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Results and Interpretations of U.S. Geological Survey Data Collected in and around the Tuba City Open Dump, Arizona

By Raymond H. Johnson, James K. Otton, and Robert J. Horton

Open-File Report 2009–1154

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Geological Survey, Reston, Virginia: 2009

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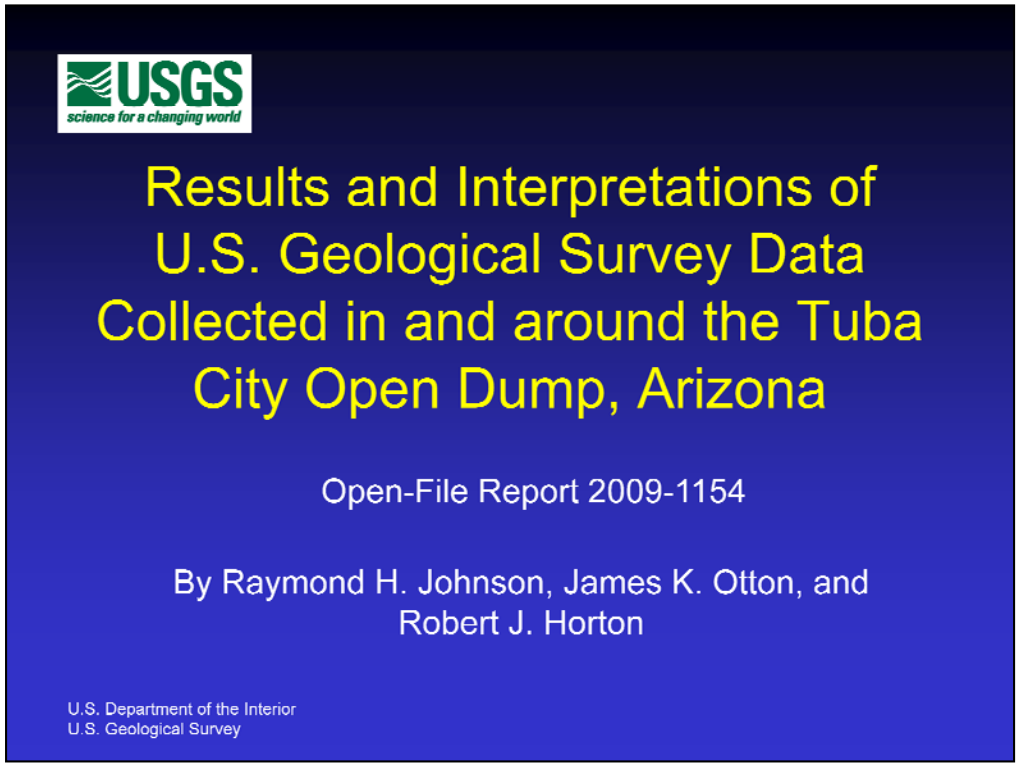
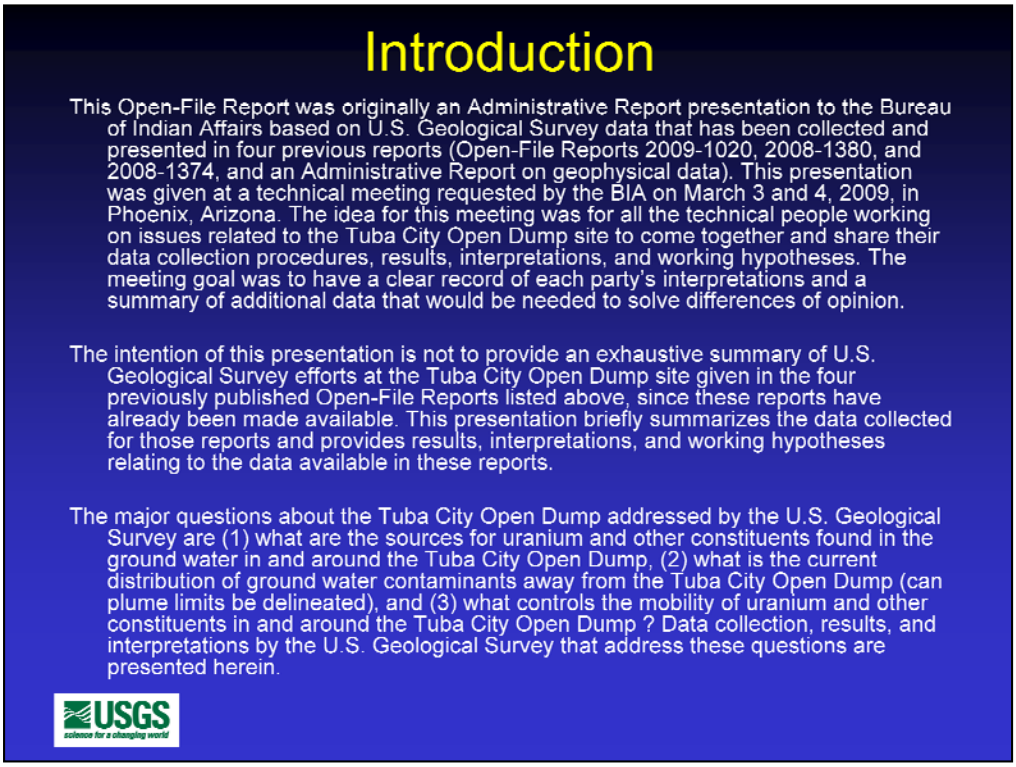
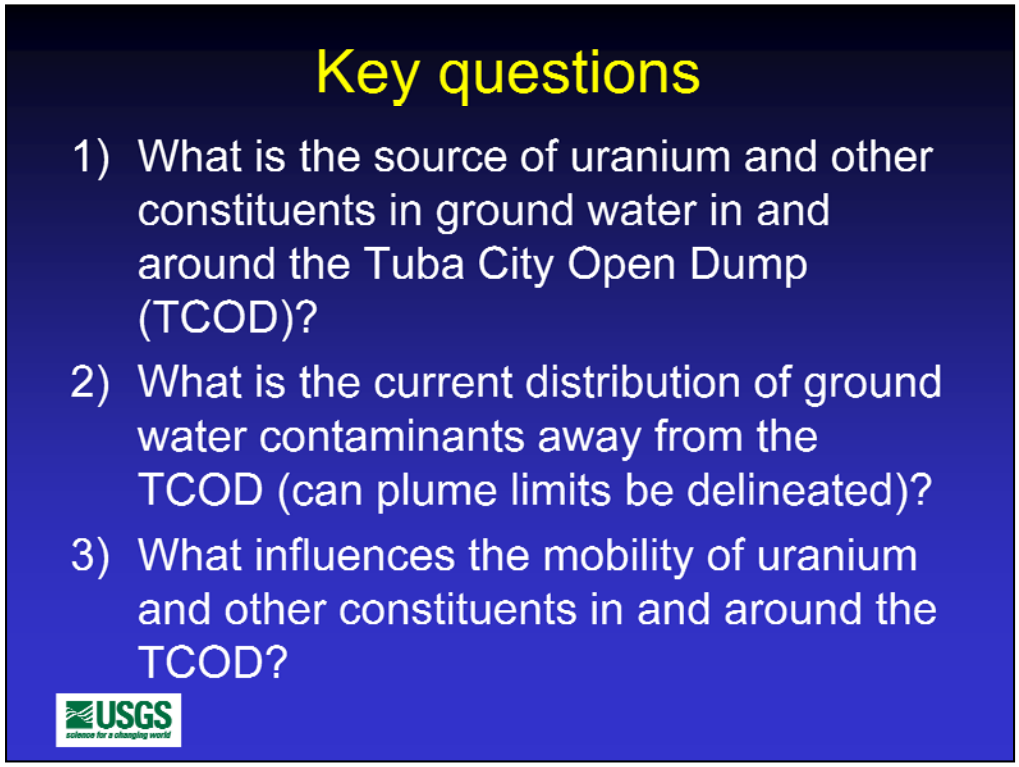


Presented on March 3 and 4, 2009, in Phoenix, Arizona, for a technical meeting called by the Bureau of Indian Affairs. A select number of technical experts who have worked on issues related to the Tuba City Open Dump were present to discuss their findings (data collection, results, and interpretations). Jim Otton presented geologic maps and cross sections in poster format during this presentation.

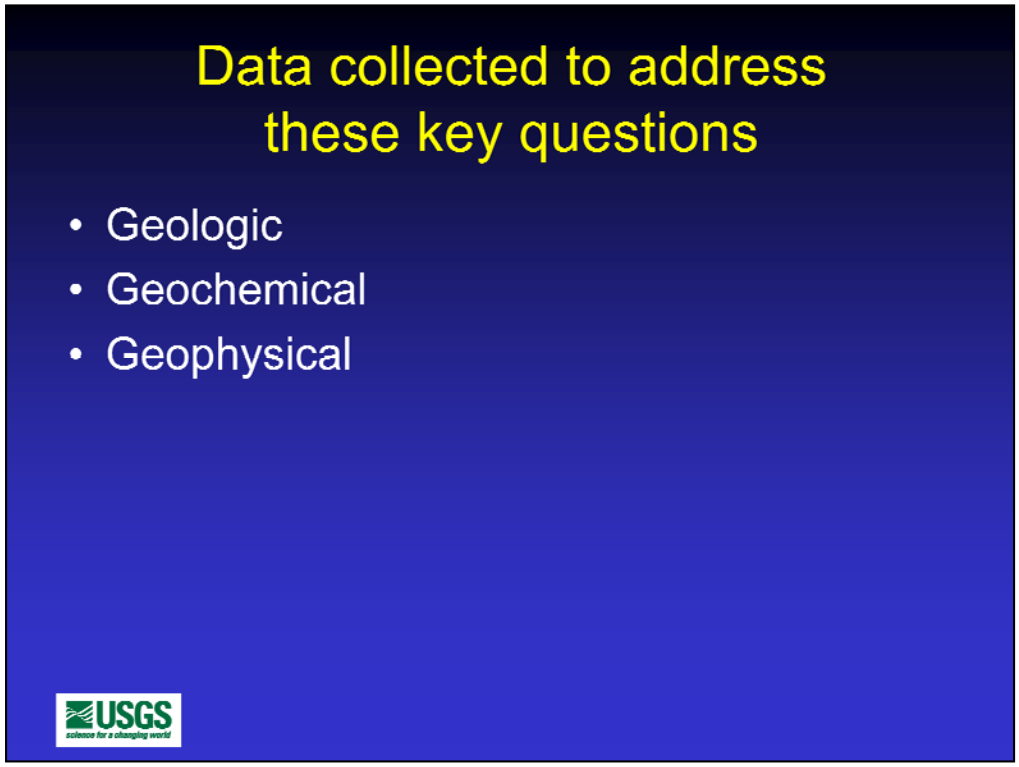


Abstract for this presentation.

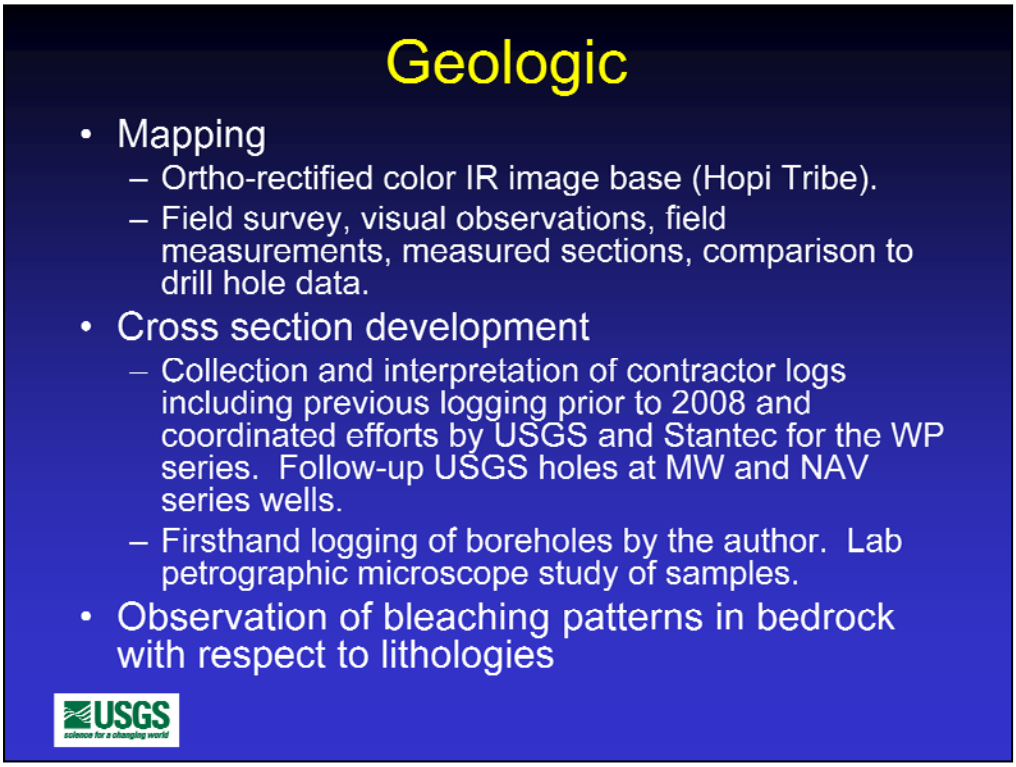


READ

This talk will focus specifically on these questions. Other questions may be important, but are not the focus of this talk.



General categories of data collection. Each category and the data collected are briefly summarized in the next few slides.



MW wells were installed in the first phases of the Tuba City Open Dump investigations by Daniel B. Stephens and Associates on Hopi lands.

NAV wells were installed by Walker and Associates on Navajo lands.

WP wells were installed by Stantec, Inc. during the most recent investigations and are on Hopi and Navajo lands.

Regional geochemistry

- Major cations and anions plus trace elements in:
  - Water (wells, springs, and streams)
  - Whole rocks and sediments
  - Rock and sediment leachates
- Isotopes
  - ^{18}Oxygen/Deuterium, Sulfur, Uranium, Strontium
- Age determination
  - Tritium and C-14

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TCOD geochemistry

- Downhole field parameters in wells (plus water levels)
- Tritium in downgradient wells (helium in-growth method in Denver)
- Hand augering to understand geology, get solid samples, and install ground water piezometers
- Solid samples of soil, sediment, and bedrock with whole rock acid digestion (ICP-MS, ICP-AES)
- Water samples from piezometers and selected wells (field parameters and ICP-MS, ICP-AES, and IC)
- Water samples for duplicate lab analyses
- Deionized water (DI) and landfill leachate type dissolution (TCLP) of solid samples

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ICP-MS = inductively coupled plasma – mass spectrometry

ICP-AES = inductively coupled plasma – atomic emission spectrometery

IC = ion chromatography

DI leaching procedures

- 50 grams of solid in 1 liter of water (20:1 ratio)
- 24 hours of total contact time (modified EPA method 1312)
- Leachate fluid was filtered and analyzed using ICP-MS and lab measurements of conductivity, pH, alkalinity, and chloride were taken
- See OFR 2008-1374 for additional details

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OFR = USGS Open-File Report

TCLP procedures

- TCLP = Toxic Characteristics Leaching Procedure
- Intended to provide information on leachability of solids in direct contact with landfill leachate (modified EPA method 1311)
- Same procedures as DI leach, just using a different fluid (TCLP fluid #1: deionized water with addition of acetic acid and sodium hydroxide to give a pH of 4.93)
- See OFR 2008-1374 for additional details

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Geophysics

- Airborne radiometric data from U.S. Environmental Protection Agency (EPA) and National Uranium Resource Evaluation (NURE) programs are summarized
- Geophysical field survey methods at the TCOD
  - Direct current resistivity (dc)
  - Capacitively-coupled resistivity (CCR)

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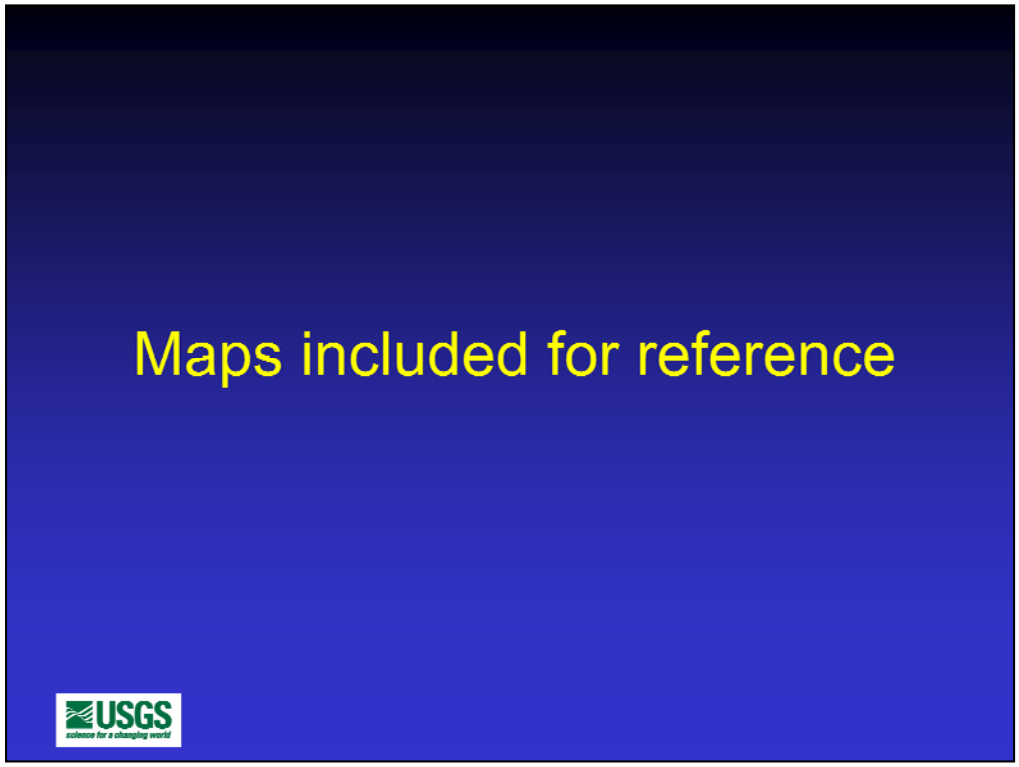
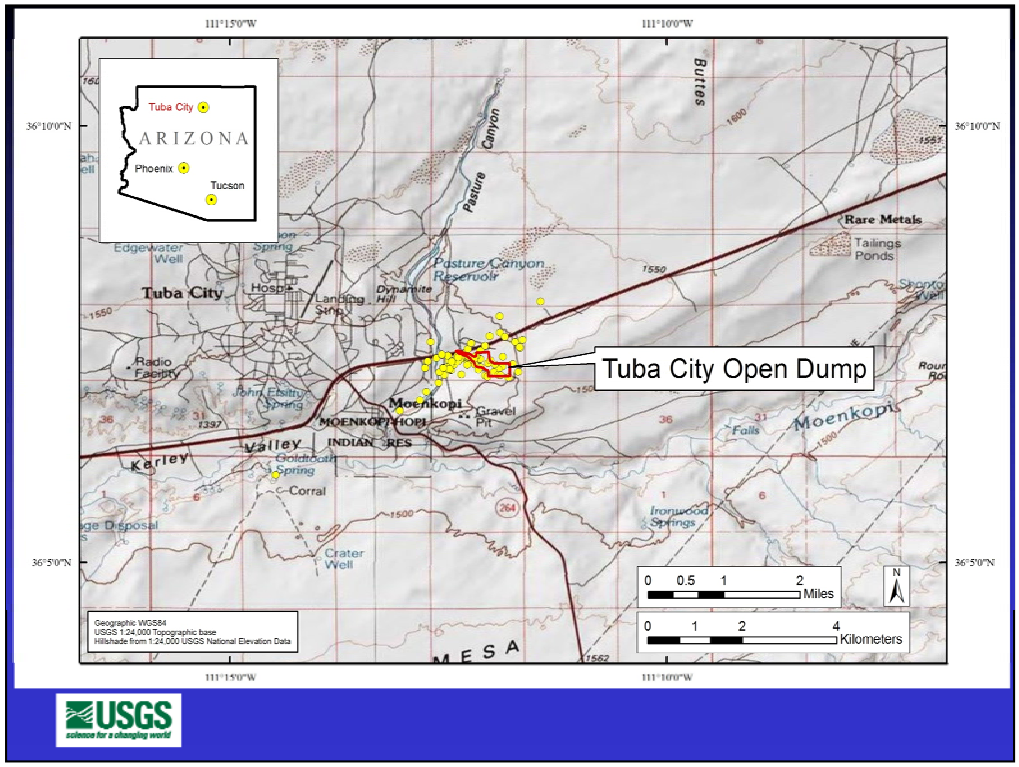
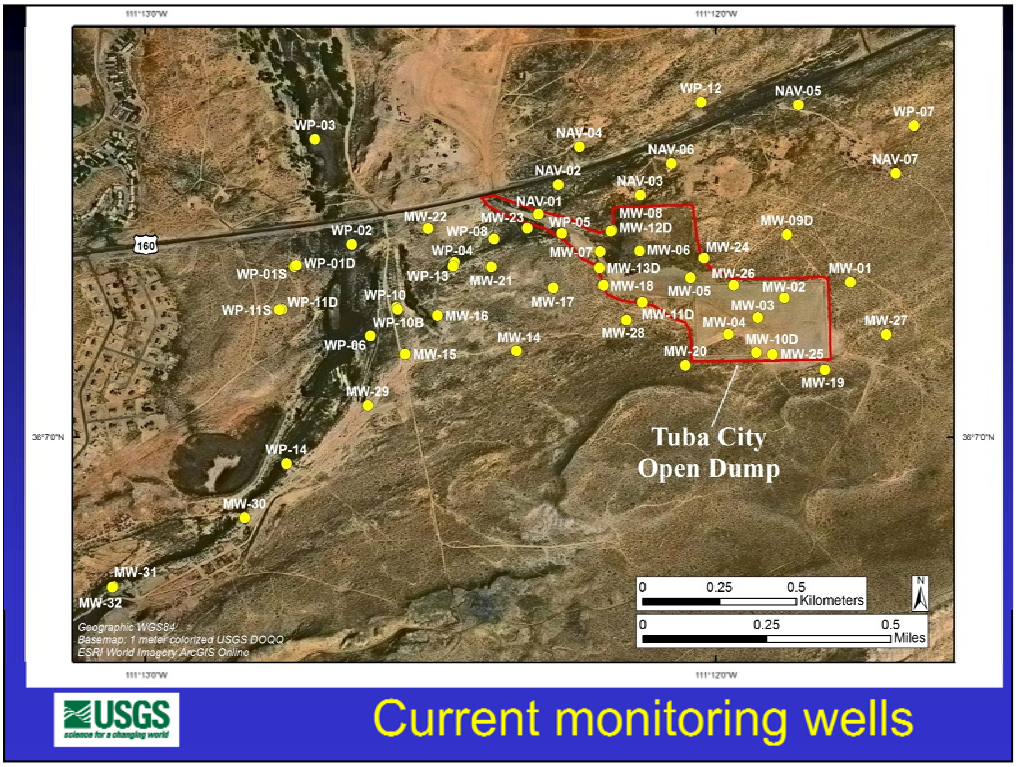


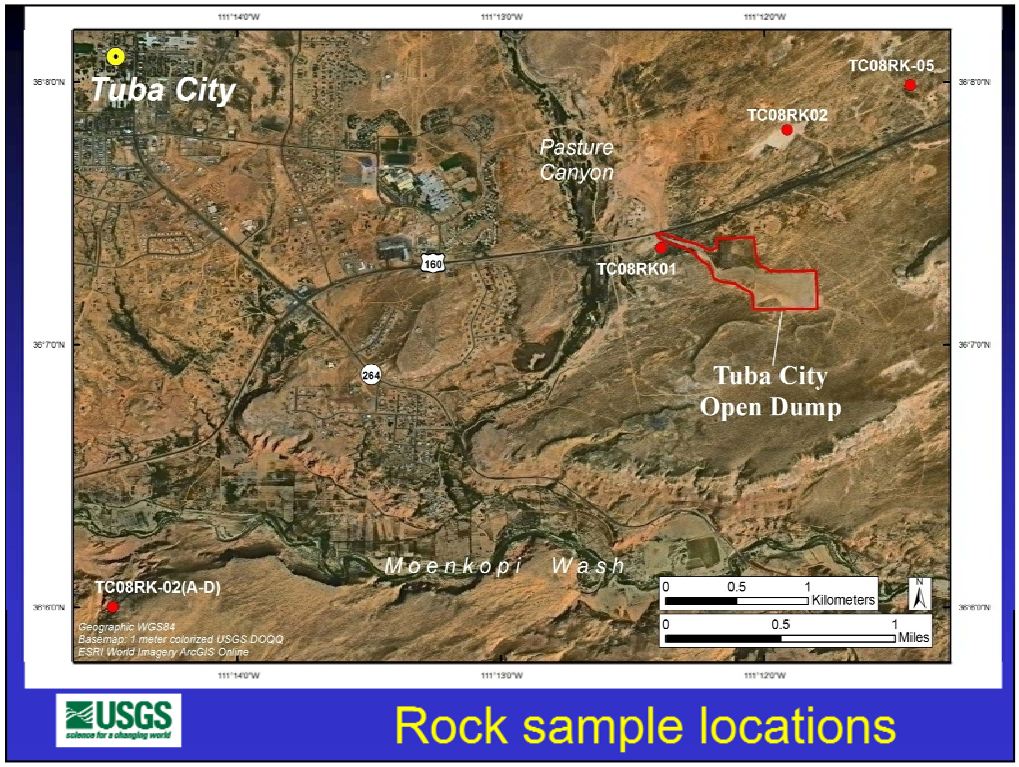
The following maps, which were created specifically for TCOD related USGS reports, are included for reference. Stantec, Inc. provided additional maps related to the TCOD during the meeting on March 3 and 4, 2009. The discovery of elevated uranium concentrations at MW-07 in the initial investigations at the Tuba City Open Dump is what prompted additional investigations at the site.



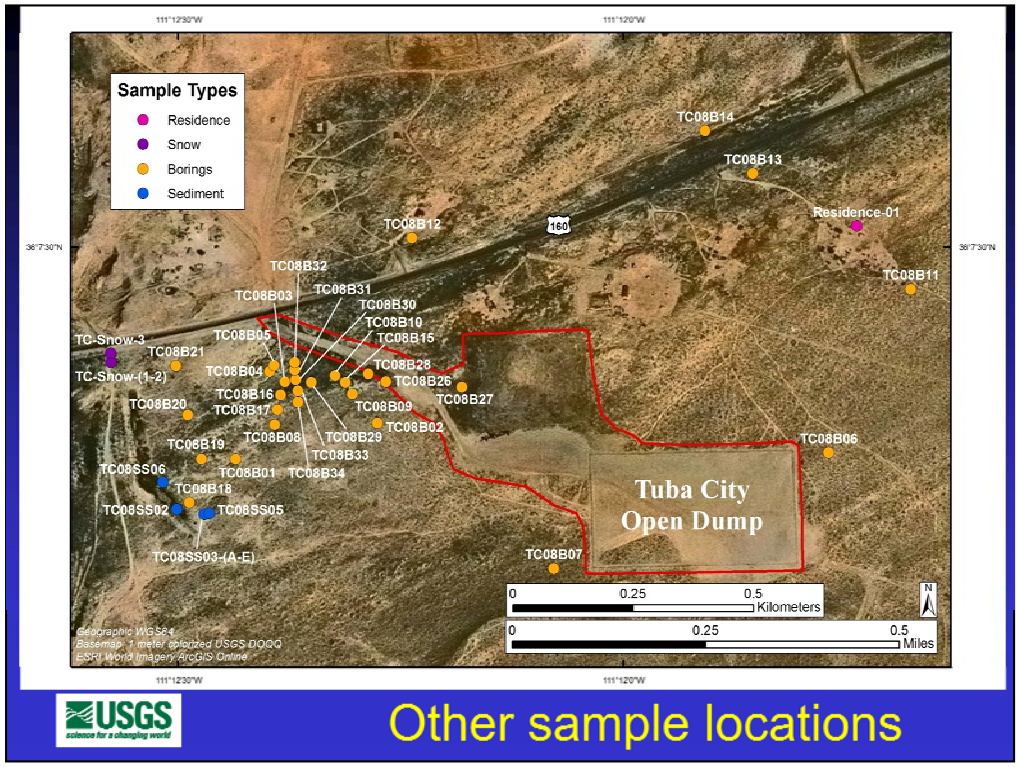
Site location outlined in red.



Monitoring well locations.



