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A role for fluid flow and dissolution in extended terrains, eastern Great Basin

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Many low-angle normal faults (LANFs) in tectonically extended areas of the western U. S. were channelways for concentrated fluid flow during their Cenozoic development, as evidenced by fault-parallel zones of chloritic alteration and/or hydrothermally altered rock, mineralization that spans a wide range of paleodepths and paleotemperatures, and oxygen isotope depletion patterns. Our study of seven LANFs in Nevada, Utah, and Arizona, and casual observation of others, shows that fluid-flow-driven dissolution creep and collapse formed many of the structures previously interpreted as formed in simple shear. Structures are scale independent ranging from microscopic to outcrop-scale megafeatures, and include dissolution boudins and bands, high- to low-amplitude interpenetrative dissolution seams, collapse breccias, and high-angle accommodation faults. Strong compositional shifts, revealed by chemical and stable-isotope data representing sampling across LANFs, are generally restricted to very narrow (< 1m to 8 m) zones which, in the spatial/geologic context of the faults, suggest that the dissolution is controlled by thin-film disequilibrium between highly contrasting geohydrologic depth domains. Many exposed LANFs are end-stage snapshots of dissolution and collapse processes that probably spanned most of the time characterized by extensional deformation in the region--estimated to be several million years in most areas. Early extension was generally contemporaneous with local magmatism that may have supplied heat and fluids to the LANFs, consistent with most chemical and stable-isotope data that show a consistent pattern of major involvement of heated meteoric fluids. In two well-studied areas, lower-plate rocks (siliciclastic in one and silty carbonate in the other) apparently served as aquitards to descending meteoric waters and, through channeling fluid flow and resulting dissolution at that level, served to limit the depth of penetration of upper-plate faults. We suspect that this is a common condition of LANFs. In some areas, geomorphic evidence indicates that the processes of dissolution and collapse are currently active. Although we recognize that lateral shear translation is important in the development of LANFs, removal of large volumes of rock from LANFs by dissolution has far-reaching implications for: (1) models of extensional deformation that call exclusively on large-magnitude simple shear to remove (attenuate) the rocks and (2) depth of penetration and strain-accumulation histories of upper-plate faults--two important factors in earthquake hazards assessment.

Anderson, R. E. and Diehl, S. F., 1999, A role for fluid flow and dissolution in extended terrains, eastern Great Basin: Geological Society of America Abstracts with Programs, v. 31, no. 4, p. A2.

Declining herbicide concentrations in Midwestern streams, 1989-98

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Herbicide concentrations in Midwestern streams are affected by a number of factors, including climate, soils, agricultural practices, and the rate of herbicide use within the associated basin. Pre-emergence herbicide concentrations are likely to be near their annual maximum in streams during the first major runoff event after herbicide application (post-application runoff).

The USGS sampled 52 sites on Midwestern streams during post-application runoff in 1989, 1990, 1994, 1995, and 1998. The 1998 samples contained the highest concentrations in a single sample for acetochlor, atrazine, cyanazine, metolachlor, and simazine that have been measured at these sites.

However, analysis of the entire data set shows that the median concentration for several herbicides in post-application runoff declined significantly. For example, the median atrazine concentration in the sampled streams was 10.9 micrograms per liter (ug/L) in 1989, 5.5 ug/L in 1995, and 4.3 ug/L in 1998. The median alachlor concentration was 1.9 ug/L in 1989, 0.13 ug/L in 1995, and less than the detection limit (0.05 ug/L) in 1998. The median cyanazine concentration was 2.6 ug/L in 1989, 1.3 ug/L in 1995, and 0.44 ug/L in 1998. The median metolachlor concentration was 2.5 ug/L in 1989, 1.7 ug/L in 1995, and 1.4 ug/L in 1998. Only the median acetochlor concentration increased, from less than the detection limit in 1994 (33 percent detections) to 0.4 ug/L in 1995, and 0.7 ug/L in 1998.

Battaglin, W.A., and Goolsby, D.A., 1998, Declining herbicide concentrations in Midwestern streams, 1989-98, abstract, Eos, Transactions, American Geophysical Union, vol. 79, no. 45, p. F313.

SURFICIAL GEOCHEMISTRY RELATED TO PAST MINING IN THE COOKE CITY, MT, AREA AND ITS ENVIRONMENTAL IMPACT DOWNSTREAM IN YELLOWSTONE NATIONAL PARK

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Documenting the effects of past mining on the environment provides useful information for building models for future mitigation studies as well as for planning for new mine development. This case study describes the effects of intermittent surface and underground mining for base and precious metals between the 1870's and 1953 in the New World mining district, near Cooke City, MT, just northeast of Yellowstone National Park. Geologically, the area is mostly composed of intermediate-composition Tertiary volcanic rocks. Precambrian gneisses, Paleozoic clastic and carbonate rocks, and Tertiary intrusive rocks are present locally. Of the elements determined, those found to be enriched during Tertiary mineralization, which deposited the significant ore deposits of the district, include Ag, As, Au, Bi, Cu, Fe, Hg, Mo, Pb, S, Sb, Se, Te, Tl, W, and Zn. Exposures of mineralized rock, as well as mine dumps and a large mill tailings pile from the 1950's, remain in the upper catchment area of Soda Butte Creek, a stream originating in the area of the mining district and flowing into the Park. In June, 1950, a flash flood in the Cooke City area carried a part of the tailings pile, which is located along the side of Soda Butte Creek, downstream about 18-19 miles (29-30 km), into Yellowstone National Park. Small deposits of these flood-plain tailings can still be found in a few localities within the Soda Butte Creek drainage basin.

Samples of water and stream sediment were collected to characterize the downstream chemical effects of past mining and the flash flood. The water samples, which were collected during low flow, in September 1996, provide data describing the geochemical character of the water at that time. In contrast, data for the sediment samples document cumulative past migrations of elements. Of the 69 variables measured in the water samples, only Mo and SO_4 show anomalies that are probably related to the mineralized area. The weak anomaly for SO_4 extends from the area of past mining downstream in Soda Butte Creek to its junction with the Lamar River, a distance of about 20 miles (about 32 km). The similarly weak anomaly for Mo may extend as much as 12 miles (19 km) downstream. The water analyses show that at the time of sampling, there was no significant movement into the park of any of the other elements determined that are associated with the mineralization (Ag, As, Au, Bi, Cu, Fe, Pb, Sb, Se, Tl, W, and Zn).

The stream-sediment samples were analyzed for 53 variables. The effects of past mining are best characterized by the distributions of weakly anomalous concentrations of As and Au, which extend from the mineralized area downstream to the junction of the Lamar River, where sediment from background areas dilutes the chemistry of transported, mineral-rich sediments to background levels. Anomalous Cu, Fe, S, Te, and Zn are found to distances of 10-19 miles (16-30 km) downstream. Except for their possible presence in flood-plain tailings material, element anomalies for Ag, Bi, Hg, Mo, Pb, Sb, Se, Tl, and W in stream sediments do not extend more that about 1 mile (1.6 km) below the immediate area of past mining above Cooke City.

With the exceptions of Bi and Mo, the flood-plain tailings contain anomalous concentrations of all of the ore-related elements found in the ore dumps and the original mill tailings pile. Thus, trace-element chemistry can be used to positively identify suspected mill tailings material along the Soda Butte Creek flood plain.

For the water and stream-sediment samples collected below the area of past mining, the concentrations of most of the ore-related elements determined for this study are only weakly anomalous relative to background concentrations. Many of these same ore-related elements are also associated with geothermal features in other parts of Yellowstone National Park, commonly in much higher concentrations than those found in Soda Butte Creek.

Chaffee, Maurice A., and Miller, William R., 1999, Surficial geochemistry related to past mining in the Cooke City, MT area and its environmental impact downstream in Yellowstone National Park, p. 62, in Fletcher, W.K., and Elliott, I.L., editors, Symposium Program and Abstracts Volume: 19th International Geochemical Exploration Symposium, April 10-16, 1999, Vancouver, Canada, 143 p.

