02	0.054	0.092	0.72	4.86	750	6.89.E+07	5.40.E+08	3.65.E+09
Tapeats south	0.60	1.20	3.00	0.0051	0.02	0.054	0.0031	0.024	0.16	750	2.30.E+06	1.80.E+07	1.22.E+08
Tapeats NE	0.04	0.07	0.18	0.0051	0.02	0.054	0.00019	0.0015	0.0099	750	1.40.E+05	1.10.E+06	7.40.E+06
										Total	1.34.E+09	8.28.E+09	3.25.E+10

*Values are approximations from various lithologies in the United States, as given by Litynski et al. (2010)

**E+09 indicates $x10^9$

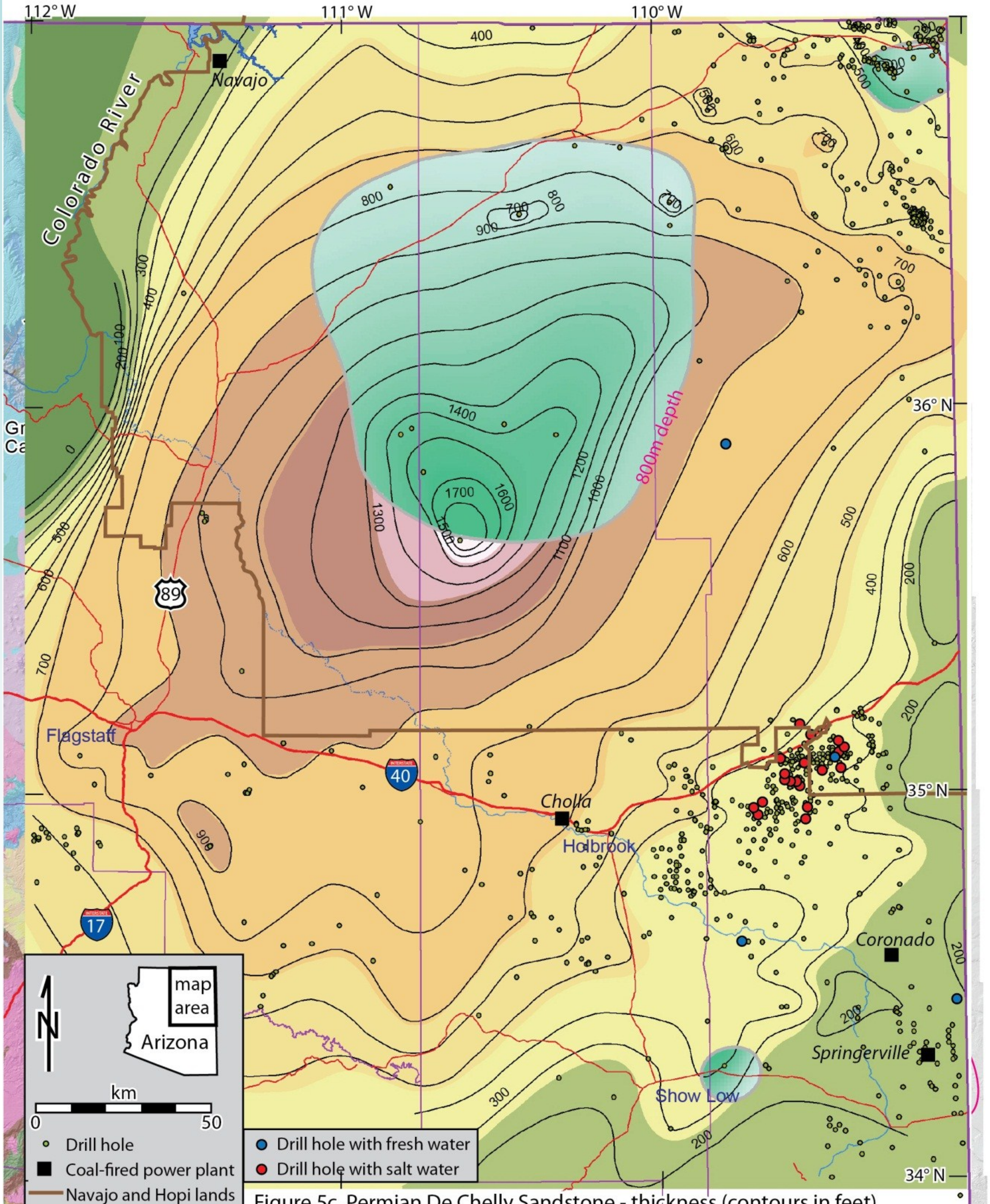
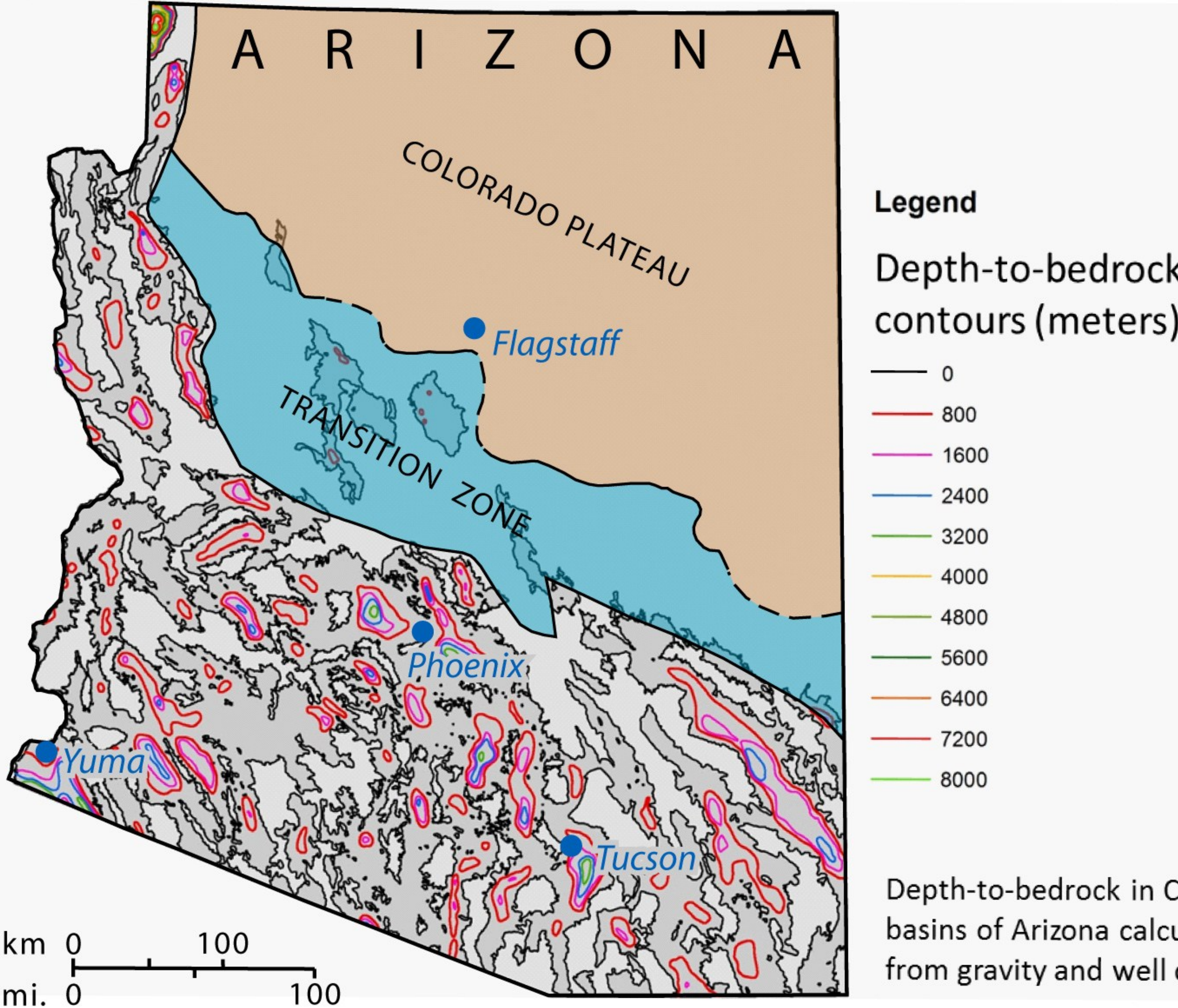
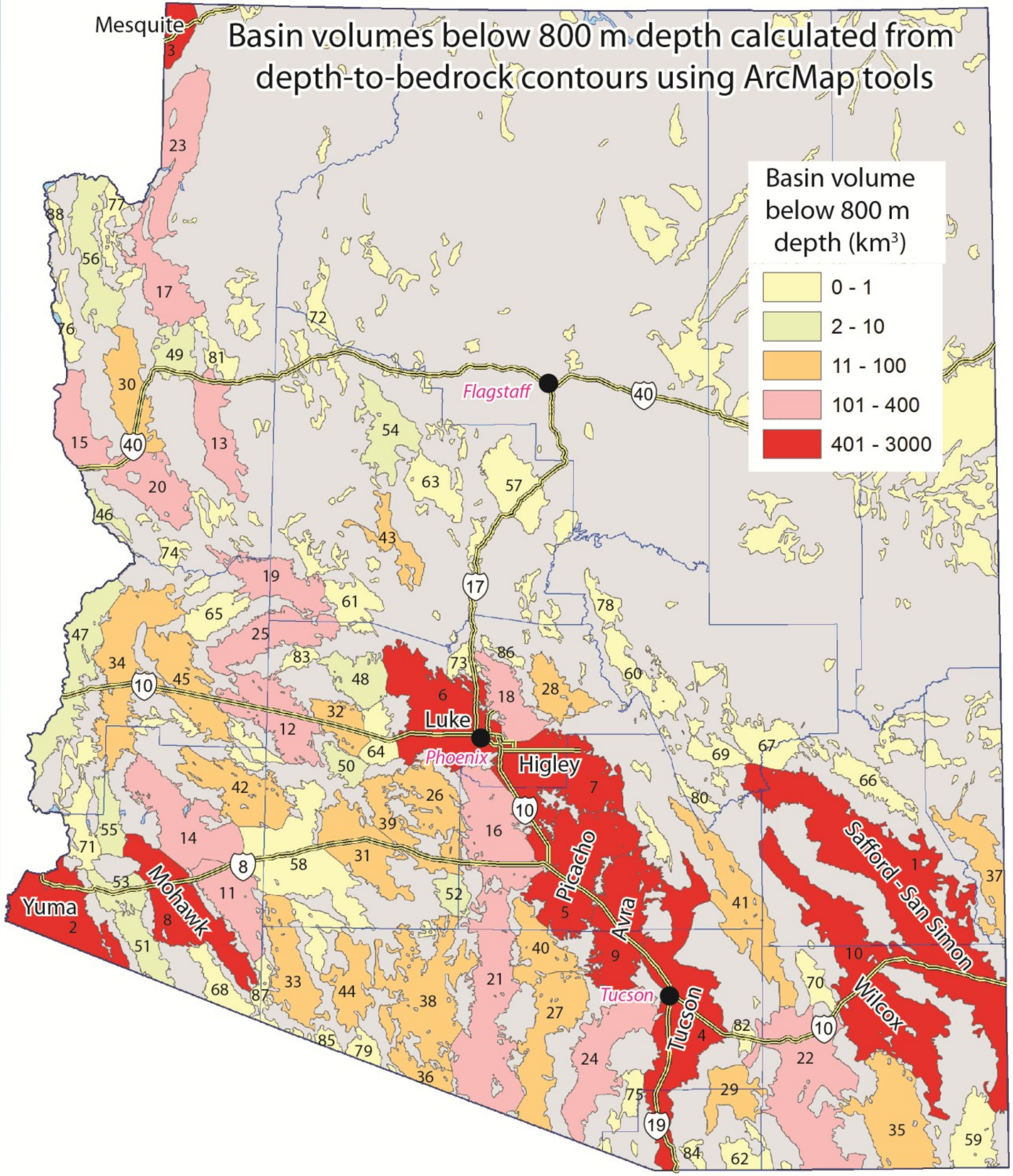