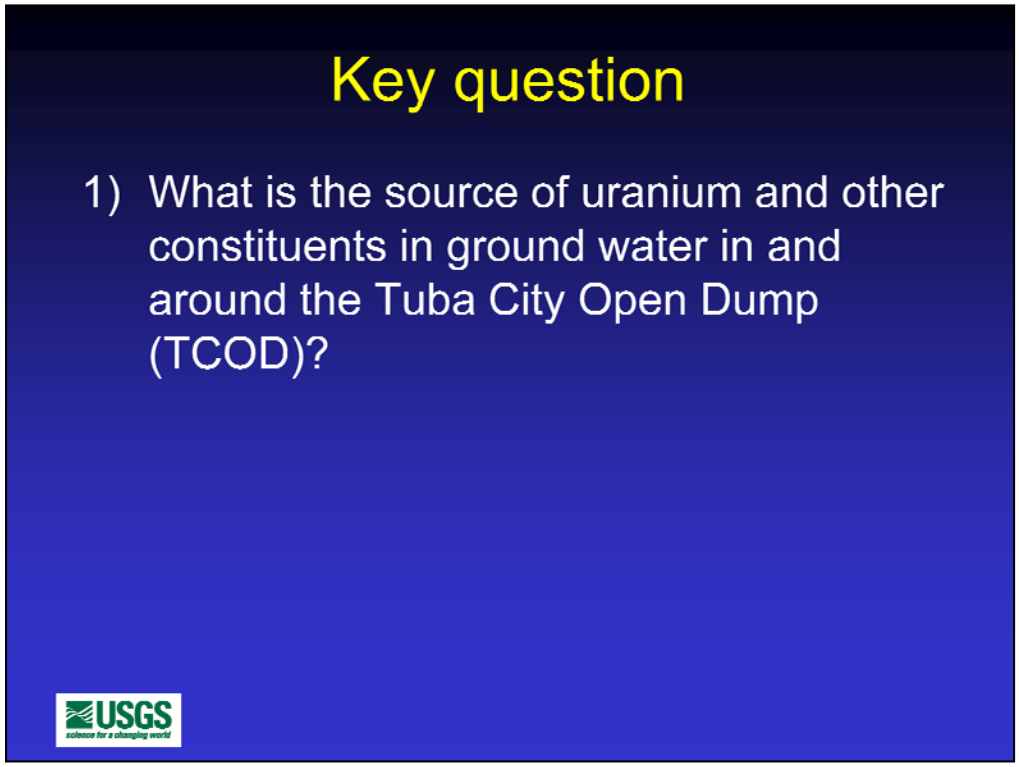
Rock sample locations.



Residence = residence water tap sample.

Borings = hand auger locations.

Sediment = surficial grab sample locations.



Reminder of the first key question. Format from here is to discuss each key question, provide conclusions and interpretations for that question, and then provide supporting evidence for each key conclusion/interpretation.

Key conclusions (1)

a) Uranium and associated major and trace elements in and around the TCOD do not appear to be derived from the Navajo Sandstone or the Kayenta Formation.

b) Uranium and associated major and trace elements are emplaced, concentrated, and stored in the vadose zone through windblown deposition from upwind sources (such as the Chinle Formation) and evapotranspiration.

c) These constituents are locally transferred to the shallow ground water by natural processes and human disturbance throughout the area.

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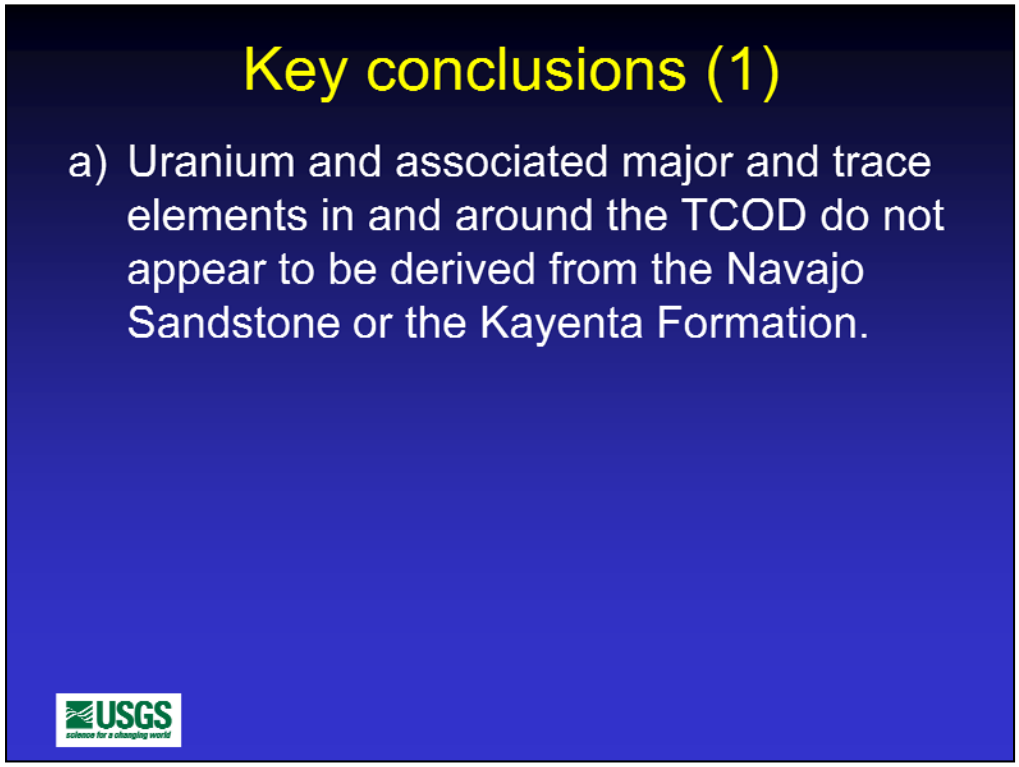

Reminder on conclusion (a) related to key question number 1.

Key conclusions (1a)

Supporting evidence

- Uranium and other elements do not occur in the Navajo Sandstone and Kayenta Formation in concentrations as high as the Chinle Formation.
- DI leaching of Navajo and Kayenta bedrock produces much less uranium in the leachate waters than from the Chinle Formation DI leaching.

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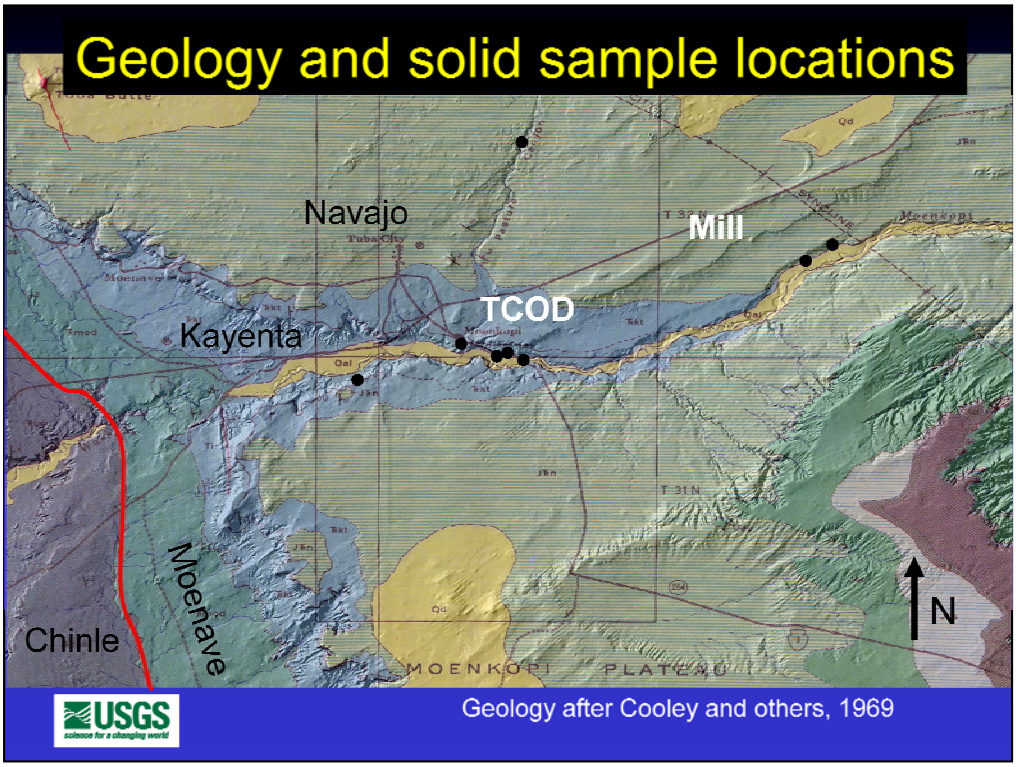
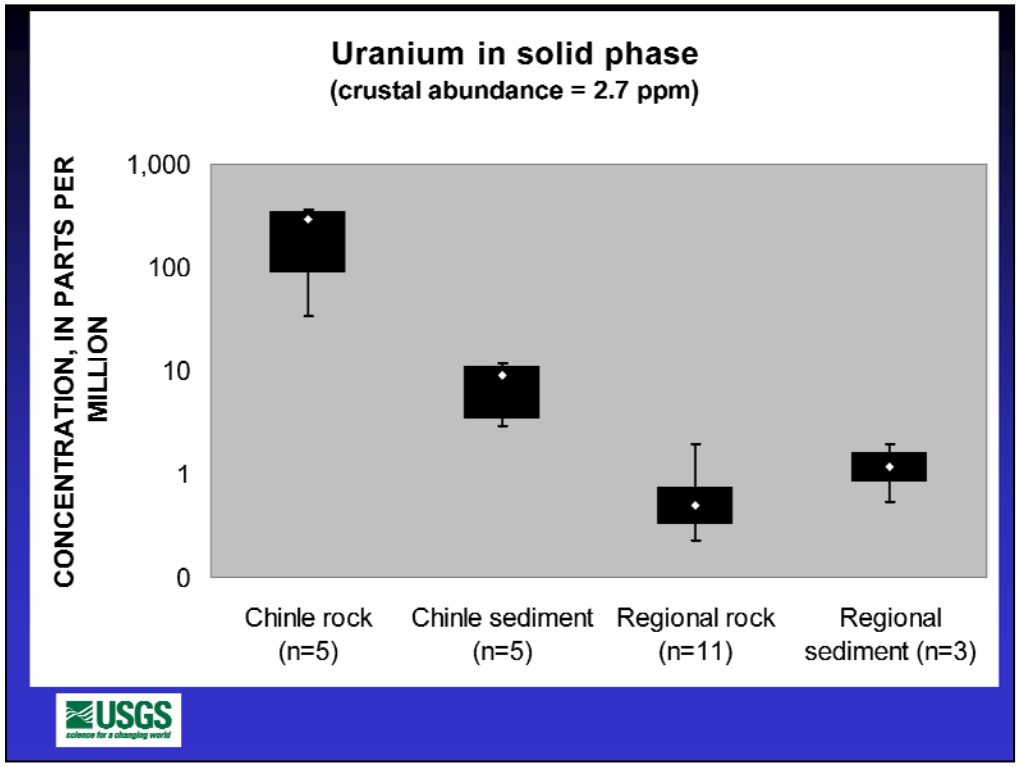
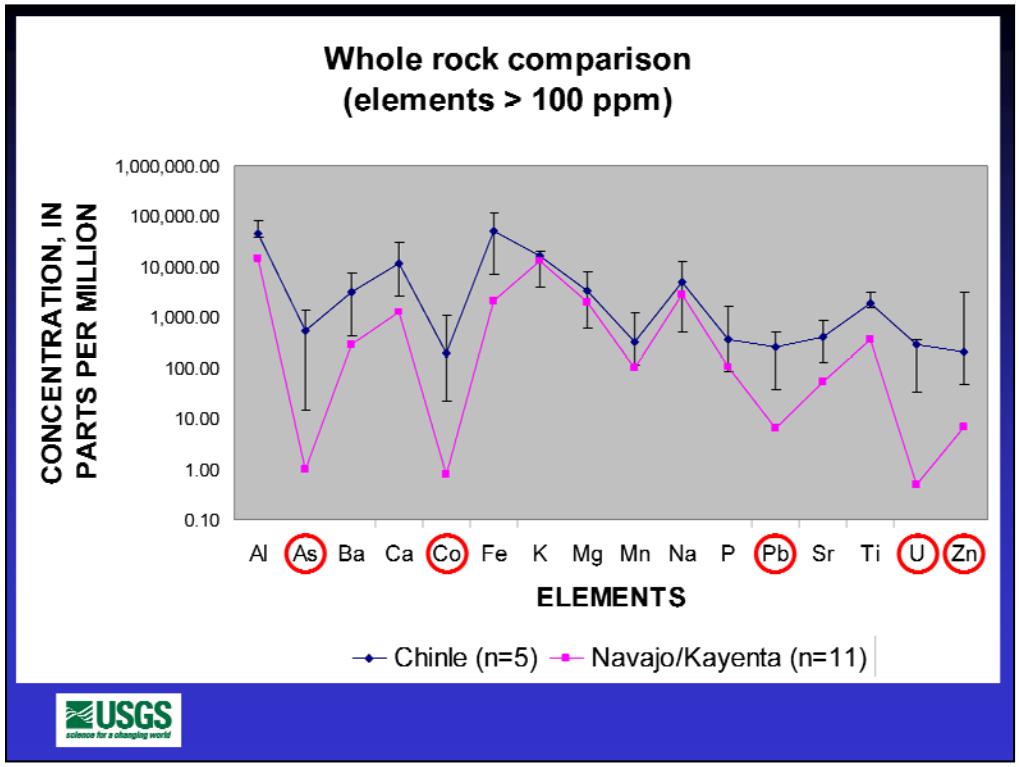


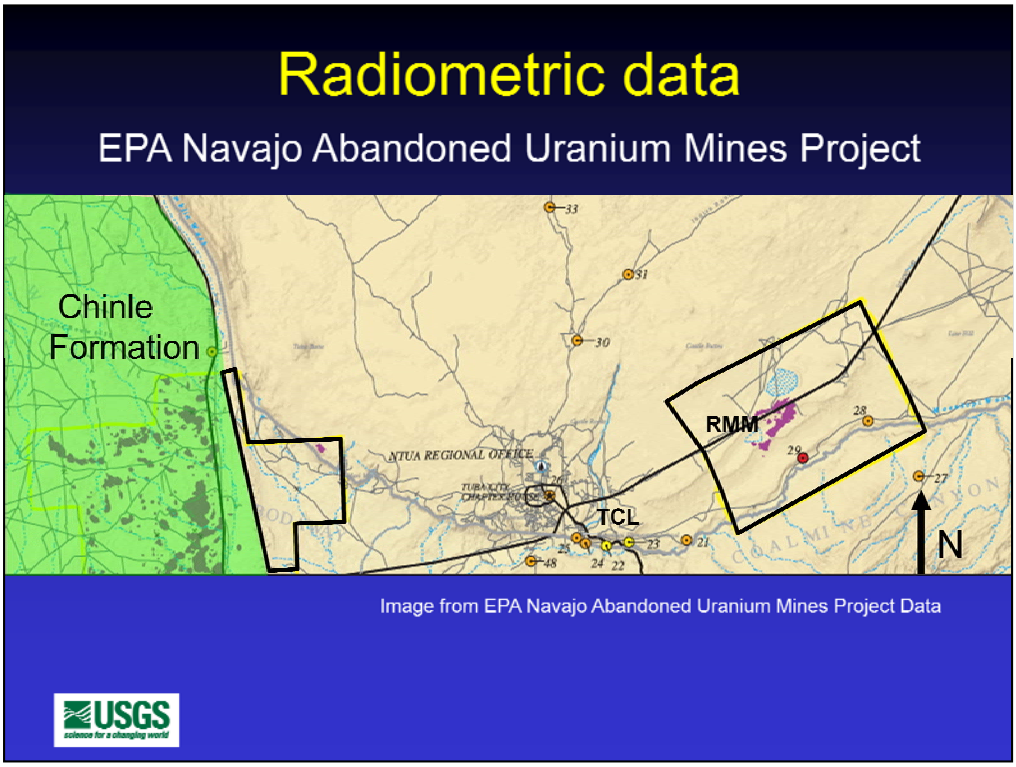
Geology by Cooley and others, 1969. This mapping was based on a much different scale, so the Kayenta/Navajo boundary is not that precise. Regional samples were collected by Laurie Wirt. Samples were also taken in the Chinle Formation at old mining sites (map not presented here, but is available in OFR 2009-1020).



As expected, rock from the Chinle Formation is elevated in uranium concentration, as are the sediments derived from the Chinle Formation. Chinle Formation rocks were collected in old mining areas and(or) prospect areas. Chinle Formation sediments are surficial grab samples generally taken near the rock samples of the Chinle Formation. Regional rocks are Navajo Sandstone and Kayenta Formation samples, which generally have concentrations of uranium below the crustal abundance. Note the slightly elevated solid phase uranium concentration in the regional sediments over the regional rock samples. The regional sediment samples are surficial grab samples generally taken near the rock samples. Regional indicates Navajo Sandstone and Kayenta Formation samples in the area in and around Tuba City. Exact rock type and collection location details are found in OFR 2009-1020.

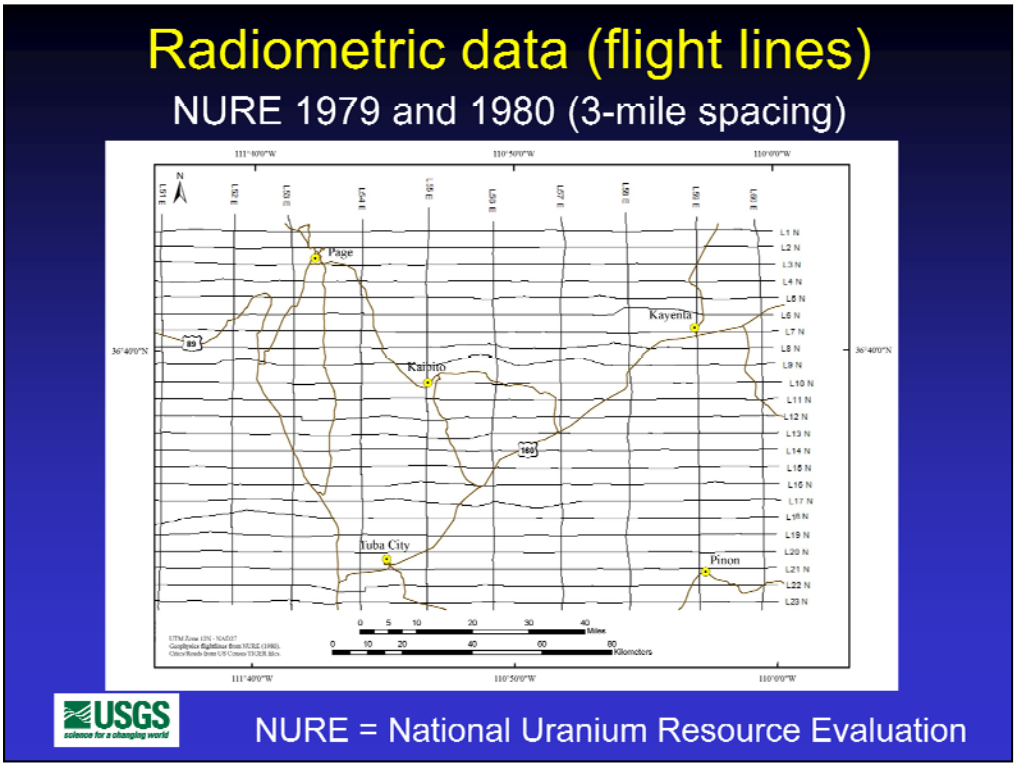


Chinle Formation whole rock elements are most elevated in As, Co, Pb, U, and Zn compared to the Navajo Sandstone and Kayenta Formation whole rock elements. Orders of magnitude greater concentration in the Chinle Formation are 3, 2.5, 1.5, 2.5, and 1.5, respectively for As, Co, Pb, U, and Zn.

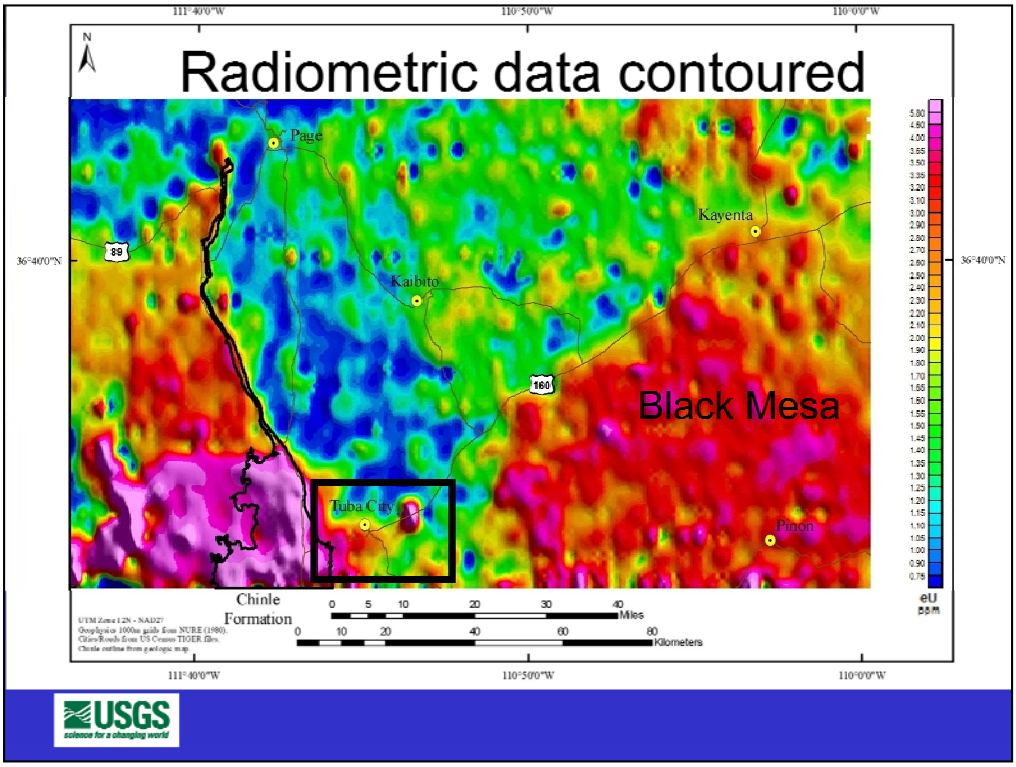


Only outlined boxes were flown. TCL = Tuba City landfill.

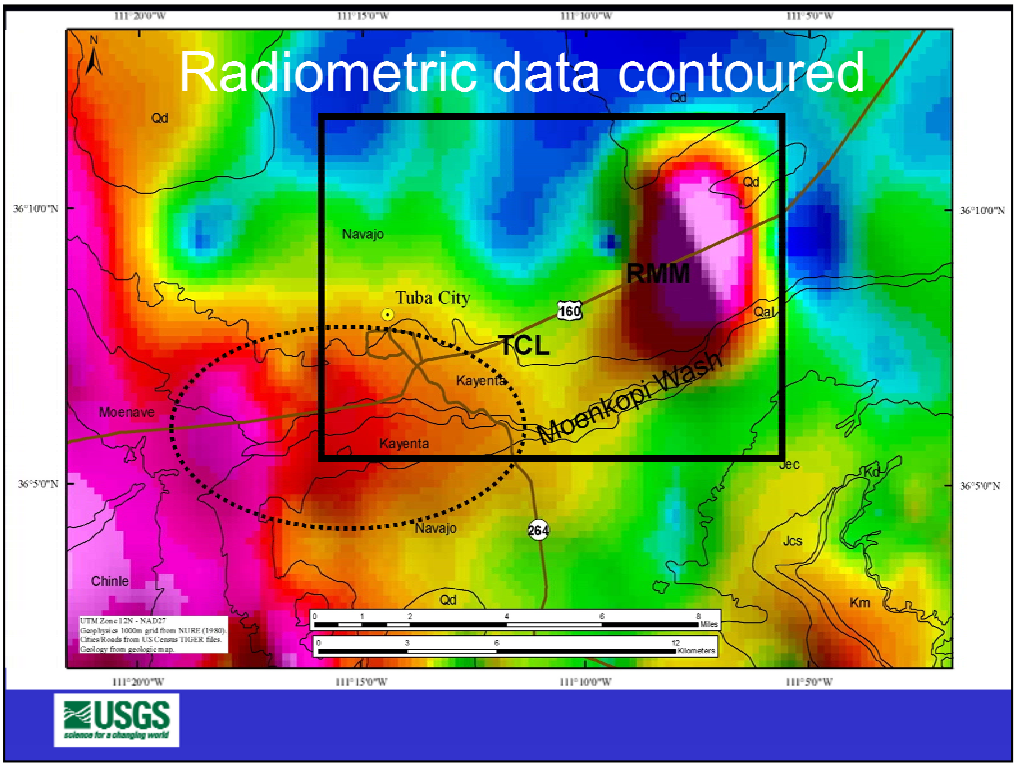
Very little radiation above background outside of the Chinle Formation, except for an area downwind of the RARE Metals Mill site (RMM in this slide and following slides).



Flight lines for radiometric data collected during the NURE program in the Marble Canyon quadrangle.

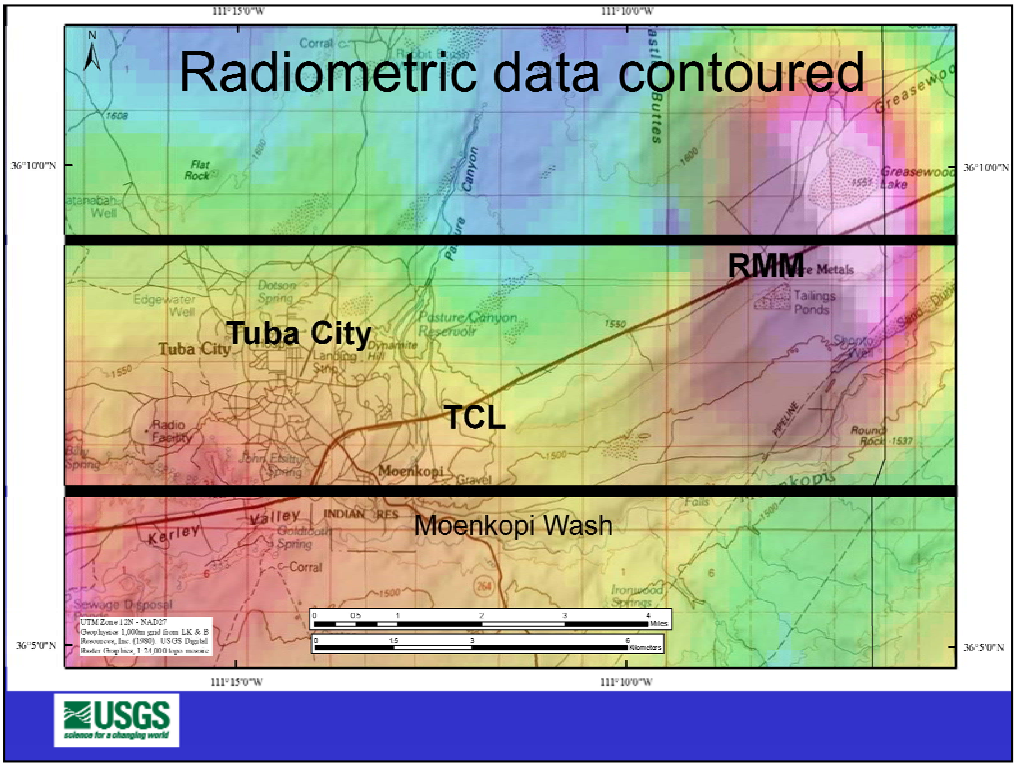


Radiometric data for uranium (Marble Canyon) that has been contoured. Note outline of area for Chinle Formation outcrop. Note that value for crustal abundance of uranium at 2.7 ppm is a moderate orange color and note that this data is only detecting surficial material (< 5 cm). Will zoom into boxed area for the next slide.



Again, contoured radiometric data for uranium with same uranium concentration scale as last slide. RMM = RARE Metals Mill. TCL = Tuba City Landfill. Geology is based on Cooley and others, 1969. Note that the red area of higher uranium concentrations follows up the valley of Moenkopi Wash. This may be due to slightly higher uranium in the Kayenta Formation and(or) wind blown sediment from the Chinle Formation at the surface. The winds in this area often come from the southwest and blow up the Moenkopi Wash valley (based on personal observation and information from local residents). Dashed black outline indicates possible elevation of uranium in surficial sediments due to wind blown deposition up the canyon of Moenkopi Wash. Box indicates area zoomed into for next slide radiometrics slide.

Dust storm along Moenkopi Wash just SW of Lower Moenkopi, April 2008. Photo by James K. Otton.



Again, contoured radiometric data for uranium with same uranium concentration scale as last two slides. RMM = RARE Metals Mill. TCL = Tuba City Landfill. Black lines indicate flight lines and thickness is approximately equal to the area that is actually being detected on the ground. Note that the Tuba City landfill is not below a flight line detection zone. High detection of radiometrics downwind of the RMM site is similar to the EPA data. Note that the apparent spread to this zone to the north and south may be an artifact of contouring, as the only measurements detected were directly below the black flight line detection zone.

Regional geologic studies: Implications for the TCOD site

- Study by Cooley and others (1969) shows that the Tuba City area is a major discharge zone for the N-aquifer (includes the Navajo Sandstone and sandstone aquifers in the Navajo-Kayenta transition zone). Local mapping confirms this.
- Logical conclusion is that the ground-water chemistry in the Tuba City area should be dominated by the chemistry of the discharging N-aquifer waters, unless the ground water is from another source and(or) modified in some way.