Unconventional Natural Gas Resources on U.S. Federal Lands

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The UNCLE (unconventional energy) petroleum resource assessment system, developed from analytic probabilistic methodology, was used to calculate estimates of technically recoverable natural gas resources for continuous-type (unconventional) plays in sandstones, shales, chalks, and coals on Federal Lands of the conterminous United States for the assessment regions and entire Nation.

Crovelli, R.A., Schmoker, J.W., and Nuccio, V.F., 1999, Unconventional natural gas resources on U.S. Federal Lands [abs.]: Institute for Operations Research and the Management Sciences (INFORMS) Conference Program, Cincinnati, May 2-5, 1999, p. 5.

Relation between seismic velocity and hydraulic conductivity at the USGS Fractured Rock Research Site

Karl J. Ellefsen, Paul A. Hsieh, and Allen M. Shapiro

An analysis of velocities, derived from crosswell seismic data collected at the USGS Fractured Rock Research Site, shows that the velocities are related to the hydraulic conductivities of the fractured bedrock. The conductivities are calculated from measurements made with a straddle packer. A histogram of conductivities associated with low velocities (less than 5100 m/s) shows that low velocities are indicative of a wide range of conductivies. In contrast, a histogram of conductivities associated with high velocities (greater than or equal to 5100 m/s) shows that high velocities are indicative of low conductivities. Using these histograms, a frequency distribution of conductivity could be assigned to every point in a seismic velocity tomogram.

USGS Toxic Substances Hydrology Program Meeting, March 8-12, 1999, Charleston, SC.

Geophysics in exploration for sand and gravel

Karl J. Ellefsen, Jeffery E. Lucius, and David V. Fitterman[1]

A geophysical investigation can provide valuable geologic information needed to characterize sand and gravel deposits and can be an attractive complement to more common characterization methods like drilling. Although such investigations have already been conducted, a comparison of the different geophysical methods used in these investigations apparently has never been done. For this reason, a study was initiated by the Mineral Resources Program of the U. S. Geological Survey. The goal is to determine the advantages and the limitations of different geophysical methods when used to evaluate alluvial sand and gravel deposits. The study is focused on those geophysical methods that are commonly available because these are most likely to be used by industry. Furthermore, the study is focused on surface geophysical methods.

Heretofore, four different methods have been evaluated. Three of the four methods — time-domain electromagnetic soundings, frequency-domain electromagnetic profiling, DC resistivity soundings — are similar in that they all measure the electrical resistivity of the ground with depth. Ground penetrating radar, however, maps changes in the dielectric permittivity and the electrical resistivity with depth. For all four methods, the objective is to relate the measured physical quantity to the stratigraphy of the alluvial sediments.

The study was conducted at two sites in the South Platte River valley, northeast of Denver, Colorado. One site was adjacent to an active sand and gravel pit, where the sediments and the underlying bedrock are well exposed. These alluvial sediments are roughly 7 m thick and consist of gravel, sand, and some clay. The bedrock beneath these sediments is mudstone. The water table is within the alluvial sediments — there are roughly 6 m of unsaturated sediments and 1 m of saturated sediments. The thickness of the unsaturated sediments was accurately determined with the time-domain electromagnetic soundings (Figure 1) and the DC resistivity soundings (Figure 2); the thickness was determined moderately accurately with the frequency-domain electromagnetic profiling. The thickness of the saturated sediments could not be determined with any of the tested methods because its electrical conductivity is practically identical to that of bedrock. Sedimentary structures, such as foreset beds, were detected with ground penetrating radar; the bedrock surface was possibly detected when a low-frequency, high-power radar antenna was used.

The other site was a transect across the entire South Platte River valley, and the subsurface geology here had been determined from 12 test holes. The alluvial sediments consist of gravel, sand, and some clay, and the sediments are covered with soil that is 1 to 2 m thick. In the center of the transect, the sediments and the soil are between 9 and 16 m thick; on the western and the eastern sides, they are between 15 and 25 m thick. The underlying bedrock is mostly shale. Across the entire transect, the water table is believed to be 2 or 3 m below the ground surface. In the center of the transect, the combined

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thickness of the sediments and the soil was accurately determined with the time-domain electromagnetic soundings and the DC resistivity soundings. However, on the western and the eastern sides of the transect, the thickness could not be determined with either method; rather, layers in the alluvial sediments that are not present in the center of the transect were detected. Ground penetrating radar could not detect any sediments beneath the soil because the soil is clay-rich.

LAYER	RESISTIVITY (Ω-m)			
1	92 (56-240)	95 (59-220)	100 (63-240)	110 (63-280)
2	12 (11-14)	12 (11-13)	10 (9.4-11)	7.8 (7.5-8.3)
3	5.8 (5.5-6.1)	5.6 (5.3-5.8)	5.8 (5.5-6.1)	6.1 (5.6-6.4)

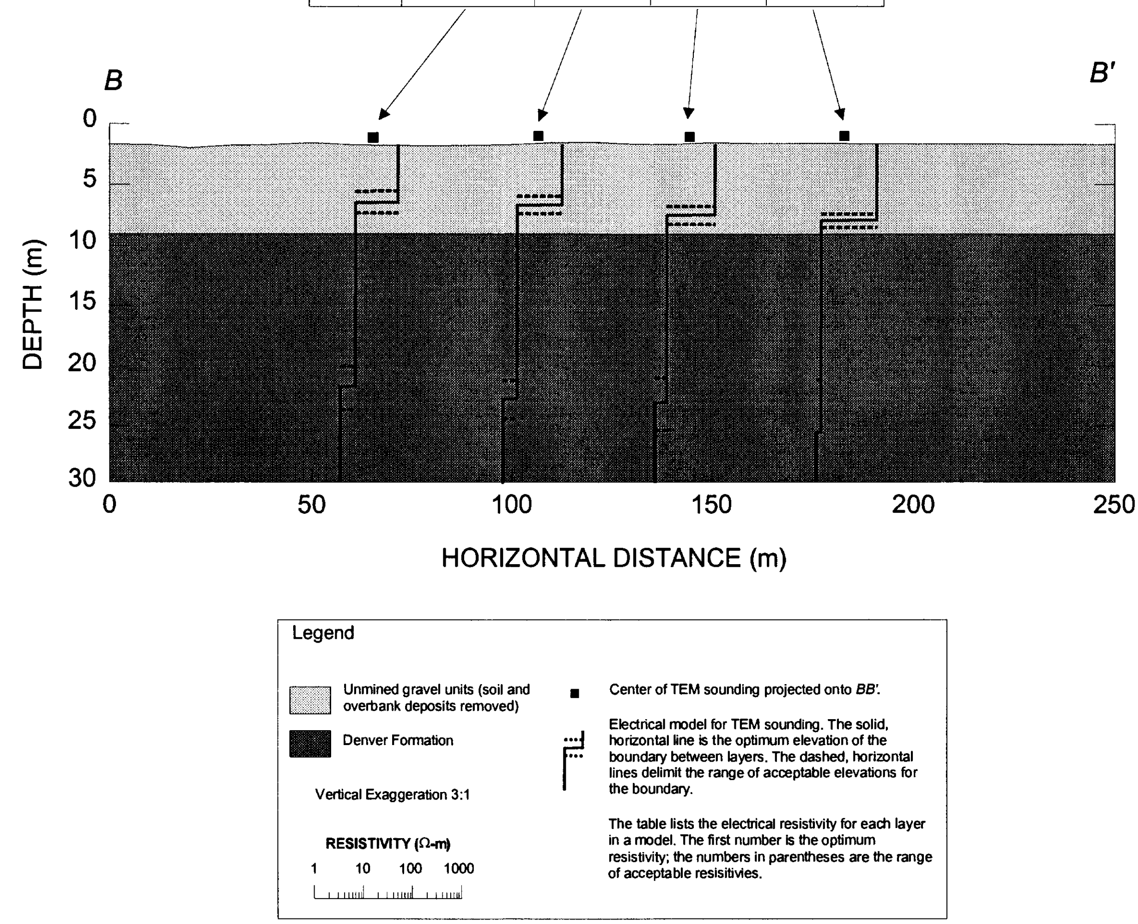

Figure 1. Cross section of the Howe Pit and the electrical models from the TEM soundings.

