# A test of the utility of otolith chemistry for studying movements of fishes in the Colorado River

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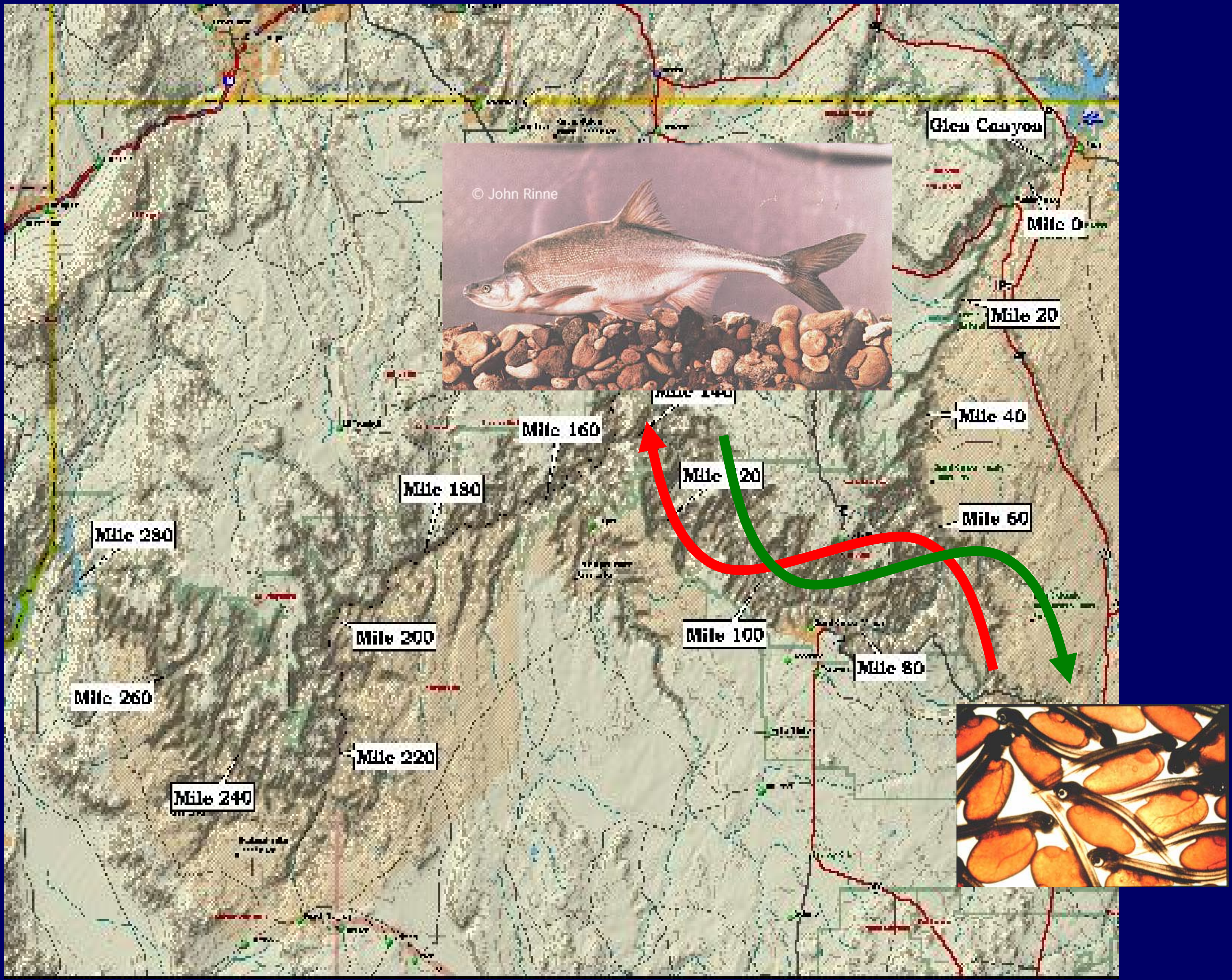
*US Forest Service, Northeastern Research Station*

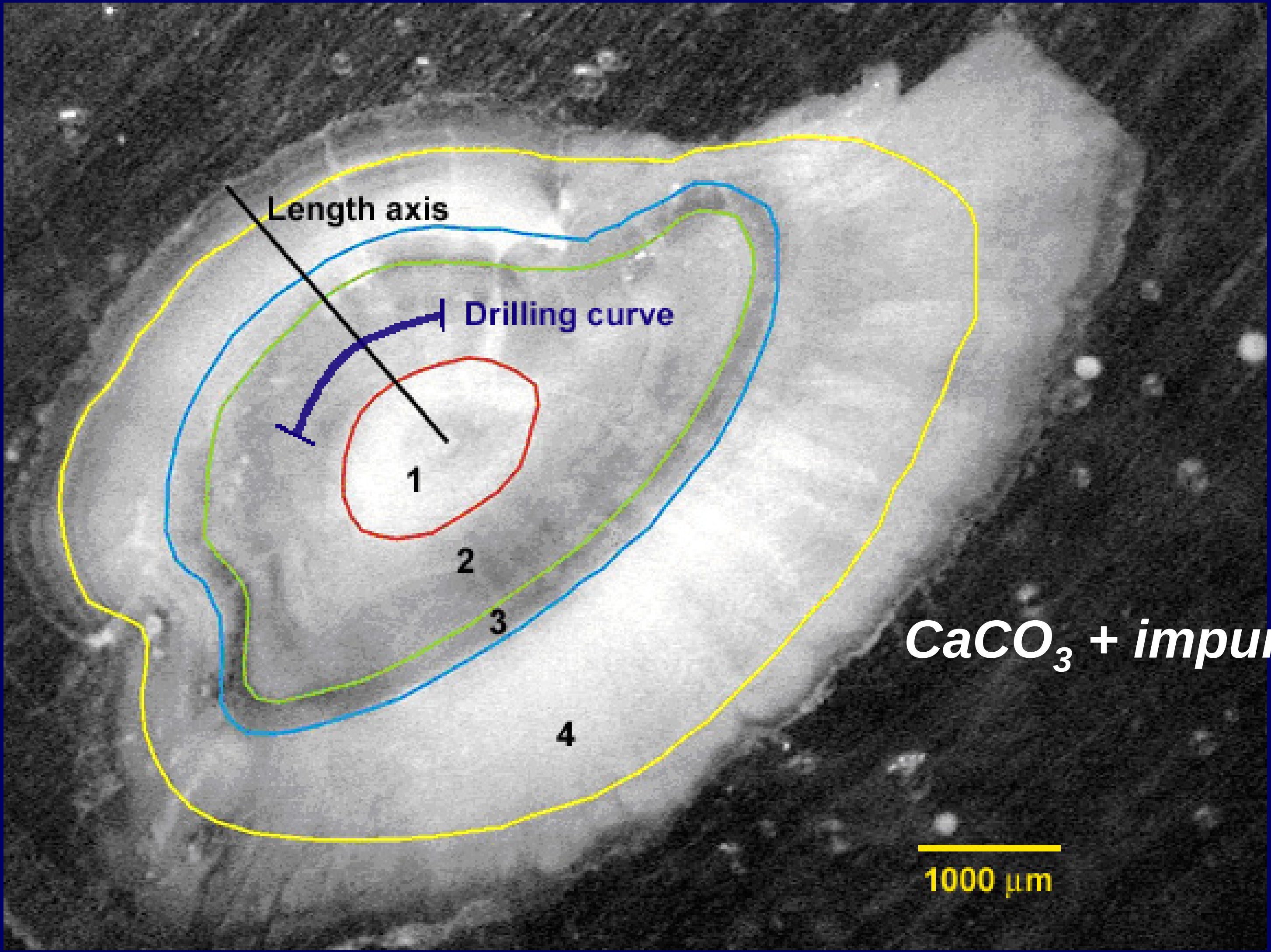
**Lew Coggins**

*Grand Canyon Monitoring and Research Center, USGS*


Glen Canyon
Mile 0
Mile 20
Mile 40
Mile 60
Mile 80
Mile 100
Mile 160
Mile 180
Mile 200
Mile 220
Mile 240
Mile 260
Mile 280
© John Rinne

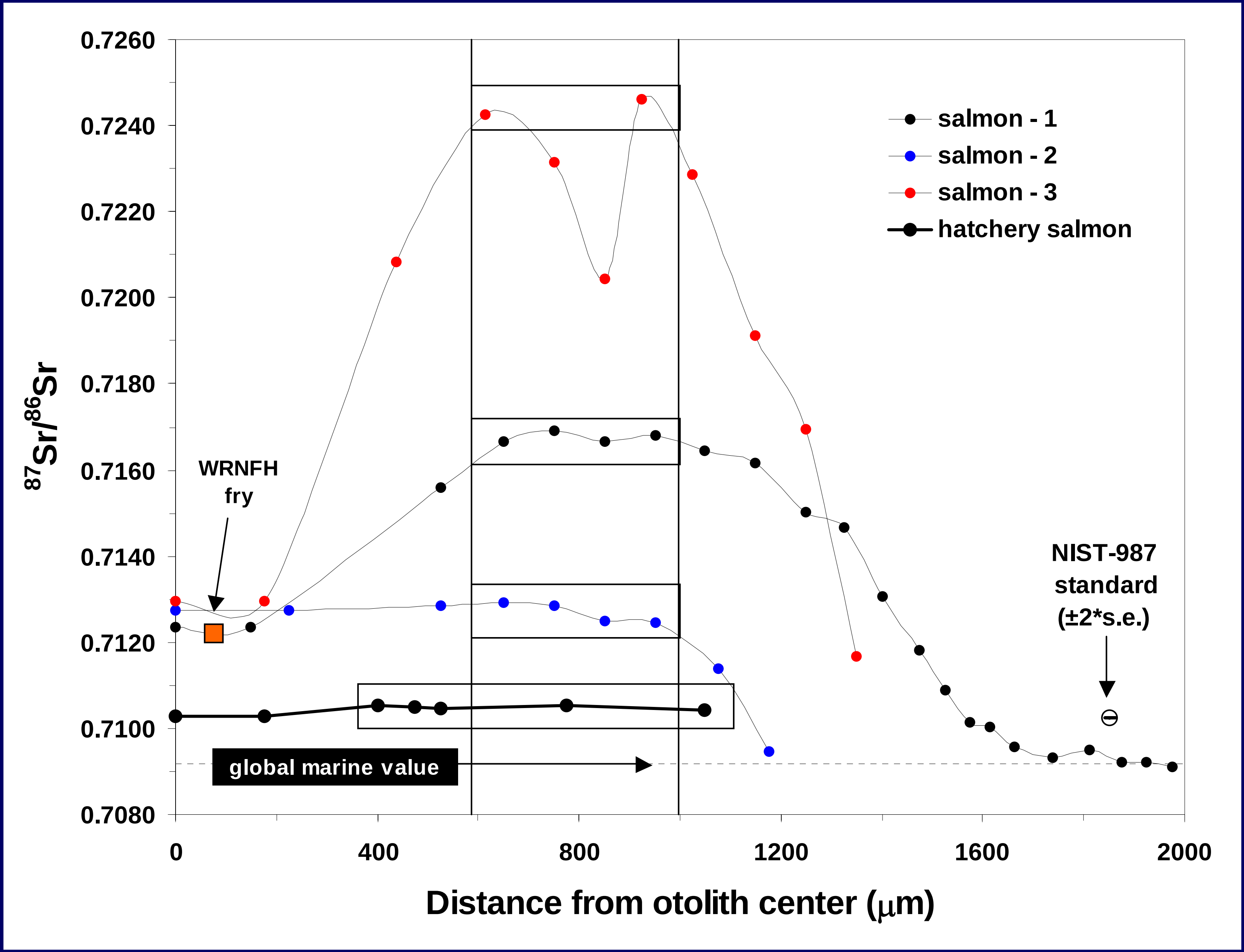
Glen Canyon
Mile 40
Mile 60
Mile 80
Mile 120
Mile 140
Mile 160
Mile 180
Mile 200
Mile 220
Mile 240
Mile 260
Mile 280

# *Fish otoliths*




***$CaCO_3$ + impurities***

Kennedy et al. *CJFAS* 2002




Kennedy et al. *CJFAS* 2002

# *Objectives of this study*

- **Develop a geochemical map of drainages in the Grand Canyon based upon geology and water chemistry.**

- **Characterize the temporal and spatial variation of water chemistry in Colorado River.**

- **Compare discriminatory power of otolith chemical and isotopic signatures.**

- **Develop a *predictive* model of otolith microchemical variation.**

# *Ideal characteristics of chemical tag*

- **Predictable spatial patterns**
- **High spatial variability among sites/regions**
- **Low temporal variability**
- **No metabolic interferences or fractionations**
- **Easily recovered and measured**

# *Elemental ratios (Sr/Ca) and Strontium isotopes ($^{87}Sr/^{86}Sr$)*

- **Geologically-derived signature**

  $^{87}Sr/^{86}Sr_{\textit{stream water}}$ = f (bedrock age and composition)

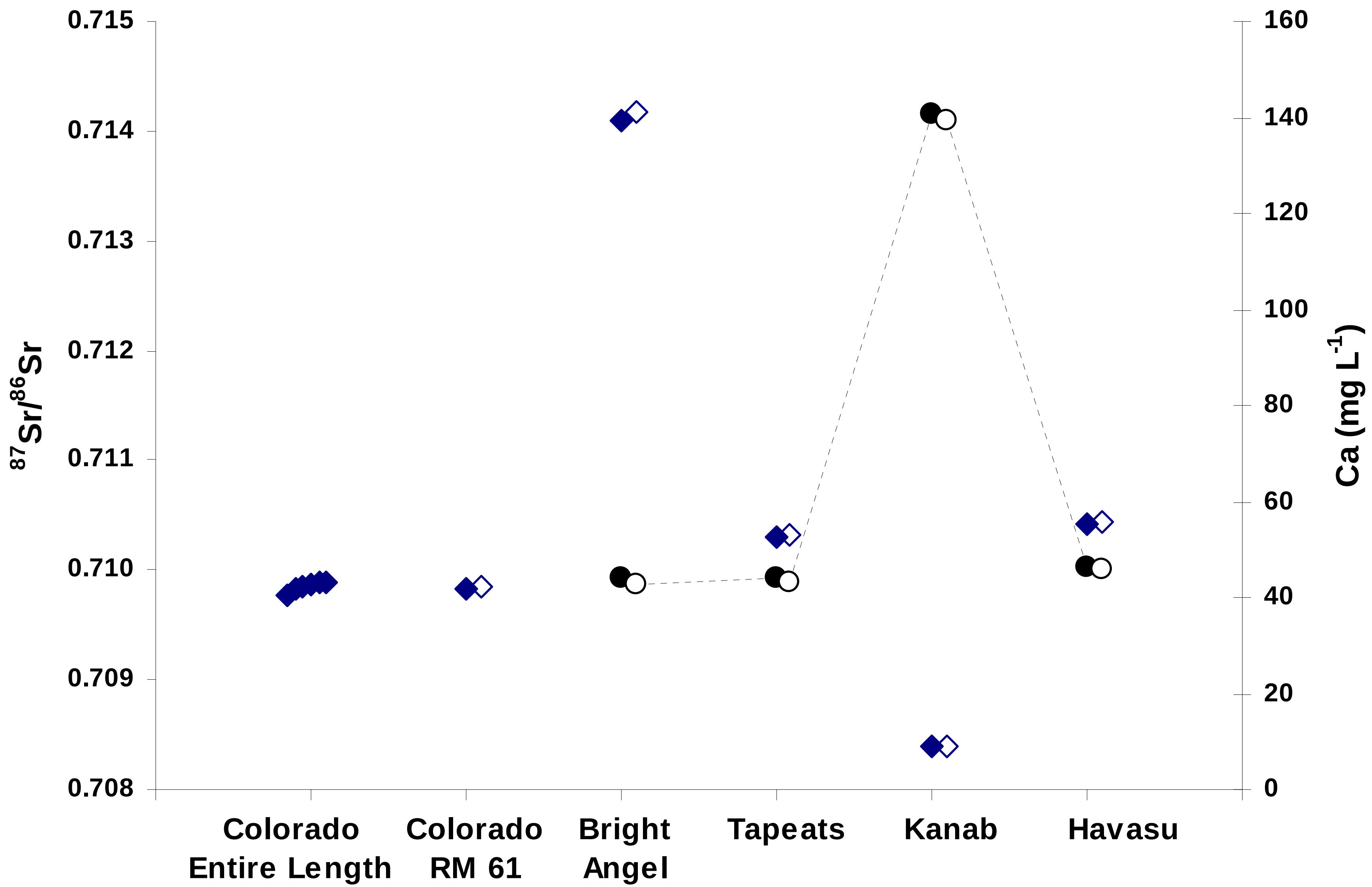
- **No biological fractionation**

  $^{87}Sr/^{86}Sr_{\textit{stream water}} = {}^{87}Sr/^{86}Sr_{\textit{resident organisms}}$

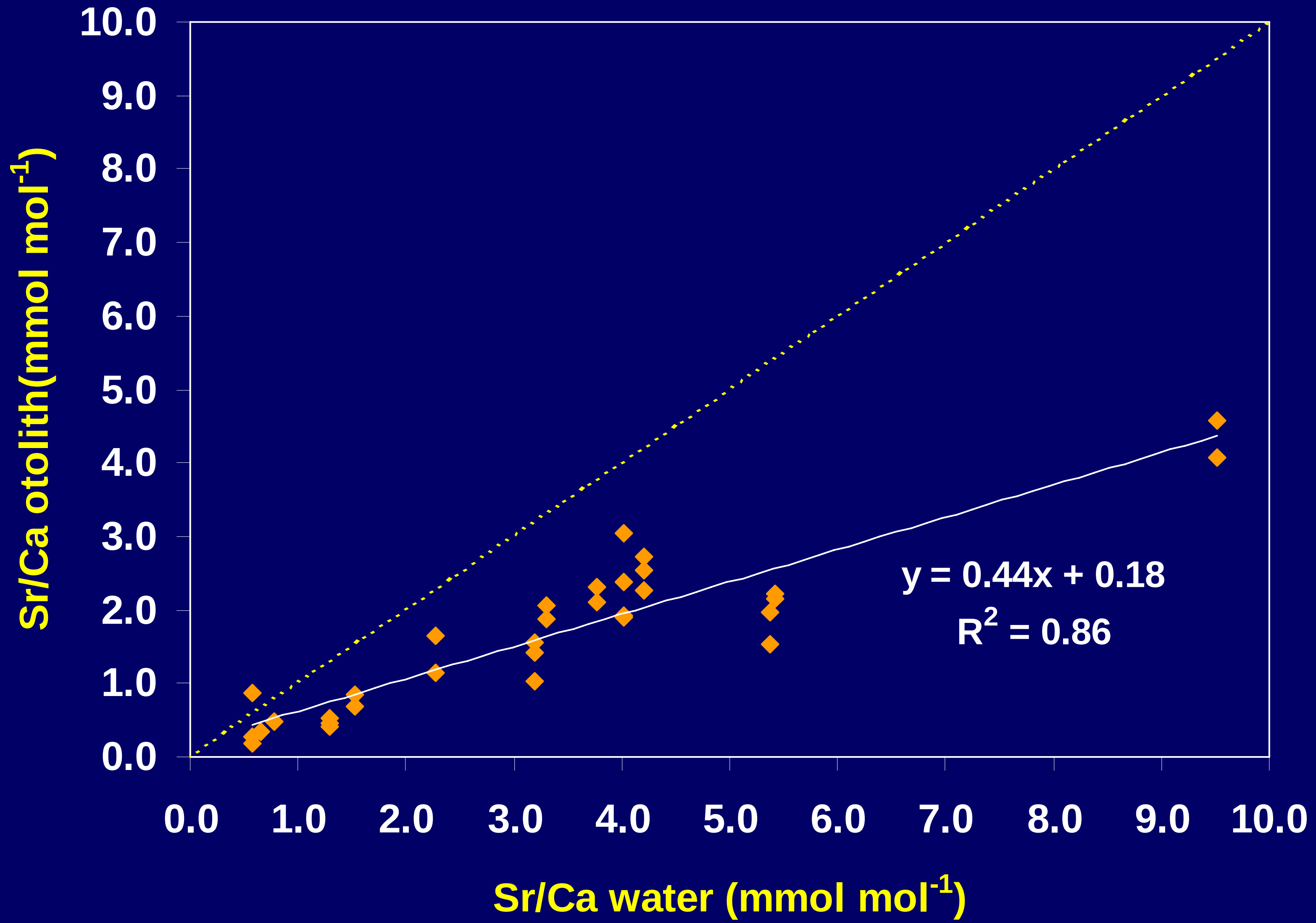
# *Analytical Methods*

- Water and fish** sampled at two times in 2002.
- Samples digested and prepared for isotope and elemental analysis in class-100 clean laboratory.
- Elemental ratios analyzed in solution with Finnegan MAT Element II ICP-MS.
- Sr isotopes analyzed with Finnegan MAT 262 multi-collector thermal ionization mass spectrometer.
- Analytical precision: $^{87}Sr/^{86}Sr_{standard} = 0.710243 \pm 0.00001$

