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Compiled by

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ELEMENT CHARACTERIZATION OF COALS FROM THE FRANKLIN COAL ZONE, PUGET GROUP, JOHN HENRY NO. 1 MINE, KING COUNTY, WASHINGTON

By
Michael E. Brownfield, Ronald H. Affolter, and James D. Cathcart
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Late middle and late Eocene coal-bearing strata in the Green River coal district are part of the undivided Puget Group. Coal-bearing strata accumulated in supratidal, intertidal, and deltaic environments along a tidally influenced delta plain. Numerous shale and tonstein partings within the coals suggest the mires were topogenous. To evaluate variations in element distribution within these coals, we collected vertical bench channel samples from the Franklin No. 7-8-9 (n=24) and the No. 10 (n=11) coal beds. Coal beds in the John Henry No. 1 mine have an apparent rank of high-volatile B bituminous and have a mean sulfur content of 0.67%, which is slightly lower then other western U.S. Tertiary coals.

When compared statisically to other western U.S. Tertiary coals the John Henry No. 1 mine coals are significantly higher in contents of ash, Si, Al, K, Ti, Ag, As, Cu, F, Ga, Hg, Li, Nb, Ni, P, Sc, Sr, V, Y, Yb, and Zr, and have significantly lower in contents of Ca, Na, B, Nd, and Se. Mean contents of several elements in the Franklin No. 7-8-9 and No. 10 coal beds are unusually high when compared to western U.S. Tertiary coals. The No. 7-8-9 bed is higher in Cu (4X, 42 ppm), Mn (2.7X, 170 ppm), Nb (4.4X, 10 ppm), Ni (3.4X, 16 ppm), V (4X, 68 ppm), and Zr (4.8X, 88 ppm). The No. 10 bed is higher in As (12X, 81 ppm), Hg (63X, 7.5 ppm), P(5.6X, 1300 ppm), Sc (4.2X, 8 ppm), and Sr (2.4X, 680 ppm).

X-ray diffraction analysis of the low temperature ash from the these coals detected quartz, clay (kaolinite, minor illite, smectite group, and mixed layer), plagioclase feldspar, and carbonate (calcite, siderite, and ankerite). Minor crandallite group minerals, pyrite, and zeolites were found. The presence of smectite group clays and mafic pyrogenic minerals (augite and hornblende) in the tonsteins suggest a volcanic source that was intermediate in composition.

The higher contents of F, P, Sr and Zr in the coals are the result of the alteration volcanic ash in the mires. Apatite, found in volcanic ash, contains major amounts of F and P, while feldspar and zircon are Sr- and Zr-bearing minerals, respectively.. Crandallite group minerals are major P minerals in the coals. Higher As and Hg contents result from post-Eocene hydrothermal mineralization. Mines in the nearby Green River Gorge contain cinnabar, realgar, and orpiment. Realgar and orpiment were found in a fractured sandstone above the No. 10 coal bed.

Geological Society of America Abstracts With Programs, V. 26, No. 7, 1994, Annual Meeting, p. A215

Distribution of hazardous air pollutant trace elements, total sulfur, and ash in coals from five Tertiary basins in the Rocky Mountain Region

by
Margaret S. Ellis, Gary D. Stricker, and Romeo M. Flores

A study of proximate and elemental analyses of Paleocene coals from 5 Tertiary basins in the Rocky Mountain Region indicate a relationship between trace element concentrations and Paleocene drainage patterns and provenances. Arithmetic mean values of the percentages of ash and sulfur and concentrations (in parts per million on a whole coal basis) of environmentally sensitive trace elements named in the 1990 Clean Air Act (antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium, and uranium), were statistically compared.

Most economic coals in the Rocky Mountain Region are found in the Williston, Powder River, Bull Mountain, Hanna, and North Park Basins. The Williston and Hanna Basins contain coals with the highest mean concentrations (in ppm) of environmentally sensitive trace elements (As=10.9, Be=1.2, Cd=.3, Co=1.4, C=7.1, Mn=78, N=14, P=9.7, Se=1.9, and U=4.5) and percents of ash and sulfur (19 and 1.9 respectively). Coals in the Powder River, Bull Mountain, and North Park contain considerably lower concentrations of these trace elements and ash, with the exception of the highest mean concentration of H (.4 ppm) in North Park coals, and S (1.7 ppm) in the Bull Mountain Basin.

Significant differences in the concentrations of environmentally sensitive trace elements, sulfur, and ash may be partly explained by the locations of the basins with respect to the fluvial-system continuums that drained them and the nature of the provenance uplifts. The Williston and Hanna Basins were located at the distal ends of two separate flow-through systems through Paleocene time. In these systems fine-grained detritus were derived from unroofing of mainly marine Paleozoic and Mesozoic sedimentary rocks and were deposited rapidly in subsiding basins. Most peat in these basins probably accumulated in low-lying or topogenous mires. The Powder River, Bull Mountain, and North Park Basins were at the proximal ends of two separate flow-through fluvial systems. In these basins coarser-grained detritus were deposited near provenance uplifts and peat accumulated in predominantly raised mires. Unusually high concentrations of H and S in some samples from the North Park and Bull Mountain Basins may be due to local variations in provenance uplifts and deposition of material from basement core rocks and volcanic sources, in the peat.

Ellis, M.S., Stricker, G.D., and Flores, R.M., 1994, Distribution of hazardous air pollutant trace elements, total sulfur, and ash in coals from five Tertiary basins in the Rocky Mountain Region: Eleventh Annual International Pittsburgh Coal Conference, Coal-Energy and the Environment-Abstract, Sept. 12-16, 1994, Paper No. 28-f (extended abstract *in* Eleventh Annual International Pittsburgh Coal Conference, Chiang, Shiao-Hung, ed., Coal-Energy and the Environment, v. 2, pp. 1106-1110.)

LATE CAMPANIAN COAL-BEARING AND TIDALLY INFLUENCED STRATA OF THE NESLEN FORMATION, BOOK CLIFFS, UTAH AND COLORADO

By Mark A. Kirschbaum, Robert D. Hettinger, and Peter J. McCabe

The 80 to 120 m thick Neslen Formation crops out along 100 km of the Book Cliffs. The formation contains coal beds, up to 2 m thick, interbedded with siliciclastic strata. In the west, lenticular sandbodies, up to 5 m thick, have crossbeds with unidirectional paleocurrent indicators, and are interpreted as fluvial channel deposits. The sandbodies grade downstream into inclined heterolithic units that contain cross lamination, mud drapes that extend all the way down the inclined surfaces, and a diverse trace-fossil assemblage. The inclined units are interpreted as the fills of tidal channels. Farther east, wavy-bedded units, burrowed sandstones and fossiliferous shales interfinger with cross-bedded sandstones that have multiple reactivation surfaces and bidirectional paleocurrent indicators. These units are interpreted as lower estuarine deposits.

In the east, the Neslen Formation is interbedded with hummocky and swaley cross-stratified beds of the Corcoran and Cozzette Sandstones, which are interpreted as shoreface deposits. Extensive erosion surfaces with up to 20 m of relief cut into the shoreface strata and are interpreted as sequence boundaries cut during lowstands of relative sea level. The erosion surfaces can be traced over distances of 30 km and are overlain by estuarine and coal-bearing strata. Although previous studies suggested a delta-top setting for coal deposition, the coals apparently formed within valleys as part of a transgressive systems tract.

Kirschbaum, Mark A., Hettinger, Robert D., and McCabe, Peter J., 1994, Late Campanian Coal-Bearing and Tidally Influenced Strata of the Neslen Formation, Book Cliffs, Utah and Colorado: American Association of Petroleum Geologists Program with Abstracts, v. 3, p. 188.

LATE CRETACEOUS PALEOGEOGRAPHY, SEDIMENT ACCUMULATION, AND COAL DISTRIBUTION, THE WESTERN INTERIOR OF MIDDLE NORTH AMERICA

By Laura N. Robinson Roberts and Mark A. Kirschbaum

A synthesis of Late Cretaceous paleogeography and sediment accumulation of the Western Interior, from Mexico to southwestern Canada, provides insight into the relative importance of sea-level variation and tectonism as factors controlling the distribution of Late Cretaceous coal. Results include a sequence of paleogeographic maps of six biostratigraphically constrained intervals that depict depositional environments and emphasize the areal distribution of peat-forming environments. Isopach maps of strata for each time interval were also constructed. Information from these maps, and a knowledge of sea-level variation during the Late Cretaceous, allowed comparison of areas of thick coal with areas affected by varying sediment accumulation rates and by varying sea level.

