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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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TWO-PHASE FLUID INCLUSIONS IN VADOSE CEMENTS OF THE PLEISTOCENE MIAMI LIMESTONE, SOUTHEAST FLORIDA

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The Late Pleistocene Miami Limestone has not been heated by burial, yet contains two-phase aqueous fluid inclusions. The inclusions occur in some vadose cements as irregular spindle-shaped vacuoles, arranged in bands crossing bundles of columnar crystals, or as isolated individuals within single crystals. These seemingly primary fluid inclusions homogenize to liquid between 75° and 130°C and have melting temperatures between -0.3° and 0.0°C. These are relatively narrow temperature ranges for vadose cements, considering that the range of homogenization temperatures (T_h) may have been increased by inclusion stretching during measurement.

The $\delta^{18}O$ composition of these cements (-4 to -5.5 per mil, PDB) and the near-fresh water in the fluid inclusions are consistent with precipitation from low-temperature meteoric water. The carbon-isotope composition of vadose cements that contain only rare two-phase fluid inclusions are comparable to the host-rock matrix ($\delta^{13}C$ between 0 and +4 per mil, PDB). Cements that contain common two-phase fluid-inclusions have a distinctly lighter carbon isotopic compositions of -3 to -5 per mil.

The properties of the two-phase inclusions and the host calcite suggest several possible origins involving a uniform trapping mechanism, or volume changes (stretching) from overheating single phase inclusions. One possibility is that these inclusions trapped gas and water in a somewhat uniform ratio along surface irregularities and crystal defects. Another hypothesis is that natural overheating, caused by peat fires that have locally affected the Miami Limestone, has stretched some single-phase inclusions and produced two-phase inclusions upon cooling. Finally, the carbon isotopes of cements that contain two-phase fluid inclusions are on the average 6 per mil lighter than those of other vadose cements, perhapse the result of precipitation from water that has been supersaturated in CO_2 by biotic respiration. Trapping of CO_2-charged water in the vadose cement may result in later phase separation and two-phase inclusions.

Regardless of the explanation, a mean T_h of 100°C is surprising because these 130,000 yr old sediments have never been buried, and the vadose cements precipitated from meteoric waters that should not have exceeded 20-25°C, based on present-day ground-water temperature. Also, other studies have shown that two-phase fluid inclusions in the vadose zone usually have highly variable liquid/vapor ratios, resulting in T_h spreading over a range up to 200°C. Yet the fluid-inclusions of the Miami Limestone have fairly uniform liquid/vapor ratios as shown by the relatively narrow T_h range of 55°C.

Program and Abstracts, American Current Research on Fluid Inclusions, 1987, unpaginated

REFLECTANCE SPECTROSCOPY OF MINERALS AT HIGH SPECTRAL RESOLUTION AS AN ANALYTICAL TOOL

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Many minerals show diagnostic absorption bands in the region of solar reflected light (0.3 to 3 um), due to vibrational overtones, electronic transitions, charge transfers, and conduction bands. The spectral properties of minerals as a function of resolution have been poorly known because most commercial instruments use a dynamic slit width (resolution) that is dependent on signal level. Thus, resolution is affected by such things as detector gains and dirt on optics. However, to properly compare laboratory spectra with those obtained by imaging spectrometry or other field instruments, resolutions must match.

An initial investigation using a fully computer controlled spectrometer concentrated on obtaining high resolution data on minerals that have "sharp" absorption bands in existing published spectra. Spectra of the minerals (e.g., phyllosilicates, carbonates, sulfates, amphiboles, and others) were measured as a function of resolution from resolving powers of about 200 (similar to imaging spectrometers) to over 2000. In many cases, minerals were found to display fine structure in the absorption bands. More importantly, these sharp features can be useful in identifying minerals, especially when in mixtures. In some cases, what appears as a single absorption feature at a resolving power of 200 is seen as at least 8 absorptions at a resolving power of 2200. High resolution spectroscopy is shown to distinguish among the isochemical end members of a mineral group, the composition of minerals in a solid-solution series, and the detection of minor element substitutions in a crystal.

This study has shown that reflectance spectroscopy can be a more diagnostic mineralogical identification tool than previously believed. With appropriate spectrometers and a spectral database derived from these new data, high resolution spectra can now be used as an analytical tool both in the laboratory and in the field.

EOS, 1986, v. 67, p. 1271

COMPUTER AUTOMATED ANALYSIS OF REFLECTANCE SPECTRA

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The analysis of reflectance spectra has traditionally been a task requiring days of work. The new mapping spectrometers to be flown on Mars Observer and CRAF as well as terrestrial instruments such as AVIRIS will return millions of spectra to analyze. New and fast analysis techniques to handle such data have been developed. These techniques are a first attempt at complete automation of the spectral analysis methods that have traditionally been interactive and have taken days, weeks, or months for a single reflectance spectrum.

The analysis of a reflectance spectrum typically involves removing a continuum, analyzing band positions, comparing band positions to the positions observed in known materials and estimating the abundances. The continuum analysis has not been automated before. Band position analysis has also been too slow with routines such as fitting Gaussian profiles to absorption features. Band position analysis with a library is common in commercial packages for transmittance spectra, and similar techniques work with reflectance spectra.

Continuum analysis, band position and shape analysis, and spectral feature analysis using a library has been automated. The resulting code is very fast: a 200 point spectrum involving 20 features can by analyzed in about 2 to 4 seconds on a 1 MIPS machine. A spectral library has been formed and is being used to test the algorithms which are about 1500 lines of Fortran. The spectral library can be convolved to any instrument spectral resolution (e.g. VIMS) and a feature library generated. The current spectral feature library contains about 8000 entries. It appears that complete identification of the minerals from a reflectance spectrum is possible on a real-time basis from spacecraft instruments such as the Mars Observer VIMS. The Mars Observer VIMS instrument could return a spectrum every 2 seconds for 2 years.

