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Compiled by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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COAL GEOLOGY

ECONOMIC GEOLOGY AND MINERALOGY

High chromium content in Tertiary coals, northwestern Washington
- A key to their depositional history

by
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Twenty coal samples were collected from the basal part of the Eocene Chuckanut Formation, which crops out along the western flank of the Cascade Range in Skagit and Whatcom Counties, northwestern Washington. The peat accumulated in mires formed in rapidly subsiding small basins that developed during the uplift and erosion of the pre-Tertiary ophiolite terrains in early Chuckanut time. These lenticular coals were analyzed for contents of major-, minor-, and trace-elements and ash mineralogy. Ash content ranges from 12 to 45 percent, and coal apparent rank ranges from subbituminous to anthracite. Chromium content in these samples are anomalously high (mean of 120 ppm and range of 30-300 ppm) when compared to other U.S. Tertiary coals (mean of 7 ppm). Mineral matter isolated from the samples and analyzed by x-ray diffraction and SEM methods contains angular fragments and euhedral crystals of spinel (chromite, magnetite, and trevorite); kaolinite-serpentine (antigorite and chrysotile); chlorite; and pyroxene mineral groups, which are commonly enriched in chromium.
Although associated primarily with the inorganic fraction of the coal, concentrations of chromium in the samples show no clear relationship with ash content. We conclude that the detrital chromium-bearing grains in the coal were transported to the peat accumulating mire by streams from nearby dismembered ophiolite bodies.

Geological Society of America Abstracts with Programs, National Meeting, San Deigo, California, October, 20-24, 1991, Vol. 23, No. 5, P. 144.

DOLOMITE-RICH CLASTIC DIKES AND SILLS INTRUDING CAMPANIAN COALS OF CENTRAL UTAH.

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Clastic dikes and sills intrude 13 commercial Blackhawk Formation coal beds along the Wasatch Plateau and western Book Cliffs. Dikes occur in three populations that reflect different modes of origin and distribution. Channel-related dikes, composed of dolomitic sandstone, are infrequent and scattered intrusions that display a variety of shapes and attitudes and exhibit shallow penetration through the top part of the coal. Their composition and physical attachment to roof channels suggest that they formed either from infilled extension fractures caused by differential compaction or from infilled fractures along peat slump blocks undercut by channeling. Joint-fill dikes, composed mostly of dolomitic siliciclastic material, are rare and scattered intrusions that have been traced hundreds of feet across mine entries. Their occurrence near tectonic elements, distribution, high penetration angle cutting entire coal seams, and sharp contacts suggest formation by joint filling. Load-compaction dikes and clastic sills composed of >95% authigenic dolomite are abundant and are concentrated in the central Wasatch Plateau. Dike shapes include broad pyramids that penetrate the lower part of the coal; narrow, high-angle sigmoidal intrusions penetrating the entire seam; and rare, low-angle dikes resembling broad, recumbent folds. Their occurrence in swarms, similar composition to floor rock, and high penetration angles from the floor suggest that they formed from loading water-saturated pods of dolomitic marl sandwiched beneath the peat. Seismic activity and peat characteristics probably influence dike formation. Abundant sills, composed of microcrystalline dolomite, are traceable for >100 m from their origins at sigmoidal and pyramidal dikes. Their continuity with dikes along coal bedding and laminar flow structure suggest formation by hydroplastic flow of dolomite-rich material forced from dikes along peat bedding during compaction.

Hardie, J.K., 1991, Dolomite-Rich Clastic Dikes and Sills Intruding Campanian Coals of Central Utah: in Geological Society of America Abstract with Programs.

ORIGIN OF THICK EARLY TERTIARY COAL IN THE POWDER RIVER BASIN, WYOMING AND MONTANA; SOME PALEOGEOGRAPHIC CONSTRAINTS

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The Powder River basin contains extensive deposits of thick low-ash coals, primarily in fluvial rocks of late Paleocene (Tongue River Member of the Fort Union Formation) and late Paleocene and early Eocene age (Wasatch Formation). The thick coals reach 75 m in thickness and collectively contain more than 80 percent of Wyoming's coal resources.

In the late Paleocene, peat deposits that became the Wyodak-Anderson and Big George coal beds accumulated in dip-oriented swamps that paralleled major north-flowing basin-axis trunk streams of the central basin. A paleocurrent study of the Tongue River Member showed that basin-axis streams flowed north-northwest through the geographic center of the basin and joined an east-flowing stream at the Montana-Wyoming state line. Coal beds also formed from peat deposits that accumulated in dip-oriented swamps along this east-flowing trunk stream.

A paleocurrent study of the late Paleocene and early Eocene Wasatch Formation showed that the basin axis migrated to the westernmost part of the basin near the Bighorn uplift. Wasatch coal beds are also concentrated in the western part of the basin. The thickest, the 61-m-thick DeSmet coal bed, is dip oriented and lies adjacent to the basin-axis trunk stream.

Many recent investigators have proposed raised swamps fed only by rainwater (ombrogenous swamps) to explain the lack of flood-borne sediment and the resultant low-ash coals of the basin. The scarcity of thick, low-ash coals in the equivalent early Tertiary rocks of the adjacent climatically and tectonically similar Wind River and Bighorn basins is a clear indication of the inadequacy of this model. I postulate that the abundance of coal in the Powder River basin is a consequence of a major extrabasinal water source (the Wind River basin) that caused conditions favoring peat accumulation, and more important, preservation, by insuring water-saturated anoxic conditions in major low-lying swamps that paralleled the basin's trunk streams after basinal drainage developed in post-early Paleocene time. The lack of flood-borne sediment in these low-lying swamps can be attributed to the humic acids of the swamp that flocculated clays at swamp margins during flooding.

Seeland, David, 1991 Rocky Mountain Section of the Geological Society of America, Abstracts with Programs, vol. 23, no. 4, page 92.

BASAL TERTIARY VOLCANIC ROCKS AT NANNY CREEK, NORTHERN PEQUOP MOUNTAINS, NE NEVADA

By

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A sequence of late Eocene andesitic to rhyolitic rocks, approximately 4,000 ft thick, is exposed near Nanny Creek in the northern Pequop Mountains, approximately 20 miles east of Wells, Nevada. This calc-alkaline sequence comprises: (1) a basal crystal-rich, biotite-hornblende ash-flow tuff (about 75 ft thick), with 68-71 weight percent SiO_2, and a $^{40}Ar/^{39}Ar$ biotite age of 41.09+/-0.16 Ma; (2) a quartz-biotite ash-flow tuff (about 175 ft thick), with 75-78 weight percent SiO_2, and a $^{40}Ar/^{39}Ar$ biotite age of 39.89+/-0.12 Ma; (3) a series (about 4,000 ft thick) of two-pyroxene andesite breccia flows and high-silica (77-80 weight percent SiO_2), crystal-poor ash-flow tuffs; and (4) a hornblende-biotite rhyolite flow (thickness unknown) with 71 weight percent SiO_2.

These volcanic rocks dip easterly about 40° and occur in wh-
paleodepression; the lower two ash-flow units are ... The
basal Tertiary unconformity cuts across Paleoz ... n on
the south to Permian Pequop Formation on the ...
Paleozoic strata terminate at the unconformity. ...
establishing the extent of Eocene volcanism in no. ... s
not been identified. Volcanic rocks with similar st...
been found approximately 20 miles to the west in th...
similar stratigraphy and rock chemistries 25-30 miles ...
and southern ends of the East Humboldt Mountains a...
approximately 15 miles northwest of Nanny Creek.

10/4 We'll need 2 vertical 4' x 8'
Thanks, Earl

in C.H. Thorman, ed., Some Current Research in Eastern Nevada and Western Utah by the U.S. Geological Survey: USGS Open-File Report 91-386, 28 p.

PRIMARY AND SECONDARY DISPERSION PATTERNS ASSOCIATED WITH MOTHER LODE-TYPE GOLD MINERALIZATION, HODSON DISTRICT, CALAVERAS COUNTY, CALIFORNIA

CHAFFEE, M.A., AND KUHL, T.O.

ABSTRACT

The Hodson district lies along the West Gold Belt, about 17 km west of the main Mother Lode Gold Belt and the town of Angels Camp. Rocks in the area consist of two major units: (1) metasedimentary rocks comprising mainly tuffaceous wackes and carbonaceous slates and phyllites, and (2) metavolcanic rocks comprising flows, tuffs, and agglomerates mainly of andesitic basalt to basaltic composition. Rocks in the region have been metamorphosed to greenschist facies. The entire area has been intensely faulted; the Mother Lode-type, gold-pyrite deposits are in or near quartz veins associated with some of these faults, mainly the large Hodson fault, which trends northwest and has many splays.

The three orebodies in the district contain zones of altered rock that surround the Au-bearing mineralized structures. The extent and mineralogy of these zones varies with each host lithology and orebody. Typical alteration assemblages include quartz, sericite, pyrite, calcite, ankerite, and mariposite in the metavolcanic unit, and quartz, sericite, and pyrite, plus bleaching, in the metasedimentary unit.

A total of 300 samples of core and cuttings were collected from drill holes on three sections, each of which transects an orebody. Analyses for 37 elements (Ag, Al, As, Au, Ba, Ca, Cd, Ce, Co, Cr, Cu, Fe, Ga, Hg, K, La, Li, Mg, Mn, Mo, Na, Nd, Ni, P, Pb, S, Sb, Sc, Si, Sr, Te, Ti, Tl, V, W, Y, and Zn) and for loss-on-ignition (LOI) at 925°C were evaluated.

Pathfinder elements with positive anomalies spatially associated with anomalous Au zones include Ag, As, Hg, S, Sb, Te, Tl, and W, plus LOI. Elements with negative anomalies in the same zones include Al, Li, Na, and Ti. Pathfinder elements with the broadest anomalies include Ag, As, Li, S, Tl, and W; those for Ag, As, and W extend farthest (at least 60 m) from mineralized structures. These three elements thus should be especially useful in delineating the outermost manifestations of alteration associated with blind Au mineralization in this district.

Chemical abundances are useful in distinguishing rock lithologies, particularly where the rocks have been strongly altered. Elements that seem to best discriminate lithology, mainly below the weathered zone, include Ce, Co, and Zn.

Chemical weathering has overprinted and modified primary hydrothermal zoning. Many elements (Ag, Al, As, Au, Ba, Ce, Mo, Pb, SiO_2, Ti, and W) have been enriched or relatively unaffected in near-surface areas, whereas other elements (Ca, Co, Cr, Mg, Mn, Ni, S, and Sr) have been strongly leached in the zone of weathering. Cadmium, Cu, and Zn are locally enriched secondarily near the base of the zone of weathering.

