THREE-DIMENSIONAL ARCHITECTURE OF BEDROCK LITHOLOGY, WEATHERING, AND PRODUCED WATER MOVEMENT AT THE USGS OSAGE SKIATOOK PETROLEUM ENVIRONMENTAL RESEARCH (OSPER) SITE A, NORTHEAST OKLAHOMA

James K. Otton*
Robert A. Zielinski
U.S. Geological Survey
MS 939 Box 25046
Lakewood, CO 80225
Voice: 303-236-8020
Fax: 303-236-0459
E-mail: jkotton@usgs.gov

Drillcore description and analysis of aqueous extracts of core samples from the USGS' OSPER Site A provide a three-dimensional view of the complex sequence of variably weathered Pennsylvanian sandstone, mudstone, and shale beds, and the movement of saline produced water through them. Aqueous extracts of core samples show that Cl-rich salts extend north and west from two pits that are the primary source for Cl-rich produced water releases at the site. Saline rock extends for a distance of at least 125 meters and to depths of as much as 13 meters. Surface releases of produced water from the pits initially followed the surface topography to the north and west and more permeable zones and channels in the local colluvium to the northwest and west (Otton and others, IPEC, 2003), but releases from the pits also directly entered or moved down into the underlying bedrock. Immediately underlying the two pits, a sheet-like sandstone up to 5 m thick forms the local bedrock. This sandstone dips gently (about 1°) to the west-northwest and is underlain by 2-3 m of mudstone and shale that, in turn, are underlain by a second sandstone 5-8 m thick, second mudstone-shale 2-4 m thick, and third sandstone sequence not fully penetrated. The upper sandstone is intensely weathered as indicated by its friable character and heavy iron-staining, and was probably a favored conduit for movement of produced waters. Shale and mudstone directly below the upper sandstone also contain Cl-rich salts indicating that permeability of these finer-grained rocks was sufficient to allow produced water infiltration. The second sandstone is variably weathered and variably contaminated by salt suggesting that produced water migrated into it locally. Deeper, unweathered, dolomite-cemented sandstone and mudstone, identified by their generally gray color and hard, dense character in core specimens, are generally devoid of salt and were apparently sufficiently impermeable to be the limiting factor for downward salt penetration at the site.

HYDROLOGY AND SUBSURFACE TRANSPORT OF OIL-FIELD BRINE AT THE OSAGE-SKIATOOK PETROLEUM ENVIRONMENTAL RESEARCH "A" SITE, OKLAHOMA

William N. Herkelrath*
Yousif K. Kharaka
U.S. Geological Survey
345 Middlefield Road, MS 496
Menlo Park, CA 94025
Voice: 650-329-4625
Fax: 650-329-5590
E-mail: wnherkel@usgs.gov

As a part of a multidisciplinary study of the impact of oil wells and oil production on the environment, we are investigating the hydrology of the depleted OSPER "A" site, which is located at Skiatook Lake in Osage County, Oklahoma. Contamination of soil, ground water, and surface water at this site from crude oil and brine produced from oil wells is extensive today, over 60 years after oil production ceased. We drilled 44 wells at the site for ground-water sampling and hydraulic testing. Cores from the well bores indicate there are relatively thin (<2 m thick) permeable sandstone beds separated by thicker shale and mudstone confining units. Water samples from the wells indicate there is an extensive subsurface plume of salt water (2,000-30,000 mg/L TDS) down slope from the former oil and brine handling facilities. Continuous water pressure monitoring indicates well water levels respond rapidly to changes in barometric pressure, and the wells have high barometric efficiency. There is little response to rainfall, suggesting recharge is slow. Slug tests run on the wells indicate the hydraulic conductivity of the permeable sandstone units is only about 1 cm/day. These results are consistent with the conceptual model that the brine is present in relatively low permeability, confined sandstone beds. We hypothesize that when oil production was active, a large volume of brine infiltrated from storage ponds and channels located on top of the sandstone, and moved down slope in the sandstone beds. Once the source was removed, recharge and flow through the salt plume zone was greatly reduced, effectively trapping the salt water in the subsurface. At the present slow rate of flow, we expect the brine plume will exist for many years, and continued environmental damage at discharge points is anticipated.

REMOVAL OF CONTAMINANT SALT FROM A DEPLETED PETROLEUM FIELD BY RUNOFF: RESULTS FROM THE OSPER "A" SITE, OSAGE COUNTY, OKLAHOMA

James Thordsen*
Yousif K. Kharaka
Evangelos Kakouros
U. S. Geological Survey
MS-427
345 Middlefield Rd.
Menlo Park, CA 94025
Voice: 650-329-4557
Fax: 650-329-4538
E-mail: jthordsn@usgs.gov

A multidisciplinary group of ~20 scientists are investigating the transport, fate, natural attenuation and ecosystem impacts of inorganic salts, organic compounds and radionuclides present in releases of produced water and associated hydrocarbons at the Osage-Skiatook Petroleum Environmental Research (OSPER) sites, located in Osage County, Oklahoma. Results from repeated sampling of 44 wells from the depleted OSPER "A" site show that the contaminant salts have been leached from the soil and surficial rocks, but that a plume of high salinity groundwater (2,000-30,000 mg/L TDS) with BTEX and other VOCs, extending beyond the 1.2 hectare visibly impacted area is present at intermediate depths. This plume intersects the surface at the lower, steeper, more heavily salt-impacted northern portion, which has been eroded to depths of as much as 2 m. It also intersects the adjacent Skiatook Lake, a 4250-hectare reservoir that provides drinking water to the local communities and is a major recreational fishery.