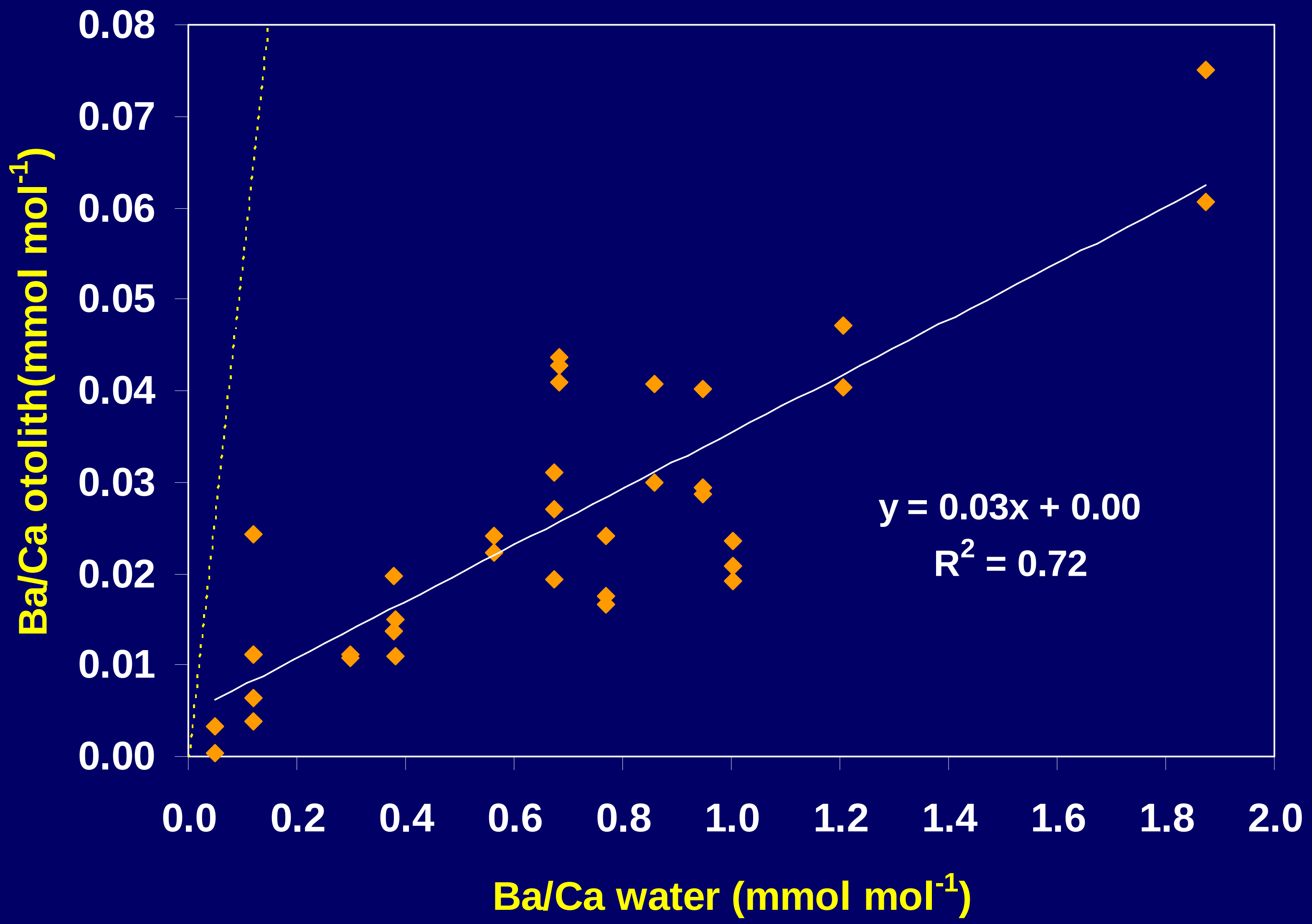

KAIBAB FORMATION
TOROWEAP FORMATION
COCONINO SANDSTONE
HERMIT SHALE
SUPAI GROUP
ESPLANADE SANDSTONE
WESCOGAME FORMATION
MANAKACHA FORMATION
WATAHOMIGI FORMATION
SURPRISE CANYON FORMATION
REDWALL LIMESTONE
TEMPLE BUTTE LIMESTONE
TONTO GROUP
MUAV LIMESTONE
BRIGHT ANGEL SHALE
TAPEATS SANDSTONE
VISHNU SCHIST
© Jim Thomas www.seek



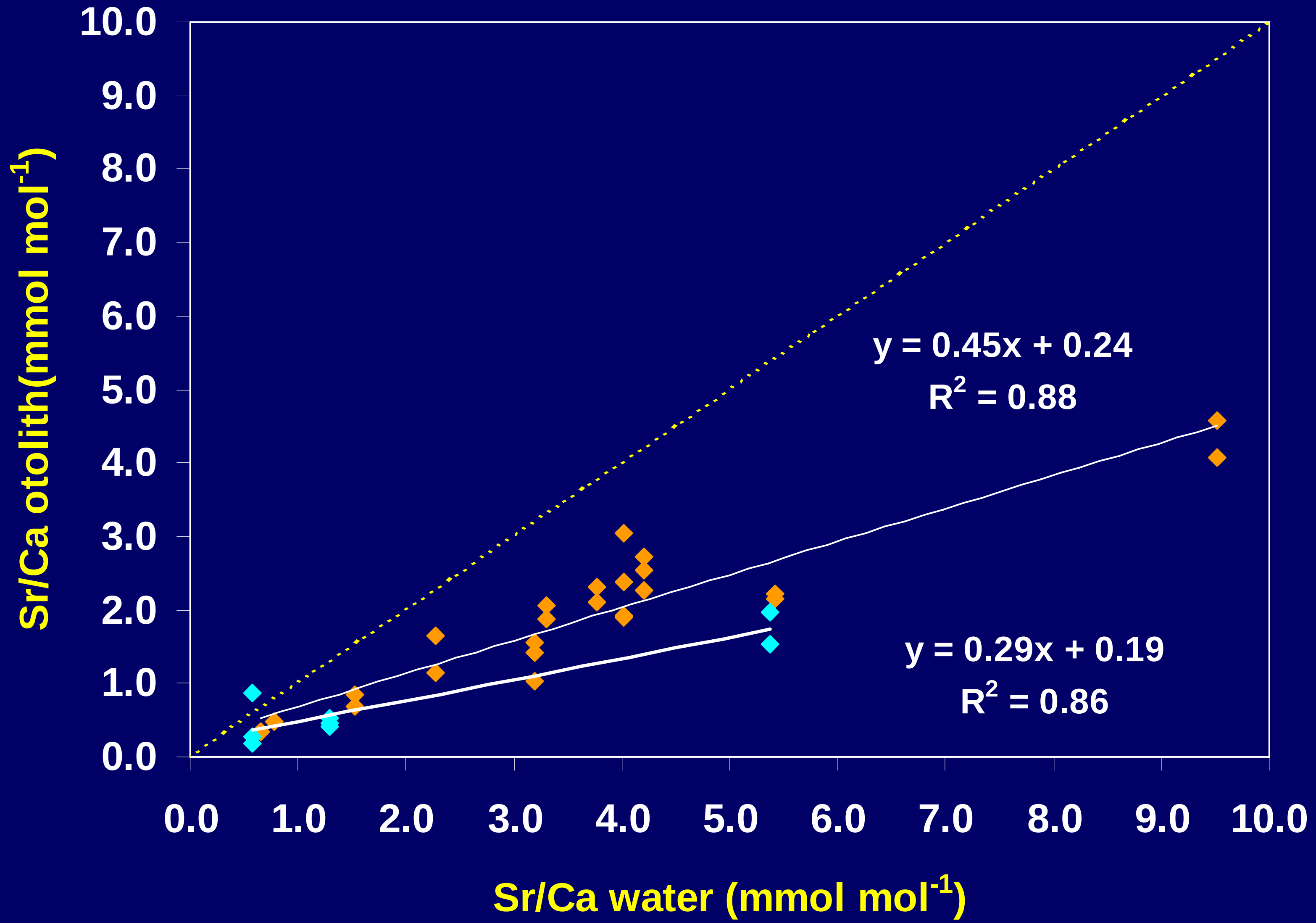
0.715
0.714
0.713
0.712
0.711
0.710
0.709
0.708
$^{87}Sr/^{86}Sr$
160
140
120
100
80
60
40
20
0
Ca (mg L$^{-1}$)
Colorado Entire Length
Colorado RM 61
Bright Angel
Tapeats
Kanab
Havasu



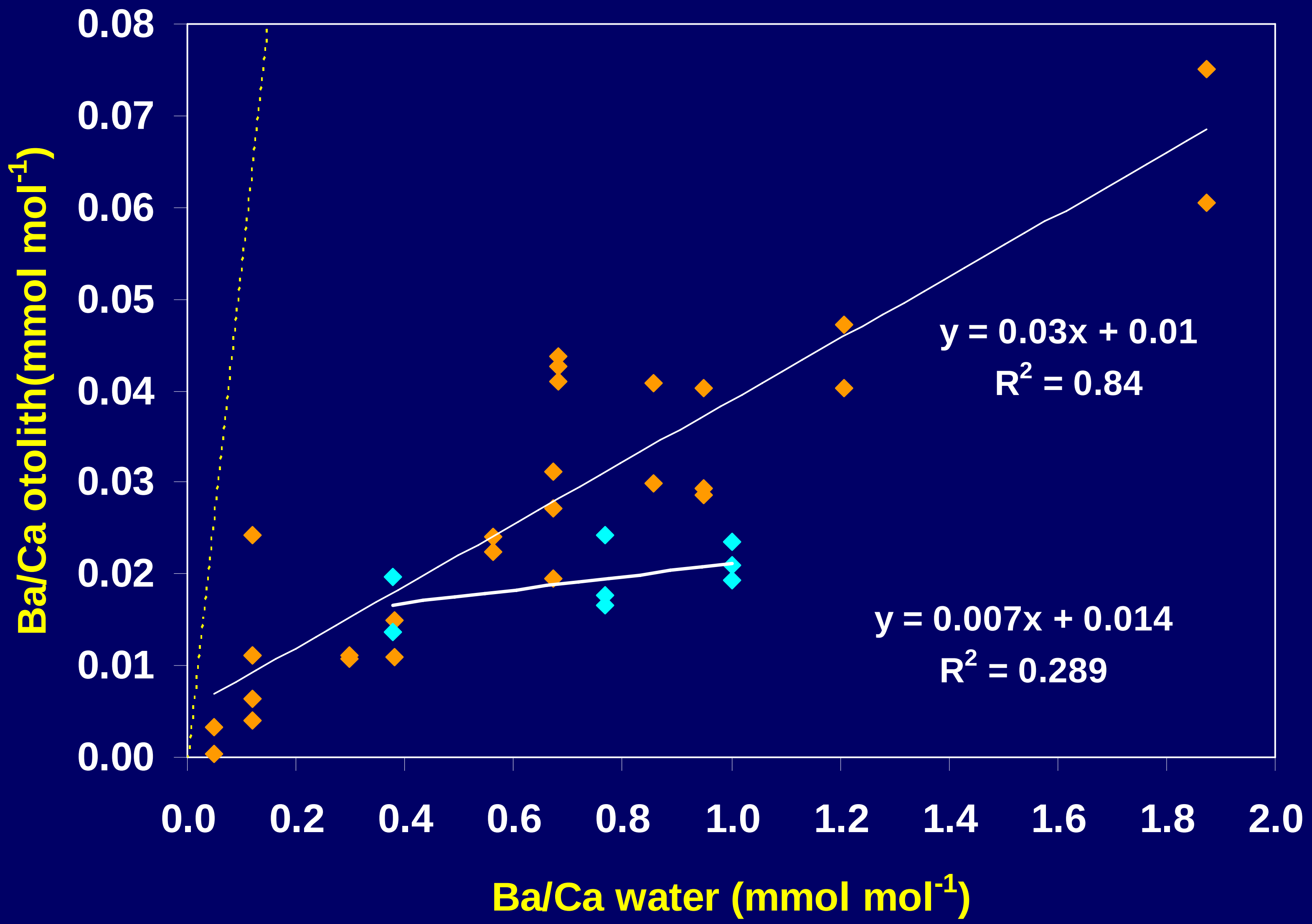
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Sr/Ca otolith(mmol mol-1)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Sr/Ca water (mmol mol-1)
y = 0.44x + 0.18
R2 = 0.86



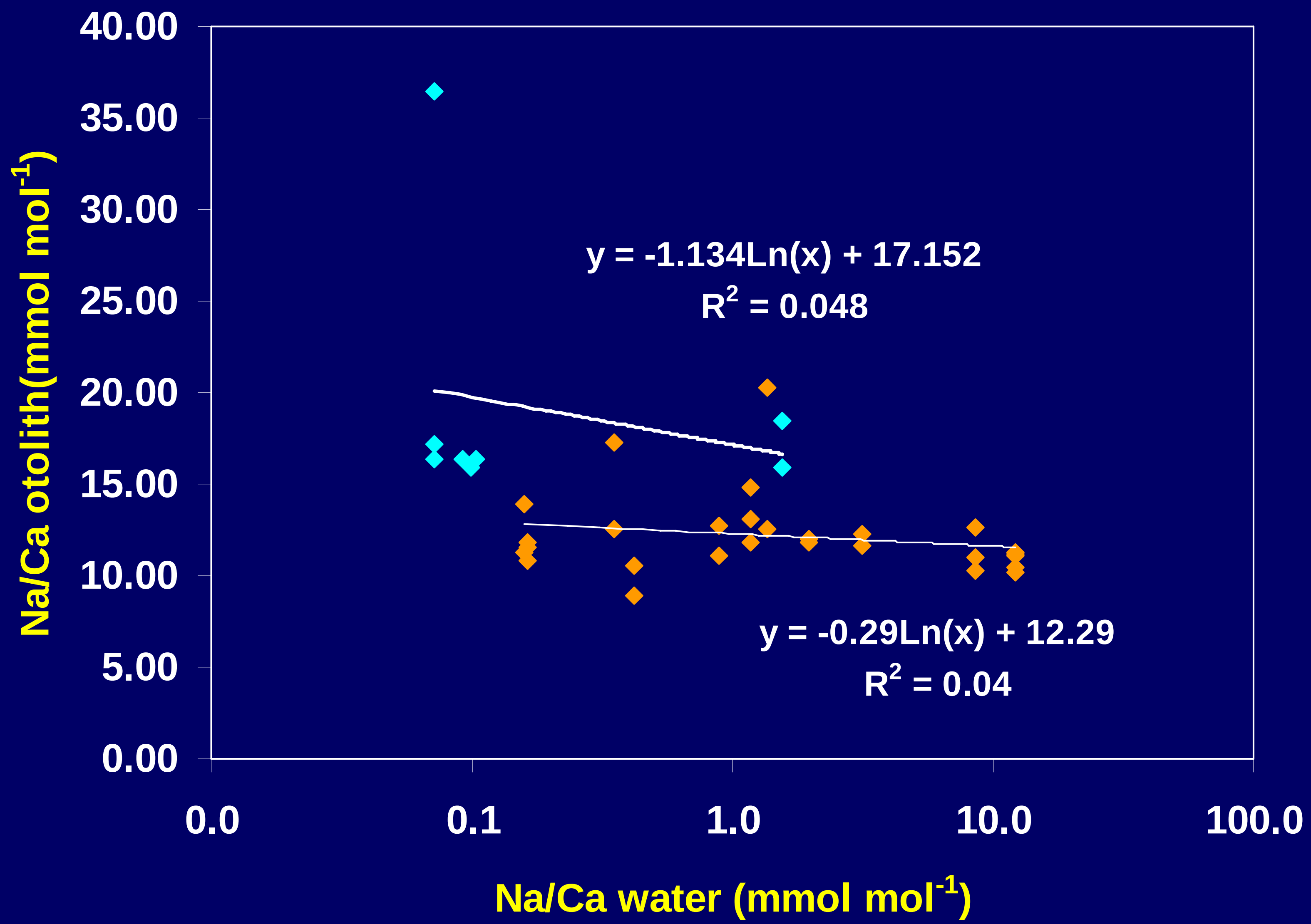
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Ba/Ca otolith(mmol mol-1)
y = 0.03x + 0.00
R2 = 0.72
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Ba/Ca water (mmol mol-1)



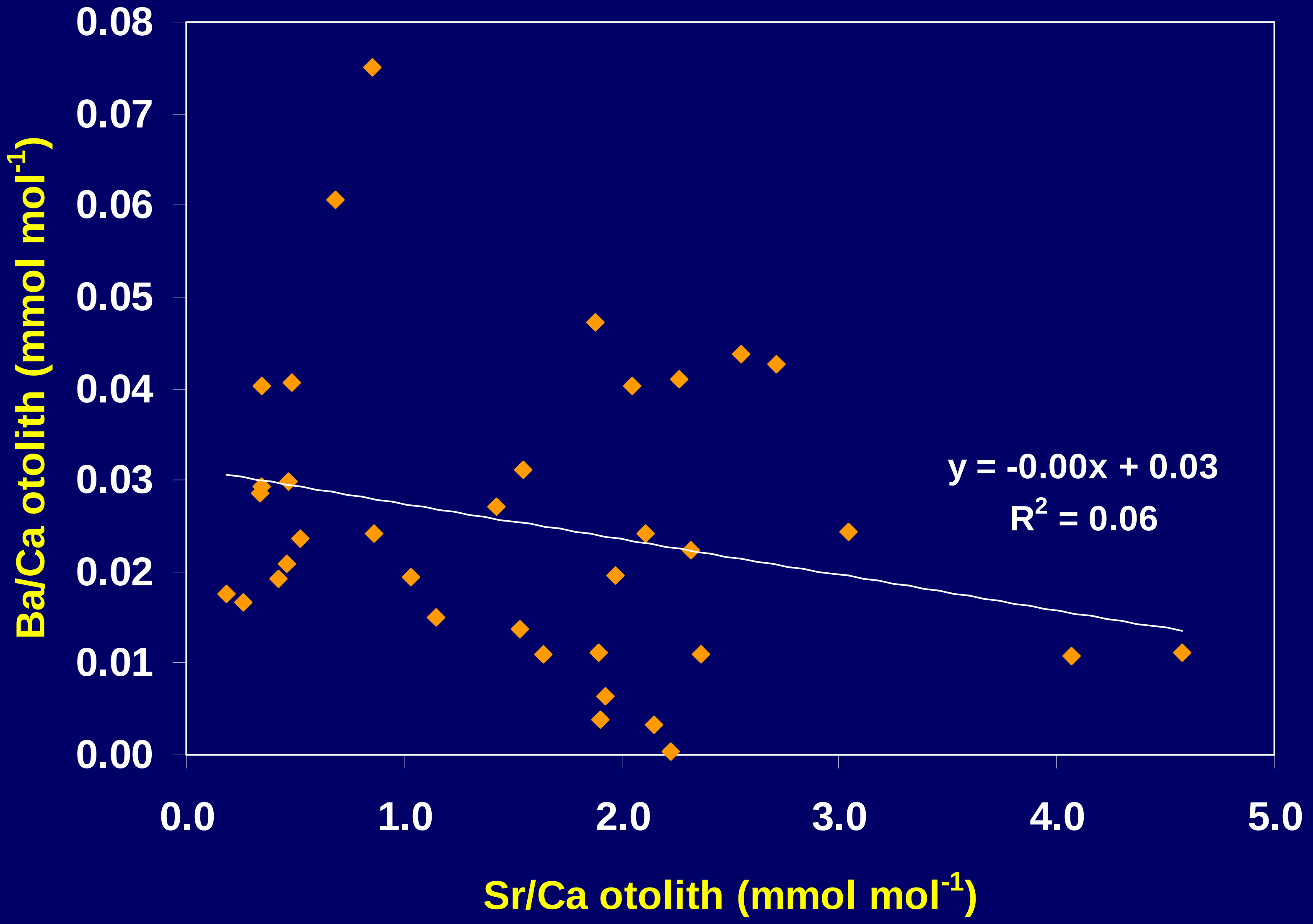
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Sr/Ca otolith(mmol mol-1)
y = 0.45x + 0.24
R2 = 0.88
y = 0.29x + 0.19
R2 = 0.86
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Sr/Ca water (mmol mol-1)