Figure 5c. Permian De Chelly Sandstone - thickness (contours in feet)

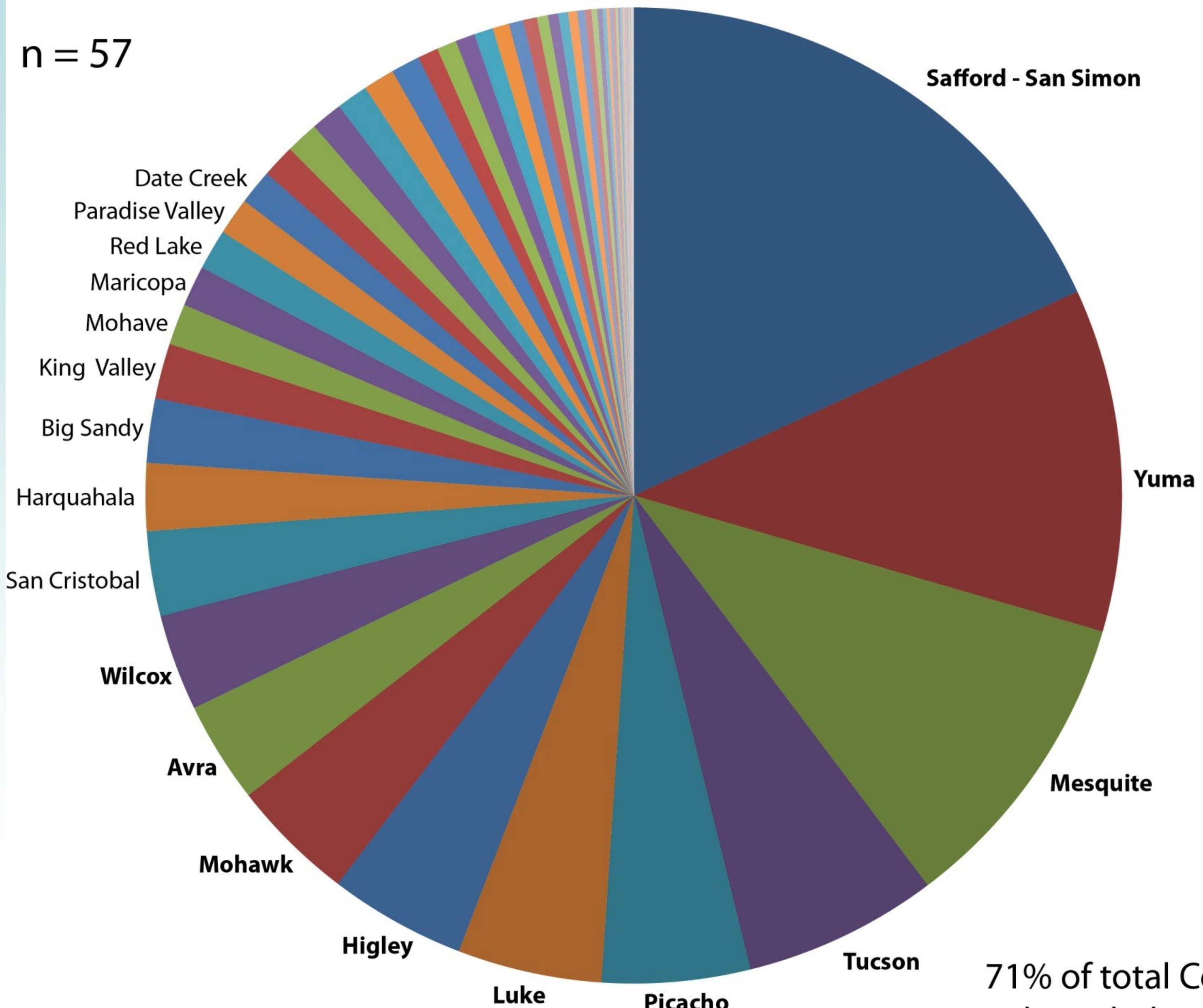


Depth-to-bedrock in Cenozoic basins of Arizona calculated from gravity and well data

Basin volumes below 800 m depth calculated from depth-to-bedrock contours using ArcMap tools

