GEOC5089 ME5089
Exploration Geochemistry

Examples

INSTRUCTOR—Dr. Virginia T. McLemore

FALL 2023

Safety

Camping Safety

by: Oscar Scholten

Gear

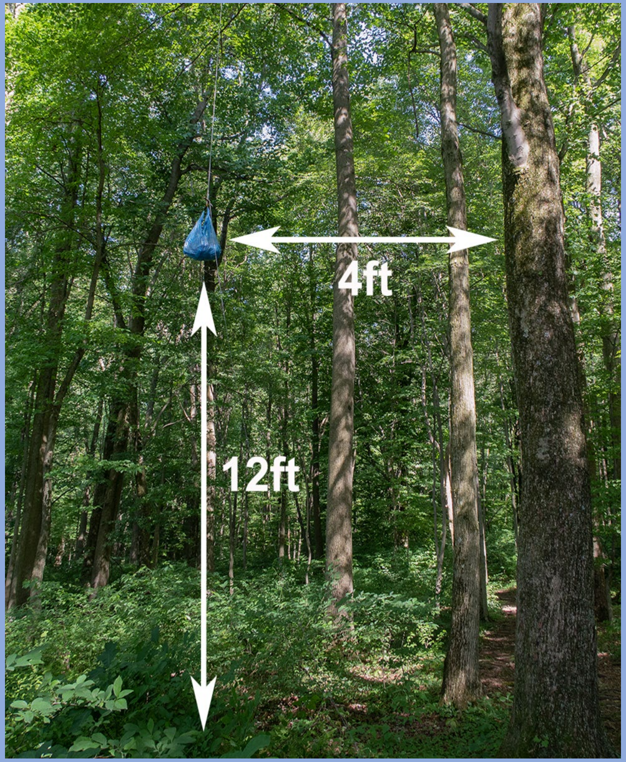
- Tent / Sleeping Bag / Sleeping Pad / Backpack
- Pack warm layers. Extra socks
- ALWAYS be waterproof
- Extra Water. Water filter
- Stove & Food
- Extra Bags
- Toilet Paper & Hygienics (Baby Wipes, Kleenex
- Trash Bags, pack in pack out!
- Beacon / Map
- Boots, break them in
- Tell someone your plans!

Where to Sleep?

- Not too close to water, especially rivers/streams
- Think of flash floods!
- Avoid cliffs
- Look at the ground beneath your tent
  - Slopes
  - Rocks
  - Ants

Food

- NEVER bring food into the tent
- Store in separate location from tent. If it's in a bag, avoid bringing that bag into your tent if you can
    - Vans :)
    - Bear bins
    - Bear cans
    - Tie it up
- If you're on a long trip, get used to the food



Cleaning

- Bring biodegradable dish soap
- EVEN IF YOUR SOAP IS BIODEGRADABLE

  Do **<u>NOT</u>** put it in a lake/stream/whatever

- According to the EPA, 1 ounce of biodegradable soap needs to be diluted in 20,000 ounces of water
- Bring water away from lakes edge (60m/200ft) and wash there
- If you can, pouring soapy water into a hole is ideal
- Same goes for brushing your teeth, or body soap
- Make sure you wash off ALL the soap

Bathroom

- Once again, 200ft away from water
- Similarly away from your campsite
  - Goats and other animals will seek out the salt. Do not let them near your tent
- If you need to poo, dig a 6-8 inch deep cathole (length of your trowel)
- Not always possible, do your best

Wild Animals - Bears

- If you’re in bear country, be loud
- Bluff Charge
  - More common
  - Head & ears up & forward. Bear will puff itself up to look bigger
  - Hold your ground. Make yourself big. Do your best to stay & talk calmly, then back away slowly
- Aggressive Charge
  - Bear yawns/clacks teeth. Pounds ground. Huffs
- Black Bear
  - Fight back!
- Brown Bear (or Grizzly)
  - Play dead

DO NOT RUN

Wild Animals - Other

- Don’t feed animals
- Mountain Lion
    - Stay calm. Hold ground/back away slowly
    - Stand up straight, DO NOT crouch, DO NOT run
    - If it starts to approach, make yourself big & scary. Throw things at it
    - Fight back

Questions?

Paper

BreX

Bre-X Scandal: A History Timeline

- 1989 David Walsh founded Bre-X Minerals as a subsidiary of Breaea Resources Ltd.
- 1993 Walsh bought a property near Busang River, Borneo, Indonesia
  - Estimated 2 mill ounces Au
- 1994 drilled
- 1997 estimated the resources as 70 mill ounces Au
  - Stock prices soared

http://www.visualcapitalist.com/bre-x-scandal-history-timeline/

Bre-X Scandal: A History Timeline-2

- But project manager Michael de Guzman was filing gold from his wedding ring and adding the flakes to the crushed core samples
- De Guzman used realistic ratios of gold to rock and the project kept going
- De Guzman then bought $61k of panned gold from the locals to use in salting

http://www.visualcapitalist.com/bre-x-scandal-history-timeline/

Bre-X Scandal: A History Timeline-3

- Independent auditors were fooled
- Reported 200 million oz of gold ($240 billion in 2014 prices)
- De Guzman, Felderhoff, and Walsh sold some of their options for $100 million
- 1996 Indonesia revoked their exploration permits
- 1997 a fire destroys many of the sample records

http://www.visualcapitalist.com/bre-x-scandal-history-timeline/

Bre-X Scandal: A History Timeline-4

- 1997 Joint venture established between Indonesia (40%), Bre-x (45%), and Freeport McMoRan (15%)
- Freeport begins due diligence and twin previously drilled holes
- Freeport reports minor amounts of gold
- De Guzman falls to his death from a helicopter on the way to meet Freeport geologists
- May 1997 investors were trying to get their money back
  - Ontario Municipal Employees Retirement Board (loss of $45 million)
  - Caisse de dépôt et placement du Québec Quebec Public Sector Pension fund ($70 million
  - Ontario Teachers' Pension Plan ($100 million)

http://www.visualcapitalist.com/bre-x-scandal-history-timeline/

Bre-X Scandal: A History Timeline-5

- Bre-X went bankrupt November 5, 1997 although some of its subsidiaries continued until 2003
- Walsh died of an aneurysm in 1978
- 1999 Felderhof charged with insider trading, but found not guilty

http://www.visualcapitalist.com/bre-x-scandal-history-timeline/

Red Flags

- Only 10-cm length of core per meter retained, but industry standard is to retain entire ½ core
  - Reanalyses failed to find any gold
- Core treated differently (sample preparation, storage, transit)
  - Core classified as mineralized or in-fill
  - Each type subjected to different prep, storage, and transit
- Long time lapse between samples leaving site and arriving at lab
- Early met tests indicated >90% of gold was recoverable by gravity separation and particle shapes were mostly rounded (but this was a vein deposit)
- Sample grades difficult to reproduce

Canadian Instrument 43-101

- Set of rules and guidelines for reporting information relating to a mineral property in order to present these results to the Canadian stock exchange
  - created after the Bre-X scandal to protect investors from unsubstantiated mineral project disclosures
  - gold reserves at (Bre-X's) Busang were alleged to be 200 million ounces (6,200 t), or up to 8% of the entire world's gold reserves FRAUD
- Similar to JORC (joint ore reserves committee code, Australia)
- South African Code for the Reporting of Mineral Resources and Mineral Reserves (SAMREC)

Qualified person (43-101)

- Engineer/geoscientist with a university degree, or equivalent accreditation, in an area of geoscience, or engineering, relating to mineral exploration or mining
- Has at least five years of experience
- Has experience relevant to the subject matter of the mineral project and the technical report
- Is in good standing with a professional association

CLASSIFICATION OF MINERAL RESOURCES ON U.S. FEDERAL LAND

Types of ownership

- Federal
- State
- Private
- Tribal
- Split estate

Locatable Minerals are whatever is recognized as a valuable mineral by standard authorities, whether metallic or other substance, when found on public land open to mineral entry in quality and quantity sufficient to render a claim valuable on account of the mineral content, under the United States Mining Law of 1872. Specifically excluded from location are the leasable minerals, common varieties, and salable minerals.

Leasable Minerals The passage of the Mineral Leasing Act of 1920, as amended from time to time, places the following minerals under the leasing law: oil, gas, coal, oil shale, sodium, potassium, phosphate, native asphalt, solid or semisolid bitumen, bituminous rock, oil-impregnated rock or sand, and sulfur in Louisiana and New Mexico.

Salable Minerals The Materials Act of 1947, as amended, removes petrified wood, common varieties of sand, stone, gravel, pumice, pumicite, cinders, and some clay from location and leasing. These materials may be acquired by purchase only.

It is important to recognize that mineral deposits are controlled by geological processes, not land ownership or classification, and that mineral resources are found in areas where the geology is favorable for the occurrence of mineral deposits, and not just anywhere on earth. Mineral deposits cannot be moved and can only be developed where they are discovered.

Water sampling

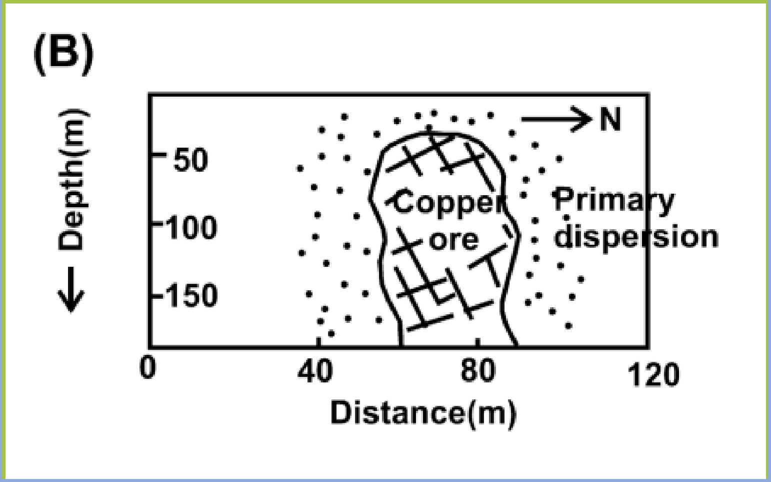
2.1.2. Pathfinder Elements

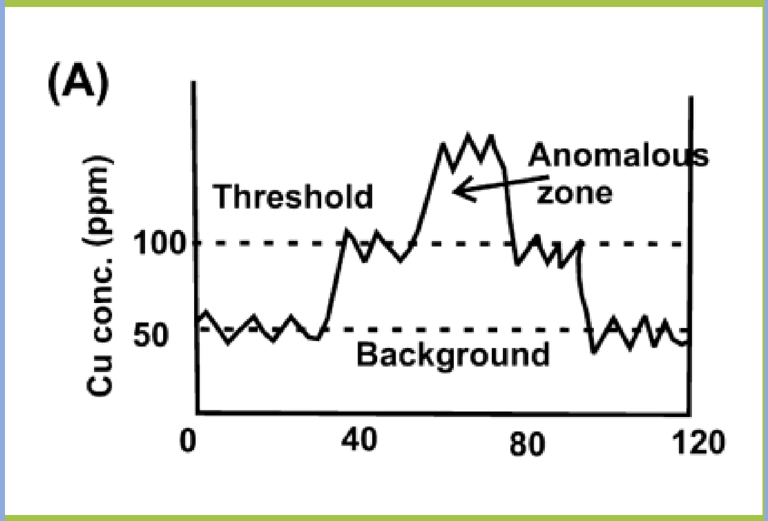
"Pathfinder" or "indicator" elements are characteristic parameter in geochemical prospecting. These are relatively mobile elements due to physicochemical conditions of the solutions in which they are found or in volatile state (gaseous). They occur invariably in close geochemical association of the primary minerals being searched. These elements can be more easily found either because they form a broader halo around the deposit or because they can be detected more easily by simpler and less expensive analytical methods. Pathfinder elements play great role in locating concealed deposits due to these special properties. the use of radon as a pathfinder for uranium deposits and As is Pathfinder for gold.

2.1.3. "Background" and "Threshold" value

"Background" values are characterized by the normal range of concentration of elements in regional perspective rather than localized mineral occurrences. It is significant to establish the background value of the area against which the anomalies due to economic mineral accumulations, if any, can be identified. Large number of samples comprised of rock, soil, sediments, groundwater and volatile matters are analyzed for multiple elements separately for each area before the exploration begins.

"Threshold" value is defined as the probable upper or lower limit of the background value (Fig. 2.1A) at some statistically precise confidence level. Any sample that exceeds this threshold is considered as possibly anomalous and belongs to a separate population. It may vary for each element, each rock type, different types of samples and in each area. The negative anomalous threshold defines the lower limit of background fluctuation. A geochemical section of a traverse-line is given in Fig. 2.1B.





Signatures - Commodities

Deposit Type	Examples	Geochemical Signature
Magmatic Sulphide	Norilsk, Merensky Reef, Sudbury.	**Cu**, **Ni**, **PGE**,
Porphyry Copper	Bingham, Collahuasi, Tintaya, Los Bronces	**Cu**, **Au**, **Mo**,
VMS	Cyprus, Kuroko, Kidd Creek, 777	**Cu**, **Zn**, **Pb**
IOCG (F-U-REE)	Olympic Dam, Manto Verde	**Au**, **Cu**, **U**,
Sediment Hosted Cu	Zambia/Congo Cu-belt,	**Cu**, **Co**,
Sandstone U	Karoo, Colorado Plateau	**U**,
Kimberlite	Ekati, Diavik, Kimberley	**C**, minerals

Signatures -Traces

Deposit Type	Examples	Geochemical Signature
Magmatic Sulphide	Norilsk, Merensky Reef, Sudbury.	**Cu**, **Ni**, **PGE**, Cr, Co, Mg, Ti, *Ag, As, Au, Bi, Fe, Hg, Pb, Sb, Te, Se, Zn, Cd*
Porphyry Copper	Bingham, Collahuasi, Tintaya, Los Bronces	**Cu**, **Au**, **Mo**, Ag, As, B, Ba, Bi, Cd, Co, Cr, Cs, F, Fe, Hg, In, K, La, Li, Na, Ni, Pb, Rb, Re, Sb, Se, Sn, Sr, Te, Tl, U, V, W, Zn
VMS	Cyprus, Kuroko, Kidd Creek, 777	**Cu**, **Zn**, Mn, Tl, Ag, As, Au, Ba, Bi, Cd, Co, Cr, Fe, Hg, In, Ni, Pb, Sb, Se, Sn, Mo
IOCG (F-U-REE)	Olympic Dam, Manto Verde	**Au**, **Cu**, **U**, **REE**, Ag, As, Au, B, Ba, Bi, Cl, Co, F, Fe, K, Mn, Mo, Na, Nb, Ni, P, Te, V,
Sediment Hosted Cu	Zambia/Congo Cu-belt,	**Cu**, **Co**, **U**, **Bi**, Ag, As, Au, B, Ba, Cd, Cr, Ge, Hg, In, K, Mo, Ni, Pb, Sc, Se, Sn, Sr, V, Zn, REE
Sandstone U	Karoo, Colorado Plateau	**U**, Ag, Cu, Mo, Pb, Rn, Se, V – redox indicators
Kimberlite	Ekati, Diavik, Kimberley	**C**, minerals, Ni, Nb, Zr, LREE, Mg, Cr, Co,

Types of water samples

- *Discrete sample,* also known as grab sample, is a single sample collected in an individual container.
  - The sample is representative of the chemistry only at the time and place at which the sample was taken.
  - The time period is generally defined to be less than 15 min.
  - Thus, discrete samples are appropriate when the sample composition is not time dependent.

- *Composite sample* consists of a series of smaller samples collected at a predetermined time or after predetermined flow and mixed in the same container.