A weir and an automated precipitation gauge were installed close to the Skiatook Lake to investigate the natural overland transport of salts from this site by measuring the volume and chemical composition of surface runoff from precipitation events draining a 1.7-hectare area. Results to date show that the initial runoff that leaches the previously precipitated surficial salts can have a relatively high salinity (up to 3,000 mg/L TDS), but that only small amounts of total salts are removed by this process. This result supports the conclusion that large amounts of salts from produced-water and petroleum releases still remain in the rocks of the impacted area after more than 65 years of natural attenuation.

HYPERSPECTRAL SIGNATURE OF THE SALT SCAR AND OTHER OILFIELD DISTURBED AREAS AT USGS OSAGE-SKIATOOK PETROLEUM ENVIRONMENTAL RESEARCH (OSPER) SITE A, NORTHEAST OKLAHOMA - A PRELIMINARY REPORT

James K. Otton*
U.S. Geological Survey
MS 939 Box 25046
Lakewood, CO 80225
Voice: 303-236-8020
Fax: 303-236-0459
E-mail: jkotton@usgs.gov

David B. Reister
Oak Ridge National Laboratory
Oak Ridge, TN

On October 12, 2003, selected areas of Osage County, including the USGS' OSPER site A, were surveyed with an airborne, 126-channel spectrometer for wavelengths from 450-2500 microns under a DOE-funded contract to Oak Ridge National Laboratory (ORNL). The survey was designed to characterize areas disturbed by oil production to determine if remote-sensing data can be used to map such disturbance and its intensity. The survey was flown at a nominal altitude of 1400 m with a 3-m ground resolution. Site A is an abandoned oil production site active from about 1913-1973. The site consists of variably vegetated open areas in oak trees. A partly revegetated salt scar about 0.2 hectares in size has formed in the north part of the 1.5 hectare site downslope from two production pits. Other smaller salt scars are present elsewhere. At the time of the flight, adjacent Skiatook Lake was down about 1.5 m from its normal pool elevation exposing lake bottom sediments along the lake margin.

The 23,100 pixels at Site A have been classified using a new clustering algorithm developed at ORNL. Many distinct root pixels were found. The members of a cluster related to a root pixel are all of the pixels with a spectral correlation coefficient above a specified limit. Varying the cluster correlation limit from 99% to 99.6% controls the number of clusters that are generated. These pixel clusters have been mapped using distinct colors. The resulting cluster map can be related to features on the ground, including salt scars, roads, pits, exposed lake bottom, other disturbed areas of varying vegetation type and density (mostly grasses and forbs), and little-disturbed oak forest. For the 99% case, the method found 46 clusters for Site A; the cluster with the most members corresponding to the dense oak forest. Based on ground mapping and aerial photos, a salt scar area was defined that contains 261 3x3 m pixels. Two clusters, containing 18 pixels uniquely associated with the salt scar, are located in the core area of the scar, which is nearly devoid of vegetation. Other clusters occur on the scar but they also occur elsewhere including lightly vegetated areas on the exposed lake bottom, an area adjacent to the nearby recently active tank battery, old well sites and associated drill pads, and roads, and lightly vegetated natural areas where thin sandy soils occur over shallow sandstone bedrock. For the 99.6% case, the method found 100 clusters for Site A. The number of clusters uniquely associated with the salt scar increases from 2 to 3 but the total number of unique pixels found on the salt scar decreases from 18 to 9. However, the number of clusters where more than half the pixels occur on the salt scar increases from 2 to 10 with 54 pixels occurring on the salt scar. At either level of analysis, the method provides a unique signature for only a small part of the salt scar, however the 100 cluster case provides greater discrimination. The signature of most of the partly revegetated salt scar is thus similar to other oilfield disturbed areas at Site A and to the exposed lake bottom. The degree of correlation between the dominant cluster (the oak tree canopy) and all other pixel clusters was calculated and the degree of correlation mapped to show the relative intensity of site disturbance.