Bulletin of the American Astronomical Society, 1987, in Press

GSA Abstracts with Programs, 1987. V. 19, No. 5, p. 322

CHROME PYOPE FROM THE SLOAN DIATREME, COLORADO, SHOWING COLOR CHANGE WITH THICKNESS AND TYPE OF ILLUMINATION

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A Cr-rich pyrope garnet from the Sloan 2 Diatreme, Larimer County, Colo., exhibits alexandrite-like color changes. This garnet is a 61-gm rounded megacryst (3.0 x 4.0 x 2.2 cm) with $n=1.783\pm.002$, $d_{meas.}=3.71$, $d_{calc.}=3.75$ and $a_o=11.627$. Alteration includes (1) kelyphytic rim as much as 0.25 mm thick and (2) fractures filled with calcite and minor serpentine. A broken surface of the megacryst appears black; thin fragments are a deep-red color under incandescent light, and bluish-green under daylight or fluorescent lighting. The apparent color varies with thickness; e.g., in a polished wedge of the garnet, color varies from blood-red (thickness >0.9 mm) through grayish-violet, to pale green (thickness <0.5 mm). The color of a powdered sample is pale greenish gray.

Electron microprobe analysis (avg. of 14 points) of the garnet (with careful attention to avoid overlap of transition metal X-ray lines) shows (wt. %) 18.01 MgO, 13.46 Al_2O_3, 40.81 SiO_2, 8.34 CaO, 0.69 TiO_2, 0.06 V_2O_3, 12.03 Cr_2O_3, 0.41 MnO, 6.68 FeO, $0.00\pm.03$ Na_2O, Total 100.49. Semiquantitative XRF analysis (wt. %) also shows 0.03 NiO, 0.02 SrO, 0.01 Y_2O_3, and 0.07 ZrO_2. The garnet is nearly homogenous in composition from core to rim. A structural formula (calculated on the basis of 8 total cations) is $(Mg_{1.98}Ca_{.66}Mn_{.03}Fe^{+2}_{.38})_{3.05}(Al_{1.17}Cr_{.70}Fe^{+3}_{.03}Ti_{.04})_{1.94}Si_{3.01}O_{12.00}$. This garnet is a titanian uvarovite-pyrope, per Dawson and Stephens (1976, J. Geol., p. 495); its major end-member components can also be expressed as knorringite$_{35}$ prp$_{31}$ grs$_{16}$ alm$_{10}$adr$_4$ schlorlomite$_2$sps$_1$. Previous analyses of garnets from the Sloan kimberlites have indicated as much as 12.7 wt. % Cr_2O_3, with an overall composition similar to our garnet; such compositions are characteristic of a lherzolitic origin.

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THROUGH THE MICROCSOPE--A LOOK AT THE LANCE FORMATION AROUND THE POWDER RIVER BASIN

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Previous studies of various aspects of the Upper Cretaceous Lance Formation in the Powder River Basin, Wyoming and Montana, except for paleontologic studies, have focused on the few restricted areas of moderately good exposure. In this study samples for thin-section analysis were collected around the entire basin at approximately 50-mile intervals. At each sample site, channel sandstones were sampled where available across the entire outcrop belt to check for stratigraphic as well as geographic changes in the mineralogy.

Preliminary results of this petrographic study indicate that geographically there are three mineralogic groupings of the framework grains of the Lance sandstones. In the northern part of the basin, rock fragments, commonly of volcanic origin, and chert exceed quartz grains, and plagioclases exceed alkali feldspars. In the southern part of the basin, the reverse is true: quartz exceeds rock fragments, which here are commonly of intrusive origin, and alkali feldspars exceed plagioclases. The sandstones in the central part of the basin are more like those in the northern than southern part, but are distinguished by the presence of a green hornblende, which does not occur elsewhere. No stratigraphic changes in mineralogy are apparent.

These three geographic mineralogic groupings suggest that there were at least three different source areas for the detritus in the Lance sandstones in the Powder River Basin. The general flow directions recorded in the channel sandstones indicate the general directions of those sources: a volcanic source to the northwest for the northern part of the basin, and exposed intrusive sources to the west and southwest, respectively, for the central and southern parts of the basin.

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MINERALOGY OF CAVE OF THE WINDS, MANITOU SPRINGS, COLO.

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Cave of the Winds is a phreatic cave system developed in the Manitou (Ordovician), Williams Canyon (Devonian), and Leadville (Mississippian) limestones. Recent excavation of mud-filled passages has led to discoveries of new rooms, including "Silent Splendor", a 65 m long, previously sealed chamber noteworthy for its pristine and unusual speleothems. These include beaded helictites, composed of sheaves of aragonite needles around a core of monocrystalline calcite, 1-5 mm in diameter and as much as 30 cm long. Calcium-magnesium, bicarbonate-sulfate water in Silent Splendor contains 39 mg/l Ca, 7 mg/l Mg, and higher than average groundwater amounts of Fe (330 mg/l), Zn (30 mg/l), and U (1 mg/l). Evaporation on speleothems has led, through build-up of Mg in solution, to successive crystallization of calcite (some of which is magnesian), aragonite "frostwork" anthodites, and blebs of hydromagnesite. Hydromagnesite moonmilk occurs locally on cave walls, sometimes as double, parallel tracks about 5 mm apart and as much as 0.5 m long. Much of the calcite and aragonite is luminescent under ultraviolet light, commonly bluish-white, but locally green due to UO_2^{++}. Mirabilite forms cottony efflorescences on a clay horizon at or near the top of the Manitou Limestone in Canopy Hall, near the cave entrance. Reddish-brown mud clogs or partly fills many of the cave passages; it is composed of smectite and kaolinite clays plus limonite and silt-size quartz. Mud in Snider Hall contains hexagonal, prismatic crystal impressions up to about 5 cm in length, possibly made by fossil ice crystals. A variety of scratch- or crack-like indentations of uncertain origin are associated with the crystal impressions. Other speleothems in the cave include cave pearls, "button" stalagmites, "bird-bath" conulites, gypsum needles, and limonite boxwork.

ORIGIN AND SIGNIFICANCE OF MINERALIZED PRE-TERTIARY XENOLITHS IN PUMICE BRECCIA AT OLD HORSE SPRINGS, MOGOLLON-DATIL VOLCANIC FIELD, CATRON COUNTY, NEW MEXICO

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Xenoliths of pre-Tertiary rocks occur in 33 Ma dacitic pumice breccia near Old Horse Springs, New Mexico. Many xenoliths are silicified and mineralized carbonate rocks--jasperoid--which have unbroken skarn-like reaction rims, but others are mineralized or unaltered sandstone or quartzite without reaction rims. Xenoliths, as float, occur throughout the upper half of the pumice breccia which is as much as 200 m thick; but xenoliths in outcrop are apparently concentrated where the pumice breccia contains up to 50 percent, or more, coarse-grained quartz monzonite inclusions that are cognate with the dacitic pumice.