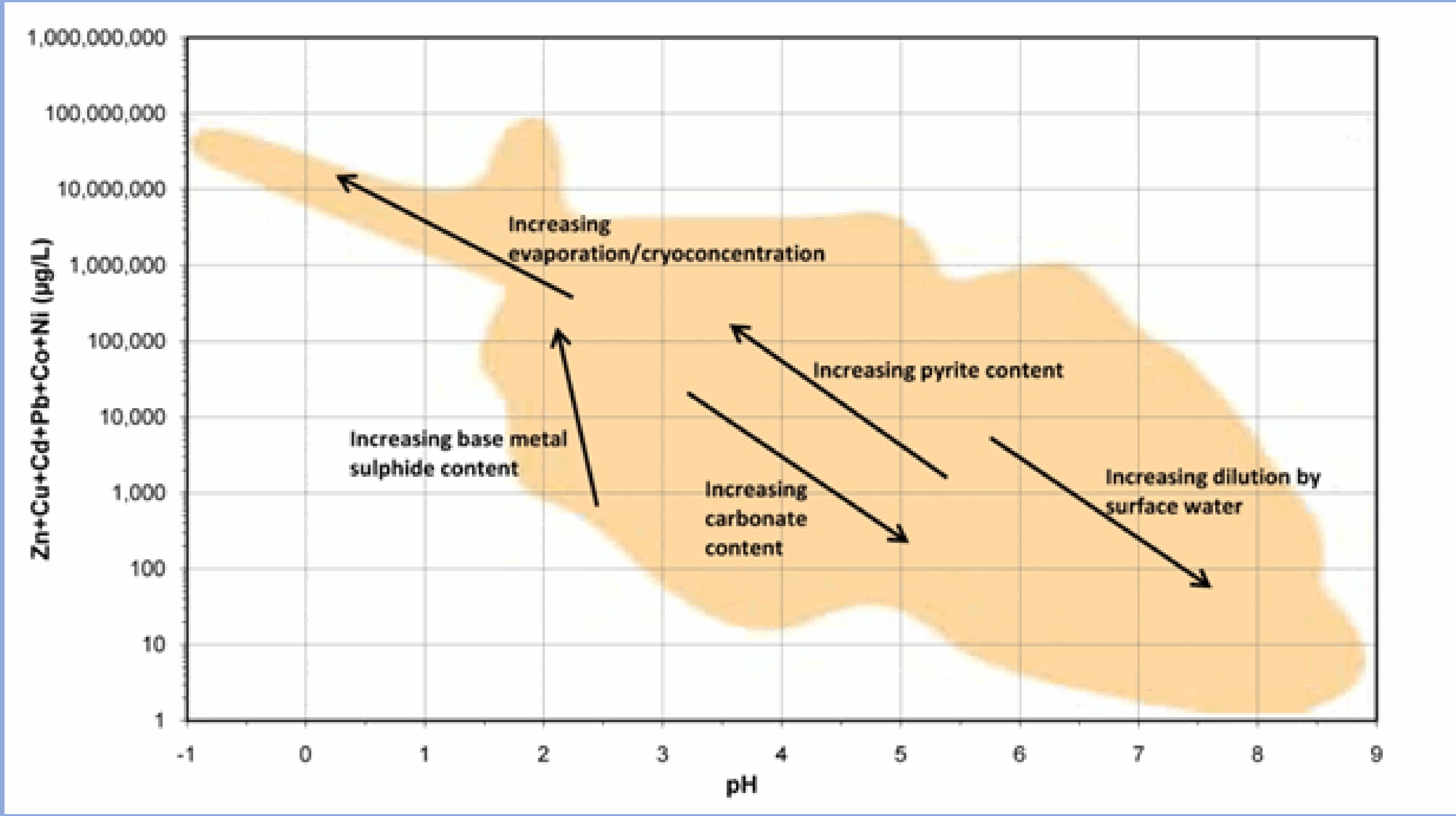
Types of water samples

- Unfiltered acidified (with several drops of ultrapure nitric acid), for the total content of major and trace elements
- Filtered (usually to < 0.1 or 0.45 μm) acidified, for the analysis of dissolved trace elements
- Filtered unacidified, for the analysis of anions
- Aqueous inorganic mercury should be collected in 10% nitric acid-washed, triple-rinsed glass jars with a Teflon cap and preserved with 0.5 ml Ultrex HCl per 30 ml of sample, and once in the lab, BrCl is added (Hageman, 2007a)

Field analytical methods

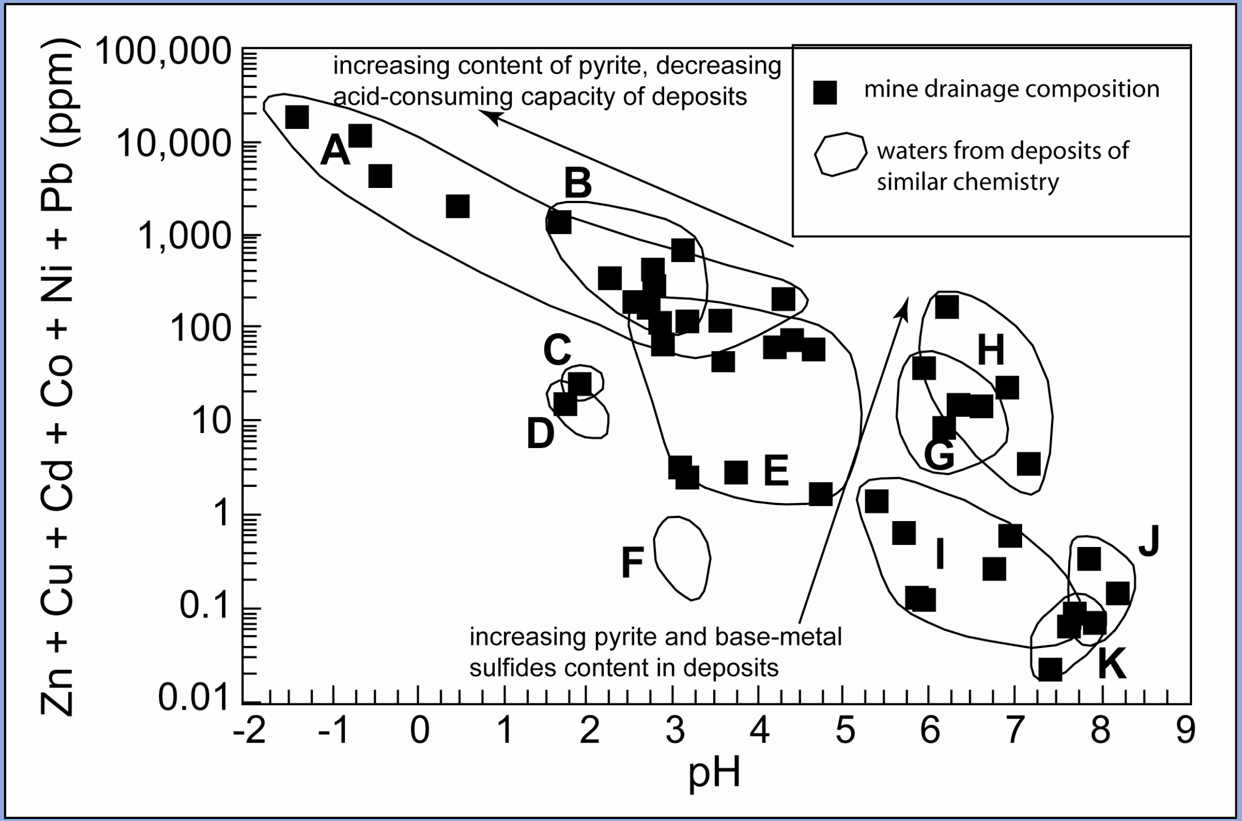
that must be used to measure unstable parameters

- Temperature
- pH
- Eh
- Specific conductance
- Dissolved oxygen
- Alkalinity
- Chloride
- Fluoride

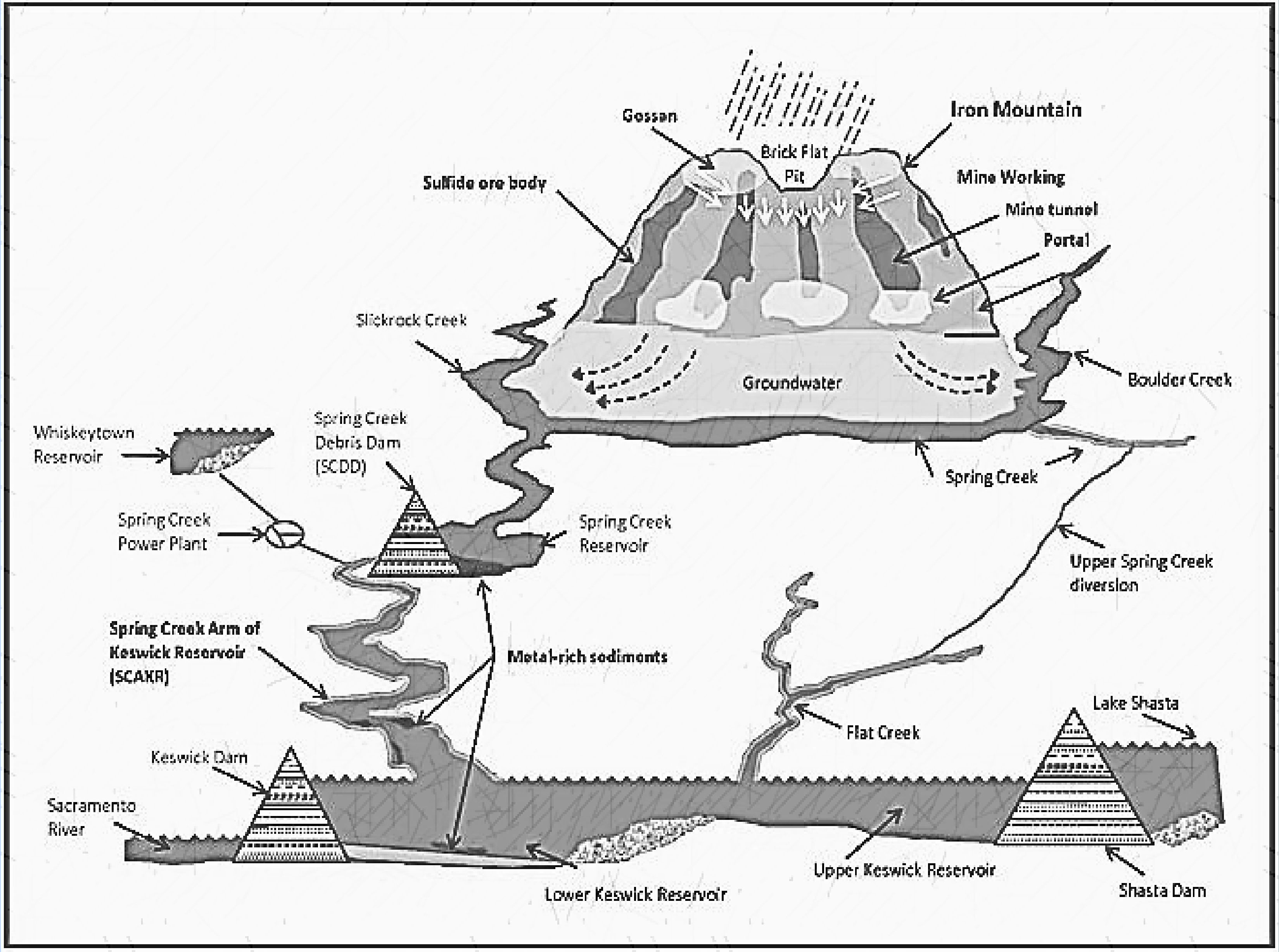


Arrows show likely path of water chemistry as a result of designated chemical processes (Revised from Ficklin, 1992; Plumlee et al., 1999; INAP, 2010)

FICKLIN PLOT



A=pyrite-rich massive sulfides, B=sulfide-rich ores with pyrite in altered wallrock, C=high sulfide, low base-metal hot spring ores in altered wallrock, D=high-sulfide, low-base metal porphyry Mo ores, E=pyrite- and base-metal-rich polymetallic veins and disseminations in wallrock with low acid-buffering capacity, F=pyrite-rich, base metal-poor veins and disseminations in wallrock with low acid-buffering capacity, G=pyrite- and base metal-rich polymetallic veins with carbonate or in carbonate wallrock, H=pyrite- and base metal-rich, polymetallic replacements and veins in carbonate-rich sediments, I=polymetallic veins with moderate to low pyrite and base metal content that are carbonate-rich or in carbonate wallrock, J=pyrite-poor polymetallic replacements in carbonate-rich sediments, K=pyrite-poor, Au-Te veins and breccias with carbonate gangue.

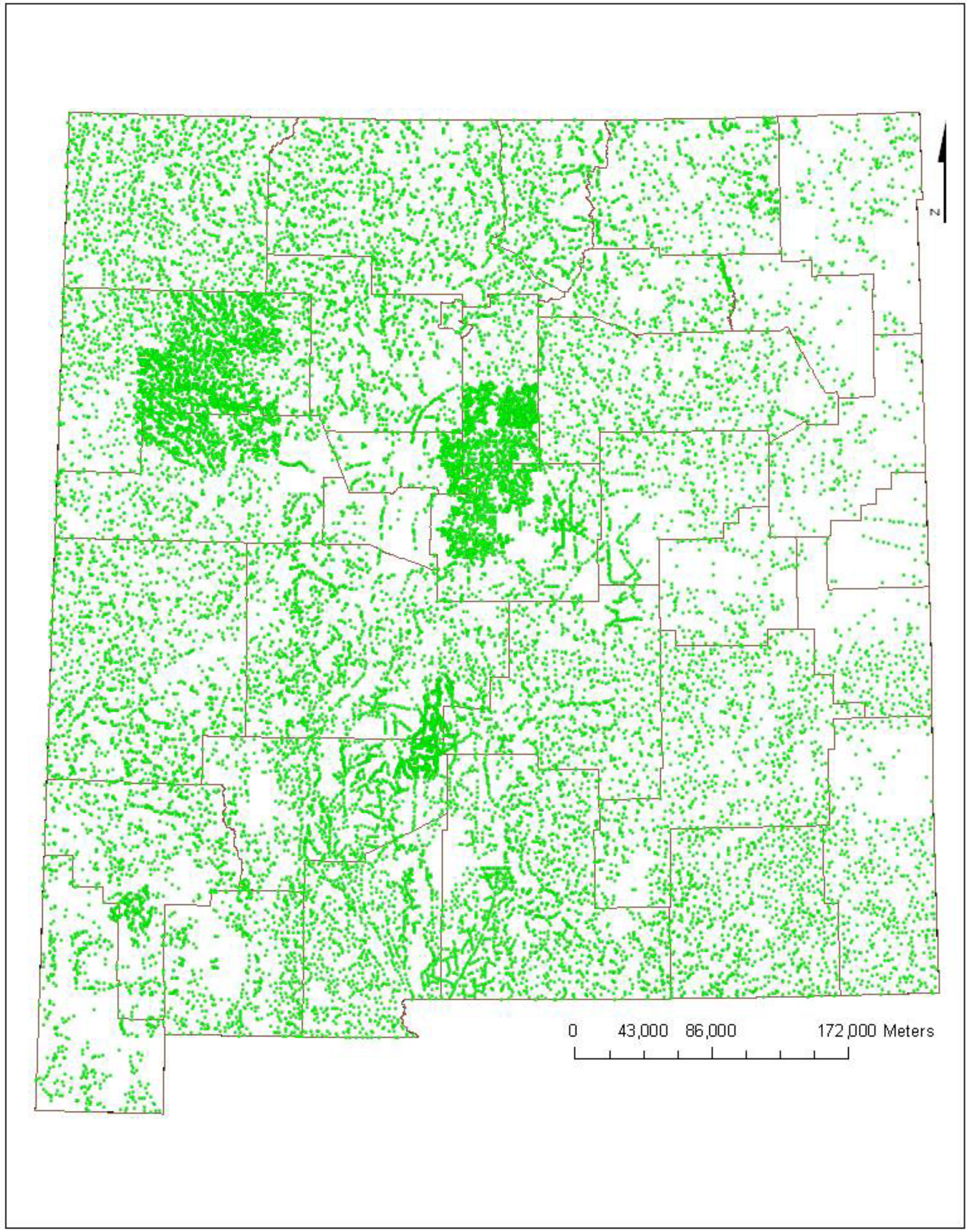


Conceptual model showing metal and acid source regions at Iron Mountain and downstream transport pathways to the Sacramento River, California (from INAP 2009).