CONDUCTIVITY DEPTH IMAGING OF AREAS OF SHALLOW BRINE PLUMES AT THE USGS OSPER SITE, OSAGE CO. OKLAHOMA

Bruce D Smith*
James K. Otton
Robert A. Zielinski
U.S. Geological Survey
PO Box 25046, MS973
Denver Federal Center
Denver, CO 80225
Voice: 303-236-1399
Fax: 303-236-3200
E-mail: bsmith@usgs.gov

Marvin M. Abbott
U.S. Geological Survey
Okalahoma City, OK

Hoaping Huang
Geophex
Raleigh, NC

Alan J. Witten
University of Oklahoma
Norman OK

Ground based electrical conductivity and resistivity geophysical surveys and borehole geophysical logging were done at the two OSPER (Osage-Skiatook Petroleum Environmental Research) sites from October 2000 through August 2004. The geophysical surveys map areas of very high subsurface electrical conductivity caused by high concentration of subsurface chloride-rich water. The apparent conductivity maps were used to guide drilling and sampling of the site. Borehole natural total gamma ray and electrical induction conductivity logs of shallow project drill holes help constrain the interpretation of the ground geophysical surveys. Borehole conductivity logs and laboratory measurements of extractable chloride in core samples were used to derive a correlation function between chloride content and electrical conductivity. In addition, borehole conductivity logs were used to calibrate ground conductivity survey measurements as a function of frequency. Images of subsurface conductivity can be used to map the subsurface extent of plumes and to estimate the possible volume of chloride.

3

IMPACTS OF PETROLEUM PRODUCTION ON GROUND AND SURFACE WATERS: RESULTS FROM THE OSPER "B" SITE, OSAGE COUNTY, OKLAHOMA

Yousif Kharaka*
Gil Ambats
U. S. Geological Survey
Mail stop-427
345, Middlefield Rd.
Menlo Park, CA 94025
Voice: 650-329-4535
Fax: 650-329-4538
E-mail: ykharaka@usgs.gov

Marvin M. Abbott
U. S. Geological Survey
Oklahoma City, OK 73116

We are involved in a multidisciplinary investigation to study the transport, fate, natural attenuation and ecosystem impacts of inorganic salts, organic compounds and radionuclides present in releases of produced water and associated hydrocarbons at the Osage-Skiatook Petroleum Environmental Research (OSPER) "A" (depleted) and "B" (active) sites, located in Osage County, Oklahoma. About 1.0 hectare of land at the OSPER "B" site is affected by salt scarring, soil salinization and brine and petroleum contamination due to the leakage of produced water and associated hydrocarbons from brine pits and accidental releases from active and inactive tank batteries. Geochemical data collected from nearby oil wells show that the produced water source is a Na-Ca-Cl brine (~150,000 mg/L TDS), with high concentrations of Mg and Sr, but low SO_4.

More than 100 water samples have been obtained from OSPER "B" site; from the two brine pits, several brine pools and seeps, local streams, Skiatook Lake, and from 40 boreholes (1-71 m deep), recently drilled and completed. Results show diluted brine (up to ~25,000 mg/L TDS) and minor amounts of oil flow from the brine pits through the shallow eolian sand, colluvial and alluvial deposits towards the Skiatook Lake, a 4250-hectare reservoir that provides drinking water to the local communities and is used as a recreational fishery. Preliminary results from four relatively deep wells completed in May 2004 clearly show that produced-water brine and minor oil have penetrated the thick (3.5-6 m) shale unit and contaminated the underlying aquifers. The chemical composition of released brine is modified by sorption, mineral precipitation/dissolution, transpiration, volatilization and bacterially mediated oxidation/reduction reactions, in addition to mixing with percolating precipitation water, lake water and pristine groundwater.

MODE OF OCCURRENCE AND ENVIRONMENTAL MOBILITY OF OILFIELD NORM AT USGS RESEARCH SITE B, OSAGE SKIATOOK PROJECT, NORTHEAST OKLAHOMA

Robert A. Zielinski*
James R. Budahn
U.S. Geological Survey
MS 973, Denver Federal Center
Denver, CO 80225
Voice: 303-236-4719
Fax: 303-236-3200
E-mail: rzielinski@usgs.gov

A field survey at this active E&P site using a hand-held radiation exposure meter indicated marginally elevated radioactivity (2-5 times background) at the exterior of a produced water holding tank, but not in sediments of an adjacent pit used to temporarily collect tank water overflows. Suspended solids in 2 liters of water drained from the bottom of the tank were collected by filtration. Radioactivity of the solids was measured by high-resolution gamma-ray spectrometry and derives from two isotopes of radium (226Ra and 228Ra) and their decay products. Treatment of the solids with concentrated HCl to dissolve abundant red iron oxides had little effect on radioactivity levels. SEM-EDAX observation of the remaining grains indicated abundant small euhedral (5-50 µm) barite grains of variable morphology that occur as individuals, as composite grains, and as coatings on 50-100 µm quartz grains. Barite is a well-documented scavenger of radium from solution and is a common host of radioactivity in oilfield scale and sludge. Less abundant and smaller (2-20 µm) barite grains were observed in a heavy mineral concentrate from surficial sediments of the overflow pit. Sampled tank and pit waters are chemically oversaturated with barite, based on mineral/solution equilibrium calculations. Regular depth-wise declines of excess (unsupported by thorium parent) 228Ra activity in a 28 cm core from the pit suggests closed-system decay of radium in a buried, insoluble host (barite?). The apparent average sedimentation rate in the pit based on 228Ra (t1/2= 5.76 years) decay is ~3-4 cm/year. Barite is a geochemically stable radium host that limits the solubility and environmental mobility of radium at this site.