LAYER	RESISTIVITY (Ω-m)						
1	1900 (1500-2300)	960 (850-1100)	390 (340-440)	1500 (1400-1700)	2100 (1900-2200)	550 (520-590)	5100 (4400-6100)
2	600 (540-650)	33 (21-46)	9.7 (7.7-12)	22 (17-28)	760 (610-910)	160 (98-280)	950 (600-1400)
3	31 (24-38)				9.2 (6.2-13)	4.8 (3.9-5.9)	27 (18-35)

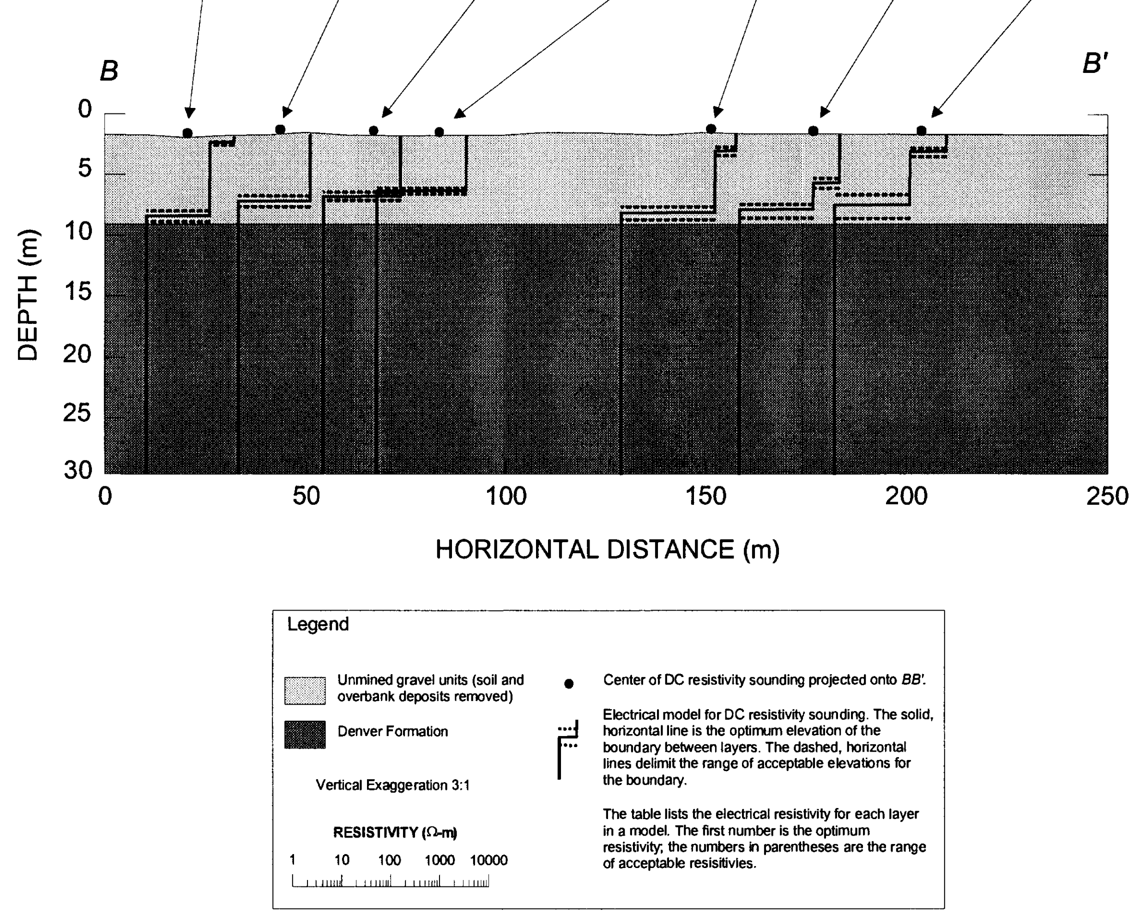

Figure 2. Cross section of the Howe Pit and the electrical models from the DC resistivity soundings.

Case study: environmental investigation of mineral deposits in Wrangell-St. Elias National Park and Preserve, AK

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The U.S. Geological Survey (USGS) and Wrangell-St. Elias National Park and Preserve (WRST) National Park Service (NPS) staff are completing a cooperative study to determine modern-day effects of mining activities within the Park. Deposits studied were selected by WRST staff to address specific land-management concerns, but the data collected will also aid the USGS Minerals Resources Program in an on-going effort to build geoenvironmental models for various types of mineral deposits throughout the U.S. and abroad. The study included determination of water and stream-sediment quality (1) around the historic Nabesna mine and mill--a lode gold *skarn* deposit where mining operations continued into the 1940s; (2) at Gold Hill--a small, active gold *placer* camp in the Preserve portion of WRST; (3) at Orange Hill and Bond Creek--two large, unmined copper-molybdenum *porphyry* deposits where active claims are still held and pre-mining background information was desired; (4) in the Bremner mining district--where early 20th-century exploitation of lode gold deposits included the use of a small mercury amalgamation milling operation; and (5) at Kennecott--a popular tourist destination that was discovered and mined in the early 20th century for rich deposits of copper. Sediment and water data from this study provide an important foundation to, and help define the scope of, on-going remediation work at Nabesna. At Gold Hill, samples were collected during a period of inactivity and the data provide a baseline to compare against when collecting samples during short periods of summertime placer activity. Data obtained from Orange Hill and Bond Creek reveal large, pristine, mineralized deposits exposed at the surface—natural laboratories that demonstrate that water and sediment quality can be influenced by purely natural phenomena. Data from the Bremner district reveal that although mill tailings contain relict mercury from the amalgamation processes, none of the mercury appears to be entering the surface waters downstream. Data from the Kennecott copper deposits show that the general lack of acid-generating minerals, combined with the widespread presence of carbonate rocks, result in minimal impact to surface-water quality in the area. At Kennecott, these data and interpretations were used to address questions of impact from mining during recently completed land acquisitions by the National Park Service. The success of this joint USGS-NPS study has resulted in a similar cooperative study just beginning in Denali National Park, AK.

ENHANCEMENT OF ANHYSTERETIC REMANENT MAGNETISM IN MODERN SOILS FROM THE NORTH AMERICAN MIDCONTINENT—IMPLICATIONS FOR PALEOCLIMATIC RECONSTRUCTIONS

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Recent detailed studies of soils and paleosols in loess sequences suggest that magnetic properties may contain important paleoclimatic information. For example, studies in China have shown that modern loess-derived soils and paleosols are enhanced in magnetic susceptibility (MS) relative to parent material due to the formation of ultrafine superparamagnetic minerals during pedogenesis. The amount of superparamagnetic material appears to be positively correlated with precipitation. It has been suggested, therefore, that the degree of enhancement of MS in Chinese loess-derived paleosols defines paleoprecipitation during the period of soil formation.

We tested the possibility that precipitation controls magnetic properties in modern loess-derived soils from eight localities in the North American midcontinent across a precipitation range from less than 400 mm a^{-1} in western Nebraska to about 1100 mm a^{-1} in central Ohio. The soils usually show elevated MS in the A horizons, but the magnitude of MS declines sharply in the B and upper C horizons. In contrast to the magnetic properties of Chinese soils, the overall magnitude of MS in the A or B horizons does not show a consistent relation with respect to precipitation, but the enhancement of MS (enhanced $\chi = \chi_{soil} - \chi_{parent}$) decreases from west ($5.2x10^{-6}$ m^3 kg^{-1} at McCook, NB) to east ($2.0x10^{-7}$ m^3 kg^{-1} at Mt. Vernon, IN) and shows an overall *negative* relationship (r^2 = -0.65) with respect to precipitation for seven of the eight localities. Anhysteretic remanent magnetization (ARM) is also enhanced in the A and B horizons of these soils, but ARM enhancement shows a *positive* correlation (r^2 = 0.68) with precipitation for all eight of the localities. No clear cut relation exists between precipitation and saturation isothermal remanent magnetization or frequency dependent magnetic susceptibility.