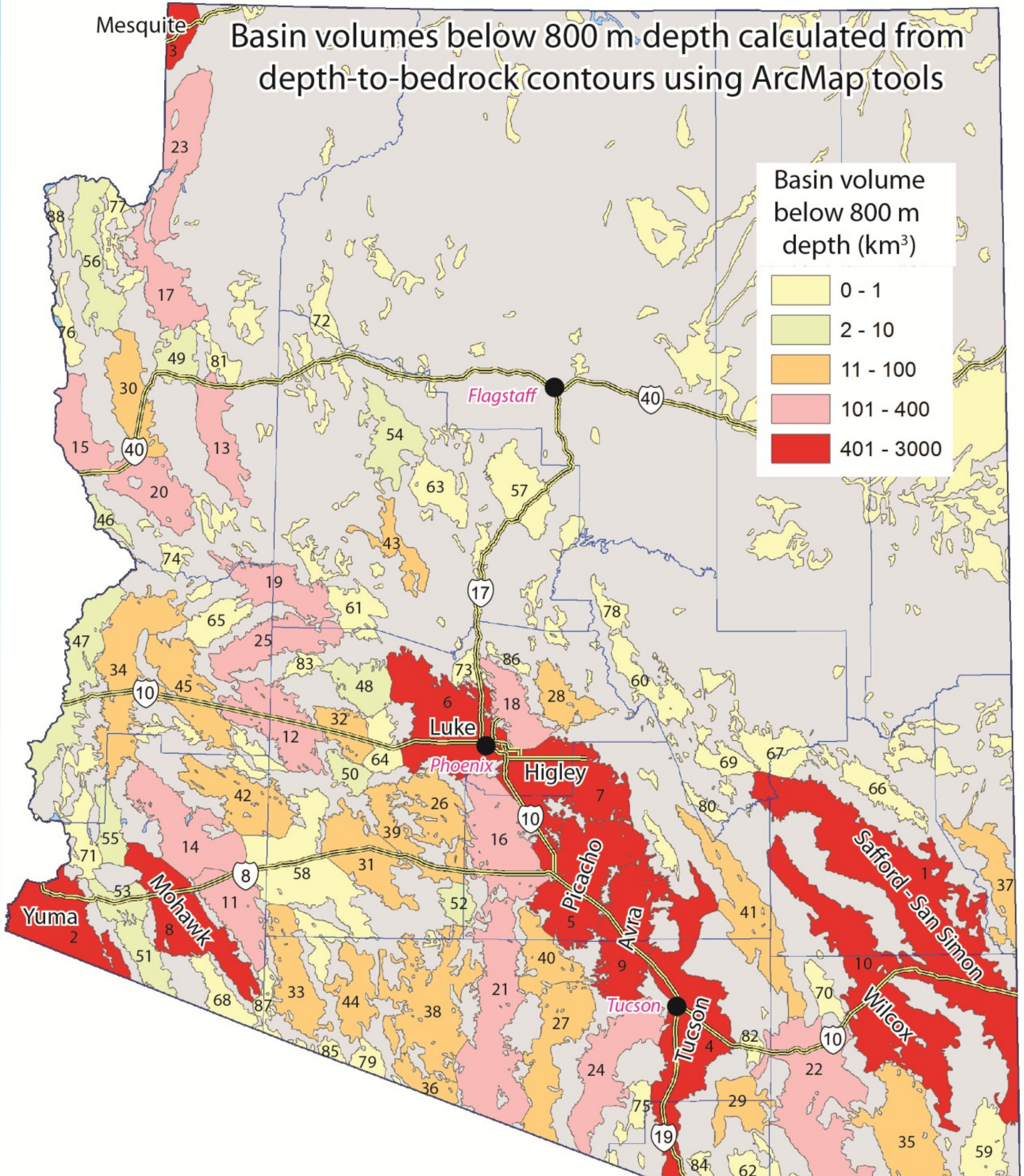


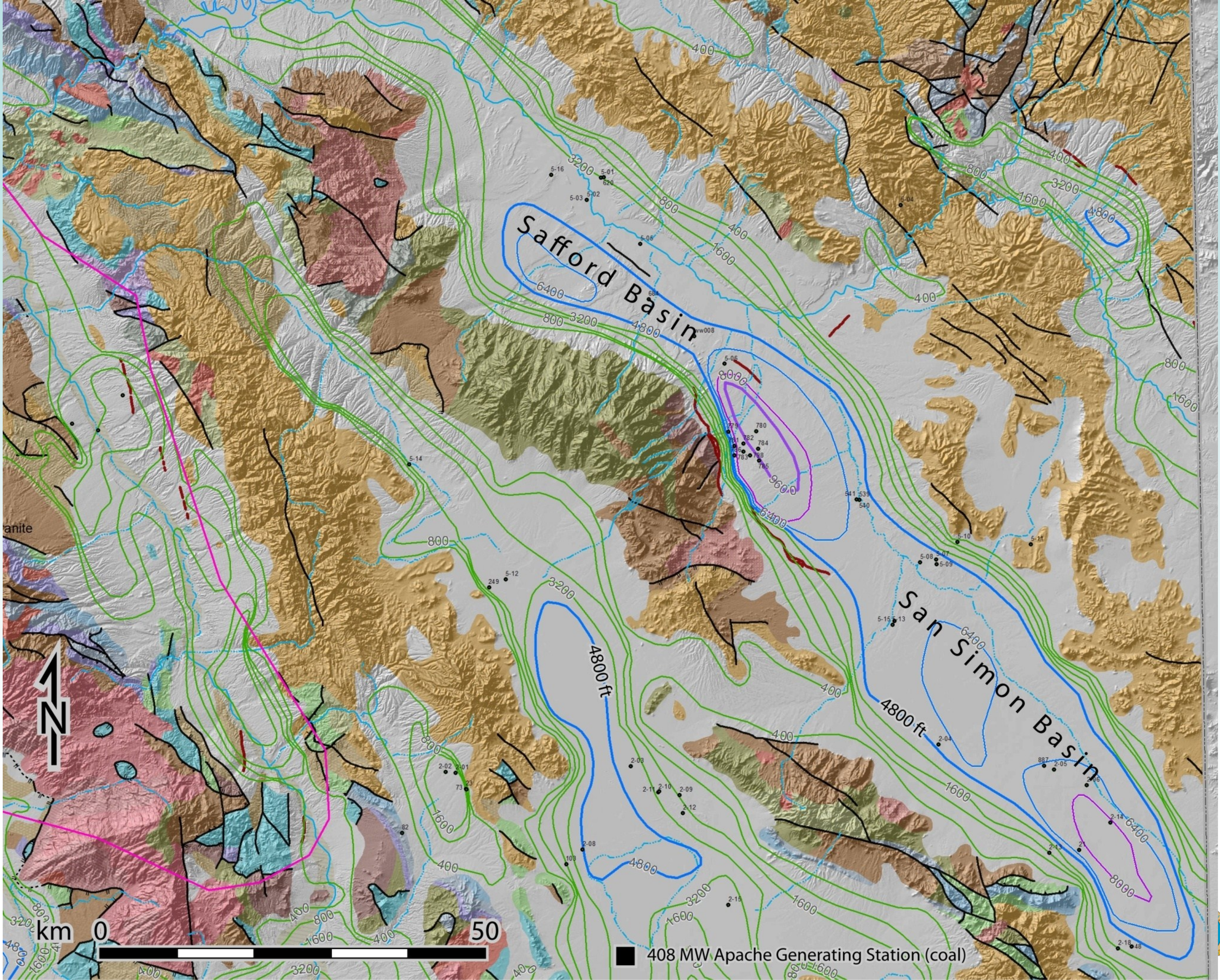
Volume below 800m depth of Cenozoic sedimentary basins in Arizona



71% of total Cenozoic basin volume below 800m depth is located in ten basins