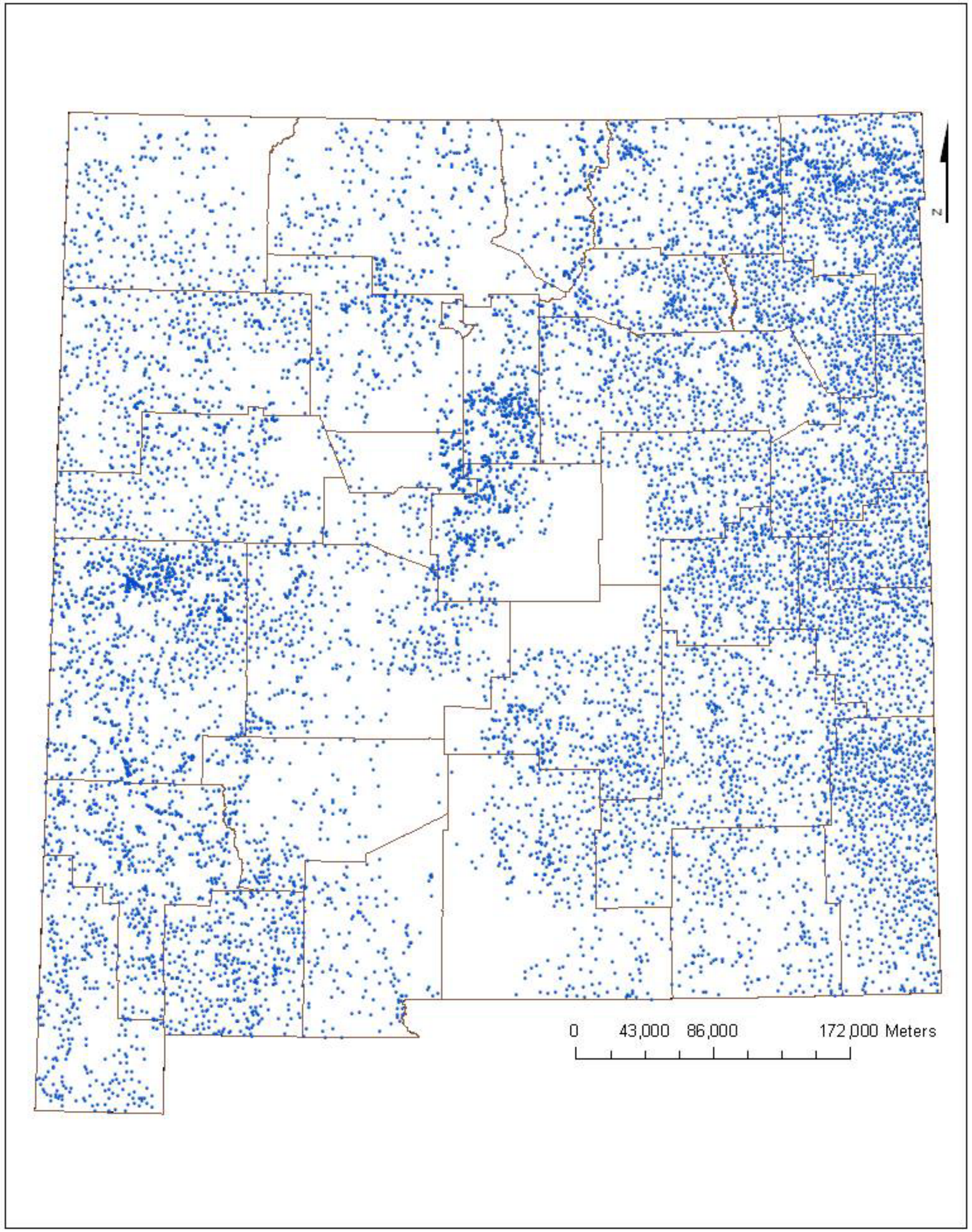
NURE DATA

NURE DATA

- National Uranium Resource Evaluation program during the 1970s
- >27,000 stream sediments samples
- >12,000 surface and well water samples
- Provides a first order of geochemical background conditions in New Mexico
- Part of the USGS National Geochemical Database http://mrdata.usgs.gov/geochem/doc/home.htm



Distribution of NURE stream-sediment samples in New Mexico



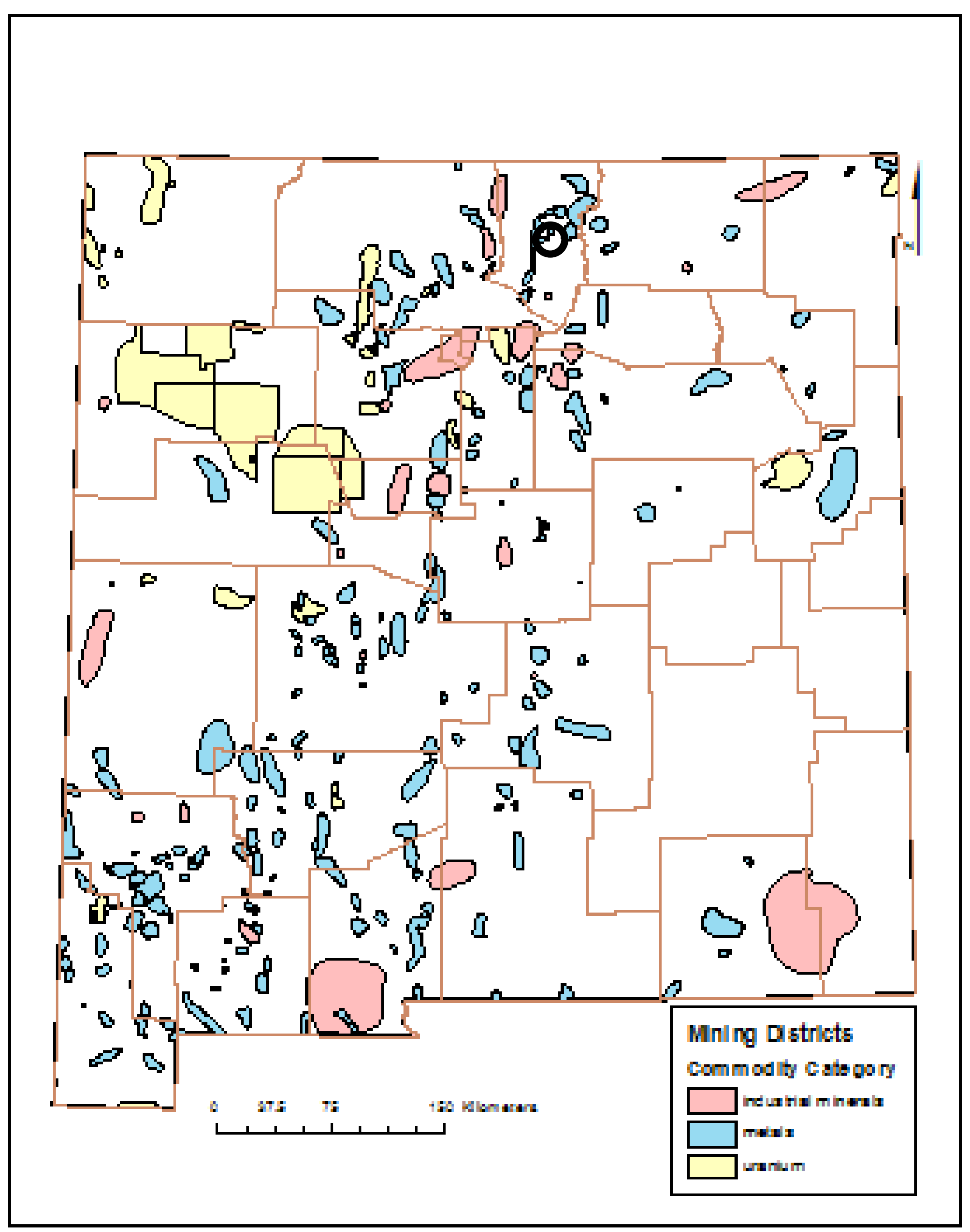
Distribution of NURE water samples in New Mexico

ISSUES AND CONCERNS ENCOUNTERED WITH THE NURE DATA

- Different laboratories
- Normality of the data
- Below detection values
- Identification of geochemical anomalies and background
- Scale of the survey
- Geochemical anomaly maps

Costilla massif, La Cueva district, Taos County

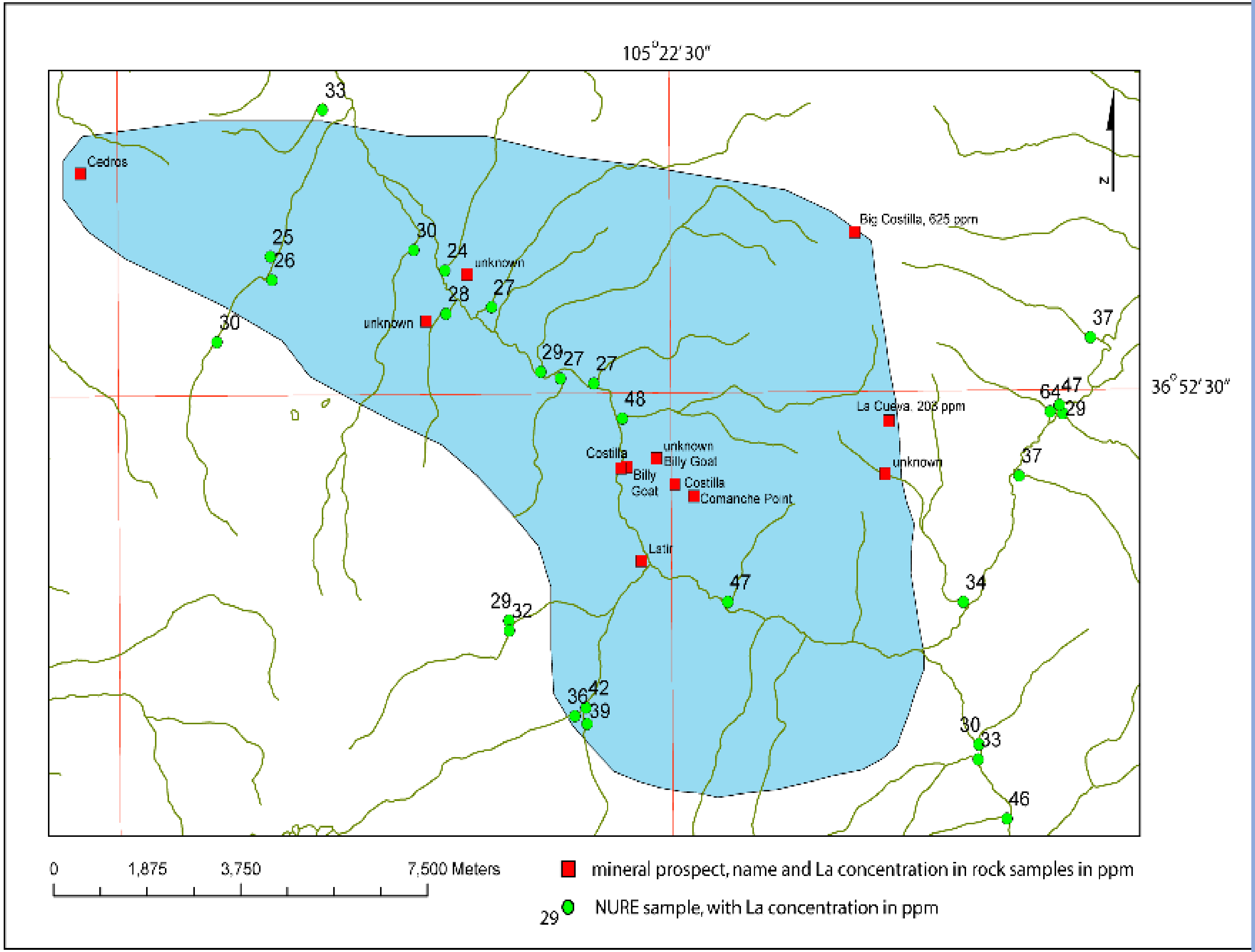
- Radioactive pegmatites intrude the granite and both intrude a complex Proterozoic metamorphic terrain of metamorphic and igneous rocks
- The granitic rocks are subalkaline, metaluminous to peraluminous.
- 1560 ppm Ce and 625 ppm La