The positive correlation between enhanced ARM and precipitation in the North American midcontinent implies greater pedogenic development of single-domain ferrimagnetic minerals with increased precipitation. At present, we do not know the genetic relation between the inferred pedogenic single-domain particles and fine superparamagnetic particles in the same soils. We conclude that measurement of only MS or other measures of the superparamagnetic fraction may not fully reveal the distribution and amount of pedogenic Fe oxides in soils, and thus may lead to poor estimates of paleoprecipitation.

S. S. Harlan, J. G. Rosenbaum, R. L. Reynolds, D. Muhs and E. A. Bettis, III, 1998, Enhancement of Anhysteretic Remanent Magnetism in Modern Soils from the North American Midcontinent—Implications for Paleoclimatic Reconstructions, Eos, v. 79, p. F238.

TEMPORAL VARIATION IN THE GEOCHEMISTRY OF ALKALINE MAGMATISM, ABSAROKA VOLCANIC PROVINCE, MONTANA-WYOMING, USA

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The Eocene Absaroka Volcanic Province is the largest of middle Eocene volcanic fields in the northern Cordillera of the western U.S., comprised of 25,000 km^2 of hypabyssal intrusives, lava flows, ash-flow tuffs and volcaniclastic deposits. It includes the remains of at least ten volcanic centers which are aligned with two northwest-southeast subparallel Precambrian lineaments. New geochronological data extend the Absaroka volcanic province to include laccolithic intrusions in the southern Gallatin Range in Yellowstone Park. Detailed mapping and field sampling from four volcanic centers for geochemistry have been augmented with sampling for $^{40}Ar/^{39}Ar$ geochronology from eight volcanic centers and six ash-flow tuffs. New age data have allowed significant revisions in regional correlations across the Absaroka province and tie eruptive activity from individual volcanic centers to the evolution of the entire volcanic field. From the oldest to the youngest, the Crandall, Ishawooa, Rampart, and Hyalite volcanic centers exhibit distinctive compositional trends that can be linked temporally to changing melt source components. Although the products of these volcanic centers are broadly similar, differing chemical and isotopic compositions suggest that early eruptions contain a lithospheric mantle component, with an increasing melt contribution from the lower crust with time. Rocks sampled from individual volcanic centers encompass a range of compositions from absarokite to rhyolite. Mafic lava flows and dikes (<53% SiO_2) are dominantly alkaline, ranging from basanite and absarokite to shoshonite. However, early erupted mafic lavas of the Crandall volcanic center (>50 Ma) are olivine- and hypersthene-normative, have low $^{87}Sr/^{86}Sr$ (0.7043-0.7044) and $^{143}Nd/^{144}Nd$ (0.5118-0.5114). Post-Crandall absarokites and shoshonites from Ishawooa and Rampart, which overlap in age, are nepheline-and olivine-normative, with low $^{87}Sr/^{86}Sr$. Lavas from these three volcanic centers show extreme enrichment in LREE, Sr, and Ba, derived from an ancient source. Late erupted mafic lavas of the Hyalite volcanic center are distinctly less enriched, quartz-normative shoshonites with higher $^{87}Sr/^{86}Sr$. The most recent eruptions in the volcanic field include rhyolite in the southern Absaroka Volcanic Province, and a basanite flow of asthenospheric isotopic composition in the northern Absaroka Volcanic Province.

Geological Society of America, Abstracts with Programs, 1998, v. 30, no. 7, p. A376.

Fits, Starts, and Headway: The Implementation of Geographic Information Systems in Beginning and Advanced High School Geography Courses

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The incorporation of GIS technology and methods has been an intensive but valuable component to new and pre-existing lessons in the geography program at Boulder High School, Boulder Colorado USA. Enhanced learning in local and international lessons resulted from making more variables available and from increased inquiry. Important ingredients of success included the integration of local and real-time data sets, networking with the USGS and the City of Boulder, and applying GIS to lessons that had previously been tested. Other key success elements included the participation and interest of the computer laboratory manager and the tenacity of the content teacher.

Poster prepared for public outreach use by the USGS National Mapping Division.

GRAVEL DEPOSITS OF THE SOUTH PLATTE RIVER VALLEY NORTH OF DENVER, COLORADO

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The valleys of the South Platte River and its tributaries contain large deposits of gravel used for construction in the Front Range Urban Corridor. The South Platte River valley north of Denver contains the last major commercial deposits of gravel in the Denver metropolitan area. Upstream from these deposits, most of the gravel has been mined or precluded from mining by urban development. North of Denver, gravel mining has steadily moved downstream since the early 1970's, and now may be approaching the downstream limit of commercial viability. When the deposits north of Denver are exhausted or preempted by other land use, aggregate for the Denver area will by necessity come from stone quarries in the mountains or from gravel deposits in valleys to the north, such as the valley of the St. Vrain River.

The quantity and quality of gravel in the valley of the South Platte River is not only of interest to producers and consumers of gravel aggregate in the area but is also relevant to urban planning. An understanding of the gravel deposits may enable better prediction of the potential downstream limit of gravel mining and of post-mining land use. To begin to assess the quality and ultimate minable extent of gravel deposits in the South Platte River valley north of Denver, the U. S. Geological Survey conducted detailed studies of the stratigraphy and composition of the gravel.

Gravel underlies multiple terrace levels in the South Platte River valley. From highest (oldest) to lowest (youngest), the terrace levels are (1) remnants of high dissected terraces of Pleistocene age, (2) high continuous terraces (Louviers and Broadway terraces) of late Pleistocene age, (3) the low Piney Creek and post-Piney Creek terraces of Holocene age, and (4) the modern floodplain. The Broadway terrace makes up most of the eastern side of the South Platte River valley north of Denver; the Holocene terraces and floodplain occupy the rest of the valley. All of the Holocene levels (Piney Creek, post-Piney Creek, and floodplain) are considered together because their gravel resources are similar. Major deposits of gravel underlie the high continuous terraces, but most gravel mining is from the floodplain and low terraces.

Approximately 15-25 feet of gravel underlie the floodplain and low terraces. The gravel forms three distinct layers, each about 5-10 feet in thickness. The layers differ in coarseness and color and they can be traced throughout the South Platte valley north of Denver, as far north as Ft. Lupton. The basal gravel is composed of coarse pebble-to-cobble gravel, the middle gravel contains more sand than gravel, and the upper gravel contains variable particle sizes with concentrations of sand. Overall, the upper gravel is coarser-grained than the middle gravel. Locally, the upper layer contains abundant wood and fossil logjams. Lenses of silty clay, which impede mining, occur locally in the upper and middle layers.

Downstream from Ft. Lupton, the coarse basal gravel disappears and sand dominates the valley fill. The present downstream limit of gravel mining near Ft. Lupton is probably already near the ultimate limit of commercial production.

Bedrock clay of the Late Cretaceous and Paleocene Denver Formation underlies the gravel fill of the valley north of Denver. The bedrock clay forms an impermeable seal at the bottom of the gravel aquifer, confining ground water flow to the gravel. After mining gravel, the pit walls can be lined with clay from the Denver Formation to create a watertight reservoir. The reservoir, separated from the gravel aquifer by impermeable clay walls, can be used to store water for municipal use.

35th Forum on the Geology of Industrial Minerals, May 2-5, 1999, Salt Lake City, UT.