Basin volumes below 800 m depth calculated from depth-to-bedrock contours using ArcMap tools

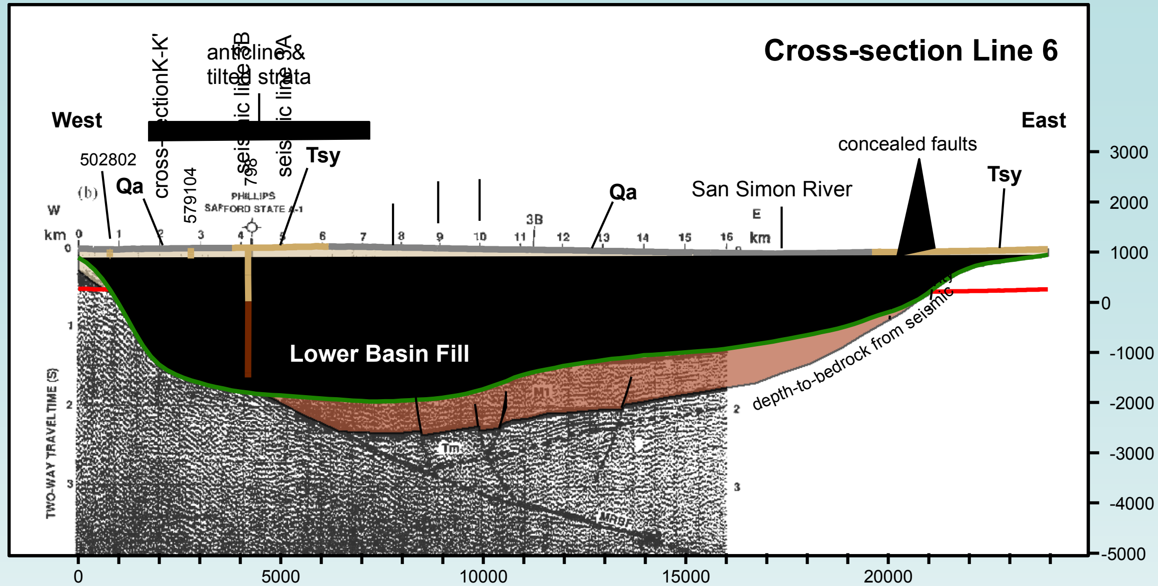


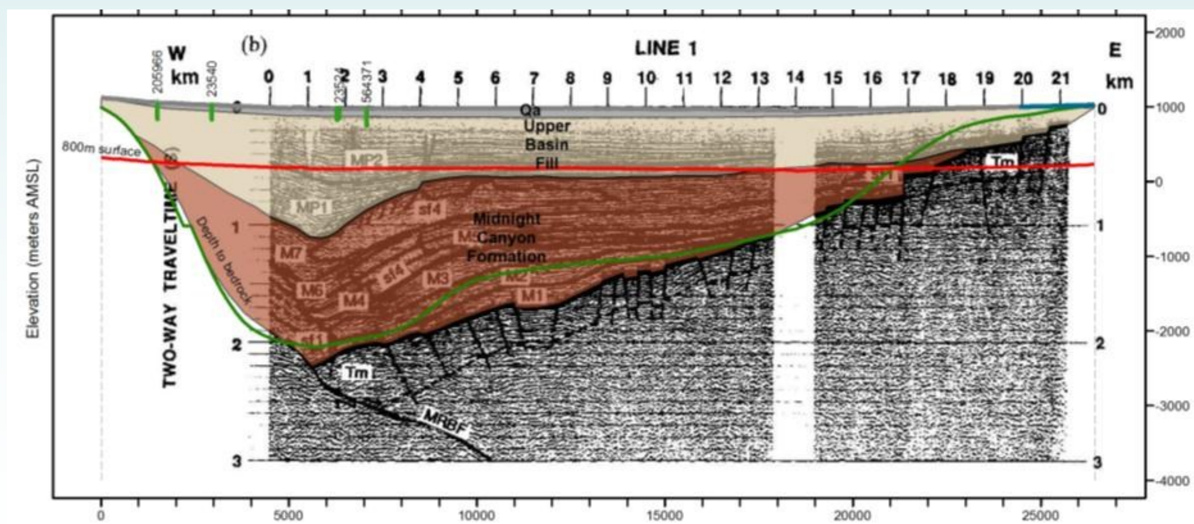


Safford Basin
San Simon Basin
4800 ft
km 0 50
408 MW Apache Generating Station (coal)