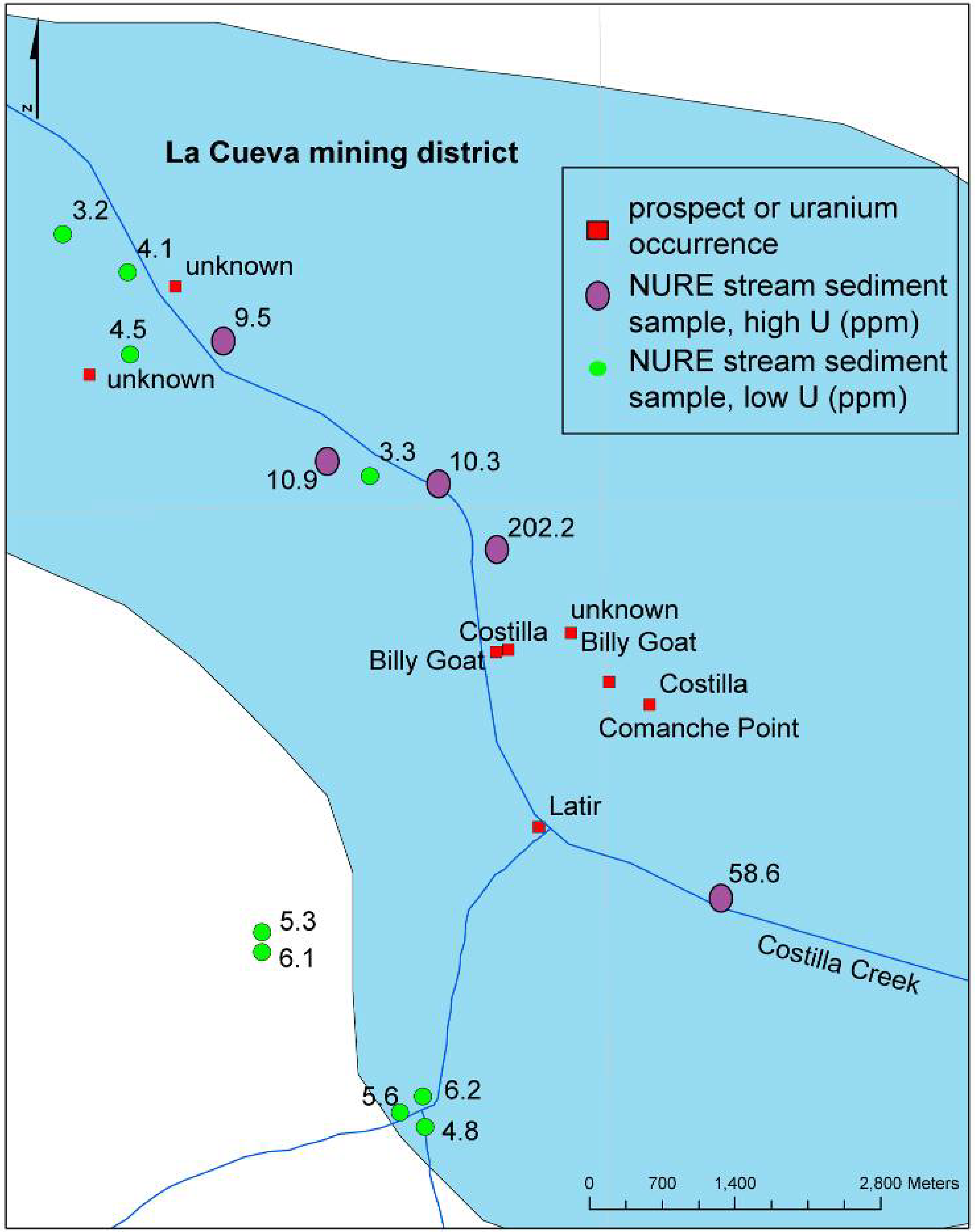


La Cueva mining district

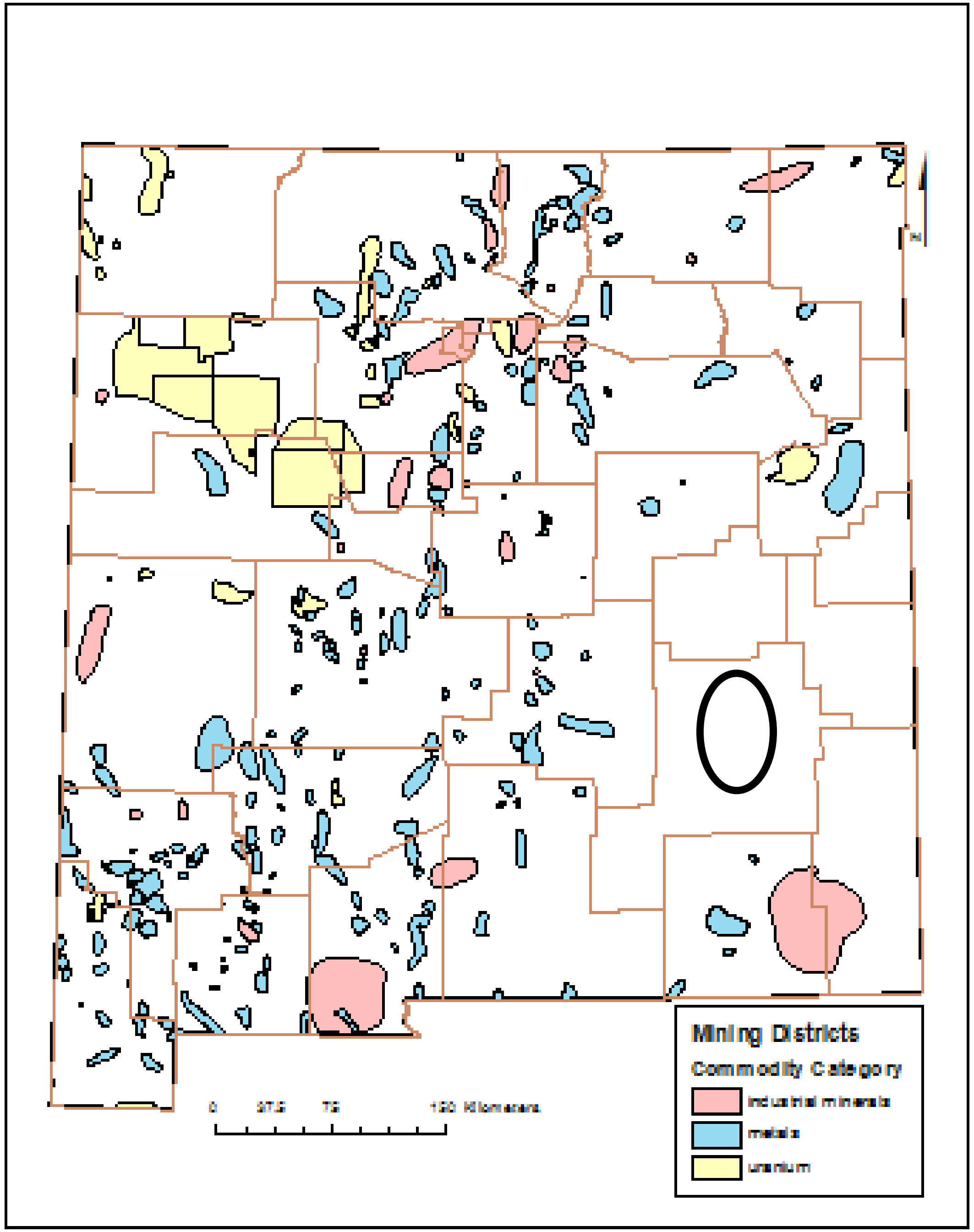
Mineralogy of Costilla massif (Zelenka, 1984)

- Uraninite UO_2 (with Ce)
- Thorite $ThSiO_4$ (with Ce)
- Uranothorite $(Th,U)SiO_4$
- Magnetite Fe_3O_4 (with U, Th)
- Zircon ZrSiO4 (with U, REE)
- Allanite $(Ce,Ca,Y)_2(Al,Fe^{+++})_3(SiO_4)_3(OH)$
- Apatite $Ca_5(PO_4)_3(OH,F,Cl)$ (with U, Th)
- Titanite $CaTiSiO_5$ (with U, Th)
- Thorogummite $Th(SiO_4)_{1-x}(OH)_{4x}$
- Uranophane $Ca(UO_2)_2SiO_3(OH)_2 \cdot 5(H_2O)$

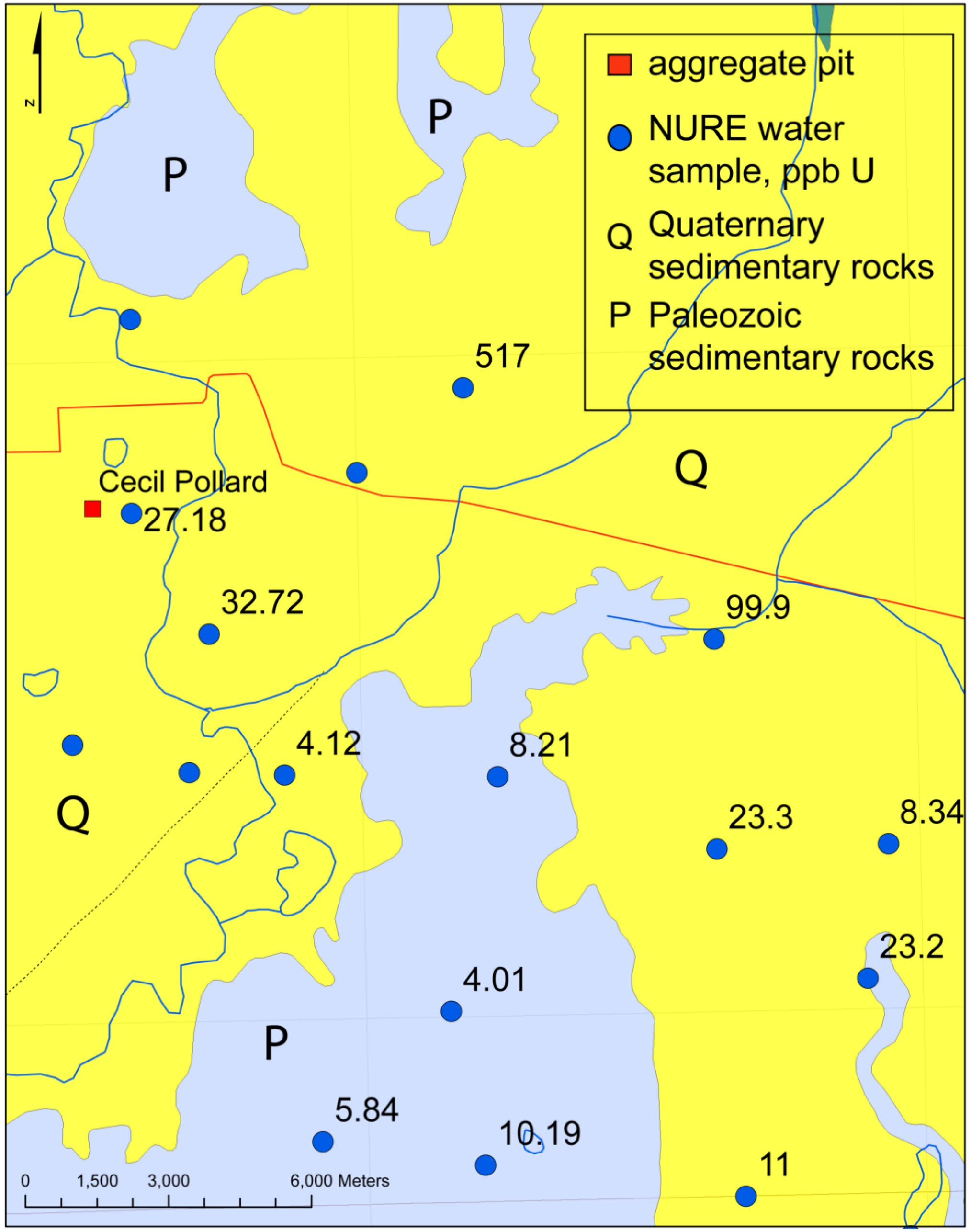

105°22′30″
36°52′30″
N
Cedros
Big Costilla, 625 ppm
unknown
unknown
La Cueva, 203 ppm
unknown
Costilla
unknown
Billy Goat
Billy
Goat
Costilla
Comanche Point
Latir
0
1,875
3,750
7,500 Meters
mineral prospect, name and La concentration in rock samples in ppm
29
NURE sample, with La concentration in ppm



Uranium in stream-sediment samples in the La Cueva mining district, Taos County

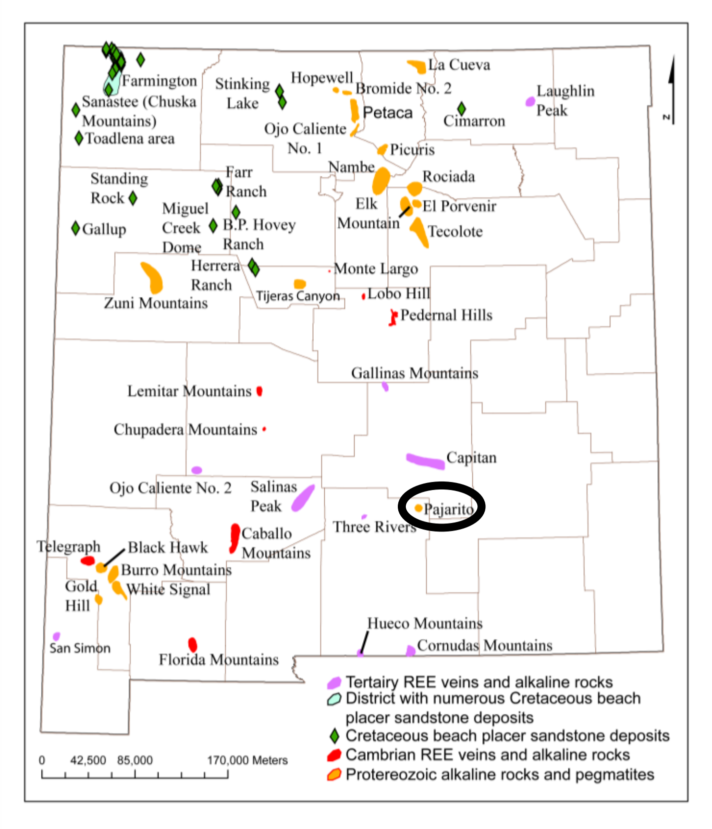


eastern
New
Mexico



Uranium in water samples in eastern New Mexico, possibly from the Ogallala Formation

Pajarito Mountain, Mescalero Apache Indian Reservation near Ruidoso—REE deposit



Proterozoic Pajarito Mountain

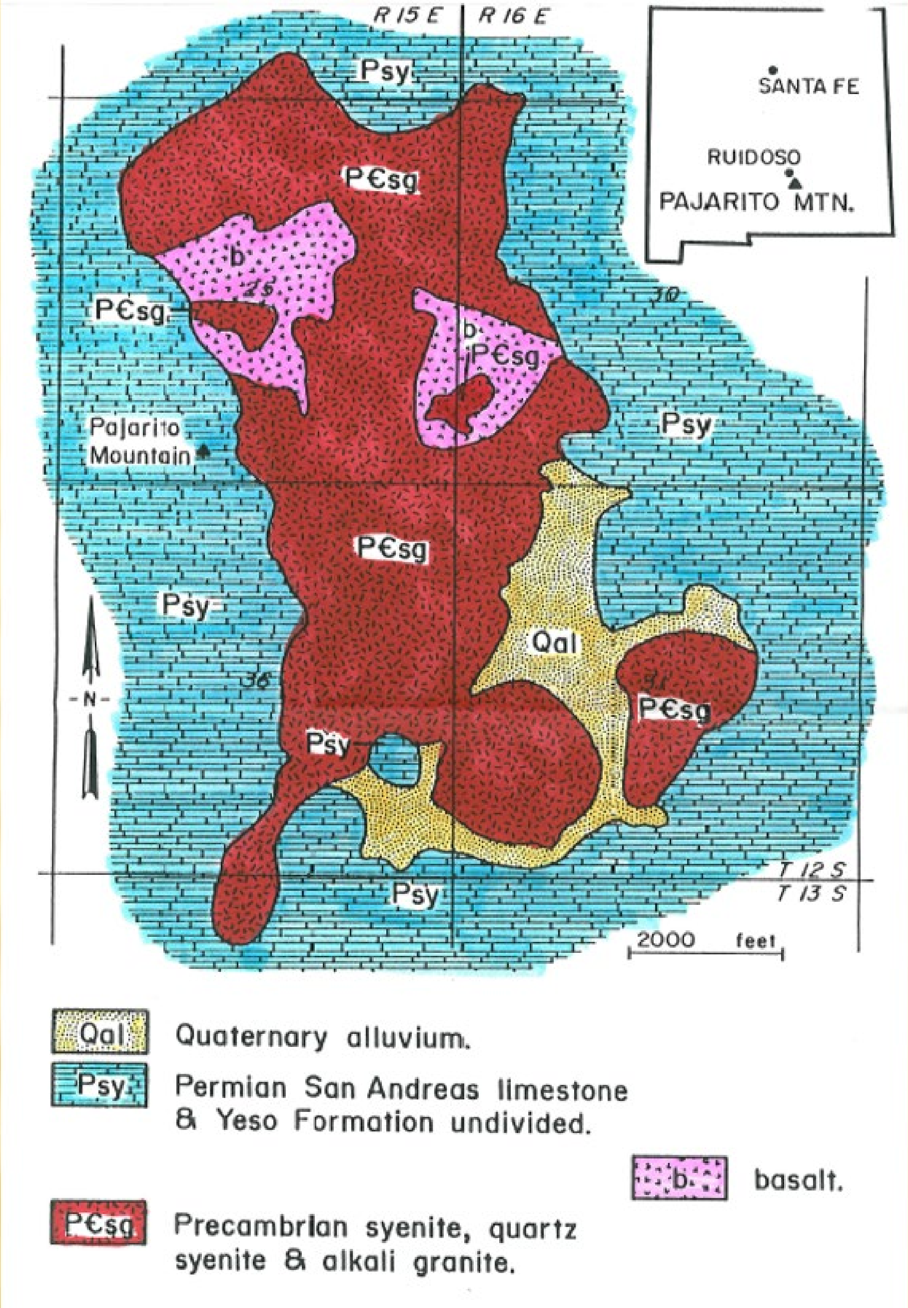
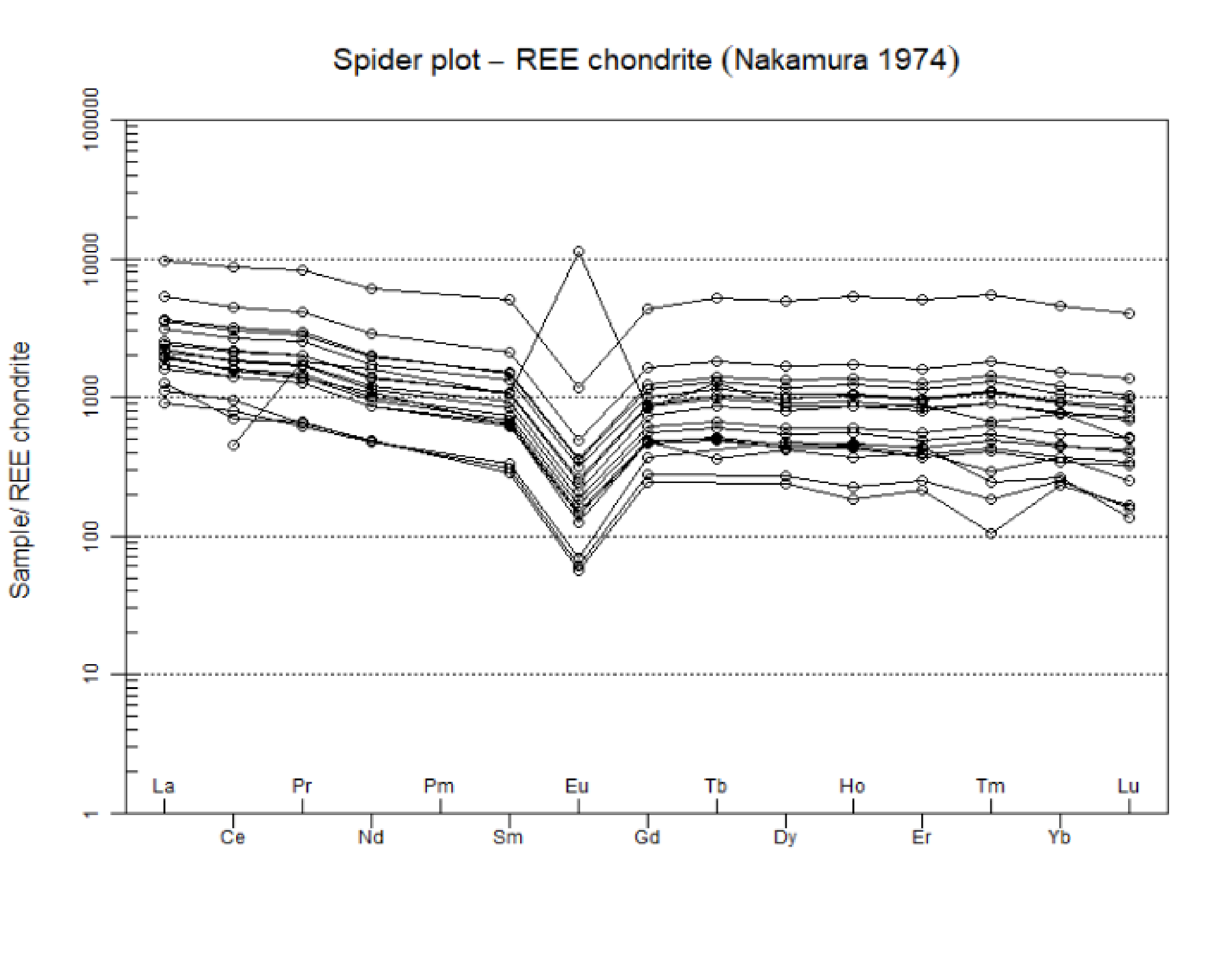
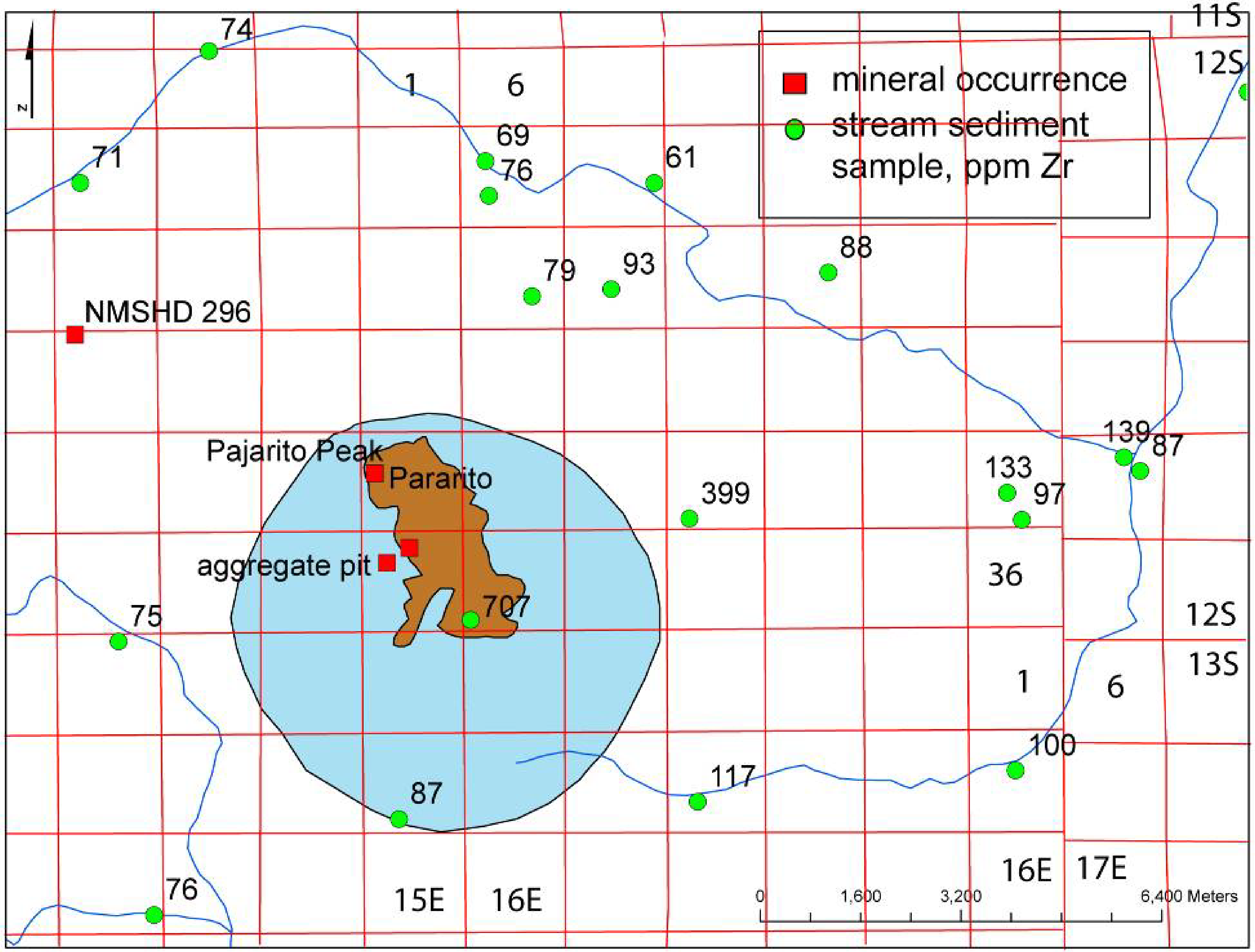