Ground Penetrating Radar Research at the Bemidji, Minnesota, Crude-Oil Spill Site

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At the Bemidji, Minnesota, crude-oil spill site, the USGS collected ground penetrating radar (GPR) data to determine the distribution of oil concentrated in two subsurface pools, which remained after cleanup efforts. Physical property information from analysis of mixtures of sand and crude oil assisted in the interpretation of the GPR data. Laboratory measurements show that the crude oil is still very electrically resistive (greater than 10^6 ohm-m). Mixing clean sand with crude oil does not significantly change the relative dielectric permittivity (RDP) or electrical conductivity of the mixture. Four GPR lines were selected, from the large number of radar lines collected at the spill site since 1984, as typical examples of 80 MHz and 300 MHz data collected over the oil pools. At the spill site, GPR is sensitive to changes in electrical conductivity and RDP related to variations in water content, due to grain size and porosity, rather than variations in the oil saturation distribution (fraction of pore space occupied by oil). The oil pools at the Bemidji site are not easily detected using GPR. Nonetheless, GPR can detect those geologic features, such as silt or gravel layers in sand, that may affect the transport and fate of petroleum in the subsurface.

Lucius, J.E., 1999, GPR investigations at the Bemidji research site, in Morganwelp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substances Hydrology Program-Proceedings of the Technical Meeting, Charleston, SC, March 8-12, 1999 - Volume 3 -- Subsurface Contamination from Point Sources: U.S. Geological Survey Water-Resources Investigations Report 99-4018C, in press.

MATERIALS FLOW – A NEW USGS RESEARCH AREA

Minerals and Materials Analysis Section, USGS Minerals Information Team

Materials extracted from the earth are necessary to produce our most fundamental needs—food, clothing, and shelter. Materials are also needed to maintain and improve our standard of living. Materials flow, in the most literal sense, is a systems approach to understanding what happens to materials we use from the time a material is extracted through its processing, manufacturing, and disposition. Traditionally, the USGS has focused on material sources. In this new research area, the USGS has expanded its materials focus to the whole cycle; from source to disposition. The purpose of this work is to understand how we use our resources, and to help identify policies and practices to make resource use more efficient and protect the environment.

WORKSHOP ANNOUNCEMENT UPON WHICH POSTER PRESENTATIONS ARE BASED

SCIENCE, SUSTAINABILITY, AND NATURAL RESOURCES STEWARDSHIP --
THE USGS AND RESEARCH ON MATERIALS AND ENERGY FLOWS

A NATIONAL WORKSHOP

USGS NATIONAL CENTER
12201 SUNRISE VALLEY DRIVE
RESTON, VA NOVEMBER 3-5, 1998

ANNOUNCEMENT

The U.S. Geological Survey (USGS) provides information on the use and flow of materials in the U.S. and world economies. The USGS also seeks to identify areas where adverse impacts of these flows could be minimized through enhanced efficiencies, such as materials recycling, reducing wastes at the source of extraction, and creative waste management.

Materials flow research can provide insights into how the use of materials affects society, the economy, and the environment from extraction through production, consumption, disposition, and losses or dissipation to the environment. It also seeks to define the relation of materials flow to energy inputs. Identifying these patterns provides a framework for identifying future materials and energy requirements, and for understanding long-term issues of resource supply and waste management. The approach also aims to inform policy makers and the public on issues related to materials and energy flows, as well as the effects of consumer decisions.

Understanding the entire system of materials and energy flows and related trends can help society better manage the use of natural resources and protect the environment. It also can motivate societies to increase economic efficiencies and improve the life span of the products they design, thereby encouraging technological innovation. In this context, universities, private-sector institutions, and all levels of government are focusing on new roles in comprehensively researching environmental systems. The emerging field of Industrial Ecology provides insights for assessing these roles.

Industrial Ecology studies the flows of materials and energy for industrial and consumer activities and their effect on the environment, as well as the economic, political, regulatory, and social factors that influence the transformations of resources. Practitioners in the field seek to organize thinking about the massive, systematic transformations of materials and energy in modern economies, and provide a framework within which to improve knowledge and decisions about materials and energy use, waste reduction, and pollution prevention.

The sustainability of the human population and our life-support system depends upon an extraordinarily complex interplay of factors affecting the availability and use of water, air, soils, land, energy, and minerals. Comprehending this interplay will require new ways of documenting, surveying, monitoring, modeling, and understanding Earth systems as a whole. The USGS, with its broad geoscientific expertise in biology, cartography, geology, hydrology, and information systems, is an agency well suited to provide leadership in many of these tasks.

This workshop brings together principals from the USGS, other Federal agencies, industry, academia, and international organizations to discuss roles of the USGS in materials and energy flows research. The participants will identify problems and explore partnerships by (1) examining the importance of materials and energy flows in United States and global economies; (2) reviewing National goals and policies that are based on materials and energy flows and sustainability precepts, and (3) envisioning integrated approaches to materials and energy flows research.

Plenary Session Presentations: The goals of these presentations are to provide (1) Background and tutorial on materials and energy flows, sustainability, industrial ecology, and related topics; (2) Alternative views on the roles of participants in materials and energy flows research; (3) Potential directions and opportunities for research in materials and energy flows.

Breakout Sessions: The goals of the breakout sessions are to (1) Provide a forum for individuals across all divisions of the USGS, other Federal agencies, private companies, universities, and disciplines to express their thinking on concepts of materials and energy flows, sustainability, industrial ecology, and related subjects; (2) Deliberate on the various roles of industry, academia, and government in materials and energy flow research, (3) Review current research directions and future research agendas, and (4) Identify roles and opportunities for the USGS in materials and energy flows research.

Facilitation and Reporting: Recorders will compile the proceedings of the plenary sessions. Facilitators will help guide the breakout sessions, and compile the results for reporting back to the plenary audience. A writing team will compile all plenary and breakout session results and other contributions, and prepare a summary report.

Displays: There will be several poster displays in the vicinity of the auditorium to provide additional information about USGS activities in materials and energy flows, and to serve as catalysts for informal discussion and interaction. Participants are invited to bring display materials, and should advise the workshop coordinators about their intentions to have a display and about their setup needs.

Poster prepared for public outreach use by the USGS Minerals Information Team.

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U-Pb ZIRCON AGES FOR THE BIG CREEK GNEISS, WYOMING AND THE BOULDER CREEK BATHOLITH, COLORADO: IMPLICATIONS FOR THE TIMING OF EARLY PROTEROZOIC ACCRETION OF THE NORTHERN COLORADO PROVINCE

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U-Pb zircon ages, determined using both the high-resolution ion microprobe (SHRIMP) and conventional isotope dilution (ID-TIMS) methods, from the high-grade, compositionally-layered, hornblende-feldspar Big Creek Gneiss and a foliated, biotite quartz-monzonitic phase of the Boulder Creek Batholith help to define the timing of three major Early Proterozoic thermo-tectonic events at approx. 1800, 1700, and 1600 Ma within the northern Colorado Province (CP) of Bickford etal. The CP, extending from the Cheyenne Belt, southern Wyoming to somewhere in north-central New Mexico, has been interpreted as a series of primitive volcano-plutonic arc systems and associated cannibalistic, basin-forming sediments.