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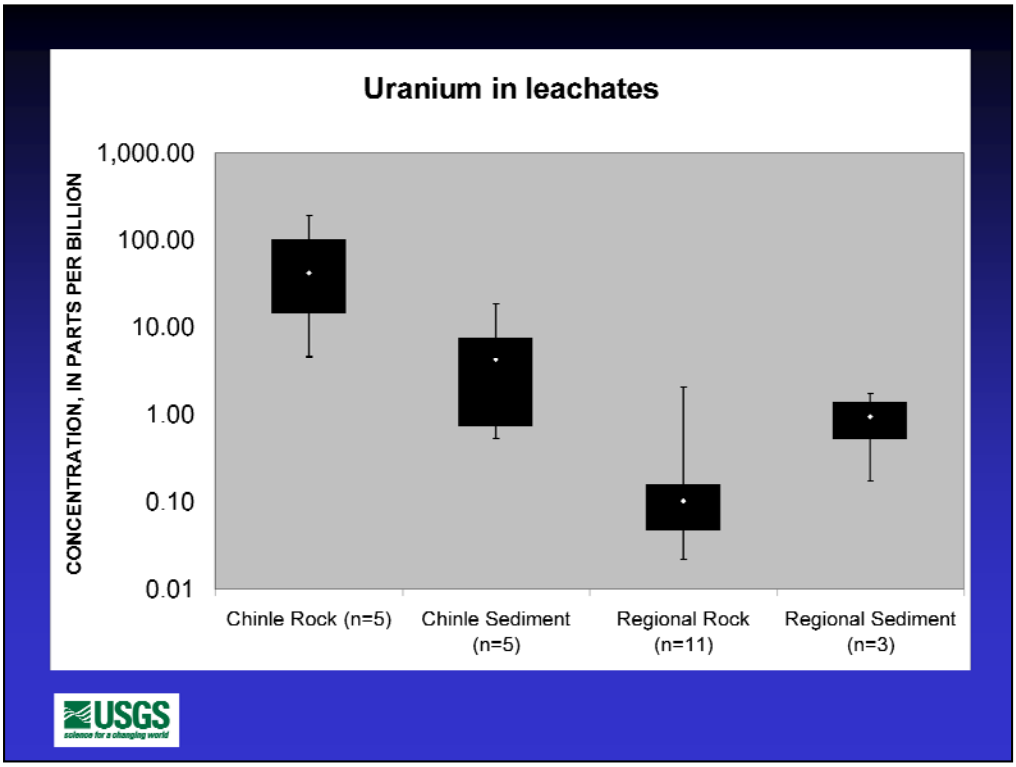
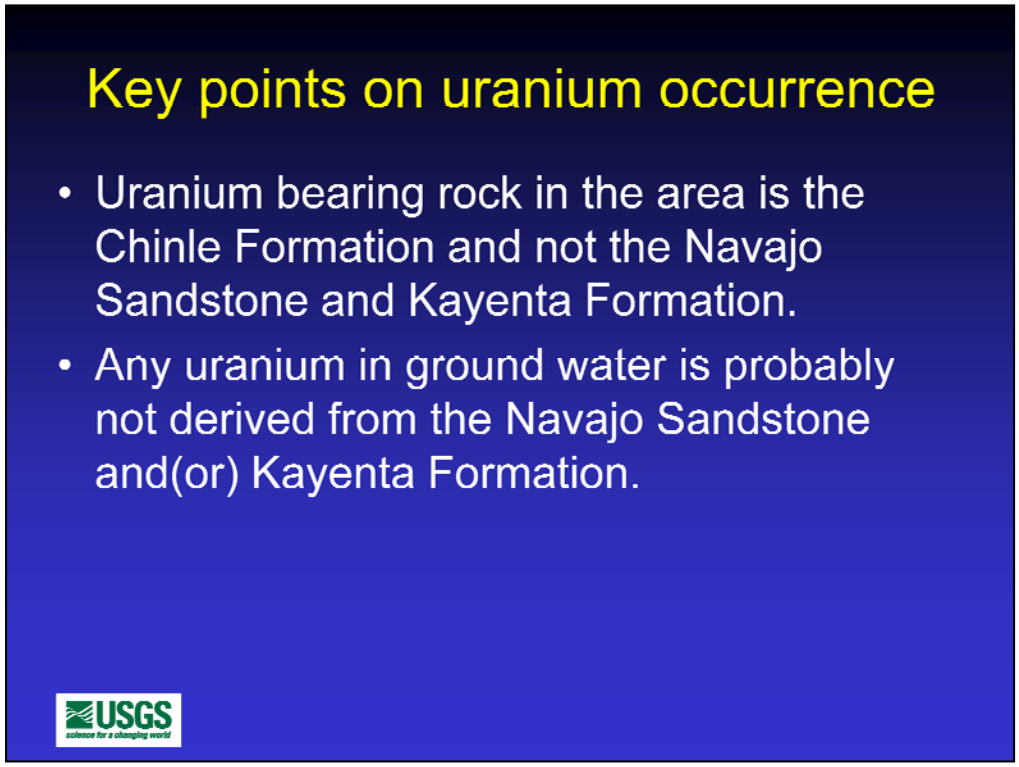
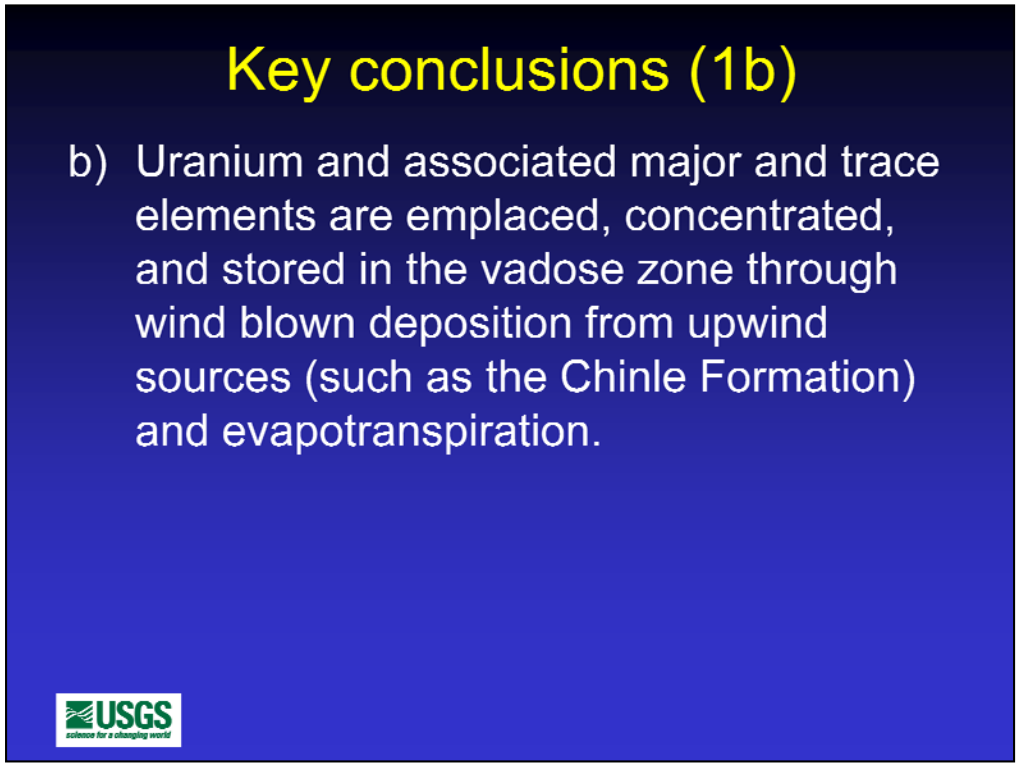


Rock and sediment samples were leached in a 20 to 1 ratio of DI water to solids. These data do not represent what actual ground water uranium concentration might be produced, but are used to directly compare different potential sources of naturally occurring uranium using a standard method to determine variations in soluble (leachable) uranium from different solid samples. Uranium concentrations are higher for Chinle Formation rocks and sediments, as expected. Note the higher amount of leachable uranium seen in the regional sediments compared to the regional rock samples. Regional Navajo Sandstone and Kayenta Formation samples (regional rock) in and around the Tuba City area are much lower in leachable uranium (note that one sample was from a rock near a spring with an evaporitic salt coating apparently containing some leachable uranium, this adds to the tail on the regional rock data). Exact rock type and collection location details are found in OFR 2009-1020.



These key points answer the question of where the uranium in the ground water is derived. Will address more in the next section.



Reminder of conclusion (b) for key question number 1.

Key conclusions (1b)

Supporting evidence

- Dune sands are not directly derived from the Navajo Sandstone.
- Whole rock data for vadose zone sediments show that salts and trace elements including uranium are stored in the vadose zone.
- Resistivity surveys show substantial salt storage in the vadose zone of TCOD surficial sediments in areas with no direct drill hole information.
- ^{18}O and deuterium isotope studies indicate that evapotranspiration has occurred, which would result in the concentration of dissolved constituents.

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Regional geologic studies: Implications for the TCOD site

- Study by Billingsley (1987) of sources for aeolian sand on the Moenkopi Plateau show that sand was derived from rock formations exposed along the ancestral Little Colorado River drainage including bedrock units from the Chinle Formation up to the Navajo Sandstone. These sand sources were cut off as the river eroded down through the bedrock leaving cliffs behind. Dune sands on the plateau (including Tuba City) may be as old as 2.4 million years.
- Chemistry of the near-surface sediment should reflect the chemistry of upwind sources of sand plus finer grained material (silt, dust, and salts) that continues to be blown and deposited across the terrain.

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Whole rock data

- Elevated salt, uranium, and other trace metal concentrations in the solid phase often occur above the water table.
- The bedrock at depth, below the water table, is very low in uranium and other trace metals (clean quartz sand).
- Scanning electron microscope images in these “salt” zones show minerals such as monazites (cerium/rare earth metal phosphates) which were not found in the Navajo Sandstone samples.

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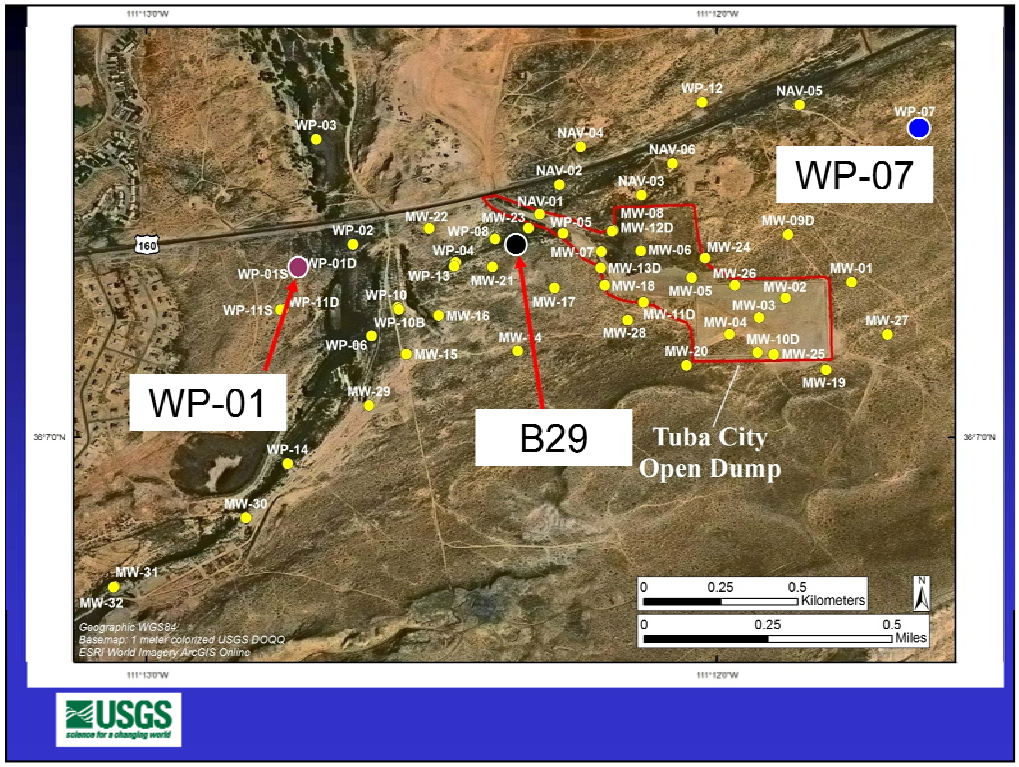
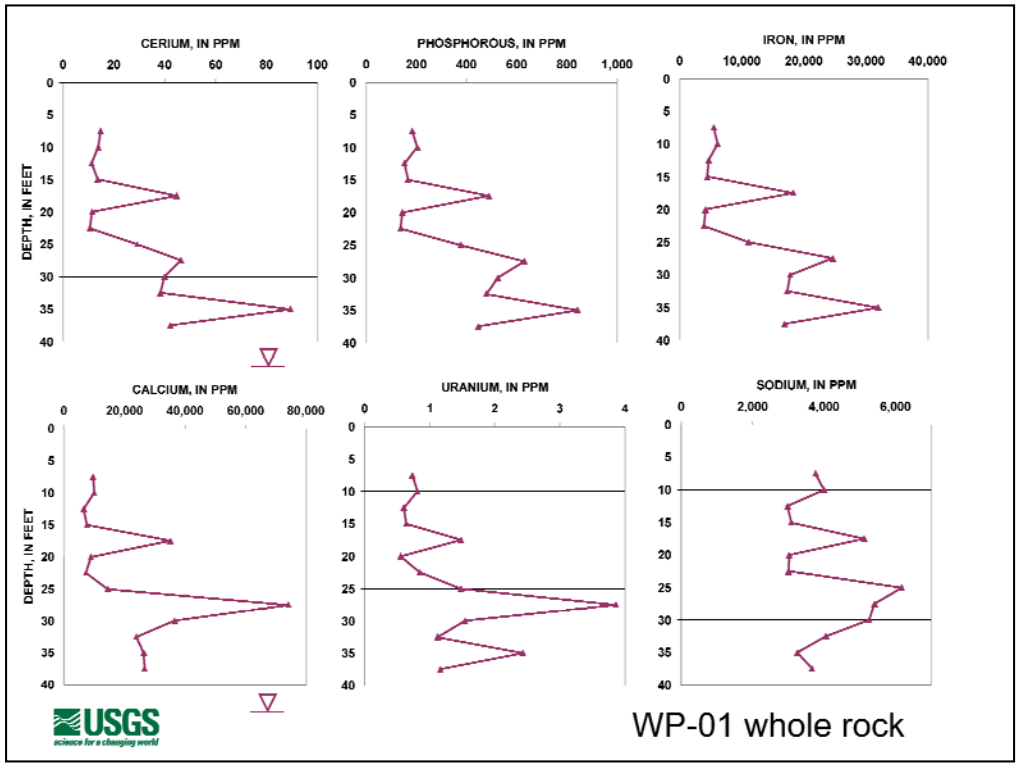
This is a summary of the evidence from the whole rock data presented in the next few slides. The main conclusion is that the surficial sands are not derived from Navajo Sandstone.



Will look at data in next slide from three sample sites for whole rock data with depth. WP-01 is upwind from the TCOD with 20 feet of sand and a water table at 46.8 feet (Stantec, Inc. borehole). B29 is a USGS hand augered hole in the gulley below the TCOD (11.4+ feet of sand and 12.5 feet to the water table). WP-07 is a Stantec, Inc. borehole with 5 feet of sand over Navajo Sandstone and a water table at 17.5 feet deep.


CERIUM, IN PPM
PHOSPHOROUS, IN PPM
IRON, IN PPM
CALCIUM, IN PPM
URANIUM, IN PPM
SODIUM, IN PPM
DEPTH, IN FEET
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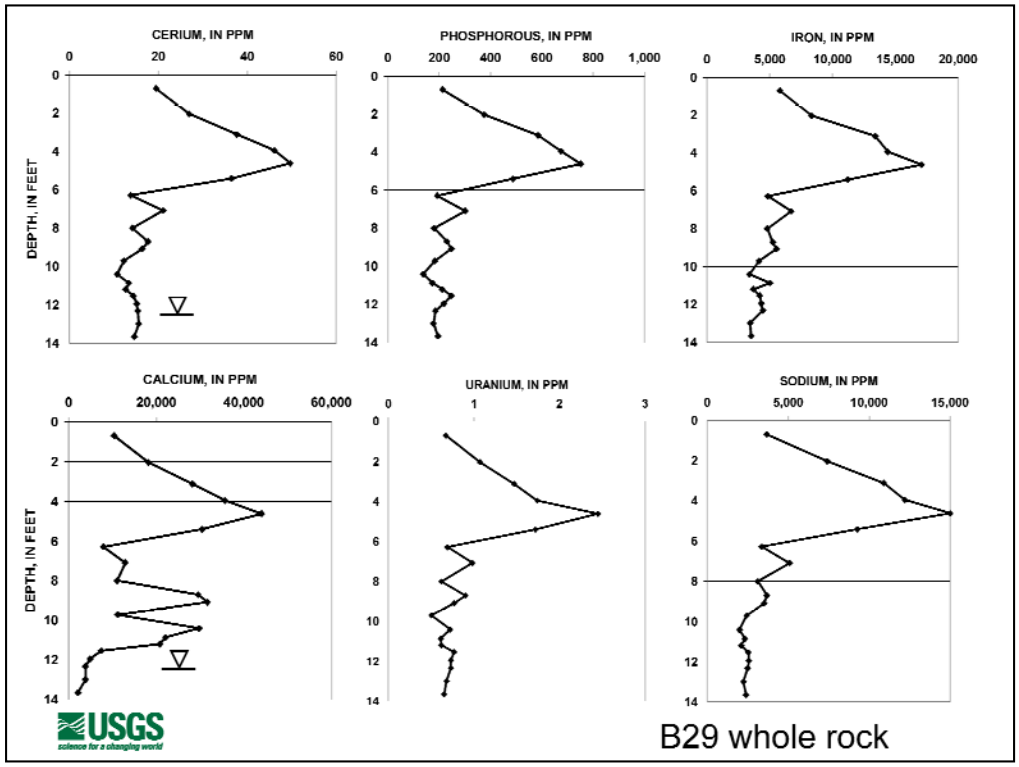
WP-01 whole rock


CERIUM, IN PPM
0 20 40 60
PHOSPHOROUS, IN PPM
0 200 400 600 800 1,000
IRON, IN PPM
0 5,000 10,000 15,000 20,000
DEPTH, IN FEET
0 2 4 6 8 10 12 14
CALCIUM, IN PPM
0 20,000 40,000 60,000
URANIUM, IN PPM
0 1 2 3
SODIUM, IN PPM
0 5,000 10,000 15,000
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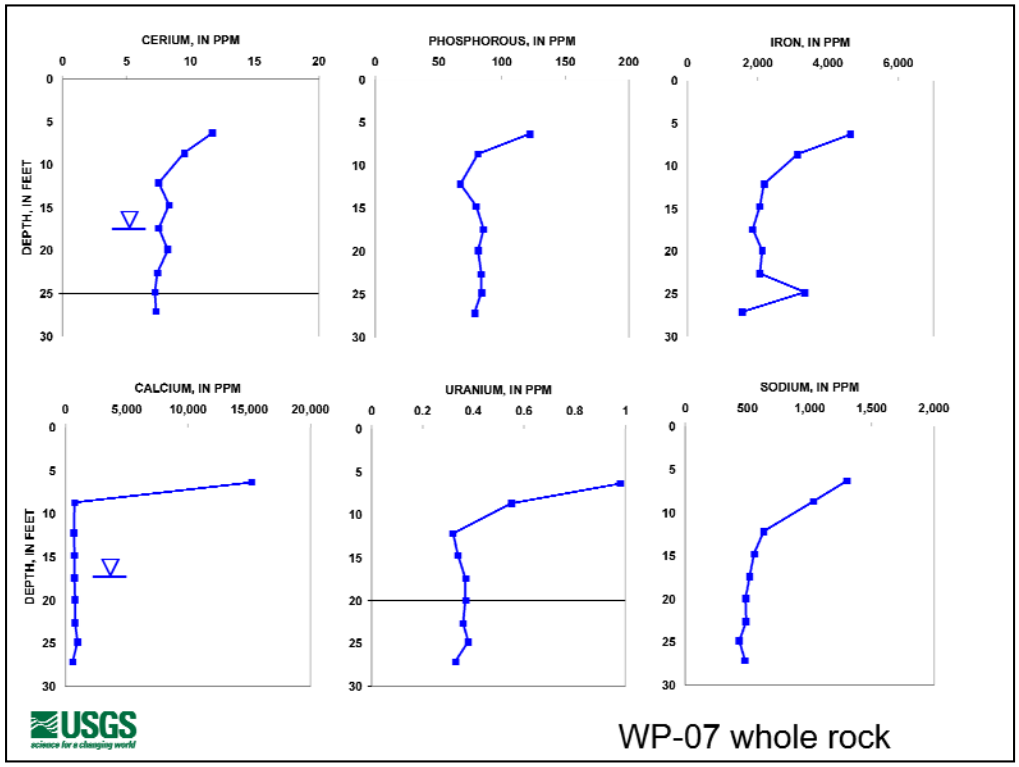
B29 whole rock


CERIUM, IN PPM
PHOSPHOROUS, IN PPM
IRON, IN PPM
CALCIUM, IN PPM
URANIUM, IN PPM
SODIUM, IN PPM
DEPTH, IN FEET
DEPTH, IN FEET
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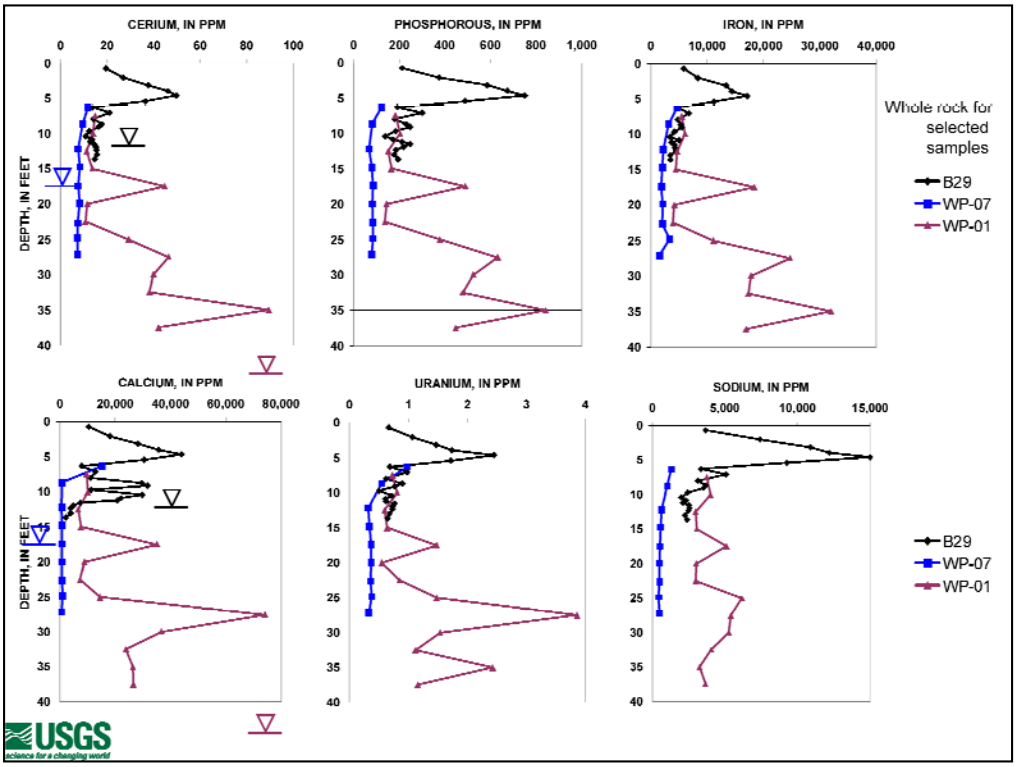
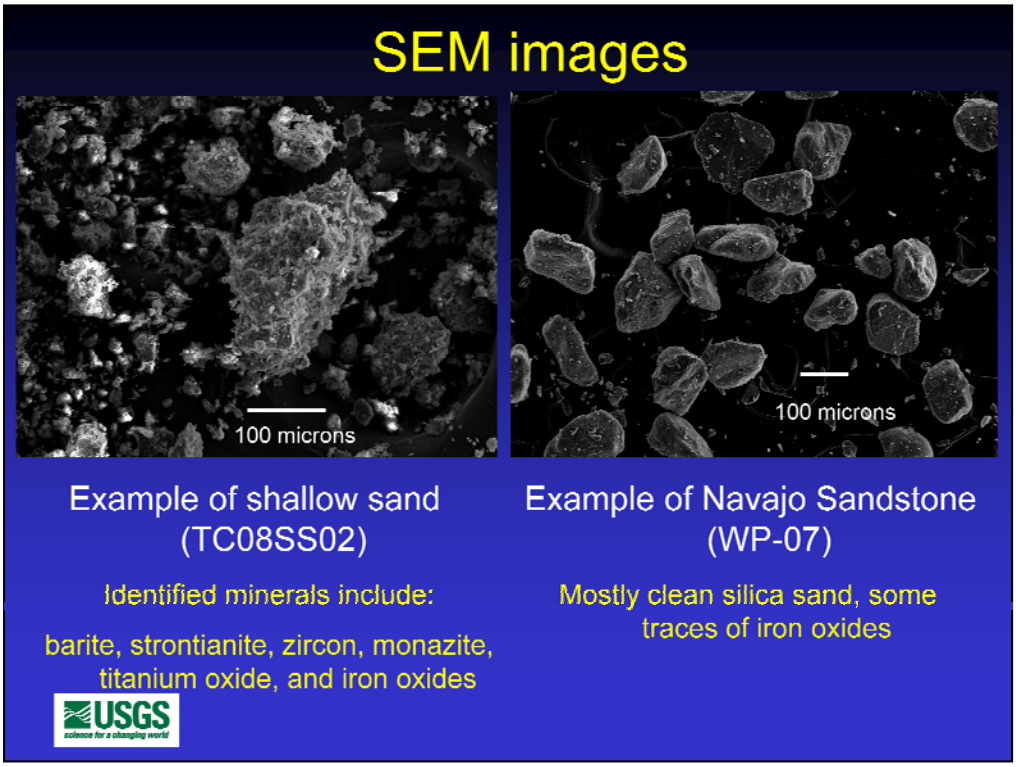
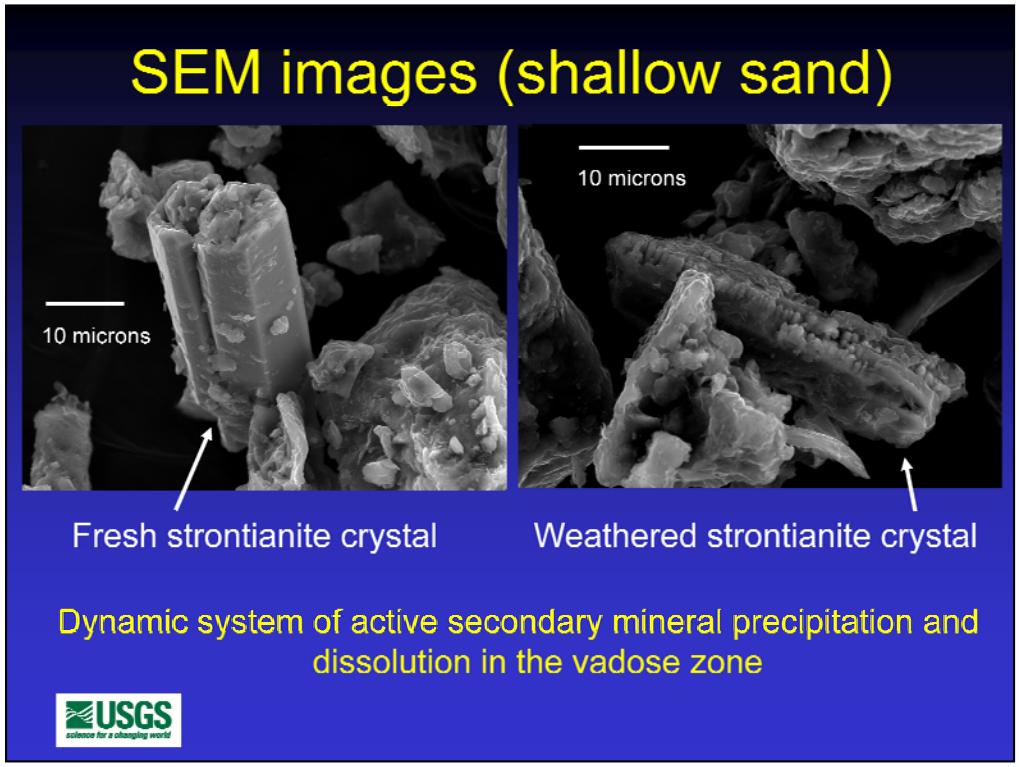
WP-07 whole rock



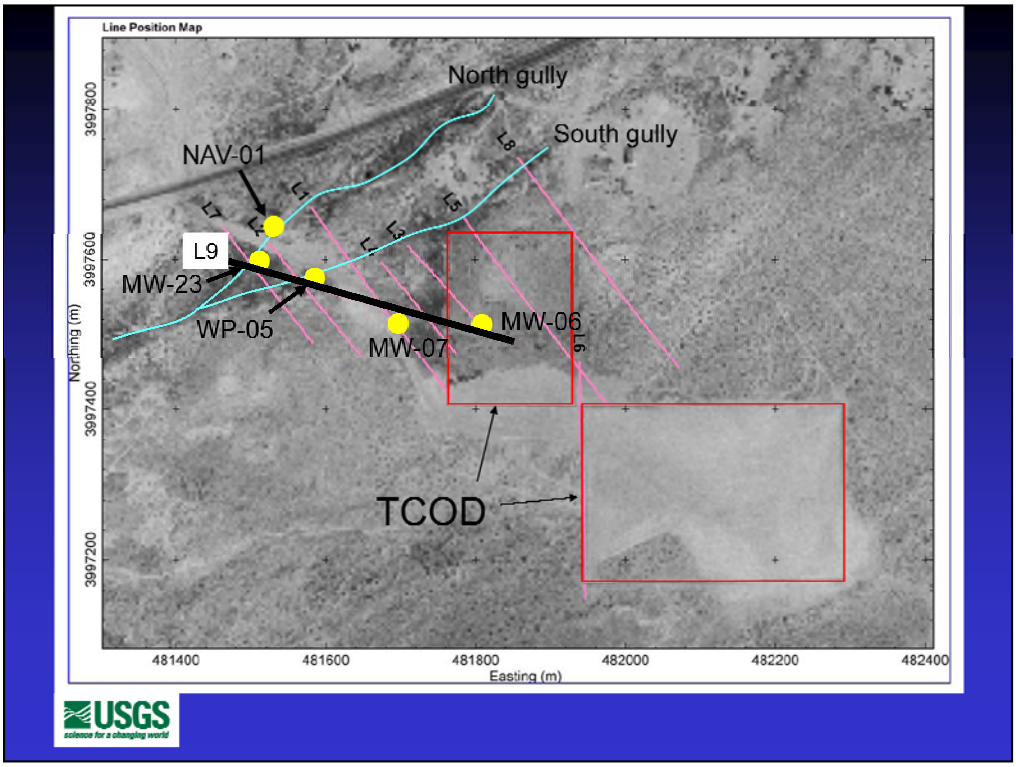
Most values for uranium are below crustal abundance (agrees with radiometric data). Main “salt” concentration zones occur above the water table. Navajo Sandstone in WP-07 is low in most all elements, especially below the water table. Water table for B29 = 12.5, WP-07 = 17.5, and WP-01 = 46.8 feet below ground surface.