Red jasperoid nodules consist mainly of fibrous radiating quartz, hematite, zinc-bearing magnesioferrite, and calcite. Other nodules consist almost entirely of ferriferous ore minerals, apparently replacing bedded sandstone. Some mineralized nodules contain as much as 10,000 ppm (1%) zinc, 3,000 ppm manganese, 300 ppm copper, 300 ppm vanadium, 100 ppm nickel and 70 ppm lead. The reaction rims around calcareous nodules are mainly finely granular diopside and garnet, but this skarn-type assemblage is accompanied by clays.

This apparently intimate association of high temperature skarn and low temperature jasperoid minerals suggests that minerals formed under fumarolic conditions in the cooling pumice deposit were superimposed upon mineralized jasperoid that formed under relatively low temperature hydrothermal conditions in the hypabyssal magmatic environment.

Whatever the process(es), the mineralized xenoliths indicate at least a moderate potential for contact metasomatic base and ferrous metal, and possibly precious metal deposits related to a quartz monzonitic intrusive in pre-Tertiary sedimentary rocks beneath the Horse Springs area.

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MECHANISM OF LITHIUM ENRICHMENT IN THE POPOTOSA FORMATION, SOCORRO COUNTY, NEW MEXICO

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Sedimentation, Li geochemistry, and clay mineralogy combined to provide a source, a concentrator, and a trap for Li in tuffs of the Popotosa Formation, central New Mexico. These Li-rich tuffs (80-3,850 ppm Li) occur in the closed-basin rocks of the Socorro paleobasin, a late Oligocene through Miocene precursor of the Rio Grande rift. The 7-to 18-m.y.-old airfall and waterlain tuffs were erupted from postcaldera-resurgence vents near the paleobasin margin. Tuffs deposited in playa sediments are thicker, more zeolitic, and more Li rich than are tuffs deposited on alluvial flats.

Li is leached preferentially from rhyolitic and dacitic volcanic glasses by fresh and alkaline ground waters. Li forms no salts in nature and has the lowest cation exchange capacity of the alkaline metals; however, it shows limited substitution for Mg in clay minerals. Airfall ashes have high porosity and permeability, which make them susceptible to leaching of Li and other cations by ground water flowing downbasin to the playa where evaporative concentration occurs.

The thicknesses of the airfall portions of the playa tuffs correlate with their whole-rock lithium contents ($r = 0.71$, $n = 13$ samples), suggesting that thicker, hence, volumetrically larger, ashes were leached of more Li by ground waters moving through the tuffs to the basin center than were thinner ones. Thus, the source of Li in Popotosa tuffs may be the tuffs themselves.

Li-rich playa tuffs consist of dioctahedral smectite, quartz, plagioclase, varying amounts of calcite and clinoptilolite, and traces of mordenite, gypsum, biotite, and dolomite. Li is contained in dioctahedral smectites, which have identical X-ray diffraction traces no matter what their Li content. When interlayer cations of high-Li smectites were exchanged for Sr, much of the Ca, Na, and K were replaced by Sr. However, the Mg and Li values remained constant because they are structural elements of the octahedral layer. Cation exchange coefficients of the clay fractions range from 0.90 to 1.75 meq/g and are proportional to a clay fractions's Li content. Li^{+1} occupies sites in the octahedral layer normally held by Al^{+3} or Mg^{+2}, leading to a net negative octahedral layer charge, balanced by the addition of Ca, Na, and K to the smectite interlayers.

Whole-rock chemistries of high-Li playa tuffs are similar to those of their cogenetic volcanic flows except for Li and Mg enrichment and K depletion. Li is elevated as much as 58 times, and Mg is 10 times higher in the tuffs than in the cogenetic flows. If Li in the tuffs was brought to the playa by groundwater dissolution and movement through the ashes, then why are calcium and sodium levels not elevated? and why do K values drop an order of magnitude in the playa facies, the center of evaporative concentration? Independent observation suggests that K in the flows was elevated by K metasomatism that did not affect the playa tuffs. However, the playa tuffs probably were enriched originally in Ca and Na by ground-water flow through the tuffs. Because those elements were not incorporated structurally into the dominant diagenetic phase smectite, their final concentrations were controlled by postdiagenetic events. Some Na and Ca and K presently are held as interlayer cations in the smectites; more of those cations may have been held as soluble salts in the tuffs, later removed by fresher waters introduced by intrabasin horsting, paleobasin breaching, and rainwater.

A delicate balance between ground-water inflow and tuff leaching and evaporative concentration and incorporation of Li into neoforming smectite was maintained to achieve high structural Li values in these dioctahedral smectites. Paleobasin breaching occured 4-7 m.y. ago; Li still in solution or in exchangeable sites would have been removed or replaced by other cations in fresher open-basin system waters.

USGS Research on Mineral Resources-1987 Program and Abstracts, U.S. Geological Survey Circular 995, p. 2-3

GEOPHYSICAL DELINEATION OF GRANITIC PLUTONS IN NEVADA AND THEIR RELATION TO GOLD DEPOSITS

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Partially and wholly buried plutons, which commonly produce characteristic magnetic anomalies, were mapped within Nevada in order to investigate their association with disseminated gold deposits. The plutons were mapped by applying a mathematical technique to magnetic data of the state and by comparing these results with gravity, aeromagnetic, and geologic maps. The technique estimates the locations of steep, shallow magnetization boundaries which generally occur at pluton edges but occasionally within plutons. Pluton edges and ages were determined by comparing magnetic and gravity anomalies to mapped granitic rocks. These determinations were difficult when boundaries enclosed more than one granitic rock unit or where strongly magnetized volcanic rocks were present.

Inferred Precambrian plutons are magnetic; inferred Triassic and Jurassic plutons are generally weakly to very weakly magnetic; inferred Cretaceous plutons are generally magnetic; and inferred Tertiary and undifferentiated Mesozoic plutons are variable. Many mapped granitic rocks have no aeromagnetic expression, and therefore their lateral extents could not be delineated.

Most known deposits of disseminated gold occur next to calculated magnetization boundaries, positive magnetic anomalies, or both. Many deposits, such as the Carlin and Getchell deposits, lie next to inferred Cretaceous plutons.