Thick peat accumulated during the early Cenomanian (Dakota Formation coal) on low-gradient alluvial plains where sediment accumulation rate was relatively slow, well inland from the rising Cretaceous Interior seaway. Thicker, more extensive peats formed from the latest Cenomanian to the middle Maastrichtian within a foreland basin east of the Sevier orogenic front. The majority of peat accumulated on coastal plains in the more actively subsiding parts of the foreland basin. This time interval is characterized by fluctuating shorelines resulting from the interaction of sediment supply, basin subsidence, and eustasy. During the late Maastrichtian, when Laramide deformation predominated, less significant amounts of peat accumulated (Lance Formation coal), either confined to intermontane basins, where sediment accumulation rate was high, or scattered over short-lived coastal plains that trailed the final retreat of the seaway from the Western Interior.

Roberts, L.N.R., and Kirschbaum, M.A., 1994, Late Cretaceous paleogeography, sediment accumulation, and coal distribution, the Western Interior of middle North America: American Association of Petroleum Geologists Program with Abstracts, v. 3, p 244.

ASHER-BOLINDER, SIGRID, and ROBERT A. ZIELINSKI, U.S. Geological Survey, Denver, CO

Irrigation Leacnes Uranium from Soils and Shales and Concentrates It in Arkansas Valley Waters of Southeastern Colorado

Irrigation of the semiarid Arkansas River Valley with oxidizing, alkaline waters accelerates the release of uranium from pyritic, calcareous marine shales and their derivative soils. Irrigation waters oxidize pyrite grains in shales and soils, producing localized, transient acidity that enhances liberation of uranium from the shale fraction. Uranium is stabilized in the still alkaline and oxidizing waters by the formation of uranyl-carbonate complexes.

Leaching experiments show that 30-60 percent more uranium islabile in irrigated shaley soils than in their similar unirrigated counterparts or in fresh shale bedrock. Less shaley soils, however, transmit oxidizing, alkaline irrigation waters downward to leach uranium from weathered shale bedrock. Seeps and springs that emerge at the soil-shale interface can contain 20-150 micrograms/L uranium; the proposed USEPA drinking water standard is 20 micrograms/L.

Irrigation also accelerates uranium concentration and transport in surface and groundwaters by increasing the frequency and duration of rock-water and soil-water interactions. Artificially elevated water tables, reuse of irrigation runoff, and recycling of shallow groundwater through irrigation pumping all increase the evaporative concentration of dissolved uranium and the runoff and return of high uranium waters to deeper aquifers.

Phosphate-rich liquid fertilizers containing as much as 150 mg/L uranium are used in parts of the Arkansas River Valley, and they are potential sources of additional uranium to surface and ground waters. Preliminary results of field and laboratory studies suggest that this added uranium may be sequestered in shallow soil horizons as relatively insoluble protoapatite-like compounds that formed through the combination of added phosphate and dissolved calcium in pore waters.

Asher-Bolinder, Sigrid, and Zielinski, R. A., 1994, Irrigation leaches uranium from soils and shales and concentrates it in Arkansas Valley waters of southeastern Colorado: 1994 AAPG Annual Convention Official Program, vol. 3, Denver, CO, p. 96/

REGIONAL GEOCHEMICAL STUDIES IN THE KAIBAB NATIONAL FOREST, ARIZONA

By M.A. Chaffee, R.R Carlson, and P.M. Theodorakos

The Kaibab National Forest, northern Arizona, consists of three separate areas--the North Kaibab area, located north of the Grand Canyon; the Tusayan area, located just south of the Grand Canyon; and the Chalendar area, located farther south near the Mogollon Rim. The regional geology of the three areas is relatively simple and consists of a sequence of generally flat-lying Paleozoic sedimentary rocks that are locally folded and (or) faulted and locally covered by volcanic rocks. In the North Kaibab area, most outcrops are of the carbonate-dominant Lower Permian Kaibab Formation. Outcrops in the Tusayan area mostly include the Kaibab Formation and Tertiary and Quaternary volcanic flows, tuffs, and cinder deposits. Rocks in the Chalendar area consist predominantly of Tertiary and Quaternary volcanic flows. The region is semiarid, and the forest contains no perennial streams.

The major known mineral resources of the Kaibab National Forest are in breccia pipes, formed in collapse structures in Paleozoic sedimentary rocks in and near the Tusayan area and just west of the North Kaibab area. Hundreds of pipes have been identified; many of these pipes are mineralized and some contain economic deposits of copper and (or) uranium. Associated elements commonly include Ag, As, Bi, Cd, Co, Fe, Mo, Ni, Pb, S, Sb, V, and Zn.

For our investigations, 478 samples of bulk sediment were collected from dry first- and second-order stream channels in the forest. The samples included organic-rich to clean mixtures of sand, silt, and (or) clay-sized material. In order to create a uniform sample medium, all samples were wet sieved and two fractions (0.5- to 2-mm and <0.25-mm) were saved. Samples from both fractions were analyzed for 39 elements (Ag, Al, As, Au, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cu, Eu, Fe, Ga, K, La, Li, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Sb, Sc, Sn, Sr, Th, Ti, U, V, Y, Yb, and Zn). The analyses of the coarser fraction were found to be the most useful because more analytical results of the mineral deposit-related elements were in the range of determination.

On a regional scale, the areal extents of the different major lithologies can be delineated on the basis of their chemistry. Of the 39 elements determined, Ba, Ce, Cr, La, and Na are particularly good lithologic discriminators. The regional chemical changes within a single formation can also be seen. In the North Kaibab and Tusayan areas, Ca and Mg show a distinct regional zoning within the areas containing the Kaibab Formation, with low concentrations in the topographically higher core areas and higher concentrations in the lower perimeters. This zoning may be related to differences in annual precipitation at different elevations. This difference can affect the rate at which these two elements are leached from the relatively soluble material forming the stream alluvium.

Of the ore-related elements listed above, three (As, Mo, and Sb) were derived solely from mineralized breccia pipe deposits and showed the best spatial correlation with known mineralization. In the Chalendar area, with limited exposure of Paleozoic sedimentary rocks, no significant geochemical anomalies were found that could be related to Cu/U-rich breccia pipe mineralization. The North Kaibab area contains hundreds of sink holes; however, none has yet been found to form a breccia pipe at depth or to be mineralized. Mineralized pipes are known only to the west of this part of the forest. In the Tusayan area widespread, significant anomalies for many ore-related elements extend well beyond the areas of known deposits, suggesting that additional mineralized breccia pipes may be present in that part of the forest.

From an environmental standpoint, the stream-sediment data show that there has been only minor dispersal of material from mine dumps or prospects. Many of the elements associated with the copper-uranium mineralization in the Kaibab National Forest may be toxic to plants and(or) animals if these elements are present in high concentrations and in a biologically available form. It is beyond the scope of this investigation to determine whether any of the elements studied represent an environmental hazard.

Chaffee, M.A., Carlson, R.R., and Theodorakos, P.M., 1994, Regional geochemiical studies in the Kaibab National Forest, Arizona, *in* Carter, L.M.H., Toth, M.I., and Day, W.C., eds., USGS research on mineral resources--1994, Part A---Program and abstracts: U.S. Geological Survey Circular 1103-A, p. 15-16.

ATMOSPHERIC TRANSPORT OF ATRAZINE AND ITS SUBSEQUENT DEGRADATION AT ISLE ROYALE NATIONAL PARK

By Aron E. Cromwell and E. Michael Thurman

Atrazine used in agricultural areas is being transported atmospherically and deposited by precipitation onto pristine watersheds. The fate of atrazine was studied at Isle Royale National Park, an island park located in Lake Superior on the United States-Canadian border. Samples of rainfall, soil water, surface water, and soils were analyzed by combining solid-phase extraction (SPE) with enzyme-linked immunosorbent assay (ELISA). This SPE-ELISA combination enabled the field analysis of water samples in which the concentrations of atrazine were as low as 5 ng/L (nanograms per liter). The SPE-ELISA results were confirmed using gas chromatography/mass spectrometry (GC/MS) with isotope dilution. Maximum atrazine concentrations in rainfall occurred in late spring, approaching the U.S. Environmental Protection Agency Maximum Contaminant Level (MCL) in drinking water of 3.0 micrograms per liter. By mid-summer, rainfall concentrations of atrazine had decreased to less than 5 ng/L. Atrazine was found in small concentrations in water from all lakes that were sampled. Field data indicate that atrazine degrades rapidly in soil environments but more slowly in aquatic environments. This slow degradation rate in water has important implications for the quality of lakes in pristine areas receiving atrazine-contaminated rainfall because of the potential for accumulation of atrazine in the ecosystem.

Cromwell, Aron E. and Thurman E. Michael, 1994, Atmospheric transport of atrazine and its subsequent degradation at Isle Royale National Park [Abs.]: U.S. Geological Survey Water-Resources Investigations Report 94-4015, in press.