FIGURE 1—Location and generalized geology of the yttrium–zirconium deposit at Pajarito Mountain. SHERER (1990)



Mineralogy Proterozoic Pajarito Mountain (Berger, 2018)

- Eudialyte $Na_4(Ca,Ce)_2(Fe^{++},Mn,Y)ZrSi_8O_{22}(OH,Cl)_2$
- Fluorite CaF_2
- Apatite $Ca_5(PO_4)_3(OH,F,Cl)$ (with U, Th)
- Zircon ZrSiO4 (with U, REE)
- 2 REE-bearing silicates

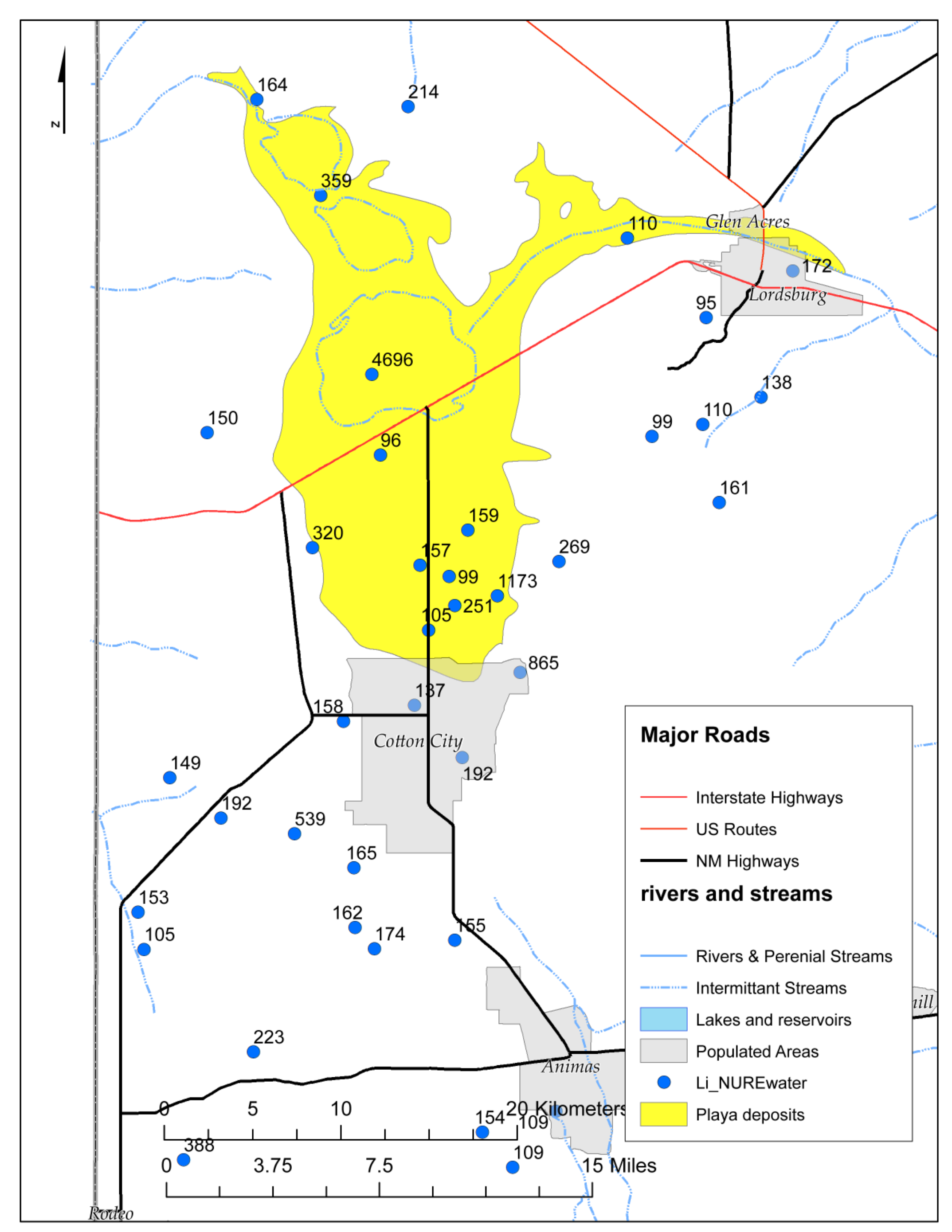


mineral occurrence
stream sediment sample, ppm Zr
N
11S
12S
13S
15E
16E
17E
1
6
36
74
71
69
76
61
79
93
88
NMSHD 296
Pajarito Peak
Pararito
aggregate pit
399
707
75
133
97
139
87
100
117
87
76
0
1,600
3,200
6,400 Meters

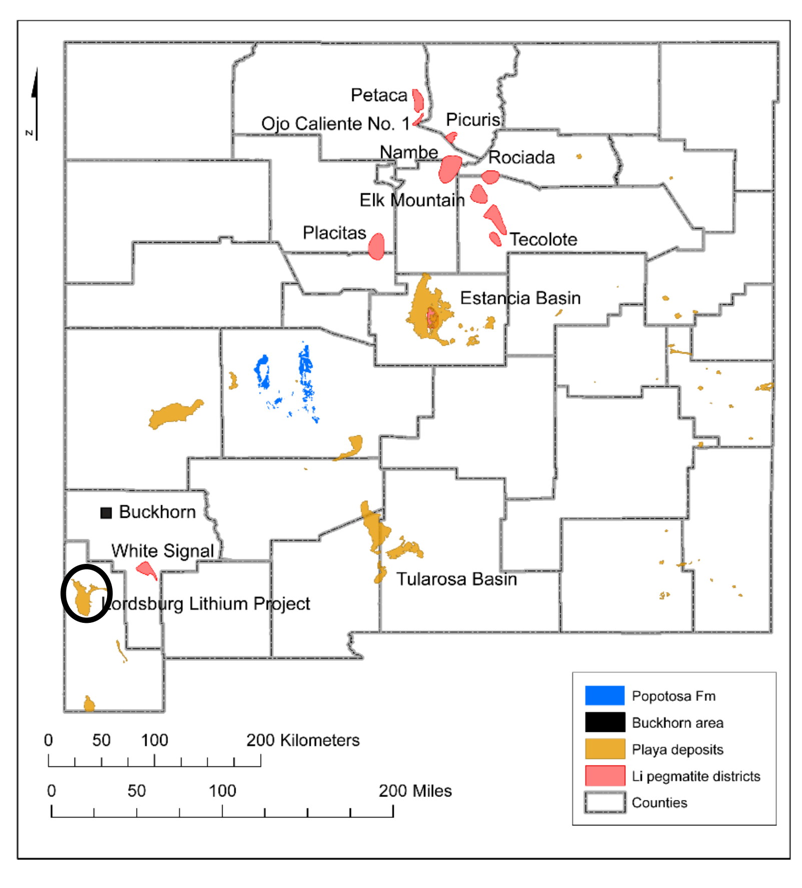
Proterozoic Pajarito Mountain

- In 1990, Molycorp, Inc. reported historic resources of 2.7 million short tons grading 0.18% Y_2O_3 and 1.2% ZrO_2 as disseminated eudialyte
- Historic REE resources—537,000 short tons of 2.95% total REE (Jackson and Christiansen, 1993)

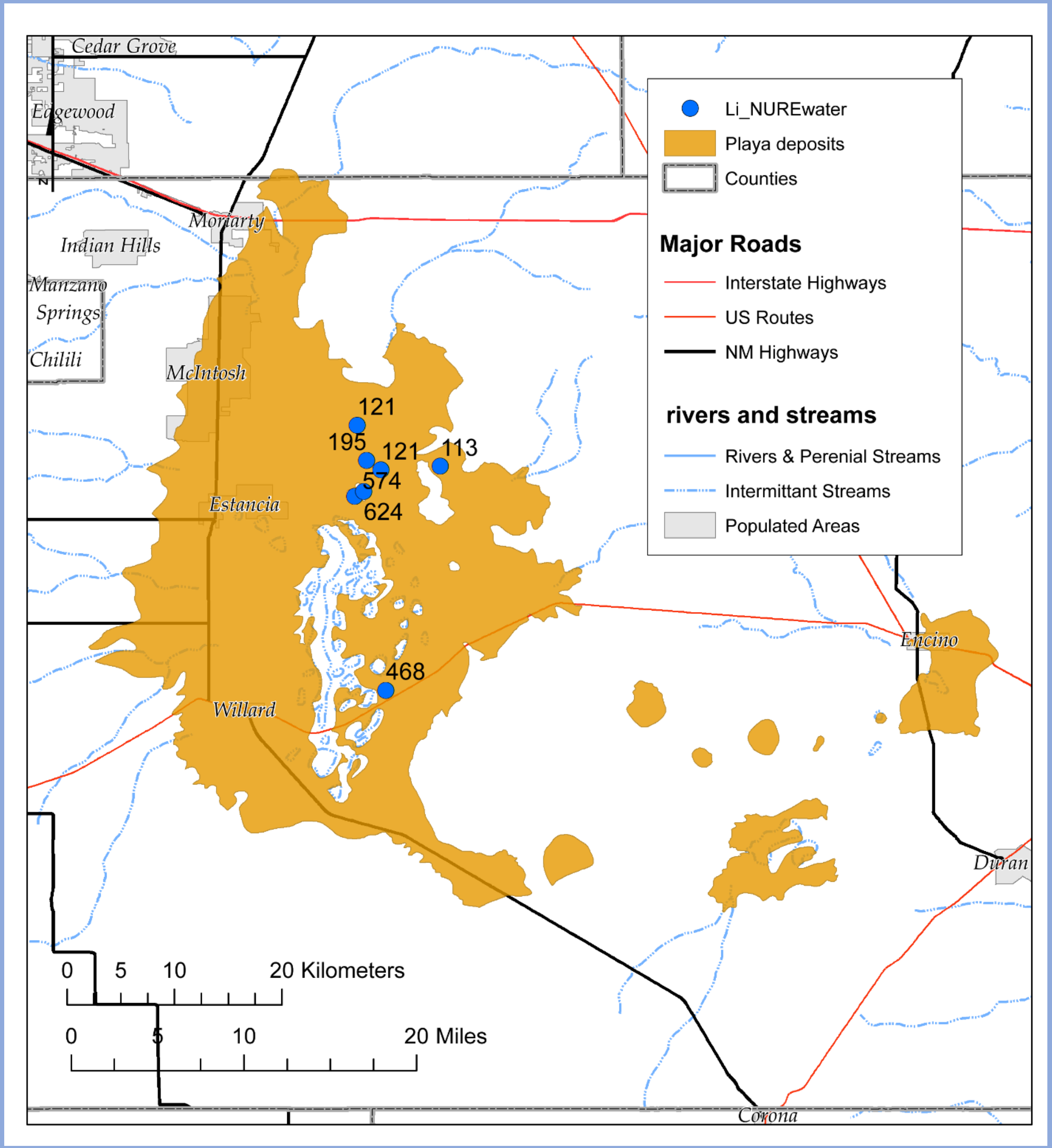
Lordsburg Lithium Deposit, Hidalgo County