The Big Creek Gneiss of SE Sierra Madre, Wyoming is apparently a high-grade, lower crustal equivalent of the oldest arc volcanics, and represents the only enigmatic block which may have been Archean or possibly derived from Archean detritus. Two samples of the Big Creek Gneiss yielded complex populations of small clear to subrounded dark grains, of which some exhibit dark cores and/or clear rims. Previous ID-TIMS work on mg-size, magnetically-separated zircon fractions from the samples yielded concordia upper-intercept ages of 1618±22 and 1684±5 Ma, and large negative lower-intercept ages (-614 and -123 Ma, respectively), indicating the likelihood of increased amounts of inherited zircon in the more magnetic, least concordant fractions, and were interpreted to represent U-Pb mixtures of primary magmatic and secondary metamorphic components, so that the ages are not reflective of actual geologic events. The actual age of the gneiss and its protolith remained elusive. The zircon population from the latter sample was analyzed using the SHRIMP, and a total of 32 spot analyses on both magmatic centers and metamorphic rims delineated four groups of different $^{207}Pb/^{206}Pb$ ages; ~1810, 1760 to 1710, ~1675, and 1610 to 1590 Ma. Although nearly 75% of these analyses are more than 10% discordant, the nine that are less than 10% discordant produced $^{207}Pb/^{206}Pb$ ages with nearly the same age groupings . The older group is interpreted to best represent the age of the protolith, whereas the others represent either portions of magmatic zircon that have experienced Pb-loss or, in the younger age case, new zircon growth during metamorphism at ~1610 Ma. This age is best represented by one analysis (1608±8.4 Ma) that is 97.4% concordant, but is also confirmed by the ID-TIMS age of 1618 Ma (above) for the Big Creek Gneiss. The Boulder Creek Batholith, long considered a key plutonic complex of the central Front Range, Colorado, had been dated by Stern etal at 1712±20 Ma based on regression of U-Pb results from six different samples, but remained tentative due to the presence of abundant inherited zircon material within all of the sample zircon populations. Subsequent ID-TIMS work defined upper-intercept ages of ~1670 Ma for two samples of a biotite quartz monzonitic phase and upper-intercept an age of 1714±6 Ma for a granodioritic phase. The nearly 45 m.y. discrepancy drew into question the true age of the batholith as well as the age for the "Boulder Creek event" samples . Both younger samples were analyzed using the SHRIMP and 22 of 29 analyses yielded an age of 1706.8±4.0 Ma for the first sample, and 10 of 12 analyses yielded 1709.5±7.6 Ma for the second. These results are comparable to some of the older determinations and establish the Boulder Creek plutonic event to be 1709.2±3 Ma (weighted average of four determinations). Furthermore, ages for the inherited component are constrained to no older than ~1725 Ma.

The SHRIMP data on these two key samples from the Colorado-Wyoming Rockies helps to establish: (1) The likelihood that high-grade gneisses within the GMMA are coeval with lower-grade metabasalts and associated plutons at ~1780 to 1800 Ma and that Archean crust was not significantly involved in their production; (B) The age of the syn-tectonic Boulder Creek batholith is 1709±3 Ma and can be used to constraint the accretionary timing between the two earliest arcs of the GMMA as crustal shortening within the composite back-arc basin is marked by regional metamorphism of the predominantly metasedimentary sequences that divide the arcs (e.g. Idaho Springs Fm) and intrusion of regional intermediate-composition plutons into the north-central CP; (C) Post-accretion tectonism along major SW-NE-trending shear zones including the Cheyenne Belt at ~1600 Ma as evidenced by high-grade metamorphism of the Big Creek Gneiss and local magmatism of peraluminous granites.

Geological Society of America, Abstracts with Programs, 1997 vol. 29, no. 6, p. A-407.

Pb ISOTOPIC SYSTEMATICS OF ANCIENT CRUSTAL LUNAR ROCKS (>3.9 Ga): CONSTRAINTS ON EARLY LUNAR EVOLUTION

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The present Pb isotopic database of over 163 analyses from 110 samples of non-mare basalt lunar rocks (>3.9 Ga) delineate at least three isotopically-distinct signatures that in some combination can be interpreted to characterize the Pb isotopic systematics of the entire database. Two are fairly new sets of lunar data and are typical of Pb data from other solar system objects, describing near-linear arrays slightly above "geochron" values with $^{207}Pb/^{206}Pb$ values <0.9.

From the Pb isotopic compositions, a source $^{238}U/^{204}Pb$ (μ) value can be calculated and differences in μ values from one Pb signature to another can have important implications on the age and evolution of Moon-forming events. The oldest Pb signature is represented solely by ferroan anorthosite 60025, presumably a piece of the early plagioclase-rich lunar crust produced from a magma ocean, and is characterized by source μ values between 35 and 100 at ~4.43 Ga. Another prominent and uniquely lunar Pb signature is representative of some ferroan anorthosites and most high Mg suite rocks, identified more than twenty years ago, is characterized by extremely high $^{207}Pb/^{206}Pb$ values (~1.45) that require extremely high source μ values (>500). Although the age and origin of this exotic Pb is not well constrainted, it is interpreted to be related to the separation of trace-element-rich (U, Th) fluids from the lunar mantle between 4.36 and 4.46 Ga (urKREEP residuum). The latest discovered Pb signature is found only in lunar meterorites and is characterized by relatively low source μ values between 10 and 50 at 3.9 Ga.

The fact that most lunar crustal rocks (>3.9 Ga) exhibit high $^{207}Pb/^{206}Pb$ values requires that they were either derived from, mixed with, or contaminated by Pb produced from early-formed, high-μ sources. The ubiquity of these U-Pb characteristics in the sample collection is probably an artifact of Apollo and Luna sampling sites, all located on the near side of the Moon that was deeply excavated during the basin-forming event(s). These newest Pb data would support the idea that the Moon originally had a μ value of ~8 to 35, slightly elevated from Earth values, and that subsequently an extreme U-Pb fractionation occurred within the Moon during its early differentiation period at ~ 4.45 Ga.

Geological Society of America, Abstracts with Programs, 1998, vol. 30, no. 7, p. A-289.

Real time monitoring of an active landslide along Highway 50, California

Reid, Mark, and LaHusen, Richard, U.S. Geological Survey

In February 1997, the USGS installed a real-time monitoring system on an active landslide. Currently, instruments at that site monitor ground movement, rainfall, ground water pressure, and ground vibration associated with sliding. For more information and updated monitoring reports, please see:
http://vulcan.wr.usgs.gov/Projects/CalifLandslides/framework.html

Poster prepared for public outreach use by the USGS Geologic Hazards Team.

Eolian processes and deposits in the southwestern U.S.--Integrated studies to evaluate impacts from climatic variability and land use

U.S. Geological Survey[1] and Desert Research Institute[2]

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Major objectives of global change studies in the USGS are to understand how climatic change and variability affect surficial geologic processes, as well as to assess future regional impacts through climate modeling. Integrated studies are being applied to understand responses of eolian processes to climatic and land-use change in the southwestern U.S., with emphasis on the Mojave Desert. Goals include: (1) Assess wind-erosion vulnerability and surface stability to assist land-management decisions; (2) evaluate the influence of dust emission and deposition on desert ecosystems; (3) investigate natural and human impacts on eolian processes of arid lands; and (4) model future regional climate of the Southwest and eolian process response using likely climate scenarios.

Wind-erosion at specific sites is investigated both with wind-tunnel experiments and with meteorological stations capable of measuring sand transport. The wind-tunnel experiments are employed to determine the effects of disturbance and recovery histories on wind-erosion vulnerability, and to evaluate the roles of different desert surfaces (e.g., natural pavement, biologic soil crust) in providing soil-surface stability. At the abandoned Greenwater townsite (Death Valley National Park), threshold friction velocities (TFV; a function of wind speed that moves particles along the surface) indicate that modern footprint and tire-track disturbances decrease soil stability. Studies elsewhere in the Mojave Desert (near Valjean, CA, and at Joshua Tree, CA) also quantitatively document that increasing disturbance results in (1) lower TFV and (2) greater sediment erosion (higher sediment production), for wind velocities that exceed TFV.

Wind-erosion is monitored at ecologically sensitive sites, using meteorological stations that measure precipitation, wind speed and direction, soil moisture, temperature, incoming solar and outgoing infrared radiation, and sand flux at various elevations in the saltation layer. Currently, six stations operate in the Southwest, with plans to install more in the Mojave Desert.