PROBABILISTIC RELATIONSHIPS BETWEEN NUMBER OF VEHICLES AND NUMBER OF VISITORS AT A GEOLOGIC SITE IN A NATIONAL PARK

By Robert A. Crovelli

Probabilistic relationships were developed between the number of vehicles (N) at one time in the Wolfe Ranch parking lot and the number of visitors (X) at Delicate Arch 1.5 miles away in the Arches National Park, southeastern Utah. The value of N is determined such that 30 or more visitors are at the arch only 10 percent of the time.

Crovelli, R.A., [submitted], Probabilistic relationships between number of vehicles and number of visitors at a geologic site in a national park [abs.]: The Institute of Management Sciences/Operations Research Society of America (TIMS/ORSA) Joint National Meeting, Los Angeles, California, April 23-26, 1995.

A FIRST APPLICATION OF ELISA FOR SCREENING CYCLODIENE INSECTICIDES IN GROUND-WATER

By T. Dombrowski and E.M. Thurman

Commercially available ELISA plate kits for screening of cyclodiene insecticides (including aldrin, chlordane, dieldrin, endosulfan, endrin, and heptachlor) were evaluated for sensitivity, cross reactivity, and overall performance as applied to ground-water samples from a contaminated site. Ground-water contaminants included several pesticide compounds and their manufacturing by-products, as well as many other organic and inorganic compounds. Cross-reactivity studies were carried out for the cyclodiene compounds of known sensitivity, and results were compared to those values listed by the manufacturer. Data obtained were used to evaluate the sensitivity of the ELISA kits to the cyclodiene compounds in (1) spiked samples using distilled water as a matrix and in (2) spiked samples using ground water with known contamination as a matrix. The method detection limit for the ELISA kit was ~ 15 µg/L (as chlordane). Gas chromatography/mass spectrometry (GC/MS) methods for cyclodiene compounds were developed as a verification for the ELISA method. Of approximately 50 ground-water samples analyzed using the ELISA plate kits, more than 70% showed cyclodiene insecticide contamination. The plate kit shows excellent potential as a screening technique for sites with suspected ground-water contamination.

Dombrowski, T. and Thurman, E.M., 1994, A first application of ELISA for screening cyclodiene insecticides in ground water [Abs.]: Immunochemistry Summit III, August 24-25, 1994, Las Vegas, Nevada.

DETERMINING THE THREE-DIMENSIONAL DISTRIBUTION AND TRANSPORT OF HERBICIDES IN RESERVOIRS USING EARTH VISION AND IMMUNOASSAY

By J.D. Fallon, E.M. Thurman, and D.P. Tierney

Earth Vision software simulated the three-dimensional distribution and transport of herbicides in a reservoir. Enzyme-linked immunosorbent assay, with confirmation by gas chromatography/mass spectrometry, inexpensively determined the atrazine concentrations of 536 water samples from a reservoir. From March 1992 to March 1993, five surveys of Perry Reservoir, Kansas, revealed that atrazine concentrations varied with the timing of precipitation, magnitude of runoff, and residence time of the reservoir. After herbicide application, a runoff pulse with atrazine concentrations as large as 27 μg/L flushed into the reservoir. Three-dimensional images showed the wedge-shaped pulse attenuated by diffusing into water containing smaller concentrations from the previous year (0.1-4.9 μg/L). A second runoff peak in July contributed approximately one-third of the total annual atrazine mass to the reservoir, before autumn runoff diluted atrazine concentrations. Runoff temporarily compressed residence times of water and accelerated the mass flux of herbicides. Gas chromatography/mass spectrometry analyses determined concentrations of other herbicides, including two atrazine metabolites, deethylatrazine and deisopropylatrazine. The ratios of deethylatrazine to atrazine helped to define the relative age of atrazine in the reservoir. Small ratios (0.09 to 0.13) identified runoff that entered the reservoir immediately after herbicide application, and larger ratios (0.13 to 0.25) identified water that entered the reservoir later in the study.

Fallon, J.D., Thurman, E.M., and Tierney, D.P., 1994, Determining the three-dimensional distribution and transport of herbicides in reservoirs using earth vision and immunoassay [Abs.]: Eighth International Congress of Pesticide Chemistry, July 4-9, 1994, Washington, D.C.

WATER FACT SHEET
U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM—Ozark Plateaus

BACKGROUND

The U.S. Geological Survey (USGS) began to implement a National Water Quality Assessment (NAWQA) program during 1991 to provide a nationally consistent description of water-quality conditions for a large part of the Nation's water resources. The long-term goals of the NAWQA program are to describe the status and trends in the quality of the Nation's ground- and surface-water resources and to provide a sound understanding of the natural and human factors that affect the quality of these resources. To meet these goals, the program will produce and integrate water-quality information useful to policy makers and managers at different areal scales—local, study unit, regional, and national.

Investigations will be conducted on a rotational basis in 60 river basins or aquifer systems (referred to as study units) throughout the Nation, with assessment activities commencing in 20 study units in 1991. The study-unit investigations comprise the principal building blocks of the program on which regional- and national-level assessment activities will be based. The 60 study units cover areas that range in size from 1,200 to more than 65,000 square miles and incorporate about 60 to 70 percent of the Nation's water use and population served by public water supply.

Regional and national synthesis of information from the study units will be the foundation for the comprehensive assessments of the Nation's water quality. Nationally consistent information on water quality, and factors such as climate, geology, hydrology, land use, and agricultural practices will be integrated to focus on a specific water-quality issue that affects large contiguous hydrologic regions. For example, a concern that will be addressed early in the program is the relation of the presence of pesticides in ground and surface water to application rates and cropping practices, and to climatic, geologic, and soil factors. In 1991, the Ozark Plateaus region was among the first 20 NAWQA study units selected for study under the full-scale implementation plan.

DESCRIPTION OF THE OZARK PLATEAUS STUDY UNIT

The Ozark Plateaus study unit is approximately 65,000 square miles in size and includes parts of four States: northern Arkansas, southeastern Kansas, southern Missouri, and northeastern Oklahoma. The boundaries of the study unit approximate the natural flow boundaries of the Ozark Plateaus aquifer system.

The extensive karst features of the Ozark Plateaus create an intricate ground-water flow system, which results in rapid and complex interactions between ground and surface water. The vast network of solution channels and conduits in the mostly carbonate aquifers directly affects the fragile environment in the study unit. Contaminants are transported quickly from recharge areas, which often include sinkholes and losing streams; the contaminants then are intercepted by wells or discharged at springs. Water-quality degradation has occurred in many areas as a result of land-use practices and increased agricultural and industrial activity.