Chaffee, M.A. and Kuhl, T.O., 1991, Primary and secondary dispersion patterns associated with Mother Lode-type gold mineralization, Hodson district, Calaveras County, California: Abstracts with Program, 15th International Geochemical Exploration Symposium, Reno, p. 43.

TRACE MINERALIZATION IN LATE CAMBRIAN REELFOOT RIFT SEDIMENTS: DOW CHEMICAL #1 GARRIGAN DRILL HOLE, MISSISSIPPI COUNTY, ARKANSAS.

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Geochemical and petrographic studies were conducted on late Cambrian siltstone and shale core samples from the Dow Chemical #1 Garrigan drill hole in the central part of the Reelfoot rift. Vertical fractures are crosscut by stratabound epigenetic mineralized fronts in the siltstones at a depth of 7,973-8,002 ft. Both the fractures and mineral fronts are rich in authigenic ferroan calcite. The mineral fronts contain coarse-grained pyrite, lesser amounts of sphalerite and galena, and micron-sized particles that contain various combinations of Au, Ag, Cr, Cu, Ni, or rare-earth elements. Geochemical analyses show a significant increase of total sulfur from $\leq$ 0.01 weight %S in unaltered rock to as much as 1.05 weight %S in the mineral fronts.

The vertical fractures have several generations of diagenetic-cement fillings that pre-date the mineral fronts. Introduction of mineralizing fluids may have caused reopening of these earlier fractures because ferroan calcite occurs in the mineral fronts and in the fractures.

Trace mineralization noted here indicates at least local migration of metalliferous fluids within the rift sediments and is also consistent with recent hypotheses that the Reelfoot rift was a migration path of Mississippi Valley-type ore fluids.

Abstract published in: Geological Society of America, Abstracts with Programs, 1990, p. A137.

Are Trace and Rare-Earth Elements in Fluorite Useful in Geochemical Exploration? Encouraging Evidence from the Sierra Cuchillo Area, New Mexico

By R.G. Eppinger, L.G. Closs, A.L. Meier, and J.M. Motooka

Fluorite was collected in the Sierra Cuchillo region of south-central New Mexico from four fluorite-bearing deposit types: Au-Ag veins, Ba-Pb veins, W-Be-Fe skarn, and barren quartz-calcite-fluorite veins apparently devoid of ore metals. The fluorite was analyzed for trace elements by inductively coupled plasma (ICP) atomic-emission spectrometry and for rare-earth elements (REE's) by ICP mass spectrometry.

Trace-element and REE patterns in fluorite samples are distinctive for the different deposit types. Fluorite from Au-Ag veins has positive Eu anomalies, a high Sr content, and low Be, Ba, Ti, U, and Y contents. Fluorite from Ba-Pb veins has negative Eu anomalies, high Ba and Pb contents, and low Sr and U contents. Fluorite from W-Be-Fe skarn has negative Eu anomalies, high Be, Ti, U, and Y contents, and low Sr and Ba contents. Fluorite from barren veins contains variable amounts of the above trace elements and exhibits variable Eu anomalies. The wide chemical variation in the fluorite studied may be due in part to changes in fluid chemistry resulting from reactions with feldspar in wall rock.

Fluorite from barren veins is more abundant than fluorite from other deposits and generally shows the most chemical variation. One group of fluorite samples from barren veins has chemical characteristics similar to those of fluorite from W-Be-Fe skarn. A second group of fluorite samples from barren veins exhibits chemical affinities with fluorite from Au-Ag veins. These similar geochemical signatures in the fluorite, coupled with favorable geologic settings, suggest the possibility of concealed skarn deposits underlying one barren vein group and precious-metal deposits underlying the other barren vein group. Thus, the geochemistry of fluorite delineates potential concealed mineral deposits in the Sierra Cuchillo area and may be a useful tool for mineral exploration elsewhere.

Published as: Eppinger, R.G., Closs, L.G., Meier, A.L., and Motooka, J.M., 1991, Are trace and rare-earth elements in fluorite useful in geochemical exploration? Encouraging evidence from the Sierra Cuchillo area, New Mexico: U.S. Geological Survey 7th Annual V.E. McKelvey Forum on Mineral and Energy Resources, Circular 1062, p. 22.

Geophysical, soil-gas, and geochemical evidence of a concealed, mineralized fault near W- and Sb-rich hot springs, Pumpernickel Valley, Nevada

By J.A. Erdman, D.B. Hoover, J.H. McCarthy, Jr., W.H. Ficklin, J.R. Watterson, T.G. Lovering, and R.W. Owen

In 1988, audio-magnetotelluric (AMT) soundings; telluric and gamma-ray measurements; soil-gas (CO_2, O_2, and hydrocarbons) determinations; soil, pebble-coating, and sagebrush geochemical data; and *Bacillus cereus* spore counts in soils were obtained along two parallel traverses across a concealed mineralized fault in the Pumpernickel Valley, Nevada. These studies attempted to locate the source of Bi, Cd, and Ag anomalies in soils, and Cd and Au anomalies in big sagebrush (*Artemisia tridentata*) found in an earlier geochemical survey. The anomalies are in basin-fill deposits of the Pumpernickel Valley, east of outcropping precious- and base-metal mineralization along an exposed range-front fault in the Preble Formation of Lower Cambrian to Lower Ordovician age.

In June 1988, multifrequency telluric traverses provided evidence of a buried fault subparallel to the exposed range-front fault. Two AMT soundings at the east ends of the traverses indicate that basement rocks east of the buried fault may be 350 m below the surface. Santa Fe Pacific Mining, Inc., drilled 213 m of fill east of the concealed fault. Subsequent controlled-source AMT soundings by the company confirmed the earlier geophysical evidence of deep fill.

The most significant feature of the gamma-ray data is a potassium (^{40}K) anomaly centered over the inferred concealed fault. Potassium haloes around base- and precious-metal deposits are well known from standard geochemical studies, and there is ample evidence that gamma-ray methods are important in gold exploration.

In October 1988, soil gases, soils, and big sagebrush were sampled along the two geophysical traverses. Concentrations of O_2, CO_2, and the hydrocarbon gases methane (CH_3^+) and propane ($C_2H_5^+$) showed marked changes over the inferred fault. The hydrocarbon-gas anomalies may result from thermal maturation of organic matter by hydrothermal solutions, as suggested in a report for one of the major sediment-hosted, epithermal gold deposits in the Carlin trend of north-central Nevada.

Spore counts of *Bacillus cereus* ranged from less than 10 to 60,000 counts per gram of soil, with some anomalous samples from sites above the concealed fault.

Residue from oxalic-acid leachate of surface pebbles showed the same metal anomalies found in the coarse fraction of the soils--in particular As, Sb, W, and Bi--but at much higher concentrations. Maximum Au concentrations of 150 ppb in soils and 33 ppb in sagebrush ash occur at sites on the exposed range-front fault; much lower Au anomalies were found in soil and sagebrush samples over the concealed fault. Soil Hg anomalies occur only at sites near the range-front fault. Cadmium in soil and sagebrush appears to best delineate the concealed fault. We believe that a fault within the valley fill may be the conduit through which these metals and gases migrated to the surface.

Condensate from a geothermal well and water from hot springs in valley fill, 300 m south of the nearest traverse, contained 15 ug/L Sb and approximately 200 ug/L W. These concentrations are very high compared to other hot springs sampled in the western United States.

The association of Sb, W, As, and Hg with Au, Bi, and some of the base metals suggests a gold-skarn system, similar to skarn systems found along the Eureka-Battle Mountain mineral belt to the southeast.

Erdman, J.A., Hoover, D.B., McCarthy, J.H., Jr., Ficklin, W.H., Watterson, J.R., Lovering, T.G., and Owen, R.W., 1991, Geophysical, soil-gas, and geochemical evidence of a concealed, mineralized fault near W- and Sb-rich hot springs, Pumpernickel Valley, Nevada [abs.]: 15th International Geochemical Exploration Symposium, Abstracts with Program, Reno, NV, April 1991, p. 26.

LATE PLIOCENE AGE OF BASIN FILL ABOVE THE RABBIT CREEK GOLD DEPOSIT, HUMBOLDT COUNTY, NEVADA

MADDEN-McGUIRE, Dawn J., NAESER, Charles W., KELLEY, Jerry R., and DETRA, David E., U.S. Geological Survey, Box 25046, Federal Center, Denver, CO 80225, and PELTONEN, Dean, Rabbit Creek Mining, Inc., Box 552, Winnemucca, NV, 89445.

Basin-fill alluvium mapped as Quaternary gravel conceals gold deposits east of the Osgood Mountains, Humboldt County, Nevada. Open-pit mining of the concealed deposits presents an opportunity to study the basin fill. The alluvium is a very poorly sorted, variably indurated conglomerate with a mean grain size ranging from medium-grained sand to pebble. Study of a 140-m section of core above the Rabbit Creek gold deposit showed a significant change in the proportions of clast types at a depth of about 90 m. Limestone makes up 35% of the clasts in the upper 90 m, but only 5% of the clasts in the lower 50 m; siltstone and metasedimentary rocks make up 26% of the clasts in the upper part versus 54% in the lower part; mafic volcanic clasts are 7% (upper part) versus 4% (lower part); silicified rocks are 10% (upper) versus 4% (lower). The change in proportions of clast types reflects a change in the source area (the northern Osgood Mountains and Dry Hills area).

Several samples of volcanic ash were collected from local lenses of channel fill cutting the alluvium about 30 m below the surface. The ash consists of about 70-90% coarse-sand-size glass shards with bubble-wall and bubble junctions (refractive index of about 1.500). Heavy-minerals, many with glass adhering to crystals, include zircon, magnetite, ilmenite, and two pyroxenes. Apatite is lacking in all samples. Six zircons per sample were visually selected to represent the youngest population and were dated by fission-track methods. Visual inspection and excessive scatter in the single-grain ages from all three samples indicate the presence of both primary volcanogenic and detrital zircons. Deleting the statistically older grains from the data set resulted in ages of 2.8 ± 0.8 Ma (4 grains) and 2.7 ± 1.0 Ma (5 grains) for two of the samples. We suggest that the two Late Pliocene ages represent the age of the volcanic ash and of the enclosing alluvium at 30 m. Thus, all deeper alluvium is Pliocene or older and the change in source area occurred before 3 Ma. All grains in the third sample yielded older ages and are probably detrital. The youngest grain counted in this sample was 7.9 ± 2.3 Ma, possibly placing a minimum age on rocks exposed in the source area.

Madden-McGuire, Dawn J., Naeser, Charles W., Kelley, Jerry R., and Detra, David E., U.S. Geological Survey, and Peltonen, Dean, Rabbit Creek Mining, Inc., 1991, Late Pliocene age of basin fill above the Rabbit Creek gold deposit, Humboldt County, Nevada, in, Thorman, C.H., ed., Some current research in eastern Nevada and western Utah by the U.S. Geological Survey: U.S. Geological Survey Open-File Report 91-386, p. 8-9.