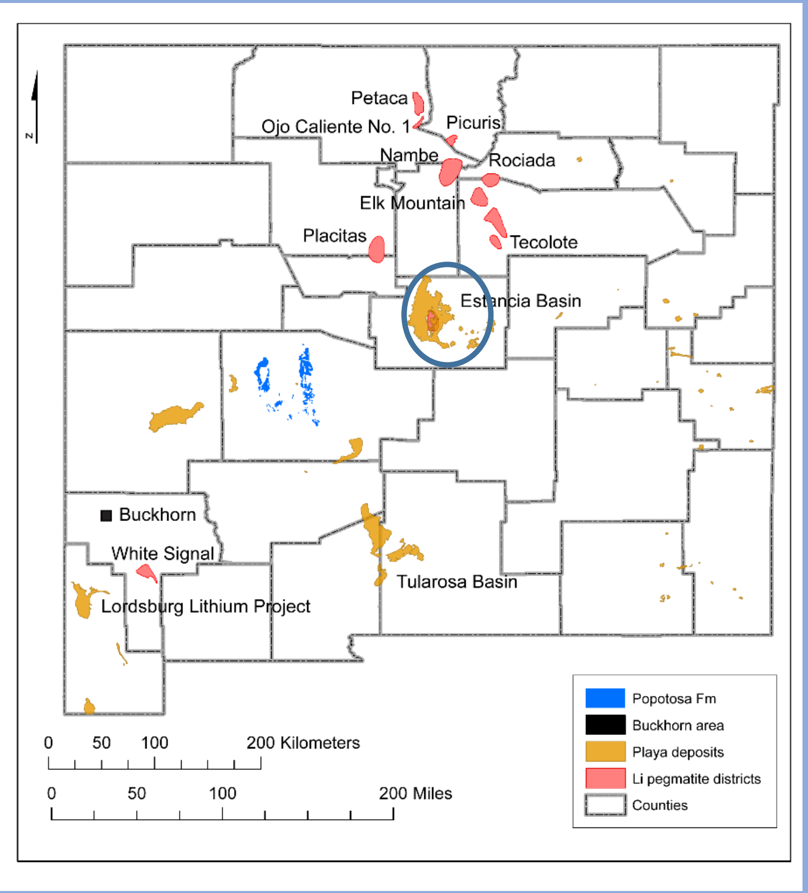


Average concertation of Li in drinking waters is 10 ppb



Estancia Lake, Torrance County





Conclusions—NURE Data

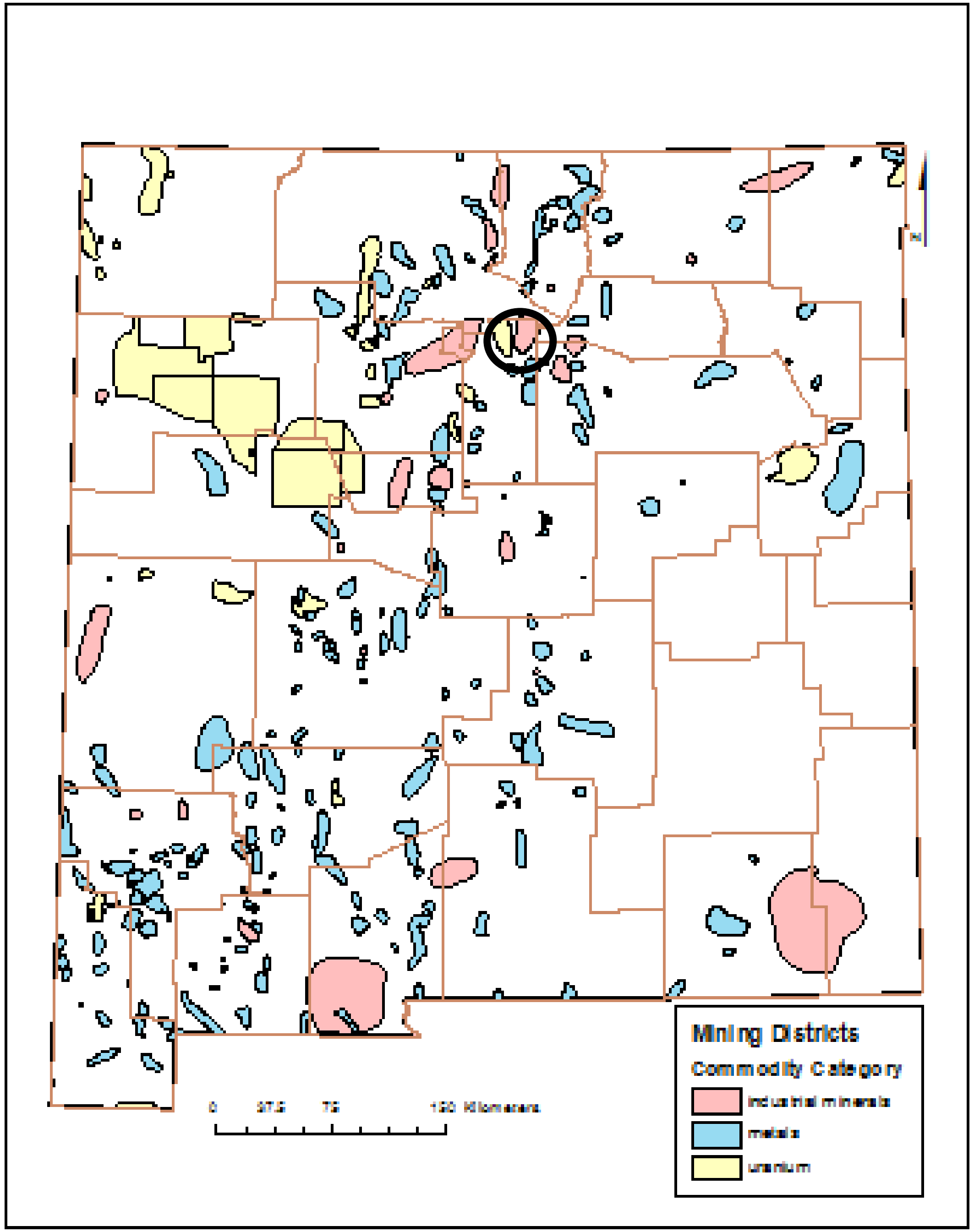
- Incorporation of various data sets into ArcMap has resulted in identification of several areas with anonymously high U concentrations
- Only a few areas examined thus far in NM at the scale of the NURE data are a result of solely contamination from mining and other anthropogenic inputs
- Most areas are a result of natural processes related to local rock chemistry, weathering, or formation of mineral deposits

Uranium in the Española Basin, Santa Fe County

Drinking-Water Treatment

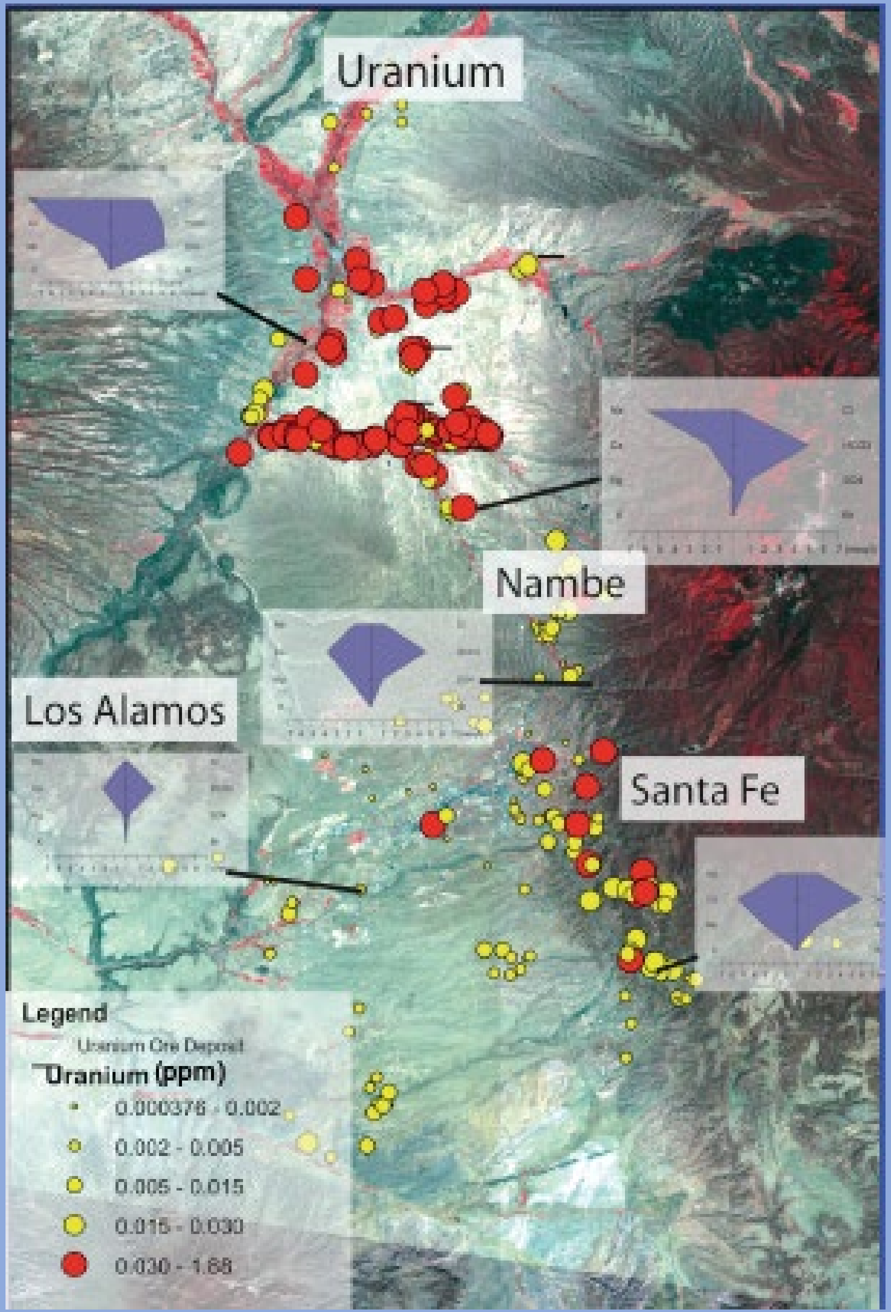

Membrane Filtration

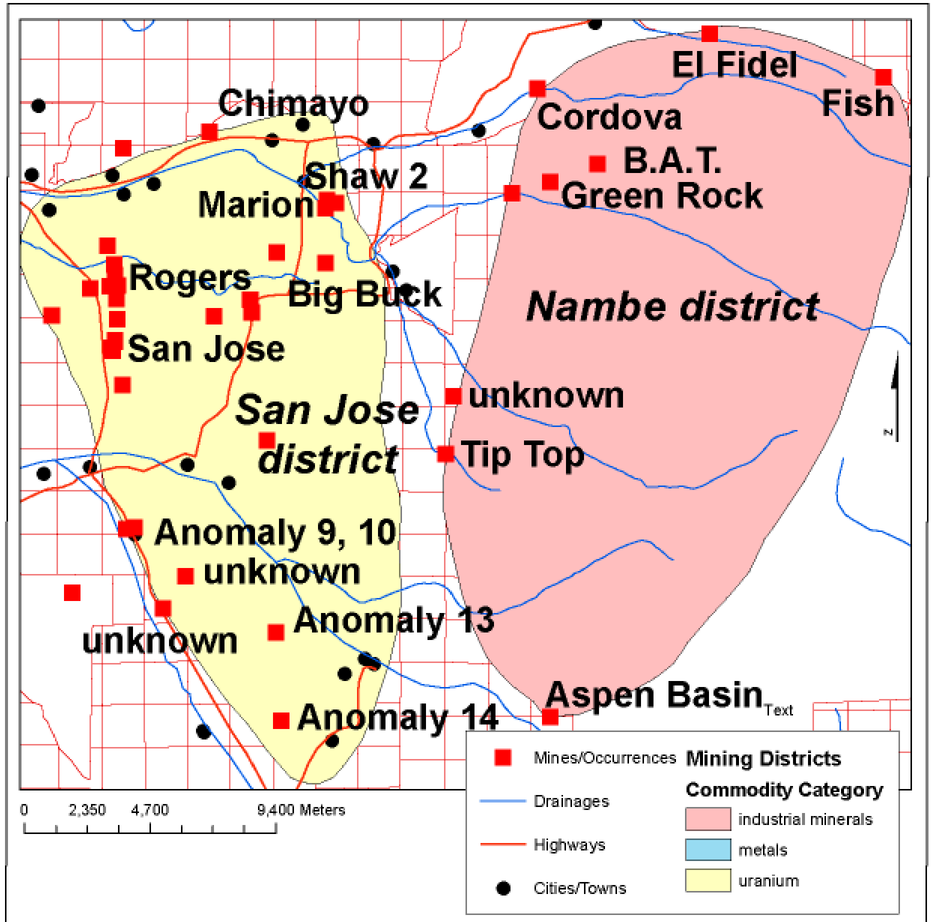

Anion Exchange



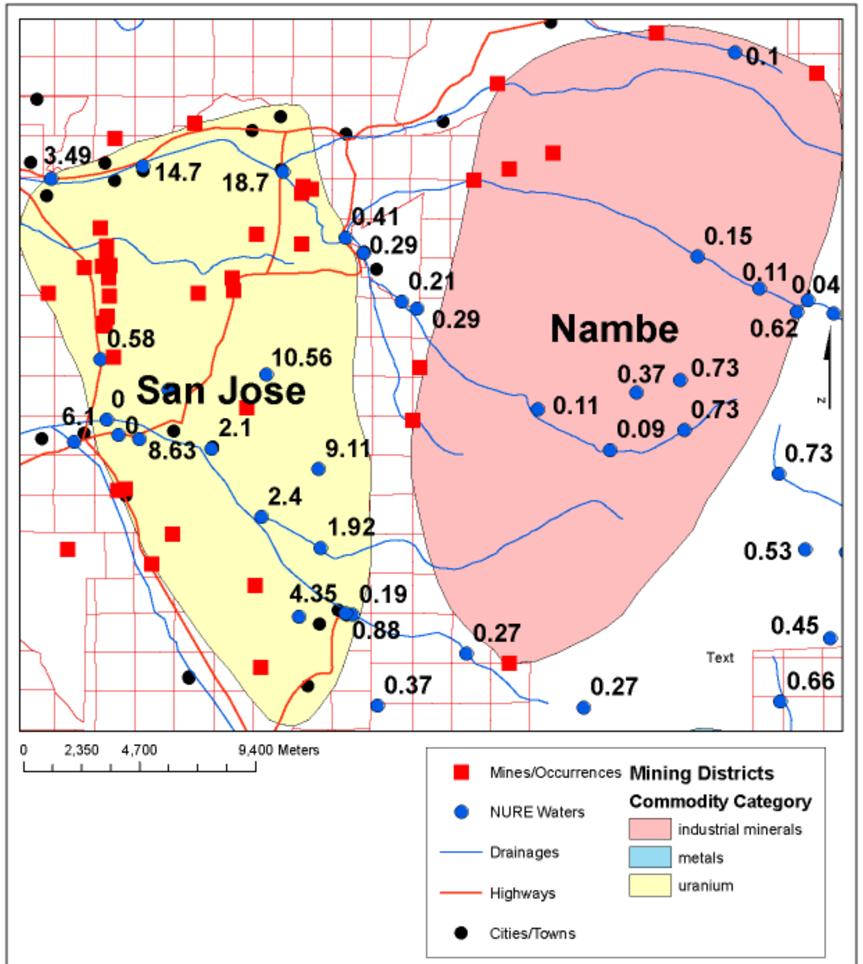
Mining Districts
Commodity Category
industrial minerals
metals
uranium
0
37.5
75
150 Kilometers

- Sampling by the New Mexico Environment Department and Los Alamos National Laboratory have shown elevated concentrations of uranium in drinking water in the Española Basin
- Many samples have concentrations of dissolved uranium that exceed 100 μg/L and some as much as 1,820 μg/L within the Española Basin