Structure

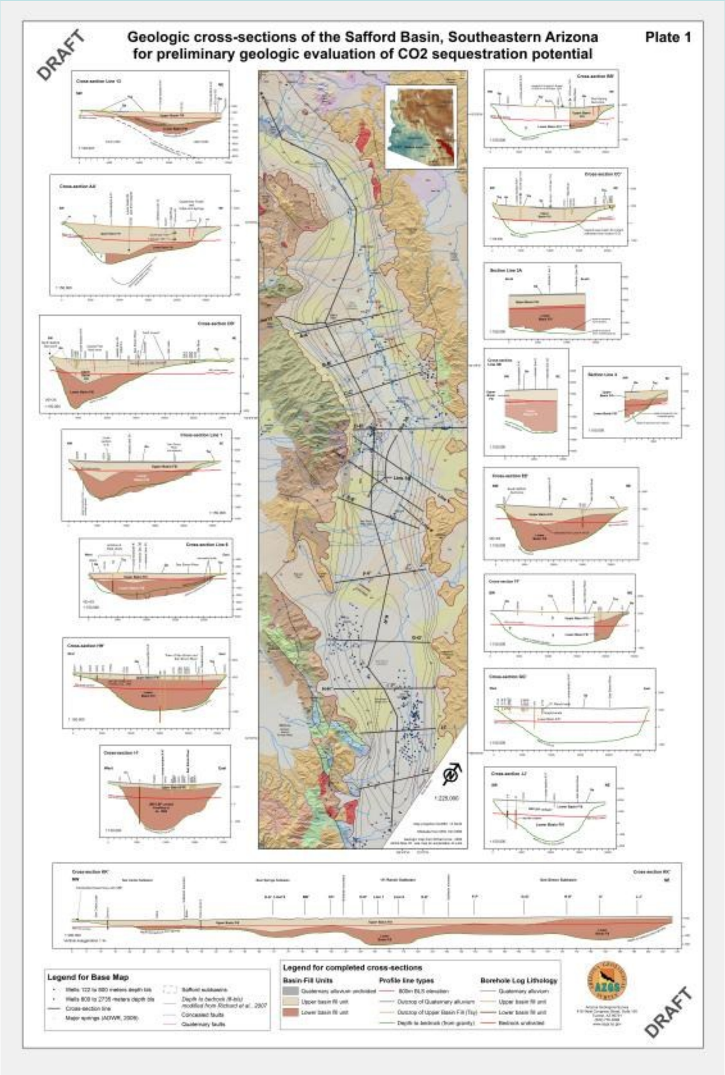
- Closed-basin in a half-graben, hinged-facies model
- Generally more deformation in the lower unit (folds, tilted bedding and faults)
- Fault activity present from late Miocene to late Pleistocene



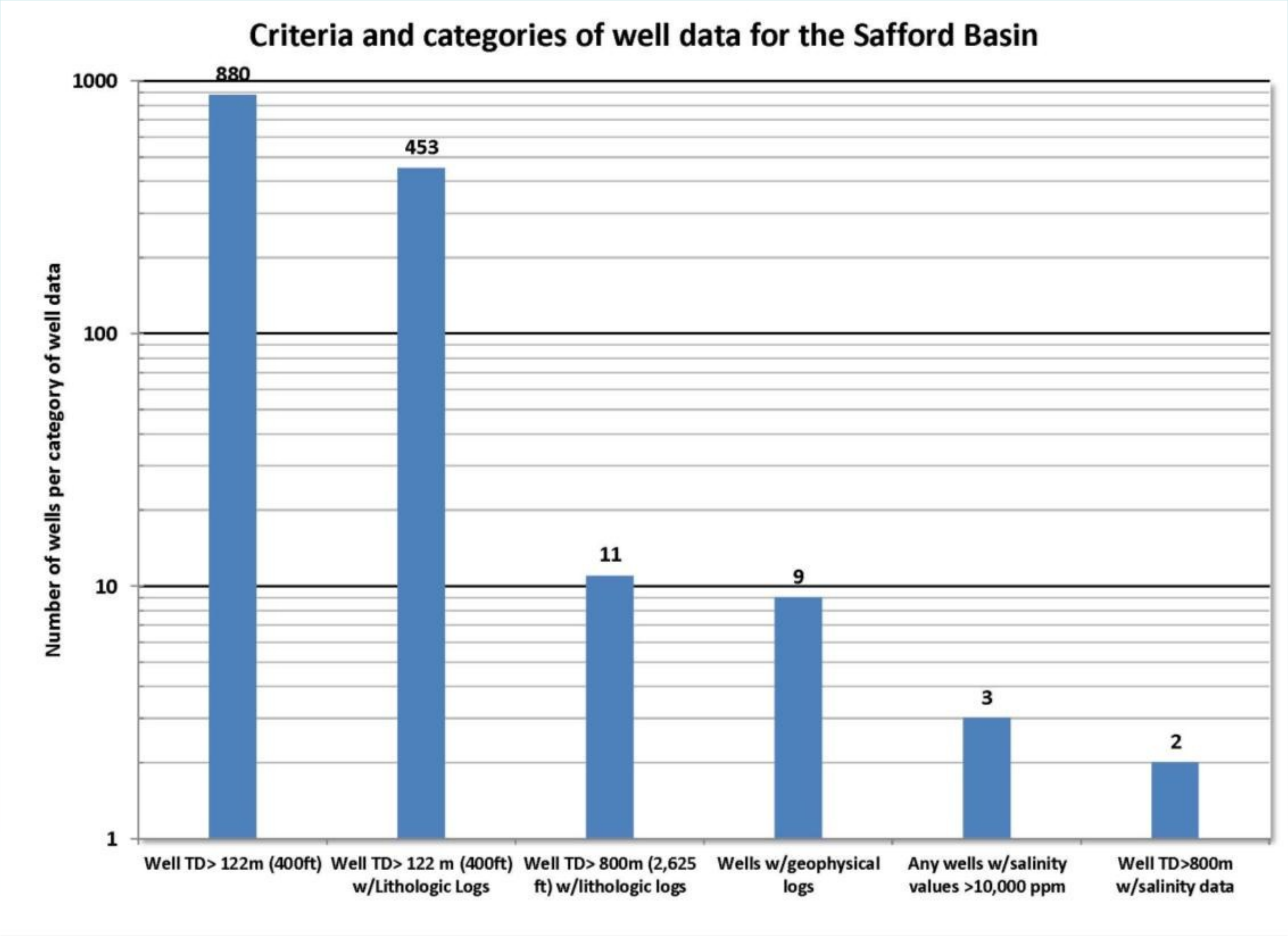


Stratigraphy and Structure in the Safford Basin

- Evaporite and lacustrine basin centers with alluvial fan margins
- Lower basin filling unit is considered the primary target for CO_2 storage
- Sealing conditions present in both units, although vertical and lateral limits are unknown (subsurface data absent in largest of basin centers)