RECOGNITION OF DISTINCT TERRANES IN LOWER PALEOZOIC HOST-ROCK UNITS IN THE GETCHELL GOLD BELT, HUMBOLDT COUNTY, NEVADA

Dawn J. Madden-McGuire and Sherman P. Marsh

The lower Paleozoic rocks that host gold deposits along the Getchell gold belt in Humboldt County, Nevada represent several allochthonous terranes rather than a simple sequence of continuous deposition. The term "terrane" is used in a descriptive sense. Evidence for allochthonous terranes in this area includes fault boundaries and differences in age, rock types, and structural style between several rock packages.

The two most widespread and distinct terranes in the area are (1) intensely deformed, regionally metamorphosed, marine rocks (Lower Cambrian Osgood Mountain Quartzite, Lower Cambrian to Lower Ordovician Preble Formation, and much of what is currently mapped as the Comus Formation), and (2) generally less-deformed chert, clastic sedimentary, and volcanic rocks (Valmy and Vinini Formations, including Lower and Upper Ordovician strata in this region). Terrane 1 bedding and foliation dip predominantly eastward and folds verge westward. Terrane 2 folds verge southeastward.

The lower Paleozoic rocks in this area, and their contact relationships, are regionally significant. Exposures of terranes 1 and 2 might preserve evidence for Paleozoic metamorphism and thrusting. Terrane 1 is intensely folded and regionally metamorphosed at map and outcrop scales. The same rock type, structural style, and predominance of west-verging folds (and east-dipping foliation) are consistently displayed along the strike of terrane 1 for a distance of 60 km from Anderson Canyon, on the northwestern flank of the Osgood Mountains, southward past Hot Springs Ranch, on the east side of the Sonoma Range. Regional deformation and metamorphism of terrane 1 probably were post-Early Ordovician and pre-Middle Pennsylvanian, because Lower Ordovician strata indisputably occur in terrane 1 and the conglomerate subunit of the Middle Pennsylvanian Highway Limestone at Edna Mountain contains clastic fragments of Preble phyllite and limestone. The Upper Permian Edna Mountain Formation contains lithic fragments thought to be Preble phyllite (terrane 1) and overlies the Preble Formation along a contact mapped as depositional at Edna Mountain; these features further suggest that deformation and metamorphism of terrane 1 occurred in Paleozoic time. In the northern Osgood Mountains, outcrops of terrane 2 are cut by granitic dikes, presumed to be Late Cretaceous in age, and tectonically overlain by strata of the Antler overlap sequence along a possible northward extension of the Iron Point thrust fault, which is thought to be pre-Late Permian in age. These contact relations suggest that terrane 2 was emplaced between Late Ordovician and Late Permian time.

The Comus Formation, which is Middle Ordovician in its type locality on Edna Mountain (south of Iron Point), might represent a third terrane situated structurally between terranes 1 and 2. Use of the name "Comus Formation" outside the type locality (particularly in the Osgood Mountains) has created confusion and needs re-examination. Most of the rocks currently mapped as the Comus Formation probably are part of either terrane 1 or terrane 2.

Madden-McGuire, D.J., and Marsh, S.P., 1991, Recognition of distinct terranes in lower Paleozoic host-rock units in the Getchell gold belt, Humboldt County, Nevada: 7th Annual V.E. McKelvey Forum on Mineral and Energy Resources, U.S. Geological Survey Circular (extended abstract), p. 49-50

EVOLUTION OF AN EARLY PROTEROZOIC RIFT BASIN IN THE LA ESMERALDA AREA, GUAYANA SHIELD, VENEZUELA

by G.B. Sidder, W.C. Day, R.M. Tosdal, S.D. Olmore, L. Guzman, and F. Prieto

New geologic mapping and geochemical and isotopic data help unravel the geologic history of an Early Proterozoic greenstone belt near La Esmeralda, 100 km southwest of Ciudad Bolívar, Venezuela. Supracrustal rocks within the area include basal feldspathic quartzite approximately 100 m thick, which is overlain by tholeiitic metabasalt, microgabbro, and thin beds of metashale, chert, and quartzite. These supracrustal rocks form an east-trending synclinal structural basin 16 km wide and 40 km long, which is underlain both on the north and south by gneissic basement of the Guayana Shield. The basal supracrustal quartzite lies uncomformably on basement of granitic gneiss, whereas thrust faults occur locally near the upper contact of the quartzite with the overlying metabasalt. The granitic gneiss was previously assigned to the Early to Middle Archean Imataca Group. However, new U-Pb zircon data indicate that this gneiss is 2,240±44 Ma, and, therefore, that the basement in this area is in part Early Proterozoic.

Two types of gold mineralization are known in the La Esmeralda area. An epigenetic type is represented by the Hueco Rico prospect, in which gold is localized within a shear zone-hosted quartz-chlorite vein that cuts ductilely deformed mafic metavolcanic rocks; S-C mylonitic fabrics are preserved within the shear zone. A syngenetic type of mineralization is observed at the Cerro La Pinto mine, where gold occurs within a finely laminated, rhythmically bedded sequence of deeply weathered graphitic metashale, mafic metavolcanic rocks, and metachert.

The supracrustal rocks formed in an Early Proterozoic intracratonic basin or along a continental margin during the early rifting phase of the Trans-Amazonian orogeny. Deposition of the basal quartzite within the incipient rift was followed by tholeiitic basaltic volcanism. Although tectonism has obscured the original texture of the mafic rocks, the presence of metashale and metachert interbedded with the basal part of the mafic metavolcanic rocks at Cerro La Pinto suggests that the volcanism was subaqueous.

Closure of the basin was accompanied by regional compressive tectonism during the later phases of the Trans-Amazonian orogeny. The tectonism produced regional amphibolite-grade metamorphic rocks that show a penetrative structural fabric. Metabasalt has a moderately strong schistosity as well as a mineral lineation. The compressive regime deformed the basin into a synclinal structure and variably thrust the metabasaltic rocks over the basal quartzite; mylonites formed locally within the basal thrust zone.

The U-Pb zircon data place a maximum age of about 2,240 Ma for rifting during the early stages of the Trans-Amazonian orogeny. The penetrative fabric preserved in the rocks of the La Esmeralda area is associated with subsequent compressional stages of the Trans-Amazonian orogeny, which took place from 2,150 to 1,960 Ma.

Sidder, G.B., Day, W.C., Tosdal, R.M., Olmore, S.D., Guzman, Luis, and Prieto, Freddy, 1991, Evolution of an Early Proterozoic rift basin in the La Esmeralda area, Guayana Shield, Venezuela, in Good, E.E., Slack, J.F., and Kotra, R.K., eds., USGS Research on Mineral Resources - 1991 Program and Abstracts: Seventh Annual V.E. McKelvey Forum on Mineral and Energy Resources, Reno 1991, U.S. Geological Survey Circular 1062, p. 69-70.

REGIONAL GEOCHEMICAL SIGNATURES OF LODE Au AND Cu DEPOSITS IN THE WESTERN HALF OF THE REDDING 1 X 2 DEGREE QUADRANGLE, NORTHERN CALIFORNIA

SILBERMAN,M.L., HASSEMER,J.R., and SMITH,S.M.

GEOLOGY:

The western half of the Redding quadrangle contains parts of two physiographic provinces: the Coast Ranges, and the Klamath Mountains. Both provinces consist of a series of accreted tectono-stratigraphic terranes of island arc and oceanic rocks. The terranes are separated by eastward dipping thrust faults, many of which contain ultramafic intrusions and gabbro plutons that are parts of ophiolite complexes. Both provinces contain meta-sedimentary and meta-volcanic rocks, but only the Klamath Mountains are intruded by granitic plutons and associated hypabyssal rocks.

MINERAL DEPOSITS:

Lode gold deposits occur throughout the Klamath Mountains, but most production has come primarily from the eastern part of the Province. The most common lode deposits are metamorphic type gold-quartz fissure veins, similar to those along the Mother Lode Belt. Host rocks include meta-sedimentary, meta-volcanic and granitic rocks. Significant by-product Au has been won from volcanogenic massive sulfide deposits; in addition, scarn deposits have also produced Au. Gold-bearing quartz veins are associated with granitic intrusions. Particularly in the more productive districts, hypabyssal intrusions related to the plutons are intimately associated with and in many cases host the veins.

Cu, with significant Zn, Pb, Ag, and Au is found mainly in volcanogenic massive sulfide deposits hosted in felsic meta-volcanic rocks in island arc terranes. The eastern part of the province contains most of the larger deposits, although smaller ones occur throughout the region where meta-volcanic rocks are present. Copper also occurs in base- metal-rich quartz veins, and with Cu-sulfides disseminated in serpentinite and diorite. Many of these deposits are also Au-bearing.

In the Coast Ranges Province, Au and Ag occur as components of Cu-,Zn-, Pb- bearing massive sulfide deposits hosted in meta-volcanic or meta-sedimentary rocks of the Franciscan Assemblage. They also occur within quartz veins and are associated with Cu sulfides disseminated in serpentinite and diorite. Small gold-bearing quartz veins are also found in sandstone, shale, and glaucophane schist.

GEOCHEMISTRY OF DEPOSITS:

Regional stream-sediment geochemical sampling, both within and outside of areas containing known Cu and Au deposits, complimented by detailed study of the geochemistry of lode Au deposits and reconnaissance study of massive sulfide Cu deposits is in progress. Trace-element associations in the Au-bearing quartz veins varies from district to district. Quartz veins hosted in the same lithologies have similar overall trace metal assemblages, but differ in some element concentrations and ratios. The volcanogenic massive sulfide deposits also have overall geochemical similarity, but differ in some element concentrations. Many elements, including important indicators such as As, Ag, Zn, Hg, and Au occur in both Au and Cu deposits. Cu, Pb and Zn also occur in both deposit types, although contents are much higher in the massive sulfides.

STREAM SEDIMENT GEOCHEMISTRY:

Orientation stream-sediment sampling was carried out within the French Gulch-Deadwood and Canyon Creek-East Fork mining districts, two of the larger Au producers in the Klamath Mountains (1 million and 200 thousand ounces, respectively). Both districts contain metamorphic, fissure- vein-type, Au-bearing quartz veins. At French Gulch high As content is associated with Au in the quartz veins, which are hosted in argillite, greywacke and hypabyssal intrusive rocks. At Canyon Creek moderately high As, Pb and Zn, and strongly anomalous Hg are associated with Au in quartz veins hosted in amphibolite and schist. In both districts Ag is associated with Au in the veins, but in variable and inconsistant amounts.