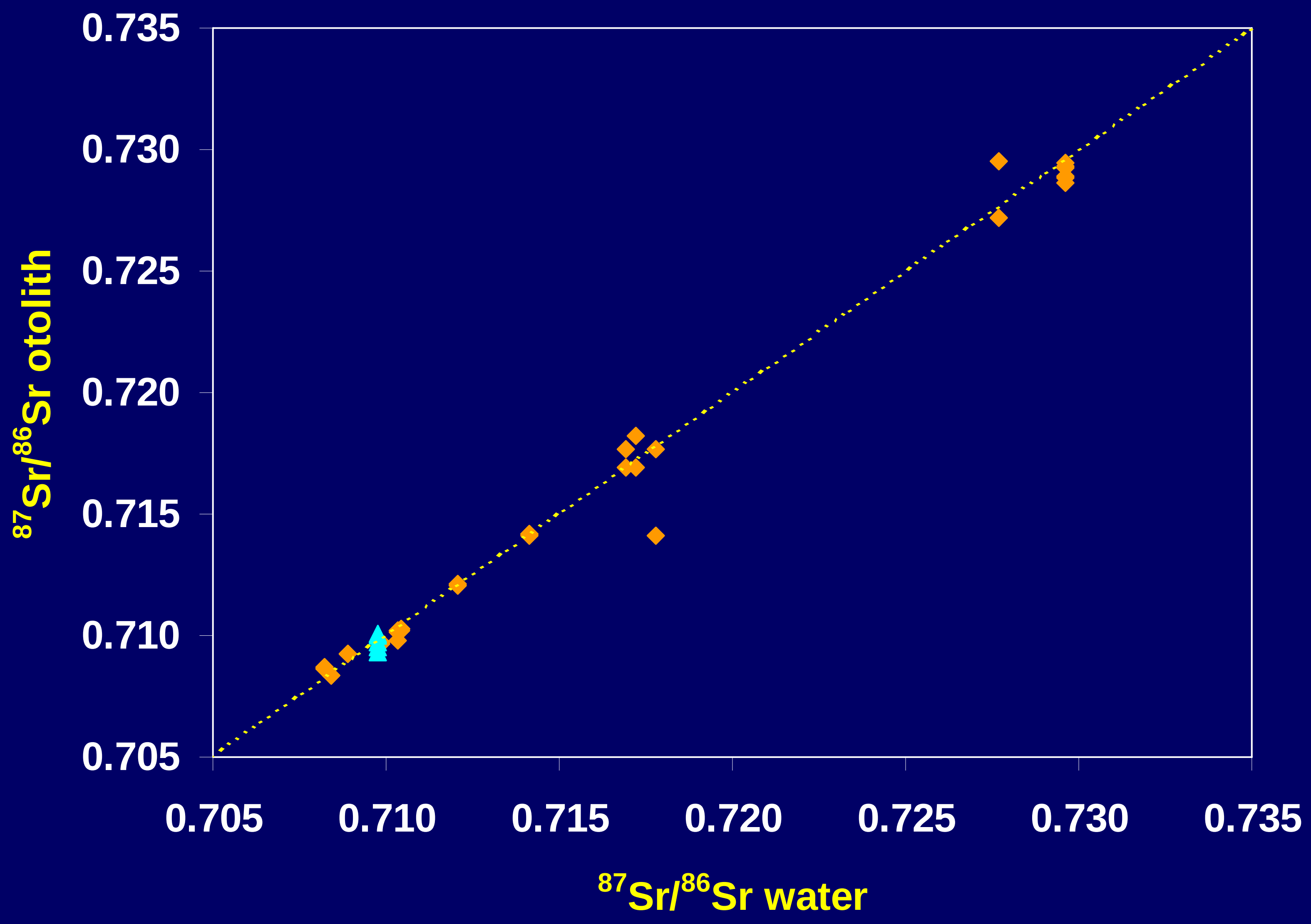
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Ba/Ca otolith(mmol mol-1)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Ba/Ca water (mmol mol-1)
y = 0.03x + 0.01
R2 = 0.84
y = 0.007x + 0.014
R2 = 0.289

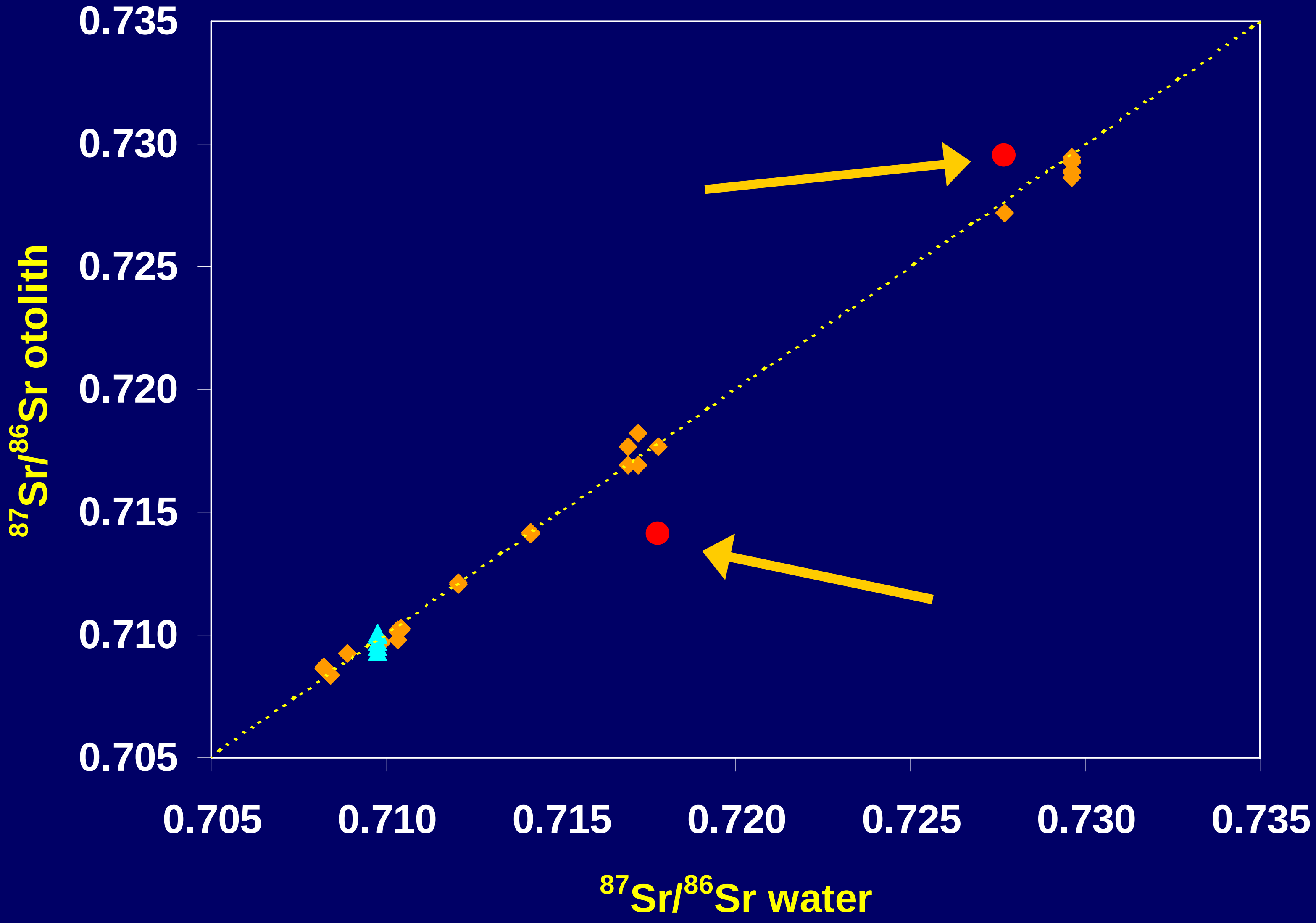


40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Na/Ca otolith(mmol mol-1)
y = -1.134Ln(x) + 17.152
R2 = 0.048
y = -0.29Ln(x) + 12.29
R2 = 0.04
0.0
0.1
1.0
10.0
100.0
Na/Ca water (mmol mol-1)

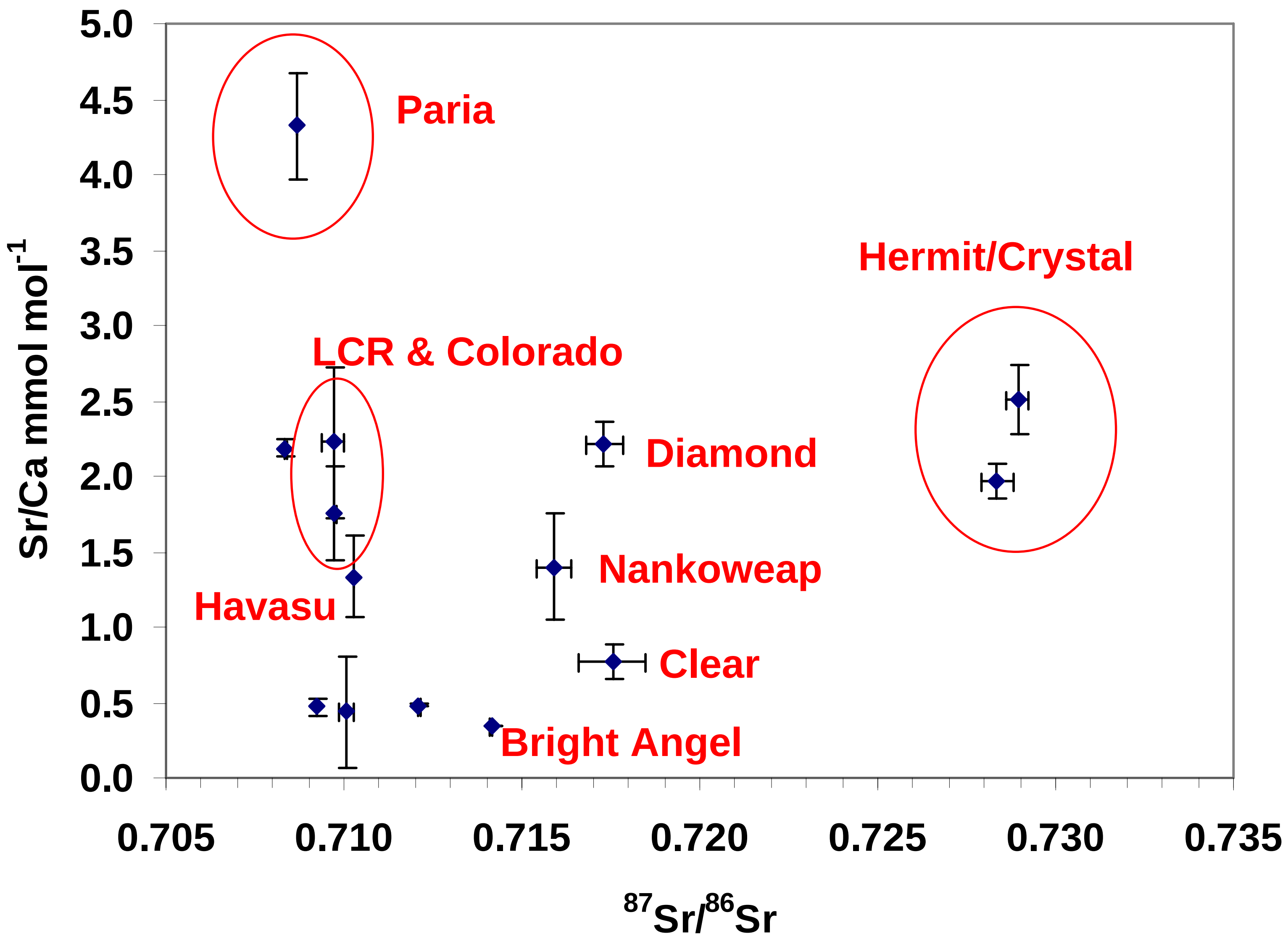


0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Ba/Ca otolith (mmol mol-1)
y = -0.00x + 0.03
R2 = 0.06
0.0
1.0
2.0
3.0
4.0
5.0
Sr/Ca otolith (mmol mol-1)


0.735
0.730
0.725
0.720
0.715
0.710
0.705
0.705
0.710
0.715
0.720
0.725
0.730
0.735
$^{87}Sr/^{86}Sr$ otolith
$^{87}Sr/^{86}Sr$ water

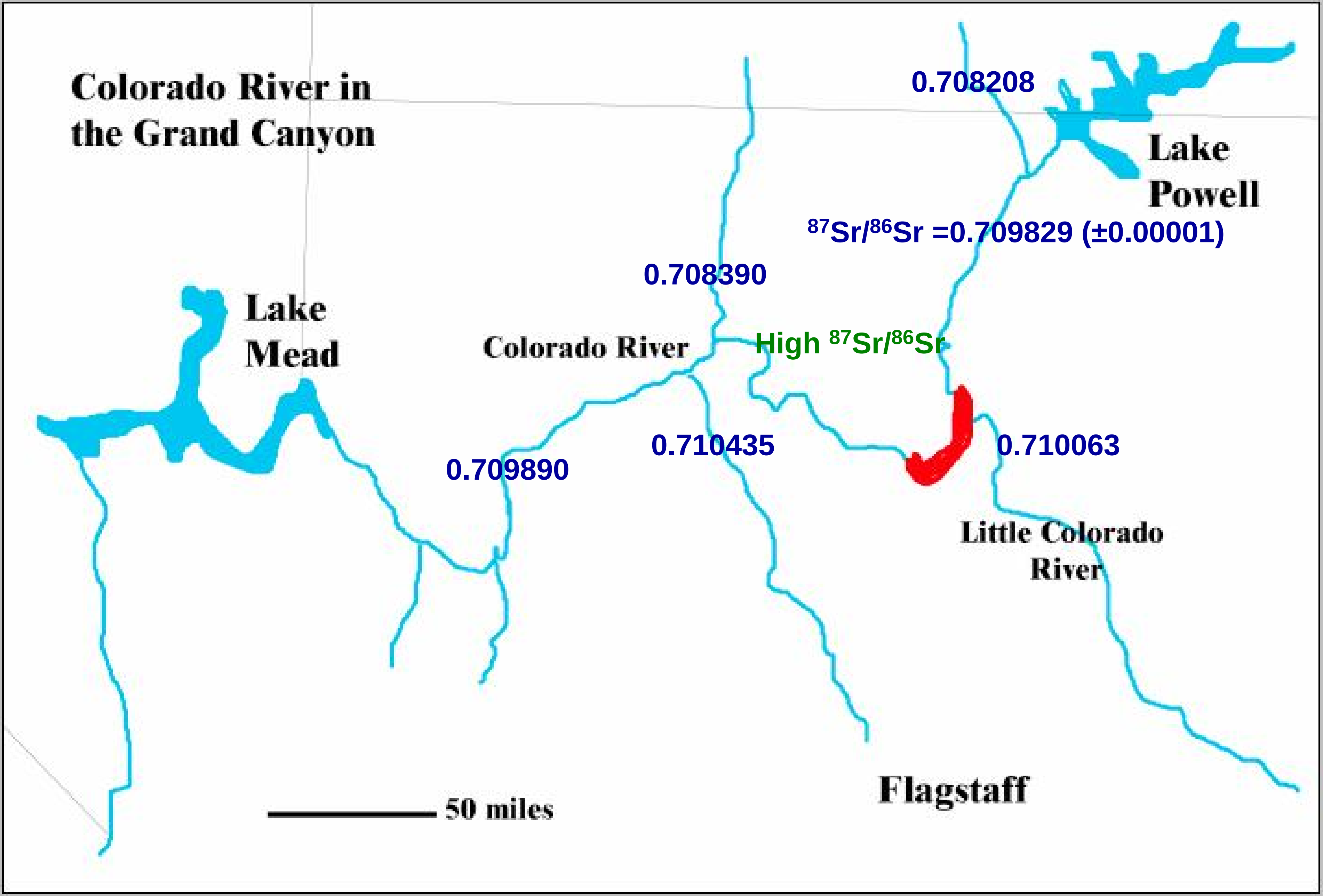


0.735
0.730
0.725
0.720
0.715
0.710
0.705
0.705
0.710
0.715
0.720
0.725
0.730
0.735
$^{87}Sr/^{86}Sr$ otolith
$^{87}Sr/^{86}Sr$ water

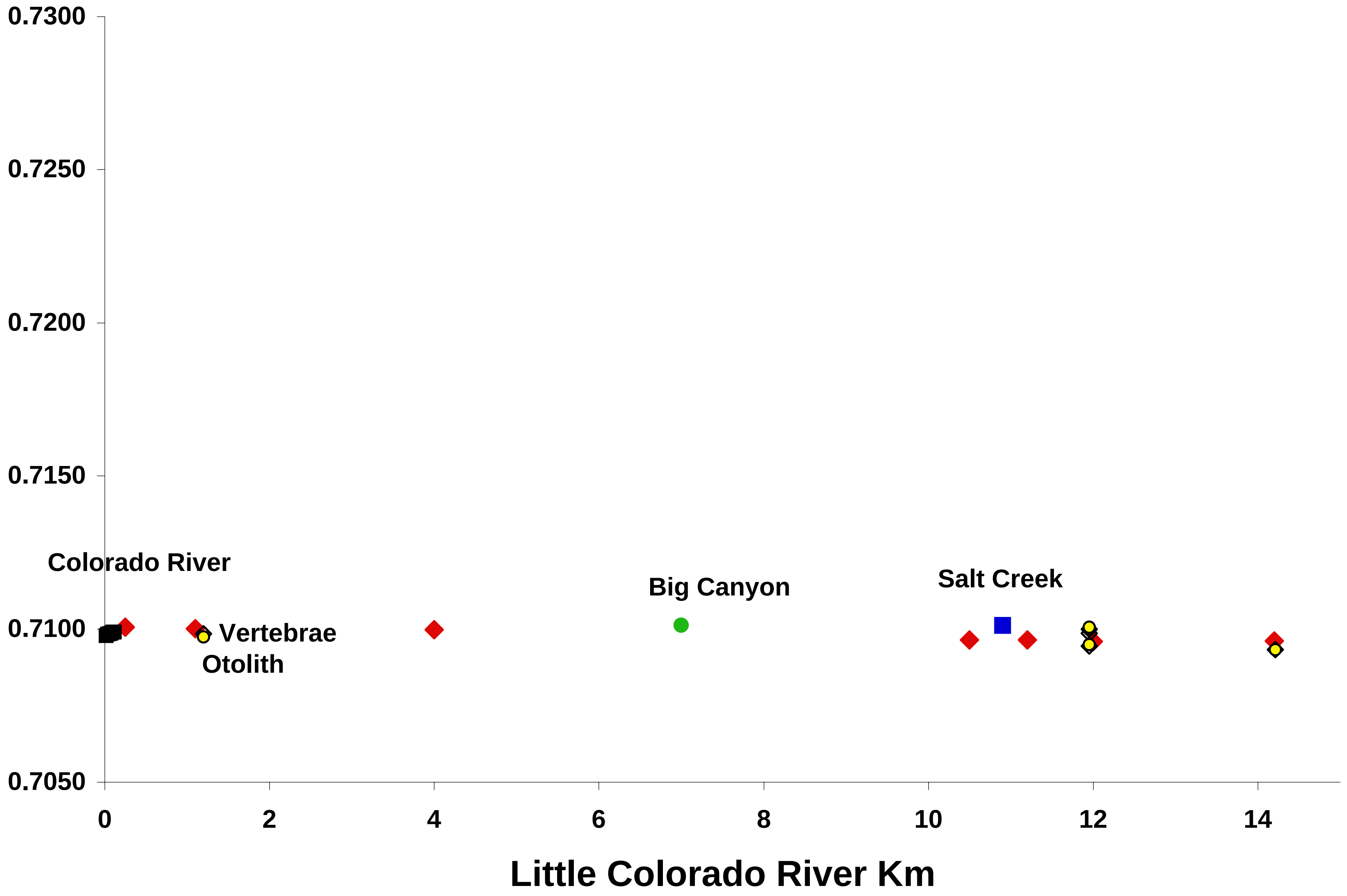


5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Sr/Ca mmol mol-1
Paria
Hermit/Crystal
LCR & Colorado
Diamond
Nankoweap
Havasu
Clear
Bright Angel
0.705
0.710
0.715
0.720
0.725
0.730
0.735
87Sr/86Sr