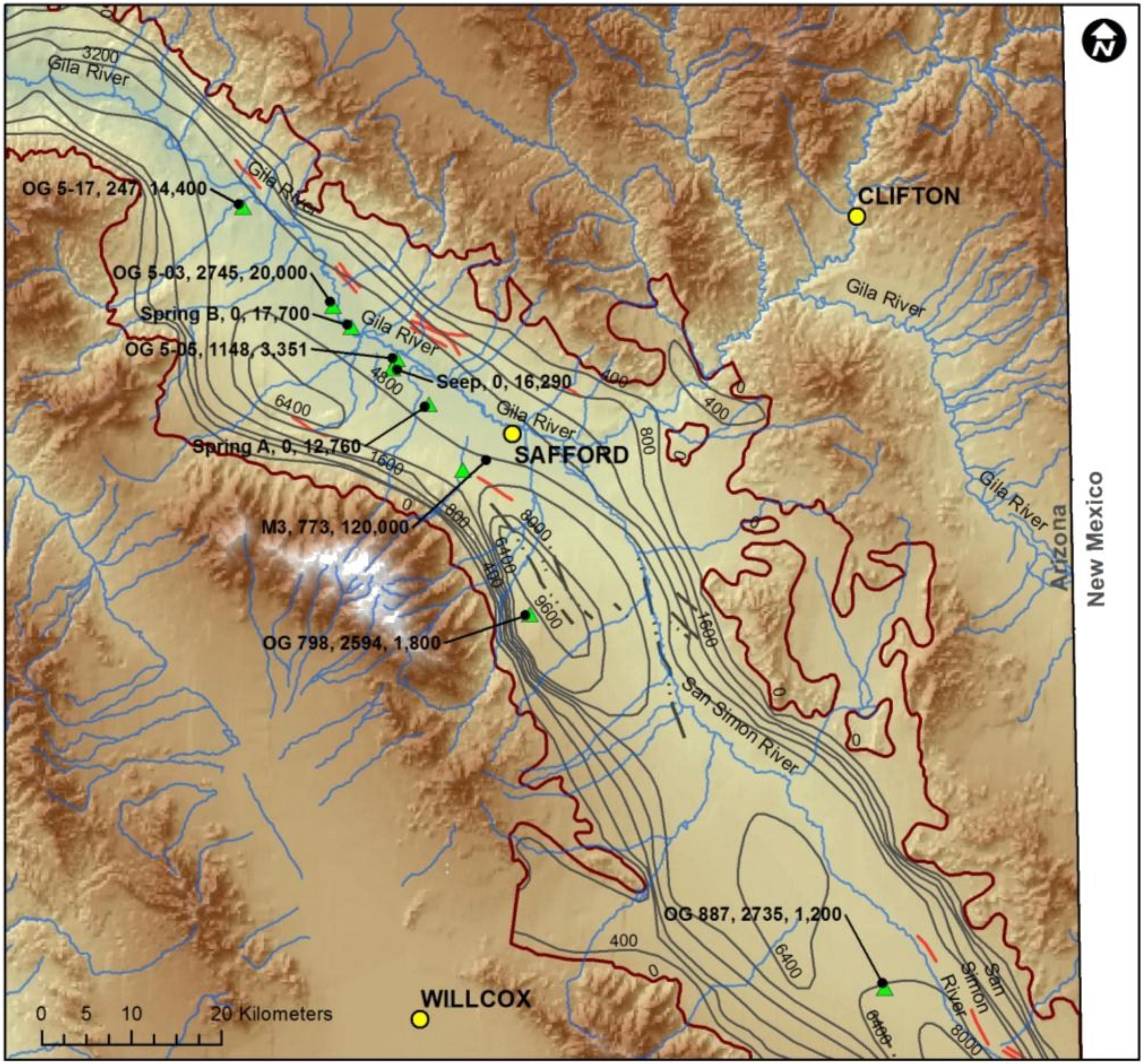
Well Data



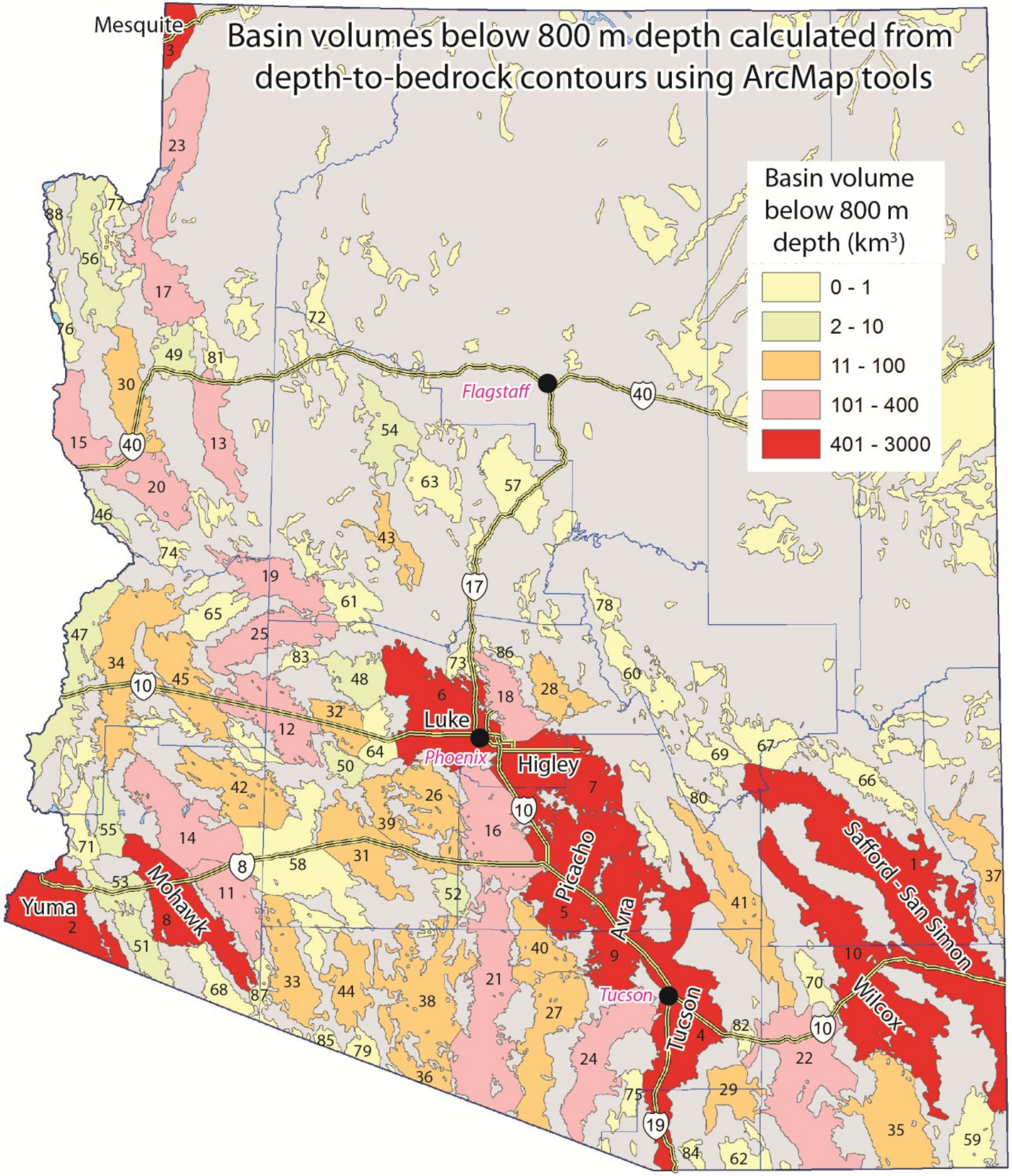
Criteria and categories of well data for the Safford Basin
Number of wells per category of well data
1000
100
10
1
880
453
11
9
3
2
Well TD> 122m (400ft)
Well TD> 122 m (400ft) w/Lithologic Logs
Well TD> 800m (2,625 ft) w/lithologic logs
Wells w/geophysical logs
Any wells w/salinity values >10,000 ppm
Well TD>800m w/salinity data