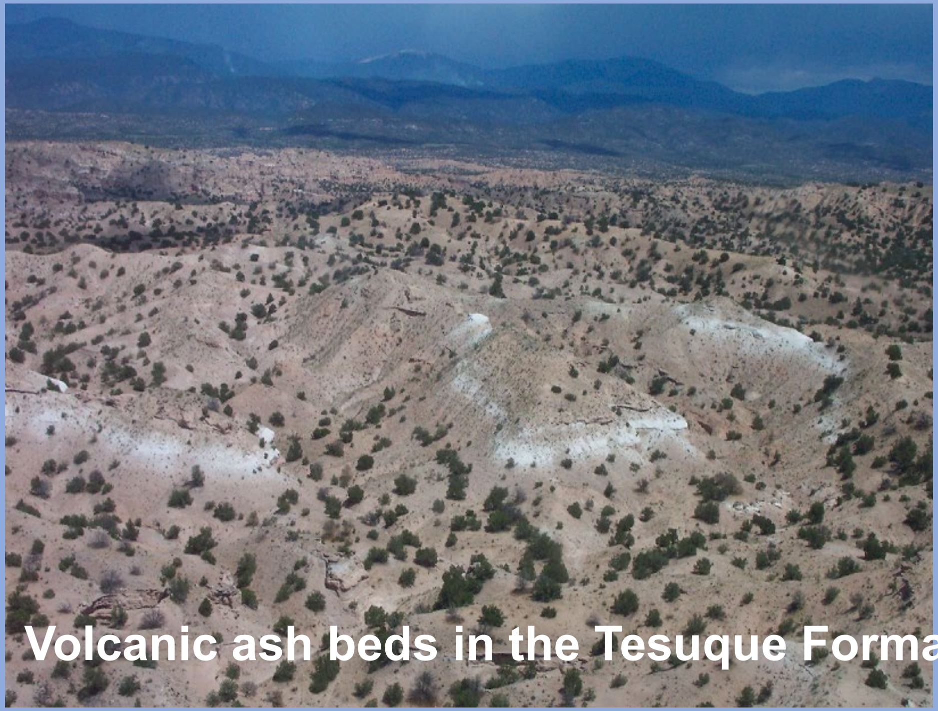
Uranium mines and occurrences in the San Jose and Nambe mining district, Santa Fe County, New Mexico



Uranium in Water NURE Samples in the San Jose and Nambe district, Santa Fe County, New Mexico

Uranium prospects (red), mining districts (yellow, pink), water samples (blue) in the San Jose and eastern Nambe mining districts, Santa Fe County

SOURCE OF URANIUM



Volcanic ash beds in the Tesuque Formatio

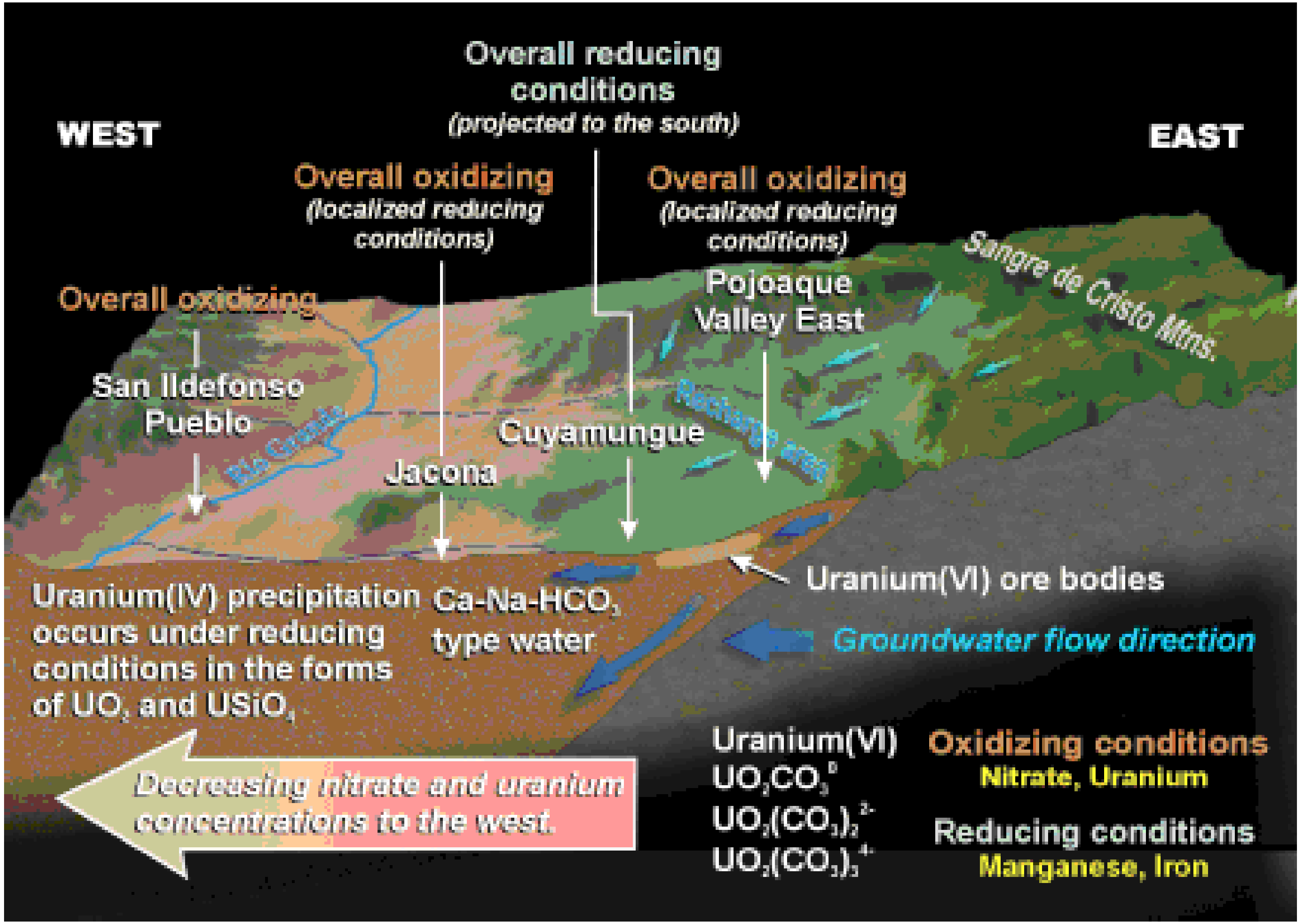
Shaw No. 2 prospect

Reworked ash beds

Uranium with clay galls and organic material, San Jose mine

ect.

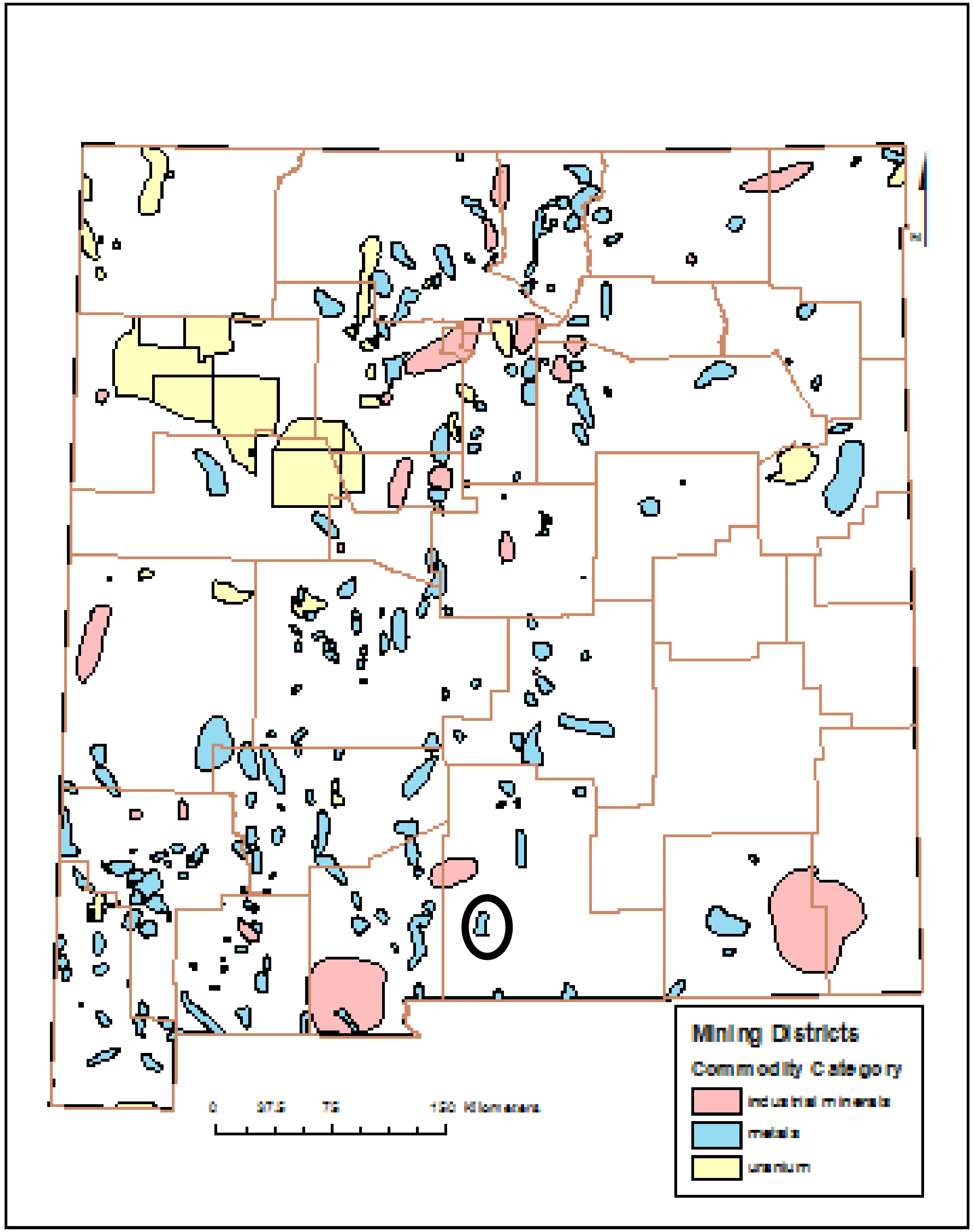
Hydrochemical Conceptual Model for Part of the Española Basin, New Mexico



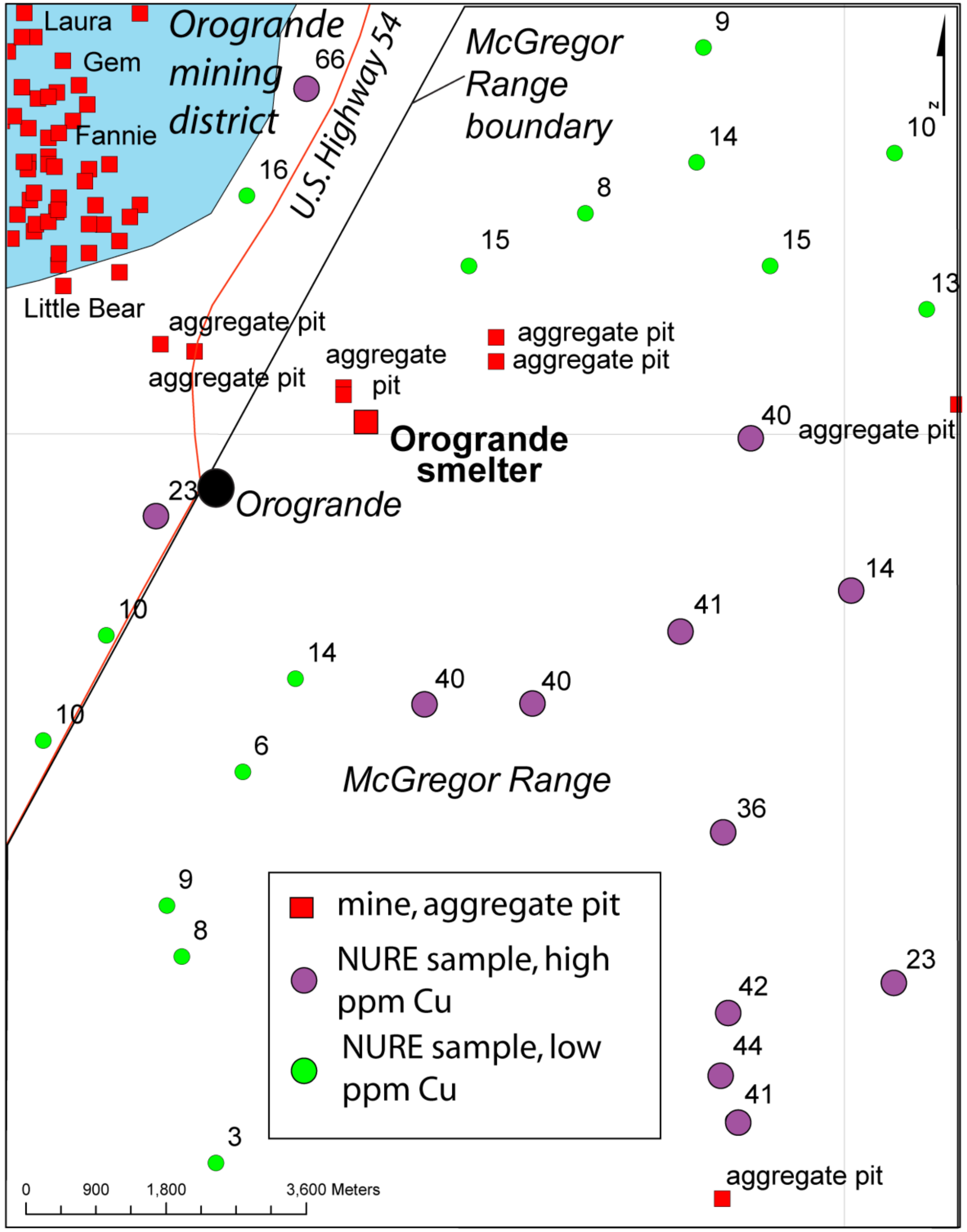
Conclusions—U in Española Basin

- Uranium from
  - Proterozoic granite, pegmatites, and veins
  - Tesuque Formation sandstone U deposits
  - Rhyolitic ash beds found interbedded within the Tesuque Formation
- Mineralization that is not of economic grade can be of great concern for contaminating water supply wells

Orogrande district, Otero County

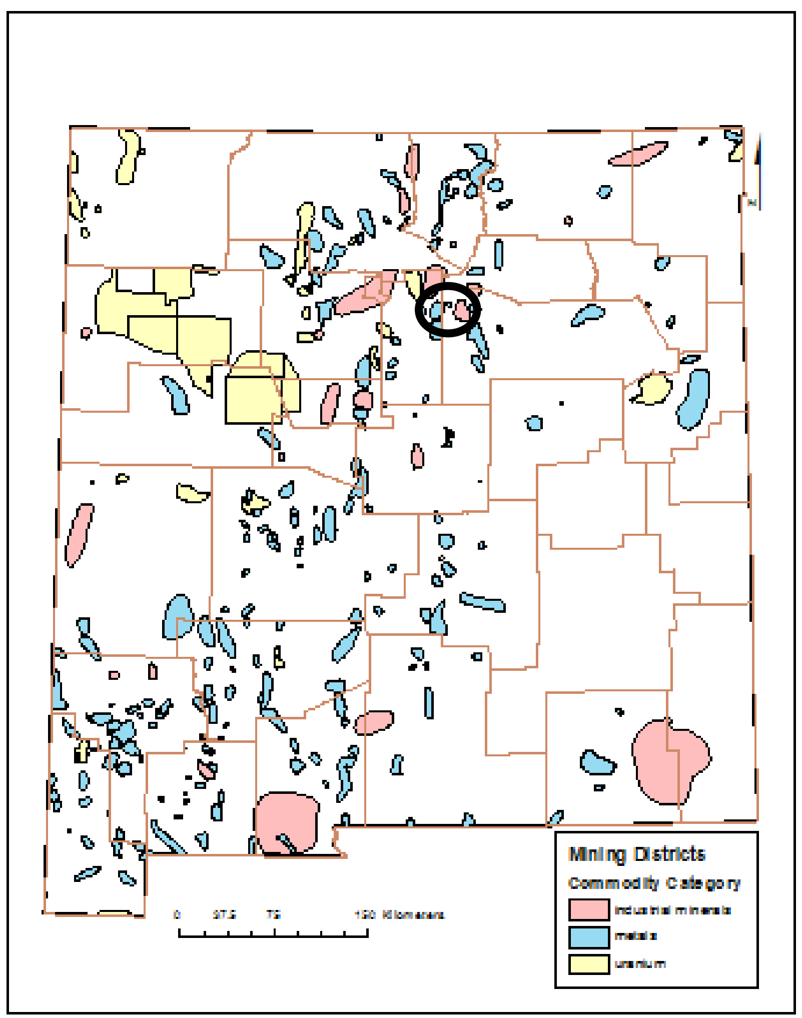


Mining Districts
Commodity Category
industrial minerals
metals
uranium
0
37.5
75
150 Kilometers