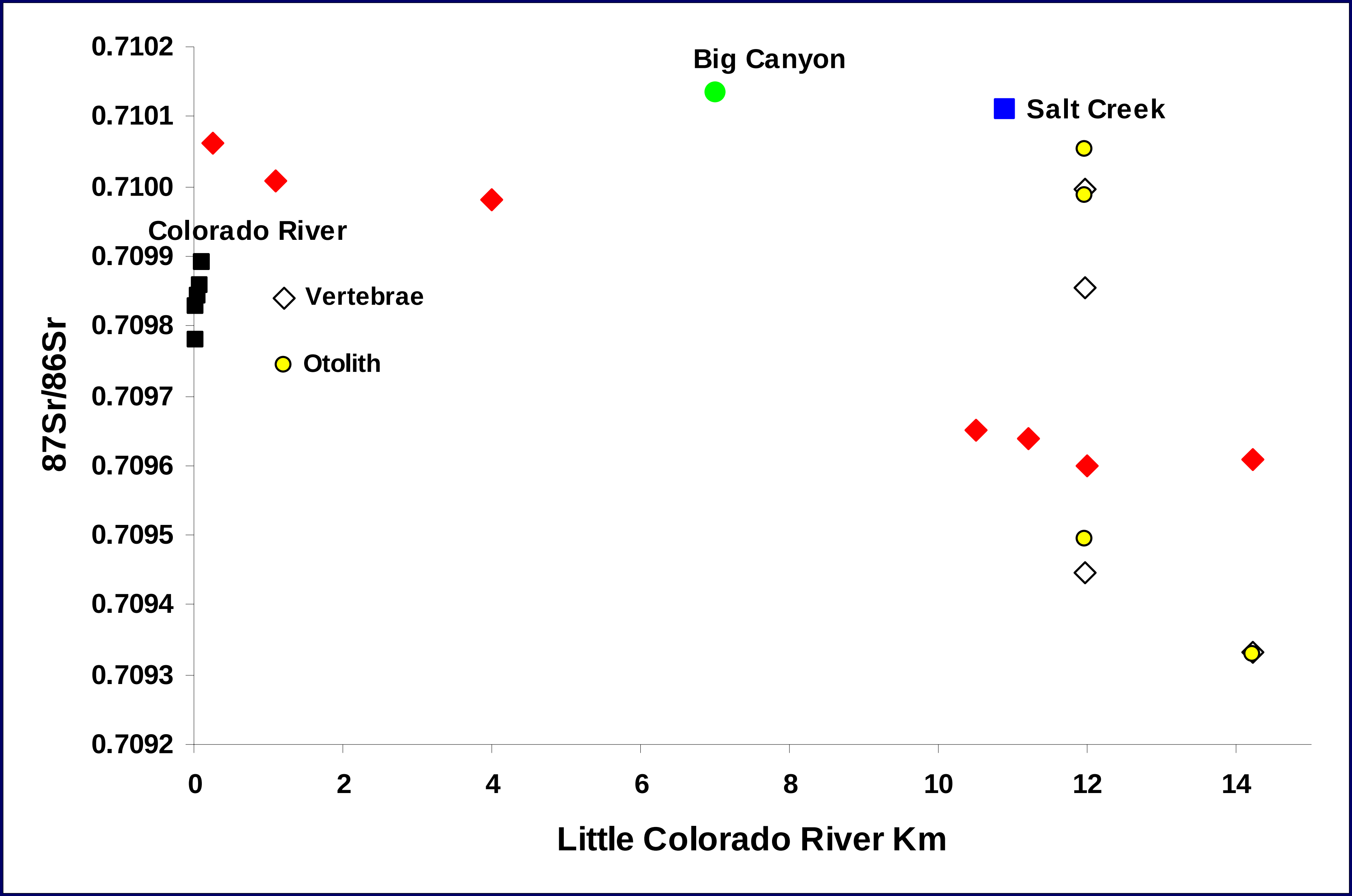
| Elements in model | Dominant eigenvalue (% of variance) | Cases correctly classified (%) | Sites with 100% classification |
|---|---|---|---|
| Sr/Ca alone | NA | 30.6% | 3 |
| Sr/Ca & Ba/Ca | Sr/Ca (89.3%), | 52.8% | 6 |
| $^{87}Sr/^{86}Sr$ alone | NA | 65.7% | 10 |
| Sr/Ca, Ba/Ca, K/Ca, Mg/Ca, Na/Ca | Sr/Ca (78.3%), Ba/Ca (11.3%) | 72.7% | 8 |
| $^{87}Sr/^{86}Sr$, Sr/Ca, Ba/Ca, K/Ca, Mg/Ca, Na/Ca | $^{87}Sr/^{86}Sr$ (90.3%), Sr/Ca (8.0%) | 94.3% | 12 |



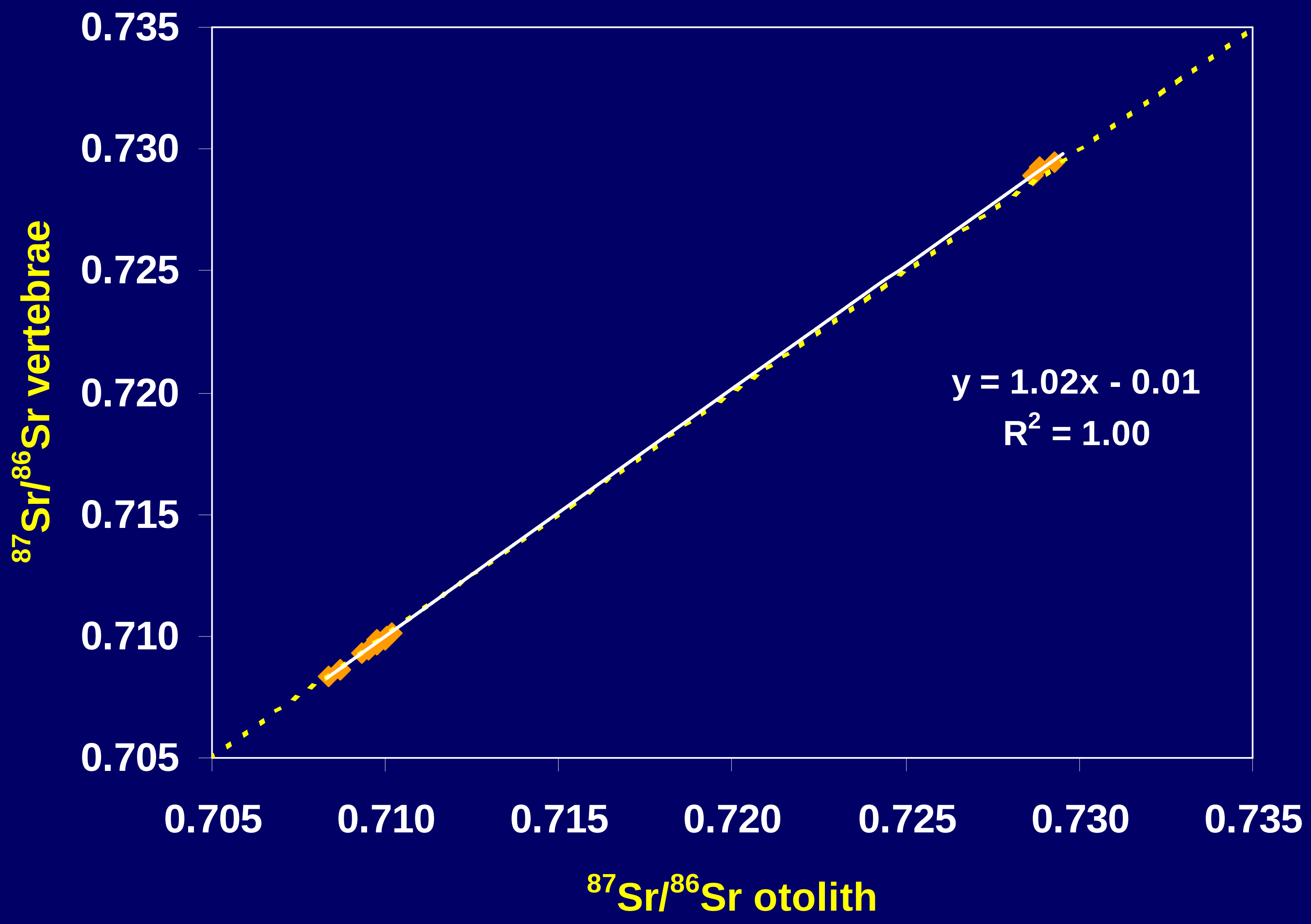
Colorado River in the Grand Canyon
0.708208
Lake Powell
$^{87}Sr/^{86}Sr$ =0.709829 (±0.00001)
0.708390
Lake Mead
Colorado River
High $^{87}Sr/^{86}Sr$
0.710435
0.710063
0.709890
Little Colorado River
Flagstaff
50 miles



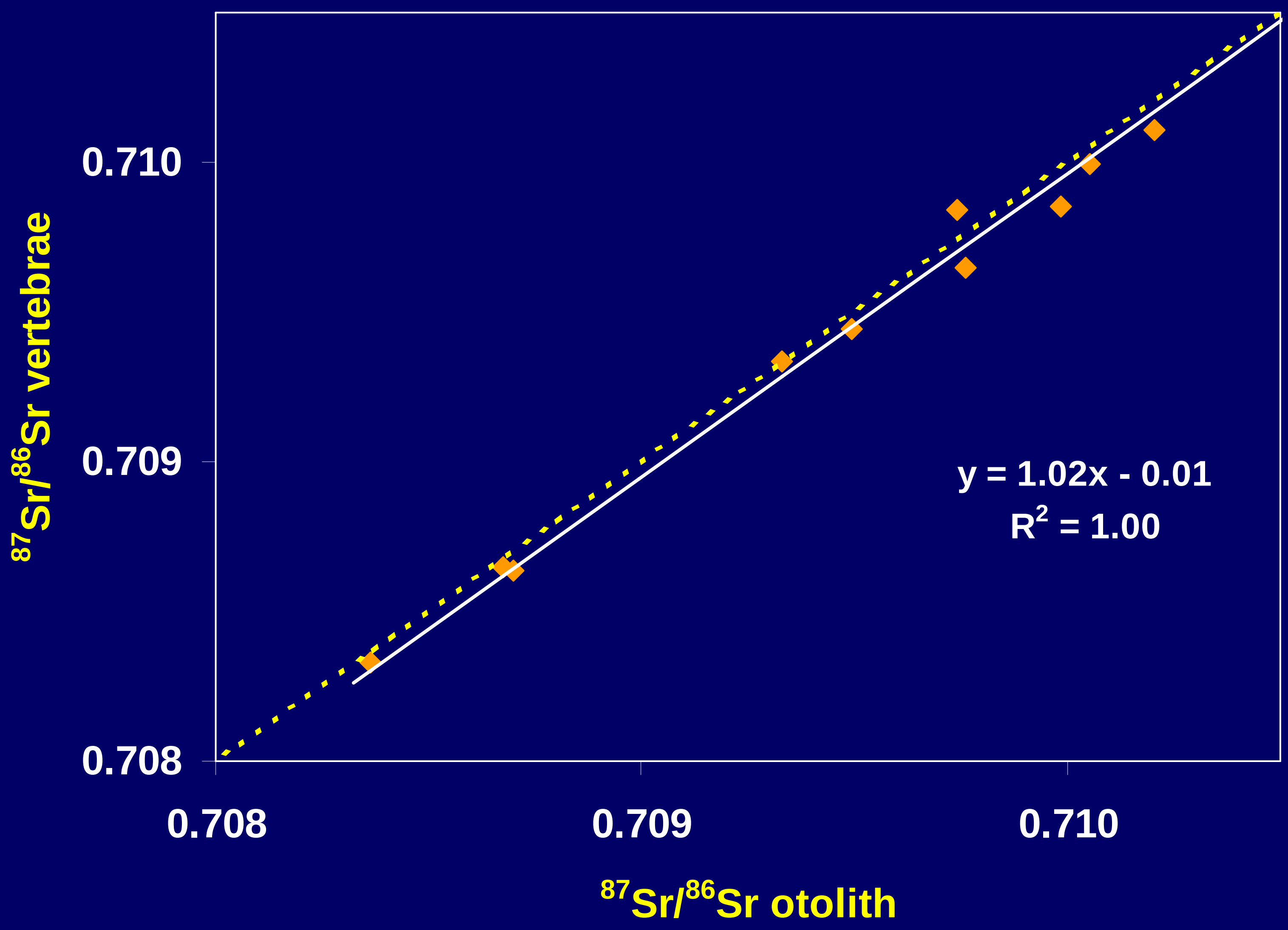

**Solid symbols = water; and open symbols = fish**

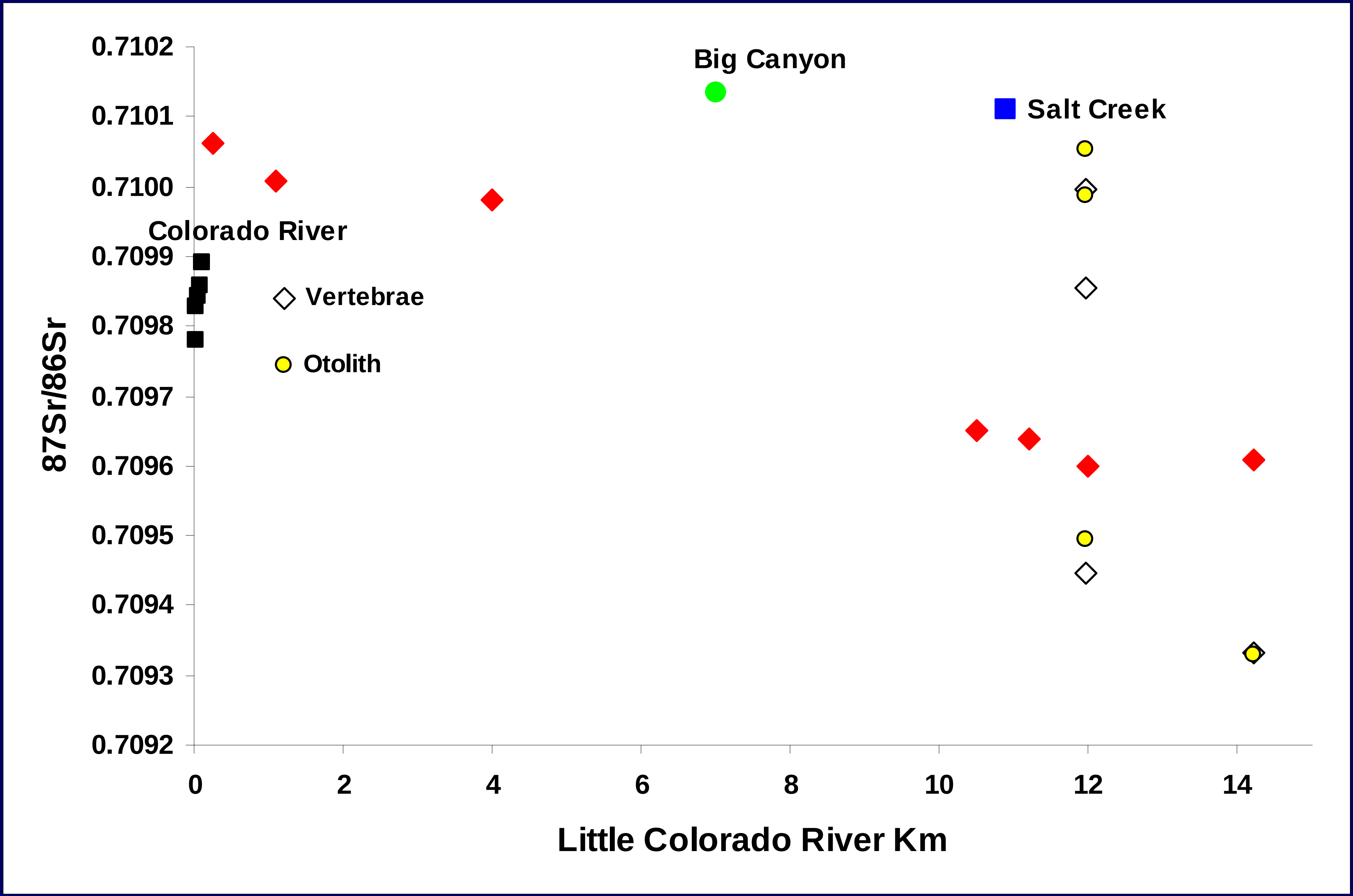



**Solid symbols = water; and open symbols = fish**



0.735
0.730
0.725
0.720
0.715
0.710
0.705
0.705
0.710
0.715
0.720
0.725
0.730
0.735
y = 1.02x - 0.01
R2 = 1.00
87Sr/86Sr vertebrae
87Sr/86Sr otolith


0.710
0.709
0.708
87Sr/86Sr vertebrae
y = 1.02x - 0.01
R2 = 1.00
0.708
0.709
0.710
87Sr/86Sr otolith




**Solid symbols = water; and open symbols = fish**

# *Summary & Conclusions*

- Significant spatial differences in both isotopic and elemental signatures exist.
- Chemical signatures appear to be stable over time and reflect differences in geologic features.
- Sr isotopes provide some advantages as a population marker in freshwater systems with geologic variability.
- Combining chemical tracers provides the best resolution for discriminating populations.
- Fish in the LCR have mixed signatures stressing the importance of time resolved analysis.