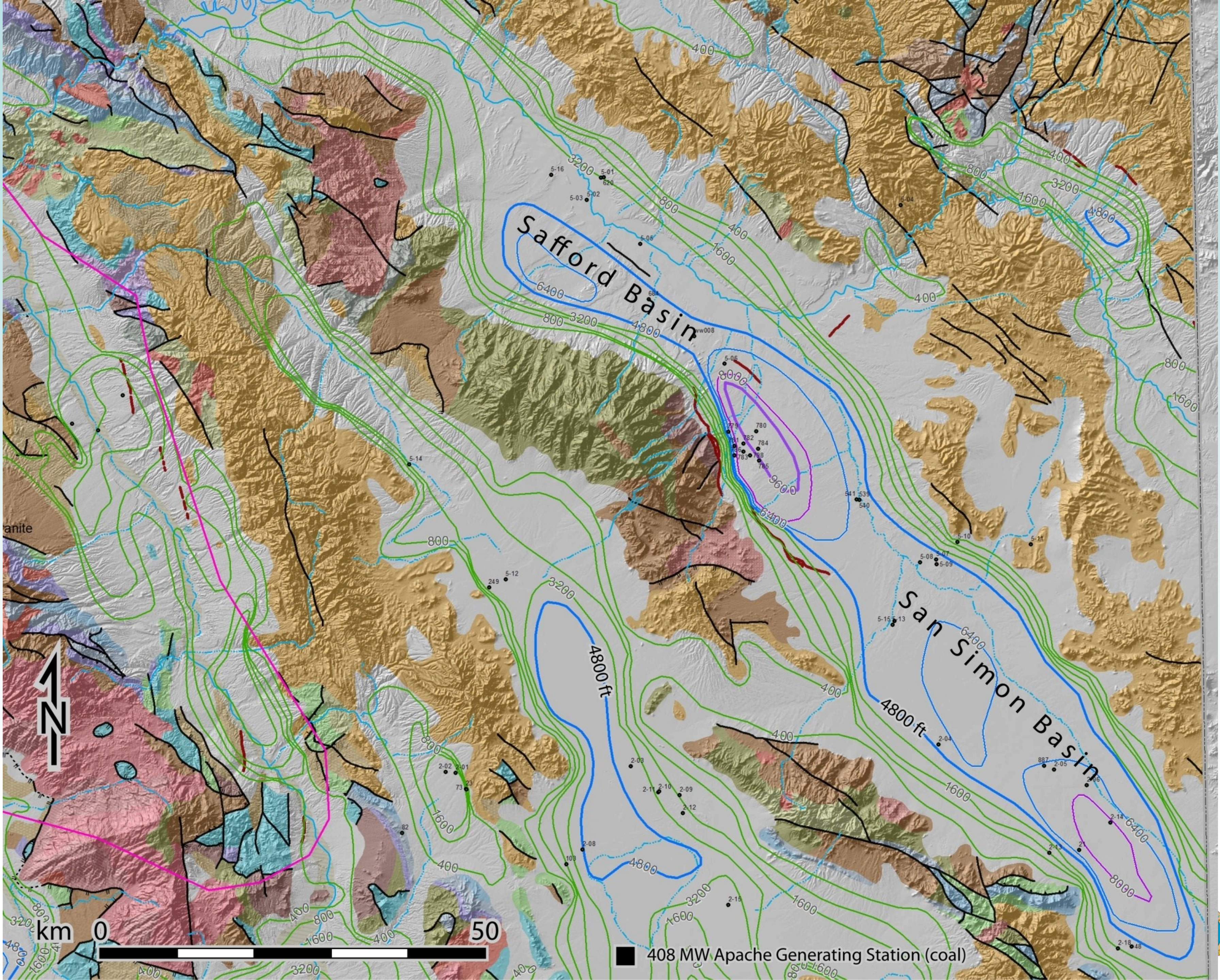
Salinity

- Limited to six wells and 3 springs
- Ranges from 300 to 120,000 ppm
- Only one well >800m depth at 14,000 ppm
- Confining and geothermal conditions
- No iso-salinity contours