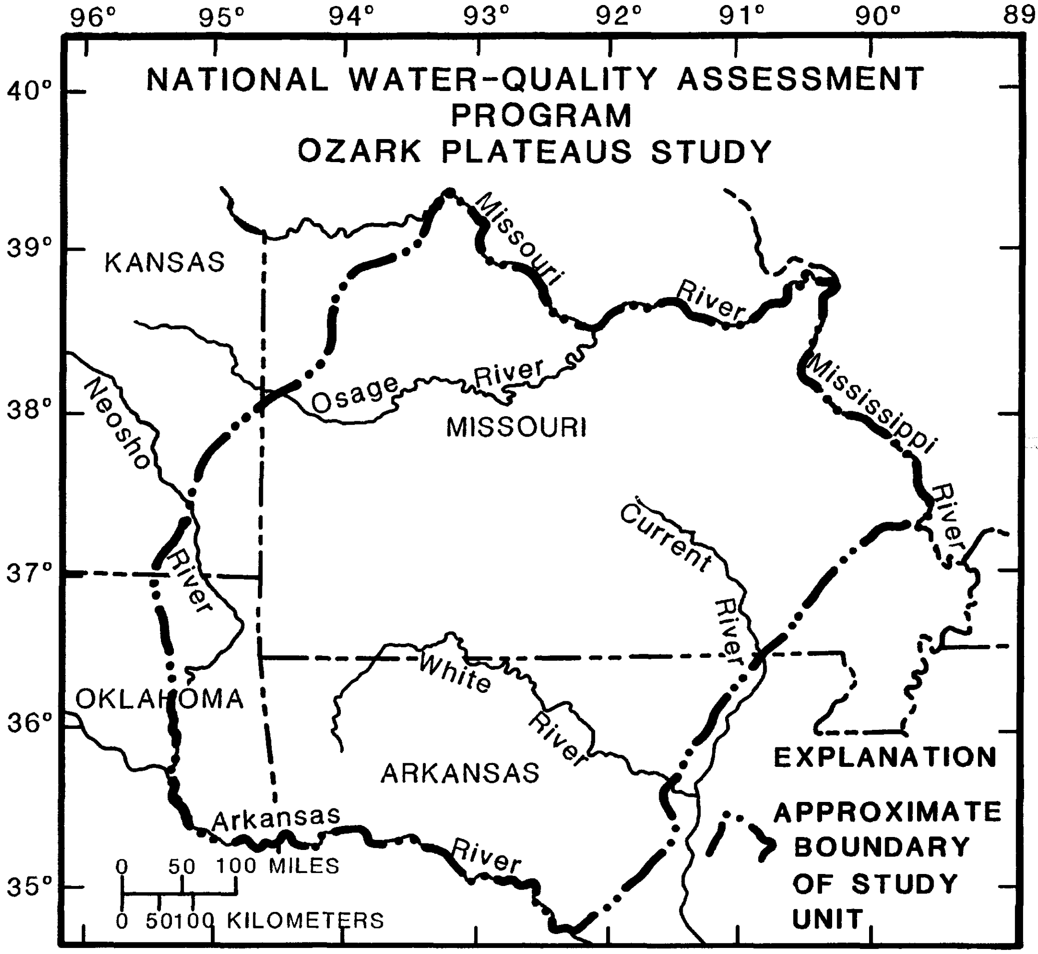
WATER-QUALITY ISSUES

Recurring local and regional problems related to managing and protecting water quality in the Ozark Plateaus study unit will be addressed. Waste products from poultry, cattle, and swine production, along with waste discharges from septic tanks, sewage-treatment lagoons, and municipal wastewater-treatment facilities have introduced elevated concentrations of nitrate, ammonia, and bacteria in surface and ground water in the area. Degradation locally in the quality of surface and ground water has occurred because of abandoned lead and zinc mines in parts of Kansas, Missouri, and Oklahoma, and active lead mining in southeastern Missouri. Elevated levels of radionuclides (radium 226 and 228) are evident in numerous public water-supply wells throughout the Ozark area, and highly saline ground water along the western boundary has resulted in abandoned wells. Hazardous-waste sites, underground storage tanks, solid-waste landfills, and the transportation of petroleum products and agrichemicals via railroads, trucking, and pipelines are other potential major sources of contamination.

STUDY OBJECTIVE AND APPROACH

The objective of the Ozark Plateaus NAWQA study is to identify, describe, and explain the major factors that affect observed water-quality conditions and trends. Major activities include formation of a liaison committee during the initial planning stage for external coordination of local interests; compilation and analysis of existing water-quality information; network design and intensive sample collection and analysis for a wide array of physical, chemical, and biological properties for ground- and surface-water resources; and interpretation and reporting of results.

External coordination at all levels is an integral component of the NAWQA program in the Ozark Plateaus study. Information exchange and coordination through a study-unit liaison committee will help ensure that the water-quality information produced by the program is relevant to local and regional



interests. The Ozark Plateaus NAWQA liaison committee will include representatives from academia; local, State, and Federal agencies; and the private sector with water-related technical and management interests in the Ozark Plateaus region of Arkansas, Kansas, Missouri, and Oklahoma.

Water-quality data available from all sources will be assembled, screened, evaluated, and stored in a computerized USGS data base during the early phase of the study. These data will provide an initial description of water-quality conditions and help define additional data needs. Supplemental data, including quality assurance and ancillary information, such as local climate, geology, hydrology, land use, and agricultural practices, also will be stored in the computerized data base.

A 3-year sample network design and intensive sample-collection program will emphasize regional water quality, including water-quality degradation caused by point and non-point sources. Fixed-station surface-water sampling will describe the seasonal and long-term variation and frequency of the occurrence of selected water-quality constituents at selected sites; intensive sampling at a large number of sites during a short period will provide an instantaneous description of conditions for specific times; and studies of selected stream-sampling reaches will address narrowly focused water-quality issues. Ground-water sampling activities include regional sampling throughout each major aquifer, targeted sampling of known or suspected water-quality problem areas, and long-term sampling to describe trends.

Analysis of water samples will focus on a national list of physical properties and target constituents, including pesticides and other synthetic organic compounds, nutrients, certain metals and trace elements, radionuclides, and sediment. Biological measurements will be used to assess the biological processes that affect the physical and chemical aspects of water quality as it relates to the protection of fish and wildlife resources and public health.

The Ozark Plateaus NAWQA study will be headquartered in the USGS, office in Little Rock, Ark., with assistance from USGS personnel in Lawrence, Kans.; Rolla, Mo.; and Oklahoma City, Okla. Further information on the National Water-Quality Assessment program and the Ozark Plateaus study can be obtained from:

District Chief, Water-Resources Division
U.S. Geological Survey
2301 Federal Office Building
700 West Capitol Avenue
Little Rock, Arkansas 72201

Open-File Report 91-162 D.A. Freiwald, 1991

PART-PER-TRILLION ANALYSIS OF SOIL FOR ATRAZINE USING IMMUNOASSAY

By Brandan J. Hill, Diana S. Aga, E.M. Thurman, and Kyle E. Juracek

Soils from an agriculture-intensive area in Harvey County, Kansas, were analyzed for the herbicide atrazine during the 1992 and 1993 growing seasons. Enzyme-linked immunosorbent assay (ELISA) was performed on three sets of 60 soil cores collected at varying depths along the soil profile during pre-plant and post-harvest periods. A 3:1 methanol/water mixture was used to extract atrazine from the soil, followed by a clean-up procedure using solid-phase extraction (SPE). The SPE extract was evaporated to dryness, reconstituted in 2 mL of 20% methanol/water solvent, and analyzed by immunoassay using a commercially available magnetic particle-based ELISA test kit. By coupling ELISA with SPE, samples were characterized for atrazine with a detection range of 20 ppt to 1 ppm. A subset of the soil-core samples was analyzed by gas chromatography/mass spectrometry (GC/MS), which confirmed the ELISA results (r^2+0.83). SPE linked to ELISA was shown to be a cost-effective method for the analysis of herbicides in soil.

Hill, Brandan J., Aga, Diana S., Thurman, E.M., and Juracek, Kyle E., 1994, Part-per-trillion Analysis of Soil for Atrazine using Immunoassay [Abs.]: American Chemical Society, 207th ACS National Meeting, March 13-18, 1994, San Diego, California.

TERTIARY AND QUATERNARY ALLUVIAL HISTORY OF THE LOWER VIRGIN AND MUDDY RIVERS, CLARK COUNTY, NEVADA

WILLIAMS, Van S., U.S. Geological Survey, Box 25046, MS 913, Federal Center, Denver, CO 80225

Deposits of river, pediment, and fan alluvium along the lower Virgin and Muddy rivers of southern Nevada record at least four cycles of incision and aggradation. For 72 km from the west edge of the Virgin Mountains to Lake Mead, the Virgin River flows across the Mesquite basin in a narrow valley incised in sandy basin-fill deposits of the Miocene Muddy Creek Formation (Tmc). The river was not present in the basin while most of Tmc was being deposited, but localized thin beds of distinctive gravel in the uppermost 50 m indicate the river had entered the basin prior to the start of incision. During the earliest cycle, the Virgin River incised more than 200 m to an altitude equal or lower than that of the present stream bed, and then aggraded more than 100 m. Breaching of the closed Muddy Creek basin is a likely cause of the first cycle. The incision probably began about 5.5 Ma, shortly after stream capture diverted flow from the upper part of the Colorado River basin into the lower part of the Muddy Creek basin. Subsequent cycles of lesser magnitude probably resulted from climate fluctuations. Gravelly terrace surfaces about 60 m above the present stream bed are estimated to be of middle Pleistocene age based on development of calcic soil horizons. An extensive late Pleistocene gravel terrace occurs at 20 m, and a sandy Holocene terrace at about 6 m. Graded to the terraces are wide pediment surfaces that have been cut on the soft Tmc sediments along the Virgin River between the Virgin Mountains and Mormom Mesa. Deposits along the Muddy River described by Gardner in 1968 and 1972 correlate with those along the Virgin River.

Williams, V.S., 1994, Tertiary and Quaternary alluvial history of the lower Virgin and Muddy Rivers, Clark County, Nevada: Geological Society of America Abstracts with Programs, v. 26, n. 7, p. A-302.

COMPUTER ATLAS AND DATABASE OF EARTHQUAKE INTENSITIES FOR THE CENTRAL UNITED STATES

By Margaret G. Hopper

Information about earthquake damage and other effects has historically been organized as separate reports on each earthquake. Obtaining information about effects at a given site for multiple earthquakes is a laborious process of searching many publications. This computer atlas brings together into one easily searchable database all the damage-level data for sites in the region around the New Madrid seismic zone.

The atlas includes (1) regional seismicity maps, (2) a list of epicenters, (3) an isoseismal map for each shock, (4) a list of accounts and interpreted intensities for each shock, and (5) a FIND utility. Navigation buttons easily transfer the user among the various parts of the atlas. The atlas is designed for ease of use by anyone interested in the distribution of earthquake damage in the central United States.