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URANIUM SERIES DISEQUILIBRIUM IN A HOLOCENE URANIUM DEPOSIT IN NORTHEASTERN WASHINGTON

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A recently discovered ore-grade accumulation of uranium in post-glacial, organic-rich sediments provides an opportunity for studying the early association of uranium and organic matter in a natural setting. The uranium occurs in valley-fill sediments of peat, peaty clay, silt, and sand along the north fork of Flodelle Creek, Stevens County, Washington. Sixteen lithologically distinct intervals in a 290 cm core were measured by high-resolution gamma-ray spectrometry and by thin-source alpha spectrometry to determine the abundance and distribution of uranium series nuclides and the extent of secular equilibrium within the uranium decay series. On the basis of the youth of the host sediments and the paucity of associated radioactivity, large excesses of uranium relative to daughters were expected and observed. Samples taken above the 6,700 to 7,000 year old Mazama Ash (0-127 cm depth) are clearly most deficient in daughters, but a simple increase of daughters relative to uranium as a function of depth was not observed, probably because chemically diverse daughters that are decay-generated in situ have differing mobilities, and because upwelling ground waters continuously add more uranium and minor amounts of daughters. Measured alpha activity ratios of $^{234}U/^{238}U$ (1.31-1.38) are analytically indistinguishable from those measured in coexisting waters, suggesting a rather constant isotopic composition of introduced uranium and little preferential recoil of ^{234}U daughter from sediment surfaces. A consistent excess of ^{210}Pb relative to ^{226}Ra is observed throughout the core, suggesting ground-water input of the highly mobile intervening daughter, ^{222}Rn. The abundance of uranium (160-3,300 ppm) correlates highly with the abundance of organic matter (3-60 wt. %) as do abundances of ^{226}Ra, ^{230}Th, and ^{210}Pb below 127 cm depth.

GSA Abstracts with Programs, 1985, v. 17, no. 7, p. 758

GEOMORPHIC EVOLUTION OF THE LOWER BIGHORN RIVER AREA, MONTANA

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The lower Bighorn River between Bighorn Canyon and the Yellowstone River in south-central Montana is flanked by a discontinuous sequence of 12 terraces that range in height from 3 to 350 m above the river. The ages of individual terraces, which range from 20 ka to 2.2 Ma, have been estimated using radiometric ages of volcanic ash in the underlying gravels (0.62-Ma Lava Creek B ash), by correlation with other ash-dated terraces in the northern Bighorn Basin area (2.0-Ma Huckleberry Ridge ash), and by local incision rates calculated from the elevations of these ash-dated terraces.

All terraces have similar gravel thicknesses (3-8 m) and cobble diameters (at comparable locations along the longitudinal profile), suggesting similar fluvial regimes. Although none of the terraces can be directly related to glacial events upstream, the similarity of the lower Bighorn River sequence to glaciofluvial terrace sequences in the northern Bighorn Basin suggests a regional climatic control.

Several anomalies in the terraces suggest that the area has been tectonically active in the Quaternary. Pebble counts show the terraces older than 1.2 Ma contain 25% volcanic gravel whereas younger terraces contain 50%. This reflects the capture of the volcanic-gravel-bearing Shoshone River into the Bighorn River from its previous course through the Pryor Mountains, possibly due to Quaternary fault movements in the Pryor Mountains. Terraces are preserved on both sides of the river at levels below about 40 m, but the six highest terraces (older than 260 ka) occur only on the west side. This pattern is repeated along the three major tributaries of the Bighorn, suggesting that all these streams have undergone a net eastward migration due to regional tilting. The lower four terraces (below 20 m; younger than about 120 ka) show a slight convergence downstream while all higher terraces show a marked divergence downstream, possibly due to isostatic rebound of the basin. Irregularities in the longitudinal profiles of the Bighorn River and its terraces may reflect differential vertical movements.

GSA Abstracts with Programs, 1987, v. 19, no. 5, p. 257

FRAMEWORK AND SEDIMENTATION PATTERNS OF THE TULLOCK MEMBER OF THE FORT UNION FORMATION, EAST-CENTRAL POWDER RIVER BASIN, MONTANA AND WYOMING

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Regional subsurface and outcrop studies of the fluvial Tullock Member of the Paleocene Fort Union Formation in the east-central Powder River basin, Montana and Wyoming, indicate basin filling from the west by low-energy fluvial systems grading upward to stacked channel systems. Maps of sand-body geometry, lithofacies variations, and paleogeographic reconstructions were prepared from the analysis of approximately 200 well logs. Emphasis on subsurface data was necessitated by poor, inaccessible, or nonexistent outcrops in the study area. Where possible, subsurface models were field tested by matching paleocurrent data with inferred sand-body axes, as well as by comparing vertical and lateral grain-size variations with nearby well-log signatures.

In outcrops of the east-central Powder River basin, the lower part of the Tullock Member is composed of thin, lenticular sandstones, interbedded with mudstones, carbonaceous shales, and a few thin, impure coals. The carbonaceous shales display thin, laminated bedding, leaf fragments and impressions, and rooted texture. The upper part of the Tullock contains 20-80 ft (6-24 m) thick yellow, moderately well sorted, structureless or large-scale trough cross-bedded sandstones that have erosional bases.

In the subsurface of the study area, the Tullock Member is 200-600 ft (61-183 m) thick. The thickest sandstones in the study area are concentrated in a broadly elongate zone parallel to and slightly northwest of the eastern basin margin. Highest percent sand contours define an elongate northwest-trending zone superposed and generally coincident with isopach trends in the area. Well-log interpretation suggests fining upward, locally stacked, fluvial sandstone bodies adjacent to and intertongued with fine-grained overbank deposits. Stacked fluvial sandstones are 30-55 ft (9-17 m) thick and are separated by fine-grained intervals 10-20 ft (3-6 m) thick.

The orientation of framework sandstones shows east to northeast deposition of fluvial channel sandstones associated with interfluvial zones of flood plains and swamps. Local stacking of some channel sandstones in the upper part of the Tullock suggests the initiation of basin subsidence during the Laramide orogeny.