Several approaches are taken to monitor and characterize modern dust—its sources, flux, and composition–to document potential aridification and wind erosion, as well as to understand soil destruction and formation. New remote sensing methods have been developed to determine the location, frequency, magnitude, and duration of dust-emission events. Remote sensing images of vegetation change, combined with those that illustrate high soil reflectivity, complement dust-detection methods to identify areas especially susceptible to wind erosion.

Dust trapped in collectors and snow is being characterized for its physical and chemical properties. Annual collection and analysis from passive-type pan samplers at numerous sites in southern Nevada and California since 1984, combined with soil and weather data, shed light on: (1) The genesis of soils formed under arid conditions; (2) the relation between dust storms and climate, such as the finding that high dust flux follows periods of high precipitation, because floods deposit fine-grained sediment susceptible to deflation; (3) natural dust sources, such as along a Death Valley transect showing that the modern playa contributes salt- and carbonate-rich dust, but the wide plain of the Amargosa is a more important source of silt and clay; (4) Owens (dry) Lake as a source for a significant part of deposited dust as much as 400 km downwind; and (5) human disturbances in the desert, revealed by signatures of agricultural and construction dust.

Dust trapped both in snow at high elevations and on passive, air-foil collectors, is analyzed in minute quantities by microbeam methods and ICP-MS. The dust from snowpack provides a record of regional background composition and flux, and it is strongly enriched in trace elements (e.g., Cu, Zn, As, Ag, Cd, and Pb) relative to an average crustal rock composition.

A new combination of magnetic and chemical methods has been developed for the rapid recognition of eolian dust in soils and surficial deposits of ecosystems, with applications to understanding plant distribution and substrates for biologic soil crust. This approach reveals a large component of eolian silt in the surficial deposits, which harbor much of the biologic fertility of Colorado Plateau. Moreover, the biologic soil crust there is a natural dust trap that records over the past several decades a shift in dust source, from relatively mafic to more silicic, on the basis of relative abundances of magnetite to titanomagnetite, and of Zr to Ti. Human activities in deserts off the Colorado Plateau, such as the Mojave Desert, may be partly responsible for this shift in dust source.

Sand-dune fields in the Mojave Desert, as well as those on the Colorado Plateau and Southern High Plains, are being investigated for their evolution, sand transport pathways, and vulnerability to future climate change. A recently developed concept is that eolian sand is moved between basins in the Mojave Desert along distinct sand transport pathways. Part of this model is that sand dunes near Parker, Arizona, east of the Colorado River, may be the endpoint for one of these sand transport pathways. If this hypothesis is true, it implies a period(s) in the past when the Colorado River was completely dry to allow sand transport by wind across the river valley. Chemical and mineralogic tests of this hypothesis indicate that the Parker dunes have compositions that are very close to Colorado River sediments and much different from dunes in the Mojave Desert of California. Therefore, the Parker dune field has a different origin from those in the Mojave, and it is derived from Colorado River sediments, similar to the Algodones dunes. The sand transport pathway model may be partly correct for the Mojave Desert, but it does not apply across the Colorado River.

The modeling component includes the development of a wind-erosion model based on wind strength, atmospheric shear stress on the surface, and atmospheric stability. This model will be linked with a regional climate model and an interactive vegetation package to forecast how critical wind speeds required to move surface materials change with various climatic and land-use scenarios. We will attempt to answer the following questions: How does wind strength vary with natural climate cycles on decadal and century time scales? If climate changes as a result of human activities, to what extent will winds become stronger or weaker? How have soil moisture and vegetation changes affected wind erosion in the past? What can we expect in the future? As an example, 2 x CO_2 projections for the Southwest suggest a decrease in the diurnal temperature range, which will affect atmospheric stability, and a decrease in soil moisture, especially during the winter. The latter effect may lead to enhanced wind erosion in the future.

In Slate, J., Proceedings of conference on status of geologic research and mapping in Death valley National Park, Las Vegas, Nevada, April 9-11, 1999: U.S. Geological Survey Open-file Report 99-153, p. 146-147. 1999

Magnetic record of hydrochemical change at Owens Lake (California) between 134 and 46 ka.

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Lacustrine sediment in a 323-m drill core from Owens Lake contains an 800 ka record of climate change, expressed mainly as precipitation cycles that correspond to marine isotope stages (MIS). Evidence for such cycles, which represent alternating closed and overflowing lake conditions, includes changes in limnology based on diatom and ostracode populations, in mineralogy that reflects detrital vs. chemical sedimentation, and in geochemical signatures of sediment composition and water chemistry. As part of a detailed multi-parameter examination of MIS 5, we have obtained magnetic property (444 samples), petrographic (13 magnetic separates), and XRF geochemical data (165 samples) from a 51-m-thick interval that represents about 134 to 46 ka, spanning the latter part of MIS 6 to the early part of MIS 3.

Variations in the amounts and types of Fe-Ti oxide minerals, as well as the sporadic presence of greigite (Fe_3S_4), produce large changes in magnetic susceptibility (MS), isothermal remanent magnetization (IRM), anhysteretic remanent magnetization (ARM), "hard" IRM (HIRM), and S parameter ($IRM_{0.3T}/IRM_{1.2T}$). Combined with textural observations that reveal origins of the magnetic minerals and with contents of Fe, Ti, and Zr, the magnetic properties provide a high-resolution record of erosional, depositional, and diagenetic events in the lake-watershed system.

For example, dominant Fe oxides in samples are found as fine silt-size, angular, and optically homogeneous magnetite derived as glacial flour from Sierran granites; as small (< 5 micrometers) particles in mafic volcanic rock fragments; or as large (coarse silt), subrounded titanomagnetite grains perhaps derived from dacitic rocks. In some intervals, such large titanomagnetite is replaced extensively by pyrite, representing diagenesis under saline conditions when the lake was mostly stagnant. Greigite (indicated by high IRM/MS) probably represents sulfate-limited Fe-S diagenesis under hydrologic conditions intermediate between closed and overflowing.

Sediments in the 134-120 ka interval contain glacial-flour magnetite, lack Fe-S minerals, and are characterized by high MS, IRM, Fe, and Ti, as well as by low IRM/MS and Zr/Ti. A ca. 2.8 ka zone above this interval is dominated magnetically by greigite, representing the transition from overflowing to closed conditions. Most of the MIS 5 sediments above are characterized by low detrital magnetite content, some of it replaced by pyrite; by low MS, IRM, IRM/MS, Fe, and Ti; and by relatively high Zr/Ti. At least two major intervals of greigite-bearing sediment, however, are found within the 41.6-m-thick MIS 5 section. These intervals (ca. 89.7-88.3 ka and 69.9-66.3 ka) may represent times of freshening lake water from increased precipitation in the watershed. Our petrologic data lack evidence for major glacial flour runoff into the lake during MIS 4 but point to overall increased freshening, based on increasing proportion of magnetite unaffected by pyrite. At least one major and perhaps two minor intervals of dominant greigite interrupt this freshening trend and may represent episodes of lower precipitation and higher salinity.

Eos, Transactions, American Geophysical Union, 1998, v. 79, no. 45, p. F239.