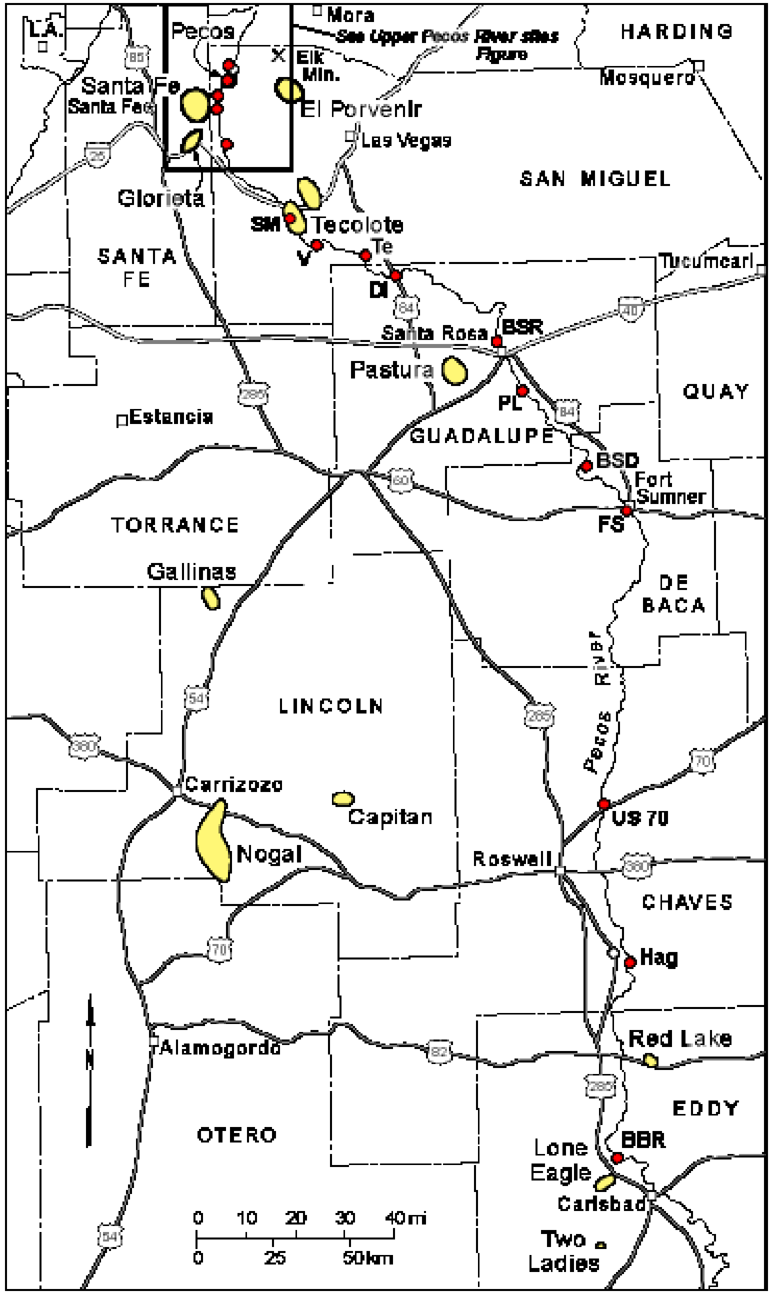
Copper in stream-sediment samples in the Orogrande area, Otero County. Note the samples (in purple) high in copper south and east of the Orogrande smelter (section 14, T22S, R8E) that is likely due to contamination from the smelter

Terrero (Pecos) mine, Willow Creek district, San Miguel County



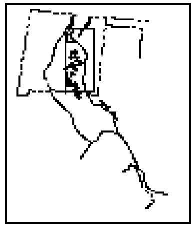
Terrero (Pecos) mine

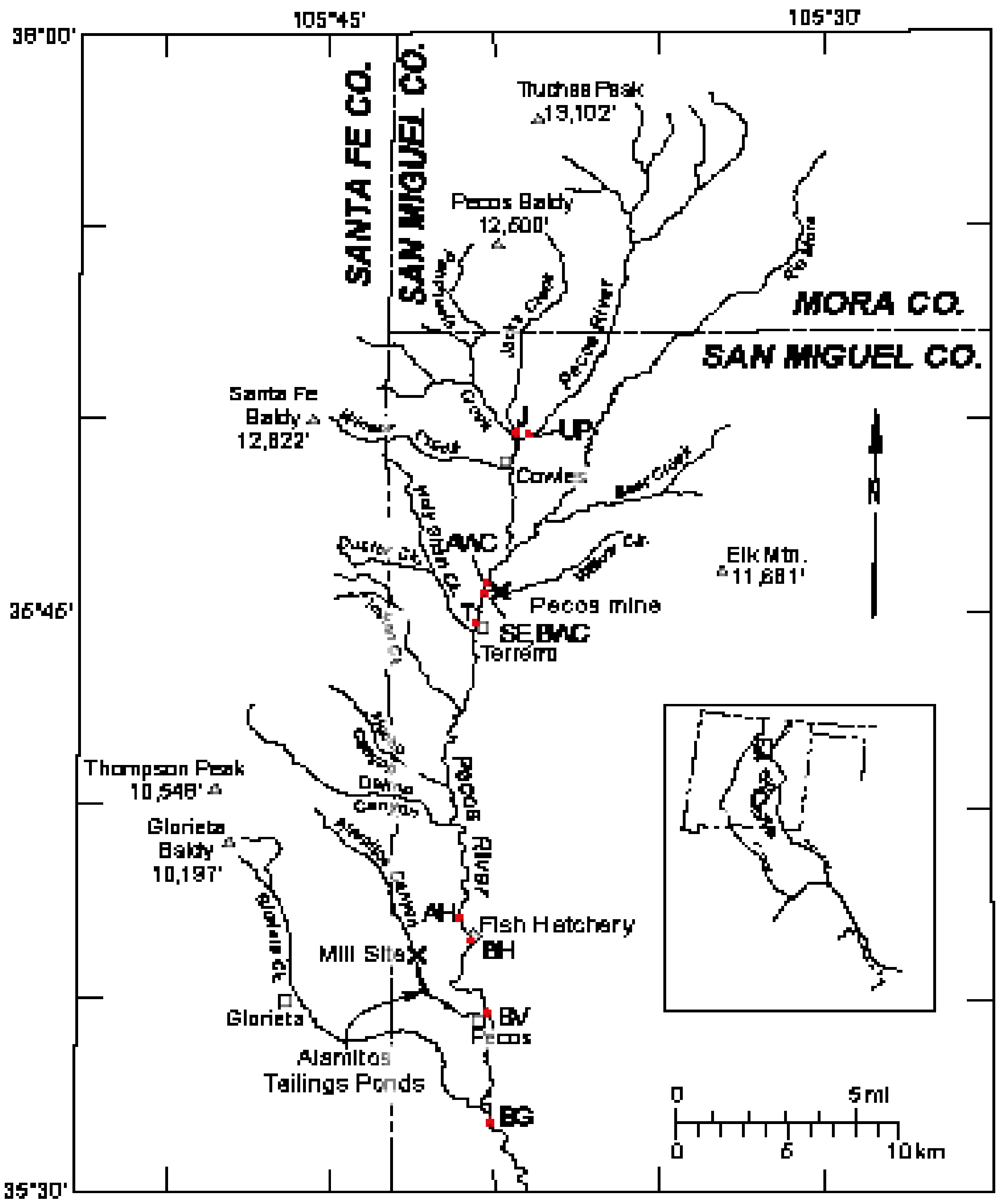
- Volcanogenic massive-sulfide deposit containing Pb, Zn, Cu, Ag, and Au as sulfide minerals with pyrite
- Mined on and off for 42 years beginning in 1902
- Generated ~70,000 cm of waste rock, which was a source of acidic drainage
- The ore was shipped 18 km SW by aerial tram to the Alamitos Canyon mill where the mill tailings were deposited along Alamitos Canyon
- Point sources of contamination for Pb, Zn, Cu, Se, Cd, and Cr
- Reclamation began in the early 1990s until about 2003
- 9 yr study (1992-2000) of geochemistry of stream sediments and water along the Pecos River



Key To Sites

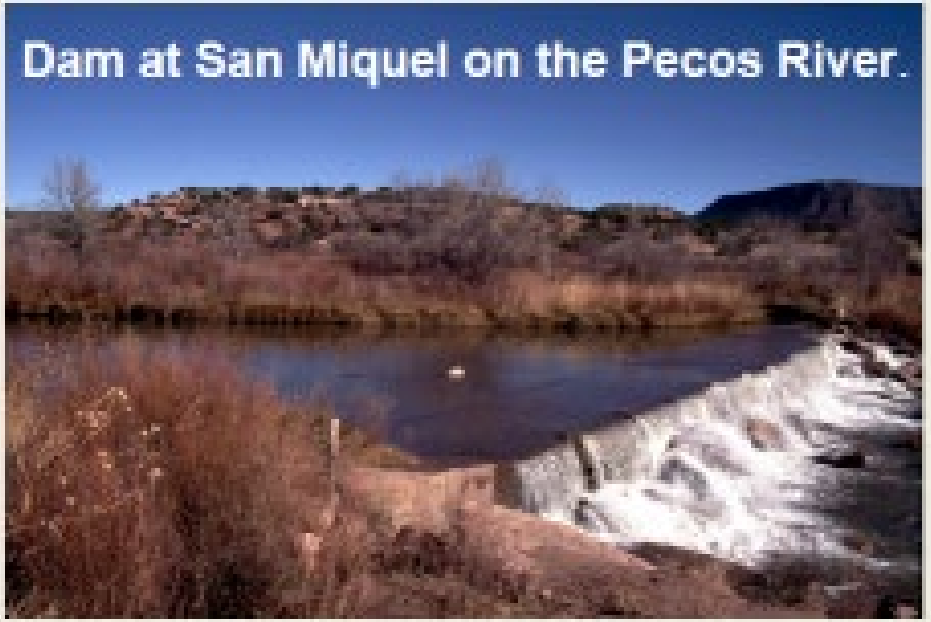
Symbol	Description
SM	San Miguel
V	Villanueva
Te	Tecolotito
DI	Dilia
BSR	Below Santa Rosa Dam
PL	Puerto del Luna
BSD	Below Sumner Dam
FS	Fort Sumner
US70	Highway U.S. 70 bridge
Hag	Hagerman
BBR	Below Brantley Dam



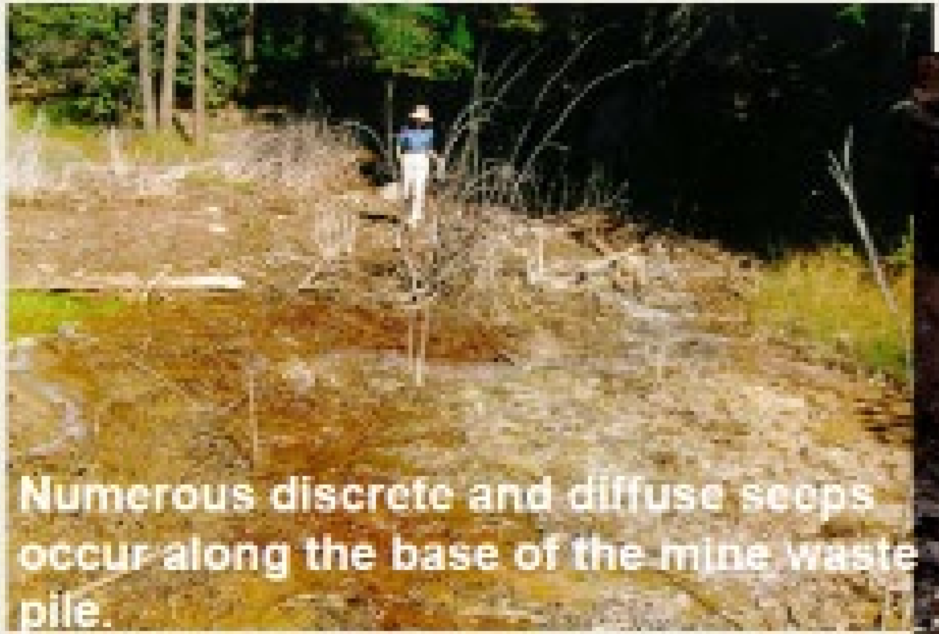


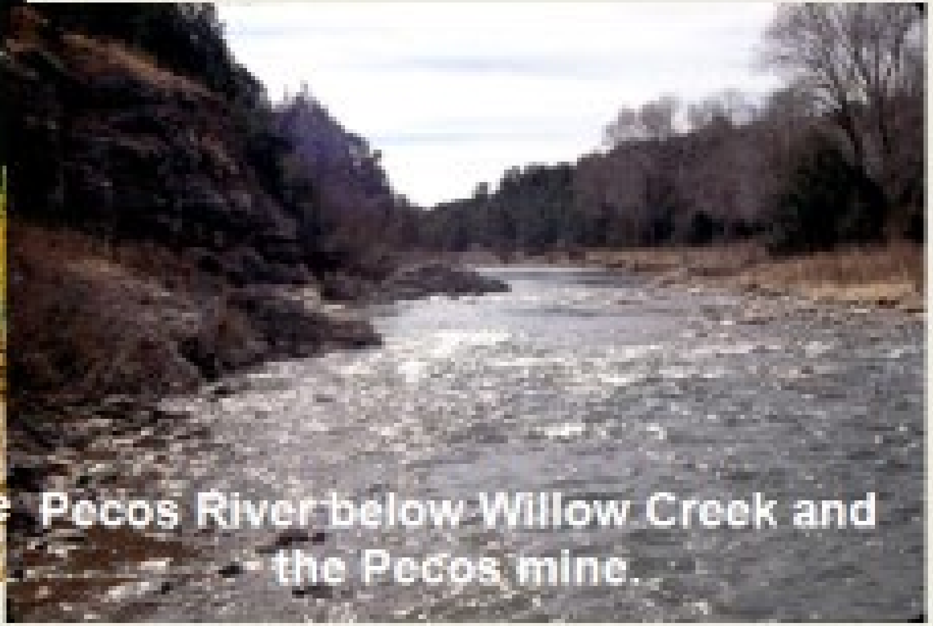
KEY TO SITES

Symbol	Description
UP	Upper Pecos
J	Jacks Creek
AWC	Pecos above Willow Creek
SE	Seep below mine
BWC	Pecos below Willow Creek
T	Pecos at Terrero
AH	Pecos above the hatchery
BH	Pecos below the hatchery
BV	Pecos below Pecos village
BG	Below Glorieta Creek



Pecos River area—stream sediments draining a VMS deposit





Conclusions—Terrero mine

- Cu, Pb, Zn, and other metals were eroded and leached from the Terrero mine waste pile and the tailings
- Overall metal concentrations dramatically decrease in stream sediments below Pecos Village, mostly due to dilution of sediment derived from the red bed sedimentary units
- Decrease in concentrations with time since reclamation began, especially in the immediate vicinity of the Pecos mine
    - Cu levels from 310 to 92 ppm
    - Cd from 17 to 4.7 ppm
    - Pb from 300 to 160 ppm
    - Zn from 3100 to 2080 ppm

Other data

Other data

- Geochemical analyses of mineral deposits throughout New Mexico
- Geochemical analyses of mine dumps in Sierra and Otero Counties

LESSONS LEARNED

- NURE data can provide a first order of geochemical background conditions in NM, especially for U
- Some areas in NM have elevated U in water, which is a result of natural processes not mining
- Some areas in NM have elevated metals in stream sediments or soils, but not in water that are possibly a result of mining

LESSONS LEARNED

- Differences in chemistry of MIW within the various mining districts in NM are due to differences in geology, type of mineral deposits, and alteration of adjacent rocks, including weathering
- Each area is site-specific and must be examined in detail and over a period of time to determine the cause of the adverse MIW

LESSONS LEARNED

- However, as more people are building houses in and near mining districts, even natural geochemical anomalies could become a health problem and may have to be addressed in some manner
- More detailed sampling is required in these areas
- Additional analysis and evaluation of these data sets is on-going

Mark will discuss databases Sept 19

Evan will discuss IoGas and data presentation Oct 17