# *Acknowledgements*


- Collaborators
  - Joel Blum
  - Keith Nislow
  - Lew Coggins
- Collections
  - Bill Persons
  - Scott Rogers
- Funding
  - USGS/GCMRC



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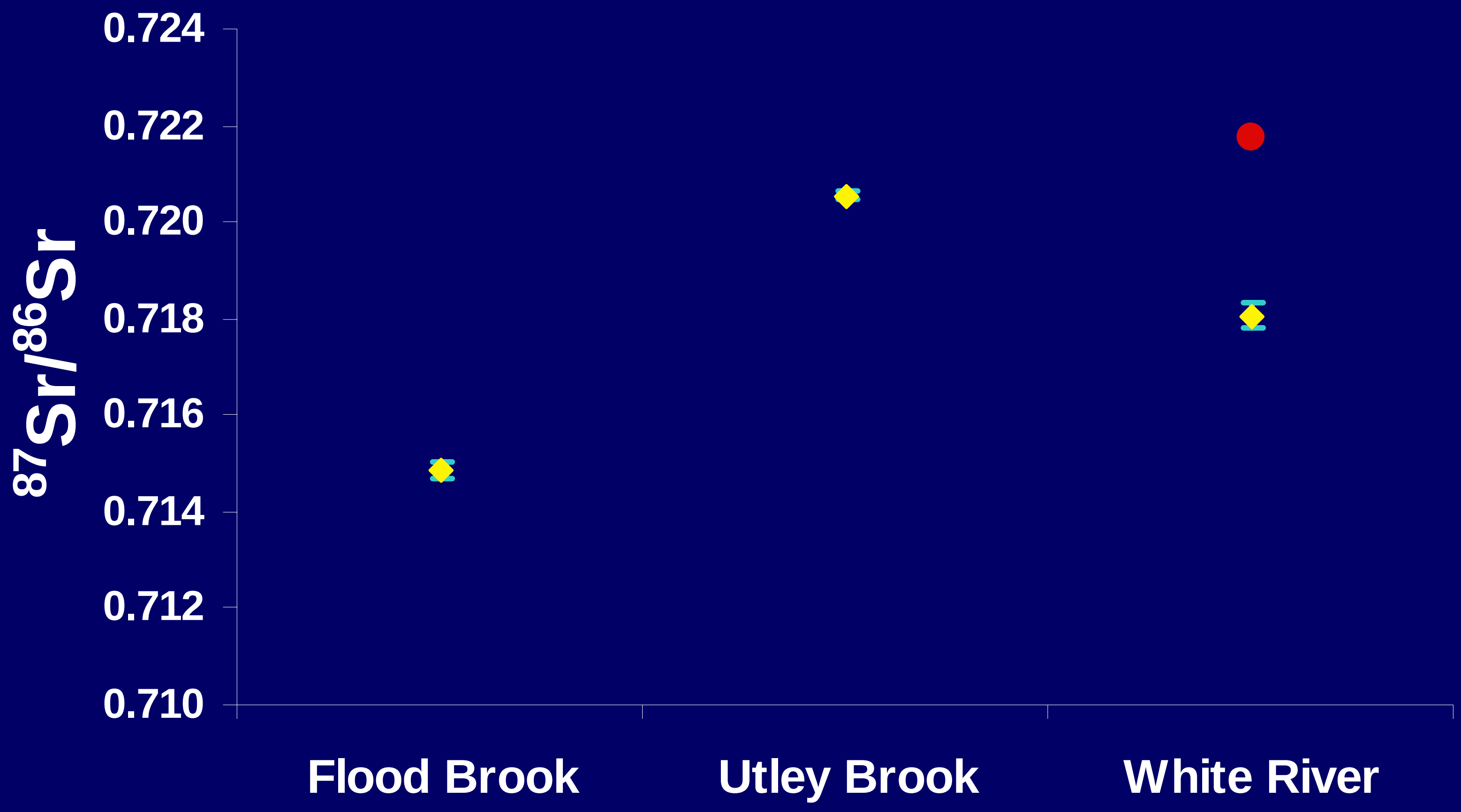
# *EXTRA SLIDES*

# *Sr signatures of movers*




Kennedy et al. *CJFAS* 2000

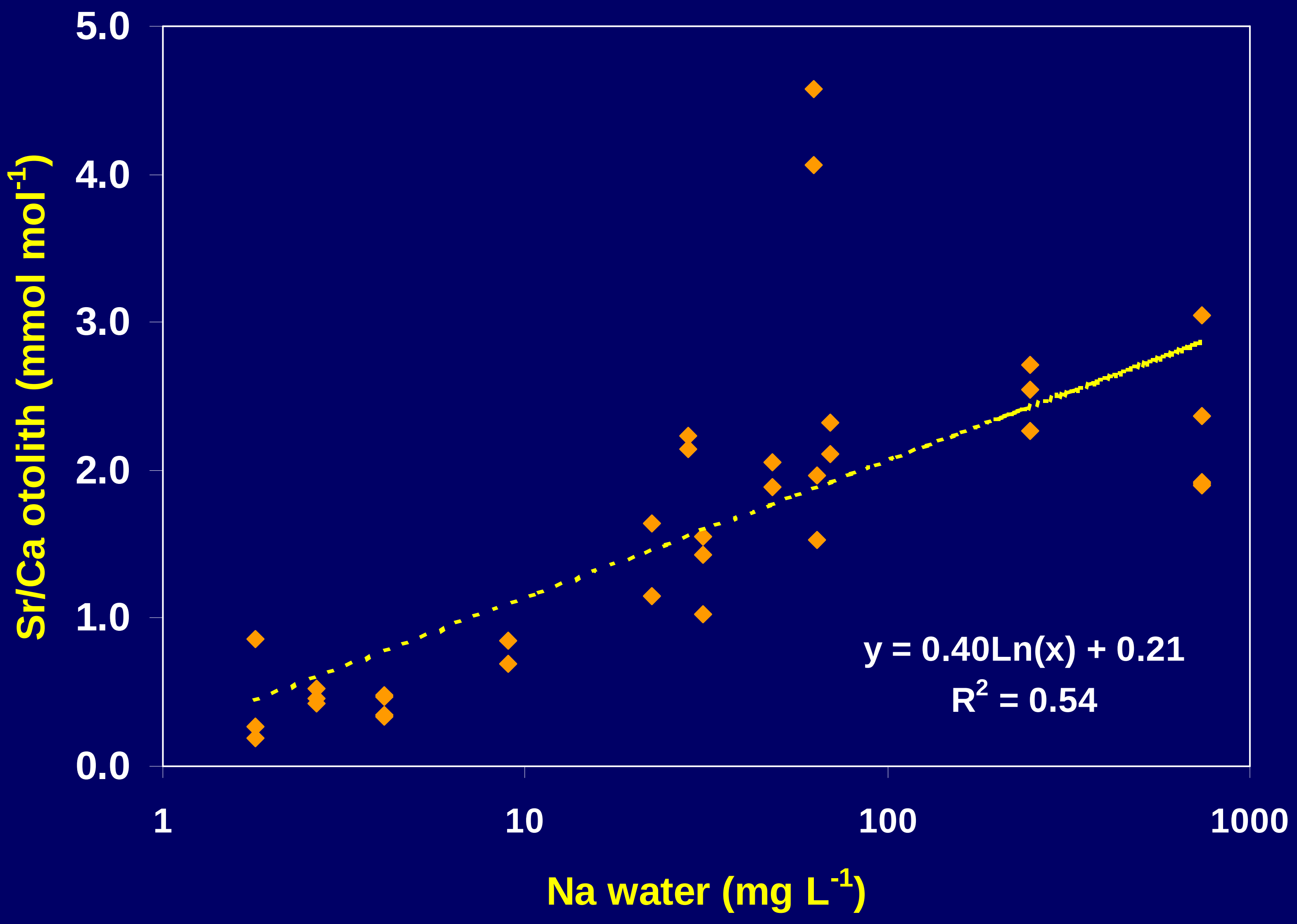
# *Objectives*

- Characterize the spatial and temporal variability of water chemistry in the Colorado Basin.

- Quantify the effect of water chemistry on Sr isotopic and elemental ratios in resident fish tissues.

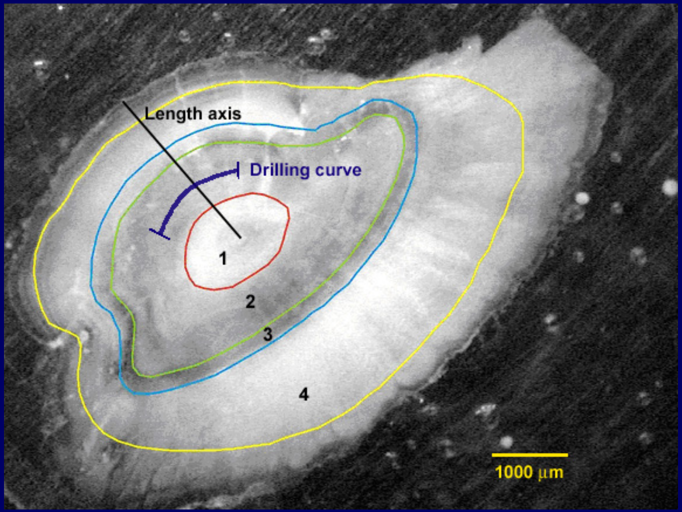
- Compare the incorporation of elemental ratios with Sr isotopes.

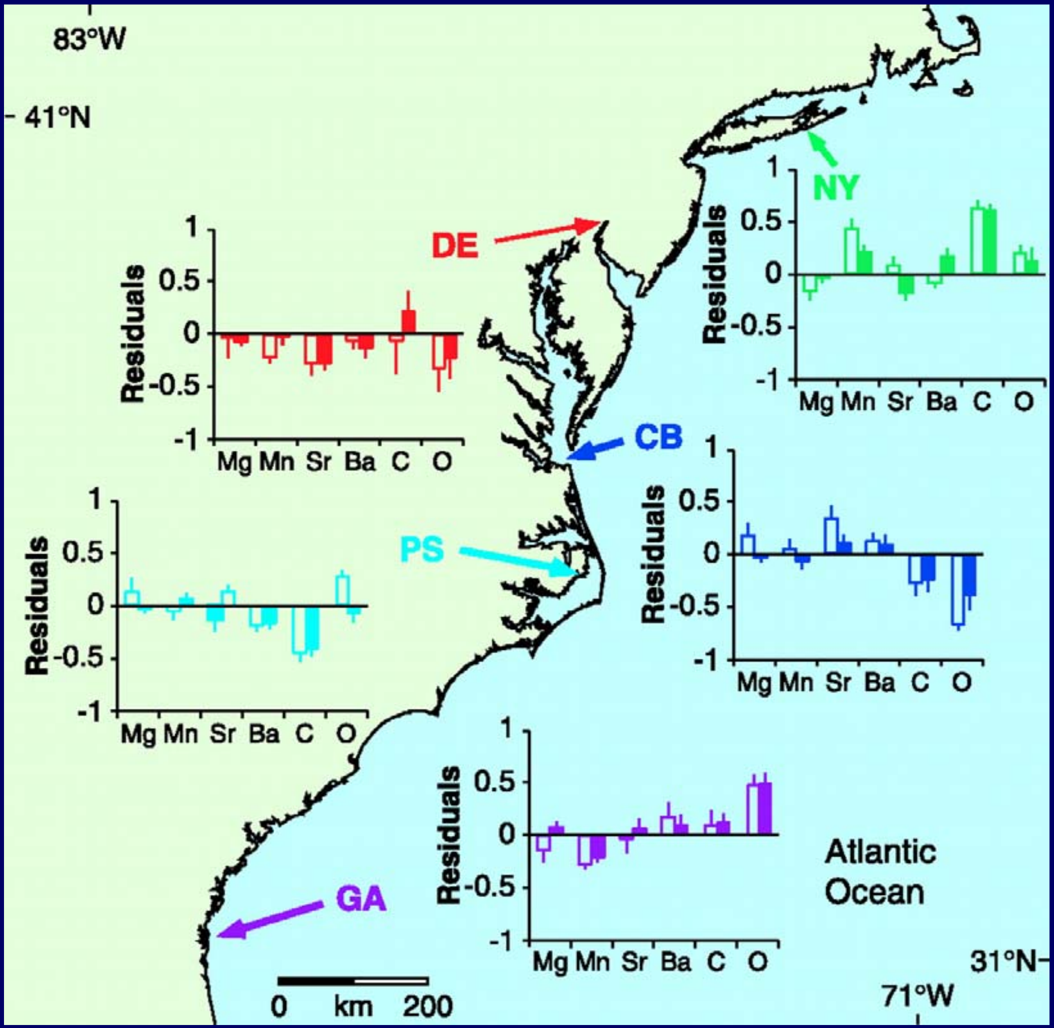
- Assess the ability for Sr isotope ratios in concert with elemental ratios to distinguish among source streams.



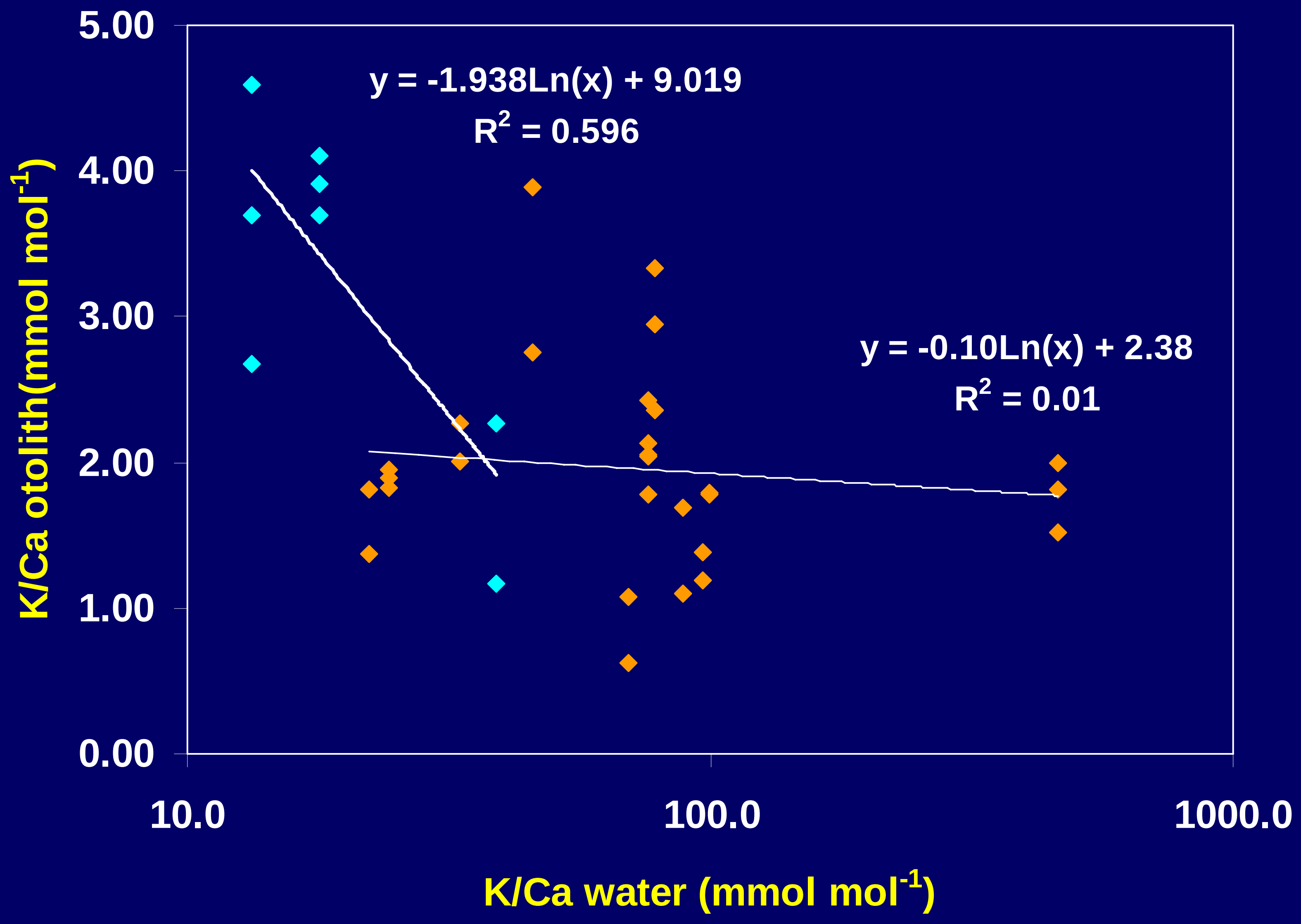
5.0
4.0
3.0
2.0
1.0
0.0
Sr/Ca otolith (mmol mol-1)
1
10
100
1000
Na water (mg L-1)
y = 0.40Ln(x) + 0.21
R2 = 0.54