The FIND utility is designed to quickly answer such questions as: "How many times have earthquakes caused architectural damage (Modified Mercalli intensity ≥ VII) at St. Louis?" (the found list shows six earthquakes—in 1811, 1838, 1895, 1917, 1947, and 1968). "How many times have earthquakes caused architectural damage in the St. Louis area (e.g. ± 1° from St. Louis or 37.6–39.6°N, 91.2–89.2°W)?" (eight—the above list plus 1891 and 1903). "How many earthquakes with maximum intensity ≥ VI have occurred in Tennessee?" (seven—in 1865, 1889, 1952, 1955, 1962, 1980, and 1981). "How many earthquakes have caused damage (site intensity ≥VI) in Tennessee (including out-of-state epicenters)?" (22—with 68 total accounts listed). "What is the highest intensity that has been experienced at Memphis?" (VII in 1843 and again in 1865. VI was experienced there in 1878, 1889, 1895, 1970, and 1976.) "What places in Missouri have experienced structural damage (intensity ≥ VIII) from earthquakes?" (Caruthersville (Little Prairie), Charleston, Dorena, and Puxico based on accounts and intensity estimates. Additional places not having actual accounts in the database could be inferred from inspection of the isoseismal maps.)

The U.S. Geological Survey plans to publish the atlas as a read-only application requiring no additional software for use on either Macintosh or IBM personal computers. In addition, the atlas will be available to researchers having access to FileMaker Pro, the database manager in which the atlas was developed. Researchers will be able to do complex searches on the central United States data and will also be able to import their own intensity data into empty copies of the database, enabling them to take advantage of the developed structure.

Hopper, M.G., in press, Computer atlas and database of earthquake intensities for the central United States [abs.]: Seismological Research Letters, v.65, no. 4.

Geologic Implications from Gravity Anomaly Maps of the Crescent Valley 1/2° x 1° Quadrangle Including Pine Valley, Nevada

Four hundred and twenty new gravity stations have been added to the data set (USGS, OF 91-386) for the Crescent Valley quadrangle, north-central Nevada (lat 40°00' to 40°30'N., long 116°00 to 117°00'W). These combed data provide new subsurface structural constraints in an area of geologic and economic importance. The quadrangle contains the mid-Miocene northern Nevada rift and the middle Paleozoic Roberts Mountains thrust. Pine Valley is one of only two valleys within Nevada that is currently producing oil. One of the largest gold discoveries in recent years was made at the southwestern end of Crescent Valley.

Complete Bouquer, isostatic residual (IRA), and horizontal gradient anomaly gravity maps have been generated and are included in this study. The IRA map shows that the Blackburn and Three Bar oil fields lie near a gravity saddle across the middle of the large (-32 mGal) gravity low over Pine Valley. At least three of the oil fields in Pine Valley were discovered on small gravity anomalies (Nevada Petroleum Society, 1990 Fieldtrip Guidebook). Interpretations of the IRA map, seismic data, and Jachens and Moring's (USGS, OF 90-404) density-depth model show Pine Valley to be the deepest basin in the quadrangle, with an estimated 5 km of Cenozoic fill. In the southwest portion of this quadrangle, a -28 mGal gravity low is centered over what may be a Tertiary caldera. The recent gold discovery appears to be located near the northeastern boundary of the caldera.

Robbins, S.L., Williamson, Courteney, and Oliver, H.W., 1994, Geologic implications from gravity anomaly maps of the Crescent Valley 1/2° x 1° quadrangle including Pine Valley, Nevada [abs]: American Association of Petroleum Geologists Annual Convention June 12-15, Denver, Colorado, Official Program, v. 3, p. 244.

REE, Th, Nb, F ENRICHMENT IN THE NEW MADRID TEST WELL, REELFOOT RIFT, SOUTHEAST MISSOURI-- EVIDENCE OF A DEEP CARBONATITE COMPLEX?

By S.F. Diehl and M.B. Goldhaber

Geochemical and petrographic studies of Paleozoic (Bonneterre Formation?) limestone/dolomite breccia samples from the New Madrid test well (NMTW) at the crest of the Pascola arch in the Reelfoot rift, southeast Missouri, have shown the carbonate-free fractions of Paleozoic rocks in this well to be highly enriched in Nb (500 ppm), La (500 ppm), Th (1,000 ppm), and F (2,400 ppm) compared to other midcontinent Paleozoic carbonates. Pb-isotope ratios of this fraction are enriched in ^{208}Pb relative to ore and non-ore samples from correlative rocks.

In the NMTW core, microcrystalline clusters of rare-earth, Th, U, and sulfide minerals occur primarily in vugs or along a fracture network at 629.1-628.8 m and 641.9-634.9 m. Scanning electron microscope and energy-dispersive X-ray data are consistent with allanite, zircon, monazite-group minerals such as cheralite, and rhabdophane-group minerals such as brockite. These epigenetic minerals encrust etched hydrothermal saddle and ferroan dolomites that line the vugs. This REE and metal mineralization postdate the regional Paleozoic Mississippi-Valley type ore-fluid flow event that produced hydrothermal dolomite. Epigenetic minerals also contain high contents of Ba, Zn, Pb, Cr, Y, and V.

The REE, Th, U-mineral assemblage, Pb isotope ratios, and elemental enrichments are similar to the Hicks Dome carbonatite complex at the northeast edge of the rift and to the Magnet Cove carbonatite near the southwest portion of the rift. We interpret the observed alteration mineralogy to indicate hydrothermal activity associated with a deep carbonatite body. Well and spring-water samples in and near the Pascola arch are enriched in fluorine, which may indicate that the hydrothermal alteration is widespread.

Published geophysical data suggest that the NMTW lies at the margin of an igneous ring complex and is underlain by an ultramafic igneous body. The Reelfoot rift is an intracontinental failed rift system and is a suitable structural site for carbonatite activity. By analogy with similar igneous complexes in the midcontinent and elsewhere, the Pascola arch area is prospective for fluorite, Nb, REE, Th, Ti, and P deposits.

Diehl, S.F., and Goldhaber, 1994, REE, Th, Nb, F enrichment in the New Madrid test well, Reelfoot rift, southeast Missouri--Evidence of a deep carbonatite complex?: Geological Society of America, Annual Meeting, Programs with Abstracts, v. 26, no. 7, p. A500.

THE DEVELOPMENT AND APPLICATION OF AN ANALYTICAL METHOD FOR THE DETERMINATION OF GOLD IN GROUND WATER

MC HUGH, J.B., AND GRIMES, D.J.

An analytical technique was developed to determine low levels of gold in ground water samples collected around disseminated gold deposits in Nevada. A one-liter water sample is filtered, acidified, and brominated, and the gold-complex is extracted with an anion resin. The gold on the resin is eluted with an acetone/nitric acid solution and evaporated to dryness. The evaporite is taken up with a hydrobromic acid/bromine solution and extracted with methyl isobutyl ketone. The extract is electrothermally atomized in an atomic-absorption spectrophotometer. The limit of determination is 1-part-per-trillion.

Ground water samples were collected from drill holes near the Pinson, Rabbit Creek, and Summer Camp disseminated gold deposits in northern Nevada. The water samples were analyzed for gold at the 1-part-per-trillion level to determine if gold is being hydromorphically mobilized from these deposits. Analytical results indicate the presence of hydromorphic dispersion anomalies of gold in the ground water associated with the buried disseminated gold deposits.

McHugh, J.B., and Grimes, D.J., 1993, The development and application of an anlytical method for the determination of gold in ground water [abs.]: AEG, 16th International Geochemical Exploration Symposium, Sept. 1-6, 1993, Beijing, China, p.130.

GENESIS OF THE HOMESTAKE BRECCIA Au-Ag-Cu DEPOSITS, NEW WORLD DISTRICT, COOKE CITY, MONTANA

by
Bradley S. Van Gosen

The Homestake mineral deposits 2.5 miles north-northwest of Cooke City, Mont., are hosted by a heterolithic breccia pipe composed of mineralized and altered bodies of intrusion breccia, rotated shatter zones in host sedimentary and intrusive rocks, and diatreme breccia. Within the breccia complex, blocks and clasts of limestone were selectively replaced by massive sulfide- and iron-oxide minerals rich in Au, Ag, and Cu. The Homestake breccia developed within a dacite porphyry stock, one of four superimposed Tertiary intrusive complexes in the northern part of the New World mining district. Crown Butte Mines and Noranda Exploration discovered the Homestake deposits during exploratory drilling in 1990. Identified resources are estimated at 6.6 million tons of ore containing more than 1.478 million ounces of Au, 93.7 million pounds of Cu, and 5.478 million ounces of Ag. Proposed development of these resources is currently in a late stage of permit review.