TC08SS02 is a surficial grab sample and WP-07 sample is from 17.4 foot depth (Navajo Sandstone). SEM = scanning electron microscope. Note large amount of surficial coatings (secondary mineral precipitation and(or) blown in?) in TC08SS02. Shallow sand has a greater number of smaller grains. SEM images taken by Raymond H. Johnson.

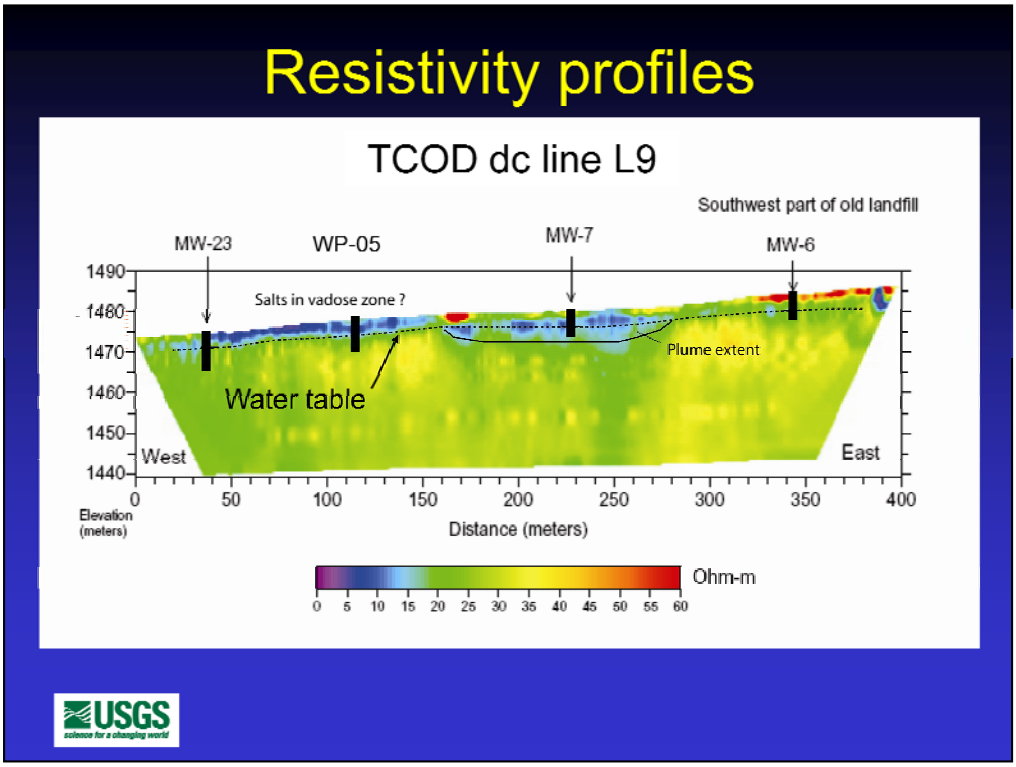


Example of secondary mineral precipitation of strontianite (strontium carbonate) in WP-01 sample (at 27.5 feet). This is 20 feet above the water table. This demonstrates likely active precipitation and dissolution of strontianite occurring in the vadose zone. SEM images taken by Raymond H. Johnson.



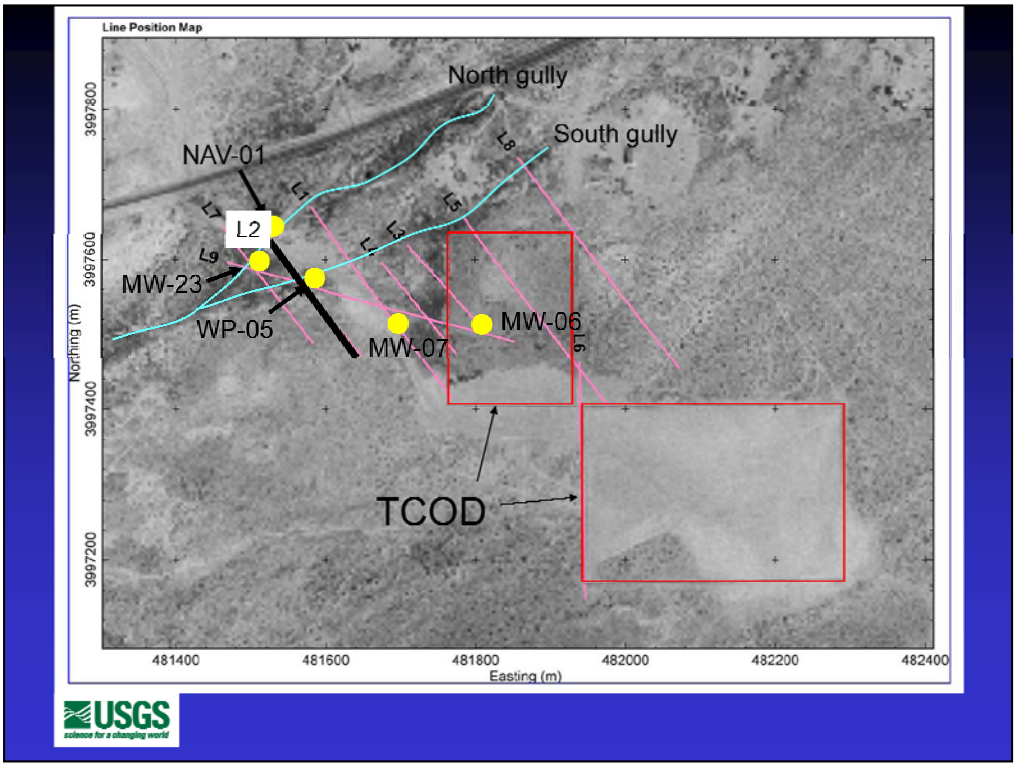
Significant landmarks to see on dc line L9 in next slide are north gully (at MW-23), south gully crossing (just before WP-05), MW-07, and the portion of the old dump.

dc = direct current.



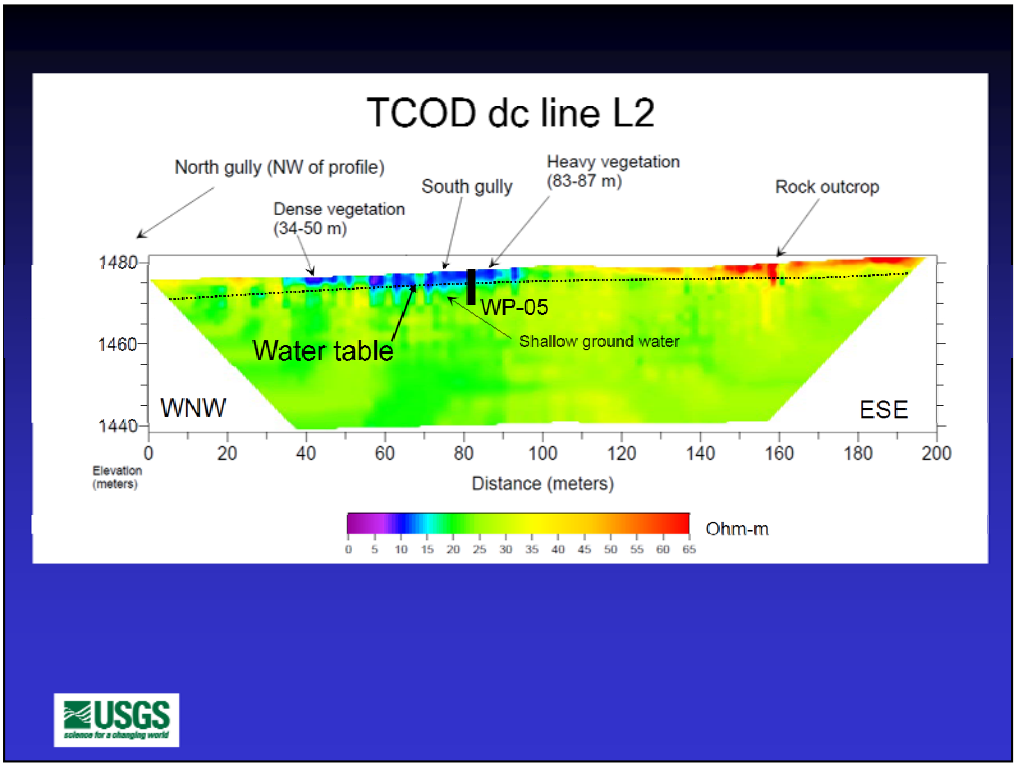
Well depths are drawn to scale. A highly conductive zone near the surface between WP-05 and MW-23 is most likely a damp salt zone. This is confirmed by borings in the area, which do not indicate significant clay zones. Note that resistivity surveys would detect dry salt zones as very resistive, thus a water table close to the surface is required to detect these zones with dc resistivity.

dc = direct current.



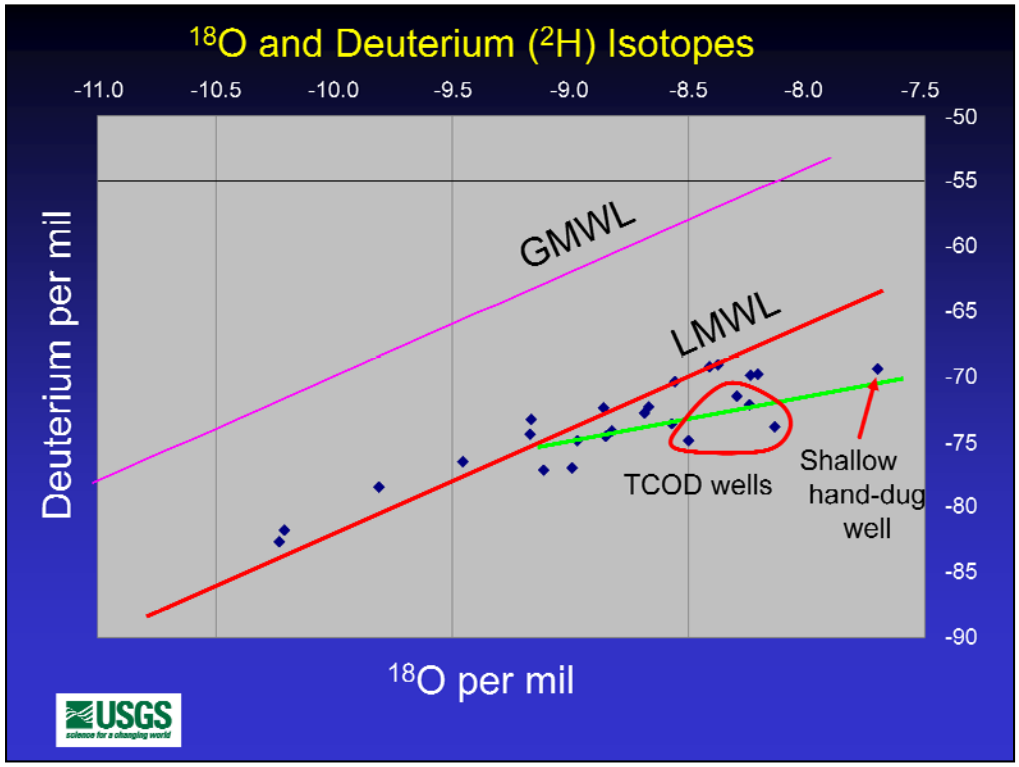
Significant landmarks to see on dc line L2 in next slide are north and south gully crossing, MW-07, and the edge of the old dump.

dc = direct current.



Well depth is drawn to scale. Similar evidence of “salt” zones in the vadose zone along south gully. These profiles will be revisited later in the talk from the aspect of transferring the “salts” into the ground water.

dc = direct current.



Red outline highlights the four landfill wells that show some evaporation (lie below the LMWL near the green line). Arrow points to a hand-dug well sample that shows a strong evaporation signature. GMWL = global meteoric water line and LMWL = local meteroic water line. All other samples are regional water (OFR 2009-1020).

Key points on uranium and trace element sources

- Uranium and associated major and trace elements are stored in the vadose zone through a possible cycle of wind blown deposition, dissolution, and concentration by evapotranspiration.
- Below the water table, soluble solid phases have already been dissolved away.

Key conclusions (1c)

c) These constituents are locally transferred to shallow ground water by natural processes and human disturbance throughout the area.

READ

Key conclusions (1c)

Supporting evidence

- Elevated uranium and other constituents occur in shallow ground water throughout the area, except where N-aquifer water discharges at the surface.
- Resistivity surveys indicate some transfer of dissolved constituents to the shallow ground water.
- Uranium isotopes indicate a vadose zone source for the uranium in the shallow ground water.

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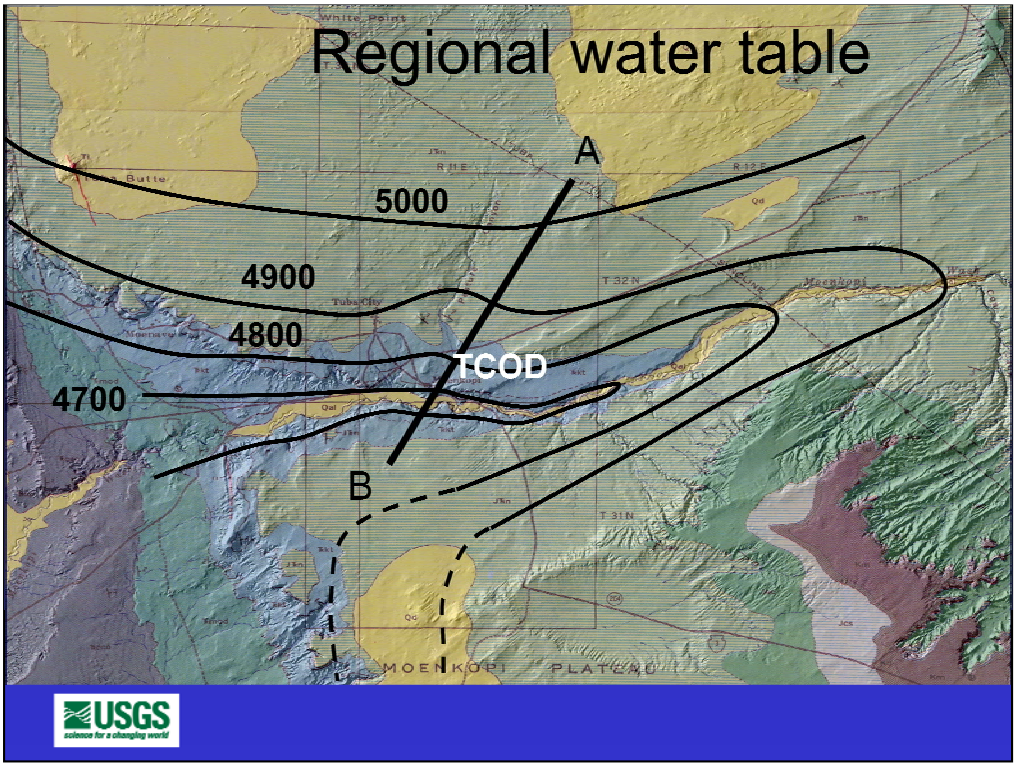
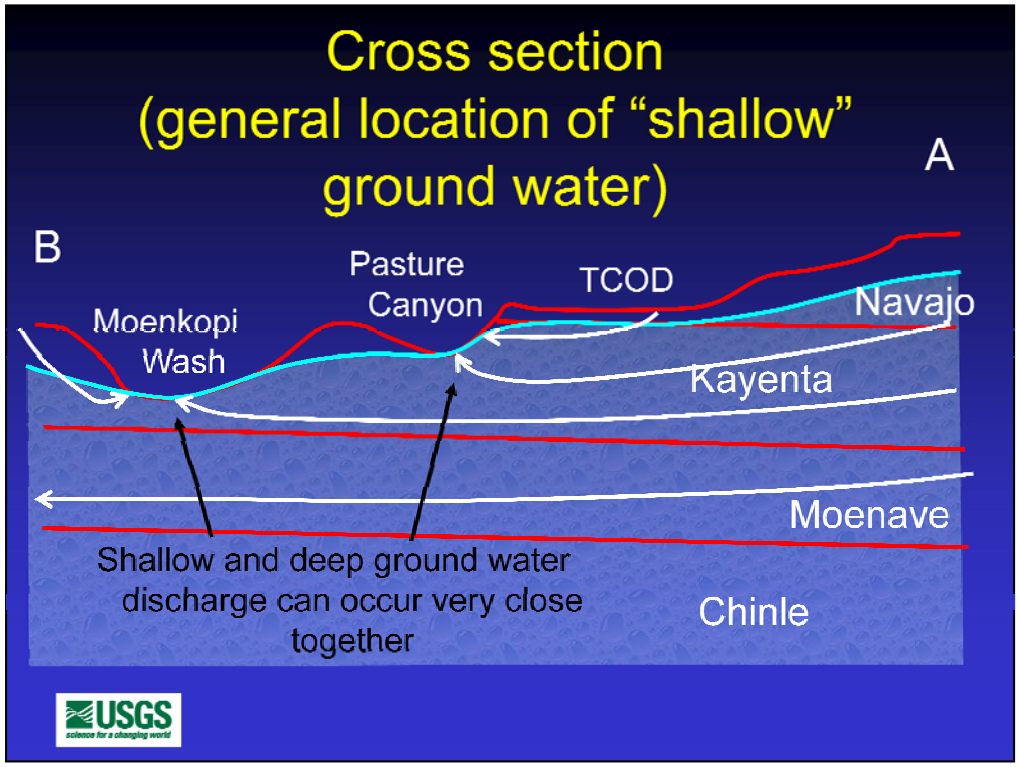
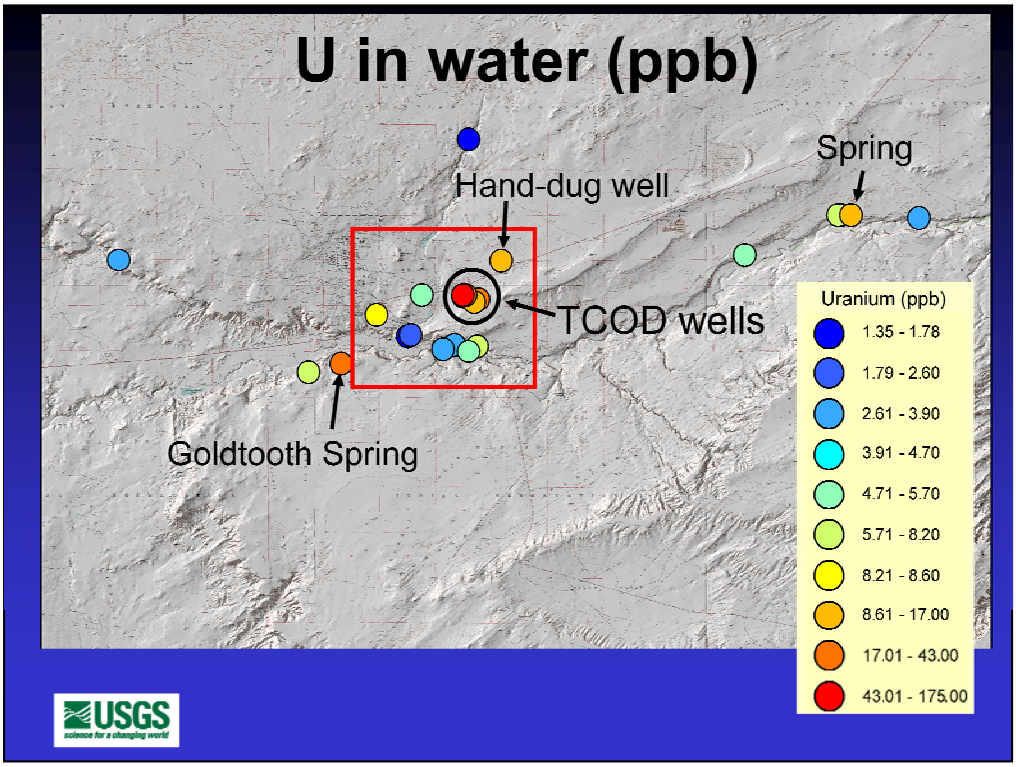
READ



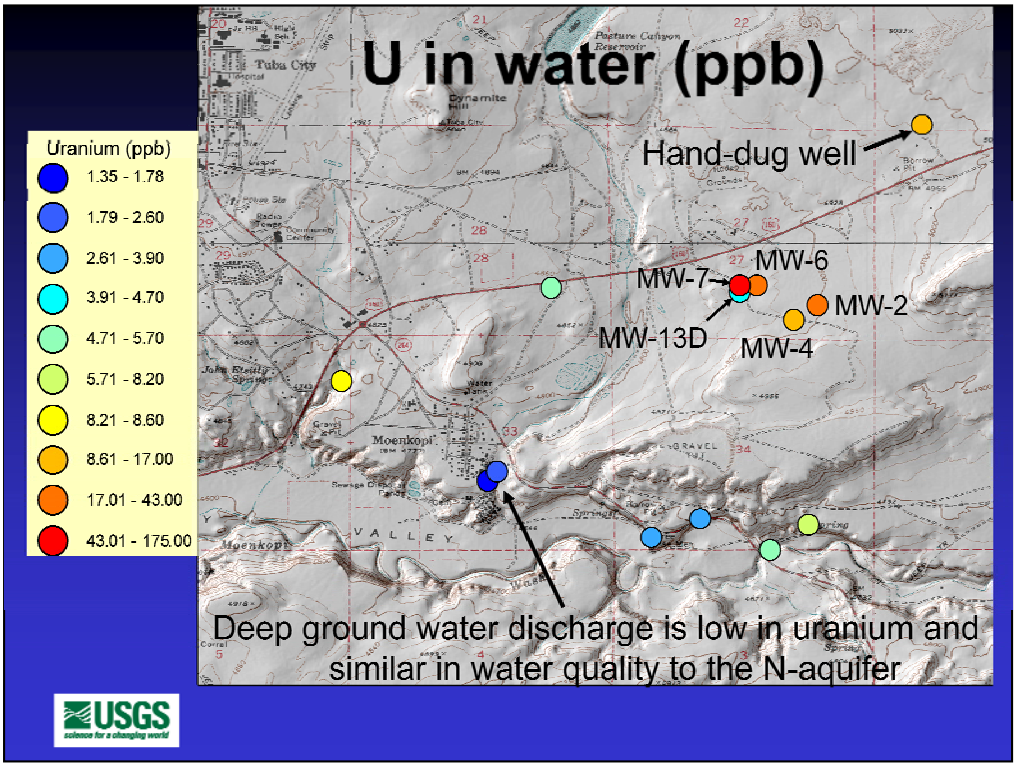
Regional water table based on spring elevations; generally follows topography.



Conceptual cross section based on expected ground-water flow in a regional setting. Note that shallow and deep ground water may discharge at Pasture Canyon and Moenkopi Wash.



Some regional water samples do show elevated uranium concentrations in shallow ground water. Highest is Goldtooth Spring at 41 ppb. Zoom into boxed area for next slide.


U in water (ppb)
Uranium (ppb)
1.35 - 1.78
1.79 - 2.60
2.61 - 3.90
3.91 - 4.70
4.71 - 5.70
5.71 - 8.20
8.21 - 8.60
8.61 - 17.00
17.01 - 43.00
43.01 - 175.00
Hand-dug well
MW-6
MW-7
MW-2
MW-13D
MW-4
Deep ground water discharge is low in uranium and similar in water quality to the N-aquifer
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Key points on uranium in ground water

- Deep ground water is low in uranium and similar to N-aquifer water.
- Shallow ground water can have higher uranium concentrations.

Inferences from regional studies

- If no additional recharge is occurring, the ground-water chemistry in the TCOD area should be dominated by the chemistry of the discharging N-aquifer waters.
- However, shallow ground waters are modified by interaction with “modern” precipitation and surficial sediment plus near-surface processes such as evapotranspiration.

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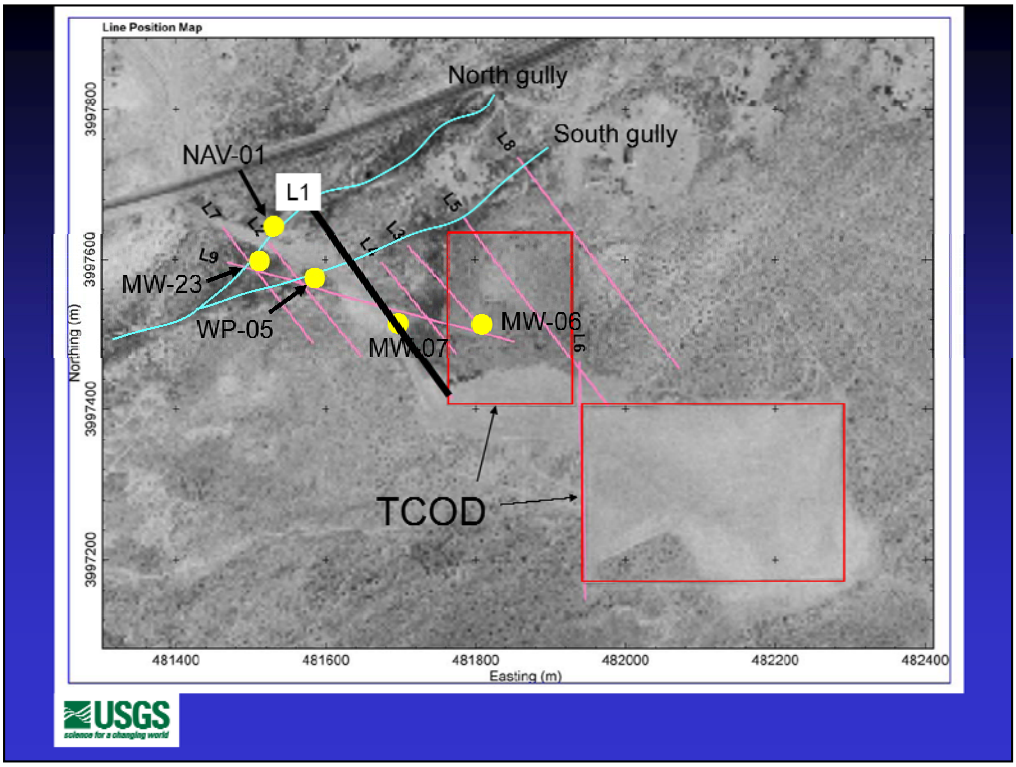
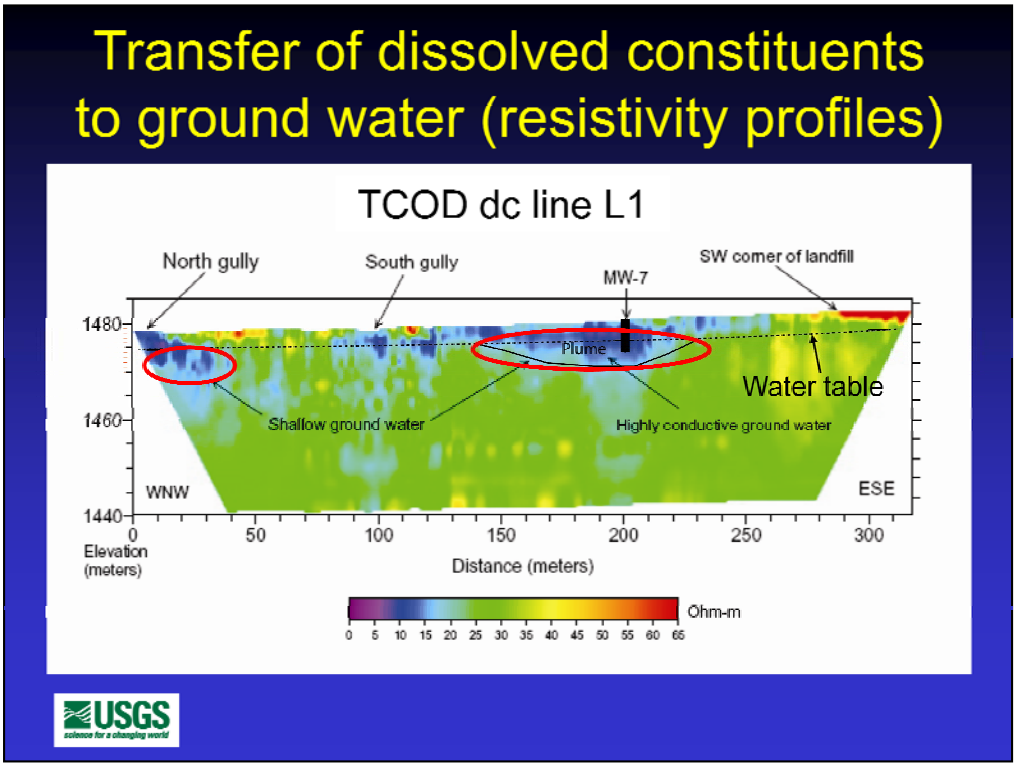
READ – “modern” precipitation can mean within the last few thousand years.