# Homing of marine fish



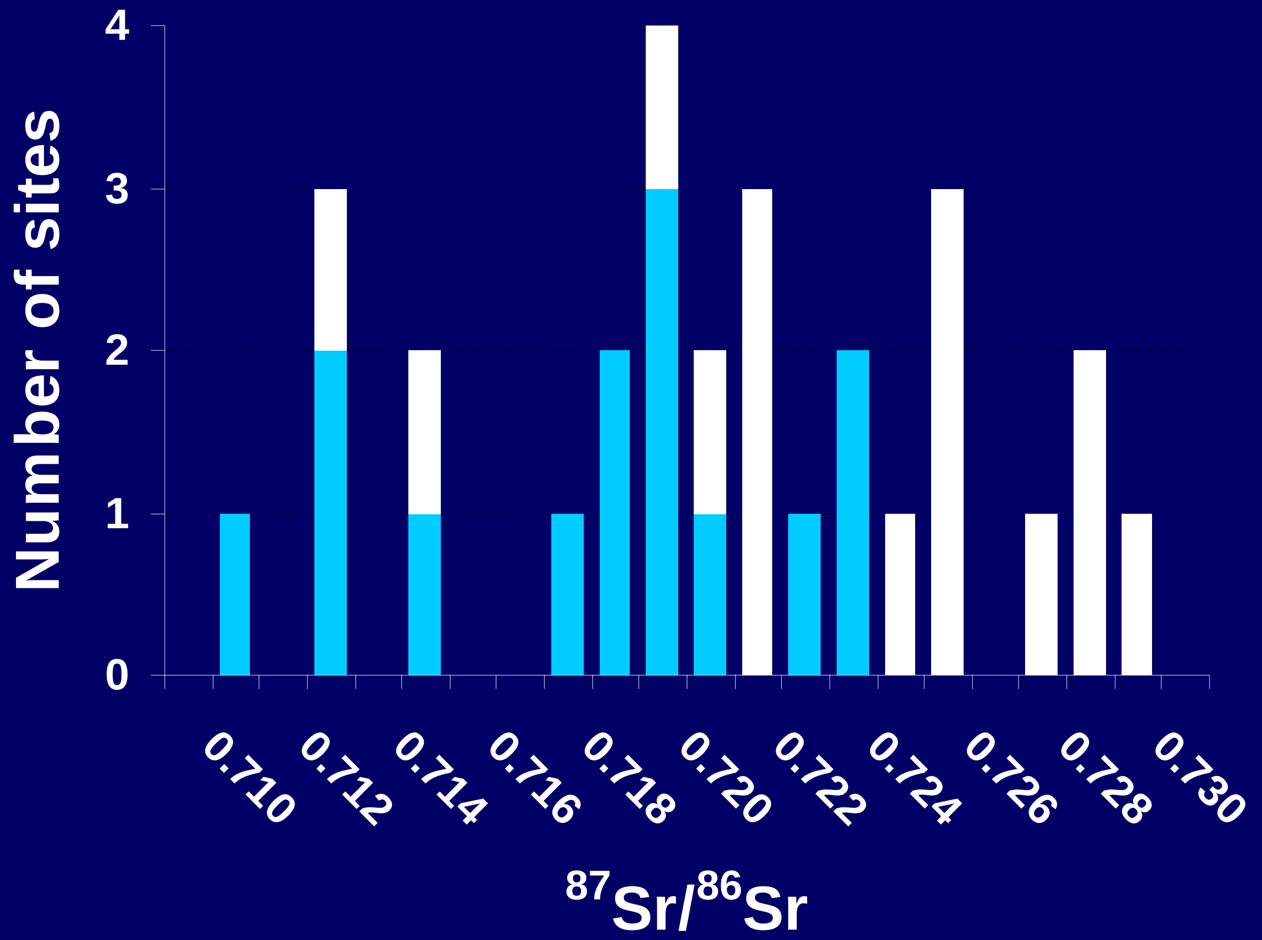




Thorrold et al. 2001

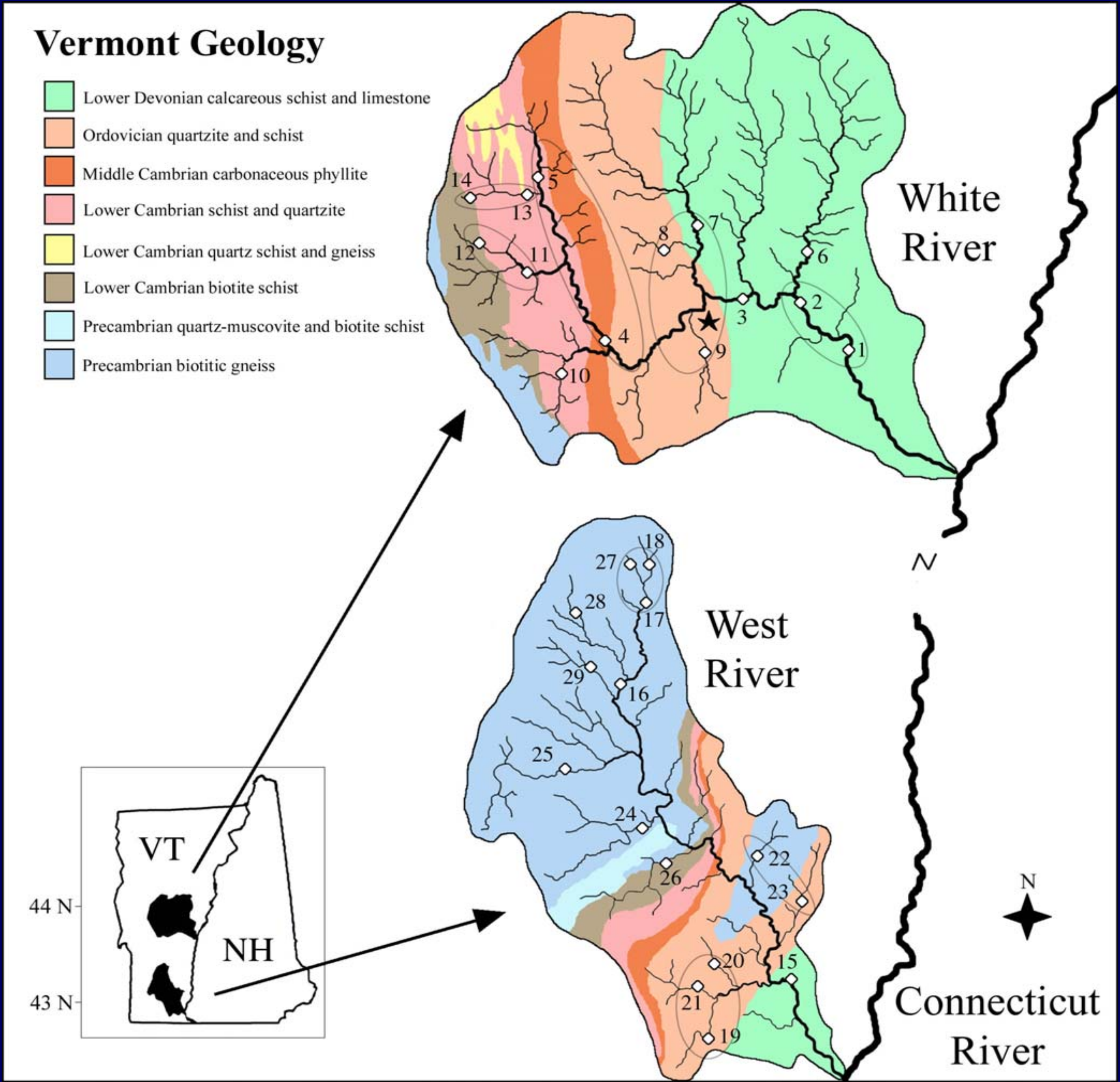


y = -1.938Ln(x) + 9.019
$R^2$ = 0.596
y = -0.10Ln(x) + 2.38
$R^2$ = 0.01
5.00
4.00
3.00
2.00
1.00
0.00
10.0
100.0
1000.0
K/Ca otolith(mmol mol$^{-1}$)
K/Ca water (mmol mol$^{-1}$)

# *Sr variability across 29 sites*

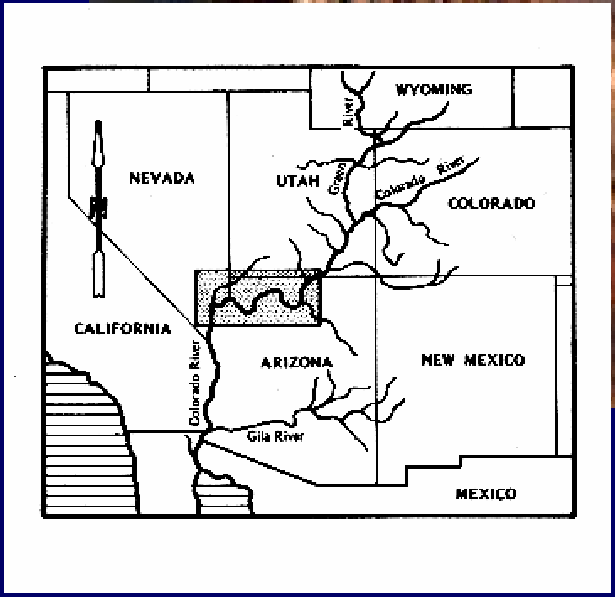


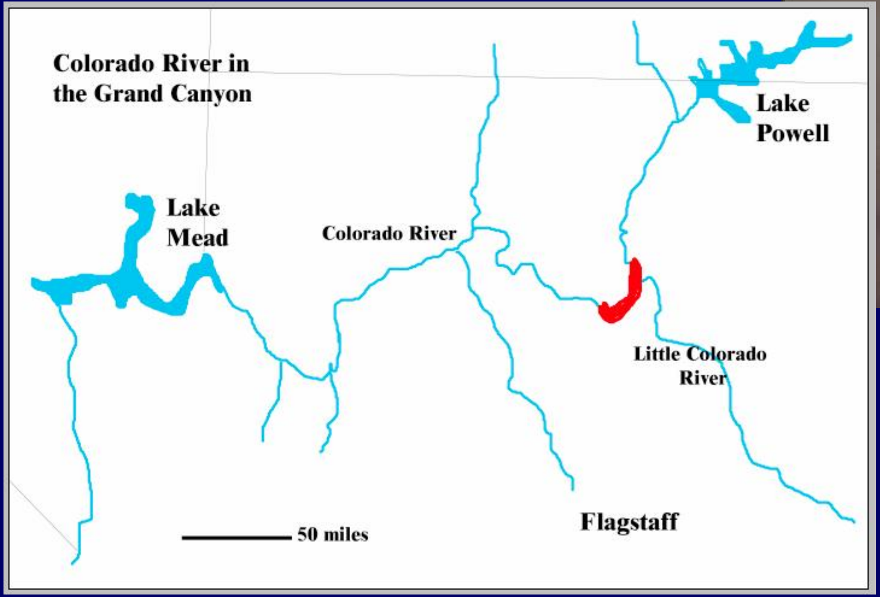

Kennedy et al. *CJFAS* 2000

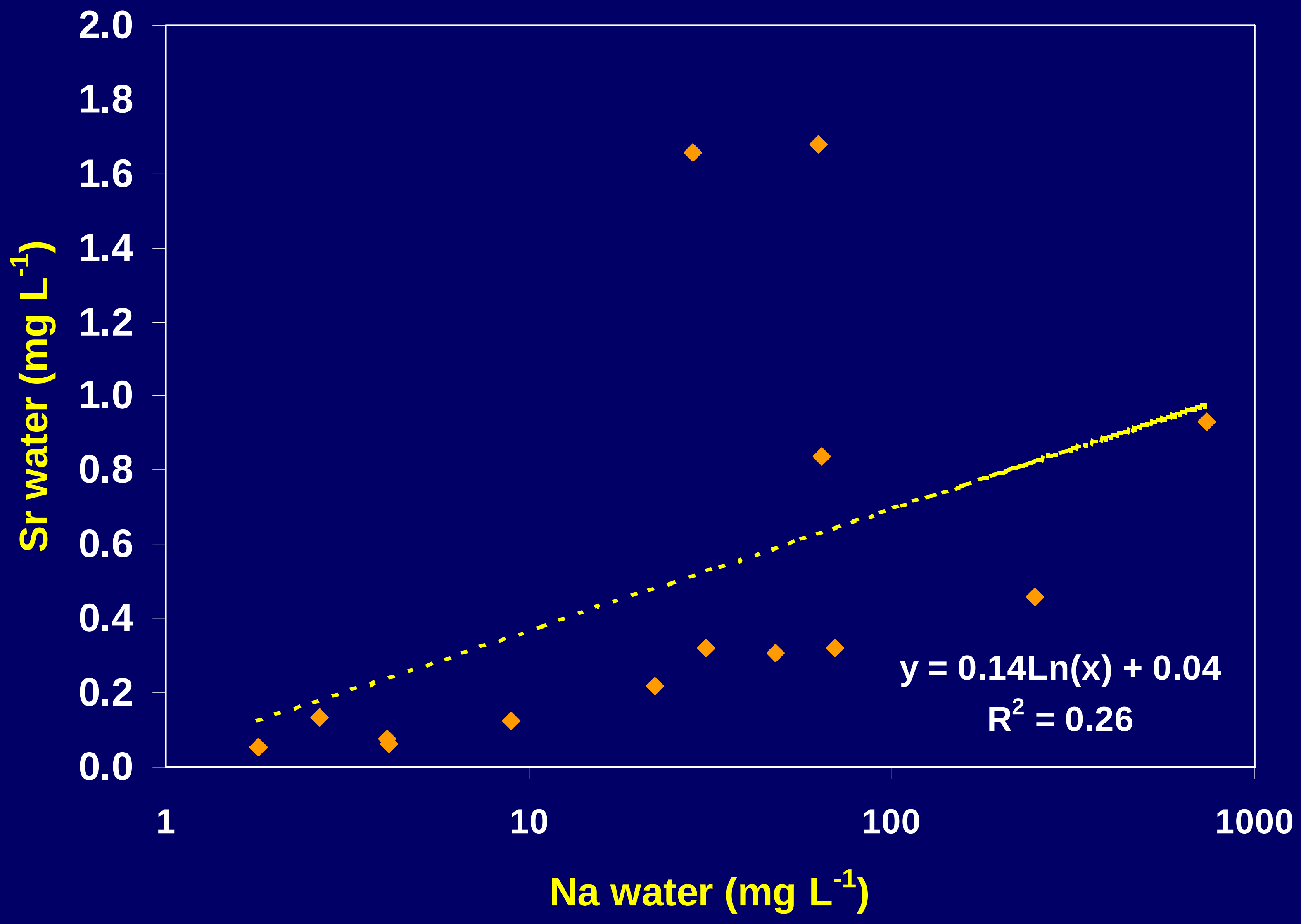


Vermont Geology
Lower Devonian calcareous schist and limestone
Ordovician quartzite and schist
Middle Cambrian carbonaceous phyllite
Lower Cambrian schist and quartzite
Lower Cambrian quartz schist and gneiss
Lower Cambrian biotite schist
Precambrian quartz-muscovite and biotite schist
Precambrian biotitic gneiss
White River
West River
Connecticut River
N
VT
NH
44 N
43 N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29

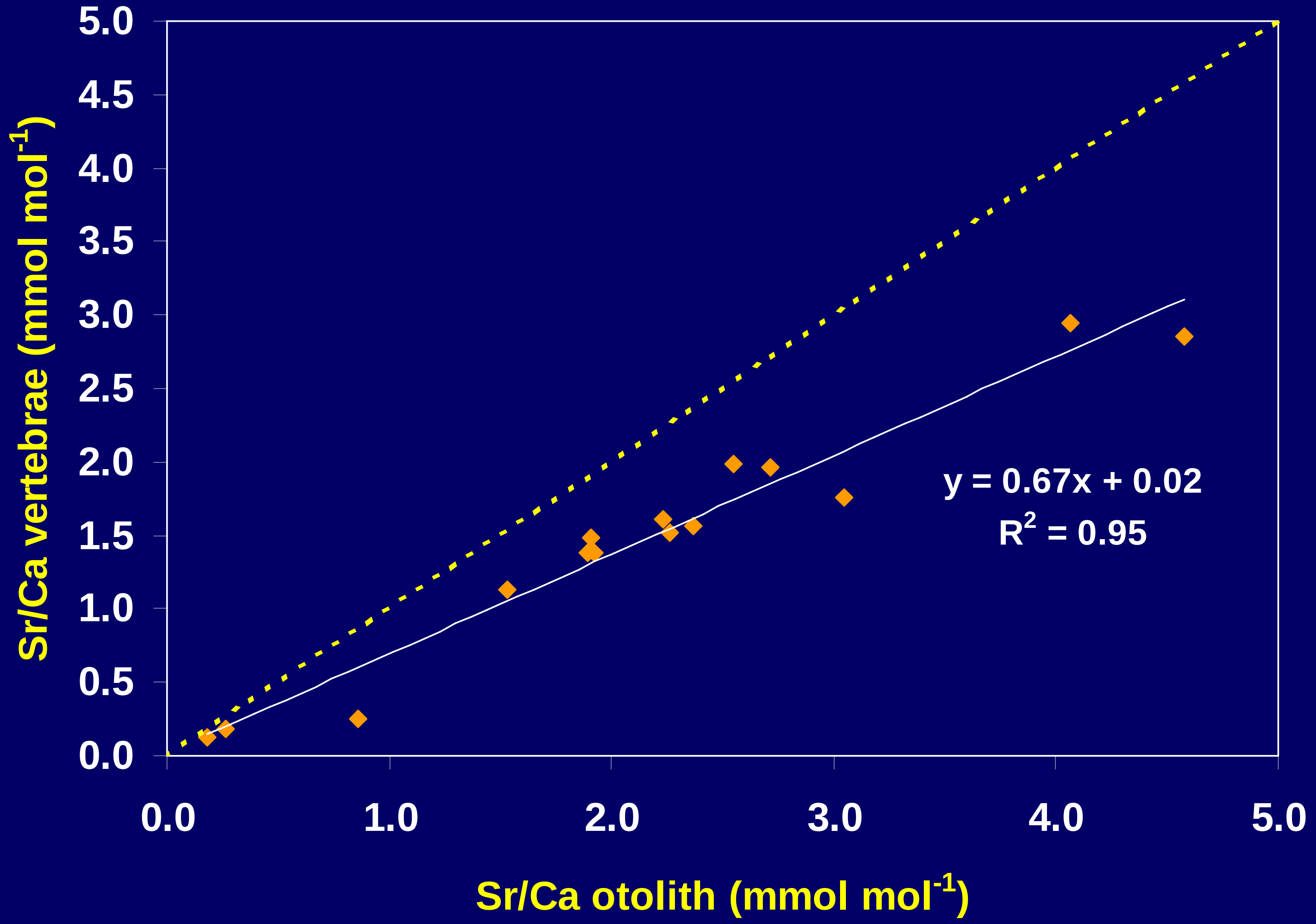
# Humpback chub, *Gila cypha*
# Colorado River



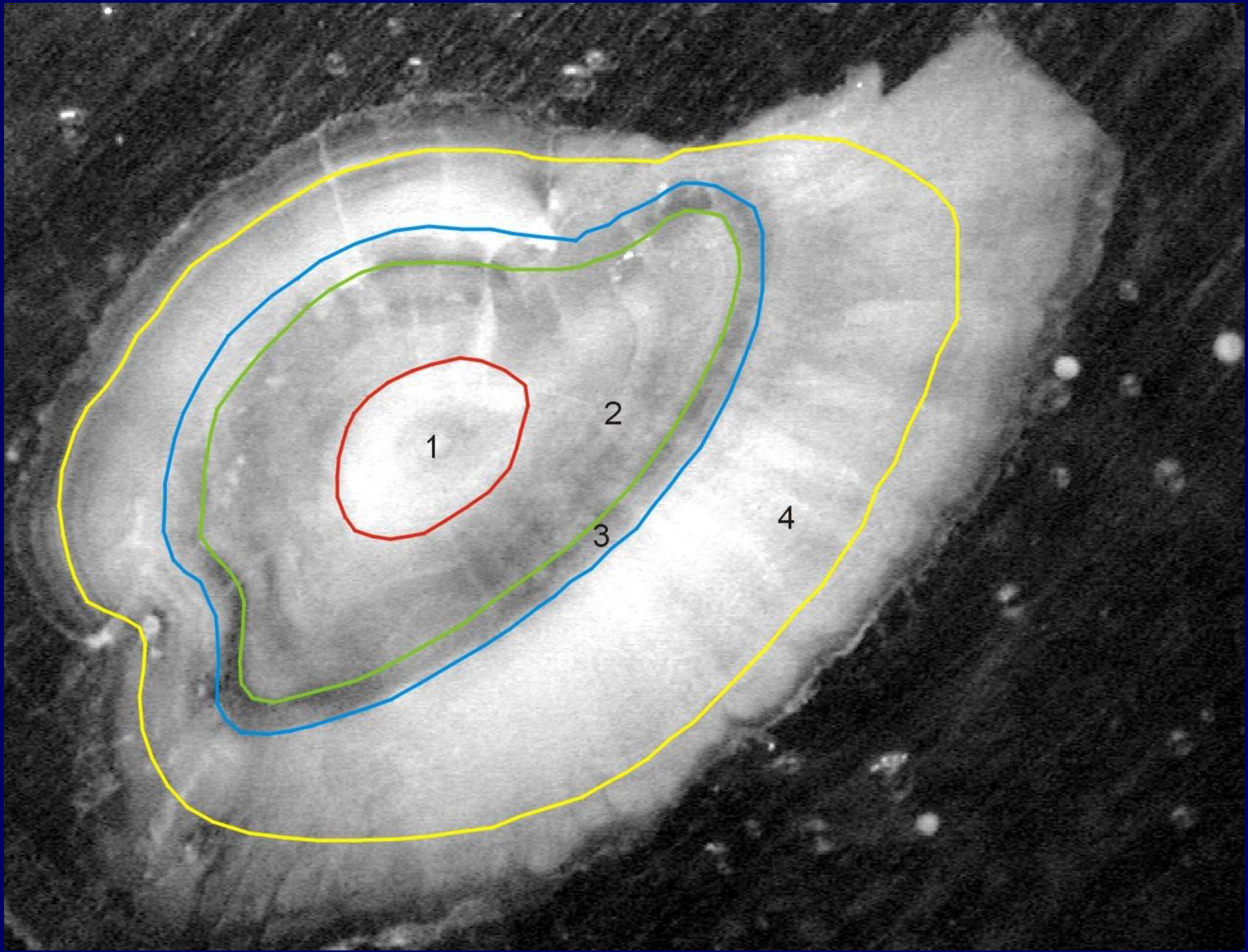


Colorado River in
the Grand Canyon
Lake
Powell
Lake
Mead
Colorado River
Little Colorado
River
Flagstaff
50 miles