The Homestake stock, hosting the breccia bodies and the ore deposits, was emplaced during the Eocene, about 40-44 Ma. The magma chamber intruded a part of the Cooke City sag zone, a northwest-trending zone of crustal weakness formed in Precambrian rocks of the region. Intrusion by the Homestake magmas locally uplifted roof rocks and, at lower horizons, assimilated and entrained Cambrian strata into the ascending intrusive body while concurrently injecting intrusion breccias. At the same time, a metasomatic halo of calc-silicate alteration developed in the clastic Cambrian strata enveloping the intrusive body. Solidification of the intrusion breccias was followed by multiple events of hydrothermal shattering, which were accompanied by a flood of relatively oxidized sulfur-rich fluids that permeated upward through the Homestake breccia. Argillic alteration developed in the deep intrusion breccias nearly simultaneous with the massive replacement of limy clasts and blocks in upper breccias (fragmented Cambrian strata) by ore minerals. Cross-cutting and inclusion relations observed in thin sections show that the hydrothermal fluids simultaneously (or nearly so) precipitated a replacement ore assemblage of abundant pyrite, chalcopyrite, specularite, and magnetite; the assemblage also includes trace amounts of argentiferous galena, native gold with silver, a Ag-Bi-sulfosalt, a Cu-Bi-sulfosalt, mckinstryite, aikenite, and tetrahedrite. After ore deposition, phreatic explosions burst through the breccia complex, forming vertical, pipe like bodies of diatreme breccia, followed by collapse of the entire complex. Dikes and sills then invaded cavities and other weak zones in the complex and vicinity, but they imparted only minor mineralized material.

Van Gosen, B.S., 1994, Genesis of the Homestake breccia Au-Ag-Cu deposits, New World district, Cooke City, Montana: Geological Society of America Abstracts with Programs, v. 26, no. 6, p. 67.

Natural Desorption of Gas as a Cause of Overpressuring in the Madden Anticline, Wind River Basin, Wyoming

C.E. Barker, B.L. Crysdale, U.S. Geological Survey

Increasing burial in the Lake Cretaceous Mesaverde Group coals from southwest to northeast across the Wind River Basin has produced thermogenic gas during peak burial at about 37 to 10 Ma and at peak paleotemperatures of 80-200°C. Peak temperatures appear to have been produced by an increase in heat flow related to a period of volcanism around 22 Ma in the southwestern Wind River Basin and 22 to 25 Ma throughout northwest Wyoming. Except for portions of the basin trough, peak temperatures have now locally declined because of reduced heat flow and erosion of about 3,000 ft of rock. Kinetic modeling shows that the present day, below peak, temperatures are insufficient for ongoing gas generation.

Overpressuring of sandstones in the Mesaverde Group is still observed although active thermal gas generation apparently ceased near 10 Ma when basin cooling commenced. Present-day overpressuring is attributed to desorption of gas from coals during decompression as the basin is eroded. Industry experience shows that coal can contain 3 to 4 times the gas contained in a sandstone reservoir of similar thickness. Thus, desorption from coal is a possible voluminous source of late gas. If our hypothesis is correct, the filling of gas traps after the onset of erosion is mostly driven by optimal coal bed gas storage capacity and retention occurs at about 1.1 to 1.5% mean random vitrinite reflectance ($R_{v\text{-}r}$), our present depth-$R_{v\text{-}r}$ data suggest that overpressuring should occur near a depth of 7,000 to 15,000 ft depending on the local thermal maturation gradient. Pressure data from drill stem testing indicates that this is the approximate depth range of overpressuring within the Mesaverde Group.

We conjecture that much of the tight gas found in Laramide basins, which are often eroded, may be the result of late gas desorption from coal. This late gas desorption would charge sandstones that have a lowered porosity resulting from prior diagenesis at higher burial depth and temperatures. Also, the widely observed changes in the coal rank gradient near the top of overpressured zones may be the result of heating caused by the rise of warm fluids driven by natural gas desorption occurring below.

Paper 28-g, Abstracts, 11th Annual Pittsburgh Coal Conference, September 12-16, 1994, unpaginated.

CRYSDALE, B.L. and C.E. BARKER, U.S. Geological Survey, Denver, CO

Comparison of Vitrinite Reflectance Models: Examples from the Late Cretaceous Mesaverde Formation, Wind River Basin, Wyoming

Reconstruction of the post-Early Cretaceous burial history of the Wind River Basin indicates almost continuous deposition in the basin trough from the Late Cretaceous to the end of the Laramide orogeny in the early Eocene. Upper Cretaceous Mesaverde strata in the basin trough reach a depth of 18,500 ft, a present temperature of more than 200°C, and mean random vitrinite reflectance (R_{v-r}) of more than 2.0%. In contrast, the Mesaverde Formation along the southwestern margin of the basin records several cycles of deposition and erosion and has reached only 80°C and 0.5% R_{v-r}. Peak temperature (T_{peak}) in the basin was reached during maximum burial in Oligocene to Miocene time, and most of the basin has now cooled by 10-20°C due to regional uplift beginning about 10 Ma.

Cyclical deposition of the Mesaverde Formation on the basin margin versus continuous deposition in the basin trough allows different vitrinite reflectance evolution models to be compared by tracking one rock unit through a wide range of temperatures and burial conditions. A limited-heating-duration vitrinite reflectance geothermometer model, based on T_{peak} and an R_{v-r} data set from Barker and Pawlewicz (1993), was compared to the unlimited-heating-duration LLNL kinetic model. Burial temperature was assessed by varying heat flow until peak paleotemperature matched the prediction from fluid inclusions or from the vitrinite reflectance geothermometer. These comparisons suggest close agreement between predicted and observed vitrinite reflectance and peak temperature. The LLNL kinetic model implies vitrinite reflectance evolution ceases within 10 m.y. after T_{peak} is reached in wells where temperature remains near maximum during the peak burial phase. Both models indicate that the continuing effects of vitrinite reflectance reactions are restricted soon after T_{peak} is reached.

American Association of Petroleum Geologists 1994 Annual Convention, Abstracts with Programs, v. 3, p. 129.

3-D Fluid-flow model of the House Creek field, Powder River Basin, Wyoming

By Debra K. Higley

Oil is produced from four separate marine-ridge sandstones of the Upper Cretaceous Sussex "B" sandstone in the House Creek field. Compartmentalization of these ridges results from complex interbedding of high- and low-depositional-energy facies, from laterally continuous permeability boundaries, and from early-diagenetic cementation of some sandstone beds. Core porosity, permeability, and bulk-density porosity for more than 120 wells were used with well-log, outcrop, and petrologic data to map the distribution of porosity in three dimensions for lithologic layers within the field. 3-D gridding and display techniques used EarthVision computer modeling on an IRIS workstation. Shown on the computer model are 1) stacking patterns of the four sand ridges, 2) permeability barriers and areas of potential bypass of production, 3) lateral and vertical distribution and 4) connectivity of porous sandstones.

The four major reservoir sand ridges step shoreward in an upward direction--this corresponds to transgressive deposition of the offshore-marine Sussex sand-ridge system. Sand ridges consist of mainly tabular, massive to ripple-laminated, fine-grained sandstone; trough cross-bedded to planar-tabular bedded fine to medium-grained sandstone is concentrated near the top of the "B" sandstone and along the eastern field margin. Both upper and lower reservoir layers exhibit an upward increase in porosity and a corresponding increase in sandstone grain size; both reservoir intervals are perforated in most wells. Sandstones with the highest depositional energy exhibit the greatest porosity--these are largely the upper and ocean-facing trough cross-bedded units. Average porosity for reservoir sandstones is about 13 percent; reservoir-grade porosity is greater than 8 percent.

Higley, D.K., 1994, 3-D Fluid-flow model of the House Creek field, Powder River basin Wyoming: American Association of Petroleum Geologists Bulletin, June 12-15 National Convention program and abstracts.

Pre-Oligocene structure of central Railroad Valley area and adjacent Pancake Range, Nevada, western margin of the Paleogene Sheep Pass Basin

By W.J. Perry, Jr. and J.A. Peterson

Lacustrine rocks of the Paleocene to Eocene Sheep Pass Formation, penetrated in wells of the Eagle Springs Oil Field in eastern Railroad Valley, Nevada, rest unconformably on Pennsylvanian Ely Limestone and are buried beneath younger Tertiary volcanic rocks. Three miles to the west, the Meridian 32-29 Federal deep test penetrated a similar sequence above the Mississippian Chainman Shale. Farther west, in the Trap Springs Field, the Sheep Pass Formation appears to be absent; Devonian Guilmette Formation is buried beneath Tertiary volcanic rocks. Where present, the intervening Sheep Pass Formation appears to comprise basin-margin colluvial deposits, fault-separated from the Paleogene downthrown block to the east. Several hundred feet of Sheep Pass Formation (primarily redbeds and red-matrix limestone conglomerates) are exposed and mapped along the western margin of Railroad Valley near latitude 38°45' N. In the Pancake Range, four miles northwest of this exposure, a similar subvolcanic conglomeratic redbed rests on east-dipping Devonian Simonson Dolostone. On the next fault block to the west, pockets of similar subvolcanic Sheep Pass(?) rest on easterly dipping Lower Pennsylvanian Ely Limestone and underlying Mississippian Chainman Shale. Farther west in the Pancake Range, but still east of recognized contractional deformation, an east-dipping mass of Upper Mississippian, Pennsylvanian and basal Permian rocks rests in low-angle fault contact on the Chainman Shale and is interpreted as an extensional klippe. The northern part of this mass is also overlapped by late Eocene volcanics and pockets of subvolcanic Sheep Pass(?) conglomeratic redbeds. The geometry of the fault beneath the klippe is that of a nearly flat portion of a west-dipping listric normal fault. Observations indicate that eastward-dipping panels of Paleozoic rocks are bounded by west-dipping Paleogene or Late Mesozoic normal faults older than the late Eocene Stone Cabin volcanic rocks and older than the Sheep Pass of Railroad Valley and the adjacent Pancake Range to the west.