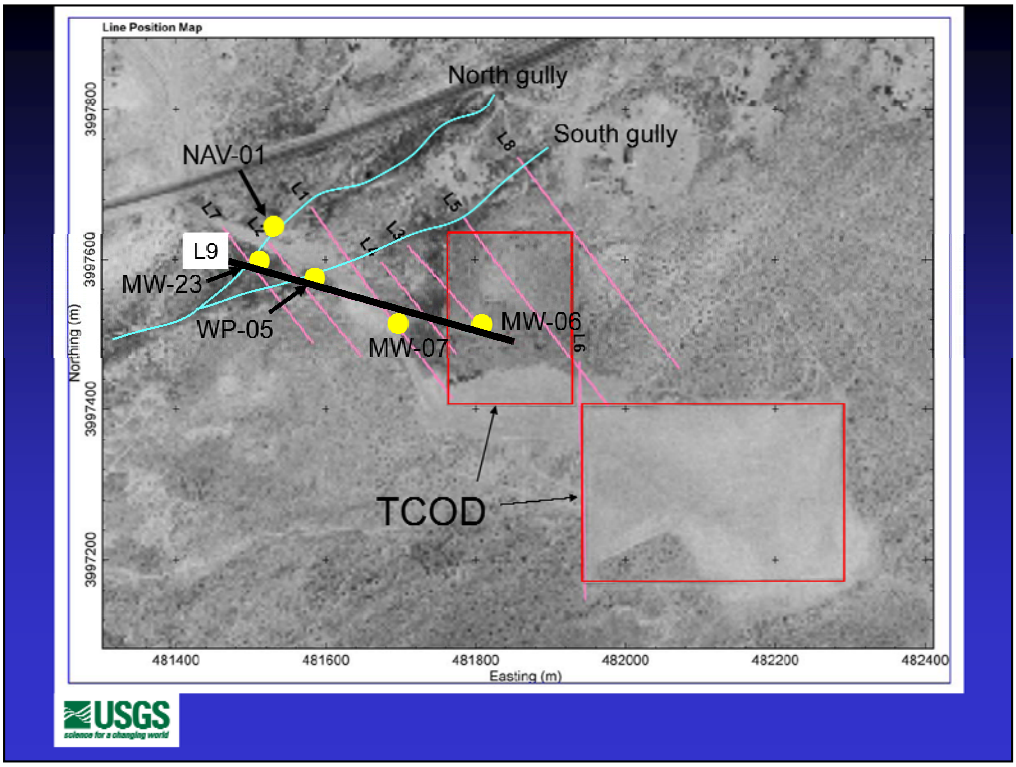
Significant landmarks to see on dc (direct current) line L1 in next slide are north and south gully crossing, MW-07, and the edge of the old dump.

dc = direct current.



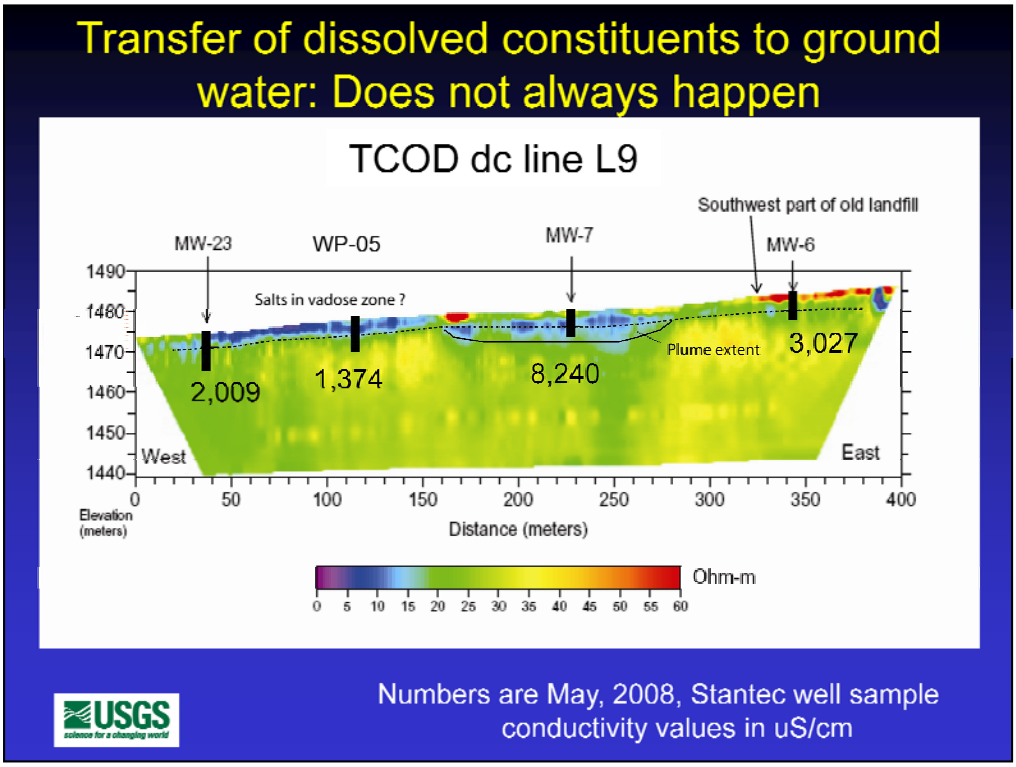
Well depth is drawn to scale. Areas with red outlines are zones of more conductive ground water (no change in geology based on borings in the area), which appear to be close to highly conductive zones in the above vadose zone. Note that the north gully has few ground water samples, except for the Begay hand-dug well (no USGS data for this well, but reported by Brown and Caldwell, 2008 as 580 uS/cm specific conductance).

dc = direct current.



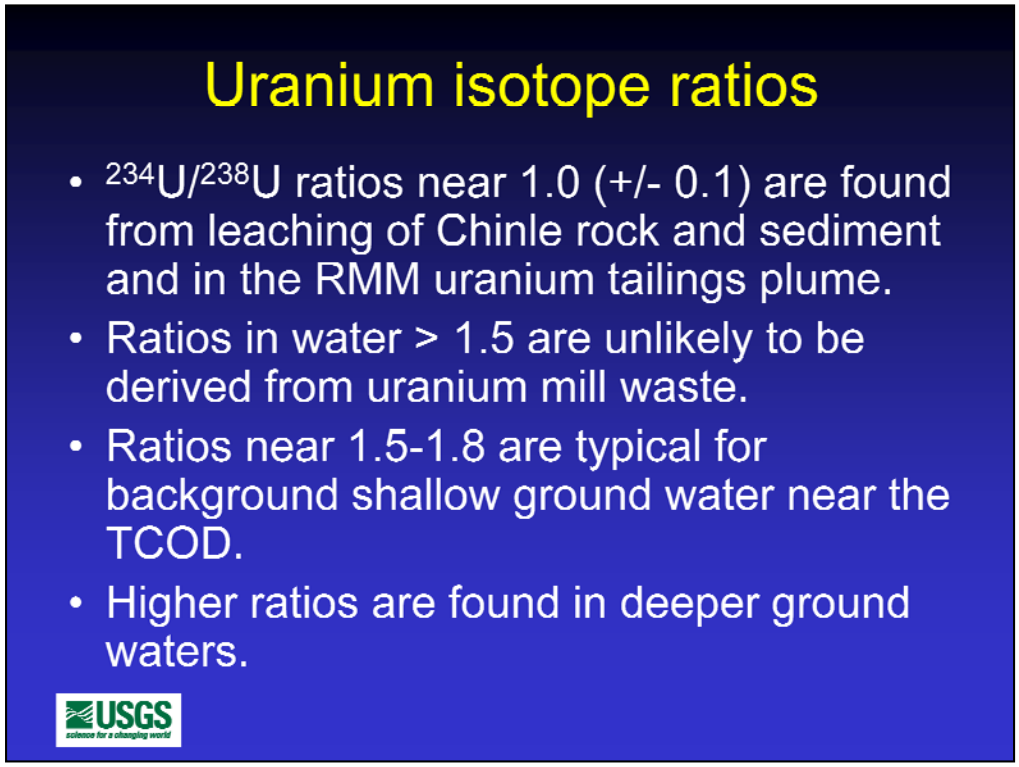
Significant landmarks to see on dc line L9 in next slide are north gully (at MW-23), south gully crossing (just before WP-05), MW-07, and the portion of the old dump.

dc = direct current.

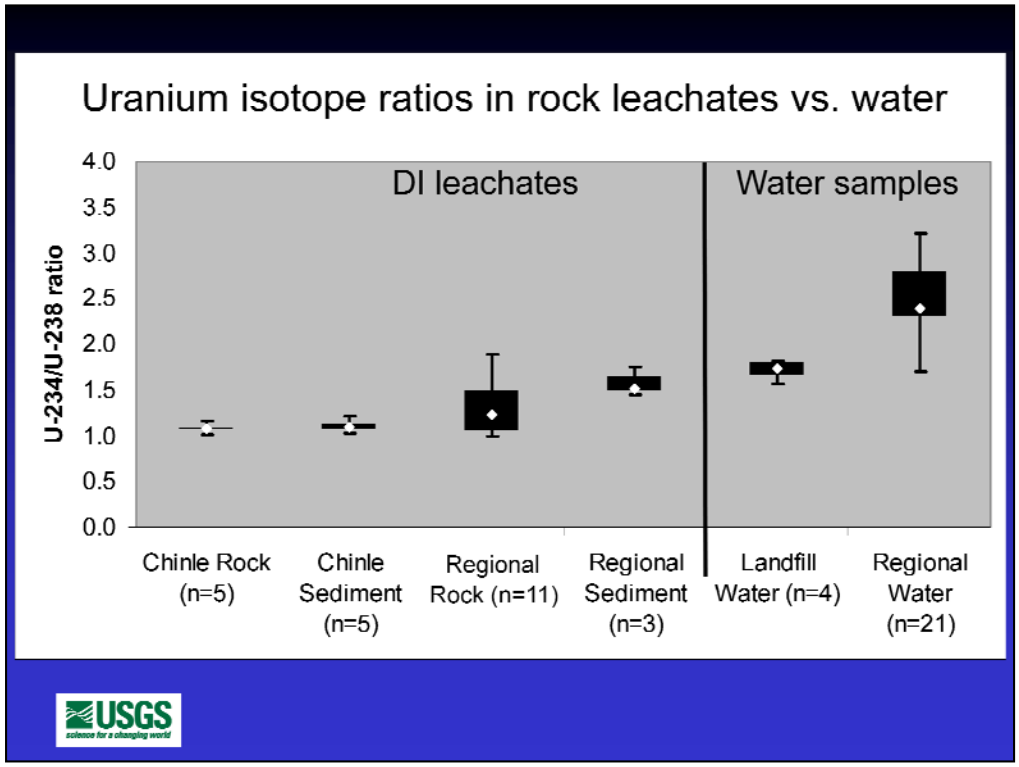


Well depths are drawn to scale.

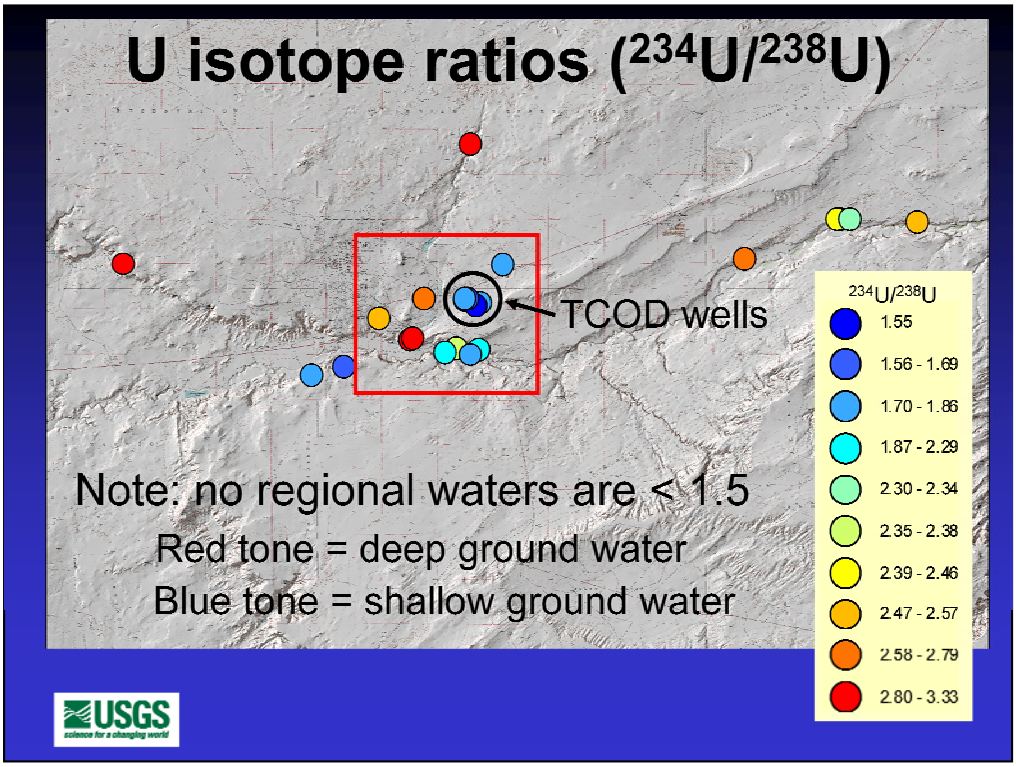
dc = direct current.



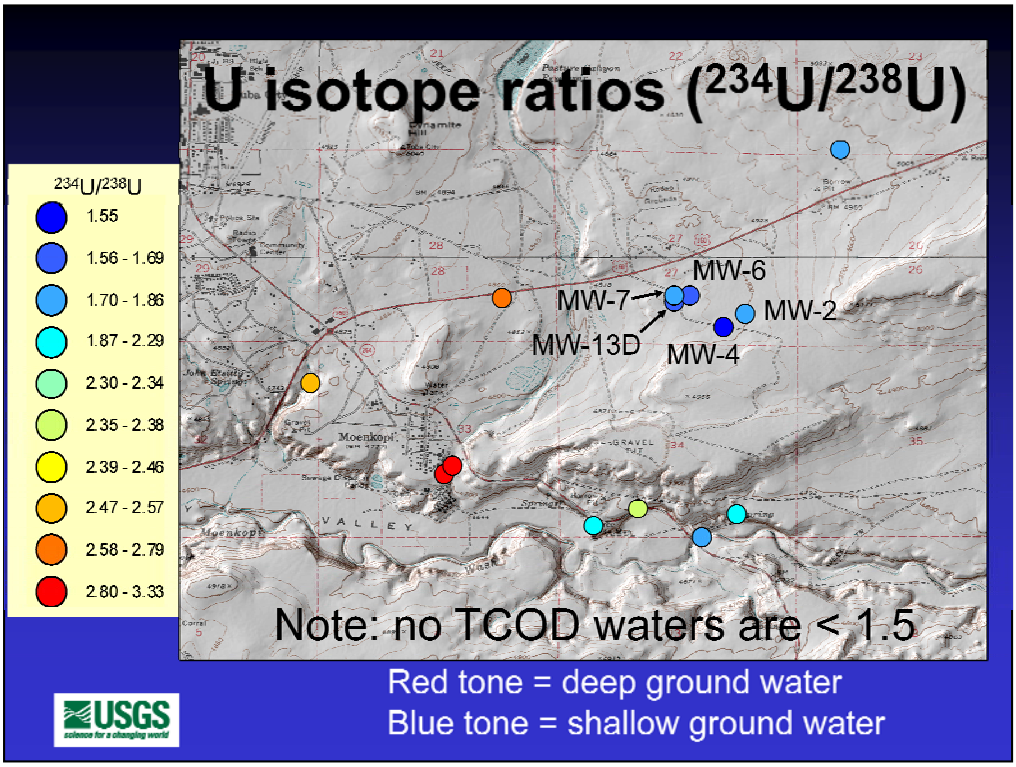
Leaching of uranium ore-bearing material (Chinle rock and mill tailings) produce a ratio near 1. This is because the ore material is near secular equilibrium (long enough time for uranium decay series to reach similar U-234 and U-238 concentrations). Dissolution of the soluble uranium gives values similar to or less than the rock values (1 or less). In slow moving ground water, the alpha recoil mechanism produces uranium isotope ratios greater than 1 (Zielinski and others, 1997).



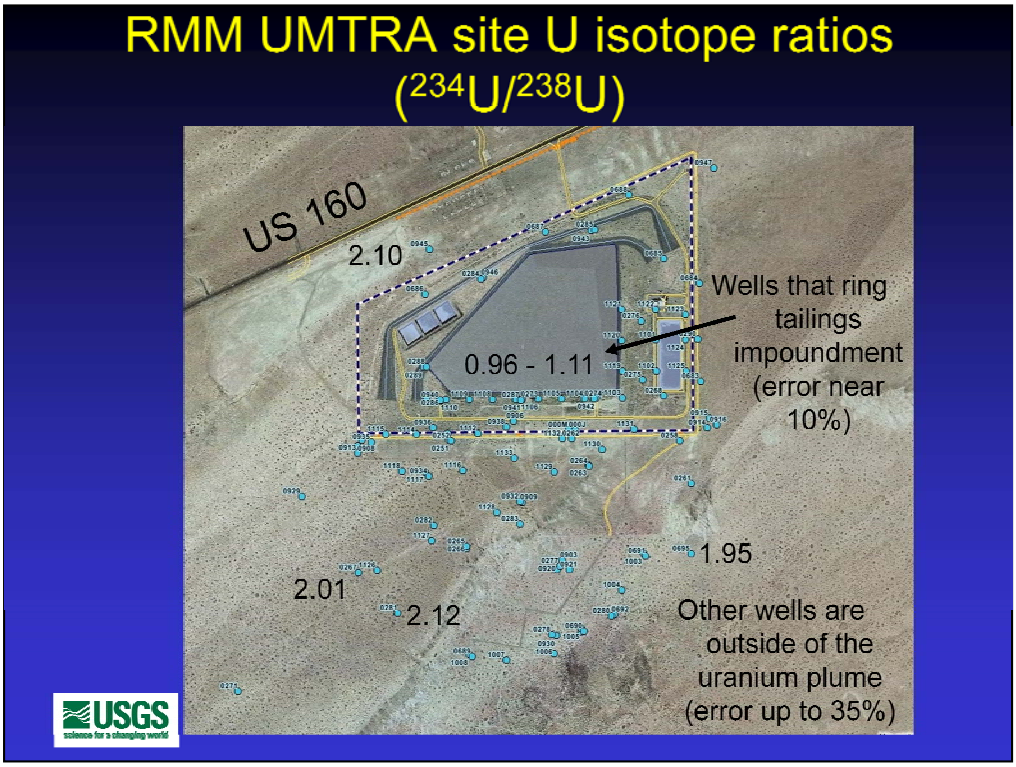
Uranium isotope ratios from TCOD ground-water samples overlap with regional waters and regional rock and sediment leachates. Leachate from Chinle rock and sediment do not overlap with the TCOD ground water samples for uranium isotope ratios.



Blue tones generally indicate shallow ground water and red tones generally indicate deeper ground water (this is confirmed by geochemistry and tritium/C-14 data). The red outline indicates the zoomed in area shown on the next slide.



Blue tones generally indicate shallow ground water and red tones generally indicate deeper ground water (this is confirmed by geochemistry and tritium/C-14 data). This slide is the zoomed in area shown in red on the previous slide.



Data source from DOE Office of Legacy Management web site (*http://gems.lm.doe.gov/imf/imf.jsp?site=tubacitydisposal&title=Tuba City, AZ, Disposal Site*).

UMTRA = Uranium Mill Tailings Remedial Action.

Inferences from uranium isotopes

- The majority of the uranium in the ground water in and around the TCOD
  - Appears to be derived from regional sediments which are composed mostly of dune sand and reworked dune sand, which include Chinle and(or) other sources (uranium is continually cycled in the shallow subsurface to get a isotope ratio > 1.5).
  - Not likely to be derived from uranium mill tailings or waste material (isotope ratios do not match).

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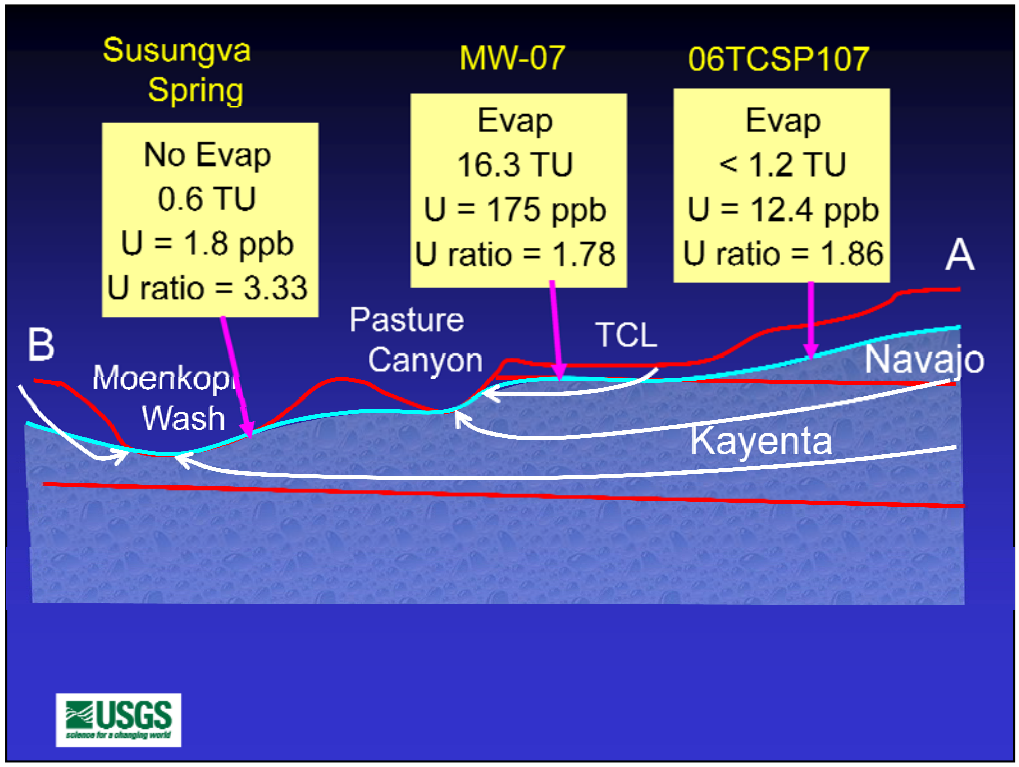
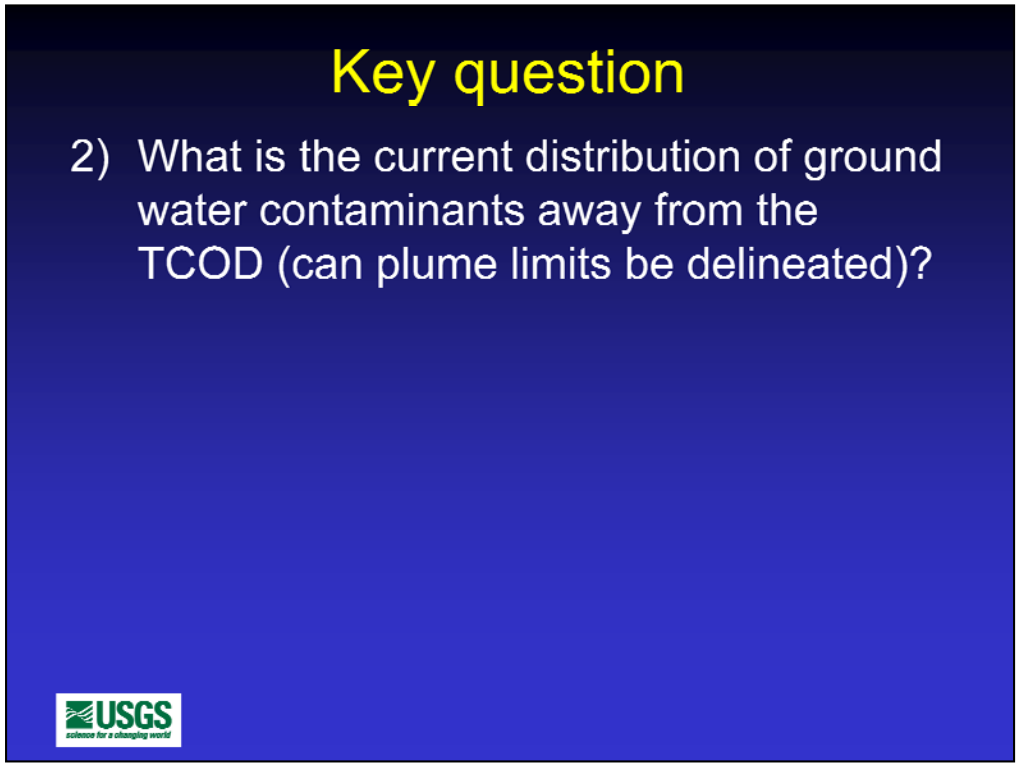
READ



Conceptual model of ground water flow and associated data. Evaporation (evap) is considered based on ^{18}O and deuterium isotopes. Susungva Spring stands out as being on a deep ground-water flow path containing N-aquifer water. Other wells are on a more shallow ground water flow path. Note that the uranium isotope ratios for TCOD up gradient well and MW-07 are similar (does not allow for a mixing scenario).



READ. Reminder of key question #2.

Key conclusions/interpretations (2)

a) Focus on MW-07 area within a contaminant plume. Water table elevations indicate a westward migration of ground water.

b) Ground water at MW-07 is characterized by high specific conductance from well sampling and high conductivity ground water in geophysical profiles.

c) The plume west of MW-07 does not reach well WP-05 and geophysical profile dc line L2. More data is necessary to clearly define the plume in this area.

d) Other areas with highly conductive ground water (WP-08 and B33) may be contaminated by dumping or other disturbances, but may not be affected by TCOD leachate.