Testing Sedimentary Paleomagnetic Records Using Anisotropy of Magnetic Susceptibility: A Reevaluation of Core OL-92 (Owens Lake, California)

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The best way to evaluate the fidelity of sedimentary paleomagnetic records is to compare multiple records from a given sedimentary sequence. Lacking multiple records, other methods must be employed to discriminate between directional changes due to field behavior and those due to other factors, such as core deformation. Sediments deposited in quiet water typically have planar anisotropy of magnetic susceptibility (AMS) with subvertical minimum axes (K3). Recent improvements in the speed and accuracy of measurements make it feasible to recognize core disturbance from changes in the AMS sedimentary fabric. Core OL-92 was obtained by rotary drilling and penetrated 323 m of lake sediments representing about the past 800,000 years. Glen and Coe (in GSA Special Paper 317, 1997) documented the Matuyama/Brunhes polarity boundary near the bottom of the core and tentatively identified numerous geomagnetic excursions during the Brunhes Chron. In this study, we combine detailed analysis of sedimentary structures and AMS measurements to assess the validity of the OL-92 paleomagnetic data in intervals previously interpreted to span four excursions. A reference AMS fabric for undisturbed sediment was derived from an interval of low paleomagnetic dispersion (i.e., outside of a previously interpreted excursion) and in which core disruption was not recognized. In this reference interval, inclinations of K3 axes average 84° (STD = 6.4°). Core examination identified severe core disruption in two intervals previously interpreted to span the Mono Lake and Blake excursions. Inclinations of K3 axes from these intervals are much more highly dispersed (STD ~ 25°) and have lower averages (66° and 69°) than the reference interval. Two older intervals, previously interpreted as the Jamaica/Biwa I and Pringle Falls excursions, have paleomagnetic dispersions that are intermediate between that of the reference interval and those of the interpreted Mono Lake and Blake excursions. Detailed core descriptions are lacking, but core deformation in these older intervals is indicated by average inclinations and dispersions of K3 axes intermediate between those expected for undeformed core and those from the two highly deformed intervals. The correspondence between paleomagnetic dispersion and AMS indicators of core disruption reveal that many, if not all, of the previously interpreted excursions in the OL-92 record are caused by deformation rather than geomagnetic field behavior.

Eos, Transactions, American Geophysical Union, 1998, v. 79, no. 45, p. F233.

Changes in herbicide occurrence in Midwestern streams in relation to changes in use, 1989-98

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Water samples were collected from 53 Midwestern streams in 1994-95 and 1998 as part of a study to help determine if changes in herbicide use resulted in changes in herbicide concentrations since a previous reconnaissance study in 1989-90. Sites were sampled during the first significant runoff period after the application of preemergent herbicides in 1989-90, 1994-95, and 1998. Samples were analyzed for selected herbicides, two atrazine metabolites, three cyanazine metabolites, and one alachlor metabolites. In the Midwestern United States, alachlor use was much greater in 1989 than in 1995, whereas acetochlor was not used in 1989 but was commonly used in 1995.

The use of atrazine, cyanazine, and metolachlor was about the same in 1989 and 1995. The median concentrations of atrazine, alachlor, cyanazine, and metolachlor were substantially higher in 1989-90 than in 1994-95 or 1998. The median acetochlor concentration was higher in 1998 than in 1994 or 1995.

Scribner, E.A., Battaglin, W.A., Goolsby, D.A., and Thurman, E.M., 1999. Changes in herbicide concentrations in midwestern streams in relation to changes in use, 1989-98. in Morganwalp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substances Hydrology Program--Proceedings of the Technical Meeting, Charleston, South Carolina, March 8-12, 1999--Volume 2--Contamination of Hydrologic Systems and Related Ecosystems: U.S. Geological Survey Water-Resources Investigations Report 99-4018B, in press.

Abandoned Mine Lands Initiative—Providing Science for Watershed Issues

USGS AML Science Team

Historical mining activities in the western U.S. have resulted in contaminated stream reaches in the headwaters of more than forty percent of the watersheds in and west of the Rocky Mountains. Acidic drainage and elevated metal levels affect water quality and the biota that live in these stream reaches, thereby damaging aquatic and riparian habitats, impacting human health, limiting recreational use, and lessening the aesthetic qualities of our public lands. Whereas the rocks exposed in the watershed control water chemistry, precipitation, evapo-transpiration, and temperature, depicted by ecoregions in the western U.S., are the primary variables that control the rate of weathering reactions and subsequent release of metals and acidity. There are more than 25,000 inactive mine sites and numerous exploration prospects in the western U.S., many of which are on Federal lands. Weathering of waste rock associated with inactive mines is one of the major sources of metals, but natural sources also affect stream reaches.

The geology of the watershed, that is the composition of the rocks and minerals exposed in the surface and near-surface environment within the watershed, control the surface and ground water chemistry through natural weathering processes. Exposure of pyrite to the atmosphere by past mining activity greatly accelerates the rate at which pyrite weathers to form sulfuric acid which, in turn, reacts with other sulfide minerals to release metals into the environment. The type of mineral deposit as well as the surrounding geologic setting within the watershed determine the acidity and metals released to the environment upon weathering. The relationship between pH and total metals in acidic drainage is a function of the mineral deposit characteristics. Weathering of altered rocks that surround mineral deposits may result in dispersed sources of natural acidic drainage within the watershed, or may contribute carbonate which will naturally buffer the acidity caused by weathering. Both processes must be evaluated when setting watershed-scale restoration goals.

The Abandoned Mine Land (AML) Initiative is a collaborative effort between the U.S. Geological Survey, Bureau of Land Management and National Park Service in the U.S. Department of the Interior, and the U.S. Forest Service in the U.S. Department of Agriculture. Two pilots were selected for study in 1996: the Animas River watershed in southwestern Colorado, and the Boulder River watershed in west central Montana. The science goals of the AML Initiative are:

- Develop multi-disciplinary methods of investigation that integrate geologic, hydrologic, geochemical and ecological data that can be transferred to Federal land managers,
- Provide Federal land managers with a scientific basis for successful watershed-scale mitigation strategies, and
- Create an integrated science database for use by the public, private entities, and government agencies to make land management decisions.

The science strategy for the AML Initiative is:

- Identify major sources of contaminants within the watershed,
- Determine the physical, chemical, hydrologic, and biological processes that control dispersion of contaminants,
- Determine the adverse effects on aquatic and riparian ecosystems, and
- Determine pre-mining watershed conditions to allow establishment of realistic restoration goals.

These studies are being conducted by a multi-disciplinary team of USGS scientists. AML project reports on these two pilot watersheds will be completed in 2000-2001.

The USGS AML science team is developing new multi-disciplinary methods to address fundamental watershed characterization needs:

- Characterize surface and ground water flow,
- Determine sources of acidic drainage,
- Evaluate impacts on aquatic and riparian habitats and biota,
- Assess suitable repository sites,
- Define pre-mining conditions in the watershed, and
- Use geospatial analysis to integrate science.

These tools are being developed to provide a scientific basis for effective mitigation actions at a watershed scale. The technology will be transferred to the Federal land managers for their use in watershed evaluation. Reports of the USGS scientific work are available on the internet at our AML web site at: http://rmmcweb.cr.usgs.gov/~rta/amli/. Please check this site for descriptions of specific ongoing scientific studies and for releases of our scientific results.

Successful watershed-scale restoration strategies should be developed with a knowledge of the topography, climate, geology, hydrology, and biological habitat needs of the specific environment. An understanding of the physical, geochemical, hydrologic, and biological processes must be articulated to the public in a way that balances human technical capabilities, economic limitations, and realistic restoration goals and timeframes. USGS scientists are working directly with stakeholders, including local and state agencies, private landowners and industry, and other Federal agencies including BLM, NPS, USFS, and EPA to address the restoration issues at the watershed scale and provide scientific data on our nation's clean water supply. In a science-based approach to restoration, our work provides data needed to:

- Characterize metal loads from sources within the watershed,
- Define attainable in-stream water quality standards,
- Prioritize inactive mine sites for cleanup,
- Determine feasible restoration scenarios for aquatic and riparian habitats, and
- Provide predictive models for cost effective analysis of mitigation options.

Examples of these activities include:

- Characterize metal loads contributed by sources along the stream reach to determine the relative contribution from these discrete sources to the total in-stream metal load,
- Determine water quality and habitat conditions that will allow recovery of aquatic and riparian ecosystems,
- Identify mine waste piles that generate large acid and metal loads, which if removed, would result in a significant improvement in water quality in the watershed,
- Evaluate mitigation options for large, dispersed metal sources attributable to pre-1935 milling activities where industry practice resulted in impoundment or dumping of mill tailings directly into stream valleys, and
- Analysis of seismic risk, groundwater flow paths, and geologic suitability of waste repository sites.

Poster prepared for public outreach use by the USGS Abandoned Mine Lands Science Team.