These extensional faults appear to have developed much later than the Early Cretaceous or older thrust faults and associated tight folds along the western margin of the Pancake Range. The contractional deformation (Eureka belt) may be as old as Sonoman and may represent the leading edge of the Sonoman fold-and-thrust belt in the western Pancake Range, in front of the Golconda allochthon.

Perry, W.J., and Peterson, J.A., 1994, Pre-Oligocene structure of central Railroad Valley area and adjacent Pancake Range, Nevada - western margin of the Paleogene Sheep Pass basin 9abs0: AAPG 1994 Annual Convention Official Program, Denver, Colorado, v. 3, p. 233.

BACK-THRUSTING AND TRIANGLE ZONE DEVELOPMENT ASSOCIATED WITH LARAMIDE BASEMENT UPLIFT, BRIDGER RANGE, SOUTHWESTERN MONTANA

By D.R. Lageson and Betty Skipp

The Bridger Range represents a geologic microcosm of the major tectonic events that have shaped the Northern Rocky Mountains. Over 3 Ga of history are represented by the stratigraphic and structural relationships within the range. Major tectonic events include Late Archean metamorphism of the basement complex, Middle Proterozoic extensional faulting associated with the south margin of the Belt Basin (Helena embayment), Late Cretaceous-Paleocene "thin-skinned" folding and thrusting at the south margin of the Helena salient, Laramide-style uplift in the latest Paleocene to earliest Eocene, and late Tertiary-Quaternary basin-and-range faulting. Fault zones that originally defined the Belt Basin were reactivated by subsequent tectonic events, thus producing complex "structural inversion."

Three bed-length balanced cross sections drawn through the Bridger Range and western Crazy Mountains Basin (Sedan Quadrangle, 1:48,000) are tied to limited well control and seismic data in order to define the deep geometry of the structural/tectonic elements. The most prominent structural feature is the "sub-Bridger thrust zone," a Laramide, basement-involved imbricate fan and duplex complex that dips west beneath the range. The sub-Bridger thrust zone has approximately 25,000 ft (7620 m) of throw and 9840-16,400 ft (3,000-5,000 m) of heave or "basement overhang." Early Eocene late-stage motion on the sub-Bridger thrust zone delaminated the Upper Cretaceous Livingston Group within the Billman Creek Formation to form a major back-thrust and footwall triangle zone. The triangle zone crops out up-plunge along the northern third of the Sedan quadrangle and is one of the best documented examples of a back-thrust/triangle zone associated with a Laramide-style uplift in the Rocky Mountains.

Lageson, D.R., and Skipp, Betty, 1994, Back-thrusting and triangle zone development associated with Laramide basement uplift, Bridger Range, southwest Montana [Abs.]: American Association of Petroleum Geologists Program for 1994 Annual Convention, Denver, Colorado, p. 192.

STRUCTURAL ELEMENTS RELATED TO PLATE CONVERGENCE OF THE QUETTA-MUSLIM BAGH-SIBI-REGION, BALOCHISTAN PROVINCE, PAKISTAN

By Florian Maldonado, Shahid Hasan Khan, and Jan Mohammad Mengal

The Quetta-Muslim Bagh-Sibi region is a structurally complex area within the Sulaiman-Kirthar foldbelt (Quetta syntaxis) in west-central Pakistan. The region is structurally characterized by broad and tight folds, reverse, thrust, and strike-slip faults and contains six structural terranes. These terranes are separated by four major boundary faults formed as a consequence of four major periods of deformation related to oblique convergence of the Indian and Eurasian plates.

The six structural terranes are, roughly from south to north: (1) a foredeep that represents Precambrian Indian basement rock overlain by undeformed sedimentary cover that forms the Indus Plains and fronts the uplifted deformed region; (2) a foreland fold-and-thrust belt that forms part of the uplifted deformed region and composed of a thick marine shelf sequence of late Tertiary to Late Triassic age and continental rocks of Oligocene to Quaternary age; folding and thrusting resulted from basal decoupling of sedimentary cover from basement; (3) a major deep trough that formed within the foreland fold-and-thrust belt (Sibi-Urak synclinorium) and filled with collision molasse; (4) a suture zone that contains the Muslim Bagh ophiolite complex; (5) a thick flysch deposit of Miocene-Oligocene age; and (6) a subduction-related igneous rock terrane on the margin of the Afgan block.

The four major faults that bound the structural terranes are; the Frontal (F), Ghazaband-Zhob (GZ), Gwal-Bagh (GB), and Chaman (C) faults. The F fault is a blind fault that separates the foreland fold-and-thrust belt from its foredeep; The GZ fault is mainly a thrust fault with sinistral strike-slip motion that separates the Muslim Bagh ophiolite complex from the flysch zone and locally the flysch zone from marine shelf rocks; the GB fault is a thrust fault that separates Muslim Bagh ophiolite complex from the marine shelf rocks; and the C fault is a sinistral transform fault between the Indo-Pakistan and Afgan continental blocks that connects the Makran convergence zone in the south with the Himalayan convergence zone in the north and separates the flysch zone from the Afgan block.

Four major periods of deformation are recognized; (1) emplacement of ophiolitic rocks onto the continental margin of the Indian plate (Late Cretaceous to Paleocene); (2) convergence, resulting in thrusting and minor folding (Eocene or early Oligocene?) of the marine shelf rock sequence and initiation of a major trough (Sibi-Urak synclinorium); (3) deposition of molasse units (Urak and Sibi Groups) of Oligocene to early Pleistocene age followed by major folding and thrusting, and formation of strike-slip faults; and (4) deposition of post-Sibi Group units of Pleistocene age (Bostan-Dada Formations) with subsequent folding, thrusting, and strike-slip motion that continues to the present.

Maldonado Florian, Khan Shahid Hasan, and Mengal Jan Mohammad, 1993, Structural elements related to plate convergence of the Quetta-Muslim Bagh-Sibi-region, Balochistan Province, Pakistan [Abs.]: Geological Society of America Abstracts with Program, v.25, no. 6, p. A-482.

ABSTRACT

FOOTPRINTS IN THE ROCKS--NEW EVIDENCE FROM THE RATON BASIN THAT DINOSAURS FLOURISHED ON LAND UNTIL THE TERMINAL CRETACEOUS IMPACT EVENT

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In recent months, we have found convincing evidence that dinosaurs were present and probably flourished in the Raton basin, southern Colorado and northern New Mexico, either until, or only a very short time before, the asteroid impact at the end of the Cretaceous Period. This evidence consists of impressions and natural casts of dinosaur footprints that occur in the lower part of the Late Cretaceous and Paleocene continental Raton Formation within 1 meter below the Cretaceous-Tertiary (K-T) boundary claystone layer. Tracks are also present at several other horizons farther below the boundary. Curiously, Raton basin rocks have never produced dinosaur skeletons. Although rare fragmentary remains of fish, crocodiles, and turtles have been identified in samples from the Cretaceous portion of the Raton Formation, only one bone attributed to a dinosaur has ever been found.

In the southern part of the Raton basin, the K-T boundary occurs at the top of the lower coal zone of the Raton Formation. This zone consists of sequences of rocks comprising beds of mudstone, carbonaceous shale, and thin beds of coal with interbeds of sandstone; sandstone beds at the base of the lower coal zone are commonly conglomeratic. The depositional environment is fluvial, consisting of broad flood plains characterized by mudflats and swamps that were periodically flooded by crevasse splays from meandering channelways. Crevasse splays occur when natural levees are breached along river channels and sediment-laden water pours out over the floodplain. Footprints and other impressions in silty muds of the mudflats were quickly buried by sand as crevasse splays prograded across the floodplain. Where the splay sand deposits were not subsequently eroded by crevasse channels and associated meandering rivers, the animal tracks and traces on the buried floodplain surface may be preserved as sand-filled depressions at the base of the deposits. This might be considered analogous to the making of huge plaster of Paris casts of the floodplain surface or, in a sense, to "photographing" an instant in time. Traces identified to date include: hadrosaurid and ceratopsid tracks; an unidentified trace, possibly a turtle; bird tracks; and a well-preserved natural cast of a tyrannosaur footprint. The tyrannosaur print is the first convincing record ever found of a T. rex track.