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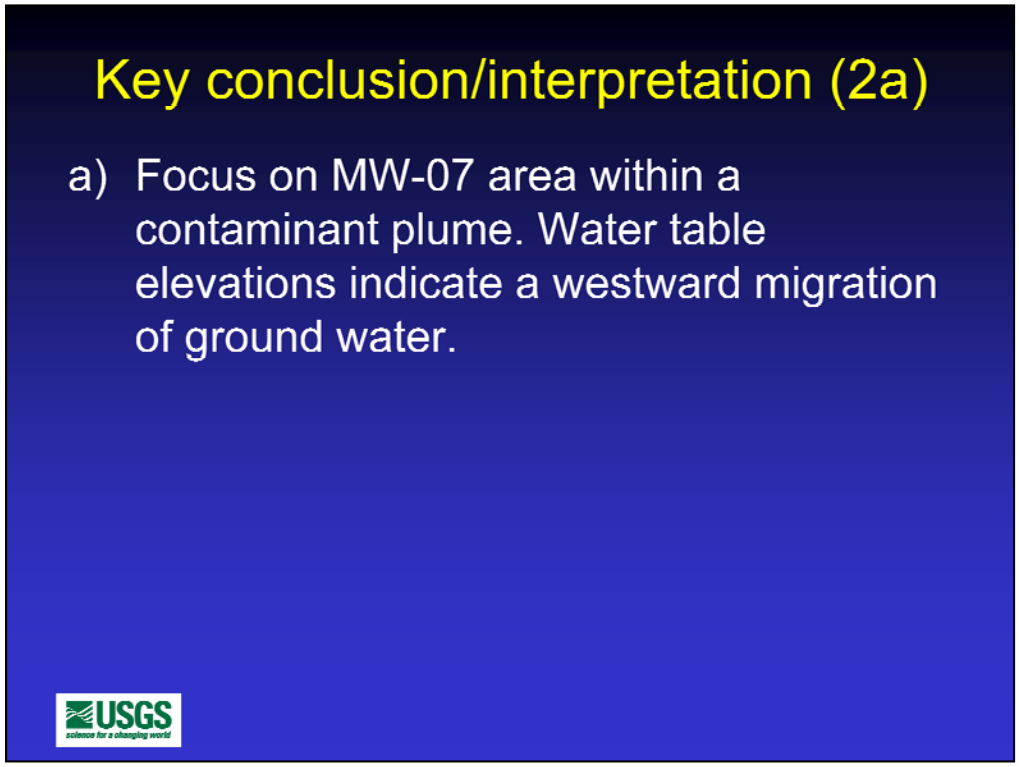
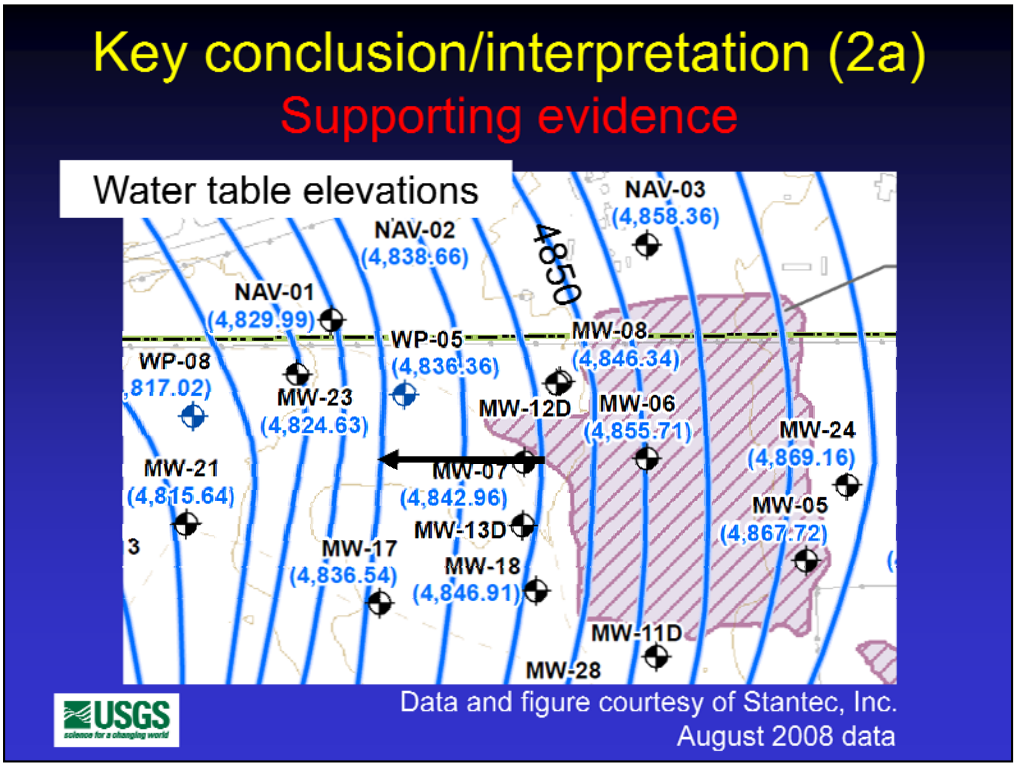
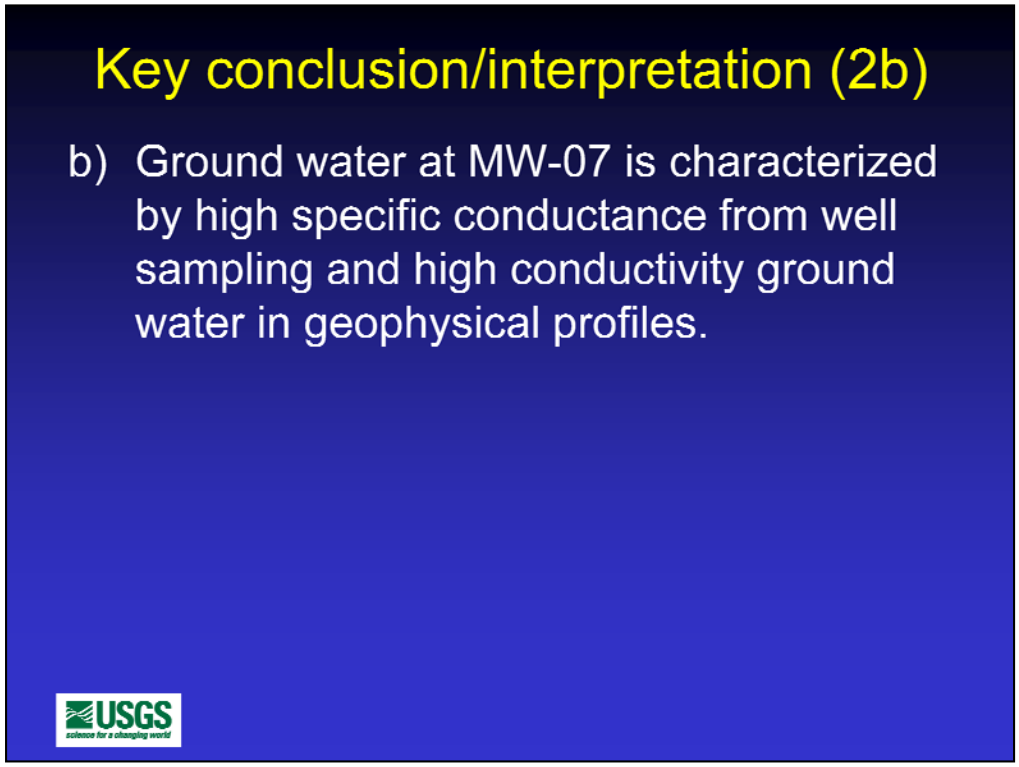


READ. Reminder of key conclusion/interpretation 2a.

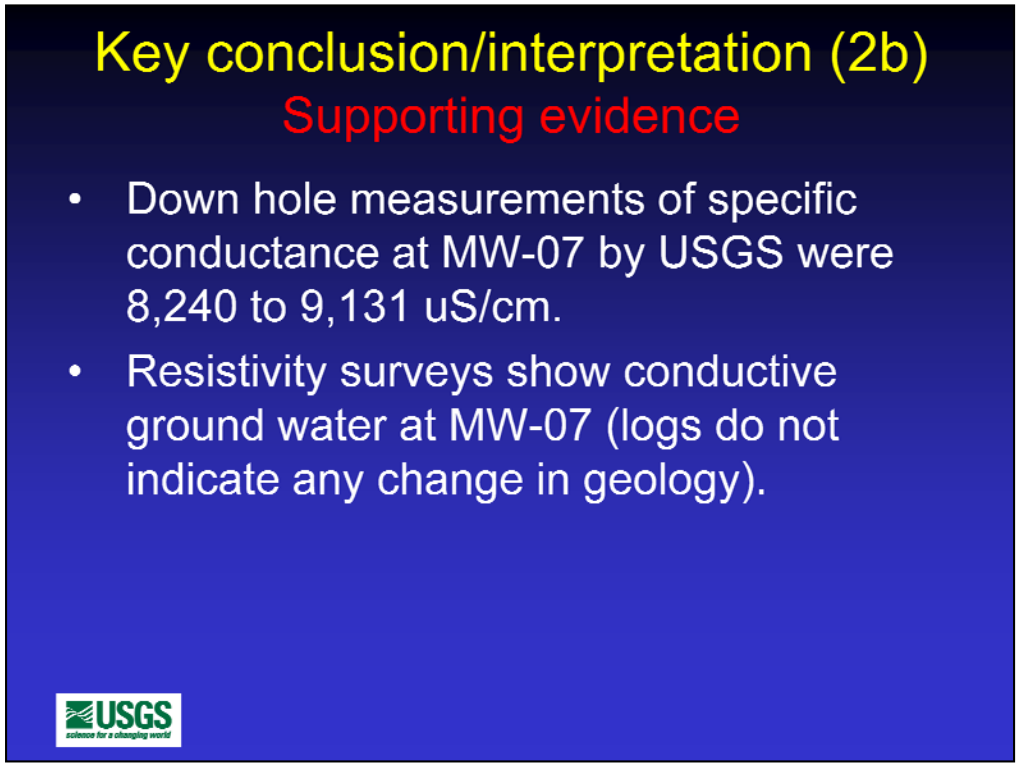


READ

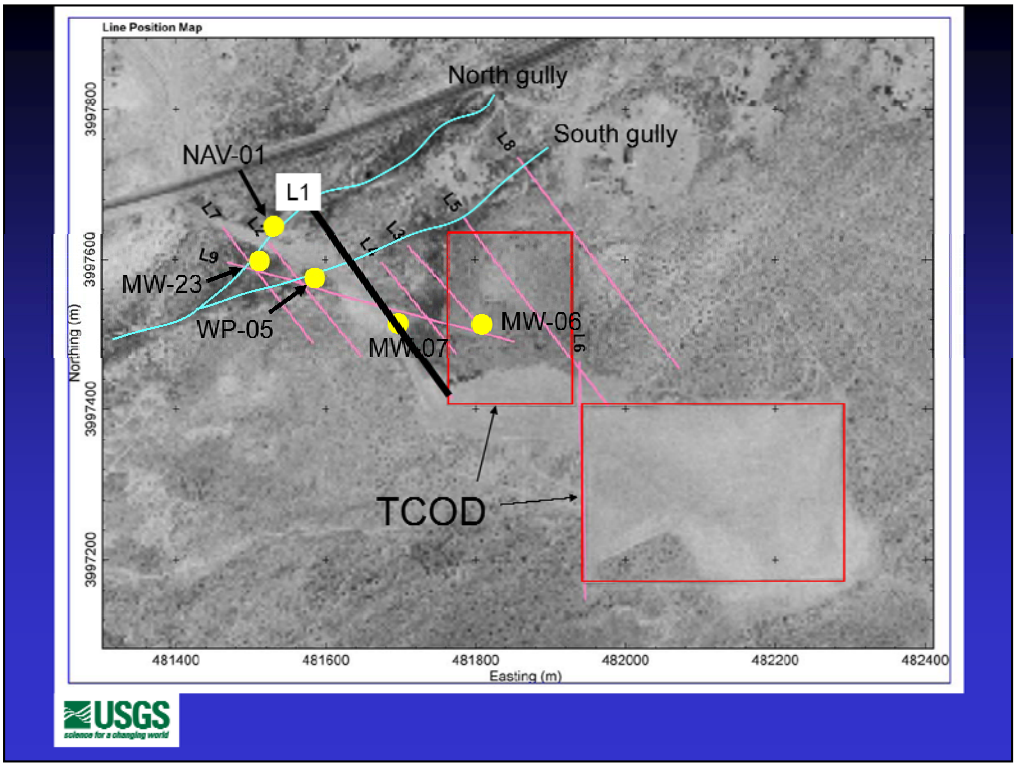
Water table elevations are in feet above mean sea level.



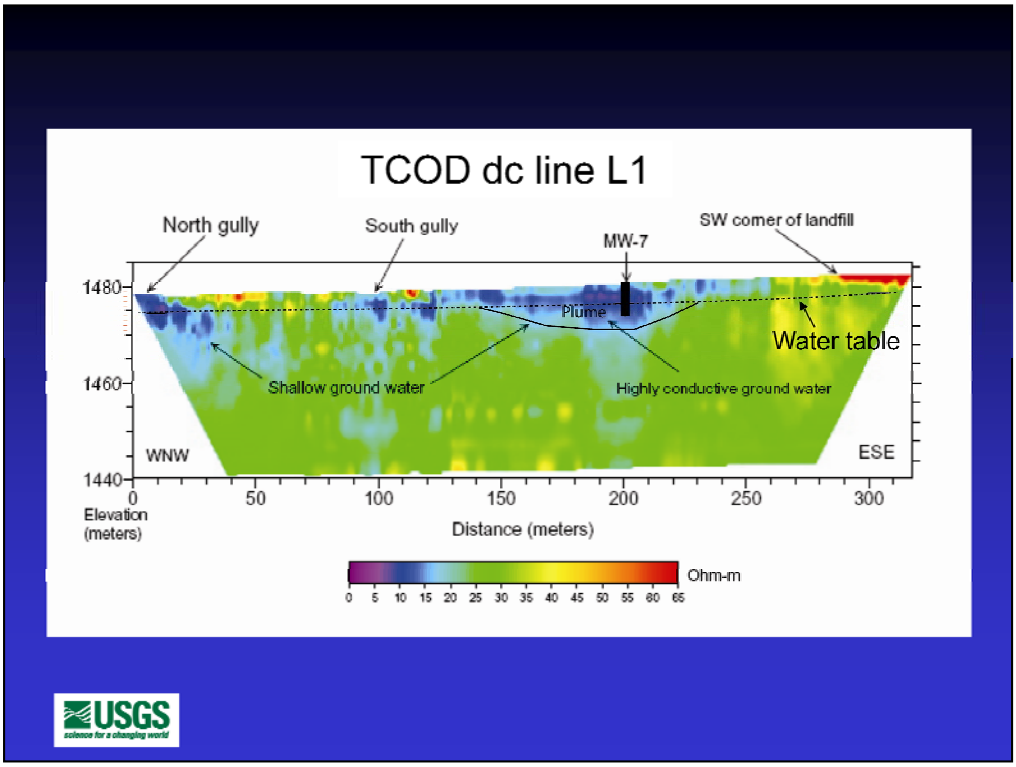
READ. Reminder of key conclusion/interpretation 2b.



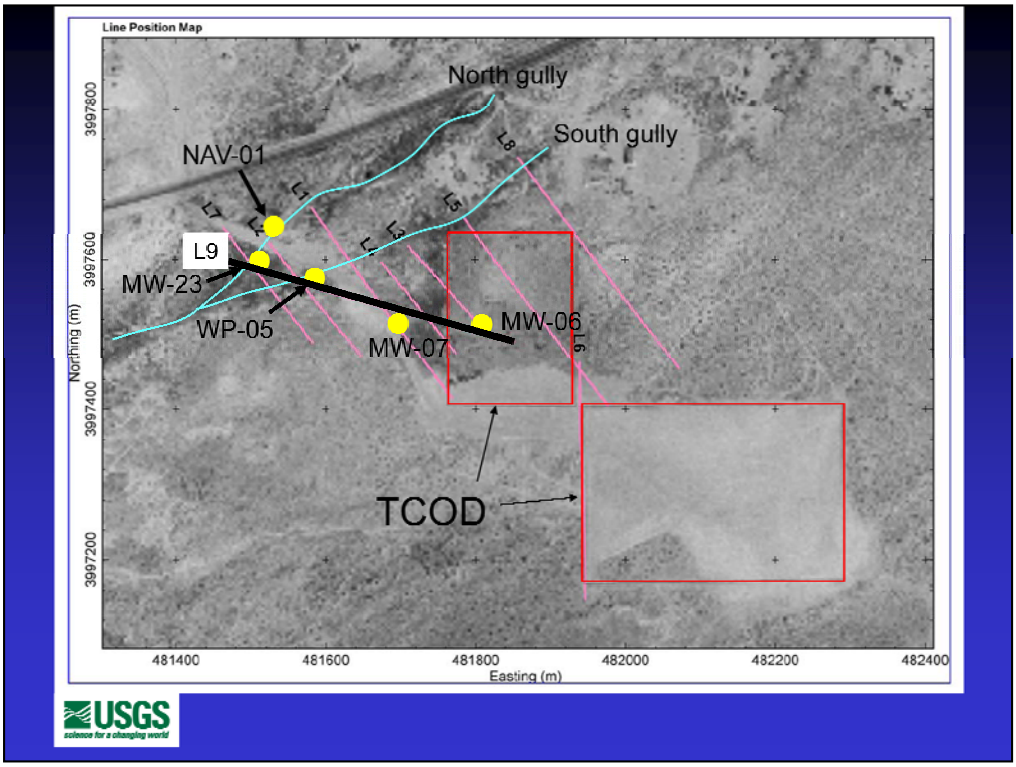
READ. uS/cm = microsiemens per centimeter.



Significant landmarks to see on dc (direct current) line L1 in next slide are north and south gully crossing, MW-07, and the edge of the old dump.

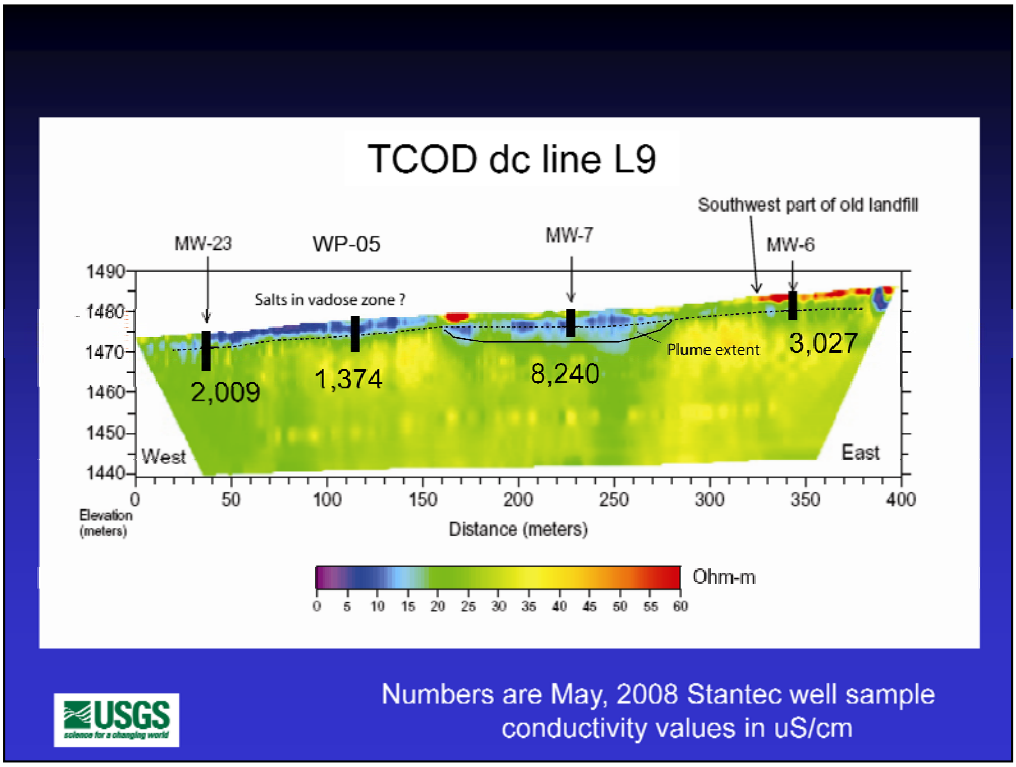


Well depth is drawn to scale. Plume is indicated by higher conductivity below the water table. Note that higher conductivity zones could indicate higher clay content (or general change in geology), but this was not noted in the well logs for MW-07.

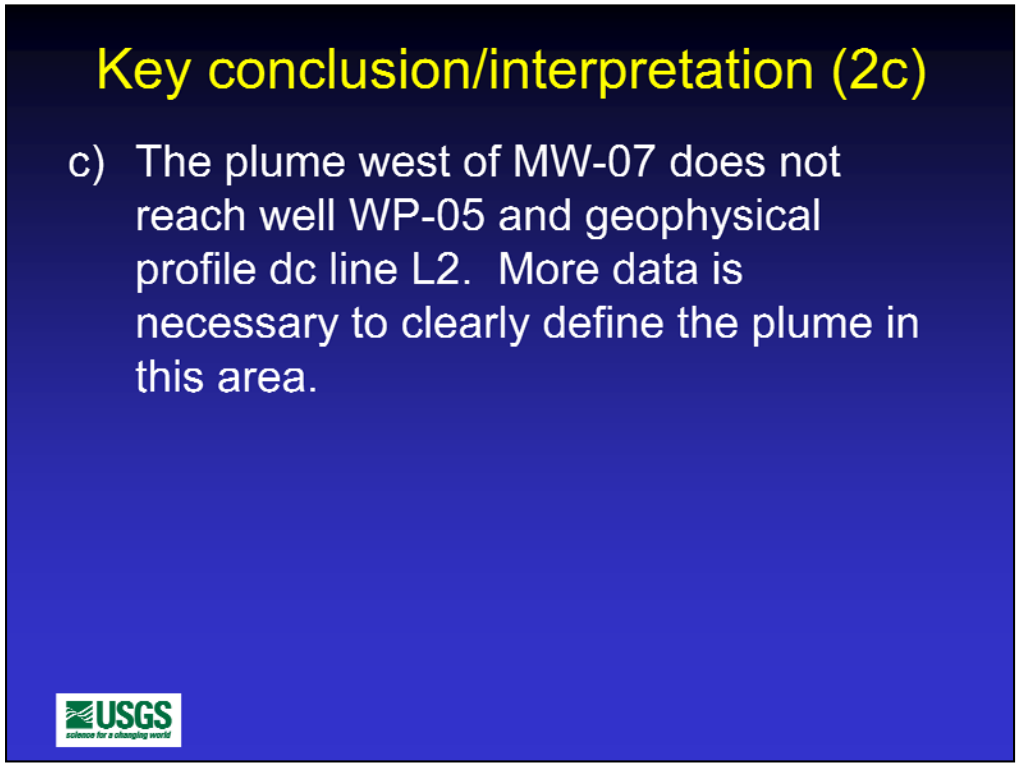


Significant landmarks to see on dc line L9 in next slide are north gully (at MW-23), south gully crossing (just before WP-05), MW-07, and the portion of the old dump.

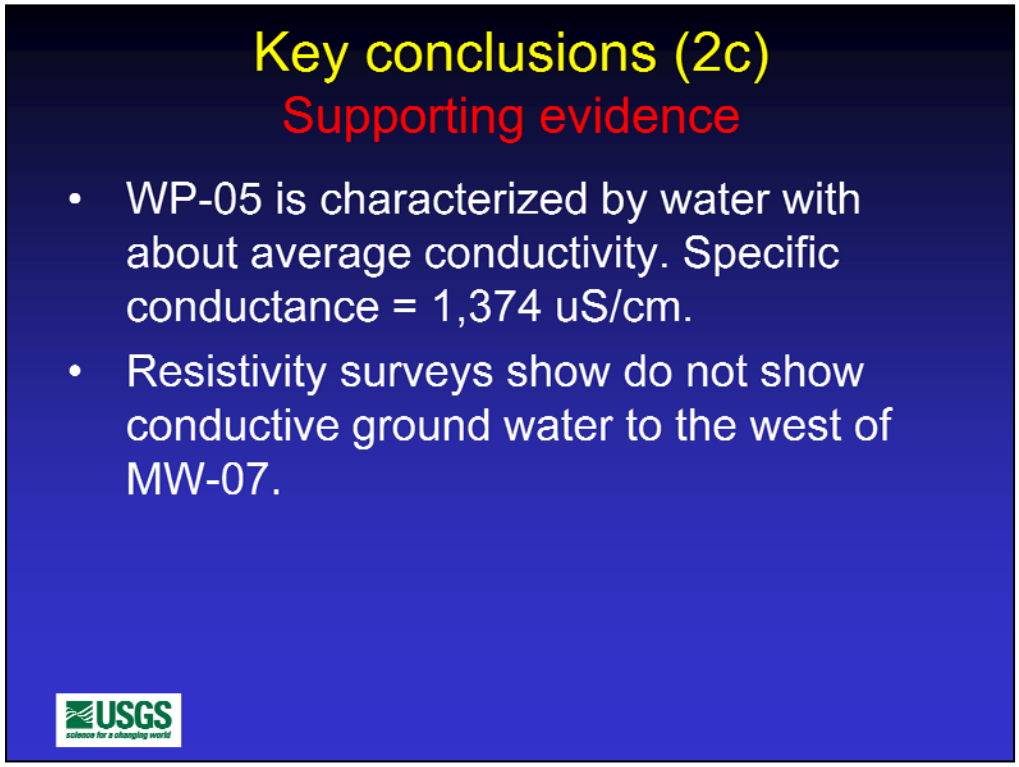
dc = direct current.



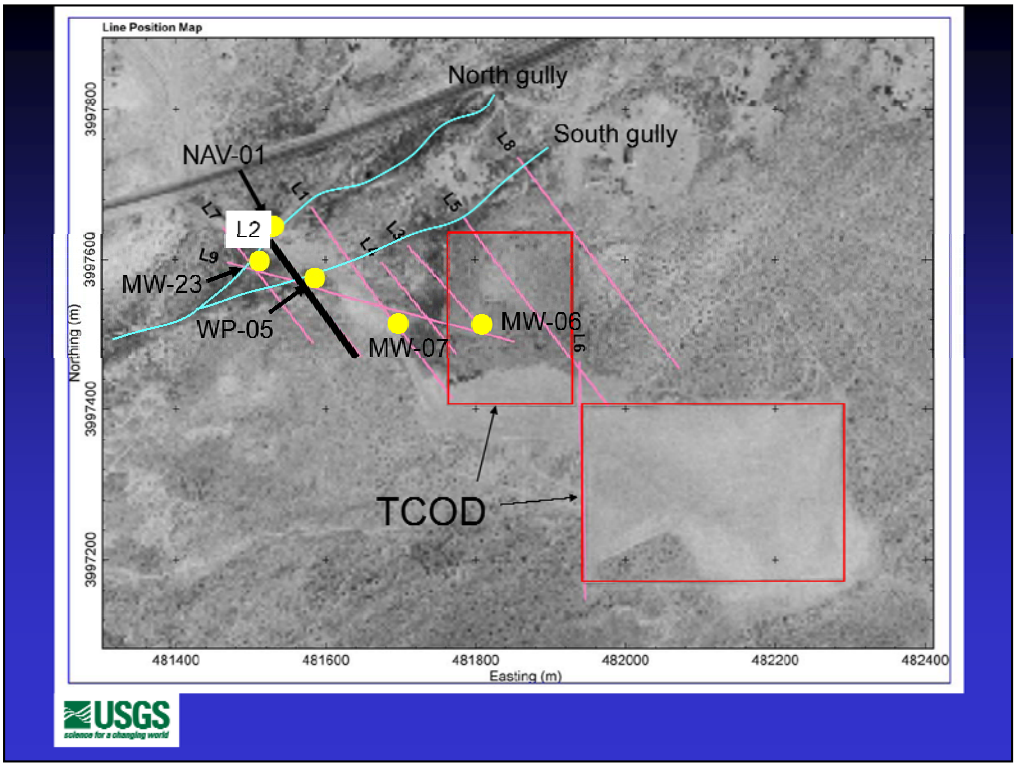
Well depth is drawn to scale.



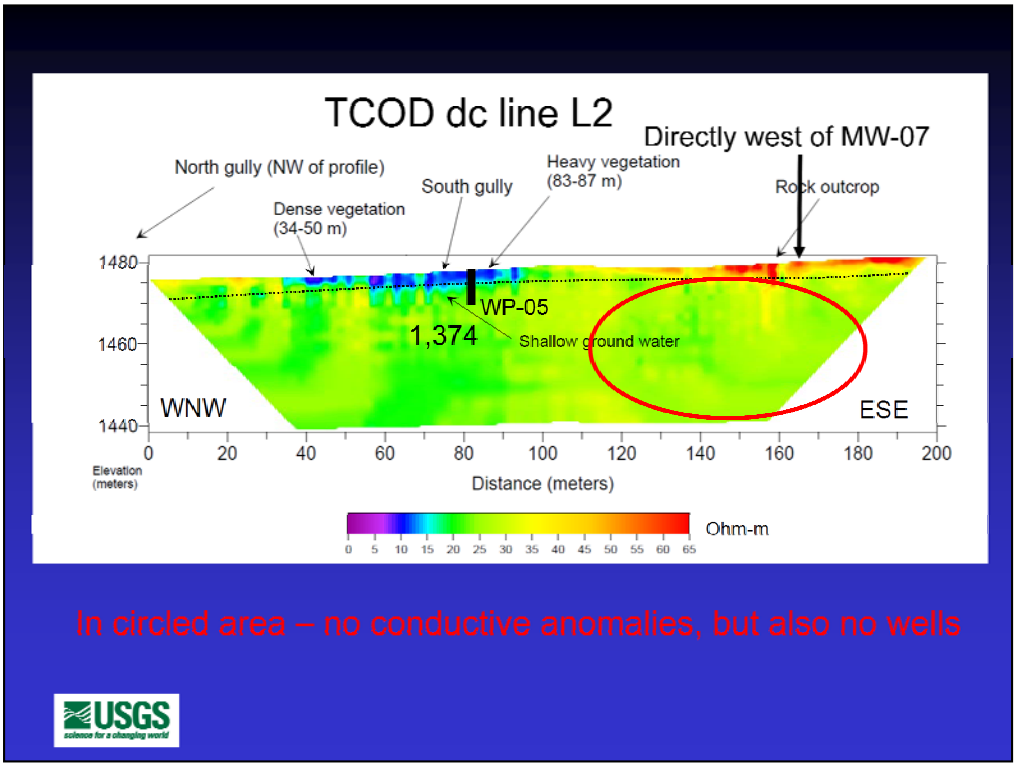
READ. Reminder of key conclusion/interpretation 2c.