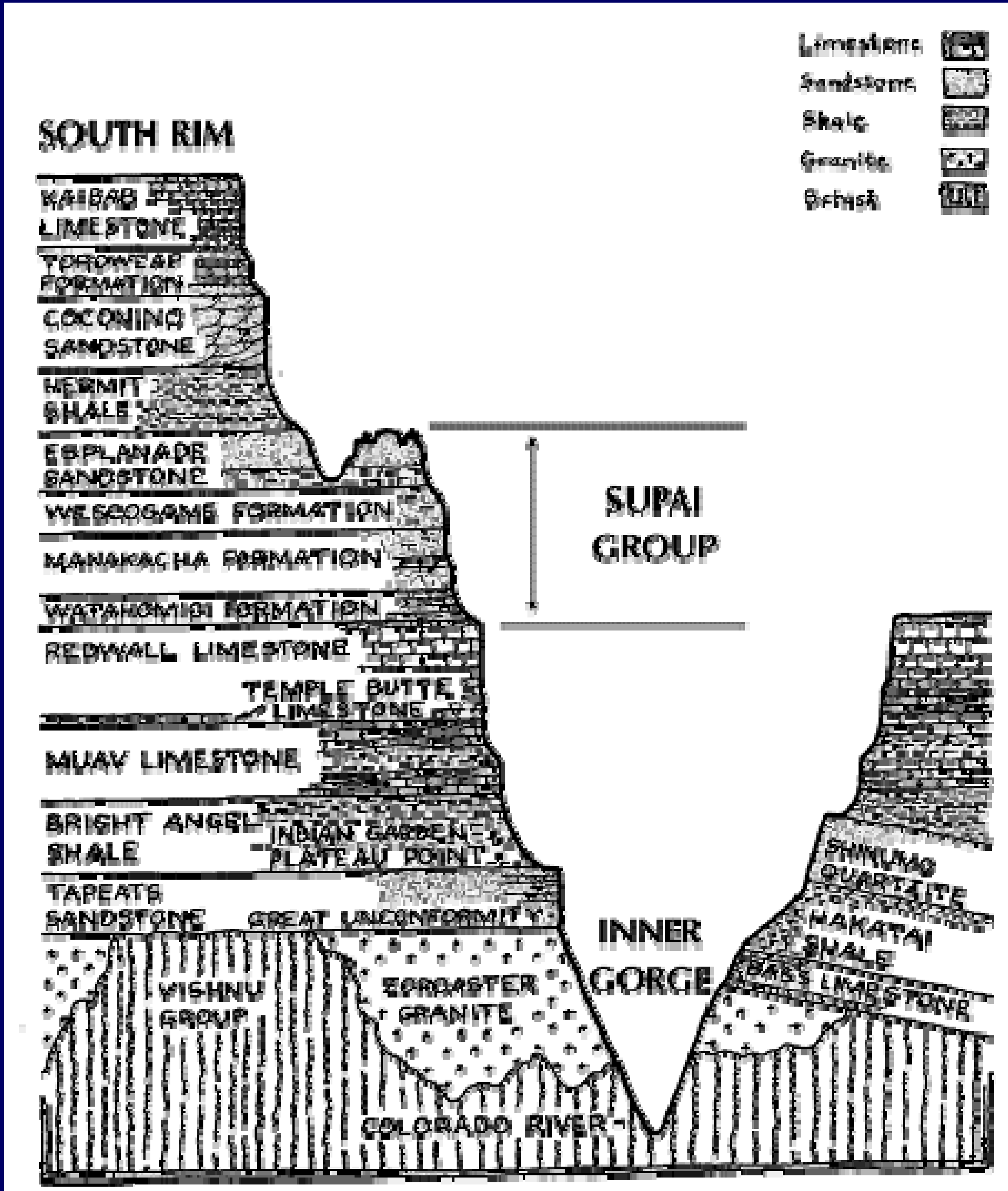
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Sr water (mg L-1)
1
10
100
1000
Na water (mg L-1)
y = 0.14Ln(x) + 0.04
R2 = 0.26



Sr/Ca vertebrae (mmol mol-1)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
1.0
2.0
3.0
4.0
5.0
y = 0.67x + 0.02
R2 = 0.95
Sr/Ca otolith (mmol mol-1)


1
2
3
4


W.U.V. copyrigth 1999


Limestone
Sandstone
Shale
Granite
Schist
SOUTH RIM
KAIBAB LIMESTONE
TOROWEAP FORMATION
COCONINO SANDSTONE
HERMIT SHALE
ESPLANADE SANDSTONE
WESCOGAME FORMATION
MANAKACHA FORMATION
WATAHOMIGI FORMATION
SUPAI GROUP
REDWALL LIMESTONE
TEMPLE BUTTE LIMESTONE
MUAV LIMESTONE
BRIGHT ANGEL SHALE
INDIAN GARDEN
PLATEAU POINT
TAPEATS SANDSTONE
GREAT UNCONFORMITY
INNER GORGE
SHINUMO QUARTZITE
HAKATAI SHALE
BASS LIMESTONE
VISHNU GROUP
ZOROASTER GRANITE
COLORADO RIVER


KAIBAB FORMATION
TOROWEAP FORMATION
COCONINO SANDSTONE
HERMIT SHALE
SUPAI GROUP
ESPLANADE SANDSTONE
WESCOGAME FORMATION
MANAKACHA FORMATION
WATAHOMIGI FORMATION
SURPRISE CANYON FORMATION
REDWALL LIMESTONE
TEMPLE BUTTE LIMESTONE
TONTO GROUP
MUAV LIMESTONE
BRIGHT ANGEL SHALE
TAPEATS SANDSTONE
VISHNU SCHIST
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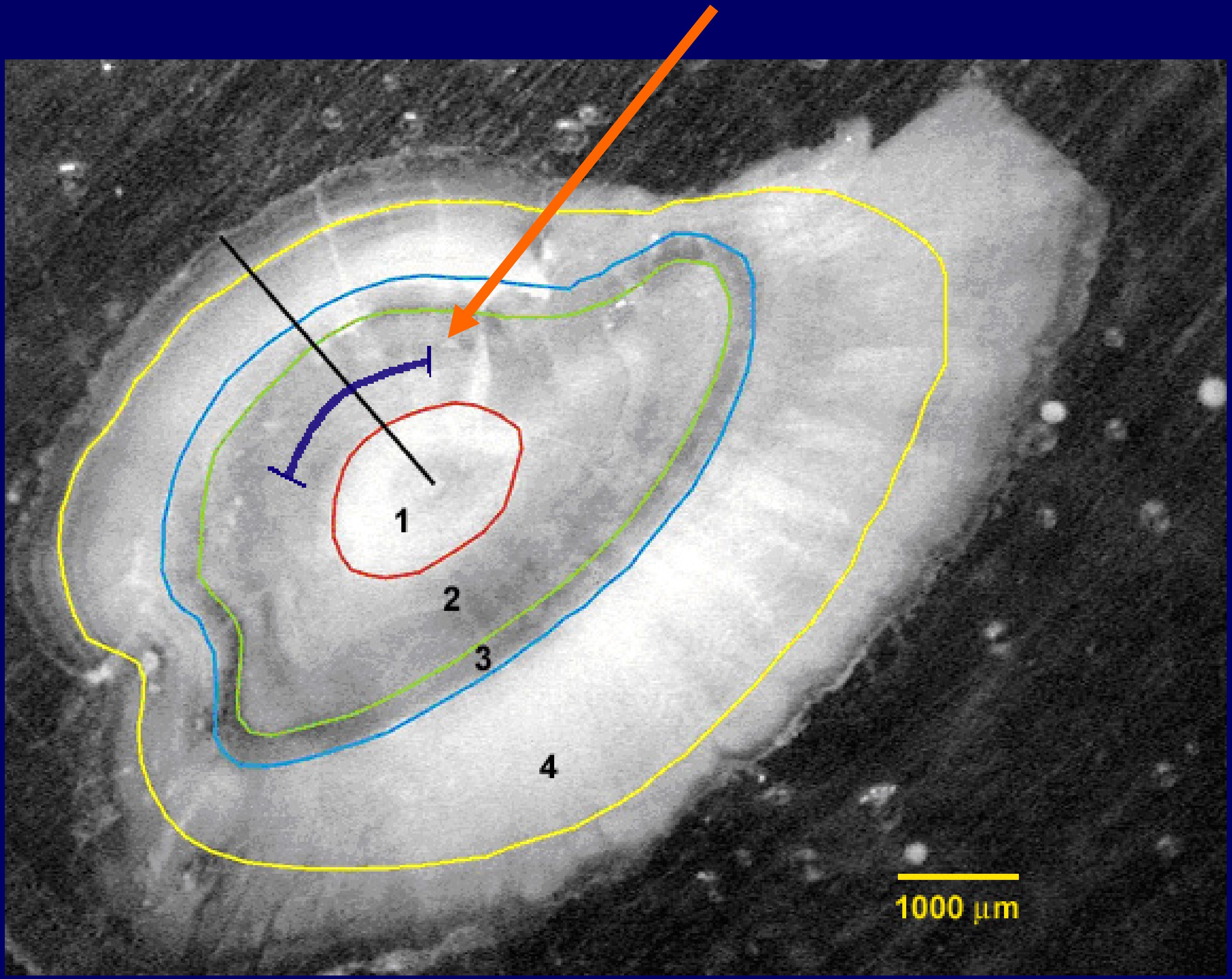
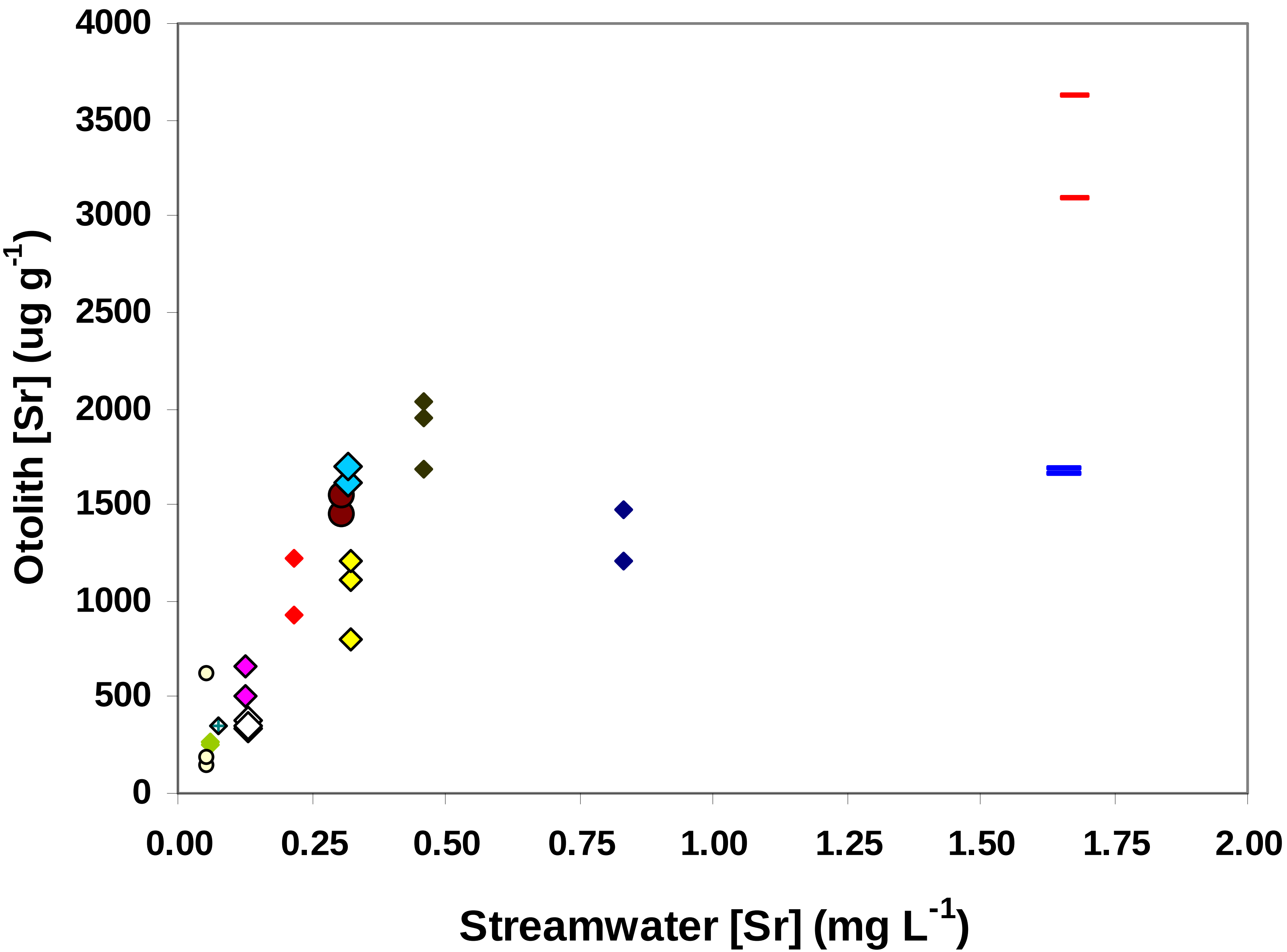
# *A bottom-up approach to using geochemical tracers in otoliths*

- **Begin with an understanding of the processes for geochemical variability across a landscape.**
- **Incorporate an understanding of the physiology of the organism.**
- **Develop analytical methods that most effectively recover time specific geochemical tracers.**
- **Establish controls when possible.**
- **Move toward a *predictive* model of microchemical variation.**