Samples of -80 mesh stream-sediment samples from both districts are anomalous in Au (up to 2 and 5 ppm, respectively). Elevated As and Hg contents in the sediments delineate Au-bearing areas at French Gulch, and are accompanied by weak to moderate anomalies of Ag, Mo, Pb, and Zn. At Canyon Creek, Fe, Hg, and to a lesser extent As in the sediments correlate with Au occurrence, and are accompanied by weak to moderate anomalies of Cu, Pb, Zn, and other elements.

Orientation stream-sediment samples in the West Shasta Cu-Zn district show moderate to strong anomalies of Fe, Ag, Cu and Zn. In the East Shasta district, Ba, Cu, Pb and Zn are anomalous. Au was not determined in these samples, which were collected in a previous study, but the massive sulfide deposits are Au- bearing, and produced significant by-product Au.

Inspection of regional stream-sediment data from the western Redding quadrangle and surrounding areas indicate that areas containing lode gold deposits have -80 mesh stream-sediment anomalies of Au, As, Hg and also Cu and Zn. Areas containing Cu deposits have anomalies of Cu, Zn, Pb, Au and Ag. An overlap occurs in anomalies that signify the presence of Au and Cu deposits.

The stream sediment data in western Redding delineate extensions to known areas of occurrence of Cu and Au deposits, and also indicate anomalies in areas where no known deposits occur. The strongest anomalies appear to cluster along certain terrane boundary thrust faults, particularly the Coast Ranges Thrust, which forms the boundary between the Klamath Mountains and the Coast Ranges. The data are suggestive of significant metal flux through some of these structures, and perhaps the presence of metal concentrations still within them.

Reference:

Silberman, M.L., Hassemer, J.R., and Smith, S.M., 1991
Regional geochemical signatures of lode Au and Cu deposits in the western half of the Redding 1 X 2 quadrangle, northern California (abs): Fifteenth International Geochemical Exploration Symposium, Abstracts with Program, p. 39.

HYDROTHERMAL ALTERATION AT THE CALICO HILLS, NYE COUNTY NEVADA

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Presence of a high-level epithermal system is suggested by a study of hydrothermal alteration and hot-spring deposits in Miocene volcanic rocks at the Calico Hills in south-central Nevada. The Miocene rocks consist of a sequence of silicic ash-flow tuffs and rhyolitic lavas that were erupted from the nearby Timber Mountain-Oasis Valley caldera complex. The Miocene section is gently domed, exposing a central core of middle Paleozoic shales and carbonate rocks. Doming and hydrothermal activity are attributed to a pre-9 Ma intrusion postulated on the basis of geophysical data and the distribution of hydrothermal effects. The entire stratigraphic section is broken by high-angle and low angle normal faults that were active between 13 and 9 Ma. The low-angle normal faults, probably related to regional extension, occur in both the Paleozoic and Miocene sections and locally between the two sections.

Pervasive silicification of the Miocene volcanic rocks is the dominant type of alteration in the Calico Hills. Comparison of altered rocks with unaltered counterparts indicates that hydrothermal fluids leached calcium, sodium, iron and manganese from the volcanic rocks and redistributed potassium and aluminum. A potassium-silicate alteration assemblage is represented by disseminated pyrite and adularia that occur withe silicification in stratigraphically and structurally controlled zones. Locally, silicification is overprinted by intense alunite metasomatism beneath paleo hot-spring sinter deposits. The hot-spring deposits occur as small vents along fault scarps and as a thick apron around one large area of hydrothermal explosion breccia. The presence of hydrothermal breccias indicates periods of self-sealing and rupture, conditions sometimes favorable for precious metal mineralization. Minor element analyses of samples from hot-spring sinter and adjacent silicification do not show a geochemical signature indicative of mineralization. However, limited analyses from the Paleozoic shales show enrichment in arsenic, antimony, copper, lead and zinc along with traces of silver and gold. The pattern of alteration indicates an early stage of potassium-silicate alteration followed by an acid-sulfate stage associated with hot-spring formation. The apparent lack of precious metals in both stages of alteration suggests that the system was barren. However, the possibility that mineralization could be contained in the shales at depth needs further examination.

Simonds, F.W., and Scott, R.B., 1990, Geology and hydrothermal alteration at the Calico Hills, Nye County, Nevada [abs]: Geology and Ore Deposits of the Great Basin, Reno/Sparks, Nevada, 1990, Program with Abstracts, p. 126.

$^{40}Ar/^{39}Ar$ THERMOCHRONOLOGY OF GRANITIC PEGMATITES AND HOST ROCKS, SAN DIEGO COUNTY, CALIFORNIA

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Within the western part of the Peninsular Ranges Batholith, complexly zoned granitic pegmatites are the youngest rocks of the batholith. No direct source for the pegmatites has been identified and limited isotopic age data are available. To define the emplacement and cooling history of the pegmatites from the three main gem- and specimen-producing districts (Pala, Ramona, and Mesa Grande), we report $^{40}Ar/^{39}Ar$ age-spectrum dates for ca. 40 samples of K-feldspar, muscovite, and lepidolite from the pegmatites and hornblende, biotite and K-feldspar from nearby host rocks. In addition, results are reported for hornblende, biotite, and K-feldspar from one sample of Woodson Mountain Granodiorite well-removed (15 km) from any pegmatite dikes.

Some results of the argon dating are as follows. The Woodson Mountain Granodiorite away from pegmatites cooled through hornblende, biotite, and microcline closure temperatures ($\approx$550°, 300°, and 150° C, respectively) at $\approx$113, 107 and 104 Ma. Hornblende and biotite from host rocks (San Marcos Gabbro and mafic and felsic units of the Green Valley Tonalite/Bonsall Tonalite) adjacent to pegmatites were reset to 100 Ma by emplacement of the pegmatites. Muscovite from the Pala Chief mine, Pala district is 99.4$\pm$0.3 Ma; lepidolite from the Stewart mine, Pala district is identical at 99.3$\pm$0.4 Ma. Three apparent ages are recorded in samples from the main Little Three pegmatite, Ramona district: Cores of muscovites from pockets within the pegmatite are 98.3$\pm$0.3 Ma; rims of the same muscovites are statistically different at 97.0$\pm$0.3 Ma; later lepidolite from adjacent pockets is 95.8$\pm$0.4 Ma. The older apparent age is corroborated by a muscovite date of 98.7$\pm$0.3 Ma from the nearby Hercules-Spessartine dike. Muscovite from the Himalaya mine, Mesa Grande district is 95.4$\pm$0.3 Ma; later lepidolite yielded identical core and rim dates of 93.1$\pm$0.3 and 93.3$\pm$0.3 Ma, respectively. These mica apparent age differences are due either to differential cooling rates, different argon closure temperatures, or different times of crystallization; we prefer the last. Throughout the districts, final cooling of the pegmatites below microcline argon-closure temperature ($\approx$150-100°C) occurred between 91 and 84 Ma.

Snee, L. W. and Foord, E. E., 1991 Annual Meeting of the Geological Society of America, Abstracts with Programs. vol. 23, no. 5, page 189.

Geology and Petrology Of Late Lavas Associated With The Newly Discovered South River Caldera, San Juan Volcanic Field, Colorado

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Postcaldera lavas in the central San Juan volcanic field south of Creede, Colorado have previously been assigned to the Fisher Quartz Latite and were considered to postdate the Snowshoe Mountain Tuff, which erupted during collapse of the Creede caldera at 26.6 Ma. Recent mapping shows, however, that these lavas include assemblages that pre- and postdate the Creede caldera. The older assemblage is more than 600 m thick within the newly identified South River caldera, source of the 27.15-m.a.-old Wason Park Tuff. Intrusive rocks near the South River caldera topographic margin (south and west) are petrographically similar; intrusions near the western margin are inferred to be the source for some of the South River lavas. A pre-South River lava assemblage, volcanics of Table Mountain, may represent precursory volcanism related to the South River caldera cycle or, alternatively, postcollapse volcanism related to formation of an older caldera. The South River and Creede caldera lava flows differ petrographically and chemically. The South River rocks are finely porphyritic andesite and mafic dacite containing plagioclase, hornblende, pyroxene, and +/- biotite. In contrast, typical post-Creede rocks are more coarsely porphyritic dacite containing plagioclase, hornblende, biotite, +/- pyroxene, and +/- sanidine. Strontium contents (0.3-0.4 wt%) of plagioclase phenocrysts in some South River rocks indicate that the high strontium is derived from the magma and not alteration induced. The interbedding of Snowshoe Mountain Tuff and the upper assemblage of South River volcanics, indicates that the South River magmatic system continued to be active during the Creede caldera cycle. The volcanics of Table Mountain are chemically distinct in some major and minor elements from both the South River and Creede assemblages.

In The Geological Society of America Abstracts with Programs 1991, v. 23, No. 4, p. 108.

VOLCANIC ASH INGESTED BY JET ENGINES

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Ingestion of volcanic ash by jet engines may cause serious deterioration of engine performance due to erosion of moving engine parts, such as compressor blades and turbine blades, and accumulation of partially melted ash in hot zones within the engine. Since 1980, at least 5 encounters between jet-powered aircraft and volcanic ash clouds have resulted in temporary engine failure.

In this study we used petrographic thin section, scanning electron microscope, and electron microprobe techniques to analyze volcanic ash deposits from the December 15, 1989, eruption of Redoubt Volcano as well as deposits found within the engines of a Boeing 747-400 that flew into the ash cloud created by the December 15 eruption.

Ash from the deposits of the December 15 eruption ranges in diameter from less than 1 micron to slightly greater than 100 microns with a mean diameter of about 20 microns. Volcanic ash was reduced to about 7 microns diameter by the time it entered the combustor section of the engine where melting occurred. Melted ash deposits in the hot combustor and turbine sections of the engine display fluidal textures that indicate flowage of material occurred during or after initial deposition. Vesicles are common in the remelted deposits. The glass is enriched in total SiO_2 as compared to the deposits from the ash cloud. In addition to the primary minerals of plagioclase, pyroxene, and Fe-Ti oxides found in deposits from the ash cloud, deposits from the engines also include metal particles derived from abrasion of engine parts, principally from the compressor area where titanium metal alloy and stainless steel are used extensively. Oxide particles rich in Fe, Cr, and Ni derived from stainless steel are found coating the surfaces of ash grains and are present as spheres in the melted ash matrix.

The principal components of volcanic ash are volatile-poor glass and minerals, which are unlikely to melt at temperatures below 900-1,000°C. By reducing engine power to the minimal setting, the engine temperature can be reduced below the threshold at which volcanic ash is likely to melt.

Casadevall, T. J. (ed.), 1991, The First International Symposium on Volcanic Ash and Aviation Safety, Programs and Abstracts: U. S. Geological Survey Circular 1065, 58p.

Relation Between Selenium and Sulfur in Alfalfa and Soil, San Joaquin Valley, California. L.P. GOUGH* and R.C. SEVERSON, U.S. Geol. Survey, Denver, Colorado.