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PRELIMINARY STATISTICAL ANALYSIS AND PROVENANCE TRENDS IN DESMOINESIAN SANDSTONES FROM CENTRAL AND EASTERN OKLAHOMA

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Desmoinesian sandstones from the northeast Oklahoma platform and from the Anadarko and McAlester basins record a complex interaction between mid-Pennsylvanian source-area tectonism and cyclic sedimentation patterns associated with transgressions and regressions. Framework grain summaries for 67 thin sections from sandstones of the Cherokee Group (Bartlesville, Red Fork, Skinner, and Prue) were subjected to multivariate statistical analysis to establish regional compositional trends for provenance analysis.

R-mode cluster and correspondence analyses were used to determine the contributing effect (total variance) of key framework grains. Fragments of monocrystalline and polycrystalline quartz, chert, metamorphic rock, and limestone contribute most to the variation in the grain population. Q-mode cluster and correspondence analyses were used to identify three distinct petrofacies. Petrofacies I is rich in monocrystalline quartz (86 to 98%) and contains rare mica and rock fragments. Petrofacies II is also rich in monocrystalline quartz (66 to 86%) and contains as much as 15% metamorphic and sedimentary rock fragments. Petrofacies III is compositionally heterogeneous and contains fragments of polycrystalline and monocrystalline quartz, mica, chert, and metamorphic and sedimentary rocks.

Quantitative analyses indicate that Desmoinesian sandstones were derived from complex sedimentary and metamorphic source areas. Petrofacies I sandstones are restricted to the southwestern part of the Anadarko basin and the northeast Oklahoma platform, whereas petrofacies II and III sandstones are distributed throughout the study area. The distribution of petrofacies within the region suggests a model of source-area interaction and cratonic sediment recycling.

AAPG Bulletin, v. 71, no. 5, p. 551

LARAMIDE TECTONICS AND DEPOSITION OF THE FERRIS AND HANNA FORMATIONS, SOUTH-CENTRAL WYOMING

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The Upper Cretaceous-lower Tertiary Ferris and Hanna formations in south-central Wyoming constitute an interval of continental rocks that contain principal coal beds in the Hanna and Carbon intermontane basins. The interval in the Hanna foreland basin consists of plane-bedded arkosic and lithic conglomerate with sandstone and mudstone interpreted as piedmont slope deposits. They wedge southward into central basin planar and trough cross-bedded sandstone and coeval parallel bedded sandstone and siltstone, dark-colored mudstone and shale, and coals interpreted as fluvial and floodplain deposits. The adjacent Carbon basin contains the fluvial and floodplain deposits. Deposition occured in a syncline situated between systems of uplifts that resulted from compressional deformation. Upper Cretaceous sediments were derived mostly from uplifts to the south, and Paleocene and lower Eocene sediments were derived mostly from north of the Hanna basin. Lower Eocene and older rocks were folded into the footwalls of a large, east-west-trending middle Eocene uplifts that were thrust southward over the northern Hanna basin margin.

Increased structural complexity from Late Cretaceous through middle Paleocene to middle Eocene time resulted from increasing uplifts and associated counterclockwise rotation from east-west to north-south-directed couple stresses. This rotation paralleled the movement of the North America plate as it overrode the Farallon plate. The north-south couple stresses produced thrusting of middle Eocene uplifts surrounding the basins, separation of the Hanna and Carbon basins, and thrusting that was at about right angles to Late Cretaceous thrust patterns. Crustal shortening was followed by extensional deformation and general regional uplift.

Paleotectonics and Sedimentation in the Rocky Mountain Region, United States, AAPG Memoir 41, p. 481

DEPOSITIONAL HISTORY AND SEISMIC STRATIGRAPHY OF LOWER CRETACEOUS ROCKS, NATIONAL PETROLEUM RESERVE, ALASKA AND ADJACENT AREAS

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Knowledge of depositional history of Lower Cretaceous rocks in the National Petroleum Reserve in Alaska is necessary for predicting the occurrence of potential sandstone reservoirs. These rocks range in thickness from 7,000+ m along the Colville basin axis to about 1,200 m on the Barrow arch. Lower Neocomian strata on the north flank of the basin consist of southward-prograding marine shelf and slope deposits of shale and minor sandstone units. Uplift, erosion, and subsequent transgression on the northernmost flank of the basin resulted in deposition of the pebble shale unit in late Neocomian time and termination of the northern provenance. Following this, the basin was downwarped, and little deposition occured on the north flank until distal, deep-water deposits of the Torok Formation onlappped and downlapped the south-dipping flank of the basin in middle or late Albian time.

On the south flank of the basin, southern-source turbidites of the Okpikruak Formation (early Neocomian) accumulated in a subsiding foredeep and were subsequently thrust northward in late Neocomian or Aptian time. The Fortress Mountain Formation (early Albian), which consists of as much as 3,000 m of mainly deep-water deposits, unconformably overlies the Okpikruak and older rocks on the southernmost flank of the basin. Filling of the Colville basin occured in middle to late Albian time as thick prodeltaic and deltaic deposits of the Torok Formation and Nanushuk Group, respectively, prograded across the basin from the south on the south side of the basin, but prograded principally from the west-southwest over most of the basin.

AAPG Bulletin, 1985, v. 69, no. 4, p. 670

A SOIL CHRONOSEQUENCE ON URANIUM-SERIES DATED CORAL TERRACES, BARBADOS, WEST INDIES

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Because there have been few studies of tropical soil chronosequences, we studied soils on six well-dated, uplifted coral terraces on barbados in order to quantify trends of development in this seasonally moist tropical environment. Detailed mineralogical and chemical analyses indicate that the soils have formed from a combination of coral reef detritus, detrital quartz from tertiary bedrock on barbados, volcanic ash from nearby St. Vincent Island, and mostly airborne dust from Africa. Soils are chiefly typic hapludolls, typic chromuderts, and typic pelluderts. Results of field and laboratory studies summarized in the table below indicate that soil rubification (reddening), maximum values for clay content and dithionite-extractable Fe, and profile summations for extractable Fe all show weak trends with age, but solum thickness and profile summations for clay show no trends. If soil chronosequence models are applicable in this environment, one explanation for the poor fit of some of the properties is erosion of thicker, well-developed soils on older terraces. This explanation is supported in part by the observation that drainage density and degree of karst development increase with terrace age. Clay mineralogy does change systematically from a suite of smectite and kaolinite-smectite to relatively pure kaolinite over 1.0 Ma. We conclude that because of erosion, only certain soil properties, such as extractable Fe, color, and clay mineralogy will be useful as relative age indicators in this and perhaps other similar tropical environments.