READ. uS/cm = microsiemens per centimeter.

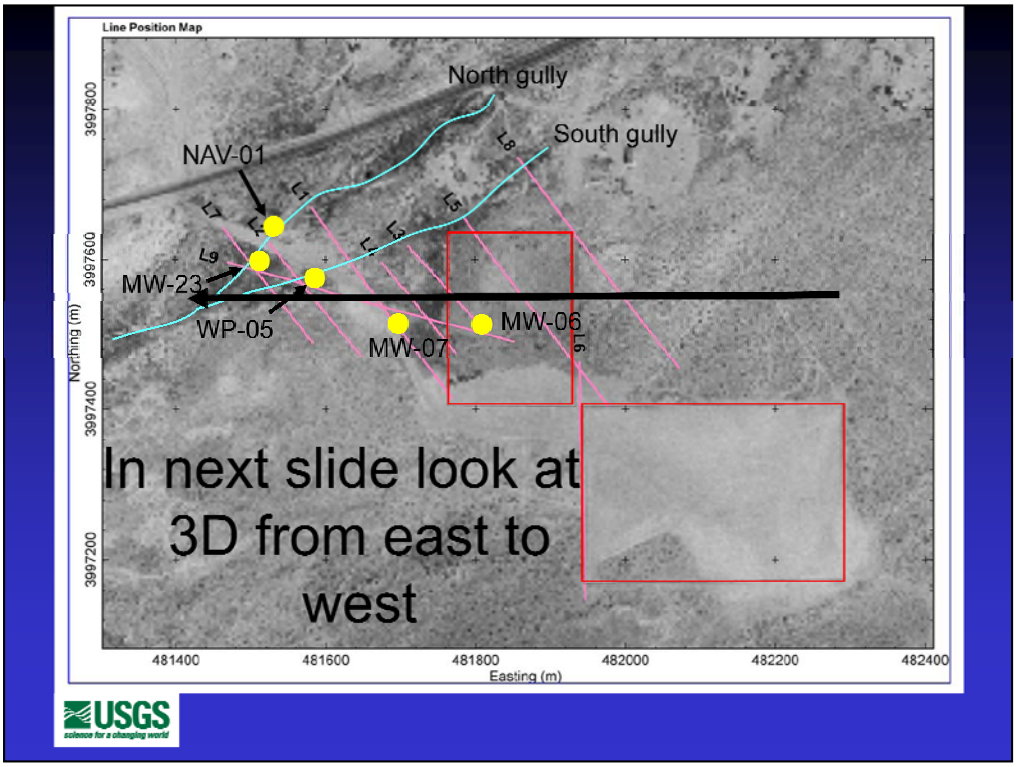


Significant landmarks to see on dc line L2 in next slide are north and south gully crossing, MW-07, and the edge of the old dump.



In circled area – no conductive anomalies, but also no wells

Well depth is drawn to scale.


Line Position Map
North gully
South gully
NAV-01
L1
L2
L3
L4
L5
L6
L7
L8
L9
MW-23
WP-05
MW-07
MW-06
In next slide look at 3D from east to west
Northing (m)
3997800
3997600
3997400
3997200
481400
481600
481800
482000
482200
482400
Easting (m)
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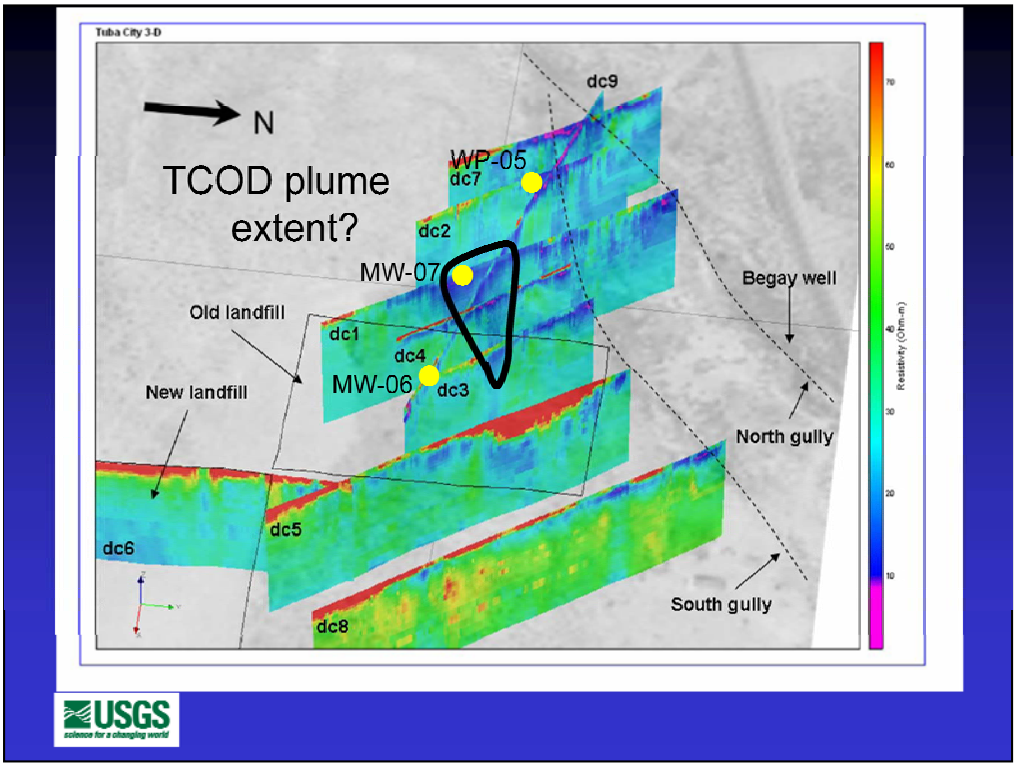
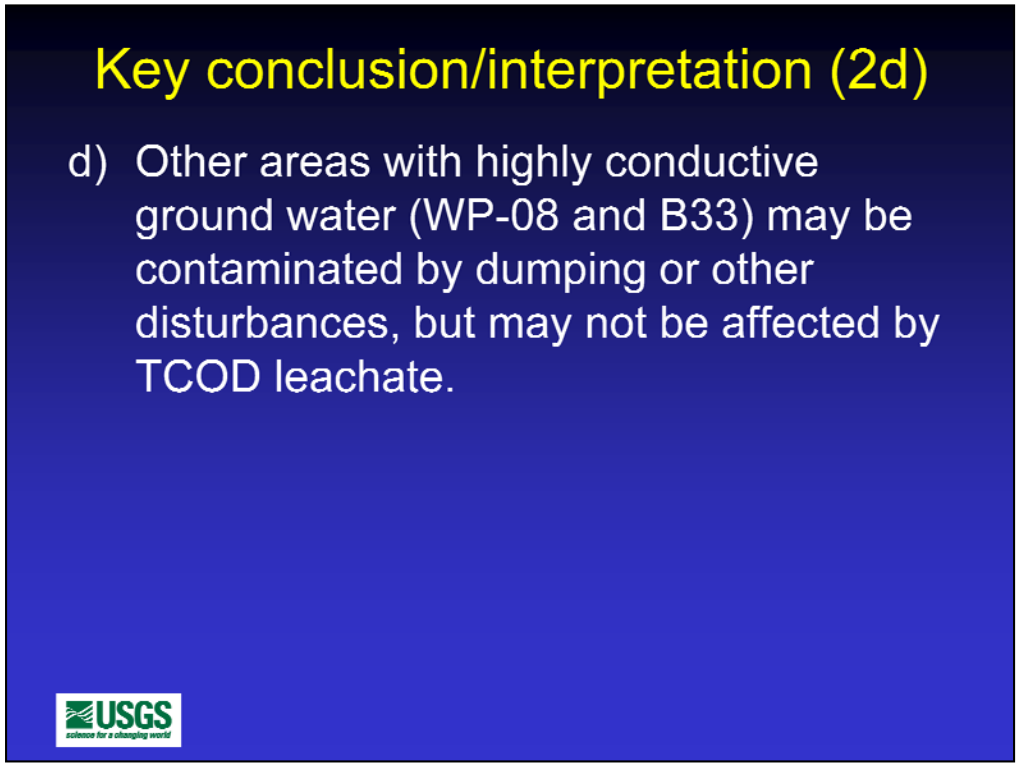


Note the labels on lines are slightly different. For example dc1 = L1 in other images.

Black outline = plume extent?

Key points on plume distribution

- Resistivity profiles and well data indicate areas of conductive ground water (contaminant plume emanating from the TCOD near MW-07).
- Area of affected ground water appears to be limited.



READ. Reminder of key conclusion/interpretation.

Key conclusion/interpretation (2d)

Supporting evidence

- Well WP-08 has a specific conductivity of 5,580 uS/cm.
- In the same area, piezometer TC08B33 also has highly conductive ground water at 4,460 uS/cm.
- Geophysical data shows some conductive ground waters in the gully areas
- Stantec will discuss ground-water quality in more detail.
- Tritium data

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Tritium

- Bomb pulse tritium can be used for age dating (tritium is only found in waters less than 60 years old).
- Exit signs and other tritiated wastes from the 1950s and later are also source possibilities.
- Excellent tracer because tritium is conservative and part of the water (for this discussion , the exact source of tritium in the dump does not matter).

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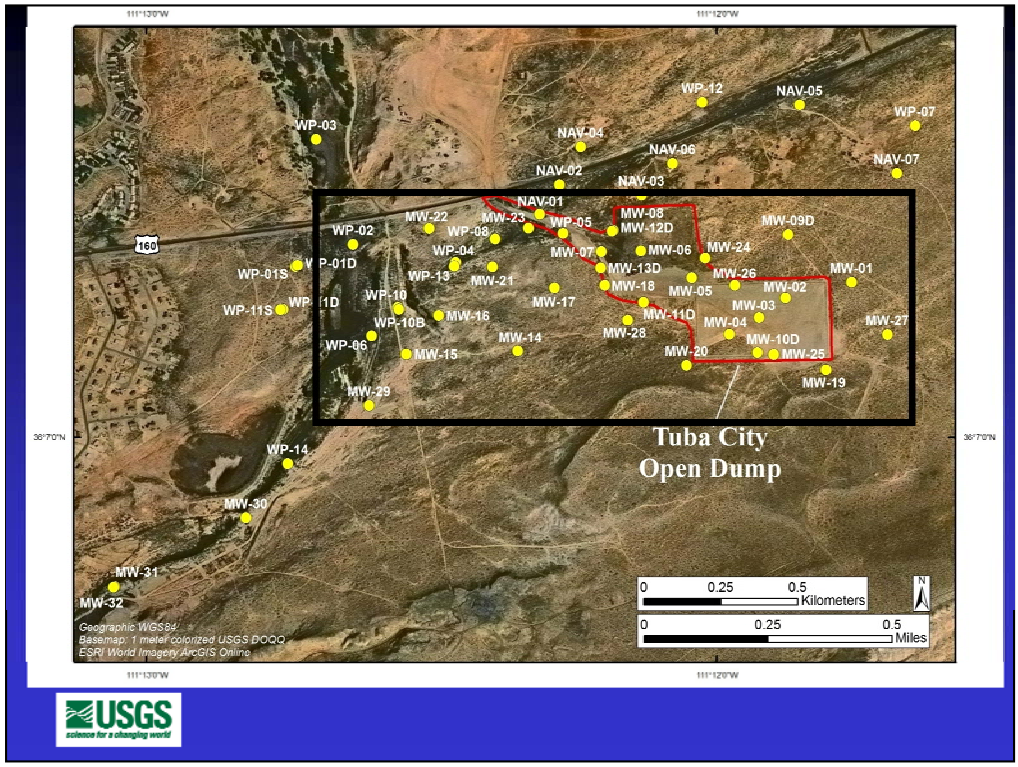
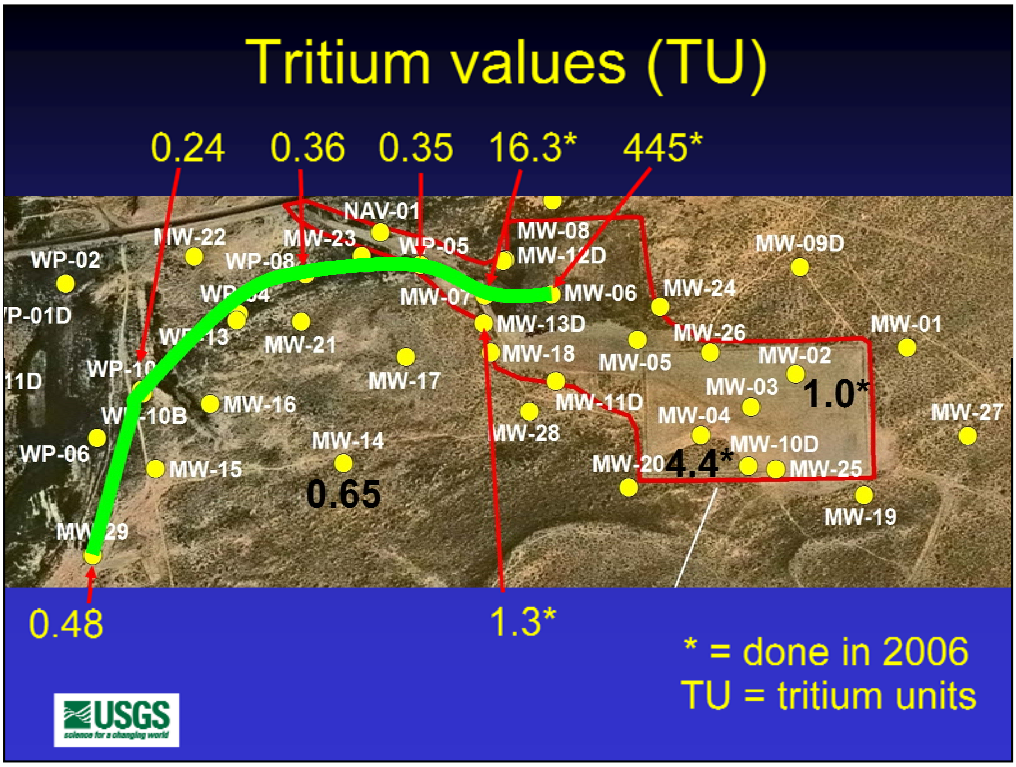


Black boundary indicates area zoomed into for next slide.



Green line indicates the idea of following a ground-water flow pathline downgradient from MW-06

Key points on plume distribution

- Areas down gradient from MW-07 have dissolved constituent levels above an apparent background (full statistical study has not been done).
- However, geophysical and well data do not show a continuous plume back to MW-07.
- No high tritium values past MW-07.

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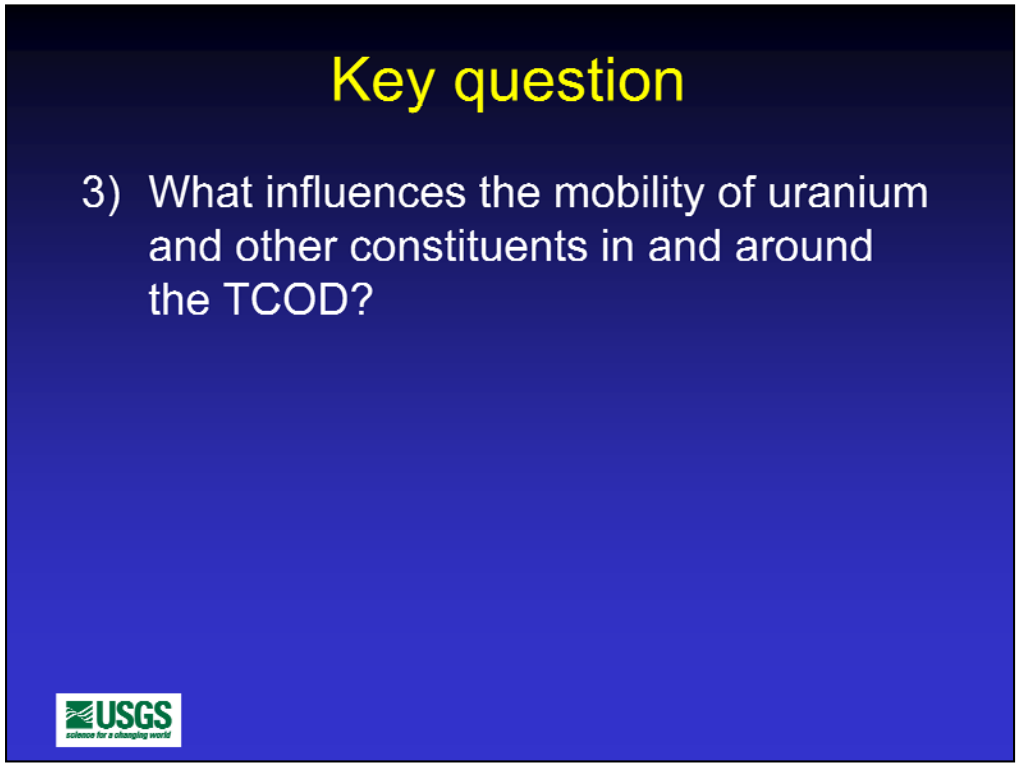

READ. Reminder of key question #3.

Key conclusions (3)

a) The mobility of uranium and other dissolved constituents can be influenced by complex solid/liquid geochemistry. Variable geochemical conditions occur in and around the TCOD.

b) The addition of water to the vadose zone can mobilize uranium and other constituents (irrigation, septic systems, ponding behind berms, extreme rain events, etc.) and the addition of lower pH waters to vadose zone solids can mobilize even more uranium.

c) The creation of the TCOD may have provided the necessary disturbances to mobilize vadose zone “salts” and create anomalously high levels of uranium and other elements in ground water.

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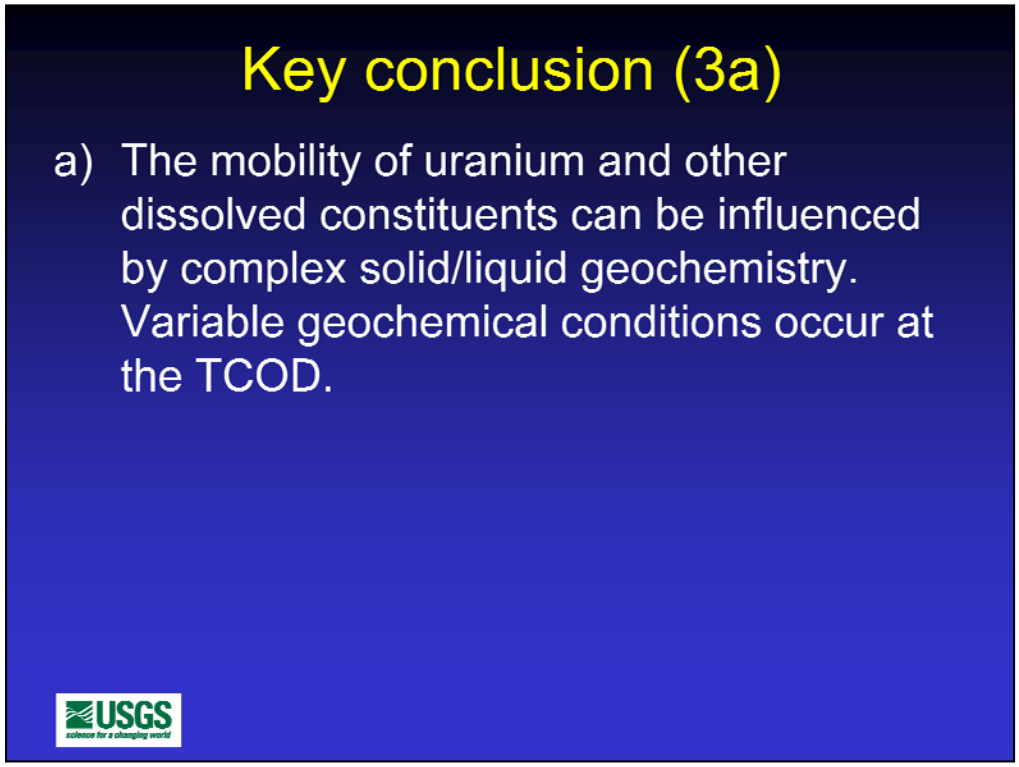

READ. Reminder of key conclusion 3a.

Key conclusion (3a)

Supporting evidence

- Uranium is readily adsorbed from oxygenated water by the iron coating on grains (lab study of TCOD samples).
- Some waters are less oxic and may cause iron coatings to dissolve into water, releasing trace metals (below the water table, bleaching of sediment is often seen).
- Less oxic waters also have the potential to precipitate uranium. Variable oxygen conditions do occur.
- Carbonate complexing of uranium in water is indicated by the correlation between dissolved uranium and alkalinity (main sources of carbonate include calcite in bedrock, caliche buildup in the vadose zone, TCOD leachate waters, septic system waters, and naturally occurring organics in Pasture Canyon).

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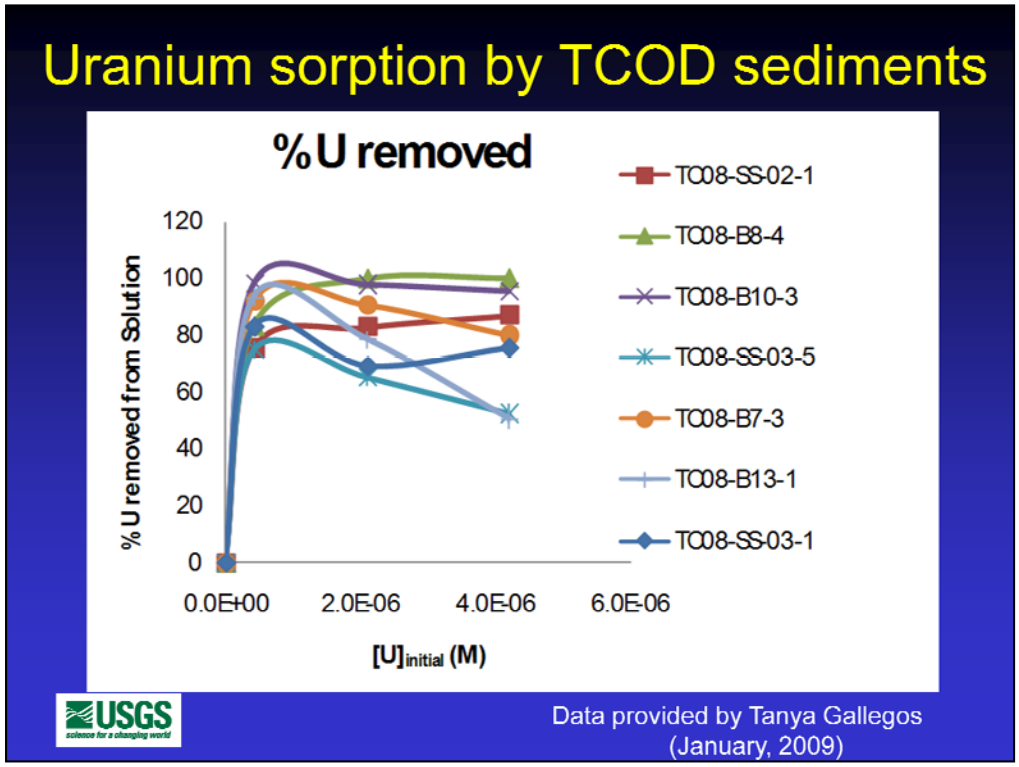

Uranium uptake by shallow sands at the TCOD is generally 60-100 percent, which suggests limited mobility for uranium.

Well	DO top (mg/L)	DO bottom (mg/L)
MW-02	0.39	0.33
MW-14	4.42	3.67
MW-27	6.64	7.03
MW-15	3.31	0.86
MW-16	3.59	0.58
NAV-04	0.56	0.47
MW-07	5.44	3.41

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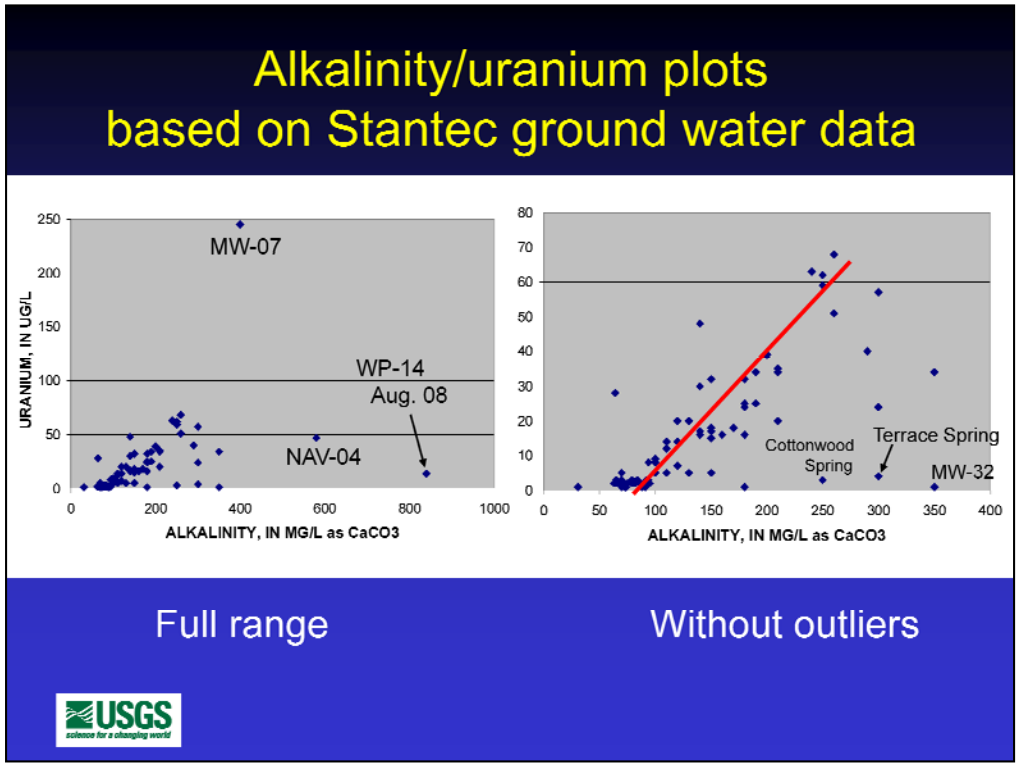
DO = dissolved oxygen

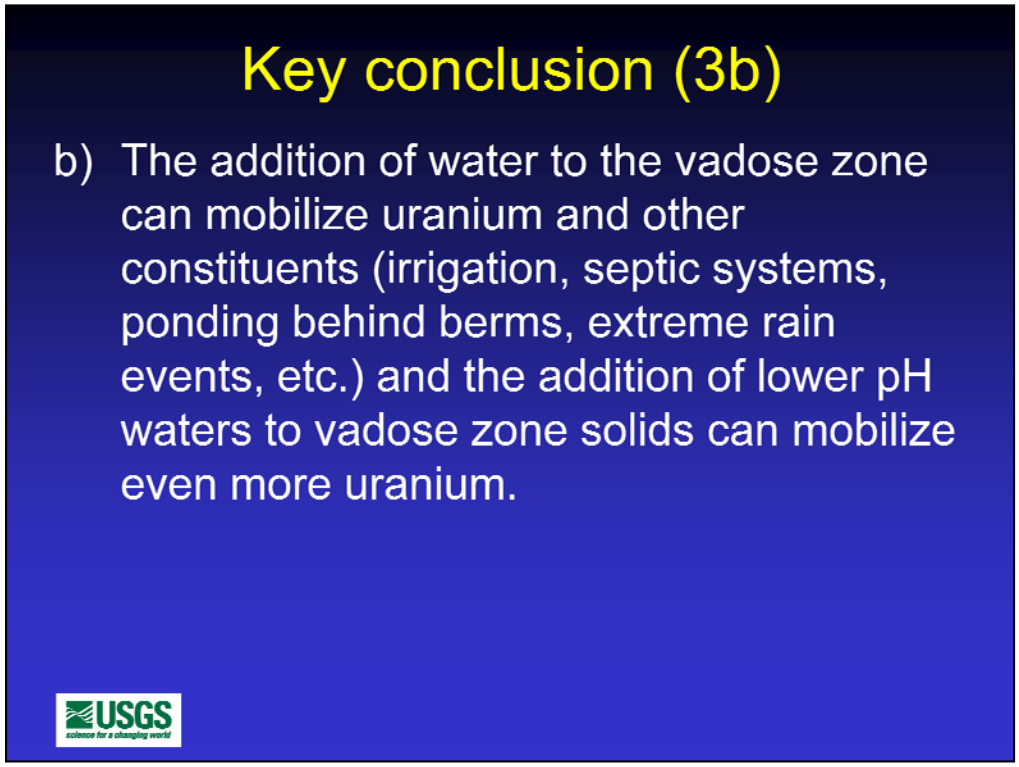
Example of variation in dissolved oxygen and some locations with low dissolved oxygen measurements. A fully DO saturated water would be approximately 8 mg/L. Low DO could produce dissolution of Fe coatings with release of any associated uranium.