A potential antagonism between selenium and sulfur in alfalfa and soil, under field conditions in the San Joaquin Valley of California, may reduce the overall uptake and accumulation of selenium in alfalfa in areas where high total concentrations of both elements exist in soil. A limited set of alfalfa and soil samples was collected from areas representing a wide range in total soil selenium and sulfur concentrations. Selenium concentrations in alfalfa were estimated by multiple linear regression, which accounted for 72 percent of the variability, from measurements in soil of total carbon, sulfur, selenium, and strontium. The regression equation was then applied to data for 721 soil samples previously collected from the same study area and maps were prepared showing the spatial distribution of the estimated concentrations in alfalfa. The resultant estimated values show that selenium is generally within an acceptable concentration range for grazing livestock; neither too high (toxic) nor too low (deficient).

Gough, L.P. and Severson, R.C., 1991, Relation between selenium and sulfur in alfalfa and soil, San Joaquin Valley, California: Agronomy Abstracts, Soil Science Society of America Annual Meeting, Oct. 27-Nov. 1, 1991, Denver, CO, p. 42.

GEOLOGIC RADON POTENTIAL OF THE UNITED STATES

Gundersen, L.C.S., Schumann, R.R., Otton, J.K., Dubiel, R.F., Owen, D.E., Dickinson, K.A., U.S. Geological Survey, MS 939 Federal Center, Denver Colorado 80225-0046.

The geologic radon potential of the United States has been the subject of a two-year project by the U.S. Geological Survey and the Environmental Protection Agency, in cooperation with the Association of American State Geologists. Indoor radon data from the State/EPA Indoor Radon Survey and from other sources were compared with bedrock and surficial geology, aerial radiometric data, soil properties, and soil and water radon studies. A numeric radon index and confidence index have been developed as part of this project to quantify and standardize radon potential assessment on a regional scale. Results indicate that approximately 35% of the U.S. population lives within areas of the United States having the highest radon potential. Geologic terrains of the United States that are predicted to have the majority of homes averaging greater than 4 picocuries/liter include:

(1) Uraniferous metamophosed sediments, volcanics, and granite intrusives that are highly deformed and often sheared: Shear zones in these rocks cause the highest indoor radon problems in the United States.

(2) Glacial deposits derived from uranium-bearing rocks and sediments and glacial lake deposits: Clay-rich tills and lake clays have high radon emanation because of high specific surface area and high permeability due to desiccation cracking when dry.

(3) Marine black shales: The majority of black shales are moderately uraniferous and have high emanation coefficients and high fracture permeability.

(4) Soils derived from carbonate, especially in karstic terrain: Although most carbonates are low in uranium, the soils derived from them are very high in uranium and radium.

(5) Uraniferous fluvial, deltaic, marine, and lacustrine deposits. Much of the nation's reserve uranium ores are contained within these sedimentary deposits, which dominate the stratigraphy of the western U.S.

Publications from this study will be released in the fall of 1991 and will include an annotated 1:7.5 million scale map of the United States with fifty-five geologic provinces and their radon potential delineated. Detailed radon potential books containing numerous indoor radon maps, geologic maps, and extensive radon bibiliographies for each state will also be available.

Gundersen, L.C.S., Schumann, R.R., Otton, J.K., Dubiel, R.F., Owen, D.E., Dickinson, K.A., 1991, Geologic radon potential of the United States: Geological Society of America Abstracts With Programs, Annual Meeting, v. 23, no. 6.

USING CATHODOLUMINESCENCE TO MAP REGIONALLY ZONED CARBONATE CEMENTS OCCURRING IN DIAGENETIC AUREOLES ABOVE OIL RESERVOIRS: INITIAL RESULTS FROM THE VELMA OIL FIELD, OKLAHOMA:

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ABSTRACT: Mappable variations in the metallic ion concentration of late diagenetic carbonate cements at the surface above Velma oil field can be correlated to a qualitative measure of cathodoluminescence (CL). This proposed measure, the carbonate CL index or CCI, compares trace element quencher and activators of CL in carbonates to visual estimates of CL intensity.

The late diagenetic aureole at Velma is well developed. In surface sandstones, the aureole contains abundant Fe sulfides and associated ferroan carbonate cements which imparts a dark-reddish-brown color to the rock. The aureole is surrounded by Fe-poor sandstone. Prior studies of the Permian siliciclastic rocks in the near-surface show that changes in Fe and Mn concentrations in carbonate cements result from Eh-pH zonation in the diagenetic aureole across the production area.

Fe^{2+} and Mn^{2+} ions are, respectively, the common quencher and activator of cathodoluminescence (CL) in carbonate minerals. Atomic absorption (AA) analysis shows these trace elements are present over a wide range of concentrations in our samples. Commonly cements with Mn concentration (concentration annotated as [Mn] in units of ppm) greater than [Fe] have bright CL, and those with [Mn] less than [Fe] will have dull or no CL. Comparison of CL quenchers and activator indices ([Fe] alone, [Mn] alone, [Fe]/[Mn]) to visual CL characteristics at Velma shows only fair agreement. Therefore, we apply a new carbonate CL index, CCI = ([Mn]-[Fe])/([Mn]+[Fe]), in an attempt to qualitatively describe the significant CL active trace element composition relative to the subjectively determined visual luminescence character. We find CCI is better than [Fe]/[Mn], [Fe], or [Mn] as a descriptor of CL because it shows a more systematic variation and clearer relationship to CL intensity than the other chemical CL indices. CCI can vary over the range -1 to 0 to +1, dovetailing with major categories of visual descriptors of intensity (non (or no), dull, or bright CL). At CCI of about -1 no luminescence will be observed from the carbonate cement; at CCI of near but less than 0, dull luminescence; and at CCI >0 the cements are brightly luminescent. The general cathodoluminescence pattern observed in the carbonate cements at Velma is related to CCI with dull- or non-luminescent cement (greater [Fe] than [Mn]) over the production area and dull to bright luminescence (less [Fe] than [Mn]) on its flanks. CCI is mostly negative over the production area and zero or positive on its flanks.

In Barker, C.E., and Kopp, O.C., editors, Luminescence Microscopy and Spectroscopy: SEPM Short Course 25, p. 155-160.

A Computer Program to Determine Probability Distributions for Modeling and Simulation in the Absence of Data

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ABSTRACT

Probability distributions for modeling and simulation in the absence of data are often required in petroleum resource assessment and many other areas of geology. This paper describes methodology and a computer program for the determination of 13 available models: two histogram, two normal, truncated normal, lognormal, truncated lognormal, exponential, truncated exponential, Pareto, truncated Pareto, uniform, and triangular distributions.

The problem of selecting a probability distribution in the absence of data can be described as follows:

- Modeling a continuous random variable, e.g., oil accumulation size;
- Subjectively estimating the minimum (most pessimistic value) and maximum (most optimistic value), and possibly other parameters;
- Placing a representative probability distribution between the minimum and maximum.

The methodology developed to assist in this problem consists of the following steps:

- Consider a menu of 13 available probability distributions with required parameters;
- View typical histogram-like graphs of potential models to aid in selection;
- Select a probability distribution model;
- Enter the estimated parameter values;
- View the histogram-like graph of the selected model;
- Print the graph;
- Compute the mean, standard deviation, and seven fractiles (*F*100, *F*95, *F*75, *F*50, *F*25, *F*5, *F*0).

The probability distribution methodology was written as a computer software package called PROBDIST. The user's documentation and program diskette of the PROBDIST system are available to the public through the U.S. Geological Survey Books and Open-File Reports Section. PROBDIST requires an IBM-PC/XT/AT compatible microcomputer with at least 400 Kbytes of free main memory, MS-DOS 3.1 or later, either two diskette drives or one diskette and a fixed disk, and a 132 column printer. A graphics adapter is necessary to produce graphics displays; however, the program still produces numeric output without graphics hardware. A numeric coprocessor is not required.

Crovelli, R.A., and Balay, R.H., 1991, A computer program to determine probability distributions for modeling and simulation in the absence of data, *in* Roberts, C.A., ed., GeoTech/Geochautauqua '91 Proceedings: Denver GeoTech, Inc., p. 146.

THERMAL MATURITY, POROSITY, AND FACIES RELATIONSHIPS APPLIED TO GAS GENERATION AND PRODUCTION IN TERTIARY AND CRETACEOUS LOW-PERMEABILITY SANDSTONES, UINTA BASIN, UTAH

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Uinta basin rocks include a thick sequence of low-permeability (tight) sandstones that contain a large volume of gas. Most known gas accumulations occur in the eastern part of the basin in the Upper Cretaceous Mesaverde Group, uppermost Cretaceous to early Eocene North Horn Formation, and the Paleocene and Eocene Wasatch, Colton, and Green River Formations. Most successful tight-gas completions are in Tertiary strata, but rocks in the underlying, largely undrilled Mesaverde Group in the north-central part of the basin are potential targets as well. To characterize the gas-bearing sandstones, we have constructed a series of interrelated maps and cross sections showing thermal maturity, porosity, fluid pressures, and lithofacies relations for the Uinta basin.

Vitrinite reflectance (Rm) for each of these low-permeability sequence increases to the north, and levels of thermal maturation are sufficient for gas generation over large areas of the basin. Measured Rm values at the base of the Mesaverde increase from 0.65% at shallow depths along the southern edge of the basin to 1.5% in the central basin at depths of about 11,000 ft (3,350 m). Measured Rm values at the top of the Mesaverde increase from 0.50% at outcrops along the southern edge of the basin to 2.2% near the town of Altamont, at depths of approximately 18,000 ft (5,500 m).

Projection of maturity values and fluid-pressure data into undrilled parts of the basin reveals the probability of a regional, overpressured, basin-centered gas accumulation, where gas generation is likely to be occurring at present. Published estimates of amounts of erosion in the region vary widely, ranging from 1,000 ft (300 m) to almost 11,000 ft (3,350 m). Our interpretation favors the lesser erosional estimates, because significant cooling of strata due to uplift and erosion would slow or stop the generation of hydrocarbons.

Plots of porosity versus Rm allow prediction of porosity for Mesaverde sandstones in unexplored areas of the basin. Porosities of nonmarine Mesaverde sandstones with thermal maturity less than about 0.7% or greater than roughly 2.0% decrease as thermal maturity increases, and follow "normal" sandstone trends. However, between 0.70% and 2.0%, in the window of hydrocarbon generation, porosities do not decrease as thermal maturity increases. Overpressured, gas-saturated Mesaverde sandstones are likely to have porosities in the 5% to 9% range.

Reservoir quality is related to depositional-facies. In Tertiary formations, the best gas reservoirs are in diagenetically altered, fluvial-channel, deltaic, and open-lacustrine sandstones. In the underlying Cretaceous strata, gas source-rocks and reservoirs occur in a sequence of fluvial lenticular sandstones and in marine, blanket-like sandstones.