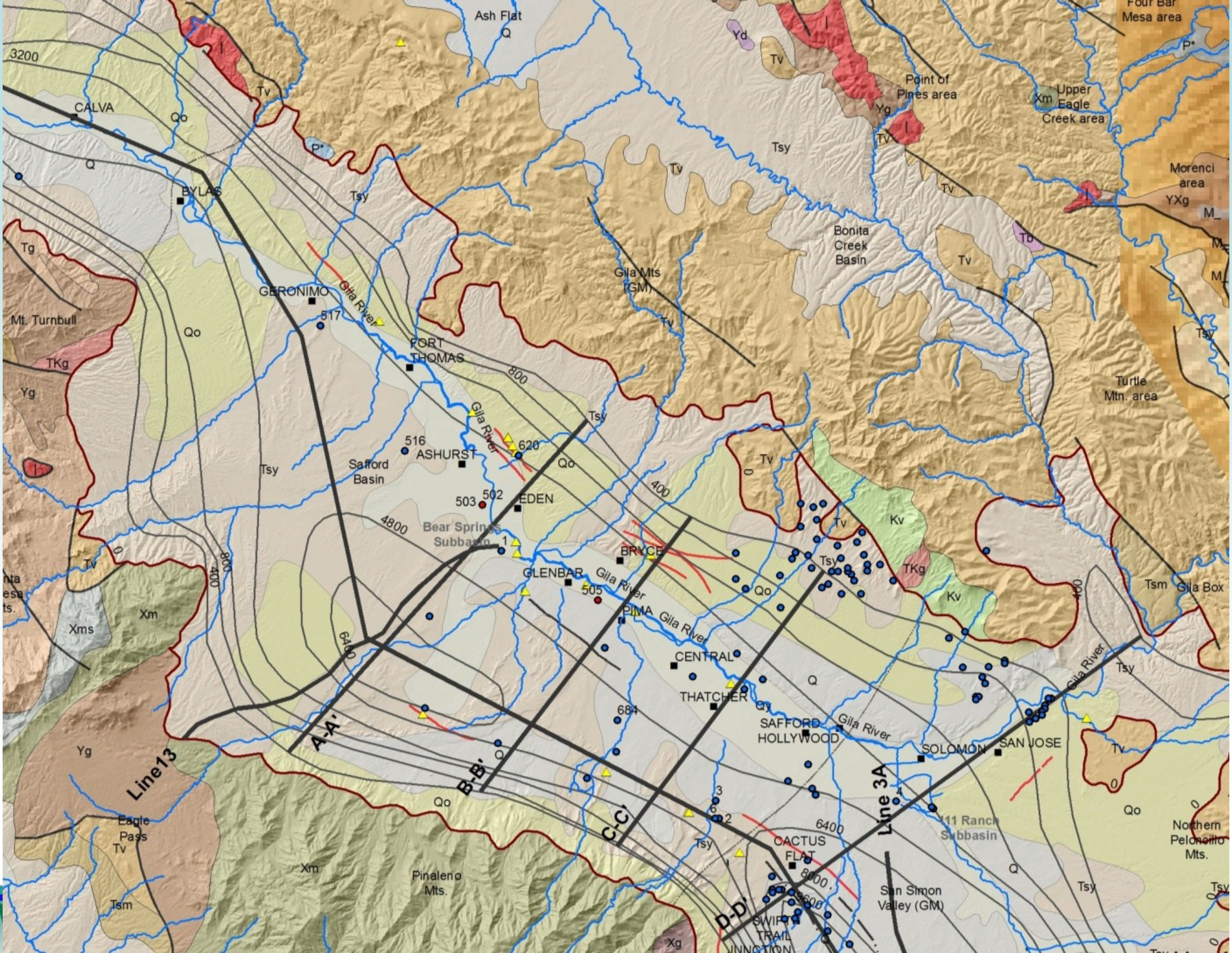


Basin volumes below 800 m depth calculated from depth-to-bedrock contours using ArcMap tools

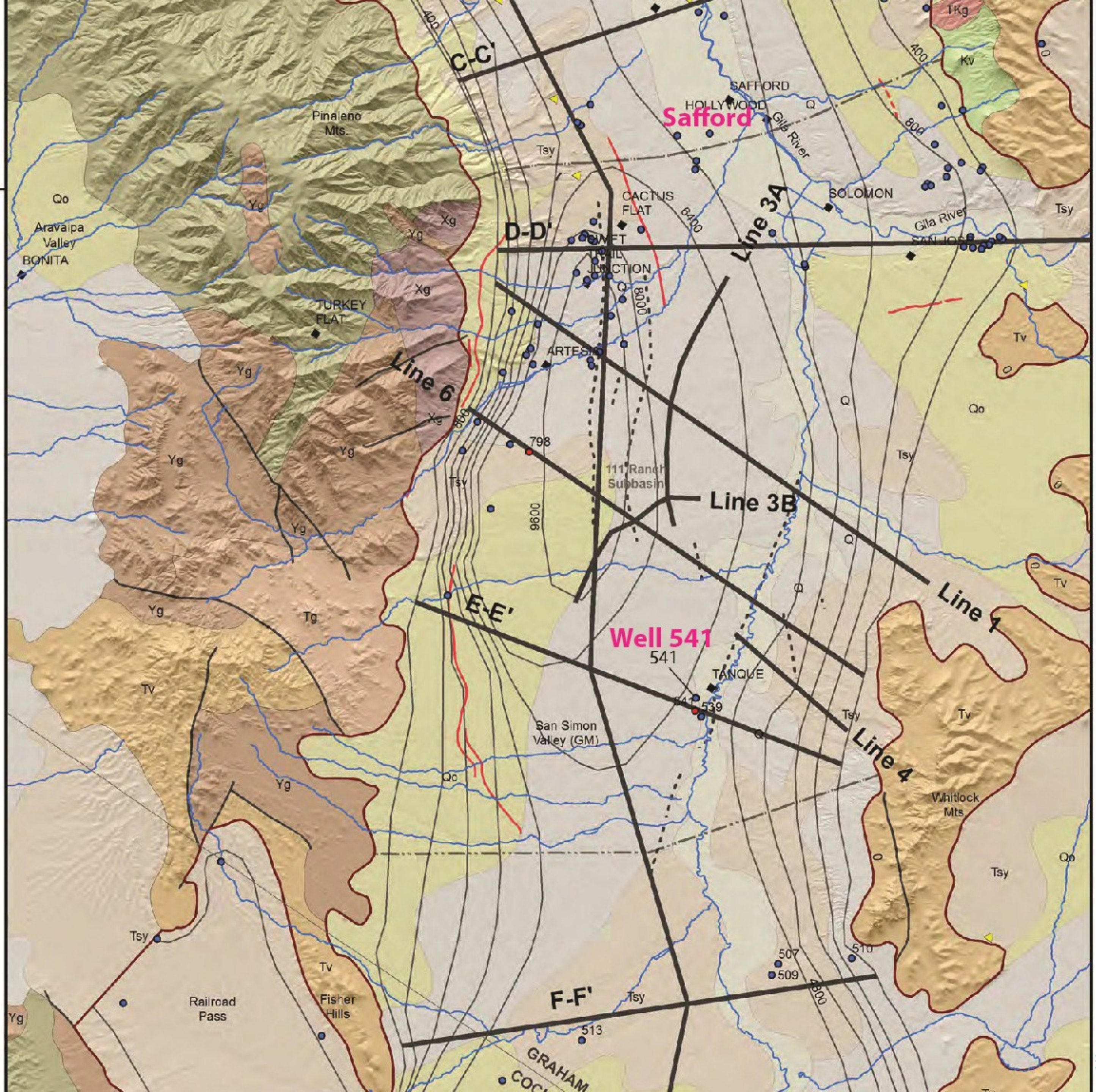




Safford Basin
San Simon Basin
4800 ft
4800 ft
km 0 50
N
408 MW Apache Generating Station (coal)



Ash Flat
Four Bar Mesa area
Point of Pines area
Upper Eagle Creek area
Morenci area
CALVA
BYLAS
GERONIMO
Gila River
PORT THOMAS
Mt. Turnbull
Bonita Creek Basin
Gila Mts (GM)
Turtle Mtn. area
ASHURST
Safford Basin
EDEN
Bear Springs Subbasin
GLENBAR
BRYCE
PIMA
CENTRAL
THATCHER
SAFFORD
HOLLYWOOD
SOLOMON
SAN JOSE
Gila Box
111 Ranch Subbasin
Northern Peloncillo Mts.
CACTUS FLAT
San Simon Valley (GM)
SWIFT TRAIL JUNCTION
Pinaleno Mts.
Eagle Pass
Line13
Line 3A
A-A'
B-B'
C-C'
D-D'


C-C'
D-D'
E-E'
F-F'
Line 1
Line 3A
Line 3B
Line 4
Line 6
Safford
Well 541
541
539
798
507
509
513
SAFFORD
HOLLYWOOD
Gila River
SOLOMON
SAN JOSE
CACTUS FLAT
SWIFT TRAIL JUNCTION
ARTESIA
TANQUE
111 Ranch Subbasin
San Simon Valley (GM)
Pinaleno Mts.
TURKEY FLAT
Aravaipa Valley
BONITA
Whitlock Mts
Railroad Pass
Fisher Hills
GRAHAM
Qo
Q
Tsy
Tv
Tg
Yg
Xg
Kv
TKg
400
800
6400
8000
9600