Downhole field parameters

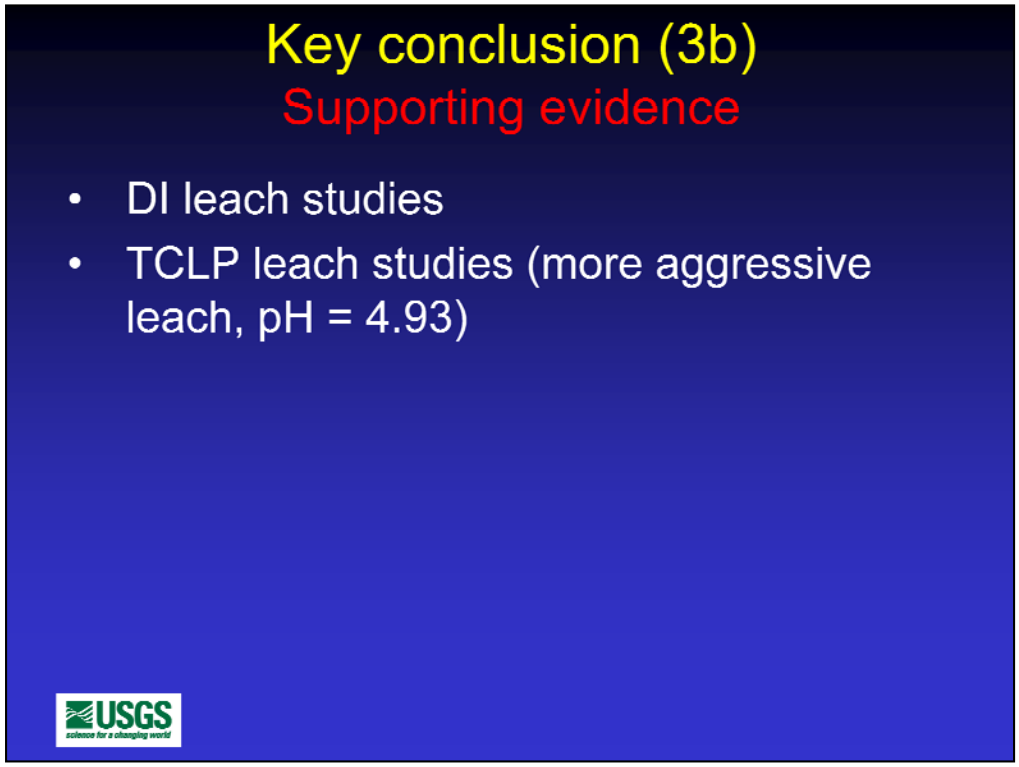
- MW-15 and MW-16 show the most significant changes in DO and conductivity with depth (organic carbon at depth on the edge of Pasture Canyon?).
- MW-07 shows some DO decrease at the very bottom and a definite trend of increasing conductivity with depth (is this well just at the top half of the landfill "plume"?).



Plots use all of Stantec's ground water sampling data in 2008 from all wells with both alkalinity and uranium values. This suggests the increased mobility of uranium when it is complexed as a carbonate-uranyl species.



Uranium and other constituents were initially concentrated by evapotranspiration and other processes discussed earlier.



TCLP leach is meant to simulate landfill leachate.

Unsaturated (vadose) zone

- The unsaturated zone appears to have areas of salt build up related to evapotranspiration.
- These “salt” zones are commonly found in arid environments and may have taken 100s to 1,000s of years to form.
- Anthropogenic disturbance of the unsaturated zone could mobilize these “salts” and associated trace elements.

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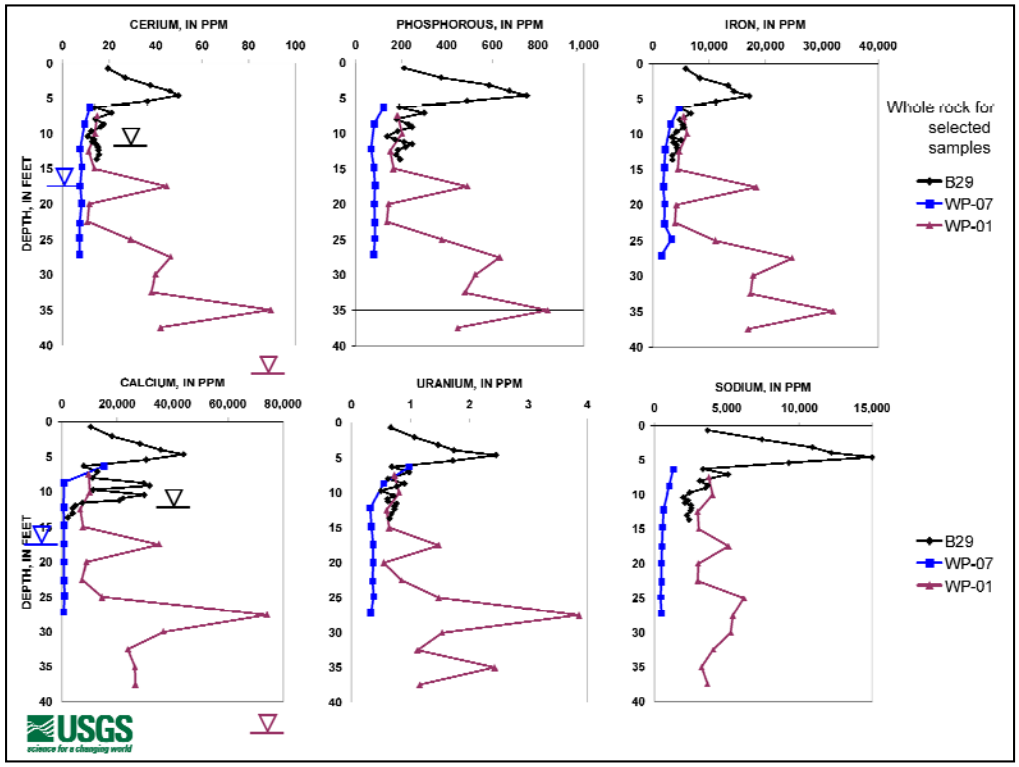

Most values for uranium are below crustal abundance (agrees with radiometric data). Main “salt” concentration zones occur above the water table. Navajo Sandstone in WP-07 is low in most all elements, especially below the water table. Water table for B29 = 12.5, WP-07 = 17.5, and WP-01 = 46.8 feet below ground surface.

B29 DI leach data

- Solid samples from USGS hand augering.
- In whole rock data, the high “salt” zone is at 4-5 feet in depth.
- 11.4 + feet of aeolian sand over Navajo Sandstone (bedrock interface is unclear).
- Water table is at 12.5 feet below ground surface (5/7/2008, Johnson and others, 2008).
- Ground water here is elevated in dissolved constituents.

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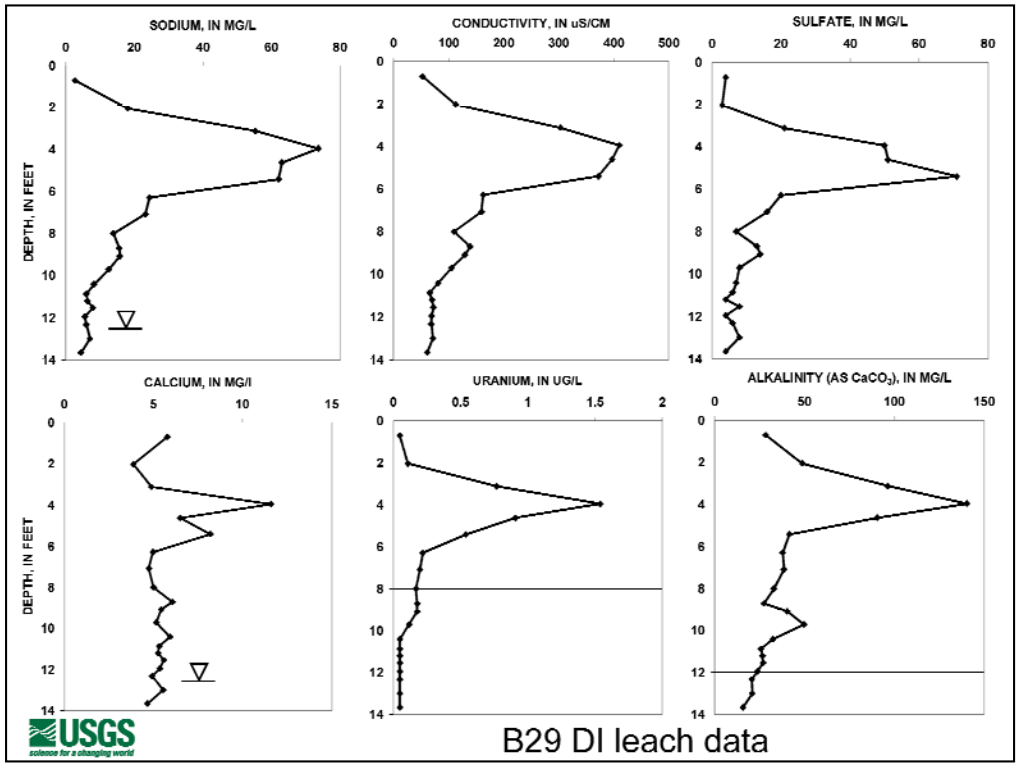

Here are some important details for interpreting the geochemical profiles:

Slight dampness first noted in the 32-43 inch interval (2.67 to 3.58 feet).

The 43-59 in interval (3.58 to 4.92 feet) is siltier than the intervals above and below. It is also pale red in color. There was no caliche observed.

Traces of soft, punky, calcite-cemented material from 103 to 112 inches (8.58 to 9.33 feet), possible older caliche zone now mostly gone (dissolved away?).

From the geochemical data it is apparent that “salts” are accumulating in the 36-60 inch (3 to 5 foot) interval where the silty zone occurs.

Almost no leachable U below 10 feet. This may represent systematic removal of uranium from the sediment in the zone where the water table fluctuates up and down. Evidence for this leaching in the geologic logging observations: above 10 feet, the sand is light to moderate red-orange except in the silty zone where it is pale red in color, and below ten feet, the sediment is mottled to streaky, light to moderate red-orange with mottles that vary in color including moderate yellow-brown, pale gray-orange, yellow-gray, gray orange-pink (some darker streaks of pale red also occur).

WP-07 DI leach data

- In whole rock data, the high “salt” zone is near the ground surface (<6 feet).
- Samples from Stantec drilling.
- 5 feet of aeolian sand over Navajo Sandstone.
- Water table is at 17.5 feet below ground surface (6/26/2008 – Stantec).
- Ground water has a moderate concentration of dissolved constituents.

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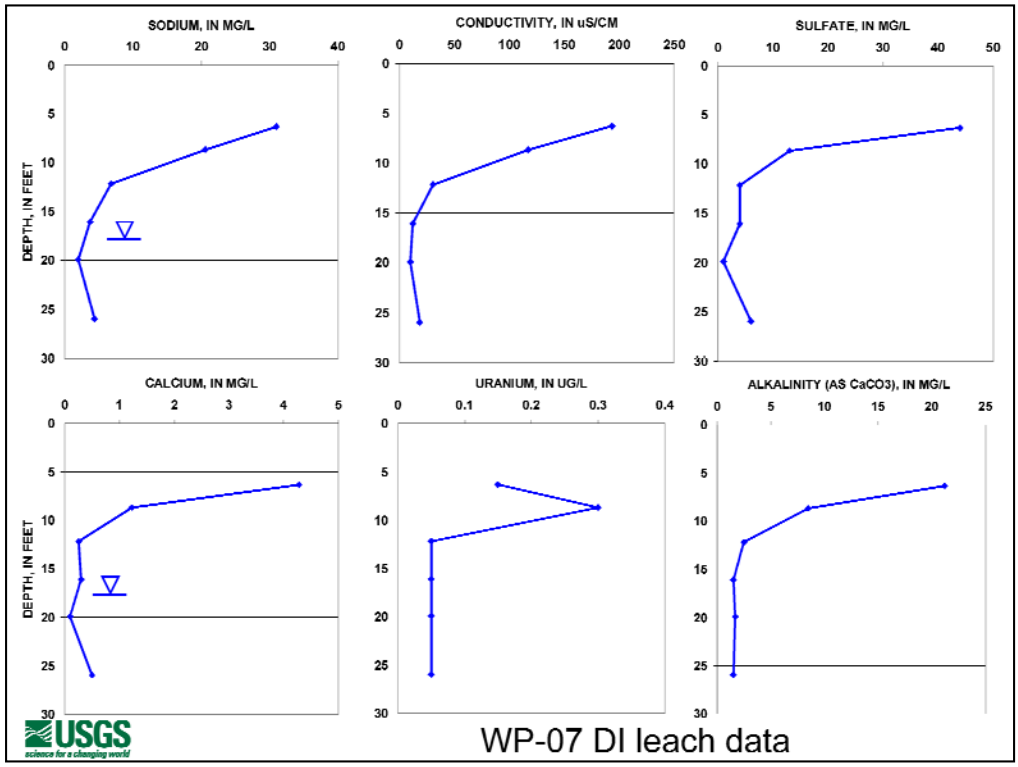
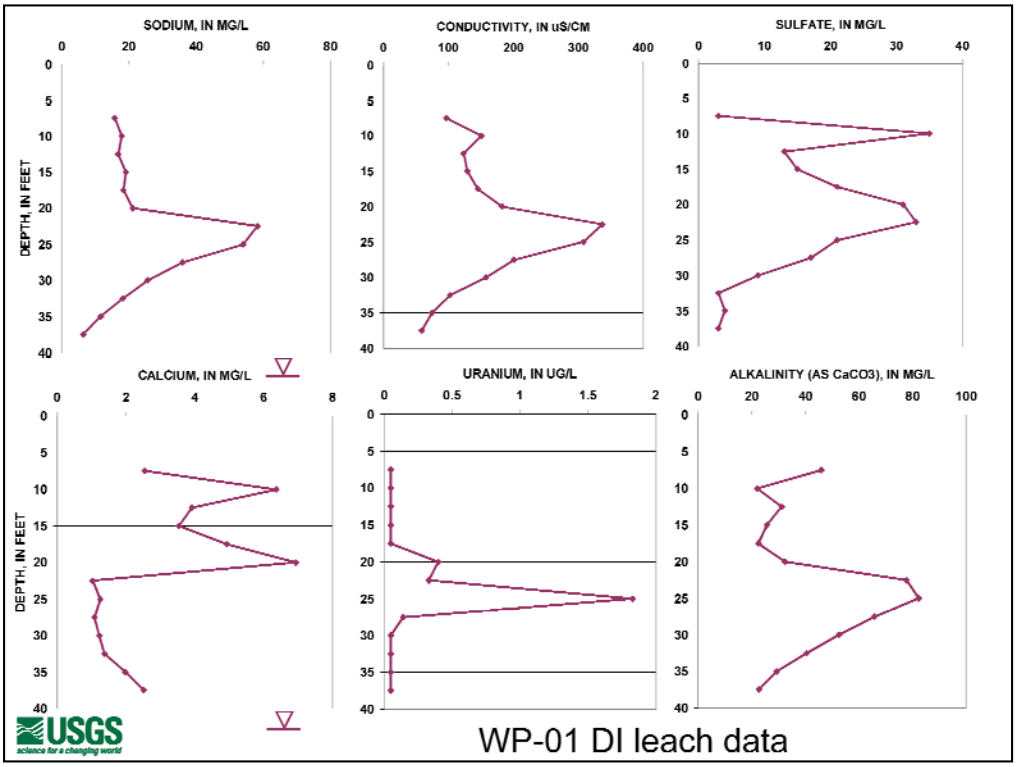


There is so little geologic detail here that there is a limited amount to say.

Caliche present from 6 feet to about 7 feet in the weathered bedrock. This appears to be the zone of salt and trace metal accumulation. Note that the detection limit for uranium was 0.1 ug/L. Samples below the detection limit are plotted as 0.05 ug/L.

WP-01 DI leach data

- In whole rock data, the high “salt” zones are at 15, 32, and 35 feet.
- Samples from Stantec drilling.
- 20 feet of aeolian sand over Kayenta Formation/Navajo Sandstone transition zone.
- Water table is at 46.8 feet below ground surface (6/26/2008 - Stantec).
- WP-01S well has elevated uranium, conductivity, and other constituents.



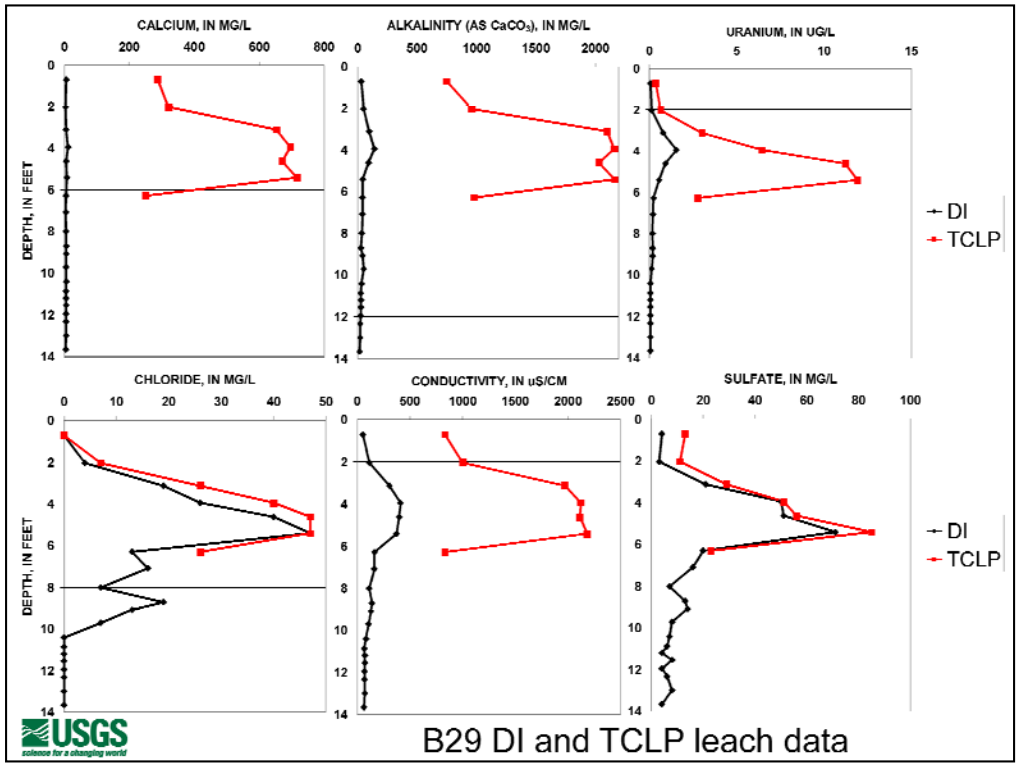
Note that the detection limit for uranium was 0.1 ug/L. Samples below the detection limit are plotted as 0.05 ug/L.

DI leach observations

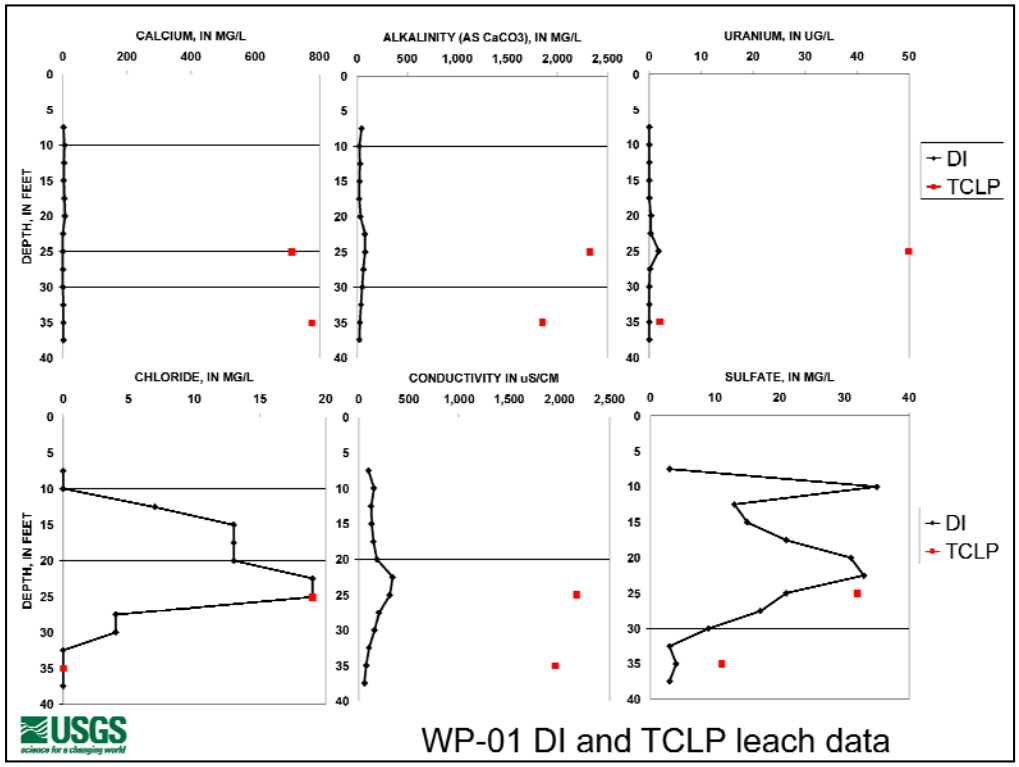
- In general, higher concentrations of “salts” in the whole rock data match higher concentrations in DI leach data.
- Zones with high calcium in the whole rock data do not always match with high calcium and alkalinity in the DI leach waters (not getting full dissolution of calcite?).

TCLP data

- Weak acetic acid buffered with sodium hydroxide (pH = 4.93).
- Simulates landfill leachate.



Note that chloride and sulfate for DI versus TCLP are not much different. Major difference is the increased calcium, alkalinity, conductivity, and uranium with the TCLP leach. Probably dissolves all of the calcite. Is uranium from the calcite and(or) iron oxide coatings? What is the influence of uranium complexes?



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TCLP observations/interpretations

- Chloride and sulfate concentrations for DI leach and TCLP are similar.
- Appears that the chloride and sulfate salts are easily water soluble.
- Most of the conductivity increase from TCLP is due to dissolution of “salts” that are less soluble (possibly calcite).
- Increased uranium solubility with TCLP may be associated with uranium/carbonate and(or) other complexing.

Additional TCLP observations

- TCLP (pH starts at 4.93) appears to leach more calcite than DI water (can use calcium and alkalinity as a proxy for calcite).
  - pH buffering up to 6.7 if enough calcite available.
  - Less calcite—pH stays lower (< 5.5).

Key conclusion (3c)

c) The creation of the TCOD may have provided the necessary disturbances to mobilize vadose zone “salts” and create anomalously high levels of uranium and other elements in ground water.

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Key conclusion (3c)
Supporting evidence

- Uranium isotope ratios
- Resistivity profiles and locations of conductive zones
- Whole rock evidence of higher uranium and other elements in the vadose zone
- Leachability of uranium and “salts” from the vadose zone (DI and TCLP)

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Possible influences of TCOD land disturbance

- Trenching the sand, trash deposition and burning, and covering trash with sand disturbed the “salt” zones.
- “Salt” zones could have potentially been placed below the water table (the TCOD area up gradient from MW-07 does have ground-water levels within the trash).
- Open trenches may have created localized recharge zones and possibly higher water tables during the TCOD operations.
- High rain events could have washed nearby shallow (previously dry) sands into the open trenches.

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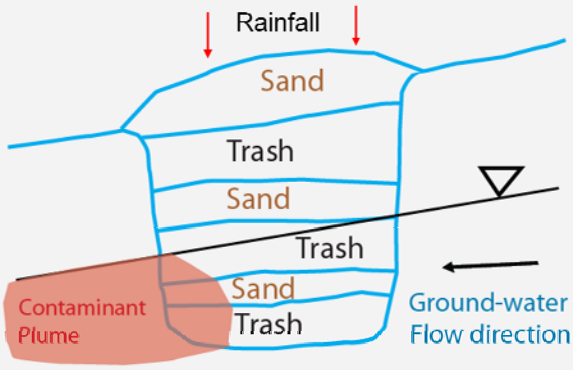
Possible result of TCOD land disturbance

- The TCOD land disturbances may have created a ground-water contaminant plume by creating conditions that could mobilize soluble constituents that were already present in the vadose zone and made even more soluble by landfill leachate.

Possible conceptual scenario



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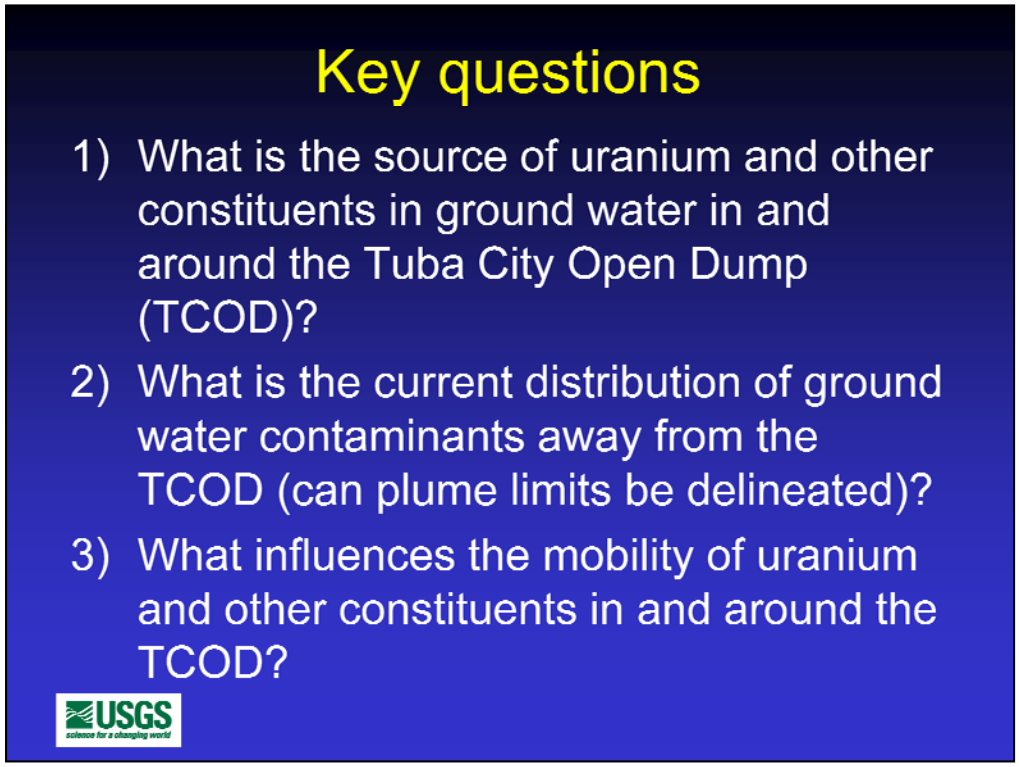

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This presentation has focused specifically on these questions. Other questions may be important, but are not the focus of this presentation.

Key conclusions (1)

a) Uranium and associated major and trace elements in and around the TCOD do not appear to be derived from the Navajo Sandstone or the Kayenta Formation.

b) Uranium and associated major and trace elements are emplaced, concentrated, and stored in the vadose zone through windblown deposition from upwind sources (such as the Chinle Formation) and evapotranspiration.

c) These constituents are locally transferred to the shallow ground water by natural processes and human disturbance throughout the area.

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Key conclusions/interpretations (2)

a) Focus on MW-07 area within a contaminant plume. Water table elevations indicate a westward migration for ground water.

b) Ground water at MW-07 is characterized by high specific conductance from well sampling and high conductivity ground water in geophysical profiles.

c) The plume west of MW-07 does not reach well WP-05 and geophysical profile dc line L2. More data is necessary to clearly define the plume in this area.

d) Other areas with highly conductive ground water (WP-08 and B33) may be contaminated by dumping or other disturbances, but may not be affected by TCOD leachate.

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Key conclusions (3)

a) The mobility of uranium and other dissolved constituents can be influenced by complex solid/liquid geochemistry. Variable geochemical conditions occur in and around the TCOD.

b) The addition of water to the vadose zone can mobilize uranium and other constituents (irrigation, septic systems, ponding behind berms, extreme rain events, etc.) and the addition of lower pH waters to vadose zone solids can mobilize even more uranium.

c) The creation of the TCOD may have provided the necessary disturbances to mobilize vadose zone “salts” and create anomalously high levels of uranium and other elements in ground water.

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Questions ?

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