Our data indicate that a large area of organic-rich, overpressured strata probably underlies the northern part of the Uinta basin. Wells drilled in the Mesaverde and lower part of the Tertiary, in the areas where Rm at the base of the Mesaverde is greater than 1.1%, should have the best potential for gas production. Overpressured gas reservoirs (Rm >1.1%) are likely to have no free water and be enveloped by successive zones of mixed water and gas (Rm 1.1% to 0.75%), and of water only (Rm <0.75%).

Nuccio, Vito F., Schmoker, James W., and Fouch, Thomas D., 1991, Thermal maturity, porosity, and facies relationships applied to gas generation and production in Tertiary and Cretaceous low-permeability sandstones, Uinta Basin, Utah: American Association of Petroleum Geologists Bulletin, v. 75/6, p. 1134-1135.

Origin and Diagenesis of Clay Minerals in Relation to Sandstone Paragenesis: An Example in Eolian Dune Reservoirs and Associated Rocks, Permian Upper Part of the Minnelusa Formation, Powder River Basin, Wyoming

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Eolian dune sandstones are the principal reservoir rocks in the Permian upper part of the the Minnelusa Formation, Powder River basin, Wyoming. These sandstones formed as shorelines retreated and dunes migrated across siliciclastic sabkhas. Sandstones are mainly quartz arenites; on average, clay minerals constitute about 5 weight percent of the whole rock. Although present in minor amounts, clay minerals play an important role in the diagenetic evolution of these sandstones.

Allogenic clay minerals are present in shaley rock fragments and laminae. Early infiltration of clays into porous sabkha sands commonly form characteristic menisci or bridges between framework grains or, when more extensive, form coatings or rims on grain surfaces. Authigenic clays include nearly pure smectite, mixed-layer illite/smectite (I/S), and late diagenetic illite and corrensite; these clay minerals are present as pore-lining cements. Smectite and I/S commonly line secondary pores following the dissolution of anhydrite cement. Kaolinite commonly fills pores in eolian sandstones at present burial depths less than 1,200 m but is rare in core samples below 2,100 m. Kaolinite formed locally from the dissolution or replacement of framework feldspars.

In addition to the deposition and neoformation of clay minerals throughout sandstone paragenesis, the conversion of smectite to illite occurred as temperatures increased with progressive burial. Illite/smectite ratios and ordering of I/S is variable. Random I/S is abundant in samples above 1,200 m and present in samples to about 3,100 m; only ordered I/S is found in samples at greater depths. In addition, the ratio of I/S to discrete illite decreases with increasing present-day burial depths.

A temperature of 103 °C is calculated at a present depth of 3,200 m using a geothermal gradient of 30 °C/km and a mean annual surface temperature of 7 °C. After correction for uplift and erosion (250 m), the maximum calculated temperature for the conversion of all random I/S to ordered I/S is 110 °C. This calculated temperature is in excellent agreement with temperatures of 100°-110 °C implied from I/S geothermometry.

Pollastro, R.M., and Schenk, C.J., 1991, Origin and diagenesis of clay minerals in relation to sandstones paragenesis: an example in eolian dune reservoirs and associated rocks, Permian upper part of the Minnelusa Formation, Powder River basin, Wyoming: American Association of Petroleum Geologists Bulletin, v. 75, p. 1136-1137.

CHEMICAL EXTRACTION OF RADIOLARIAN FAUNAS FROM SILICEOUS ROCKS AND ITS EFFECT ON FAUNAL CONTENT AND BIOZONAL CORRELATION

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Examination of radiolarian-rich siliceous rocks in the field and in thin section leads to the expectation of abundant and diverse faunas in acid-processed residue. Radiolarians are usually extracted from chert, tuff, argillite, and siliceous mudstone by etching with 10% HF solution for 24 hours, repeating the process an average of three times. However, the number of individual radiolarians visible in thin sections may be an order of magnitude greater than that observed in extracted faunal assemblages. Counts were made of individual radiolarians in thin sections (avg./cm^2) and, after the third etch, on etched thin-section blanks (avg./cm^2; 5% and 10% HF), as percentage of whole specimens on etched blanks, and in residues from the blanks (63-micron fraction; all forms counted except unidentifiable spumellarians). Average values for Jurassic Franciscan chert (California), Early Cretaceous Hawasina Formation radiolarite (Oman), and Late Triassic Rail Cabin Formation siliceous mudstone (Oregon) samples are provided below. Data for mid-Jurassic carbonate concretions (Snowshoe Formation, Oregon) etched in 10% HCl are shown for comparison.

Lithology	Samples	Thin-Section	Etched Surface		%Whole Rads		Dry Residue	
			5%HF	10%HF	5%	10%	5%	10%
Franciscan chert	10	870	ND	120	ND	30-40	ND	42
Oman radiolarite	12	1700	785	575	50-60	30-40	310	102
Sil. mudstone	8	975	780	730	ND	60-70	>1000	>1000
Carb. conc. [10%HCl]	4	[95]		[42]		[85-90]		[188]

Spumellarians dominate the forms examined in thin sections and on etched surfaces of siliceous rocks, but they are less abundant in residues. Exceptions are those with thick test walls, such as the pantanelliids and Praeconocaryomma. Nassellarians represent a smaller percentage of the forms in thin sections and on etched surfaces, but they dominate the assemblages in the chert residues.

Use of 5% HF yielded a greater number of whole individuals both on etched surfaces and in residues in comparison to values for 10% HF. Although fewer radiolarians were observed in thin sections of concretions, those extracted were better preserved, more diverse, and generally more delicate than those extracted from siliceous rocks. Concretion assemblages more accurately reflect thanatocoenosis because rapid concretion growth at or near the sediment-water interface inhibits diagenesis and crushing during compaction.

A consequence of HF processing is that much of the fauna is destroyed by etching; commonly, all that remains are robust forms. Most cherts produce far fewer individuals than were recovered from the radiolarian-rich Hawasina and Franciscan samples. Biozonations based solely on marker species from cherts (e.g., Jurassic zones of Europe) may preclude precise correlation with those constructed from limestone assemblages. Development of radiolarian biozones should incorporate assemblages from a variety of rock types whenever possible.

Blome, C. D., and Reed, K. M., 1991, Chemical extraction of radiolarian faunas from siliceous rocks and its effect on faunal content and biozonal correlation. Geological Society of America Annual Meeting, San Diego, CA, Oct. 21-24, 1991, p. A37.

FLUVIAL TO SUBTIDAL DEPOSITION -- CAMBRIAN SAWATCH QUARTZITE AND LOWER PART OF PEERLESS FORMATION, MANITOU SPRINGS, COLORADO

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Deposition of the Sawatch Quartzite and overlying dolomitic Peerless Formation near Manitou Springs, in central Colorado, was related to a transgression of the Late Cambrian sea. Detailed examination of these rocks suggests that they were deposited in fluvial, subtidal, and sabkha environments.

The Sawatch Quartzite and the lower part of the Peerless Formation are made up of five depositional units. The lowermost Sawatch Quartzite (unit A) overlies Proterozoic granite and is composed of 5 m of medium- to coarse-grained, arkosic to subarkosic, dominantly lenticular-bedded sandstone. Individual sandstone beds fine upward from thin conglomeratic bases and are 0.3-1 m thick. Unit B is a 0.3- to 0.7-m-thick bed of medium- to coarse-grained, light-colored, arkosic to subarkosic, mottled sandstone. The base of unit B shows a few centimeters of scour. Unit C consists of about 3-7 m of poorly sorted, fine- to coarse-grained, dark-colored, glauconitic and arkosic sandstone containing large-scale, low to moderately dipping, trough crossbeds. These crossbeds grade laterally and vertically into sandstone containing wave-ripple lamination. The trough crossbeds fill several broad scour-based channels eroded into underlying facies. Unit C grades upward into unit D, which is about 8-14 m of moderately to well sorted, fine- to medium-grained, glauconitic and arkosic, rippled, and bioturbated sandstone and siltstone containing some hummocky cross-stratification. Sandstones of unit D grade upward into dolomites of the lower Peerless Formation (unit E) containing algal laminations, bioherms, birdseye structures, and solution collapse breccias.

The lower Sawatch represents fluvial valley-infill deposits (unit A) capped by animal-reworked mottled sandstones (unit B) marking initial transgression of the sea. The upper Sawatch (units C and D), containing large foreset trough crossbeds, wave ripples, bioturbation, and some hummocky cross-stratification, reflects tidal channel-intertidal-shoreface environments. The lower part of the overlying Peerless (unit E), containing birdseye structures, solution collapse breccias, bioherms, and algal laminations, reflects sabkha to subtidal environments.

Charpentier, R.R., Dyman, T.S., Flores, R.M., and Hemeida, A., 1991, Geological Society of America Abstracts with Programs, v. 23, no. 5, p. A 286.

A NEW METHOD FOR THE SELECTIVE DISSOLUTION OF SEDIMENTARY ANHYDRITE

by Cynthia A. Rice and George N. Breit

Trace element concentrations in anhydrite reflect processes of brine evolution, sediment deposition, and diagenesis. The fine-grained intergrowth of anhydrite with other authigenic precipitates as well as clastic components in sedimentary rocks makes determination of trace elements in the anhydrite difficult. Physical separation of the anhydrite from other phases is not feasible so selective chemical dissolution is necessary. In previous studies, trace elements in fine-grained sedimentary anhydrite have been determined by total digestion of a raw sample or one pretreated with dilute acetic acid to remove carbonate minerals. However, these methods dissolve some or all of the other rock components which may contain significant amounts of trace elements. We have developed a method for selectively dissolving anhydrite and preconcentrating its contained trace elements through use of cation exchange resin and dialysis tubing. The technique is being used to evaluate trace element concentrations previously reported in anhydrite from the Pennsylvanian Hermosa Formation in the Paradox basin, Colorado and Utah.

One to two grams of sedimentary anhydrite of <62.5 µm are placed in a flask with a stir bar and 250 ml deionized water. Cation exchange resin "bags", made by filling dialysis tubing (1000 MWCO) with sodium-saturated strongly acidic cation exchange resin (200-400 mesh, X8-cross-linked, sulfonic acid group), are suspended in the solutions which are stirred until the anhydrite has dissolved (1-7 days). At least 2 g of anhydrite can be dissolved with 17 ml of Na-resin, and 96 percent of the cations from the anhydrite are preconcentrated on the resin. The cations are then eluted from the resin with 8 N HCl and analyzed by atomic absorption spectrophotometry. X-ray diffraction of residues from selected samples indicate that anhydrite is totally dissolved leaving a residue of dolomite (<5 percent dolomite dissolved) and silicates. Preliminary results of the Hermosa Formation indicate that the reported high concentrations of metals reside in phases other than anhydrite.