Natural casts of the hadrosaur footprints are preserved in trackways at several horizons in the lower coal zone. One horizon is only 37 cm below the K-T boundary clay bed at the Berwind K-T boundary site, about 15 km northwest of Trinidad, Colorado. Ceratopsid and hadrosaur tracks also occur only a short distance (1 to 2 m) below the boundary at the Clear Creek north site, 5 km south of Trinidad. The tyrannosaur footprint was found about 75 km to the southwest near Cimarron, New Mexico. This track as well as other traces are preserved at the base of loose sandstone blocks derived from a ledge 20 meters below the level of the K-T boundary. The position of the track-containing ledge with respect to the boundary was defined recently by palynological analyses. The Cretaceous pollen and spores recovered from a carbonaceous mudstone unit immediately beneath the tyrannosaur track-bearing sandstone ledge suggest that palms and ferns typical of a subtropical environment dominated the plant community on the floodplain around the track site.

Pillmore, C.L., Lockley, M.G., Fleming, R.F., and Johnson, K.R., and Hunt, A.P.: Footprints in the rocks--new evidence from the Raton basin that dinosaurs flourished on land until the terminal Cretaceous event; in papers presented to New developments regarding the KT event and other catastrophes in Earth history, Lunar and Planetary Science Institute contributions, no. 825, p.89-90

PRELIMINARY GEOLOGIC MAP OF THE BIG LUE MTNS. 15-MINUTE QUADRANGLE, GREENLEE CO., ARIZONA, AND CATRON CO., NEW MEXICO

by James C. Ratté, William E. Brooks, and Dana J. Bove

ABSTRACT

The Big Lue Mountains 15-minute quadrangle, in southeastern Arizona and southwestern New Mexico, is at the southwestern margins of the mid-Tertiary Mogollon-Datil volcanic field, just east of the Morenci-Metcalf mining district. It also is at the northwestern end of the Laramide Burro uplift near its intersection with the NNE-ENE trending Morenci lineament and Morenci Reserve fault zone, at the southeast margin of the Colorado Plateau.

The Big Lue Mountains quadrangle is covered largely by volcanic and volcaniclastic rocks of Oligocene to Miocene age. Total exposed thickness of the volcanic rocks in the quadrangle is on the order of 1000 meters, but no single section contains all of the various extrusive and intrusive units. The mid-Tertiary volcanic rocks unconformably overlie Precambrian and Paleozoic rocks in the Red Hill area in the southwestern corner of the quadrangle, presenting the possibility that Laramide intrusive rocks, like those that host the world-class copper porphyry deposits of the nearby Morenci-Metcalf district, could be present beneath the Tertiary volcanic rocks in the Big Lue Mountains quadrangle. Although there are no signs of significant mineralization in the quadrangle, there are several mineralized occurrences in the pre-Tertiary rocks in the Red Hill area, and quartz and carbonate veins as much as 10 meters wide along the Dix Creek fault in the northcentral part of the quadrangle, where manganese, silver, copper and gold (0.04-0.15 ppm) were found (Ratté and others, 1982).

The Tertiary volcanic sequence in the quadrangle in general decreases in age from the southwest corner of the quadrangle to the north, and the most complete sequence is exposed in the southwest-facing slopes of the Big Lue Mountains. The oldest rocks in the sequence in the Big Lue Mountains include the distal outflow facies of several caldera-related ash-flow tuffs (Cooney Tuff, about 34 Ma; Davis Canyon Tuff, 29 Ma; and Bloodgood Canyon Tuff, 28.1 Ma) from the Mogollon Mountains caldera complex to the northeast. The tuffs are overlain by various amygdaloidal and porphyritic andesite lava flows, as much as 500 m thick, and a sequence of dacitic to rhyolitic flows, flow breccias and pyroclastic beds at least 250 m thick, which are here called the volcanic rocks of the Big Lue Mountains (VRBLM). The VRBLM are overlain by andesitic flows that probably correlate with the Bearwallow Mountain Andesite.

The Big Lue Mountains volcanic sequence (VRBLM) is well exposed in the southeastern part of the quadrangle along State Highway 78, beside Blackjack Canyon, where it is interlayered and intruded? by major masses of nearly aphyric rhyolite that have been tentatively dated at about 25-28 Ma. The rhyolites include the rhyolite of Hells Hole, which forms an intrusive?-extrusive dome complex of at least 20-30 square miles, mainly east of Blackjack canyon, and the north-northeast aligned rhyolite plug domes

known as the White Peaks, in the southcentral part of the quadrangle, as well as numerous other intrusive-extrusive bodies. A spectacular carapace breccia at the margin of the Hells Hole rhyolite is well exposed at the viewpoint near the Needles Eye, a former narrow highway tunnel that has been eliminated in deference to modern traffic requirements on Arizona Highway 78. The carapace breccia is exposed intermittently beneath Bearwallow Mountain Andesite flows for about 5 miles along highway 78 between the Needles Eye and the Arizona-New Mexico State Line. Outcrops along the highway south of the Big Lue Ranch road have the typical "honey-comb" vesicular texture of much of the rhyolite on top of the dome complex. The centimeter-size vesicles commonly are lined with crystals of sanidine, niobium-rich pseudobrookite and ilmenite, and rare garnet.

Except for some older(?) volcanic rocks exposed in the Pat Mountain and Bird Canyon areas in the northwestern part of the quadrangle, the rocks in the northern part of the quadrangle are mainly younger than those in the southern half, and consist of Bearwallow Mountain Andesite, a bimodal basalt-rhyolite assemblage of Miocene age, and Gila Formation volcaniclastic sediments.

Along the gorge of the San Francisco River in the northeastern part of the quadrangle, the stacked thin flows of Bearwallow Mountain Andesite are as much as 600 meters thick. A major eruptive center for at least part of this flow sequence probably is represented by a partially exhumed cinder cone, 1/2-3/4 mile in diameter, on the south canyon wall, on the New Mexico side of the State Line.

The bimodal basalt-rhyolite assemblage consists mainly of the rhyolite domes and tuff rings of the rhyolite of Mule Creek in the Harden Cienega area near the northeastern edge of the quadrangle, and "true" basalt flows and related dikes and small cinder cones that are interlayered with the volcaniclastic sediments of the Gila Formation throughout much of the northern part of the quadrangle. The rhyolite of Mule Creek is about 18 Ma, and the basalts are about 18-19 Ma. A dacite dome in the vicinity of Tennessee Creek in the east center of the quadrangle, near the state line, is about 21 Ma.

Geologic structures in the southwestern part of the quadrangle are mainly faults and dikes that follow the northwest trend of the Burro uplift, which is represented by the small area of pre-Tertiary rocks in the southwestern corner of the quadrangle. In the rest of the quadrangle, faults are mainly north-northeast to east-northeast trending, high-angle normal faults that form a series of minor horsts and grabens that constitute the southwestern part of the Morenci-Reserve fault zone of basin and range age.

Reference cited:

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COMPARISON OF REGIONAL TRENDS OF SANDSTONE AND CARBONATE POROSITY

by Timothy C. Hester and James W. Schmoker

Predictive porosity models should account for the effects on porosity of both burial history and rock properties. Plotting porosity against thermal maturity accounts for burial history, but because sandstones and carbonates are usually treated separately, relative effects of rock properties on porosity are largely undocumented. This report uses case examples of porosity-thermal maturity trends to illustrate an empirical approach to porosity forcasting that accounts for regional processes underlying porosity change and allows porosity variation to be linked with rock properties.

The dependence of porosity upon thermal maturity is generally lower for carbonates than for sandstones. For example, correlation coefficients for the Jurassic Smackover Formation (carbonate), Alabama, and for the Cretaceous "J" sandstone, Denver Basin, Colorado, are -0.40 and -0.88, respectively. The lower correlation for carbonates reflects more porosity variability and suggests that carbonate porosity is more affected by local geologic factors than is sandstone porosity.

The coefficient, a, of the power function $\emptyset = a(\text{thermal maturity})^b$ also varies more for carbonates than for sandstones, whereas the exponent, b, is similar for both. This difference suggests that porosity may vary more between individual groups of carbonate data but that both lithologies are similarly affected by the overriding influence of thermal exposure.

Specific rock properties, such as depositional fabric, grain size, clay content, or the presence of carbonate cement, can affect porosity locally, but they are secondary effects in a regional sense. Thermal maturity usually accounts for regional porosity loss in the subsurface better than does any other single factor.

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