American Quaternary Association Program and Abstracts, 1986, p. 156

REFINING EUSTATIC SEA LEVEL CURVES WITH BALANCED PALEOGEOGRAPHIC MODELS

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Balanced paleogeographic reconstructions of the northwestern Gulf of Mexico and Western Interior provide a method for testing the magnitude of proposed eustatic sea level high and low stands. Vail et al. (1977) and Haq et al. (1987) predicted early Cenozoic high stands of approximately 200 meters. Balanced paleogeographic reconstructions of the Gulf Coast during the Cenozoic show that much of the Midwest and Gulf Coast had average elevations less than 200 meters above present day sea level. Mass balance models using the Haq et al. (1987) eustatic sea level values predict large scale continental flooding which is not substantiated by the present pattern of marine sediments of early Cenozoic age. The results of mass balance modelling suggest that although the trend of sea level rise and fall predicted by Haq et al. (1987) is represented in North American marine sediment sequences, the actual magnitude of sea level fluctuations appears to be 1/4 to 1/8 that of the Haq et al. curve. Balanced paleogeographic reconstructions of the Gulf of Mexico and western-central North America estimate maximum Cenozoic sea level rises of 40 meters.

GSA Abstracts with Programs, 1987, v. 19, no. 7, p. 840

BITUMEN AND HEAVY OIL RESOURCES OF THE UNITED STATES

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Bitumen and heavy oil accumulations represent a significant hydrocarbon resource in the United States. Bitumen deposits (<10° API) are generally located in sandstone reservoirs at or near the surface along the margins of sedimentary basins. Heavy oils (10-20° API) are predominantly found in geologically young (Tertiary age and younger) shallow sandstone reservoirs, also along the margins of sedimentary basins. Bitumen and heavy oil have high viscosities (>10,000 cp for bitumen, 100-10,000 cp for heavy oil) and cannot be recovered by conventional petroleum recovery methods.

Bitumen deposits have been evaluated in 17 states. The bitumen resource for the conterminous United States is estimated to be 57 billion barrels. Utah contains the largest resource, estimated at 29 billion barrels of bitumen, followed by California with 9 billion barrels; Alabama with 6 billion; Texas with 5 billion; and Kentucky with 3 billion. Heavy oil deposits have been evaluated in 16 states; but most heavy oil is located in California, Texas, and Arkansas. Total heavy oil in-place for the conterminous United States is estimated to be approximately 45 billion barrels; greater than 80% of this amount is in California. The giant Kuparuk deposit on the Alaska North Slope contains a heavy oil-bitumen resource estimated as high as 40 billion barrels.

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ORGANIC GEOCHEMISTRY OF OILS AND HYDROCARBON SOURCE ROCKS, ILLINOIS BASIN

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Organic geochemical analyses of 82 Illinois basin oils demonstrate three distinct oil groups. Gas chromatographic characteristics of group 1 oils (n = 12) include predominance of odd-carbon-numbered n-alkanes between n-C_{11} and n-C_{19} (CPI =1.3-1.5), relatively small amounts of branched and cyclic alkanes (including a virtual absence of isoprenoids), and relatively small amounts of alkanes with carbon numbers greater than n-C_{19}. Group 2 oils (n =4) are characterized by a predominance of odd-carbon-numbered n-alkanes that extend from n-C_{11} to n-C_{21} (CPI, n-C_{11} to n-C_{19} = 1.2-1.3) and by full n-alkane and isoprenoid profiles. Group 3 oils (n = 66) exhibit no n-alkane odd predominance and have full n-alkane and isoprenoid profiles. Pristane/phytane ratios range from 1.3 to 1.4 for group 2 oils and from 1.6 to 2.0 for groups 3 oils. $\delta^{13}C_{sat}$ ($\delta^{13}C_{arom}$) range from -29.0 to -29.7 (-28.8 to -29.9)^{o}/oo(PDB) for the group 1 oils, -29.8 to -31.8(-29.4 to -31.3)^{o}/oo for group 2 oils, and -29.1 to -30.0(-28.0 to -28.9)^{o}/oo for group 3 oils. Tricyclic terpane distributions (m/z = 191) for the oil groups are distinctive. Group 3 oils are characterized by a maximum at C_{23} and relatively abundant extended tricyclic terpanes, whereas group 1 and group 2 oils are characterized by a maximum at C_{19} and a relatively abundant C_{24} tetracyclic terpane. Group 1 oils occur primarily in late Champlainian reservoirs; group 2 oils, late Champlainian and Silurian reservoirs along the northern edge of the basin; and group 3 oils, Silurian, Devonian, Mississippian, and Pennsylvanian reservoirs.

Correlation of oils with $CHCl_3$ extracts of 40 representative rock samples from within the basin and from the stable shelf to the northwest show that source rocks form group 1 and group 2 oils are two distinct Champlainian organic-matter facies; for group 3 oils, source rocks are the Upper Devonian-Kinderhookian New Albany Shale. Extracts of organic-matter-rich samples from the Upper Ordovician Maquoketa Shale and the Middle Pennsylvanian marine black shales do not correlate with any oil, suggesting limited source rock potential for these units. Biomarker thermal maturation indicators (Tm/Ts, C_{29} sterane isomerization ratios, and triaromatic/monoaromatic ratios), API gravities, and vanadium contents in the group 1 oils are related to reservoir depths, suggesting limited vertical oil migration. In contrast, these parameters are unrelated to depth of the group 3 oils, suggesting significant vertical migration and mixing. Comparison of maturation indicators in group 3 oils and New Albany Shale extracts show the oils were generated from rocks with present-day burial depths between 3,500 and 5,000 ft (1,050-1,500 m). Migration distances of about 150 mi (240 km) are indicated for group 3 oils presently produced from Silurian reservoirs in Brown and Adams Counties, Illinois.

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FORMATION RESISTIVITY AS AN INDICATOR OF OIL GENERATION IN BLACK SHALES

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Black, organic-rich shales of Late Devonian-Early Mississipian age are present in many basins of the North American craton and, where mature, have significant economic importance as hydrocarbon source rocks. Examples drawn from the upper and lower shale members of the Bakken Formation, Williston basin, North Dakota, and the Woodford Shale, Anadarko basin, Oklahoma, demonstrate the utility of formation resistivity as a direct in-situ indicator of oil generation in black shales.