This method may be applied to determination of trace metal K_d's, to separation of clay minerals from anhydrite, or to dissolution, concentration, and separation of cations and anions from other weakly soluble minerals.

Rice, C. A. and Breit, G. N., 1991, A new method for the dissolution of sedimentary anhydrite, GSA Abstracts with Programs, vol. 23, no. 5, Sept., 1991, Abstract #022721.

SURFACE RUPTURES AND DEFORMATION ASSOCIATED WITH THE 1988 TENNANT CREEK AND 1986 MARRYAT CREEK, AUSTRALIA, INTRAPLATE EARTHQUAKES

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Because the long-term behavior of intraplate faults in 'stable' continental interiors (SCI), such as in central and eastern North America, is not well understood, we studied the two most recent of five historic Australian surface-rupturing SCI earthquakes.

The January 22, 1988, Tennant Creek, NT, earthquake sequence consisted of three *Ms* 6.3-6.7 events within 12 hrs that produced 32 km of surface ruptures along three roughly west-trending arms. Individual ruptures (6.7 to 16.0 km long) are characterized by north- and south-directed folds and reverse fault scarps (0.8 to 1.4 m high). Maps of our four trenches across the 1988 ruptures document reverse faults that dip 25°±5° and offset Proterozoic bedrock, Miocene(?) to Quaternary(?) ferricrete, and late Pleistocene eolian sand (1.5 to 3 m thick), which preserves intricate details of deformation. Thermoluminescence dating indicates that sand deposition started *ca.* 60±6 ka and continued into the Holocene. The northwestern arm ruptured first and formed mainly folds with minor thrusts. The second earthquake occurred on the southwestern arm, which coincides with a 1.6-km-long quartz ridge, and is the only arm with evidence of prior Quaternary rupturing. The maximum offset (≤2 m) occurred along the eastern arm during the last and largest of the three earthquakes. The last earthquake sequence involving all three arms occurred ≥60 ka.

The March 30, 1986, Marryat Creek, SA, earthquake (*Ms* 5.8) formed a 13-km-long, boomerang-shaped rupture. The southern arm has oblique-dextral motion and the western arm has oblique-sinistral motion, thus indicating northeastward thrusting. Scarps are 0.4-0.8 m high with subequal amounts of strike-slip offset (≤0.8 m). Our two trenches exposed reverse faults that dip 35°±5° and offset Proterozoic crystalline rock under a cover of colluvium and piedmont alluvium on which early(?) late Pleistocene or older soils (thin A, weak to moderate Bt, and stage II Bk horizons) formed. Although northeast-directed compression reactivated ancient faults, no evidence exists of prior faulting in the late Quaternary.

These investigations of historical intraplate faulting and our brief observations of a trench across the 1968 Meckering (WA) fault scarp suggest that Australian intraplate faults have long repeat times; with this in mind, the concept of recurrence intervals may not be appropriate for SCI earthquakes. Perhaps hazard assessments in Australia and other continental interiors should be based on moderate- to large-magnitude earthquakes that can occur at any time on suitably oriented faults, rather than only on faults having demonstrable Quaternary movement.

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‡ Partially supported by Electrical Power Research Institute (EPRI).

From Machette and others, 1991, GSA Abstracts with Programs, v. 23, no. 5, p. A224.

SEISMIC HAZARD AND RELATED MAPS OF PARTS OF THE CENTRAL UNITED STATES PRODUCED USING GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY*

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Geographic Information System (GIS) technology is well suited for producing maps and analyzing seismic hazard and risk in earthquake-prone regions because the user can efficiently combine, manipulate, examine, and present diverse data on maps at different scales and projections for different applications. Also, having a common database and system for manipulating map information aids communication among users. For example, the U.S. Geological Survey, in cooperation with others, is conducting a multiyear, multidisciplinary program to improve understanding of seismic hazards and to decrease seismic risk in the Upper Mississippi Embayment and the surrounding midcontinent region. Much of the geologic, geophysical, and cultural information collected during the program can be compiled on maps, and many technical, administrative, and industrial specialists may want to have access to this information in digital or map form.

Data are being acquired from many federal, State, and university sources that include political, cultural, and scientific databases. In this poster, we show sample maps to illustrate what has been produced to date. The map that covers the largest area (scale 1:2,500,000) includes the 21 States that could sustain damage in the worst-case scenario of a recurrence of earthquakes comparable to the New Madrid 1811-12 earthquakes. The map shows large, urbanized areas that represent concentrations of population, structures, local lifelines, and emergency-response facilities and personnel. The map also shows regional transportation networks and the large pipelines that carry much of the East's energy supplies northeast across the Mississippi Valley. Finally, the map shows a few elements of hazard, including the main areas that are susceptible to soil liquefaction and ground-motion amplification. Another map shows selected geologic, seismological, and other geophysical features in the area immediately surrounding the meizoseismal area of the 1811-12 earthquakes (scale 1:250,000). Important geophysical boundaries (rift and plutons) and seismicity are included on this map. A third map (scale 1:24,000) shows the locations of many survey lines along which shallow-reflection data were collected and analyzed during 1990.

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* Modified slightly from abstract published in 1991 in Seismological Research Letters, v. 62. Poster presented at 4th. International Conference on Seismic Zonation, Stanford, Calif., Aug. 25-29, 1991, and at meeting of Eastern Section, Seismological Society of America, Memphis, Tenn., Oct. 14-16, 1991.

ISOSTATIC RESIDUAL ANOMALY GRAVITY MAPS--A COMPARISON OF LOCAL VERSUS REGIONAL COMPENSATION MODELS IN WYOMING

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Isostatic residual anomaly (IRA) gravity maps are used to remove the effects of variations in crustal thickness, that cause systematic negative values in most Bouguer gravity anomaly (BGA) maps in mountainous regions. In Wyoming, BGA values range from -80 mGal over the mountains to -288 mGal over the basins. A significant part of this range also reflects a regional topographic gradient from 1200 m above sea level in northeastern Wyoming to 2500 m in southwestern Wyoming; the Wind River and Bighorn Mountains rise to above 4000 m. IRA values computed using local Airy isostatic assumptions range from -77 mGal in the basins to +75 mGal in the Bighorn Mountains; the average is, however, near zero. Seismic reflection and two-dimensional gravity models indicate that Laramide mountain ranges are underlain by low-angle thrust faults which flatten within the lower crust. Therefore, the large positive IRA values over the mountains are caused by assuming that there are local roots beneath mountains that are actually rootless.

Although IRA maps are significant improvements over BGA maps, the optimum choice of local versus regional algorithms for isostatic compensation will vary in different tectonic regimes. In Wyoming, algorithms that average topography over wavelengths of more than 100 km will be required to minimize the relief in the IRA maps and will therefore, enhance shorter wavelength gravity anomalies in the upper crust that are caused by structures of economic interest.

Robbins, S. L. and Grow, J. A., 1991 Annual Meeting of the Geological Society of America, Abstracts with Programs, vol. 23, no. 5.

High-Resolution Seismic Imaging and Gravity Analysis of Deformation Across the Wasatch Fault, Kaysville, Utah

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J. R. Pelton (Boise State University, Dept. of Geosciences, Boise, ID 83725; 208-385-3640)

High resolution seismic and gravity data were acquired at a trench site across a Quaternary exposure of the Wasatch fault, Utah. Primary objectives of the high-resolution, CMP seismic study included: 1) testing the ability of reflection seismology to delineate unconsolidated stratigraphic units of Quaternary age in the upper 50 m of the study area; and 2) developing seismic processing techniques to suitably enhance the nonconventional, high-resolution data.

Gravity data complemented the seismic data and provided a constraint on the fault zone interpretation. These data revealed major fault locations in the unconsolidated sediment; however, gravity was of more assistance in mapping the location of the sediment-bedrock interface across the Wasatch Fault Zone.

Specialized seismic acquisition equipment recorded signal up to 400 Hz. The 12-fold, high-resolution data were processed using methods similar to those of the oil industry. Static shifts (due in part to the over 35 m of topographic relief along the 154-m seismic profile) were a major interpretation problem that was resolved by refraction statics analysis. After processing, stratigraphic resolution was around 1 m, with Fresnel zone radii of 5 m on the deepest reflecting interfaces, at 40 m depth. Good resolution (80-300 Hz dominant bandwidth) in the stacked seismic data permitted a direct trench log-seismic profile comparison. The seismic data delineate fault locations and displaced, unconsolidated sediments as well as colluvial material abutting the main fault zone. The Wasatch fault is imaged as three diagonal traces offsetting gently dipping reflectors. Dip of the Wasatch fault is 70° W at the surface, and is estimated from the seismic data to be 45° W at 25 m depth. A cumulative displacement of 2 m across the antithetic fault system is observed in both the seismic data and the trench. Agreement between the trench log and the seismic data suggests the CMP reflection seismic method is a viable investigative tool in faulted, unconsolidated sediments.

from:
Stephenson, W., High-Resolution Seismic Imaging and Gravity Analysis of Deformation across the Wasatch Fault, Utah: M.Sc. thesis, University of Utah, 1991.

West-east stratigraphic transect of Cretaceous rocks-- southwestern Montana to southwestern Minnesota

by

T.S. Dyman, S.B. Anderson, E.B. Campen, W.A. Cobban, J.E. Fox, R.H. Hammond, K.W. Porter, D.D. Rice, D.R. Setterholm, and G.W. Shurr

In Montana, North and South Dakota, and Minnesota, Cretaceous strata of the Western Interior foreland basin are preserved today in Laramide structural and cratonic basins. The Western Interior basin was asymmetric: more than 17,000 ft of strata are present in southwestern Montana, less than 1,000 ft in eastern South Dakota. Asymmetry resulted from varying rates of subsidence due to tectonic and sediment loading. Cretaceous rocks consist primarily of sandstone, siltstone, claystone, and shale. Conglomerate is abundant along the western margin, whereas limestone is generally restricted to the eastern shelf. Sediment was deposited in both marine and nonmarine environments as the shoreline fluctuated during major tectonic and eustatic cycles.

A west-east transect of the Cretaceous System from southwestern to east-central Montana, the Black Hills and Williston basin, and eastern South Dakota and western Minnesota includes regional facies relations, sequence boundaries, and biostratigraphic and radiometric correlations. More than 17,000 ft of Cretaceous strata in southwestern Montana typify thick nonmarine facies of the rapidly subsiding westernmost part of the basin. These strata include more than 10,000 ft of synorogenic conglomerate facies of the Late Cretaceous Beaverhead Group. West of the Madison Range, sequence boundaries are at the base of the Kootenai and Blackleaf Formations and bracket the Frontier Formation; sequences are difficult to define because the rocks are mostly nonmarine. Cretaceous strata in east-central Montana (about 4,500 ft thick) lie at the approximate depositional axis of the basin and are mostly marine terrigenous rocks. Chert-pebble units in these rocks reflect unconformities to the west. The Cretaceous System in North and South Dakota (1,500-2,000 ft thick) represents a marine shelf sequence dominated by shale and limestone overlain by coastal sandstone and nonmarine rocks. Major sequence boundaries are at the base of the Lakota Formation, Fall River Sandstone, and Muddy Sandstone, and bracket the Niobrara Formation.