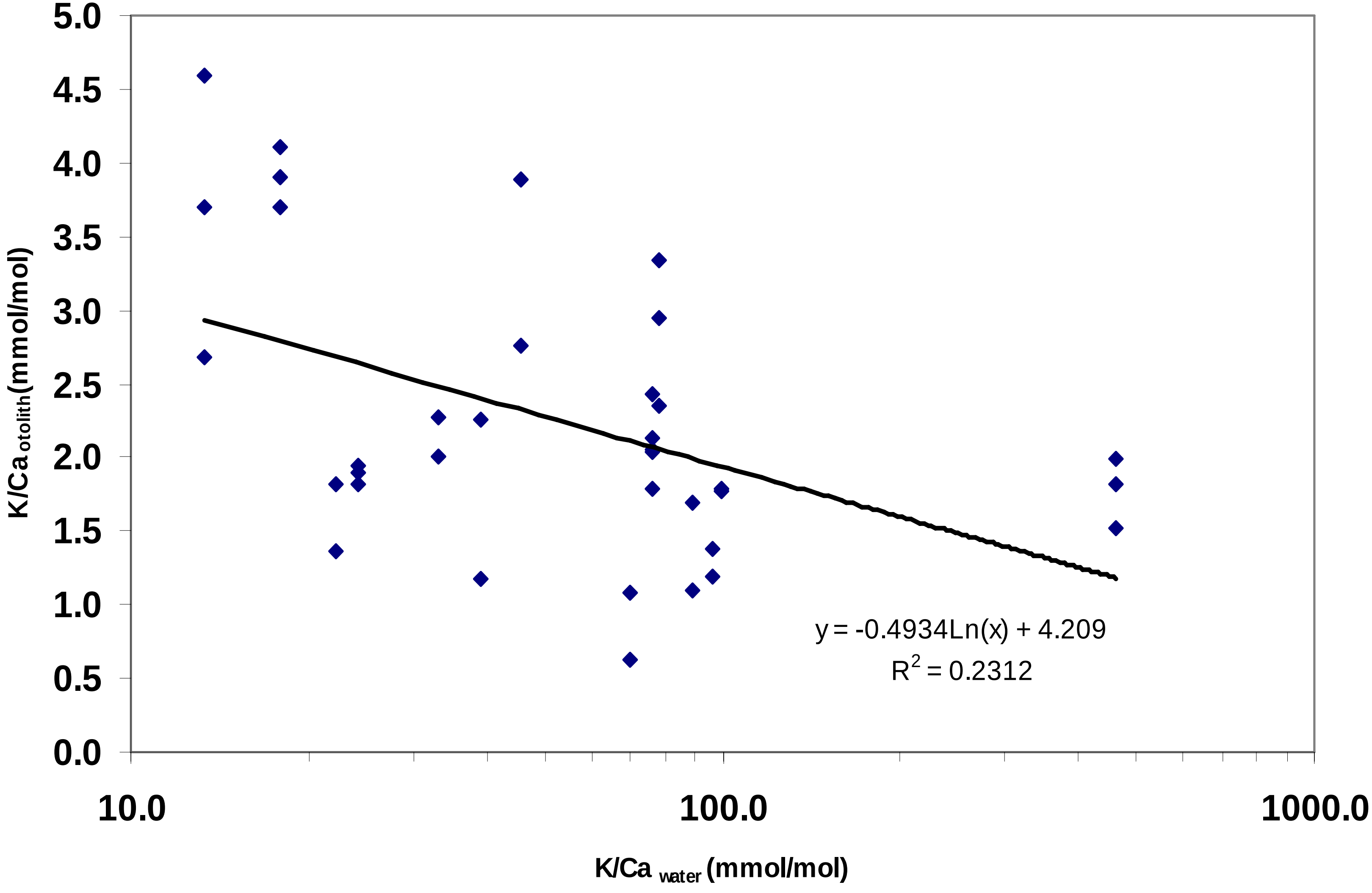
# Otolith micromill drill site



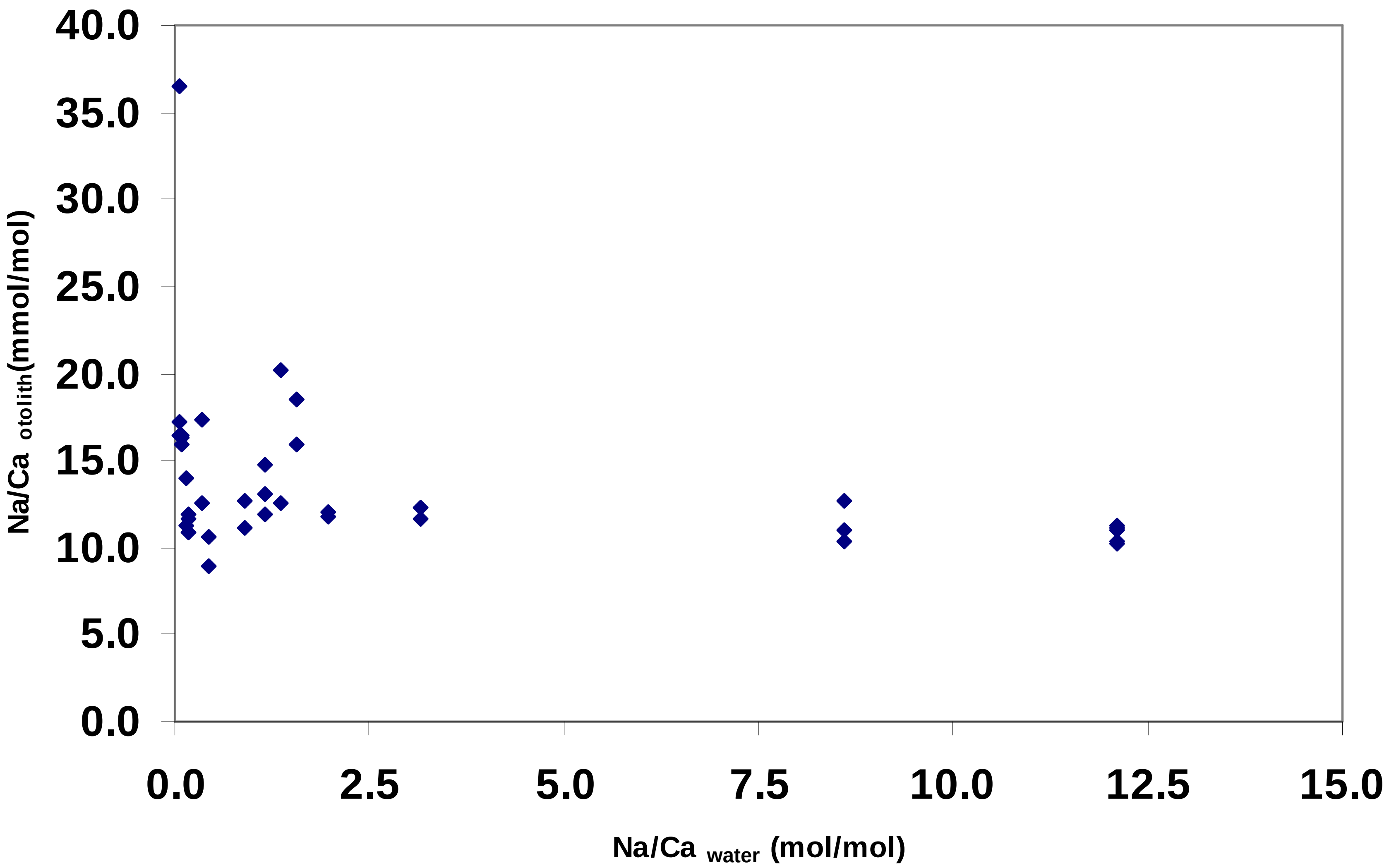

*Kennedy et al. CJFAS 2002*

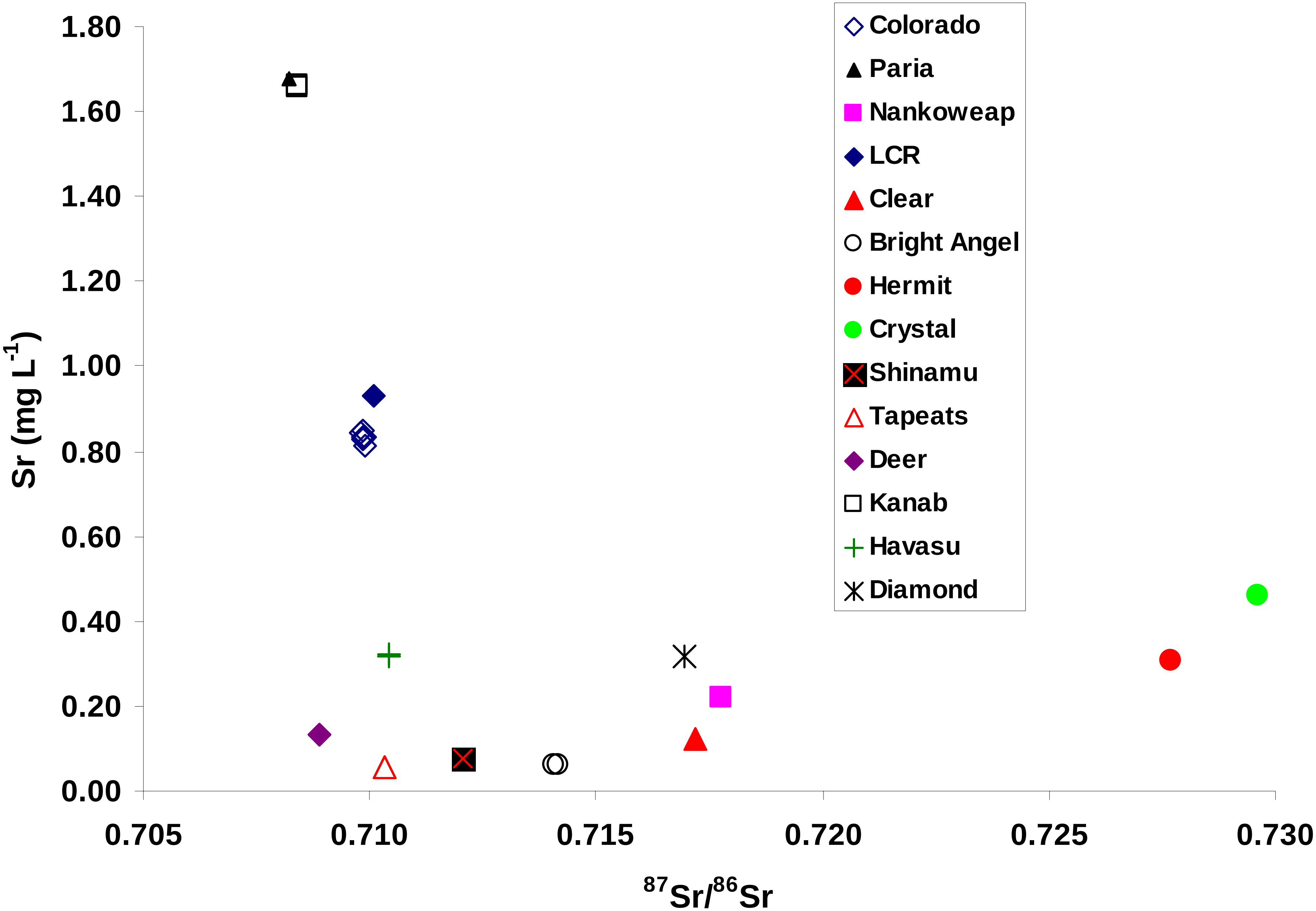


Otolith [Sr] (ug g-1)
4000
3500
3000
2500
2000
1500
1000
500
0
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Streamwater [Sr] (mg L-1)

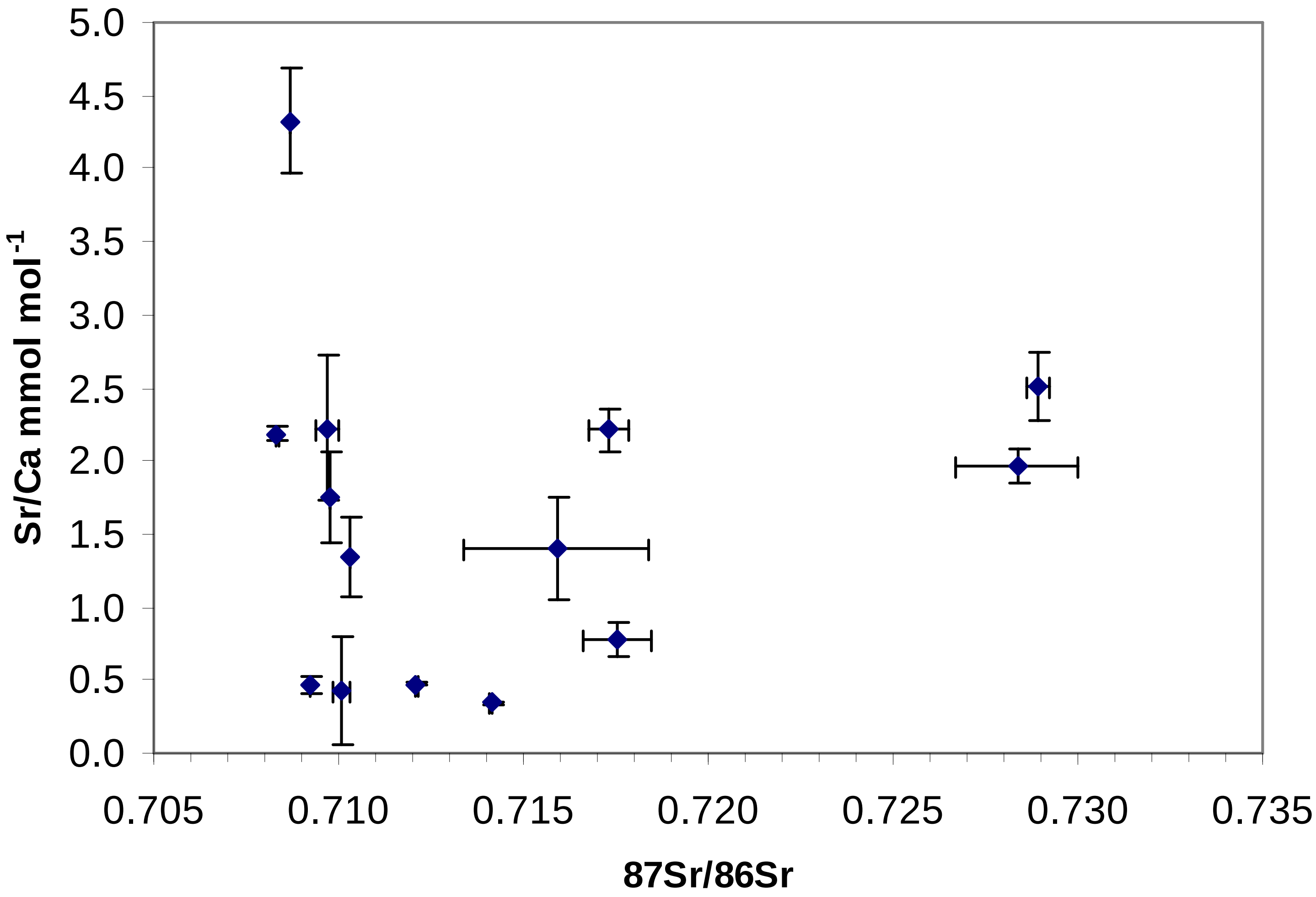


5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
K/Ca otolith (mmol/mol)
y = -0.4934Ln(x) + 4.209
R2 = 0.2312
10.0
100.0
1000.0
K/Ca water (mmol/mol)


Na/Ca otolith(mmol/mol)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
Na/Ca water (mol/mol)

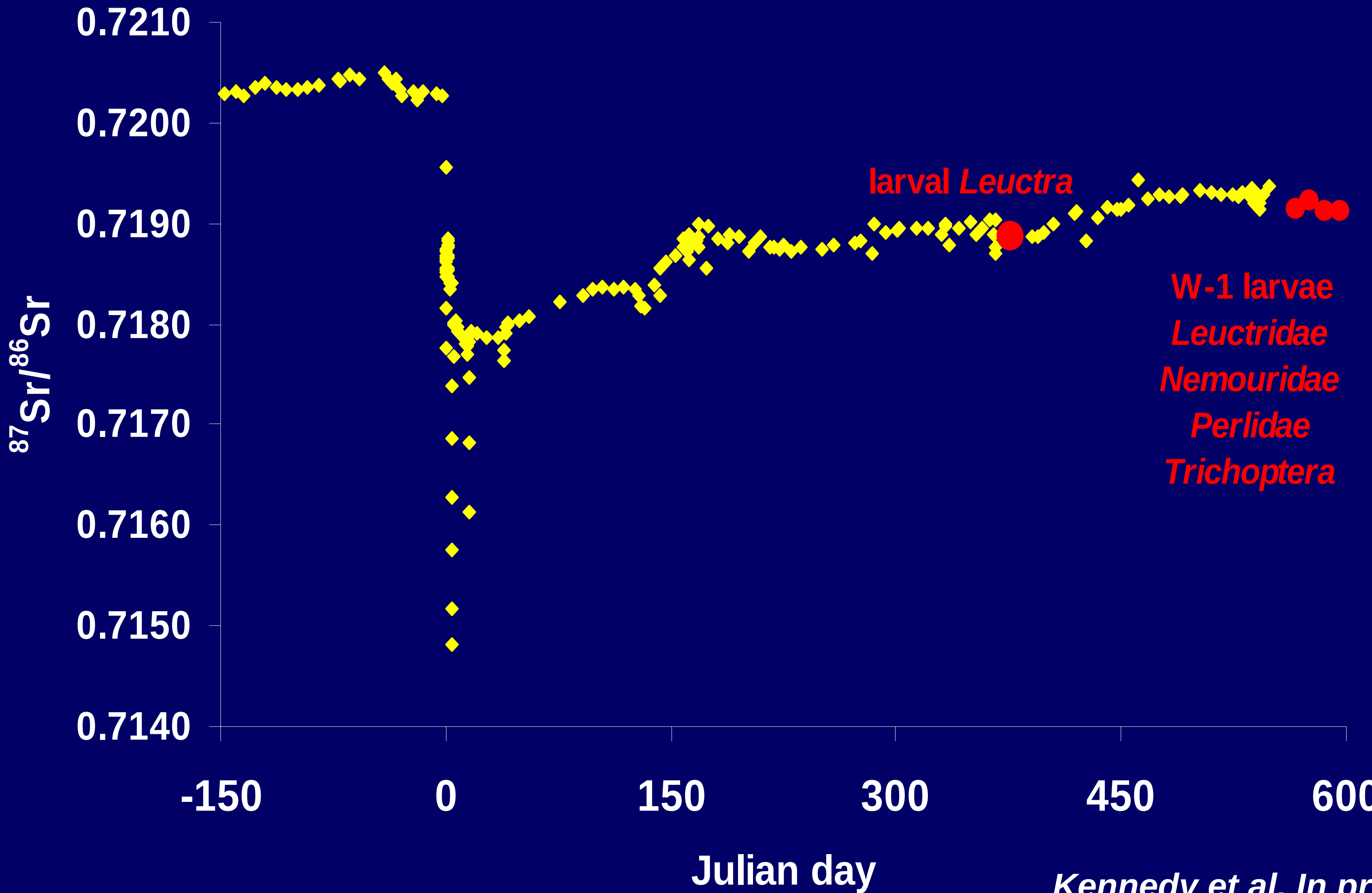


1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Sr (mg L-1)
0.705
0.710
0.715
0.720
0.725
0.730
87Sr/86Sr
Colorado
Paria
Nankoweap
LCR
Clear
Bright Angel
Hermit
Crystal
Shinamu
Tapeats
Deer
Kanab
Havasu
Diamond



5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Sr/Ca mmol mol-1
0.705
0.710
0.715
0.720
0.725
0.730
0.735
87Sr/86Sr

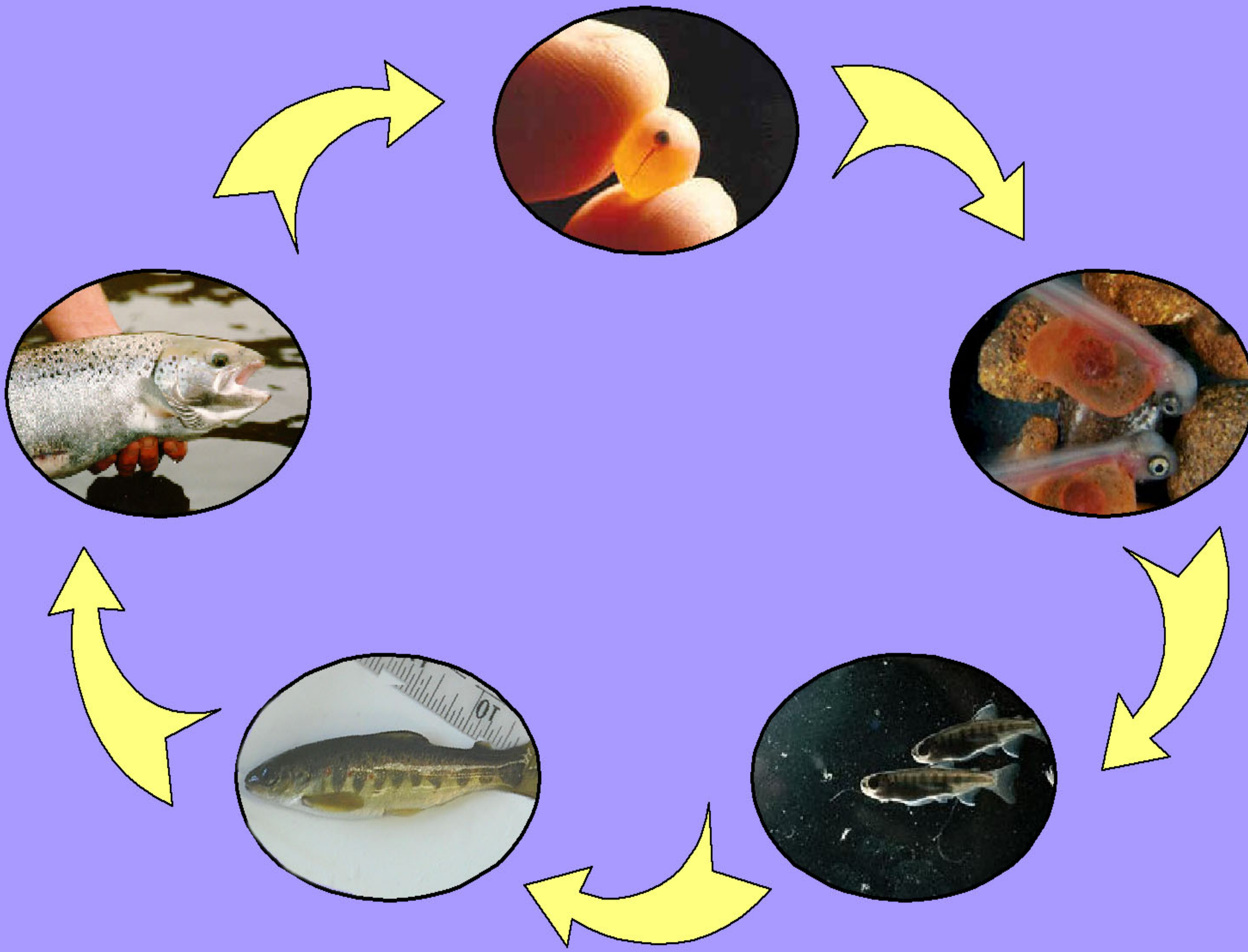
# $^{87}Sr/^{86}Sr$ at Hubbard Brook



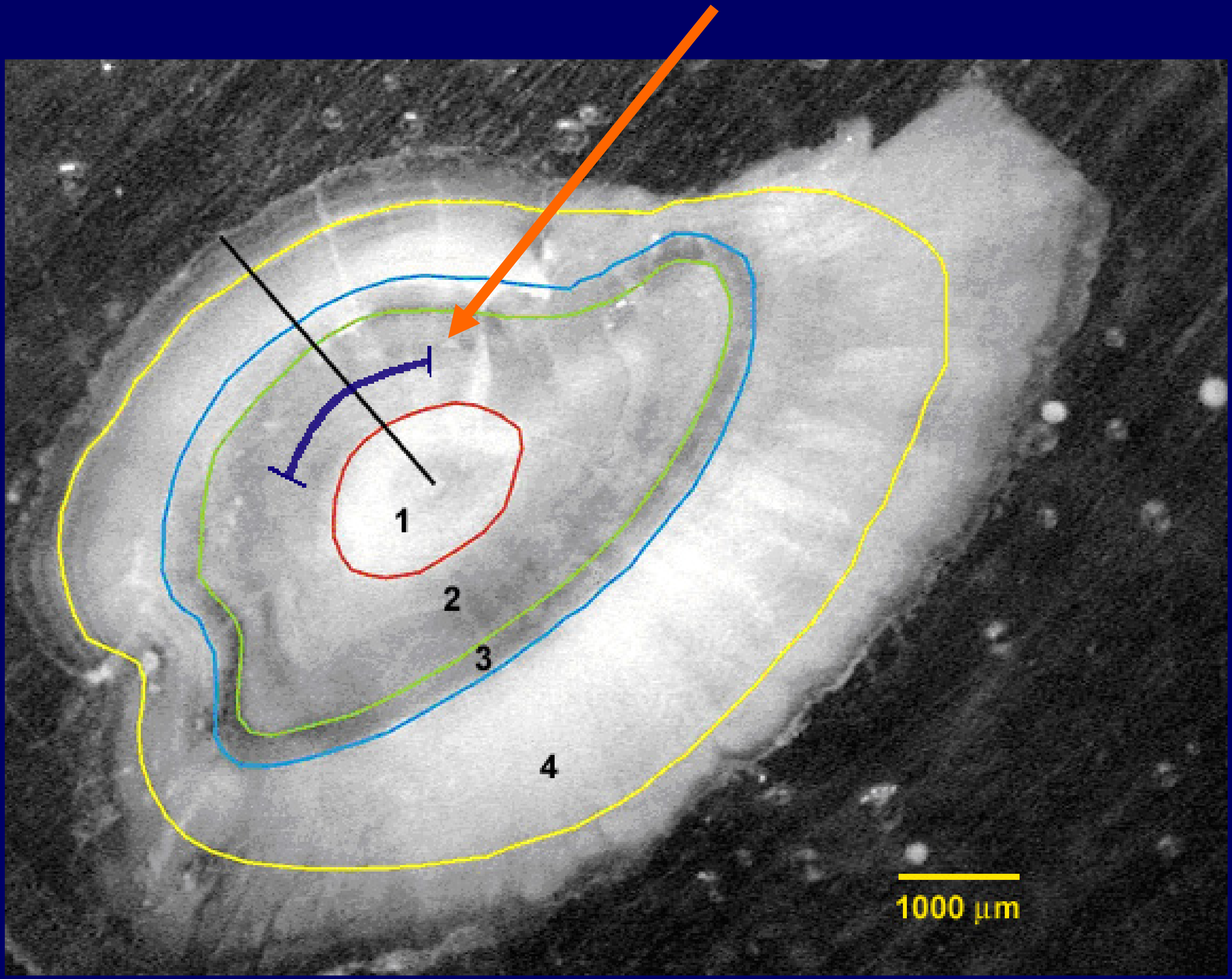

*Kennedy et al. In prep*

# Summary of results

- Significant differences in both isotopic and elemental signatures exist for water.
- Chemical signatures are extremely stable over time (however, only near baseflow conditions sampled).
- Differences reflect differences in geologic features (e.g. Walhalla plateau).
- Chemical composition of the Colorado River stays constant throughout the entire canyon.
- Of the tributaries in the canyon, the LCR looks most similar to the Colorado River, however, there are distinct upstream and downstream signatures in the LCR that are distinguishable from the Colorado.
- Fish in the LCR have mixed signatures stressing the importance of time resolved analysis.



# Otolith micromill drill site




*Kennedy et al. CJFAS 2002*

# *Conclusions*

- Sr isotopes provide clear advantages as a population marker in freshwater systems with geologic variability.

- Combinations of multiple isotopes and elemental concentrations may provide the best resolution for discriminating populations.

- More work needs to be done on understanding factors that influence elemental fractionations.