With the onset of oil generation, nonconductive hydrocarbons begin to replace conductive pore water, and the resistivity of a given black-shale interval increases from low levels associated with thermal immaturity to values approaching infinity. Crossplots of a thermal-maturity index (R_o or TTI) versus formation resistivity define two populations representing immature shales and shales that have generated oil. A resistivity of 35 ohm-m marks the boundary between immature and mature source rocks for each of the three shales studied.

Thermal maturity-resistivity crossplots make possible a straightforward determination of thermal maturity at the onset of oil generation and are sufficiently precise to detect subtle differences in source-rock properties. For example, the threshold of oil generation in the upper Bakken shale occurs at R_o= 0.43-0.45% (TTI = 10-12). The threshold increases to R_o =0.48-0.51% (TTI = 20-26) in the lower Bakken shale, and to R_o = 0.56-0.57% (TTI = 33-48) in the most resistive Woodford interval.

AAPG Bulletin, v. 71, no. 8, p. 1007

A COMPUTERIZED STRATIGRAPHIC NOMENCLATURE DATABASE OF THE U.S. WESTERN INTERIOR, AND A PROGRAM TO MANIPULATE IT

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A new database contains comprehensive information on stratigraphic units of the Western Interior of the U.S. from published reports. This large and growing database is maintained by the U.S. Geological Survey in Denver, Colorado, on a supermini-class networking computer and may be accessed by other computers--including most personal computers--with communications capability. Records in the database may be called up either by stratigraphic unit name (using the Program NAMES) or by various user-specified attributes (using the program ATTRIBUTES). In the ATTRIBUTES program, units may be selected by age (era, period, epoch, or stage), formal rank, state, geologic province or basin, lithologic type, authors, and type of information available (e.g., biostratigraphic dating, isotopic dating, areal limits). The record for each unit is divided into two parts: (1) an up-to-date summary, including the rank terms and ages assigned, a detailed description of the type locality (if designated) and the area of occurrence (states and geologic provinces or basins); and (2) an historical record, comprising the critical information abstracted from each publication that has defined the unit or modified its definition. For the most part, articles that do not affect the name or definition of a stratigraphic unit are not included.

Several limestone units that occur in the Pedregosa basin are selected to illustrate the ATTRIBUTES program. In response to the user's prompts, the ATTRIBUTES program rapidly sorts through the approximately 4,000 unit names in the databse and compiles a list of units that are (a) limestone, (b) of user-specified age, (c) in Arizona, (d) in the Pedregosa basin, and (e) dated biostratigraphically. Examination of the records from this list yields synopses of reports that present information on these units.

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EXTREME HIGH TEMPERATURE BURIAL ANNEALING OF APATITE FISSION TRACKS, SANTA FE SPRINGS OILFIELD, CALIFORNIA

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Fission-track analysis has been performed on apatites from sandstones of Pliocene to Miocene age from a deep drill hole at Santa Fe Springs oilfield, Los Angeles Basin, California. Fission tracks are preserved in these apatites at exceptionally high present-day temperatures. Annealing is not complete until temperatures reach the extreme of 167° to 178° (3795 to 4090 m). These data suggest that rapid heating to present temperatures occurred over a very short effective heating time.

The temperature gradient at Santa Fe Springs is well established from oil-field operations. Sediment burial histories are continuous and tightly constrained from about 12 Ma to present, with an important tie at 3.4 Ma. No surface erosion and virtually no uplift are recorded at Santa Fe Springs during or since deposition of these sediments, so the thermal history is simple and uniquely defined, and the rapid rate of heating is known. The data therefore provide one critical field test of kinetic models for fission-track annealing in apatite.

Annealing of fission tracks is a kinetic process dependent primarily on temperature and to a lesser extent on time. Several kinetic models have been proposed based on both laboratory data from short-duration experiments and field observations from geologic samples. The predictive capabilities of these models have been limited to qualitative or semi-quantitative at best because of uncertainties associated with the extrapolation of laboratory observations to geologic conditions or with the thermal histories of field samples. The new data from Santa Fe Springs cannot be closely predicted from any of the commonly used models available in the open literature.

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POSSIBLE NEOTECTONIC FEATURES IN GARVIN BASIN, SOUTH-CENTRAL MONTANA

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A series of prominent scarps cut Pleistocene pediments and alluvial fans in the Garvin Basin along the west flank of the northern Bighorn Mountains, Montana. These probable fault scarps are significant because evidence of large-scale neotectonic activity has not previously been recognized in this area. The nearest scarps of this size are found 200 km to the west in the Yellowstone region.

The scarps extend for 5 km in a 300-m-wide zone trending N20°-30°W about 500 m west of and parallel to the mountain front. Scarp heights range from 2 m at the northernmost end to more than 15 m at the southernmost end. Maximum slope angles range from 12° to 30° and increase with increasing scarp height. A well-defined graben, marked by dense sagebrush, occurs along the foot of most scarps. The scarps offset the two youngest (probable late Pleistocene) geomorphic surfaces of an alluvial-fan and pediment sequence that consists of at least six different ages.

The northern 1 km of the scarp zone comprises a single, straight scarp, 2 to 5 m high, bordered downslope by a shallow graben. The scarp projects to a monocline in nearly vertical, highly fractured, slightly faulted Jurassic limestone and shale exposed along Gyp Creek 1/2 km to the north of the scarp, suggesting an underlying fault control of both the bedrock monocline and the surface scarp. The southern 2 km of the scarp zone also consists of a single, relatively straight scarp. In contrast, the central 2 km of the scarp zone consists of multiple, slightly arcuate scarps of variable height. About 1000 m downslope from the main scarp zone is an irregular break in slope that may represent an older, more subdued fault scarp.

Origin of the scarps by faulting is considered most likely, but some observations suggest that landsliding may be locally involved. The arcuate central scarps, the irregular trace of the lower subdued scarp, and the somewhat irregular surfaces between these scarps collectively resemble features of a large landslide. An alternative origin of the scarps, the dissolution of Jurassic gypsum deposits, is considered unlikely due to the lack of solution features within the scarp zone and the lack of evidence of thick gypsum deposits in this area.