Dyman, T.S., Anderson, S.B., Campen, E.B., Cobban, W.A., Fox, J.E., Hammond, R.H., Porter, K.W., Rice D.D., Setterholm, D.R., and Shurr, G.W., 1991, West-east stratigraphic transect of Cretaceous rocks: southwestern Montana to southwestern Minnesota [abs.]: Bulletin of the American Association of Petroleum Geologists, vol 75, no. 3, p. 567.

Cretaceous fluvio-lacustrine facies of Upper Kootenai Formation and Flood Member of Blackleaf Formation, southwestern Montana

by

R.M. Flores, T.S. Dyman, J.N. Weaver, and R.G. Tysdal

The Flood Member of the Albian to Cenomanian Blackleaf Formation is exposed in the eastern foothills of the Pioneer Mountains, southwestern Montana. Two localities were studied along a 10 mi north-south outcrop belt: Frying Pan Gulch (south) and Apex (north). Strata are approximately 625 ft thick and composed of mixed siliciclastic and carbonate sediments; they are grouped into coarse- (CGF) and fine- (FGF) grained facies sequences. The Flood Member is underlain comformably by the upper carbonate member of the Kootenai Formation.

CGF consists of lower and upper sandstone-rich (SRSF) and middle shale-rich subfacies. Both lower and upper SRSF contain erosionally based and lenticular trough- and planar-crossbedded fine- to medium-grained sandstones. The lower SRSF occurs only at Frying Pan Gulch and forms multilateral sandstones that pass laterally into fine-grained channel plugs. Sandstones in the upper SRSF occur at both localities and are multiple stacked and laterally amalgamated. FGF consists of a lower sandstone-rich subfacies of trough-crossbedded, fine-grained sandstones and an upper subfacies of laminated siltstones and burrowed shales that only occurs at Apex. The upper subfacies contains a few thin, lenticular, basally scoured, cross-stratified, fine-grained sandstones. In both FGF and CGF facies sequences, lower sandstone-rich subfacies grades downward into bioclastic and micritic limestone facies of the Kootenai Formation. Limestones underlying the CGF at Frying Pan Gulch are mainly bioclastic and form trough-crossbedded, offset, channel-form bodies interbedded with nodular limestone and calcareous mudstone. Thin- to thick-bedded micrites with gastropod and nodular limestones underly the FGF at Apex.

CGF is meandering (lower SRSF) and braided (upper SRSF) fluvial deposits. Tan mudstones and crevasse-splay sandstones of the middle shale-rich subfacies are well-drained floodplain deposits. FGF is alluvial-plain lacustrine deposits, whereas Kootenai carbonate facies is large lake deposits. During periods of waning detrital influx from lacustrine deltas, carbonates precipitated. The Kootenai lacustrine system evolved into an alluvial-dominated system at Frying Pan Gulch and an alluvial-plain- and lacustrine-dominated system at Apex.

Flores, R.M., Dyman, T.S., Weaver, J.N., and Tysdal, R.G., 1989, Cretaceous fluvio-lacustrine facies of Upper Kootenai Formation and Flood Member of Blackleaf Formation, southwestern Montana [abs.]: Bulletin of the American Association of Petroleum Geologists, v. 73, no. 9, p. 1155.

West-East Stratigraphic Cross Section of Cretaceous Rocks, central Rocky Mountains to east-central Great Plains, Utah, Colorado, and Kansas

by

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Cretaceous sedimentary strata varies in thickness from near 3,050 m adjacent to the western thrust belt at the westernmost end of the Uinta Basin, Utah, to 1,700 m near the Colorado-Utah boundary east of the basin axis. They thicken locally to more than 2800 m near local Late Cretaceous Laramide uplifts in the region between the Piceance and the western Denver basins, Colorado, and then to less than 600 m in the eastern Denver basin, and Kansas. Depositional environments represented by the rocks include coarse grained alluvial facies deposited directly adjacent to the western thrust belt, and finer grained fluvial-deltaic and marine facies of the basin's depositional and structural axis (generally within 50 to 100 km of the thrust belt). Entirely fine-grained marine siliciclastic and carbonate rocks were formed in more slowly subsiding distal parts of the basin that are as much as 1000 km east of the depositional axis. Some thick sections represent deposition in lows created by sediment and thrust loading adjacent to local Laramide thick-skin thrusts within the limits of the overall Western Interior Cretaceous basin. Depositional and geometric asymmetry of the preserved sedimentary system are the result of varied rates of regional and local subsidence due to tectonic and sediment loading. They also result from fluctuations in sea level and concomitant erosion associated with falls, and from relative sediment starving of the parts of this depositional system that were far from sediment sources.

Major sequence boundaries correspond to regional unconformities. Of at least nine unconformities that can be demonstrated by biostratigraphic omission, paleotopography, and/or paleosols, over most of the region, six extend well east of the structural axis; of those six, four extend across the entire region. Of the nine, two occur in the Albian, one each occurs in the Cenomanian, late Turonian? to early Cenomanian?, Santonian, and Maastrichtian, and three in the Campanian rocks. Thin-skin thrust tectonics most influenced the distribution of lithofacies and the extent of unconformities west of the Cretaceous Western Interior basin's structural and depositional axis in the proximal part of the foreland. Thick-skin thrust-generated uplift in distal and proximal parts of the basin's foreland and resultant erosion of older Cretaceous strata created additional extensive unconformities.

Fouch, T.D., L.O. Anna, R.C. Johnson, T.F. Lawton, P.A. Macfarlane, L.T. MacMillan, and R.J. Weimer, 1991, West-east stratigraphic cross section of Cretaceous rocks, central Rocky Mountains to east-central Great Plains, Utah, Colorado, and Kansas [abs.-poster]: American Association of Petroleum Geologists Bulletin, v. 75, no. 3, p. 576,

THE CRETACEOUS RECORD IN A NORTHEAST-TRENDING TRANSECT (B-B'), NORTHERN UTAH TO EAST-CENTRAL WYOMING

by Merewether, E.A., U.S. Geological Survey, Denver, CO; John Dolson and W.B. Hanson, Amoco Production Company, Denver, CO; W.R. Keefer and B.E. Law, U.S. Geological Survey, Denver, CO; R.E. Mueller, Amoco Production Company, Denver, CO; T.A. Ryer, The ARIES Group, Louisville, CO; A.C. Smith, U.S. Department of Energy, Morgantown, WV; D.P. Stilwell, U.S. Bureau of Land Management, Rock Springs, WY; D.M. Wheeler, RPI International, Boulder, CO; and F.G. Ethridge, Colorado State University, Fort Collins, CO

ABSTRACT

Cretaceous sedimentary rocks in the Laramide basins of the middle Rocky Mountains include 16,600 ft (5,060 m) of dominantly siliciclastic strata in the thrust-belt of northern Utah and 7,800 ft (2,380 m) of mainly siliciclastic and calcareous strata near the craton in east-central Wyoming. Regional changes in the thickness of the strata indicate that crustal subsidence during the Cretaceous was generally greatest in northern Utah and western Wyoming where it was associated with tectonic and sediment loading. However, the considerable thickness of uppermost Cretaceous nonmarine beds in several other areas reflects pronounced basin subsidence during early stages of the Laramide orogeny.

In a transect from northern Utah to east-central Wyoming, based on outcrop sections, borehole logs, and chronostratigraphic data, Cretaceous rocks grade northeastward from mainly fluvial and nearshore-marine synorogenic conglomerate, sandstone, mudstone, coal, and bentonite to mostly nearshore and offshore marine sandstone, mudstone, calcareous shale, and bentonite. Lateral changes in the lithofacies and in the extent of enclosed unconformities indicate marine transgressions and regressions that were effected by structural deformation, sedimentation, and eustatic events. Significant unconformities have been found at the base of the Cretaceous strata, at two horizons within beds of Albian age, at two horizons within rocks of Cenomanian and Turonian ages, at one horizon within Coniacian strata, and at two horizons within Campanian beds. Most of these unconformities are either flooding surfaces or sequence boundaries.

In Merewether, E.A., Dolson, John, Hanson, W.B., Keefer, W.R., Law, B.E., Mueller, R.E., Ryer, T.A., Smith, A.C., Stilwell, D.P., Wheeler, D.M., and Ethridge, F.G., 1991, The Cretaceous record in a northeast-trending transect, northern Utah to east-central Wyoming [abs.]: American Association of Petroleum Geologists Bulletin, v.75, no. 3, p. 634.

Regional Cretaceous Stratigraphic Relationships Across the Southern Segment of the Western Interior Basin, Arizona, New Mexico, Southern Colorado, and Oklahoma Panhandle

by C. M. Molenaar, W.A. Cobban, K.J. Franczyk, C.L. Pillmore, and R.S. Zech, U.S. Geological Survey, Box 25046, Denver Federal Center, Denver, CO; E.G. Kauffman, University of Colorado, Boulder, CO; J.M. Holbrook, Indiana University, Bloomington, IN; and D.G. Wolfe, San Jose, CA

Cretaceous strata in Arizona, New Mexico, and southern Colorado were deposited in the southern part of the asymmetric Western Interior basin and consist of east- and northeastward-prograding clastic wedges of shoreface sandstones and coastal-plain deposits separated by thick tongues of west- and southwestward-extending marine shale and, on the eastern shelf, by limestone. The interlayering of the two primary facies (sandstone and shale) is the result of either regional subsidence, eustasy, sediment supply, or a combination of these. Constructing and comparing regional cross sections will aid in accomplishing one of the goals of the Western Interior Cretaceous (WIK) project of the International Union of Geological Science's Global Sedimentary Geology Program, which is to identify the global effects of eustasy.

Preserved Cretaceous strata in this part of the Western Interior basin range from a few hundred feet thick on the east to about 7,000 ft on the west. A cross section across this area reveals facies relations, major sequence boundaries, unconformities, and available biostratigraphic and chronostratigraphic data for the sections preserved in the present Laramide basins. Sequence boundaries occur in the middle late Albian, at the base of the late Turonian, and within the latest Turonian. Younger sequence boundaries, if present, are less obvious, and their associated unconformities have not been identified.

Molenaar, C.M., Cobban, W.A., Franczyk, K.J., Pillmore, C.L., Zech, R.S., Kauffman, E.G., and Wolfe, D.G., 1991, Regional relationships across the southern segment of the Western Interior basin, Arizona, New Mexico, and southern Colorado: American Association of Petroleum Geologists Bulletin, v. 75, no. 3, p. 637.