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CRUSTAL STRUCTURE OF THE MID-CONTINENTAL RIFT SYSTEM INTERPRETED FROM GLIMPCE DEEP SEISMIC-REFLECTION PROFILES

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Interpretation of GLIMPCE seismic-reflection profiles indicates that the mid-continent Rift system (Keweenawan, 1100 Ma) of volcanic, and interbedded, and post-volcanic sedimentary rock extends to depths as great as 32 km (about 10.5 s reflection time) along profiles crossing western, central, and eastern Lake Superior and the northern end of Lake Michigan. This region may be underlain by the greatest thickness of intra-cratonic rift deposits on Earth. Times to Moho reflections vary from 11.5 to 14 s (about 37-46 km depth) in western Lake Superior, to 17 s (about 55 km) in the center of the Lake, and 13 to 15 s (about 42-49 km) in the eastern end of Lake Superior. The pre-rift crust, however, is 25 to 30 km thinner beneath the central rift than beneath its flanks, providing evidence for crustal extension by factors of about 3 to 4. The midcontinent rift system differs from Phanerozoic rifts in that its total crustal thicknesses are equal to or greater than that of the surrounding (presumably unextended) regions.

EOS, 1987, v. 68, in press

OCEANIC TECTONIC BLOCKS IN THE ESK HEAD SUB-TERRANE, SOUTH ISLAND, NEW ZEALAND

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The Esk Head subterrane is a continuous belt, 10-20 km wide, of broken formation and melange on the South Island of New Zealand. It separates older and younger parts of the Torlesse terrane, an extensive accretionary prism composed mostly of Permian to Lower Cretaceous, quartzo-feldspathic, submarine-fan deposits. The Torlesse is the most Pacific-ward of several terranes accreted during Mesozoic time against the Pacific-facing Gondwana margin. In addition to its structural disruption, the Esk Head subterrane is characterized by conspicuous tectonic blocks of submarine basalt and a variety of basalt-associated seamount and sea-floor limestones and cherty rocks of especial interpretive value for the tectonic history. Limestones in tectonic blocks include (1) submarine-cemented, pelagic-bivalve, geopetal packstone-grainstone, (2) brachiopod-bryozoan encrinite, and (3) radiolarian lime mudstone. Some limestone blocks may be of Jurassic age; most are Late Triassic and have low conodont CAI values near 1.0. Radiolarian cherts (dated by C. D. Blome) are of Late Triassic, and Early, Middle, and Late Jurassic ages. Paleogeographic considerations indicate deposition of the limestones and cherts at paleolatitudes lower than that of the New Zealand part of the Gondwana margin but higher than paleoequatorial latitudes. These rocks were emplaced in the Torlesse accretionary prism by off-scraping from an extensive subducting oceanic plate--probably the Phoenix plate--convergent with the NW-trending Gondwana margin during Late Jurassic and Early Cretaceous time.

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RECENT FAULTING IN THE PIERRE SHALE NEAR PIERRE, SOUTH DAKOTA

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The evidence obtained from a field study covering a 400 mi^2 area west of Pierre, South Dakota, suggests that faulting may be active. At two locations, faulting in the Pierre Shale deformed overlying colluvial deposits less that 1300 yrs old (determined by carbon 14 dates), and at a third location, faults were found in Pleistocene sand and gravel deposits. The faults are located in an area of suspected structural instability indicated by (1) the low order of stream patterns, (2) the diversion of two major stream patterns from a dominant northwest-southeast direction to an east-west direction, (3) the marked change of stream gradients, (4) the numerous faults along stream valleys, and (5) the recent low-level seismicity along defined lineaments. Additional field evidence that supports recent faulting are numerous deep knickpoints, several hanging valleys, and the alignment of headward-developing stream valleys associated with mapped faults.

Damage of highways and appurtenant structures has been observed at fault locations. At two locations within the study area, highway construction and repair has been extensive over the past two years and at a third locaton considerable damage has been done to an abandoned highway bridge; all locations extend over faulted bedrock. Displacements causing damage have been attributed to the swelling of freshly exposed clay gouge or to gravity movements along fault planes. Active faulting, however, may be the cause for initiating these processes.

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THE UPPER CRUSTAL DETACHMENT SYSTEM AT YUCCA MOUNTAIN, SW NEVADA

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The pattern of normal and strike-slip faults in Miocene volcanic strata and Quaternary surficial deposits suggests that a shovel-shaped, upper crustal detachment system underlies a 10 x 25-km segment of Yucca Mountain. The detachment system consists of three parts: a basal detachment fault, strike-slip faults, and a newly recognized breakaway zone. Steep, west-dipping normal faults in the upper plate of the detachment system die out against the northwest-striking, right-lateral strike-slip fault zones in the vicinity of Yucca Wash on the northern side of the mountain and against the northeast-striking, left-lateral Stagecoach Road fault in the southern part of the mountain. Ridges of 13 Ma tuffs are offset in a left-lateral sense as much as 1 km and drainage channels on Quaternary bedrock pediments and on Quaternary deposits are offset 10-30 m across the Stagecoach Road fault. Both strike-slip zones appear to merge into the major west-dipping Busted Butte-Paintbrush Canyon normal fault zone near the eastern edge of the mountain, to form an arcuate breakaway zone. This zone is accentuated by a series of valleys 0.5 to 2 km wide; the southern extension of this zone intersects the Lathrop Wells cone, a Quaternary basaltic volcano. As much as 4 m of apparent vertical offset occurs in buried soils (<0.74 Ma) exposed in sand ramps along the Busted Butte fault. The amount of offset on the normal faults and strike-slip faults appears to decrease northward, suggesting a clockwise rotation of the detachment block from a pivot point in the northern part of Yucca Mountain. The basal part of the detachment system probably follows the strong physical-property boundary between zeolitized Tertiary tuffs and Paleozoic carbonates. Gravity models predict this boundary to increase from a depth of 1 km in the eastern part of the mountain (confirmed by drilling) to as much as 4 km in the northwestern part. Kinematic constraints require westward movement of the upper plate of the detachment system toward Crater Flat. We conclude that a detachment model provides the best explanation for the structural features and tectonic evolution of Yucca Mountain.

GSA Abstracts with Programs, 1987, v. 19, no. 5, p. 332-333